Fire Protection Engineering Student Class Notes

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FPE 309	Structural Fire Protection (Continued)		
FPE 420	Fire Extinguishing & Detection Systems	Fall 1964	Prof. Labes
FPE 303	FPE Laboratory	Fall 1963	@ UL, Mr. Jensen
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Condensation of
Post War Building Studies No. 20
Fire Grading of Buildings, Part I
General Principles and Structural Precautions
Joint British Fire Research Committee

SCOPE OF REPORT

The term "fire grading," as applied to buildings, may be taken to mean the grading of fire precautions in buildings, i.e. the investigation and assigning of suitable fire precautions of any kind to obtain an adequate standard of safety, according to the fire hazard of the building under consideration.

The objects of fire precautions are to safeguard life and property. They are achieved by (a) preventing or reducing the number of outbreaks of fire; (b) limiting the development and spread of a fire in event of an outbreak, and (c) providing for safe exit of occupants.

Although the importance of each of these aspects cannot be overemphasized, it is the purpose of this report to restrict itself to the second stage, i.e. limiting the development and spread of a fire in event of an outbreak.

Any rational system of fire grading should provide a combination of active and passive defence in proper balance to meet the fire hazard in each case. Undue reliance on structural means might be uneconomic as adding unduly to building costs, especially if efficient means of extinguishing the fire can be depended upon. The same emphasis need not be laid on active defence if buildings are so planned internally and constructed as to reduce to a minimum the risk of the occurrence and spread of fire. The broad question is therefore one of striking the right balance between passive and active defence, and of adjusting the total precautions to the hazard so that the most rational and economic combination can be achieved.

Precautions against fire and the fire hazard can be regarded as standing in much the same relation to each other as the strength of a structure and the loads it has to carry. A structural member is designed according to the load it has to carry plus a certain factor of safety. Similarly precautions against fire should be designed according to the fire hazard arising from the contents of the building and its structural character. Whilst the structural engineer is able to estimate with reasonable accuracy the physical loads he has to take into account, there is no means, other than in general terms, of expressing the fire hazard of a building. Recent work has enabled an approximate quantitative measurement to be made of the probable severity of fires in buildings, but this is but one factor of the many which go to make up the total hazard.

A rational scheme of fire grading should be so designed that the protection against the fire hazard would be by that combination of passive and active defence which is appropriate to the hazard involved, having due regard to practicability.

GRADING OF OCCUPANCIES ACCORDING TO DAMAGE HAZARD

So far as the occupancy is concerned the damage hazard will depend largely on the amounts, natures, and distribution of the combustible materials, and it is therefore necessary to consider the grading in respect of each of these items.

Thus in a warehouse containing large quantities of combustible material the damage to the structure and the loss of contents would be much greater than in the case of an office block because of the greater quantity of combustible material in the former. The fire would be hotter and of longer duration.

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The total weight of material is, however, not a sufficient criterion because in this respect the important factor is the total amount of heat that could be liberated. It is therefore necessary, because of the variation in the amount which can be liberated by the combustion of equal weights of different combustible materials, to use as a basis the total heat that can be liberated expressed in British Thermal Units per square foot of floor area.

FIRE LOAD AS A MEANS OF MEASURING DAMAGE HAZARD

By analogy with structural loads we have adopted the term "fire load" to describe the number of British Thermal Units which could be liberated per sq. ft. of floor area of a compartment by the combustion of the contents of the building and any combustible parts of the building itself. The fire load of a building has been used as the basis of our grading of occupancies. It may be determined simply by multiplying the weight of all combustible materials by their calorific values and dividing by the floor area under consideration. Thus, if a building or any part of a building contains 4000 lb. of combustible material of calorific value 8000 B.Th.U's./lb. over an area of 1000 sq. ft., the fire load would be:

$$\frac{4000 \times 8000}{1000} = 32{,}000 \text{ B.Th.U's./sq. ft.}$$

As the conception of fire load is new to this country, comprehensive data on the fire loads of various occupancies are not available, but investigations in this country and abroad provide a basis for a tentative grading of a number of common occupancies according to their fire load.

From data obtained from a number of sources relating to floor loads and combustible contents in buildings (including unpublished work of the Building Research Station) it appears that, in general, the fire load of residential buildings, hotels, hospitals, schools, offices, and similar occupancies, does not exceed 100,000 B.Th.U's./sq. ft.; the fire loads of shops and factories using combustible materials are usually greater than 100,000 B.Th.U's./sq. ft., whilst those of warehouses may range up to 1,000,000 B.Th.U's./sq. ft. or more.

These data suggest that a fire load of 100,000 B.Th.U's./sq. ft. would be a convenient limit for distinguishing between buildings of the first group and other occupancies such as factories, and accordingly we propose to describe these as occupancies of low fire loads. The distinction between shops and factories and storage buildings is not well defined; it has been necessary to use the relation which has been brought out by recent work in America and this country between the fire loads of occupancies and the grade of fire resistance of elements of structure required to resist fires due to those fire loads. The relation is considered more fully in a later section of the report and for the present it must suffice to note that a fire in a building having a fire load not exceeding 100,000 B.Th.U's./sq. ft. is approximately equivalent to 1 hour exposure to the heating in the standard test, a fire load between 100,000 and 200,000 B.Th.U's./sq. ft. is similarly equivalent to 2 hours of the standard test, etc. It is clear that a grading of occupancies closely related to the grades of structural fire resistance would be markedly advantageous, and we therefore propose the following grading of occupancies according to fire load:

(1) Occupancies of Low Fire Load are those in which the fire load does not exceed 100,000 B.Th.U's./sq. ft., e.g. generally domestic buildings, hotels, offices, etc.

(2) Occupancies of Moderate Fire Load are those in which the fire load exceeds 100,000 B.Th.U's/sq. ft. but does not exceed 200,000 B.Th.U's./sq. ft., e.g. generally trade and factory buildings.

(3) Occupancies of High Fire Load are those in which the fire load exceeds 200,000 B.Th.U's./sq. ft. but does not exceed 400,000 B.Th.U's./sq. ft., e.g. bulk storage buildings.

In occupancies in which the fire load consists chiefly of timber, paper, fabrics, i.e. materials having calorific values of the order of 8000 B.Th.U's./lb., these fire loads correspond to weights of about 12 lb./sq. ft., 12-25 lb./sq. ft. and 25-50 lb./sq. ft. respectively. For these materials the corresponding weights may be used instead of the values in B.Th.U's./sq. ft., but for materials having higher calorific values the above weights must be reduced in proportion to the calorific value of the materials concerned.

EFFECT OF NATURE AND DISTRIBUTION OF FIRE LOAD ON GRADING

The grading, as so far presented, is determined only by the amount and calorific value of the materials contained in the building. The same weights of different materials, which may be of the same calorific value, present considerable differences in general fire risk. For example, materials differ in their ease of ignition and the rate at which they burn; some materials may seriously hinder fire fighting because they emit noxious fumes especially when heated, or encourage the burning of other materials. Again, special risks may be found in a building because a process is introduced which involves application of heat to a combustible material, and there is then risk of frequent outbreaks of fire. It is therefore necessary to distinguish between occupancies which have a given numerical fire load but present no special risks, and those of the same numerical fire load but in which special risk arises from one cause or another. We propose to call the former normal risk fire loads and the latter abnormal risk fire loads, or for short "normal" and "abnormal," although the term "exceptional" has been considered as an alternative to "abnormal."

It is not easy to specify the factors which make an occupancy abnormal. Some are concerned with the materials involved, others relate to the process, but we give below a list of some of the factors which introduce high risks. They are separated into two groups, firstly those relating to materials, and secondly those concerned with processes. The list must be regarded merely as a guide and is not exhaustive.

MATERIALS So far as materials are concerned we are of opinion that the materials described as dangerous goods and explosives in the Memorandum of the Departmental Committee (1933) of the Board of Trade on the Carriage of Dangerous Goods and Explosives in Ships should be taken as a basis on which to grade an occupancy as abnormal.

The substances in the list are divided into seven categories as follows, and presence of an appreciable quantity forming the contents or part of the contents of a building would indicate that the occupancy should be graded as abnormal risk.

1. Explosives
2. Compressed "permanent," liquefied, and dissolved gases.
3. Substances which become dangerous by interaction with (a) water or (b) air. Substances falling under (a) also become dangerous by interaction with moisture in the air and to that extent can be included in (b).
4. All substances with flash point below 150°F.
5. Corrosive substances.
6. Poisonous substances.
7. Miscellaneous
    A. Oxidizing agents.
    B. Substances liable to spontaneous combustion.
    C. Readily combustible solids.

In addition we consider it necessary to add two categories of substances which are likely to create special hazards of fire in buildings as follows:

8. Substances likely to spread fire by flowing from one part of a building to another:

   e.g. All oils, fats and waxes, rubber, lard, bitumen, pitch, etc.

9. Substances in such a form as to be readily ignitible:

   e.g. Wood shavings, paper, pieces of fabric, cotton, rags, fibre, down, flock, kapok and similar materials, flour, coal dusts, metal dusts, and other dusts and powders.

Use of one or other of the following typical processes might also indicate that the occupancies should be graded as abnormal.

1. Those involving the application of heat, especially to combustible materials, e.g. gas singeing, ironing, drying rooms and compartments, heat treatment, creosoting, etc.

2. Those involving the production of inflammable water or dust, particularly when the latter arises through the use of disintegrators, grinders and such like reducing machines.

3. Spray painting with inflammable or explosive liquids.

4. Use of inflammable solvents.

It is clear that the presence of small quantities of these materials, or the carrying on of a process on a small scale as an accessory to an otherwise normal occupancy, might not justify grading of the occupancy generally as abnormal. For instance, that part of the occupancy which is regarded as abnormal but has the same numerical fire load as the remainder may be adequately separated from the remainder by fire resisting construction, and it would therefore be unreasonable to grade the whole occupancy as abnormal in such circumstances.

The contents of a building are rarely disposed uniformly over the whole floor area. From the fire protection standpoint it would be undesirable to have all combustible material concentrated on a fraction of the floor area, as the average taken over the whole area would not give a true representation of the actual conditions, and the resulting effects on the structure immediately surrounding would be out of all proportion to those expected on the basis of average fire load. An investigation of the effects of fires suggests that when the fire load over any 10 ft. square of the floor area does not exceed twice the average and the contents are reasonably distributed in such units, the effects on the structure are not appreciably different from those found with a more uniform distribution. For example, if the contents on a floor in an occupancy of low fire load, i.e. not exceeding 100,000 B.Th.U's./sq. ft., were reasonably distributed in units which did not exceed 200,000 B.Th.U's./sq. ft. over any 10 ft. square, the effects on the structure would not differ appreciably from those due to a uniform distribution of 100,000 B.Th.U's./sq. ft.

In almost all occupancies not specifically designed for bulk storage, some part is used for storage. Thus, in offices storage space must be provided for records; in factories and shops reserve stocks, which may locally amount to a fire load of 1,000,000 B.Th.U's./sq. ft. or more, must be kept. If high concentrations of material are taken into account in computing the fire load the result may well be to force that occupancy into a higher classification than could be justified. Again, examination of occupancies which have suffered a complete burn-out indicate that high concentrations of this kind can cause severe damage to a building, but the effects are largely determined by the area over which the concentration of load is spread. If the area is of the order of 100 sq. ft., damage is often serious, and it is desirable that where there is likely to be need for storage space of this kind, it should be properly separated from the remainder by construction of an adequate grade of fire resistance and be limited in area, but the area may be omitted from the computation of fire load.

PROPOSED THREE GRADES OF OCCUPANCY

In order to take account of factors such as those just mentioned and provide greater tolerance in practice, it is thus desirable to qualify the grading scale previously stated as follows:

~~(<100,000)~~

REQ.

1HR. (<100,000) 1. OCCUPANCIES OF LOW FIRE LOAD. The fire load of an occupancy is described as low if it does not exceed an average of 100,000 B.Th.U's./sq. ft. of net floor area of any compartment, nor an average of 200,000 B.Th.U's./sq. ft. on limited isolated areas, (provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.)

NOT >100# NEGL. if >100# + CUT OFF, NEGLECT.

2HR (1-200,000) 2. OCCUPANCIES OF MODERATE FIRE LOAD. The fire load of an occupancy is described as moderate if it exceeds an average of 100,000 B.Th.U's/sq. ft. of net floor area of any compartment but does not exceed an average of 200,000 B.Th.U's./sq. ft., nor an average of 400,000 B.Th.U's./sq. ft. on limited isolated areas, provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.

(2-400,000) 4HR 3. OCCUPANCIES OF HIGH FIRE LOAD. The fire load of an occupancy is described as high if it exceeds an average of 200,000 B.Th.U's./sq. ft. of net floor area of any compartment but does not exceed an average of 400,000 B.Th.U's./sq. ft. of net floor area, nor an average of 800,000 B.Th.U's./sq. ft. on limited isolated areas.

APPLICATION OF GRADING OF OCCUPANCY

Where the intended occupancy is known, it would be possible to determine, with the aid of material calorific value tables, the numerical fire load of the building and hence the proper occupancy grading.

While this grading scale will cover the greater proportion of occupancies, there remain a number which cannot conveniently be included in any one of the above groups. Firstly, there is a group of occupancies in which the fire load exceeds 400,000 B.Th.U's./sq. ft. There are, secondly, other occupancies which have fire loads falling within the limits of one or other of the above grades, but which require individual consideration because of the special risk, which in some cases may be very high, e.g. storage or manufacture of celluloid, but in others very low, e.g. churches and cathedrals. They will include, in addition to the above, such occupancies as underground car parks, flour mills, exhibition buildings, munition factories, tanneries, etc.

GRADING OF BUILDINGS ACCORDING TO THE FIRE RESISTANCE OF THEIR STRUCTURAL ELEMENTS

Having graded the hazards, it is now necessary to consider the measures required to give the desired structural protection. The precautions include both passive and active defence measures. Fire fighting is of course assumed to be available in all cases, and we first consider the question of structural resistance to fire by grading buildings on the basis of the fire resistance of their elements in relation to the fire load.

We have taken, as a starting-point for grading, a form of construction so protected that the structural elements will resist a complete burn-out of the combustible contents without failure, and restrict spread of fire out of the compartment in which it starts, irrespective of any other means of dealing with the fire. We then consider other forms of construction giving lower levels of structural protection. It would be unduly onerous to require that every building should be so protected that it would resist a complete burn-out of its contents without collapse, for thereby we should not only eliminate certain forms of construction which have shown themselves to be of great utility, but also would largely increase the cost of building, and at the same time neglect the effect of other means of defence, e.g. fire fighting.

Taking therefore as a starting-point the provision of structural precautions to resist the effects of a complete burn-out, it is clear that different grades of fire resistance will suffice for that purpose according to the fire severity which is determined by the fire load. Thus in a building of high fire load the fire will be longer and hotter, i.e. of greater severity, than the fire in a building of low fire load.

The British Standard 476-1932 enables various elements of structure to be graded according to the time for which they resist a certain standard fire severity determined by a time-temperature curve based on observations in actual fires. Thus if we can establish the relationship between the fire load of a building and the equivalent severity of the test fire expressed in hours of heating under test conditions, a means will be provided whereby buildings may be graded on the basis of their resistance to fire in relation to the fire load.

RELATION OF FIRE SEVERITY TO FIRE LOAD

The relation between standard heating and the temperatures and duration of fires in buildings due to the burning of various amounts of combustibles was first investigated in America. Several tests were carried out in which known weights of timber and paper were ignited and allowed to burn out in a specially built structure, the temperatures reached during the fire being recorded and plotted. It was then possible to match the curves so obtained with the corresponding curves of the various periods of the American standard test, and in this way to assess the equivalent severity of the building fire, i.e. in terms of hours of standard heating. The results of these tests are given in Table 1, where the relation is expressed in terms of the weight per sq. ft. of the combustible material burned, which had calorific values between 7000 and 8000 B.Th.U's./lb., and the fire load in B.Th.U's./sq. ft. The standard heating is expressed in terms of hours of heating according to the standard American time-temperature curve, which is sufficiently close to the British Standard time-temperature curve to permit direct application of the results to the latter.

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TABLE 1. EQUIVALENT SEVERITIES OF BUILDING FIRES (AMERICAN RESULTS)

Combustible Content		Equivalent Severity Of Fire in Hours Of Standard Test	British
Weight lb./sq. ft.	Fire Load* B.Th.U's./sq. ft.		
10	80,000	1	<100000 1HR
15	120,000	1½	
20	160,000	2	1-200000 2HR
30	240,000	3	
40	320,000	4½	
50	380,000	6	2-400000 4HR
60	432,000	7	

*Calorific value of materials 7000-8000 B.Th.U's./lb.

we seem to have considerable error comparing areas in upper end of curve

If the calorific value of the materials differs appreciably from that of timber and paper, it would be necessary to adjust the weight of the combustible materials in Col. 1 to give the same fire load, e.g. the weight of a material having a calorific value of 16,000 B.Th.U's. to give an equivalent severity of 1 hour would be 5 lb./sq. ft.

Further data on the relation have been forthcoming from recent work carried out by the Building Research Station. The method adopted in the above tests of measuring the temperatures throughout the fires virtually precludes its application to actual building fires. The Building Research Station has recently developed a method whereby the temperatures reached in the walls, concrete columns, etc., of buildings during a fire can be estimated with sufficient accuracy long after the fire. It depends on the fact that brickwork mortar and concrete made with siliceous aggregates show certain colour and other changes which develop at fairly well defined temperatures. The temperatures so recorded were compared with the temperatures reached in a similar element when subjected to the standard heating for various times. In this way it was again possible to determine the equivalent severity of the building fire, i.e. in terms of the standard heating, and, from a knowledge of the fire load, to obtain the relation between the two quantities. The method, which is more fully described in the Appendix, has the advantage that it can be applied to any building after a fire, and the effects of variations in materials which could not be dealt with in the American tests have been brought out. The results agree reasonably with the data of Table 1 for low fire loads, but indicate that the equivalent fire severities for higher fire loads are somewhat lower than those of Table 1. In arriving at the values which are given in Table 2, the relation between the conditions under test and the building fire has been fully considered. The relation is complex, and it would be beyond the scope of this Report to consider the matter in detail. We have, from a consideration of these two sets of data, adopted as a simple basis for our grading the equivalent severities given in Table 2.

TABLE 2. ASSUMED EQUIVALENT SEVERITIES OF BUILDING FIRES

Fire Load B.Th.U's./sq. ft.	Equivalent Severity of Fire In Hours of Standard Test
Less than 100,000 i.e. low fire load	1 — Type 3 const
100,000-200,000 i.e. moderate fire load	2 — " 2 "
200,000-400,000 i.e. high fire load	4 — Type 1 const

In arriving at the above figures we have considered the average results obtained for a number of occupancies, but it was clear that considerable variations could be expected from these average results. For example, there are instances where the severity of the fire would be greater than that expected from Table 2. Conversely there are instances where fire loads may give rise to fires which fall much below the equivalent severity expected, e.g. in stacks of waste paper which, owing to the close packing, cannot burn freely. These results are due essentially to variations in the rate of combustion, but there are not sufficient data to distinguish clearly between the degrees of resistance required. Again, the area of window through which heat can escape is a factor which may be important, for example, in basements with limited exit for heat.

Another factor which may have an important influence is the overall size of the building. It is clear that a very small area of high fire load may not contain sufficient heat to produce the effects expected; in a very large area, on the other hand, there may be concentration of heat at the centre of the area. There is no clear evidence to indicate how important this may be, but we consider that the data will fit the majority of cases, and general experience of the behaviour of buildings in blitz fires accords well with the results. These are points, however, which merit further research.

1955 see further work in notes

We conclude from these results that, in a building of low fire load, a fire resistance of 1 hour in the elements of structure would enable the building to withstand a complete burn-out without collapse. Similarly in a building of moderate fire load a fire resistance of 2 hours would be adequate, and for high fire loads 4 hours. We have thus obtained the necessary basis on which to formulate requirements for that grade of building which should resist a complete burn-out without failure and which we propose to call "fully protected construction."

FIRE RESISTANCE REQUIREMENTS FOR FULLY PROTECTED CONSTRUCTION

It is now possible to consider the fire resistance requirements which we propose for buildings of fully protected construction containing occupancies of low, moderate, or high fire loads, which, as indicated in Table 2, may give rise to fires of which the equivalent severities are 1, 2 and 4 hours respectively. To resist these equivalent severities, the elements of structure in the buildings would need to be of at least 1, 2, and 4 hours fire resistance. For convenience it is proposed to describe buildings with elements of structure having a fire resistance of not less than 4 hours as Type 1 construction. Buildings in which the elements of structure (excluding separating walls) have a fire resistance of not less than 2 hours are described as Type 2 construction and those in which the fire resistance is not less than 1 hour as Type 3 construction. For certain elements of structure in each of these types a higher grade of resistance than is indicated by Table 2 is considered desirable. These changes relate to external, separating and division walls and are considered below. The proposed grades of fire resistance are summarized in Table 3.

EXTERNAL WALLS

Whilst in respect of external walls we have generally adhered to the minimum grades of fire resistance to resist a complete burn-out, it is recommended that in the case of external walls of 1 hour fire resistance, their use should be restricted to the walls of buildings of framed construction not exceeding 50 ft. in height. We regard the height limitation as a temporary measure until practical experience justifies its relaxation; the need for framed construction where 1 hour fire resistance is proposed is considered desirable on grounds of stability. In all other cases of low and moderate fire-load occupancies the fire resistance of the external walls should be at least 2 hours, and 4 hours in the case of occupancies of high fire load.

SEPARATING AND DIVISION WALLS

We have considered it desirable, for the purpose of this Report, to avoid the use of the term "party wall" in view of the fact that the term is commonly used in different senses. We have therefore used the term "Separating Wall" where reference is intended to a wall which separates buildings, and the term "Division Wall" where reference is intended to a wall which separates parts of the same building. For separating walls we propose that the fire resistance should be not less than 4 hours irrespective of considerations of the fire load. This is necessary because the occupancy on each side of the wall may vary from time to time. On the other hand, the fire resistance of the division wall can be related to the fire load, so that in the case of an occupancy of high fire load the fire resistance should be not less than 4 hours, and for an occupancy of moderate fire load not less than 2 hours. On this principle the fire resistance of the division wall in a building of low fire load need be only 1 hour, but we consider that on account of the special function which the wall has to perform the fire resistance of 2 hours should be regarded as a minimum, even for occupancies of low fire load, to ensure full protection in all cases. It must be appreciated, however, that in considering separating and division walls there may be factors which justify the use of walls thicker than those which would comply with the proposed standards.

USE OF COMBUSTIBLE MATERIALS

Although a relatively high standard of fire resistance may be obtained with certain combustible elements of structure by taking special precautions, their incorporation in buildings of Types 1-3 construction would defeat the object aimed at in those types. For example, a timber joist floor may be protected by means of pugging and special ceilings so that it affords 1 hour or more fire resistance under test conditions, but fire on the upper surface may ignite the structure and lead to a complete burn-out. We therefore consider that all structural parts of buildings of Types 1-3 construction which are required to have a specified grade of fire resistance should be of incombustible material, except that timber doors which attain the required grade may be used.

burdensome

FIRE LOADS GREATER THAN 400,000 B.TH.U'S./SQ. FT.

In principle a fire resistance of more than 4 hours would be necessary in the structural elements of buildings where the fire load exceeds 400,000 B.Th.U's./sq. ft. if risk of collapse from a complete burn-out is to be expected. This fire load, which corresponds to about 50/lb./sq. ft. of combustible material of calorific value of 8000 B.Th.U's./lb. may, of course, easily be exceeded in bulk storage warehouses. For such buildings 6 hours protection could be used if desired, but in general it would probably be unduly onerous in some respects to require a 6 hours fire resistance, bearing in mind the fact that under normal conditions supplementary protection is available in the form of fire fighting, etc. It seems, therefore, that whilst it may be left to the discretion of a designer to adopt a 6 hours fire resisting construction, it would be preferable not to make this standard obligatory except for separating and division walls, but rather to require 4 hours fire resistance in the elements on the understanding that the construction should not be regarded as fully protected.

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OTHER SPECIAL OCCUPANCIES

In occupancies which are graded as "special" because of the presence of highly inflammable materials, e.g. celluloid, the actual fire severity corresponding to any given fire load may, as previously indicated, exceed the equivalent severity quoted in Table 2. The least fire resistance required may be determined solely from the estimated fire load, but special precautions may be necessary in other respects and each occupancy should be considered individually. It may, however, not be possible from the structural standpoint to describe the construction so determined as fully protected.

TABLE 3

MINIMUM FIRE RESISTANCE OF STRUCTURAL ELEMENTS IN FULLY PROTECTED BUILDINGS

Type of Construction	Walls				Columns and Beams Supporting				
	External	Separating Fire Wall	Division compartment cut off	Other Fire-Resisting or Load-Bearing Walls	External Walls	Division Walls	Other Fire-Resisting or Load-Bearing Walls	Floors	Staircases, Floors and Flat Roofs
Type 1	4	4	4	4	4	4	4	4	4
Type 2	2	4	2	2	2	2	2	2	2
Type 3	1* 2†	4	2	1	1* 2†	2	1	1	1

COLS & pilisters panel wall or curtain wall.

*In buildings of framed construction when height does not exceed 50 ft.
† Minimum for load-bearing walls, and other walls exceeding 50 ft. in height.

important & must retain stability

seems unrealistic to require > combostibility

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APPENDIX

Condensation of
National Building Studies
Technical Paper No. 4
Investigations On Building Fires
Department of Scientific and Industrial Research

One of the difficulties in the way of systematic developments in the fire grading of buildings is that of correlating the behaviour of elements of structure in laboratory tests with behaviour in actual fires. It is true that general experience shows that elements which behave well in fires also behave well in fire tests, while others which have but a short life behave poorly under test, but there still exists a need for more definite data. While a complete similarity in behaviour would hardly be expected when the variables which may be encountered in an actual fire are contrasted with the necessarily standardised condition of a fire test, it is an important step to determine what temperatures are attained in actual fires and what temperature gradients have existed in the building materials.

The method referred to in the Report for estimating the severity of building fires was developed as a result of studies made on the behavior of various types of building materials.

Visible changes in the appearance of natural stones, cement and lime mortars and concrete after exposure to fire have been observed and recorded on many occasions but no attempt appears to have been made to study their nature or causes. In connection with problems relating to the severity of building fires it is necessary to have available some reasonably reliable method of assessing the temperature and duration of the fires and as direct measurement during a building fire is obviously out of the question, recourse to other means is necessary. In the conduct of full scale fire resistance tests on brickwork, reinforced concrete, etc., at the Fire Testing Station, Mr. C. T. Webster of the Building Research Station had observed that the depth to which certain colour changes occurred in the mortar and concrete varied in a well-defined manner with the duration of heating and it appeared possible that these changes might be adapted for the purpose mentioned above, if it could be established that they occurred at sufficiently well-defined temperatures. The work described in the present paper was carried out to determine to what extent the observed changes were critical and also the temperatures at which they occurred. In the course of the work further changes have been observed which provide a means of assessing the temperatures over a wide range.

Experiments were carried out on samples of aggregates alone and on mortars and concretes.

AGGREGATES

Samples of sands and various types of aggregate were heated in an electric furnace at temperatures from 200°-1,000°C. in steps of 100°C. or in some cases 50°C. for varying periods. The observations and the conclusions drawn are given below.

QUARTZ SAND AND SANDSTONES

In all sands and sandstones except the colourless pure quartz sands there was a marked change in colour at 250°-300°C. This colour change, from the normal yellow or brown to a pink or reddish brown is well known, but no previous recording of the temperature at which it occurs has been found. The change is relatively sharp.

At 200°C. none is apparent after up to 18 hours heating; at 250°C. the colour develops slowly and is fully developed in 18 hours; at 300°C. it is fully developed in 2 hours. At higher temperatures up to 1,000°C. there is generally little further change although some samples show an intensification of the pink or red colour.

As the original yellow or yellow brown colour of many sands is due to the presence of small quantities of iron compounds it seemed that the colour change was most probably dependent upon the presence of iron compounds in the stone or coating the sand grains, and examination of the literature on the effect of temperatures upon the hydrated iron oxides shows a close agreement between the dehydration temperatures of all these compounds and the observed colour-change temperature of 250°-300°C. Fischer(*) states that limonite decomposes with a colour-change from yellow to red at 300°C. Williams and Thewlis(*) found Lepidocrite (γ $FeO(OH)_2$) was converted to the γ oxide at 250°-300°C. Posjnak and Merwin(*) also found that Goethite (α FeO(OH) lost very little water below 250°, but was almost completely dehydrated at 300°C. Hansen and Brownmiller(*) in examining precipitated ferric oxide hydrogel found that it had no structure, as judged by X-ray diffraction after heating at 200°C. but that after heating at 300°C. it had the haematite (Fe_2O_3) structure. There can thus be little doubt that the colour change in sands and sandstones corresponds with the dehydration of the iron compounds and that its presence is a reliable indication that the sample has been heated to a temperature of at least 250°-300°C. (the higher temperature with shorter heating periods).

As mentioned above there is no further change in colour of sands or sandstones, but at 573°C., the inversion temperature of the two forms (α and β) of quartz, there is a considerable expansion of the quartz grains. This usually causes internal rupturing of the grains of sand, and weakens sandstones, often making them friable to handle. Samples which are appreciably weaker or more friable than the unheated stone have therefore been heated above 573°C.

easily crumbled

FLINT

Flint gravel showed a colour change at 250°-300°C. similar to that observed with sand or sandstone. The amount of red colour developed varied with the initial colour of the flint. At temperatures above 500°C. some shattering of the flint occurred, partly it is thought as a result of removal of combined water from the flint and partly through the high-low quartz inversion; the absence of such visible effects may not, however, always be a reliable indication that this temperature has not been exceeded. Apart from the visible shattering the lighter coloured fractured surfaces became more white in appearance above this temperature.

Flint that has been held at temperatures above 1,200°C. for any length of time has a lower density than unheated flint, owing to partial conversion to cristobalite.

LIMESTONE

Limestone which contains any hydrated iron oxide was found to develop marked pink or red colours at 250°-300°C in the same way as sandstones. The colour varied considerably but was in practically all cases well defined. It sometimes increased in depth at higher temperatures up to about 600°C. At temperatures above about 700°C. calcination of the limestone occurred, becoming rapid at 850°-900°C.; when calcination occurs the red colour disappears and the specimen disintegrates slowly on exposure to moist air.

IGNEOUS ROCKS

Igneous rocks generally have been found to show no colour change on heating. The more acid types (e.g., granite) sometimes crack or shatter at temperatures above 573°C. through quartz expansion; basic types (dolerite, basalt) show no effect at that temperature but may show expansion effects when heated above about 900°C.

SLAG

Blastfurnace slag aggregates in general are unaffected by temperatures below about 1,200°C.

CRUSHED BRICK AGGREGATE

Crushed brick aggregates show no effect at temperatures below sintering temperature. This may vary, for different types of brick; "flow" of the aggregate will rarely occur below 1,000°C. and may in some cases not be observed below 1,200°C.

CONCRETE AND MORTAR

PORTLAND CEMENT-QUARTZ SAND MORTAR

Cement mortar briquettes (1:3 Portland cement:sand) made with two different sands, one of high and one of low iron content, were stored for one week in water and one week in air. Individual briquettes were then heated for two hours at various temperatures.

The changes in condition and appearance of these briquettes are shown in Table 1. The appearance of a pink colour at 300°C. corresponds with that observed on heating sand alone, but it is less marked and with a sand of low iron content can only just be observed. Most sands used for building mortar have, however, a considerable iron content and in subsequent observation of mortars in buildings which have suffered damage by fire the change has been clearly distinguishable.

TABLE 1. CHANGES IN CEMENT MORTARS HEATED TWO HOURS AT VARIOUS TEMPERATURES

Temperature	Mortar A (Pale Coloured Sand)		Mortar B (Red Sand)	
	Appearance	Strength	Appearance	Strength
Unheated	Grey	-	Buff	-
200°	Slight darkening	V. slight drop	No change	V. slight drop
250°	Ditto	Further ditto	Ditto	As 200°C.
300°	V. slight pink	Ditto	Pink	As 200°
400°	Slightly darker than 300°	Ditto	Ditto	As 200°
600°	As 400°	No appreciable strength	Sl. deeper pink	No appreciable strength
800°	Dark, but not perceptibly pink	Ditto	Deeper red	Ditto
900°	Lighter grey	Ditto	-	-
1,000°	Much lighter grey with no pink	Ditto	Pink nearly disappeared	-

Up to a temperature of about 500°C. the strength was not sufficiently affected to modify the apparent condition of the mortar, but at 600°C. it had become conspicuously weak and friable. This change is sufficiently sharp to serve as an indication that the mortar has been heated to at least 550°C. The pink colour was lost at temperatures of 600°-800°C. in the briquettes made with sand of low iron content, but remained with changes in intensity and tint even at 800°C. with the sand of high iron content; this loss of pink colour is discussed later in connection with concretes.

Small blocks of brickwork 12 in. x 9 in. x 9 in., were built with London stock brick and 1:3 Portland cement: sand mortar, using an average building sand and cured for 14 days before test. Thermocouples were embedded at various depths from the centre of one 12 in. x 9 in. face and were connected to a temperature recorder. One block was plastered with 3/4 in. of cement: lime: sand mortar and 1/4 in. of gypsum plaster on the face to be heated. The blocks were heated on one 9 in. x 12 in. face by a gas-fired furnace, the furnace temperature following as closely as possible the standard curve of the British Standard Definitions for Fire Resistance, etc. (B.S. 476, 1932) and the furnace atmosphere being fully oxidising. After completion of the heating period the furnace and specimen were allowed to cool down together.

The test results indicated that the temperatures within the block show very clearly the effect of free moisture in absorbing heat and thus delaying temperature rise above 100°C., and also show the markedly increasing lag in attaining the maximum temperature at greater depths from the heated face. The lag in heating and cooling probably helps to increase the sharpness of the visible changes in the mortar since it lengthens the period at which any portion of the material is at its maximum temperature.

The sand used in the mortar had a rather high iron oxide content and the red colour was developed strongly in each test in the mortar heated to above about 300°C. The discharge of the red colour occurred over the range of temperature roughly 550°-750°, giving an intermediate pinkish grey band about 1 in. wide. The width of this band probably results from the high iron content; it was much smaller in the tests on concrete. At about 900°C. the grey colour was changed to a buff or yellowish grey.

The plaster fell off the face of the block during the test, and its only effect was to reduce the depth of brickwork heated above 300°C. and 600°C. by about 1/2 in. as compared with the unplastered specimen.

PORTLAND CEMENT--FLINT GRAVEL--SAND CONCRETE

The experiments on concrete were carried out mainly on slabs 13 in. x 8 in. x 4 in. or 13 in. x 8 in. x 6 in., heated on one 13 in. x 8 in. face. In most cases the slabs were stored initially for 24 hours in moist air, then for 28 days at 65 per cent relative humidity and 65°F. (18°C.) Thermocouples embedded at various depths in the centre of the slab, and a sheathed-thermocouple in the furnace close to the slab, were connected to a temperature recorder, and heating was carried out as described for the brickwork specimens.

The changes observed in all these concrete slabs on breaking them open were similar and differed only in position according to the period of heating. Changes at four distinct temperatures were noted as follows:

(1) At 300°C. approximately, the red colouration previously described in the mortars replaced the normal grey of the concrete. This colouration is distinctive and the boundary between the red and grey portions could be readily defined. With different sands it was found to vary in intensity and in some cases needed a practiced eye and suitable lighting to determine the depth affected.

(2) At a temperature between 500°C. and 600°C. some cracking of the coarser flint aggregate was observable, and at the upper end of this range the concrete cracked and became friable; this is no doubt mainly a result of the quartz inversion as previously mentioned.

At a temperature similar to or slightly higher than the above a change in colour from the red or pink to grey is observable. This change is most probably due to reaction of the ferric oxide with lime, forming calcium ferrites of lower pigmenting power. This is largely confirmed by the persistence of the pink colouration in the case of materials not containing lime, e.g., sandstones, flint gravel, even at 1,000°C. Such a solid reaction will be relatively slow and the temperature at which the red colour disappears may therefore depend on the amount of iron oxide present and upon the time of exposure at the maximum temperatures. The range of variation may be taken as approximately 550°-700°C.

The colour change at this point is intensified by treatment of the broken concrete surface with a dilute acid (10 per cent acetic acid is suitable and convenient to use). The concrete above the quartz inversion temperature absorbs water or the dilute acid rapidly and the colour is darkened markedly, with a dull appearance even on drying again. Below this temperature absorption is slower, like that of the unheated concrete, the acid remains on the surface longer, and reacts with the cement giving a more intense colour with a somewhat glossy appearance.

Although the colour change (without acid treatment) does not by itself indicate a very definite temperature, the change in absorption and colour after acid treatment together with the cracking and friability of the concrete above 600°C. are sufficient to define the depth to which this temperature (600°C.) has been attained.

(3) At temperatures near 1,000°C. the colour of the concrete again changed from a cement grey to a buff shade, but the change in appearance is not always as sharply defined as the other changes at lower temperatures. The depth at which this colour change occurs can however usually be seen and may be taken to indicate a maximum temperature of about 950°C.

(4) Sintering of the concrete occurred at temperatures above about 1,200°C. to an extent which depends largely upon the amount of iron oxide present. Incipient sintering is usually seen as a "crackled" surface, with a yellow colour and individual brown spots where there is a higher iron content.

TABLE 2. MAXIMUM DEPTH (IN INCHES) OF CONCRETE SHOWING CHARACTERISTIC CHANGES ON HEATING

Concrete Heated	Maximum Surface Temperature Attained	Change			
		Development of pink or red 300°C.	Fading of red, friability and high absorption 600°C.	Development of buff 950°C.	Sintering 1,200°C.
1 hr.	950°	2¼	3/4	6	6
2 hrs.	1,050°	4	1½	¼	6
4 hrs.	1,230°	5½	2½	1	1/8
6 hrs.	1,250°	6-3/4	3½	1½	1/4

The depths at which the four changes discussed above were observed in slabs heated for 1, 2, 4 and 6 hours respectively are given in Table 2. The maximum temperatures attained in the concrete for these various periods of heating, corresponding to the various grades of Fire Resistance of B.S.D. 476, are shown in Fig. 1. It should be noted that the maxima shown within the concrete are not all attained until after the end of the heating period, the lag depending upon the depth from the heated face.

REPRODUCIBILITY AND INTERPRETATION OF OBSERVED CHANGES IN TERMS OF TEMPERATURE

In the experiments already described the various characteristic changes in appearance of the concrete were found to occur within a fairly short temperature range, the range being due primarily to the duration of exposing of the concrete to the temperature. Further experiments were carried out in a similar manner to determine whether the duration of steady maximum temperature, or the rate of cooling had any effect; no significant differences were found. The effects of carrying out the test with thoroughly wet concrete instead of dry were also found to be not significant.

The following conclusions were drawn with regard to the accuracy with which the changes in appearance can be used to judge the temperatures to which a sample of concrete or mortar has been exposed.

THE RED COLOURATION (300°C.)

The development of the red or pink colouration in concrete or mortar containing natural sands or aggregates of appreciable iron oxide content occurs at 250°-300°C. Unless the period of heating is known to have been prolonged over 6 hours or more the upper limit of this range can be taken as the transition temperature. The demarcation between changed and unchanged concrete or mortar is usually sharp and the depth which has been heated above 300°C. can generally be judged to ± 1/8 in. if a good section is available, or ± 1/4 in. in less favourable circumstances. Greater accuracy is usually possible in the case of cement mortars than with concrete, and with small depths of penetration the demarcation can generally be estimated after some practice to within the lower range.

THE SECOND GREY COLOUR AND CRUMBLING (600°C.)

The second definite change or series of changes occurs around 600°C. with siliceous aggregates, but is less sharp than the 300°C. change. The disappearance of the red or pink colour with return to a grey occurs generally between 600°C. and 700°C., depending upon the time of heating and other factors; expansion effects such as cracking of flint gravels, and general weakening or friability of the concrete or mortar are evident at 500°-600°C. Observation of these effects together, in doubtful cases, with confirmatory observations by acid treatment of the exposed section, make it possible to judge the depth heated above 600°C. to ± 1/4 in., or in less favourable cases ± 3/8 in.

THE BUFF COLOUR (950°C.)

The change from the second grey colour to a buff is often rather ill-defined and its temperature varies with the rate of heating and other factors from about 900°-1,050°C. If it be assumed that this change corresponds to a temperature of 950°C. the error in judging the depth of penetration of this temperature may be only ± 1/8 in. where the penetration's small and the temperature gradient steep, or up to ± 1/4 in. where the penetration is greater.

THE SINTERING POINT (1,200°C.)

Only in cases of exposure to the most severe and prolonged fires is mortar or concrete likely to reach a temperature of 1,200°C. to any significant depth. Sintering above this temperature is generally well marked and the depth affected, if it remains on the concrete or mortar surface and does not spall away on cooling, can often be judged to within ± 1/16 in.

It is concluded from the results of the tests on aggregates, mortars and concretes that changes in the appearance of concrete or mortar at approximately 300°C., 600°C., 950°C., and 1,200°C., are sufficiently reproducible and well defined with most siliceous aggregates to make it possible to assess with reasonable accuracy the temperatures attained by sections of concrete or mortar that have been subjected to heat above any of these temperatures. The change at 300°C. (development of red colour) is probably the most useful, but where the depths can be ascertained at which two or more of the above changes occur, it is possible to obtain the temperature gradient.

From the results produced by these studies, it was possible to examine walls and columns which had been subjected to standard fire tests (B.S. 476) at the Elstree Fire Testing Station and accurately determine the maximum temperatures which existed at various depths within the walls or columns as a result of exposure to the Standard Time-Temperature fire severity for various durations. From this point, it was then necessary to proceed one step further. Walls and columns of buildings which had been subjected to actual fires were then examined and compared with the results obtained from standard fire tests. This comparison along with a reconstruction of the fire load which had existed in the building prior to the fire made it possible to obtain the desired correlation between fire load and standard fire severity. The following example illustrates this method:

In applying the method to actual building fires the first procedure is to cut into the walls or columns of the building to determine the depths to which the change has penetrated in the mortar or concrete. A typical record of results obtained in two compartments of a storage building separated by 22½ in. brick division wall is given in Fig. 2. The record indicates that the heating in the parts adjoining this wall was, as might be expected, more severe than the heating of the walls near the windows, a feature attributable to loss of heat through the windows. The mean of these measurements on the division walls were used to plot the temperature gradient in Fig. 3. The surface temperature has been assumed to be the maximum temperature noted in the fire. This is probably higher than the actual surface temperature. The figure also shows the temperature gradients attained in a brick wall after exposure to 2 hours and 4 hours heating according to the standard time-temperature curve. It will be noted that the 2 hours test curve crosses the building fire curve, whilst the 4 hours test curve lies wholly above it. For present purposes it has been assumed that the severity of the building fire is equivalent to that period of exposure to the standard heating which causes the temperatures at all points in the thickness of the wall or column to be greater than those caused by the building fire. The equivalent severity of the fire in compartment A is therefore 4 hours. This basis of comparison gives results which are probably on the safe side, and more detailed analysis of the matter is necessary, taking into account criteria of failure, etc., before a more exact comparison can be made.

Corresponding curves for compartment B are shown in Fig. 4, whilst in Fig. 5 the results obtained in another storage building are shown. In this case the results are based on measurements of the depth to which the changes occurred in the reinforced concrete columns. The temperature gradient for the building columns and a 2 hours test on a reinforced concrete column are shown in Fig. 6, from which it will be noted, on the above assumption, that the fire was equivalent to about 2 hours exposure.

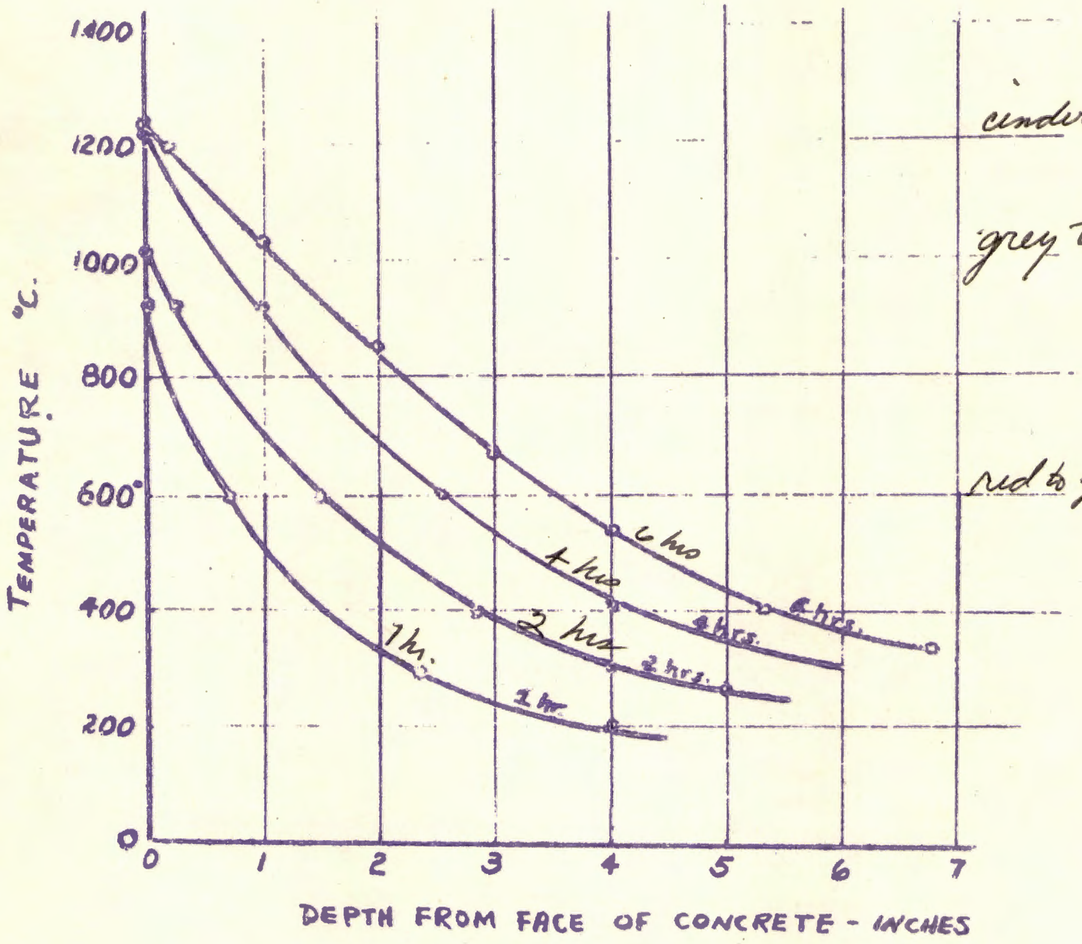
37

RELATION BETWEEN SEVERITY AND FIRE LOAD

From a knowledge of the fire load of any building or compartment it is now possible to determine the relation between the severity of the fire and the fire load. Estimates of the fire load in the examples quoted above gave values in the first case of 500,000 B.Th.U's./sq. ft. consisting chiefly of clothing for compartment A, and 400,000 B.Th.U's for compartment B, and 150,000 B.Th.U's./sq. ft. in the latter example. The method has been applied to various buildings ranging from office occupancies, having relatively low fire loads, to the storage building referred to in the first example.

Whilst the investigation has afforded much insight into the problem of fire severity, and has given results comparable with those obtained by Ingberg, analysis of the results has been concerned mainly with the immediate uses. Full analysis of the data has yet to be made.

Among the factors yet to be taken into account are the effects of rates of combustion and loss of heat on the equivalent severity and on the shape of the temperature gradient, as affecting failure.



cindering

grey to buff color

red to grey

FIG. 1. MAXIMUM TEMPERATURES ATTAINED IN certain type of CONCRETE HEATED ON ONE FACE FOR VARIOUS PERIODS IN ACCORDANCE WITH THE TIME-TEMPERATURE CURVE OF B.S. 476.

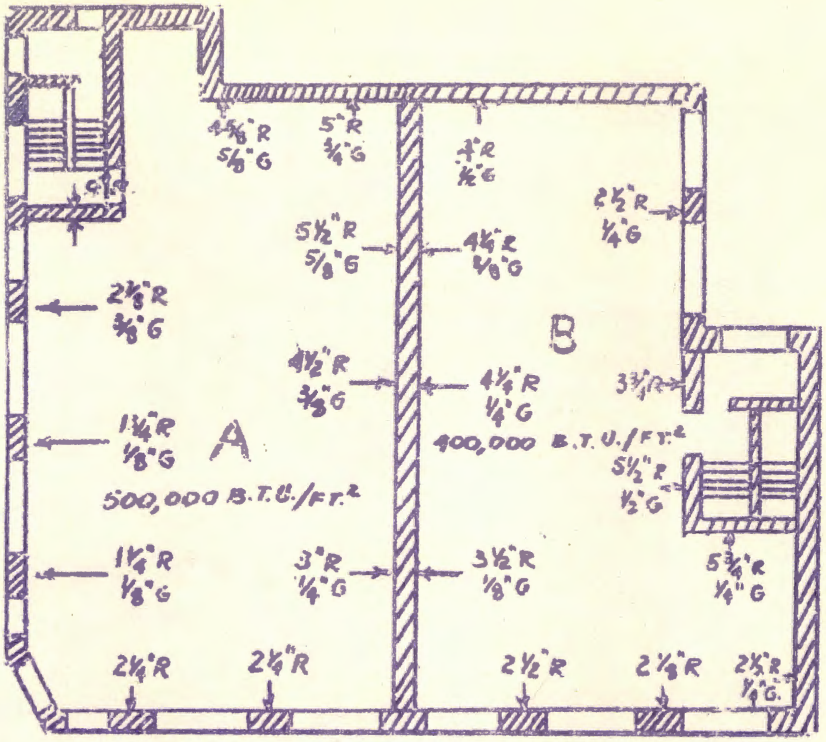


FIGURE 2 DEPTHS OF COLORATIONS
R = red G = gray

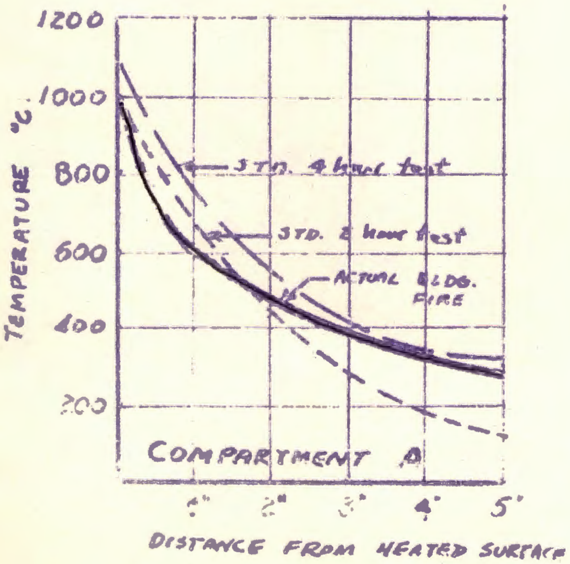


FIGURE 3 AVGE. TEMP GRADIENTS

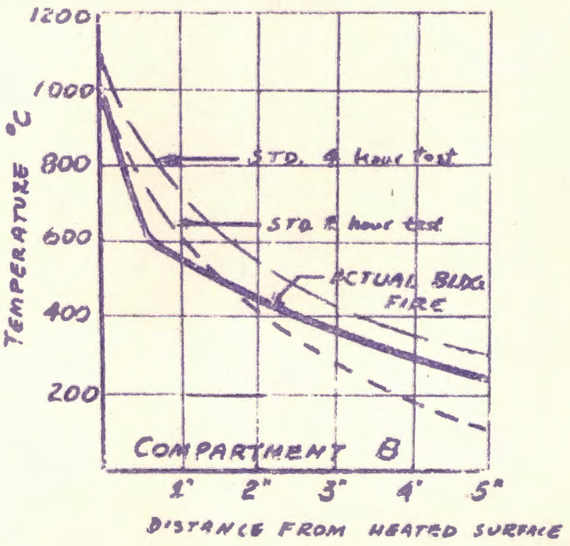


FIGURE 4 AVGE TEMP. GRADIENTS

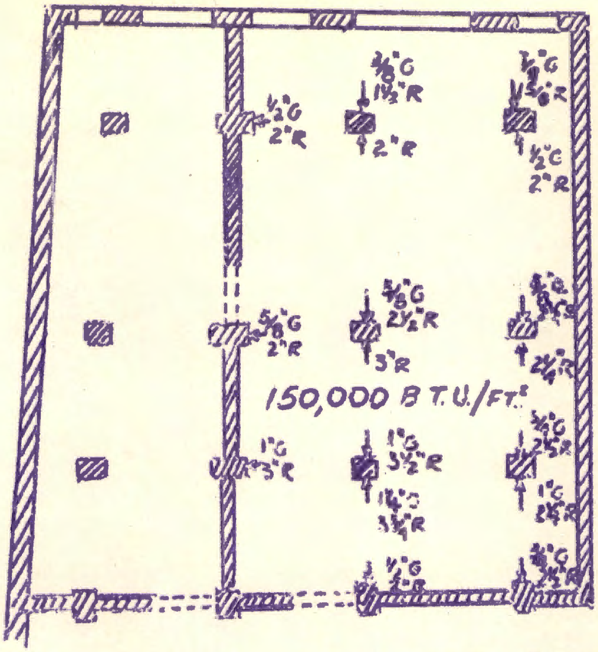


FIGURE 5 DEPTHS OF COLORATION
R = red G = gray

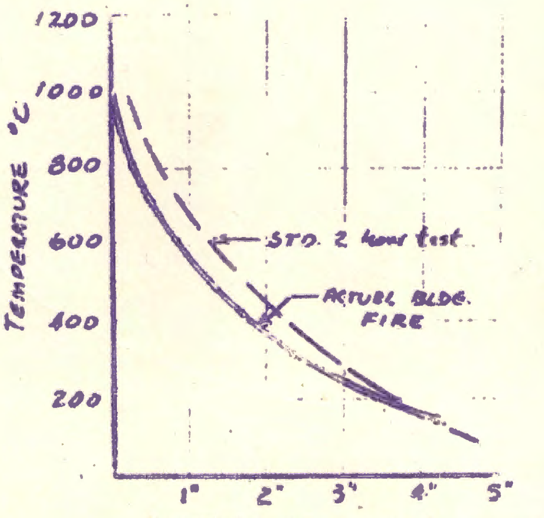


FIGURE 6 AVGE. TEMP. GRADIENTS INSIDE COLUMNS

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME DAVID LUCHT

SUBJECT FPE 309

CLASS DATE DEC. 10, 1963

INSTRUCTOR PROF. MAATMAN

1		11	
2		12	
3		13	
4		14	
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6		16	
7		17	
8		18	
9		19	
10		20	

94

Ave 69

1. Portland Cement is a mixture of Clay ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and limestone ($CaCO_3$). these components are mixed and heated to give clinkers composed of $CaO \cdot Al_2O_3$ and $CaO \cdot SiO_2$, which are ground to give the portland cement. When water is added, the CaO goes back to $CaCO_3$ i.e. $CaO + H_2O \rightarrow Ca(OH)_2$ and then upon drying, exposed to air (CO_2) $Ca(OH)_2 \xrightarrow[CO_2]{} CaCO_3$

2. a. ~~c~~ Perlite conc. is lightweight and ∴ ~~to~~ requires much less supporting steel - which is much more expensive than the perlite conc, esp. when used in lg. bldgs. Also Perlite conc has good FR properties

2. b. Gypsum plaster has very good fire restive properties and heat insul properties (protects steel). It contains lg amt of H_2O ($CaSO_4 \cdot 2H_2O$) and acts as a good heat insulator as the H_2O keeps the temp at 212° for considerable period. Also the assembly as a whole is comparatively thin and takes up less floor space

c. this assembly takes up less vertical space, than ord. steel-conc. assembly with suspended ceiling. this is because utilities can be run thru the cellular steel. the cellular steel also takes up most of the tensile stress of the assembly and often the conc requires no rienforcing rods.

d. ~~[illegible]~~. a suspended ~~ceil~~ ceil. is limited as to how many openings it may have & of what matl it may be const., esp. when fire ~~res~~ resistance of ~~steel co~~ steel bar joist-conc etc is desired. ∴ a sprayed on fireproofing on the unprotected steel will fullfill FR requirements and the suspended ceil. only must be decorative.

~~4~~

3.

1. An intumescent surface coating may be applied to the plastic after ~~or during~~ its manufacture. ~~which will increase~~

2. A mechanical mixture may be added to the plastic during its mfr. e.g. clorinated wax, antimony oxide

~~b.~~ 3. A chemical mixture may be added to the resin when formulated to form chemical bonds with the high organic polymers. also ~~to~~ e.g. clorinated wax, antimony oxide.

✓

4. a. Composite: Made up of incomb core surfaced either with a material such as wood or plastic (1HR) or steel or aluminum (3HR). these doors are good for ~~with~~ often used exits ~~an~~ as they aren't too difficult to operate and are fairly nice looking.

✓

b. Tin clad - these doors are B made up of a 2ply ~~w~~ solid wood core or a A → 3ply solid wood core, and surfaced with at least 30 ga. (?) steel. ~~the~~ ~~they~~ they provide good class A protection for fire walls when used on each ~~of~~ side of the wall. They may be either of the sliding or swinging type.

1

→ Ruggedness ?

✓ c. Kalamein - these are made up of a wood frame surfaced with 20 ga (?) steel. they are lighter weight than tin clad doors and :.

easier to operate, however
usually only give 1½ Hr. B
protection

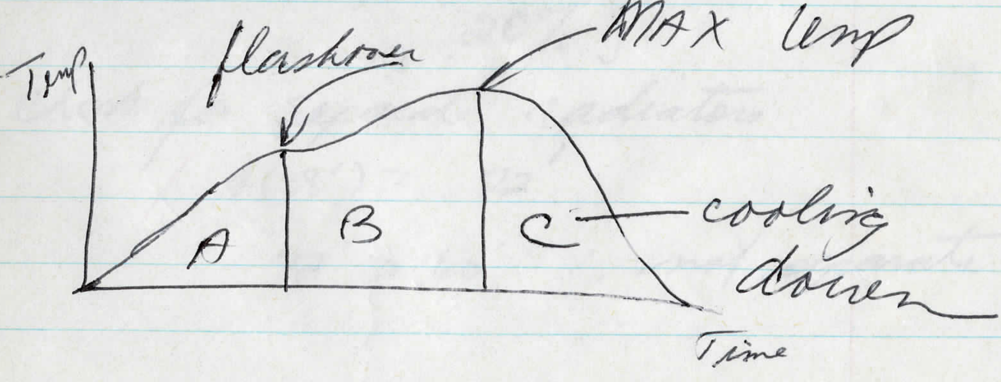
5. the NBS conducted ~~model~~ full scale bldg
burnout fires with known fire loading
and compared the (area) T-T curve
of this test with ~~the area~~
~~un~~ an equivalent area under
the ASTM std T-T curve
and obtained a corresponding
std. fire ~~severity~~ severity rating
in hours. NBS rates fire
load in lbs/ft^2

the British made a more
realistic attempt to correlate
std fire severity with fire loading

They used a std T-T curve ~ to ours and applied it to different bldg construction and found ~~that~~ conc. etc indicated different temp gradients applied by changing color. Then they went to actual bldg. fires and compared the indicated temp gradients in the actual burned out bldg construction to the std. curve. Then the calculated the actual fire load which had been present before the fire, in Btu/ft². + correlated it to the standard ~~burned with~~. Using actual bldg fires enabled them to better account for variations in forms of the matls in the fire load, whereas a high rise of temp and a small area under the ASTM TT curve was unrealistic, since it would indicate a small fire severity and actually the high temp would do considerable damage.

6. the time temp curve may be divided into 3 parts

-3



Area A ✓ More vent. makes time for
A less.

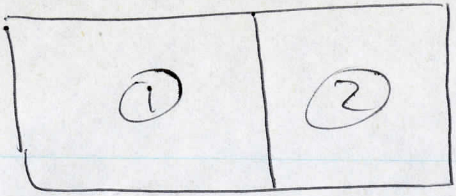
Area B ~~More~~ 25% or more
window area vent. has
✓ no marked effect on
time for Max temp (excess air)

@ < 15% ~~a~~ the time for
✓ Max temp is solely controlled
by vent. (oxygen starved)

✓ 15–25% partially controlled by vent.

Area C. More ventilation ⟹ Shorter
cooling time

→ effect on temp. of ventil.



7. ~~To~~ Consider OER for entire area ①
~~[illegible]~~ ~~[illegible]~~ ~~[illegible]~~ neglect stair windows + inset.

~~OER = 24 × 33~~

~~TWA = 10(3×9)~~

140
20
2800

OER = 24 × 142 = 34~~10~~ 08

27
20
540

TWA = 22(3×9) = 59~~4~~

$$\frac{593}{3410} = 17.4\%$$

598
3000

1/6 6)1.0

first boundary:

height 30
width 150
20%
} BD = 18'

Check for separate radiators

18
4
72

4(18') = 72'

72' > 60' ∴ not separate

OER for area ②

OER = 96 × 24 = 230~~0~~4

TWA = 16(3×9) + 2(9×40) =

16 30
480

432 + 720 = 1152

720
1152

40 9
360 2
720

50.0%

$\frac{1152}{230\cancel{0}4}$ = ~~50.2%~~

✓

height 30
width 100 } 34'

seems logical to consider 50%

check for conc. of exposure of large windows

24 40
960

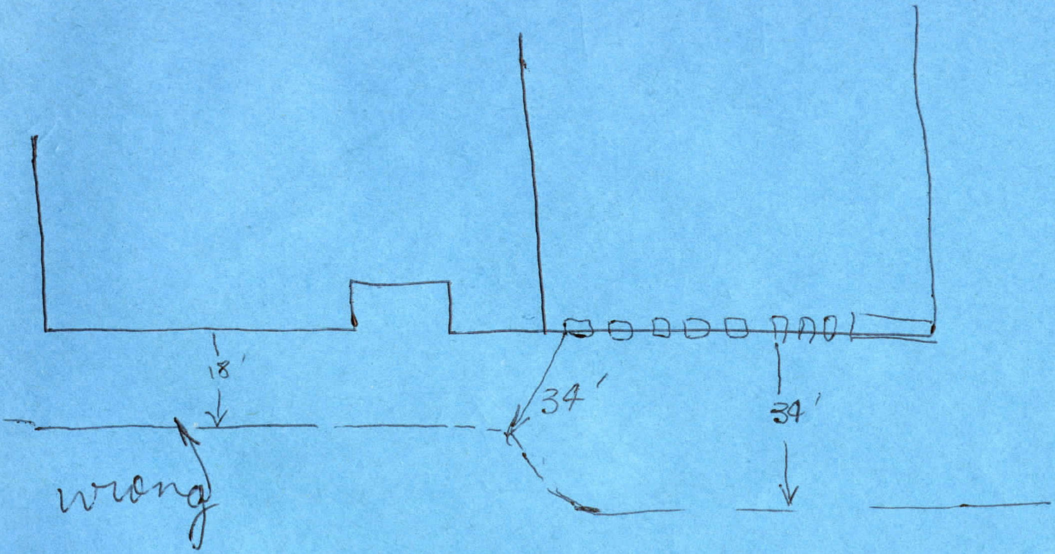
OER = 24 × 40 = 960

TWA = 2(9×40) = 720

✓

$\frac{720}{960}$ = 75%

height 30'
width 40'
100% } 34'



DOUBLE THESE separation distances for TOTAL SEPARATION between bldgs.

Check Concentration of exposure for one area in ①

ER = 42 x 24 } 1008

TWA = 12(3x9) } 324

$\frac{324}{1008}$ = 32%

42
24
168
84
1008

12
27
84
24
324

40%
height 30'
width 50' } 23'

See new book

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME LUCHT

SUBJECT

CLASS DATE

INSTRUCTOR

1		11	
2		12	
3		13	
4		14	
5		15	
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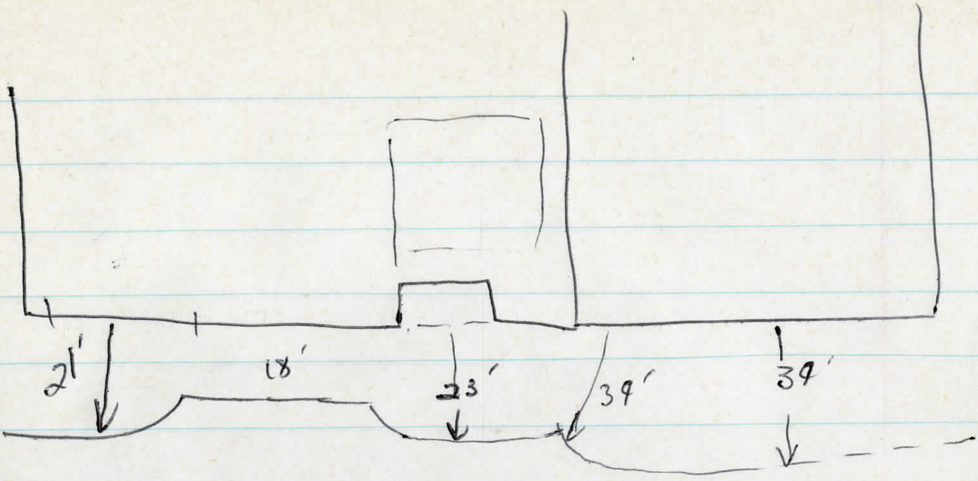


-2

another case of exp.

OER = 24 × ~~36~~ 33 = ~~860~~ 792

24/36

TWA = 10 × (3 × 9) = 270

$\frac{270}{\cancel{860}\ 792}$ = ~~31%~~ 34%

✓ 40%

ht 30' = 21'

width 40'

Need for exits governed by:

(1) Concentration of population
(2) Physical and/or mental condition of occupants.
(3) Height and area of Bldg.
(4) Extent and adequacy of public F.D. facilities (mostly ladder equip)
(5) Comb. of Interior finish

Psycological Problems.

1. People Do not Behave normally.
2. Fear is Prin. cause of Panic
3. Panic is contageous
4. People tend to leave bldg. in same manner they entered.

Basic Philosophy of Code:

(1.) * Based on concept of providing 2 independent choices for exit from any part of bldg.
- Independent - any single fire shouldn't be able to block BOTH.

(2) Based upon providing free + unobstructed path to this exit.

(3) Exits and their routes must be clearly visible and marked.

(4.) where size and arrangement of a bldg. is ∋ the presence of a fire is not ~~actually~~ immediatly apparent to all occupants, then a fire alarm sys. must be provided. (mult story + lg single story of cons. pop. density)

(5.) Code built on concept that all vertical openings must be protected. (few exceptions)

(6.) Code requires minimizing of Highly Comb. Interior trim, ~~[illegible]~~ esp in corridors, exit ways, and lg. assembly rooms.

(7) Code does not ~~to~~ generally require but recognizes the desirability of automatic fire prot systems as adjunct to life safety design.

The Code Its self -

Primarily Concerned with exits

Uses Population as yardstick.

1. Gross Area Method

e.g. 15 ft²/person - derived from extensive study. they are AVE figures - used primarily in proposed bldgs

~~2. Net Area~~ - figure based on outside demensions of bldg.

2. Net Area - inside occupied area.
Neglect corridors, rest rooms, closets etc.

3. Actual Count Method - After bldg is up you can count them.

Desirable to use all three and use one with highest safety factor. — MAX

EXIT DETAILS

What is an exit? It is a way of departure from interior of bldg to open air, outside, at ground level.

First floor - door to outside
Upper floor - corridor - stairs - etc to outside.

If enclosed stairwell - exit would be door into enclosed stair well assuming it leads directly to outside.

Somethings meet Def but not accepted, i.e. knotted rope, portable ladder etc.

Exit Measurement –

Unit of exit width 22" door or stair.

(Ave width of Person.)

Fractions ignored unless >12"

a.e. 28" = 1 unit

34" = 1½ unit

also 43" = 1½ unit

how to meas. stair width.

Ignore encroachment of rail up to 3½" on ea. side.

(recognize value of rail)

if ≥88" must have intermediate hand rail.

For door – permit encroachment of 2" ~~[illegible] [illegible]~~ for ea. 22". ~~Ae~~ a.e. permit <u>total</u> 4" jamb for 44" door.

When calculating # exits required, round off to next ray or Whole # unless fraction < 10% of whole #, drop fraction.

Code based on 2 speeds of exit travel

45 people/min/unit exit width
assumed rate down stairs

60 people/min/unit
assumed rate thru level exit (door)

Example: pg. 43

Educational — Stairs — 60 persons/unit exit width

$\frac{60}{45} = 1.33$ MIN — (not complete evac, but everyone should be in stairwe

Assembly. — pg 75 2111 b.) 75 persons/unit — wh. is protectio

$\frac{75}{45} = 1.67$ MIN

Both use same rate ∴ ea. occy requires diff time of evacuation

Distance to ~~exit~~ exits - meas. along centerline of travel

is distance to stairwell door if stairs is prot, openg to outside
If not prot, distance clear to outside.

In general code requires in open areas, meas distance from most remote point (whse etc.)

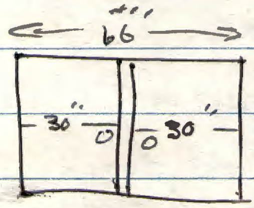
Where bldg is divided into rooms, meas from door in room ONLY if room is not occupied by > 6 persons + if not more than 50' travel dist) (hotel, apt, etc)

Isles and Corridors leading to exit
1. must have ~~with~~ width at least = to that of exit
2. must have width = 75% of total width ~~of total width~~ of ~~exit~~s they feed.
stairs

Doors – min. door width of 30" except in private dwelling. Max width of <u>single</u> swinging door is 48". (so they won't be too heavy)

2. All exits doors must swing with direction of exit travel.

In general code permits only swinging door, sometimes one swinging & one sliding in fire Wall. Where a doorway is ÷ into smaller doorways, ea. indiv. door must be Credited separately.



= 2 units

Code requires floor level to be same and horiz. on ea. side of door for width of door and width of door out on ea. side.

In general requires panic hardware for exit doors on all schools + theatres and any other place of assembly > 500 people.

Revolving doors or Turnstyles -
Only can be used as exit on street floor to outside + can't use them at foot of stairway, and credit ea. turnstyle or revolving door as $\frac{1}{2}$ unit regardless of size, and can only use them for $\frac{1}{2}$ the required exit requirement for street level, and at any given location revolving door capacity can't be greater than swinging door capacity within 20'

If you use 4 units of revolving, you need 4 units of swinging within 20'.

Stairs — Pg 147-8
Code divides stairs into 3 classes

A. — Conc. of population

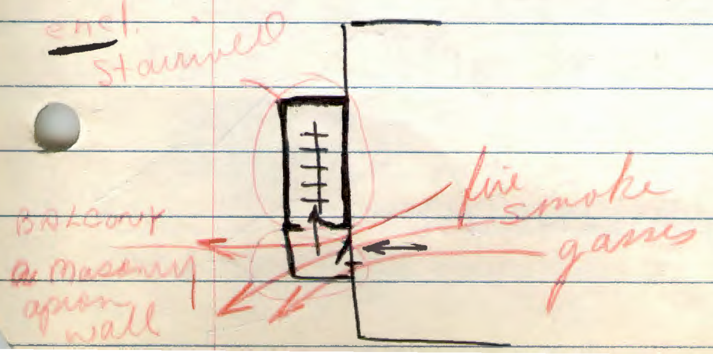
B. — all except A

C. — Permitted in Bldg built before code in B bldgs only.

Recall Max 66" betw rails
height of rail

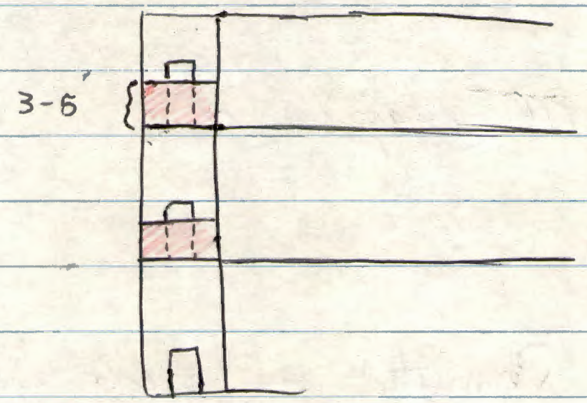
Outside Stairs 157
OK if permanently fixed
not >1 sty or appear to be >1 sty.

Smokeproof Towers 158
Considered most effective means of egress.



Called Smokeproof tower
since smoke, gases, fire
etc will vent to
outside + can't get
in stairs

In ord. stairs, door may be left open + this is obviously not too cool - in smoke proof tower, it doesn't matter since smoke won't enter stairwell.



RAMPS 159

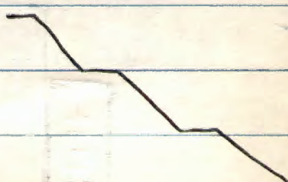
A } see book
B
C

FIRE ESCAPE STAIR 162-5

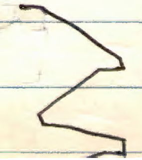
Type stairway added after bldg built - only pre ordinance (existing) bldg.

Can only be used for 50% exit req.

A. straight run type



B Return Platform



C

Don't recognize ropes, poles, etc.
portable ladders.

Some poor exits recognized to limited extent pg 169

Class D - unoccupied (e.g. ~~to~~ elevator) pent house

E - existing wood ~~ladders~~ fire escape
1 or 2 fam. dwgs or sm. dorms.

F - wood ladders

Slide Escapes - 173
In educational bldg
only on existing bldgs
up to 25% req.

Except high hazard Industrial
allowed for full req.
⇒ fastest possible exit

One unit width @ 60/min
+ must have drill program.

Escalators - 178
not on educ. bldgs, etc.

Nor

Max credit 2 units width
90/min

Many escalators may travel
>90/min, but others may fail

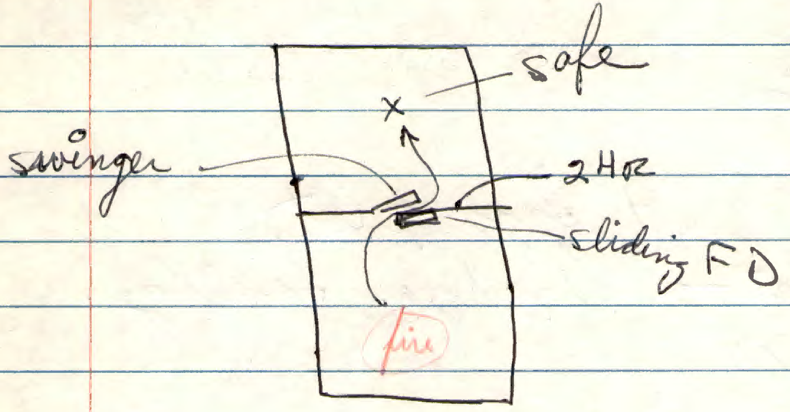
Elavators - 181
not recognized - could have power failure

Possibly people couldn't get elevator
in time

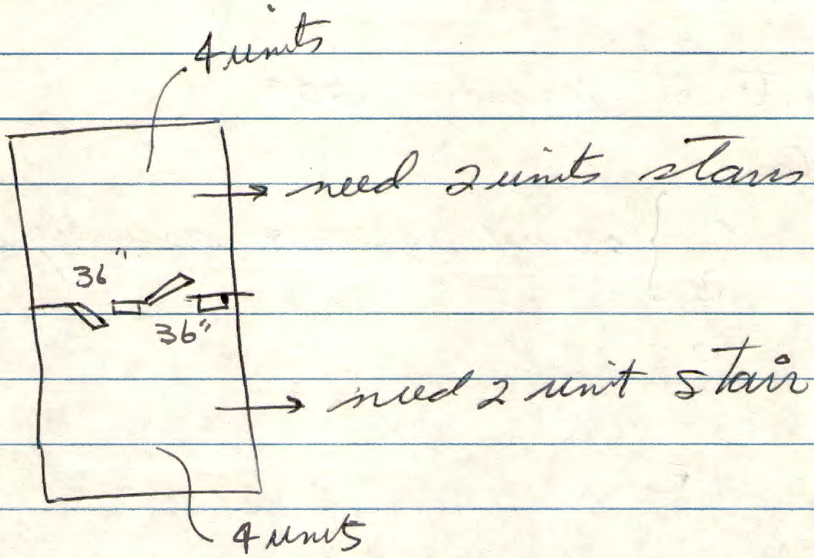
Confusion - people push wrong
buttons → may be
let off on fire floor

Elevator may not move
because door held open
by more people trying to
get in.

Horizontal Exit 182



for both directions



horiz

Advantage - don't have to provide as much stairs

Can be 50% horiz as reg.

3#/person for total floor occy must be provided on ea side

Construction & Protection 187

~~Dry Basic~~ .

P 4302 Reg. all vert. opgs. prot.
except — Low hazard + ord haz.
see pg 191

Interior Finish 200

Class
A } areas of egress + assembly area.
B }
C
D
E

Alarm Systems 203

Educational Occy 35

A - 1 STY with any type egress
mult. sty with all ext. egress.

B - mult. sty with encl. stairs
C - sprinkler See pg 40
D - open plan schools — no perm. fixed partns
E - existing schools

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BASIC PROCEDURE FOR APPLICATION

OF

N.F.P.A. BUILDING EXITS CODE

1. Calculate total population for each floor level and/or section of a building by as many of the following methods as is feasible, and use the highest population figure obtained as the basis for calculating the required total quantity of unit exit widths for each floor level and/or section. (Section 11)
    - (a) gross floor area method
    - (b) net floor area method
    - (c) actual count method
2. Calculate total number of units of stairway and ground floor exit width required for the particular occupancy in question. (Sections 21 thru 29)
3. Arrange the required aisles, corridors, doors, stairways and street floor exits in such a manner as to satisfy the various requirements of the code. These include the following:
    - (a) two independent and remote exits from each floor level or large room.
    - (b) specified "distance to exit" limitations for a particular occupancy.
    - (c) protection of stairways used as exit facilities.
    - (d) directness and continuity of path of exit travel.
    - (e) balance as much as possible the total number and capacity of exits for a floor level as between the two or more independent directions of exit travel.
    - (f) adequate path of egress outside of building leading away from street floor exits.
4. Check the various possible construction and occupancy features involved:
    - (a) interior finish requirements.
    - (b) possible use limitations on specific construction types.
    - (c) protection of other vertical openings.
    - (d) requirements for segregation of hazardous uses.
    - (e) special occupancy use requirements.
5. Check the various possible protection features involved:
    - (a) fire alarm system requirements.
    - (b) exit signs and lighting requirements.
    - (c) automatic detection and/or extinguishing system requirements.
6. Check the various possible operating features involved:
    - (a) fire exit drills.
    - (b) maintenance features.

3 basic aspects of BC.

1. Sanitation
2. Structural Reg.
3. F.P.

Mimio notes:

1. Provide life safety to occupants
2. " " " firemen
3. " " " adjoining property
4. preserve property

---

* must consider if given B.C. is within limits of local constitution - can't be excessive - just may make min. reg.

Important aspects of NBFU BC.

1. life safety aspect.
   - Exit Reg. pg. 53 - patterned after Bldg. Exits code NFPA 101, but may be slightly different? (diff times of revision)
   - pg. 170 - article 17 - only chapter wh. applies to existing Bldgs.
     - life safety
       local official usually given descretionary power.
       - only place where F.E. allowed
   - pg 56 604.2 ~ NFPA 101
   - pg 98 - 808.2 use ASTM E84 & F.S. ratings

Special Occy. Req.

Pg. 24 Sect. 312 - b. -
313 - a - one of few places where F.R. const. REQ.
314 - 319
(319 ≐ NFPA 101)
320 = NFPA 101

~~4.~~ Regulating Construction to limit spread.
vertical openings
article 6
pg 68 article 7 -
NFPA 220
Defines Const.

¶ 702.7 - gives hour. req.
703.7
704.4
705.4
for encl. shafts etc.
for ea. type Const.

Pg 39 Restrictions on ht. + area
height Table 401
Area Table 402
¶ 402.3
a - g

Note: Don't require F.R. const. but sure do encourage it. (in high cost realestate areas, very high bldgs are very desirable ∴ must be F.R.)

Sprinkler Part:

again Don't directly require it, but strongly encourage it.

~~[illegible]~~

pg. 101
810.1 "Define" Combu
~~to~~ Few places where Sprink is Req.
a., b, c, - - - - f certain ht & area & fire load
g - h Parking gar.
i - rep. gar.
j - bsmt - a lot of cities use this ¶ even if not this Code.

only places where Sprink Req.

ul

LA School Tests

Test # 1

Worked with Vents

→ didn't work.

Not too practical for life safety.

810.1 cont.
l:-

~~pg. 128~~ though basicly performance reg. code, in this
pg. 126 case SPEC. reg. code.

909.5 -

pg. 89 - sect 801 parapets

give limits for exposure problem.

pg. 91
sect 803 - exterior openings (recall British approach)

pg. 69
702.6 Limits on areas of windows to a small extent.

703.6 repeats 702.6

Pg. 38 - Concerned with conflagration Hazard.
Fire Limit:
all merc. & business districts closely built up with 200 ft belt around it.

pg. 90-91 802.
Also concerned with Conflagration Hazard.
Roof Covering Materials

Pg. 275 - Appendix L.

Suggests, if wood shingles are to be permitted, how it should be done. (In some areas it is politically impossible to outlaw it)

Mimeo notes

Pgs. 9 + 10

Comparison of other model Codes. Basic difference is in reg. wh. are judgement types (area, height, etc.) interior finish (areas in wh. more research is needed)

Pg. 10. - interior finish reg. in Southern Code - good example of effect local industry can have on B.C.

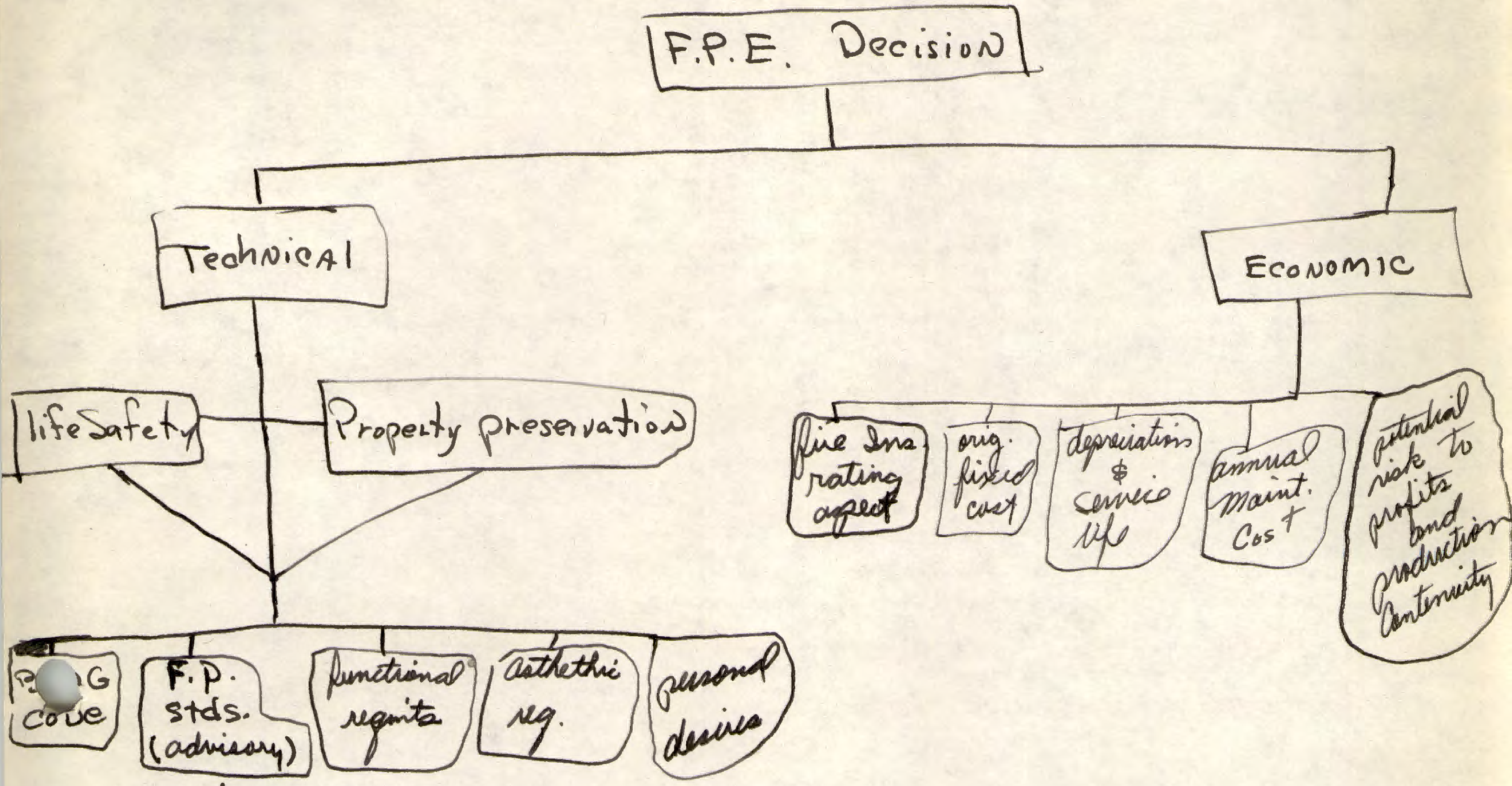
OUTLINE FOR APPLICATION OF NATIONAL BUILDING CODE

1. Determine construction classification - Article VII (pages 68-84)
   (must meet all req. to be classed certain class) (701.)
2. Determine occupancy classification - Section 300 (pages 21-23)
3. Check applicable special occupancy requirements - Sections 310-22 (pages 23-37)
4. Check restrictions if located within the fire limits - Section 400 (pages 38-39)
5. Check height and area restrictions - for its class const - Sections 401-02 (pages 39-43)
6. Check exit facilities - Article VI (pages 53-66) or Article XVII (pages 90-91) if existing building.
7. Check thickness of exterior walls - Section 909-14 (pages 126-139) and for any exposed walls, also check Article VII (pages 68-84) for wall requirements within appropriate construction classification specifications.
8. Check parapet requirements - Section 801 (pages 89-90)
9. Check requirements for protecting exterior wall openings - Section 803 (pages 91-92) and also Article VII (pages 68-84) for window area limitations.
10. Check roof covering requirements - Section 802 (pages 90-91)
11. Check interior finish requirements - Section 808 (pages 97-99)
12. Check requirements for enclosure of vertical openings - Section 604.2 (pages 56-57) and applicable partition requirements in Article VII (pages 68-84)
13. Check requirements for automatic sprinkler systems and standpipes - Sections 809-10 (pages 99-104)
14. Check requirements for various utility systems - Article X (pages 157-165), Article XI (page 168), Article XIV (page 183) and Article XV (pages 185-86)

Reference to Other Codes.

Engineering Economic Aspects of Bldg. Const.

~~F.P.E. Decision~~



↑
may be advisable to go beyond code.
NFPA stds etc. (advisory)

SUMMARY AND ANALYSIS OF 1959-61 LOS ANGELES SCHOOL FIRE TESTS

309 Conf.

11

by

Professor Gerald L. Maatman, Director
Department of Fire Protection and Safety Engineering
Illinois Institute of Technology

The tragic fire at the Our Lady of Angels School in Chicago on December 1, 1958, which took the lives of 95 pupils and teachers, produced a great amount of interest throughout the country on the subject of school fire safety. In Los Angeles, the Fire Department obtained the use of the Stevenson Junior High School which was due to be demolished and funds were obtained from the Educational Facilities Laboratories of the Ford Foundation to conduct fire tests. Other sponsoring agencies included the Los Angeles Board of Education and the California State Fire Marshal's Office. Some 61 tests were conducted between April 16th and June 30, 1959.

After the results of the first test series had been evaluated, it was decided to conduct additional tests and 101 tests were run between June 30th and July 30, 1960 at the St. Agnes High School which had been donated by the Los Angeles Catholic Archdiocese. Subsequently, 16 additional tests were conducted at the Santa Fe High School between February 6-14, 1961.

The results of these three series of fire tests have been published by the N.F.P.A. in two volumes titled "Operation School Burning."

Each test series will be separately described and evaluated and the last section of this article will then sum up and analyze the conclusions drawn by the various sponsoring agencies.

TEST SERIES NO. 1

STEVENSON JUNIOR HIGH SCHOOL, APRIL 16-JUNE 30, 1959

The building was 3 stories with part basement with brick bearing walls, part concrete and wood floors and ordinary wood joist roof. Only a 90 foot long section of the building was used for the tests. This section of the building included two open stairwells and a center corridor with classrooms on either side. Interior partitions were 6" hollow tile in corridors and metal lath and plaster on wood studs between classrooms. Doors to classrooms were of 1-3/4" wood paneled type with clear glass in wood frame transoms above.

Six thermocouples were located in the corridor on each floor level. Three were placed 8" below the ceiling and the other three five feet above floor level.

Two photoelectric cells and light sources were installed near the opposite ends of the corridor at each floor level with the light beams projected across the corridor width five feet above floor level.

Criteria for untenable smoke and temperature conditions were pre-fixed as follows:

(1) Smoke

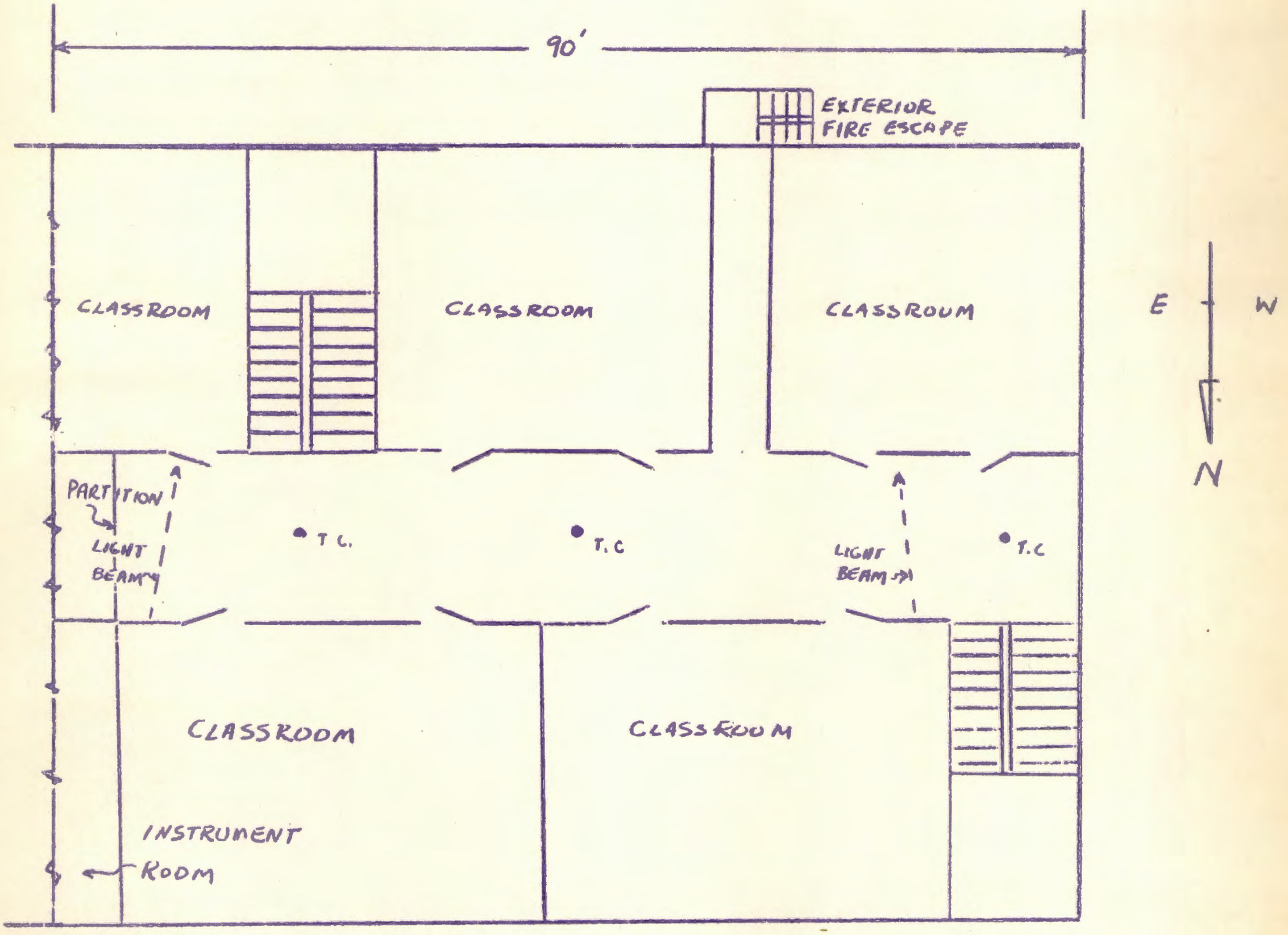
(a) visibility - illuminated placard with 12" letter placed 45 feet from observer and five feet above floor level. Conditions considered to be untenable when placard no longer visible.

(b) irritability - used judgment of observers in corridors.

(2) Temperature - established limit of 150°F. at 5 foot level in corridor.

Test fires were run with wood pallets stacked in piles with most involving 1400 lbs. of wood. Fires were ignited with two cotton and gauze torches soaked in thinner.

Purpose of Test Series No. 1 - Investigate methods of protecting multistory open stairwell school buildings to provide a safe environment for occupants under fire conditions.



**TYPICAL UPPER FLOOR PLAN
SANTA FE HIGH SCHOOL**

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TEST RESULTS

Series A-Tests With No Protection to Provide Basic Comparison

see instant smoke detection wouldn't allow 3rD. TO evacuate
a.e. 1 min/floor rule of thumb

Using a wood pallet fire located in the east stairwell basement landing, untenable smoke conditions were produced in 2 and 3 minutes respectively in the east and west sections of the first floor corridor, in 4 and 4½ minutes in the second floor corridor and 5½ and 6½ minutes on the third floor. Untenable temperature conditions were not present until 7½, 9 and 11 minutes respectively on the three floors.

When the same test was repeated with various doors and windows open (to simulate summer conditions), untenable smoke conditions were reached in about the same times except in the third floor corridor which became untenable in 4 and 4½ minutes respectively. Untenable temperature conditions were developed in 5½, 7½ and 9½ minutes on the three floors.

Using a wood pallet fire located in a second floor classroom (with windows and transom open), untenable smoke was developed in 6 minutes on the third floor and 10 minutes on the second floor. Repeating this same test under summer conditions, untenable smoke was developed in 4½ and 5 minutes respectively.

Series B-Natural Draft Vent With Fusible Link Operation

Using a 21 ft.^{2} vent, it opened after nine minutes. However, untenable smoke conditions had occurred within 4 to 5½ minutes. Increasing the vent opening to 42 ft.^{2} decreased its opening time to 7½ minutes but still occurred at least 2½ minutes after untenable smoke conditions prevailed.

Series C-Tests With Sprinkler Protection Only

These tests were conducted for the purpose of determining the effectiveness of sprinklers installed in corridors and stairways to keep smoke and temperature below untenable levels when a fire originates in a non-sprinklered area. Four tests were conducted with three involving a stairwell fire and the fourth a classroom fire. In almost every case, untenable smoke conditions were reached in most of the corridors prior to the operation of a sprinkler head and even when a head operated prior to this time, it did not prevent the subsequent rapid build-up of untenable smoke levels. Insofar as temperature build-up was concerned, the operation of sprinklers either greatly delayed or prevented the development of untenable temperature levels except in locations close to the fire.

Series D-Tests Combining Stairwell Roof Vents and Sprinkler Protection

These tests attempted to determine the effectiveness of vents in combination with sprinkler protection to control smoke and heat build-up in corridors when a fire originates in an unsprinklered area. Four tests were conducted, two involving stairwell fires and two classroom fires, the last of which involved a test with sprinkler protection provided within the room of origin.

The two stairwell fire tests and the first classroom fire test gave results similar to those of Series B and C. Untenable smoke conditions were reached before or soon after operation of the first sprinkler head and the subsequent operation of additional heads and the roof vent did not clear the building of smoke. Once again untenable temperature levels were either greatly delayed or prevented from developing.

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In the second classroom test fire, sprinklers operated within the classroom after $2\frac{1}{2}$ minutes but the wooden pallets shielded the fire from the sprinkler discharge so that the fire could only be held in check. The second and third floor corridors developed untenable smoke levels within one to two minutes later.

Series E-Tests Combining Curtain Boards and Roof Vents

Ten tests were conducted combining different sizes of stairwell roof vents with draft curtains (extending down to 7 feet above floor levels) located in various combinations. In addition, automatic door closers with fusible link hold-open devices were installed on certain corridor and classroom doors in two of the tests. Again, it was found that untenable smoke conditions developed almost as rapidly as in Series A. In addition, the hold-open devices on the various doors did not operate until several minutes after untenable smoke levels had been reached. The draft curtains did, however, slow down the development of untenable temperature levels in areas remote from the fire.

Series F-Same As Series E Except With Simulated Summer Conditions

Eight tests were conducted in this series in a manner similar to Series E. The additional venting effect produced by having various classroom windows, transoms and exit doors opened reduced the smoke build-up somewhat but untenable conditions were still reached in most cases although they did not last as long. As would be expected untenable temperature levels were reached in somewhat less time than under Series E.

Series G-Tests Combining Roof Vents and Curtain Boards With Classroom Fires

Four tests were conducted, two involving classrooms on the second floor and two on the first floor. In each case, transoms between the room and corridor were open and two classroom windows were open at the bottom. In general, untenable smoke levels developed as quickly as the comparable Series A test without protection. In addition, the draft curtains around the stairwell opening interfered somewhat with the venting action of the roof vents.

Series H-Tests Combining Roof Vents and Curtain Boards With Corridor Fires

Four tests were conducted with 700 lb. pallet fires started in the first floor corridor in each case.

Once again, the roof vents did not operate effectively enough to prevent the build-up of untenable smoke levels. When curtain boards were omitted from around the stairwell openings, the vents were able to clear the smoke conditions in the corridors in about 3 to 5 minutes after they opened. However, in such cases, untenable temperature levels were reached almost at the same time as the original untenable smoke conditions.

Series I-Tests Involving Curtain Boards and Roof Vents With Forced Draft

Three tests were conducted with fires started in a stairwell. Four 60° water spray nozzles were installed above one of the stairwell roof vent openings and discharged in a manner to produce a venturi effect. Curtain boards were installed in the corridors only. The operation of the water aspirator helped clear the smoke from the corridors more quickly than otherwise but smoke exceeded untenable levels for several minutes prior to this effect and untenable temperatures were reached in the meantime.

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Series J-Tests Combining Roof Vents, Curtain Boards and Sprinkler Protection

Five tests were conducted with all of the fires started in a stairwell. In four of the tests, no sprinkler protection was provided over the fire and untenable smoke conditions occurred within 3 to 4 minutes which in each case was prior to the operation of any sprinkler head or the opening of the roof vent. In the fifth test, sprinkler protection was provided in the stairwell where the fire was originated. It was unable to completely extinguish the fire due to shielding by the uppermost wood pallets but controlled it and untenable smoke conditions resulted only in the portion of the first and second floor corridors located adjacent to the stairwell. Venting was rather poor due to the relatively small temperature differences which gave an insufficient stack effect.

Series K-Tests Supplementing Series J With Aspirator for Roof Vent

Three tests were run, one in a sprinklered second floor classroom, another in an unsprinklered first floor classroom and the third in a stairwell to determine the possibility of increasing the venting effectiveness by the use of an aspirator in connection with the stairwell roof vent.

In the case of the unsprinklered first floor classroom fire, the venting action was insufficient and the first floor corridor was untenable in 4 minutes with 6 and 9 minutes respectively for the second and third floors. However, temperatures were kept within the tenable range in the first floor corridor for 13 minutes.

The fire in the second floor sprinklered classroom was shielded from sprinkler discharge by two inches of newspapers on top of the stack of wood pallets and thus the fire could only be controlled. Consequently untenable smoke conditions were produced in the second floor corridor in 2 and 5 minutes in the east and west sections and in 6 minutes within the third floor corridor.

Series L-Tests to Study Performance of Combustible Acoustical Tile

Three tests were conducted, the first with ordinary combustible acoustical tile on the ceiling of the first floor corridor and the fire ignited on the basement landing of a stairwell, the second identical except that the east half of the corridor ceiling tile had been covered with a fire retardant paint and the third identical with the second except that the fire was started in the first floor corridor at the west end.

neglected to meas smoke + gasses in CLASSRMS

In the first test, the ceiling ignited after ten minutes and flashed the full length of the first floor corridor. However, it should be noted that both untenable smoke and temperature conditions existed in the first floor corridor after 1½ minutes and untenable smoke on the second and third floors after 2½ and 4 minutes respectively.

In the second test, the small blue flames were evident around the area where the exposure fire impinged on the ceiling tile but no propagation of flame occurred down the ceiling. However, once again untenable smoke and temperature levels were reached in the corridors at times almost identical to the first test.

In the corridor fire test (500 lbs. of wood pallets), the ceiling tile ignited after 18 minutes and flashed over the half of its length which was not protected by a fire retardant coating. Here again, untenable smoke conditions existed in the first floor corridor after 10 minutes and were developed in only 8 minutes in the second floor corridor.

Series M-Tests to Study Performance of Smoke Detection Units

Six tests were conducted to measure the effectiveness of ionization type smoke detectors. All of the test fires consisted of 1400 lbs. of wood pallets and were set in the west end of the first floor corridor. Two detectors were installed in both and second and third floor corridors and one was provided near the east end of the first floor corridor.

In the six tests, smoke detection time varied from 1 to 2-1/3 minutes on the first floor and 1-1/3 to 2 and 2-1/3 to 3-1/4 minutes on the second and third floors respectively.

It should be also noted here that automatic fire detectors (rate-of-rise heat detection type) were installed within the building throughout most of the tests within Series B through L and that, in general, they detected the test fires at about the same time that untenable smoke conditions developed in each case.

Conclusions of Testing Agencies

1. With the type of fires used in these tests and no fuel added due to the construction of the building, smoke was the principal life safety hazard. Untenable smoke levels preceded untenable temperature levels in nearly every test. usually true except if you have fast burning flamm. liq.

2. Natural draft roof vents of the sizes (21'-42'-63') tested and the manner opened did not keep corridors and stairways tenable for exit use. Where fusible link devices were used, untenable smoke conditions occurred in every case before the vents opened. Even when vents were opened prior to the start of the test, untenable smoke conditions followed in some cases. Also, in those cases where better venting action was achieved from a smoke standpoint, untenable temperatures were reached much more quickly.

3. The addition of draft curtain boards did not materially cut down the rate of smoke distribution within the building and, in some cases, made the situation worse by reducing the effectiveness of the roof vents. They did, however, prove to be effective in reducing the rate of temperature build-up.

4. The forced draft induced by the use of a water aspirator was of insufficient capacity to materially increase the effectiveness of the roof vents. It would appear that extremely high water discharge rates or the use of a relatively expensive motor driven fan would have to be used to be effective. In addition, the operation of such forced draft would have to be automatic and would have to be actuated early in the fire development.

5. Partial automatic sprinkler protection did not prevent smoke spread throughout the building even when installed to provide a water curtain between the test fire and the corridors.

6. Complete automatic sprinkler protection will maintain low temperatures and will prevent the build-up of smoke and irritating gases to untenable levels if the fire is not shielded from the sprinkler discharge.

7. A combination of roof vents and partial sprinkler protection will not prevent the rapid build-up of untenable smoke levels throughout the building.

8. A combination of roof vents, curtain boards and partial sprinkler protection will not prevent the rapid build-up of untenable smoke levels throughout the building.

9. The use of fusible link actuated devices on doors, vents, etc. are not satisfactory as untenable smoke levels are built-up before the devices will operate. Bldg. exits code agrees.

Fail safe electro magnet door holders have been developed wh. act on smoke detect. + sprink. + F.A. etc.

10. Enclosed stairways will not provide protection against the spread of heat and smoke unless the doors are kept closed or are closed immediately after an outbreak of fire.

11. Automatic heat detection devices operated so as to detect the fire at about the same time that untenable smoke conditions were reached in the building and therefore are not satisfactory for life safety purposes in this particular type of building.

12. Automatic smoke detection devices detected the presence of fire before untenable smoke conditions were reached but not always in sufficient time to allow complete evacuation of the test building and therefore it is questionable if they would prove satisfactory under all conditions.

13. The untreated cellulose fiberboard acoustical tile, when ignited, spread flame quite rapidly down the corridor. This performance was quite radically altered when tile which had been coated with a fire retardant paint was substituted.

ANALYSIS OF TEST SERIES NO. 1

His Comments

It would appear that the use of a considerable weight of wood pallets (either 700 or 1400 lbs. in the various tests) to create the test fire was somewhat unrealistic insofar as simulating a normal school fire was concerned. This large amount of concentrated fuel produced a fairly fast developing fire of considerable magnitude which I do not feel was representative from a time or severity sequence of fires in school occupancies.

In addition, no attempt was made to monitor temperature and/or smoke levels in individual classrooms during any of the tests to determine how long occupants could safely remain in those rooms awaiting evacuation by fire department ladder equipment. Also, no attempt was made to monitor toxicity, CO, CO_2, content, etc. in the corridors during any of the tests.

Very little effort was made to determine the potential effectiveness of complete automatic sprinkler protection to restrict the development of untenable smoke levels.

Not enough classroom and corridor tests were performed to form any definite conclusions as to the particular characteristics of the life safety problems involved therein.

The problem of the life safety aspects of combustible acoustical tile was given only a cursory examination and the brief data obtained would make it appear that the flame spread characteristics of the tile were not too significant because of the development of both untenable smoke and temperature levels in the corridors several minutes prior to the ignition of the tile itself.

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TEST SERIES NO. 2

ST. AGNES CATHOLIC HIGH SCHOOL, JUNE 30-JULY 30, 1960

The building was three stories and full basement with brick bearing walls and wood joisted floors and roof. The building had three open stairwells all emptying into a center corridor (see diagram). Interior partitions consisted of both w.l. and p. and m.l. and p. on wood studs. Classroom doors were combination wood paneled with plain glass in top half with plain glass transoms above. The building was L shaped but only the 155 foot long main section was utilized for the tests.

Six thermocouples were symmetrically located in the corridor on each floor level. Three were placed 8" below the ceiling and the other three five feet above floor level.

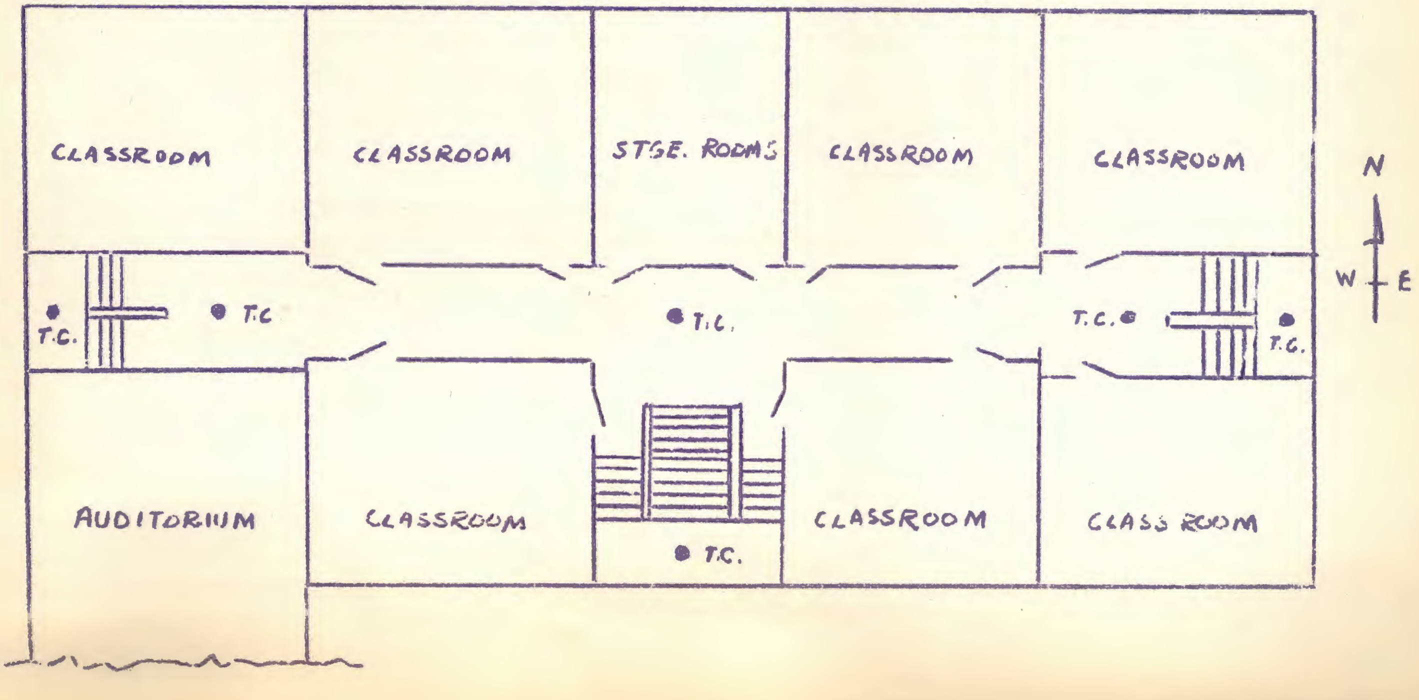
Light sources and photoelectric cells were installed across the entrance to each stairway at each floor level with the light beam projected five feet above the floor level.

Criteria for untenable smoke and temperature were identical with those used in Test Series No. 1.

Subsequent to Test Series No. 1, the Los Angeles Fire Department had conducted numerous unannounced fire drills at various schools. Their results indicated that it takes approximately one minute per floor to evacuate a school building. On this basis, it was assumed that it would take three minutes to evacuate the St. Agnes School after the receipt of a fire alarm.

Approximately one-half of the test fires involved wood cribs, 2'x2'x2' with an approximate weight of 75 lbs. Three different types of cribs were used, varying in construction and arrangement of igniting combustibles beneath them. These were designated as slow, medium and fast depending upon rate of temperature rise.

The remaining half of the test fires were set up to simulate typical school fires and included waste basket, baled newspaper, ditto fluid, paper supplies, arson fires, etc.



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PURPOSE OF TEST SERIES NO. 2 - To investigate the potential effectiveness of various types of automatic detection devices and sprinkler systems to provide life safety protection in multi-story open stairwell school buildings when subjected to a considerable number of different types of fires. In addition, the investigation of various types of ceiling finishes to determine their potential hazard to life safety.

TEST RESULTS

Series A-Basic Automatic Detection Device Tests

A total of 14 tests were conducted, 7 in classrooms, 4 in small storage rooms or closets and 3 at the base of stairwells. In all of the 11 room fires, doors and/or transoms and in several cases room windows were at least partially open to create some favorable draft conditions. The following eight basic types of fire detection devices were evaluated in each test:

(1) fixed temperature type heat detector - operates on the principle of heat causing an unequal expansion of the laminated parts of a bi-metal disc causing an electrical contact to close the alarm circuit.

(2) pneumatic, rate of rise type heat detector - operates on the principle of an abnormal rate of temperature increase causing air within small diameter tubing to expand and increase pressure on a diaphragm until an electrical contact closes the alarm circuit.

(3) thermopile, rate of rise type heat detector - operates on the principle of radiant and/or convective heat energy falling upon an exposed thermocouple junction which is connected with another shielded thermocouple junction. Their difference in temperature produces a voltage difference and a subsequent flow of current which is used to trigger an alarm circuit.

(4) combination rate of rise and fixed temperature type heat detector - combines both features using an air chamber and diaphragm for the rate of rise effect and a fusible element (136°F.) for the fixed temperature detection. Design is intended to detect both fires which increase rapidly in temperature and also the "smouldering" type which slowly build up temperatures.

(5) rate anticipation, fixed temperature type heat detector - varies slightly in purpose from (4) above in that it not only combines the rate of rise and fixed maximum temperature detection functions but also automatically adjusts itself to compensate for changes in rate of temperature rise.

(6) beam type smoke detector - operates on the photoelectric cell principle. Smoke from a fire obscures the amount of light being received by the cell from a light beam source directed toward it from across a room, etc. and therefore reduces the current being delivered from the cell which can be used to actuate an alarm circuit.

(7) refraction type smoke detector - also operates on the photoelectric cell principle. However, in this instance, the cell and light source are both located within a small chamber open to the atmosphere and the light source is not directed at the cell. When smoke from a fire enters the small chamber, it reflects the light from the source into the cell thus changing its current output.

(8) ionization type smoke detector - operates on the principle of ionized air being able to conduct an electrical current. A radioactive source is located within a small chamber which ionizes the air within it allowing a minute electrical current to flow through a circuit thus created. When smoke particles enter the chamber, they interfere with the ionization process thus reducing the current flow. This current reduction is used to actuate an alarm circuit.

In four of the test fires (two first floor classrooms, first floor storage room and basement kindergarten room), untenable smoke conditions occurred in less than 3 minutes and therefore, although some of the detection devices operated within 30 seconds, it was concluded that the building could not have been safely evacuated due to the assumed 3 minute limitation. Two of these fires simulated arson conditions with accumulations of combustibles and the use of accelerants, one involved ignition with flammable paint thinner in a laboratory and the other involved a kindergarten room with fairly substantial amounts of combustibles.

In the other ten test fires, the various automatic heat and smoke detection devices provided an alarm in sufficient time to allow safe evacuation of the building. These included 3 classroom, 4 storage room and 3 stairwell fires. In five out of these ten, untenable smoke conditions were not created in corridors within the time limit of these tests. (It is possible that they would have created untenable smoke conditions if allowed to burn long enough but at the time which they were terminated, the detection devices had already given more than sufficient notification to safely evacuate the building). ? Were these fires of the type wh. would have EVER been serious as to life hazard)

Series B-Detection Device Response Time As Affected By Location, Spacing and Other Physical Factors

They cut test to [illegible] finish

A total of 33 tests were conducted in order to study the effectiveness of the eight basic types of detection devices under varying locations, spacing, room volume, ceiling height, ventilation and types of fires. 18 tests were conducted in classrooms, 6 in the basement cafeteria and 9 in the first floor auditorium. The following general conclusions were obtained from the test data:

depends on config. of bldg

1. The smoke detectors operated faster than the heat detectors when both were located within the room of origin but did not respond significantly faster when both types were located outside the room of origin.
2. The rate of rise and rate anticipation type detectors operated faster than the fixed temperature detector.
3. The pneumatic rate of rise type detector operated considerably faster when installed in a "U" loop as compared to a straight tubing run.
4. All types of heat detectors operated equally as well when mounted on a side wall 4" or 12" below the ceiling as when mounted on the ceiling, 6" out from the wall.
5. When mounted on side walls 5 feet above the floor, none of the heat detectors were of any value in detecting the test fires.
6. Increasing ceiling height from $11\frac{1}{2}'$ to 19' and 26.5' resulted in considerably slower response time for all types of detectors.
7. Under good draft conditions, the heat detectors operated equally as well as in closed rooms. The smoke detectors operated slower under draft conditions but still faster than the heat detectors.
8. Reducing the detector spacing below the maximum recommended by U.L. gave a faster response time, but the improvement was not significant from a life safety standpoint.

Series C-Performance of Automatic Sprinkler Protection

A total of 30 fire tests were conducted to evaluate the effectiveness of automatic sprinkler protection from a life safety standpoint. These included 17 tests in classrooms, 3 in storage rooms, 4 in stairwells, 4 in an auditorium and one each in a cafeteria kitchen and a corridor. 10 of the fires were set in wood cribs and the remaining consisted of various combinations of combustibles commonly found in schools.

In 27 of the tests, the fires reached sufficient magnitude to operate sprinklers and in all but one instance the sprinklers extinguished the fire before untenable smoke conditions were created. In the remaining three tests, the fires neither operated sprinklers nor were dangerous from a life safety standpoint.

In the single test where untenable smoke levels were produced, the test fire was set in a 55 gallon drum located at the base of the west stairwell. The fuel consisted of oil soaked cloth tubular filters and a sheet of metal was placed over the drum to prevent sprinklers from discharging directly on the fire. Untenable smoke conditions occurred in the west end of the second floor corridor in 5 minutes, west end of the third floor corridor in 6 minutes, center and east end of the third floor corridor in 17 minutes and in the center and east end of the second floor corridor in 24 minutes. The first sprinkler operated after 25½ minutes.

In the other 26 tests where sprinklers operated, this occurred within 1 minute in 6 tests, within 3 minutes in a total of 14 tests, within 4 minutes in 18 tests, within 6 minutes in 23 tests and within 8 minutes in 25 tests. The remaining test, consisting of a waste paper basket fire in a music room storage area, gave operation of the first sprinkler in 12½ minutes.

recall in previous tests untenable smoke was in 3-6 min.

Series D-Performance of Ceiling Finish Materials

A total of 11 tests were conducted in this series, 10 involving corridor fires and one in a classroom. In both types, a "fast" 75 lb. wood crib fire was used and in each of three of the corridor tests, three "fast" wood cribs were used. All of the tests involved acoustical tile ceiling finish varying in flame spread rating (A.S.T.M. E-84) from 3 to 85. The results of the tests indicated that acoustical ceiling tile within the given range of flame spread ratings does not produce a rapid flame spread down a corridor under the specific fire exposure conditions used. In addition, the various test results appeared to generally follow the relative flame spread rating scale (see table on next page).

they were under too much pressure & influence by people who donated equip. automatic (FA) + sprink.

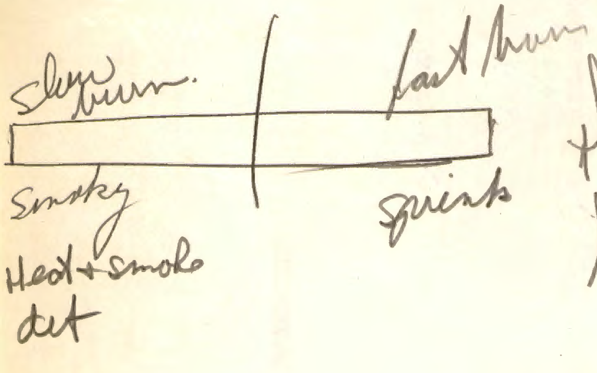
they don't know if these fires were comparable to automatic fire detection sys. test fires.

Should have:
1. run ~~the~~ fire with no protection.
2. " same " " detection
3. " " " " sprinkler.
COMPARE

over

Sprinkler has disadvantage
that it takes longer to
operate, but when it
does operate it does
something.

with (FA) it acts faster,
but then you have to
rely on people to get the
Hell out



the Comparison has to
be made on identical
fires ~~te~~ on all kinds
of fires slow burn to fast burn.

Seems smoke det would be
best on end of spectrum wh
is slow burn - hi smoke + sprink
best on fast burn - hot
fires; then after careful
testing draw line
in spectrum

PERFORMANCE OF CEILING FINISH MATERIALS

Test No.	Description	A.S.T.M. E-84 Flame Spread Rating	Test Fire Crib	Initial Flame Exposure	Ignition of Ceiling Finish	Time of Max. Flame Prop.	Max. Flame Prop.	Untenable Smoke	General Remarks
D-1	Mineral Base Tile	3	115 lb.	2:20	None	-	0	5:00	-
D-2	Cellulose Treated Tile	51	75 lb.	2:30	None	2:30	2'	None	4' diameter charred
D-3	Cellulose Treated Tile	10	" "	2:15	None	-	1'	None	2' diameter charred
D-4	" "	85	" "	2:00	2:40	3:00	4'	5:00	7½' diameter charred
D-5	" "	49	" "	1:45	2:40	2:40	4'	5:00	8' diameter
D-6	" "	49	3 arranged in "T"	1:15	2:10	3:45	12'	?	relatively slow flame spread
*D-7	Existing Class D Tile	77	75 lb.	2:20	3:00	3:30	4'	?	flames receded and died out in room
D-8	Cellulose Treated Tile	85	75 lb.	1:45	3:00	3:30	2.5'	None	-
D-9	" "	85	3 arranged in "T"	1:00	1:50	3:10	9'	7:00	relatively slow flame spread
D-10	" "	49	75 lb.	2:00	2:30	4:00	2.5'	Less than 10 min.	relatively slow flame spread
D-11	" "	49	3 arranged in "T"	1:35	2:10	4:30	12'	?	slow flame spread

*Test conducted in classroom.

Series E-Performance of Plastic Light Diffusers and Windows

Six tests were conducted; two in a corridor, one in the auditorium and three in a classroom. The two corridor tests involved exposure of acrylic (methyl methacrylate) plastic light diffusers set in fluorescent light fixtures to a "fast" wood crib fire. One test was made using a fire retardant type and the other with an untreated type. In the former, the four diffusers dropped out in from 3 to 8 minutes with no ignition and in the latter test, the diffusers dropped out in from 3½ to 6 minutes with brief ignition but self-extinguishment after drop-out.

The auditorium test involved exposure of a 17'x6¼' polyester fiberglass reinforced window to a fire in two "fast" wood cribs. Direct flame impingement began at 2-1/3 minutes and rapid burning of the window began 15 seconds later with the release of large quantities of black smoke.

The three classroom tests consisted of polyester fiberglass reinforced plastic window glazing (22 ft.^{2}) exposed to "fast" wood crib fires. No ignition of the plastic was obtained in two of the tests where only a single crib fire was used. However, when two wood cribs were used in the remaining test, the plastic glazing was ignited within 2 minutes. However, it was felt that the amount of smoke produced was not objectionable.

why did they test this? Seems UL would be better.

The general conclusions which were drawn from this series were: (1) plastic materials of the type tested should be used in classrooms only with definite limitations on total area of plastic used within a given room, (2) limitations should be placed on permissible vertical dimensions of plastic materials and (3) proper separation should be required between adjacent plastic panels.

Series F-Comparative Smoke and Heat Patterns

Five tests were conducted, three with large wood pallet fires (1000 lbs.) and two with considerable accumulations of ordinary combustibles, to determine whether the build-up of smoke and heat in the St. Agnes School were comparable to that experienced in the 1959 tests in the Stevenson School. It was concluded that the pattern of smoke and heat development was indeed comparable. Four of the tests involved classroom fires and the remaining one a stairwell fire.

Series G-Evaluation of Partial Sprinkler Protection

Two tests were run to verify the performance of partial sprinkler protection which was evident during the 1959 Test Series. Both tests involved 1000 lb. wood pallet fires started in a non-sprinklered classroom with sprinkler protection provided in adjacent corridors. In both tests, untenable smoke conditions occurred within 4½ to 6 minutes throughout the corridors with several corridor sprinklers having operated in from 4½ to 10 minutes. However, the operation of corridor sprinklers did prevent the development of untenable temperature levels in areas remote from the fire.

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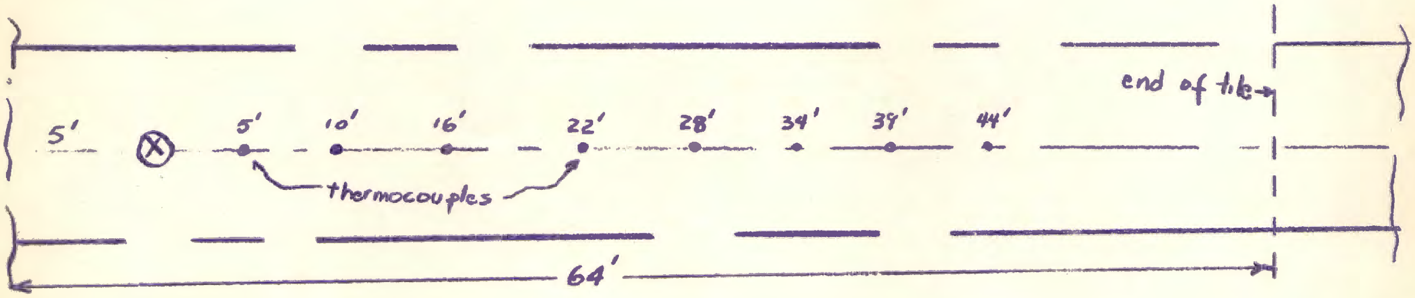
TEST SERIES NO. 3

SANTA FE HIGH SCHOOL, FEBRUARY 6-14, 1961

The building was two stories with part basement with reinforced concrete walls and wood joisted floors and roof. Interior corridor partitions and ceilings were also reinforced concrete. Only the second floor corridor was used in this series of tests. Thermocouples were placed 8" below the ceiling as shown in the following diagram:



A total of 16 tests were conducted, 15 involving corridor ceiling finishes and one to investigate the performance of two types of automatic door closures. All of the tests were conducted in the second floor corridor using wood cribs of various sizes (see table on next page). It was found that the use of 330-360 lb. cribs could produce significant flame spreads on various interior finish materials which were generally grouped in accord with their "tunnel test" ratings but that it was necessary to use a 500 lb. crib in order to produce a flame spread on "standard" red oak which propagated the entire 50 foot corridor length. The only exception occurred in the case of 1/4" plywood which produced a 50 foot flame spread when exposed by a 367 lb. crib fire.

A single test was conducted with a 352 lb. crib to compare operating times of smoke and heat actuating door-closing devices and to determine if any significant improvement could be obtained in either case from the unsatisfactory performance which was experienced with fusible link (135°F.) closers in the 1959 Test Series. Devices were installed on a door located 32' down the corridor from the test fire and both the smoke and rate-of-rise heat actuated devices operated in 2 minutes while a 135°F. fusible link closer took 7-1/3 minutes to actuate.

PERFORMANCE OF CEILING FINISH MATERIALS

Test No.	Description	A.S.T.M. E-84 Fl.Sprd.Rating	Test Fire Crib	Initial Fl. Expos.	Ignition of Ceiling Finish	Time of Max. Flame Propagation	Max. Flame Propagation	Remarks
D-12	3/8" gypsum wallboard	10-15	242 lb.	1:30	?	?	4'	
D-13	5/8" gypsum wallboard	10-15	235 lb.	1:45	?	?	4'	
D-14	13/16" T. & g. red oak	100	249 lb.	1:00	2:30	3:30	30'	
D-15	3/8" gypsum wallboard	10-15	328 lb.	1:00	?	?	6'	
D-16	13/16" T & g. red oak	100	328 lb.	1:00	2:00	3:30	35'	flame receded and then spread back 25' at 10:00
D-17	3/4" treated cellulose tile	77	331 lb.	1:00	1:55	2:50	40'	
D-18	3/4" mineral tile	5	337 lb.	0:40	1:00	?	?	recording instruments inoperative
D-19	3/4" treated cellulose tile	92	331 lb.	1:00	1:35	3:40	37'	
D-20	5/8" treated cellulose tile	21	337 lb.	1:00	?	3:00	18'	
D-21	3/4" treated cellulose tile	87	360 lb.	1:00	?	4:00	30'	
D-22	5/8" mineral tile	8	333 lb.	1:00	?	3:10	10'	flame spread only from exposure fire
D-23	13/16" T. & G. red oak	100	*500 lb.	0:30	1:50	3:00	50' (total)	
D-24	3/4" mineral tile	15	508 lb.	0:55	1:30	2:40	25'	
D-25	3/4" pecky cedar plywood	?	367 lb.	1:00	1:30	3:10	40'	flame receded and then spread back to 45' at 13:30
D-26	1/4" Douglas Fir plywood	125-145	367 lb.	0:55	1:30	4:15	50' (total)	plywood delaminated over test fire after 5½ minutes

*Crib placed on floor, all others 3 feet above floor.

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ANALYSIS OF TEST SERIES NOS. 2 AND 3

Heat and Smoke Detectors

The tests seemed to indicate that automatic heat or smoke detection protection (except for fixed temperature thermostats) provides a satisfactory solution to the life safety problem in multi-story open stairwell school buildings with a single exception. In certain instances, where a fire develops very rapidly and produces heavy quantities of smoke so as to produce untenable smoke conditions within the time interval necessary for safe evacuation, an almost immediate detection of the fire obviously still cannot give sufficient warning time. This occurred in four instances, two involving "set" arson type fires using trailers and accelerants, one involving a flammable liquid fire in a laboratory and the other a fire started in piled combustibles. However, it should be pointed out that in each instance, doors, windows and transoms were arranged to give good ventilation and to promote smoke distribution.

Automatic Sprinkler Protection

The tests appeared to indicate that total automatic sprinkler protection provides a completely satisfactory solution to the life safety problem in multi-story open stairwell school buildings with a singular reservation. Storage of combustible materials must be controlled to the extent necessary to prevent the existence of conditions where a fire would be shielded from sprinkler discharge.

A sufficient number of tests were made under varied conditions to give substantial support to the above stated position. However, I think that it is unfortunate that the four tests conducted in Series A, which showed automatic heat and smoke detectors to be inadequate, were not exactly repeated during the automatic sprinkler test series for comparison purposes. Four somewhat similar tests were made but these were not identical either varying in the room used, draft conditions and/or combustibles and therefore a completely valid comparison between automatic heat and smoke detection protection and automatic sprinkler protection cannot be made.

It would appear from the tests, except as noted above, that automatic sprinkler protection has one potential clear cut life safety advantage over automatic heat and smoke detection. In those types of fires which develop large quantities of smoke in their early stages and thus create untenable smoke conditions in less time than would be necessary to safely evacuate the building even assuming immediate detection of the fire, the automatic sprinkler operates a number of seconds after the heat or smoke detector but nevertheless immediately thereafter begins to control the fire and consequently reduces the smoke production and either significantly delays or prevents the build-up of untenable smoke levels.

Performance of Ceiling Finish Materials

A total of 26 tests were made, 10 in the third floor corridor of the St. Agnes High School, 15 in the second floor corridor of the Santa Fe School and one in a second floor classroom of the St. Agnes School. I do not feel that these test results were too significant from the standpoint of increasing our knowledge of the relative life hazard properties of interior finish materials. The wide variance in flame spreads which were obtained with the various sized cribs merely reflected the basic heat balance problem which existed in the particular volume of corridor and draft conditions found in the two schools used for the tests. With 75 lb. wood crib fires, the rate of heat output was insufficient to cause much flame propagation down the ceiling. When the size of the cribs was increased during subsequent tests at the Santa Fe School, the length and rate of flame spread was correspondingly increased.

It would appear that the tests showed only that if corridor ceiling finish of the types tested is subjected to a severe enough direct fire exposure, it will ignite and propagate flame down the corridor in general agreement with its relative performance and rating under the A.S.T.M. E-84 Test Method (Tunnel Test).

Some of the questions which were certainly not answered in these two test series concerned the build-up of smoke and temperature levels throughout the building prior to propagation of flame down the corridor ceiling, the subsequent increase in these two factors during and after flame propagation and the effects of significant variations in draft on this performance.

The difference in flame spread behavior obtained in these two test series as opposed to the 1959 Test Series appears to have been due to the fact that the 700 to 1400 lb. wood pallet fires used in the latter were set at the base of a stairwell and provided a situation where there was a considerable indirect preheating of the ceiling finish so that when ignition occurred, it resulted in a much faster flame spread down the ceiling. Therefore, we have two basic situations to evaluate: (1) indirect heating with longer ignition time but more rapid flame spread after ignition occurs and (2) direct flame impingement with shorter ignition time but somewhat slower rate of flame spread. In this country, the U.L. Tunnel Test Method (A.S.T.M. E-84) which simulates the latter situation is most widely accepted while in Great Britain and most of Europe, their test methods more closely approximate the former situation.

The important basic question of what contribution combustible interior finish materials make to the life hazard problems in a multi-story open stairwell school building under various fire conditions simply was not answered in these Test Series.

Performance of Plastic Light Diffusers and Windows

The number and arrangement of tests conducted in this series was much too meager to draw any definite guidelines with reference to the use of plastic products in school buildings. In addition, practically no definitive information was published on the smoke contribution from the samples in the tests which constitutes one of the main points of interest with plastics nor were any observations made of the toxicity of the products and their effects on the room environment which is also of paramount interest with plastics.

Performance of Heat and Smoke Actuated Door Closers

The single test which was made on these devices was encouraging enough to warrant a substantial amount of additional testing. The day to day problem of maintaining self-closing stairwell doors in the closed position in multi-story school buildings is of paramount importance and deserves considerable emphasis in any school fire research studies.

GENERAL CONCLUSIONS

The three series of school fire tests conducted in Los Angeles in 1959-61 represent a significant contribution to our knowledge of the life safety problems associated with school fires. However, in interpreting their test data and examining the various conclusions which were reached by the testing agencies, it would be well to keep in mind that from a scientific standpoint, it is absolutely necessary to control all of the many fire variables if it is desired to accurately reproduce fire exposure conditions in order to compare the performance of various alternative materials, devices, equipment, etc.

It would appear that such an approach was not faithfully followed in these test series. Factors such as draft conditions, fuel load and arrangement, location of test fire, igniting source, etc. were varied so often that it is difficult to find more than a few tests which can be accurately compared with one another. Therefore, the various test results produce a scattering of data which, in my opinion, should rightly be evaluated only in a general qualitative manner.

The fuel loads and types of fires used in Test Series No. 2 appeared to be generally more representative of actual conditions than in Test Series No. 1 but, especially in the case of the 30 automatic sprinkler tests, the absence of duplicate tests conducted without protection to determine the time sequence of untenable smoke and temperature development make it difficult to determine in many cases whether the sprinklers controlled fires which indeed would have ever been dangerous to life safety within a reasonable period of time.

ACHIEVING FIRE PROTECTION THROUGH MODERN BUILDING CODES

By

Professor Gerald L. Maatman, Director
Department of Fire Protection and Safety Engineering
Illinois Institute of Technology

INTRODUCTION

Since almost the beginning of time, society has been concerned with the problem of safety in building construction. Archeologists have unearthed relics which indicate that as far back as 2100 B.C., laws existed in Babylon which provided that "in the case of collapse of a defective building, the architect is to be put to death if the owner is killed by the accident; and the architect's son if the son of the owner is killed." During the Roman era, it became necessary to pass laws restricting the heights of buildings to 70 feet because of the frequency of collapse of taller buildings.

Later in history, numerous regulations began to appear which were concerned with preventing and restricting fire spread. The City of London as far back as the 14th Century required that chimneys be built of stone, tile or plaster. It was not uncommon in the larger closely built-up towns of the early American colonies to require that roof coverings be of slate or tile.

From these meager beginnings, slowly evolved groups of regulations which we know today as building codes. Most of the early building codes were written on a so-called "specification" basis. That is, they spelled out in considerable detail what specific materials could be used to construct buildings. This regulatory method provided no particular problems at that time because the architect had only a limited choice of materials to choose from in any case. However, in the past two or three decades, the building materials industry has undergone a rapid technological change and, as a result, it has become necessary to rewrite codes on a "performance" or functional basis, wherein the code spells out only the desired functional end requirement and leaves the architect free to choose from a variety of materials.

BASIC PURPOSE OF A BUILDING CODE

Stripped of its legal and technical phraseology, a building code is simply a set of laws intended to keep people from getting hurt. A man may be physically hurt from being struck by a collapsing structure, by falling through unguarded openings, by being burned, through sickness resulting from improper sanitation, or from any number of other causes. The same occurrences may cause him financial loss, whether he be owner, occupant or merely a passerby.

Not only does a building code concern itself with individuals, but, in addition, it must of necessity be concerned with the welfare of the community in general. The basic objectives of a code can be divided into three broad classifications:

(1) structural integrity
(2) health and sanitation
(3) fire protection

① Structural integrity is dealt with by specifying various engineering design criteria which must be adhered to by the building designer to insure that the structure will carry its intended dead, live and wind loads with a liberal safety factor.

② Health and sanitation regulations cover the factors of plumbing, sewage, ventilation and light as they bear on the problem of providing a healthy atmosphere for the building's human occupants.

③ However, it is in the 90% field of fire protection where the building code probably is most concerned with the welfare of the community as a whole. Mr. B. L. Wood in his book, "Fire Protection Through Modern Building Codes" states that, insofar as fire protection is concerned, a code has the following four objectives in order of importance:

*(1) To provide for the safety of occupants of buildings and to make provision for their exit without loss of life during a fire.
*(2) To provide for the safety of firemen fighting fire.
*(3) To provide for the safety of adjoining property and to prevent the spread of fire.
*(4) To provide for the preservation of the property itself.

In writing a building code to achieve its three basic purposes, it must be kept clearly in mind that the governmental agency, be it a municipality, township, county or state, has authority under its general police powers only to regulate to the extent necessary to achieve minimum reasonable safety for the public. In addition, under our democratic form of government and relatively free economic system, it would be against the public good to unduly restrict the construction of buildings through the use of excessive regulations. Thus, the basic difficulty, especially in the rather intangible area of fire protection, is to determine what regulations will provide minimum reasonable safety without being unduly restrictive.

Building code regulations pertaining to fire protection are still, to a large extent, based upon past fire experience and the judgment of mature fire protection engineers. For this reason and because of the great increases in new building materials and methods, which do not always lend themselves to analysis by past experience alone, there has developed a strong need for a more sophisticated scientific analysis of fire protection factors. However, until the last decade or two, there has been little emphasis placed on this area of study by the scientific community and therefore, for the present at least, modernization of building codes from a fire protection standpoint must continue to be made largely based on experience and judgment.

Mr. Wood, in his previously mentioned book, discusses the basic problem of defining "minimum reasonable safety" as it applies to fire protection needs and presents a case in favor of eliminating the element of "safety factor" from fire protection determinations. Although it is customary for building codes to include a safety factor in all of its structural design criteria, Mr. Wood argues that the same analogy cannot be applied to fire protection requirements because, while a building must constantly sustain its designed load and frequently be subjected to overloads, the chance of a fire occurring in a particular building is about one in 1,000 years. One might compare this argument with the endless controversy over whether the capacity of a municipal storm sewer system should be designed to carry off a rainfall which occurs once each twenty years, fifty years, 100 years, etc. Within the last four years, for example, the Greater Chicago Area has endured two of the so-called fifty year rainfalls. Therefore, although the frequency of fire occurring in any one particular building is admittedly remote, no one can fortell which buildings will suffer fires and it cannot be denied that a tremendously large number of building fires occur each year. It follows then that the degree to which codes regulate fire protection factors must, in the end, be a compromise between judgment and the capacity of the public to bear the cost of such protection.

ANALYSIS OF BASIC FIRE PROTECTION OBJECTIVES

The various structural factors which have a bearing on the development and spread of a building fire are well known from past experience and a brief list of these factors and how they are inter-related to the four basic fire protection objectives previously enumerated follows:

1. Safety to Building Occupants
    - a. adequate and reliable exit facilities.
    - b. protection of all vertical openings.
    - c. limitation of use of combustible interior finish.
    - d. limitation of basic construction type to some extent.
    - e. limitation of allowable height and area of buildings to some extent.
    - f. segregation of hazardous portions of an occupancy.

2. Safety to Firemen Fighting Fire
    - a. protection of stairwells and other vertical openings so as to provide interior access for fire fighting purposes.
    - b. limitation of allowable height and area of buildings.
    - c. minimum requirements for masonry wall thickness.
    - d. fire resistance requirements for structural elements.
    - e. requirements for automatic sprinkler systems and other protective equipment.

3. Safety of Adjoining Property
    - a. limitation of allowable heights and areas of buildings.
    - b. limitation of allowable roof coverings.
    - c. protection of exterior wall openings and/or building separation requirements.
    - d. parapet requirements.
    - e. restrictions on construction within the "fire limits."
    - f. requirements for automatic sprinkler systems and other protective equipment.
    - g. fire resistance requirements for exterior walls and various load bearing members.

4. Preservation of Property Itself
    - a. limitation of allowable heights and areas.
    - b. protection of vertical openings.
    - c. requirements for vertical separation between openings in exterior walls.
    - d. fire resistance requirements for structural elements.
    - e. minimum requirements for masonry wall thickness.
    - f. segregation of hazardous portions of an occupancy.
    - g. requirements for automatic sprinkler systems and other protective equipment.
    - h. requirements dealing with chimneys, flues, vents, heat producing appliances, heating, ventilating and air conditioning systems, gas piping and electrical power and lighting systems.

ACHIEVING - FIRE PROTECTION OBJECTIVES IN BUILDING CODES

The intelligent promulgation of building code requirements to achieve the four basic fire protection objectives by regulating the numerous factors outlined above is a complex problem and one upon which there has never been an unanimity of opinion. There are still many examples of widely varying requirements between building codes in use in various cities. In many cases, this is due to honest differences of opinion or to erroneous ideas on what factors have a bearing on the fire problem. However, unfortunately, some of these divergences are due to improper pressure having been brought to bear upon code writing authorities by special interest groups in the building materials industry who seek to obtain an unfair advantage over their competitors.

At the present time in the United States, approximately 80% of the existing building codes are based entirely, or in part, on one or more of four regionally or nationally recognized model codes. These are:

1. National Building Code of the National Board of Fire Underwriters
2. Basic Building Code of the Building Officials Conference of America
3. Uniform Building Code of the International Conference of Building Officials
4. Southern Standard Building Code of the Southern Building Code Congress

Although these codes differ in some important respects, their increased acceptance has produced an overall beneficial effect in the promotion of safe building construction in this country.

The various specific standards of the National Building Code will be reviewed in some detail as this is the only model code which is promulgated exclusively by fire protection engineering interests and the three remaining codes will then be compared with the N.B.F.U. code where they differ in important aspects.

NATIONAL BUILDING CODE

CLASSIFICATION OF CONSTRUCTION - There are seven basic types of construction recognized by the code and these are defined in detail on a performance basis. The construction elements considered are (1) columns and piers, (2) floors (3) roofs (4) beams, girders and trusses, (5) walls, (6) partitions, (7) ceilings and (8) firestopping. A.S.T.M. E-84 fire resistance test standard (N.F.P.A. No. 251) is used as a measure of performance.

1. Type A - Fire Resistive (3 hour construction)
2. Type B - Fire Resistive (2 " ")
3. Protected Non-Combustible(1 " ")
4. Unprotected Non-Combustible
5. Heavy Timber (Mill or slow-burning construction)
6. Ordinary (masonry-wood joist construction)
7. Wood Frame

The code for the most part does not directly require that a particular building be built to meet the standards of any particular class of construction but strongly encourages the use of fire resistive buildings by limiting the allowable heights and areas of non-fire resistive structures. However, in a few cases, the code does directly restrict construction type for certain occupancies. For instance, institutional buildings such as hospitals, asylums, jails, infirmaries, etc. must be of fire resistive construction. In addition, theaters must be fire resistive except

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if not over one story or 45 feet in height in which case the roof may be only of one hour fire resistance. Also, schools over two stories in height must be of at least protected non-combustible construction. Another notable exception to the general rule involves the prohibiting of wood frame or unprotected non-combustible construction from within the fire limits of the city. This will be discussed in greater detail in the next section.

RESTRICTIONS WITHIN THE FIRE LIMITS - Except for a few minor exceptions, the code prohibits the erection of or moving of wood-frame or unprotected non-combustible buildings or additions into or within the city's fire limits. In addition, the code regulates the permissible areas and heights of all except Type A fire resistive buildings erected within the fire limits. The boundaries of the fire limits are normally specified in a separate ordinance, usually the Zoning Code, and are intended to cover all areas within the city which are or could be subject to a concentrated build-up of mercantile buildings plus a belt of exposing area around such mercantile concentrations. The object of these regulations is, of course, to minimize the fire conflagration potential of the city's closely built-up mercantile areas.

LIMITATIONS OF ALLOWABLE HEIGHTS AND AREAS - The code limits the permissible heights of all buildings except Type A-fire resistive and residential or business occupancies in Type B-fire resistive. The height limitations are graduated from 35 feet for wood frame and unprotected construction to 85 feet for Type B-fire resistive (except as noted above.) In addition, there are several specific height limitations for high hazard and certain institutional occupancies when located in non-fire resistive buildings. Thus, the code recognizes the inherent problems involved in meeting all of the four basic fire protection objectives in the case of multi-story non-fire resistive buildings.

The code limits the permissible ground floor areas of all buildings except Types A and B fire resistive. The area limitations are broken down into two groups, one story buildings and multi-story buildings, with the limitations being more restrictive for the latter group. The maximum permissible areas are graduated from 6,000 ft.^{2} for a one story wood frame building (4,000 ft.^{2} for multi-story) to 18,000 ft.^{2} for one story protected noncombustible construction (12,000 ft.^{2} for multi-story.) The basic reasons for limiting building areas are, of course, to reduce the conflagration potential, to restrict the maximum amount subject to any one fire, and more important, to avoid an impossible fire fighting problem due to the practical limitations on the reach of fire department hose streams. In accord with this same reasoning, the code permits a 200% area increase when any building is sprinklered, increases varying from 20% to 50% when a building is located outside of the fire limits and structural load bearing members have a specified fire resistance, and increases ranging up to 100% for buildings which have one-fourth or more of their perimeter fronting on a public street or public way at least 21 feet in width. This latter factor, of course, governs to a great extent the number, arrangement and effectiveness of fire department hose stream operations.

Conversely, the code requires in certain cases where the combustible fire load of an occupancy is quite high, that buildings exceeding specified height and area limitations must be provided with an automatic sprinkler system. This requirement will be discussed in greater detail in another section.

EXIT REQUIREMENTS - The code regulates exit standards in a manner which closely follows the provisions of the N.F.P.A. Building Exits Code (N.F.P.A. No. 101) and to some extent the recommendations of the National Bureau of Standards (Report No. M-151 "Design and Construction of Building Exits.") The more important basic provisions include adequate exit capacity and arrangement, enclosure of stairwells and free and unobstructed access. The various structural factors having a bearing on life safety such as enclosure of other vertical openings and the regulation of interior finish are covered in separate sections of the code.

The code also makes an important necessary distinction regarding safety to life requirements as between "existing" buildings and buildings built after the code is enacted into law. In general, provisions of a new building code cannot be made retroactive to apply to buildings already in existence. However, in the area of life safety, legal authorities have consistently held that retroactive laws may be enforced which are necessary to maintain minimum standards of life safety. Therefore, the code contains a separate section applicable only to existing buildings which regulates to some extent exit facilities, interior finish, protection of vertical openings, chimneys and vents and heat producing appliances.

PARAPETS - The code requires parapets on all fire walls and exterior walls required to have 2 hours or more fire resistance except (1) in the case of a fire resistive roof, (2) when roof of adjacent building or any opening in adjacent wall is at least 3 feet higher, (3) when building is at least 30 feet distance from nearest line to which other buildings can be or are built and (4) when the roof has a 20 degree or more slope with the horizontal. Parapets are required to have the same fire resistance as the wall and must be at least 24 inches high on a 2 hour wall and 36" high on walls required to have greater fire resistance.

ROOF COVERINGS - The code uses the roof covering classification system set forth in N.F.P.A. Standard No. 203 which is based upon a fire test method developed by Underwriters Laboratories (U.L. Standard No. 790.) This method provides for three types of approved roof coverings:

Class A - effective against severe fire exposure and possess no flying brand
Class B - " " moderate " " " " " " hazard
Class C - " " mild " " " " " " "

The code requires either Class A or B roof coverings to be provided on all buildings except (1) dwellings, (2) wood frame buildings and (3) all buildings located outside of the fire limits whose height and area do not exceed the code limitations for wood frame buildings. These latter three classes are permitted to have Class C roof coverings.

The code does not permit wood shingle roof coverings as this type can not pass the Class C fire test. However, in recognition of the fact that some code enforcing agencies nevertheless want to permit such types of roof coverings, the appendix of the code suggests that if this is desired, the use of such shingles should be restricted to a good grade (U.S. Dept. of Commerce Std. CS 31-52) and should be applied in a manner to provide maximum thickness, close spacing and firm anchorage. In addition, the code recommends that such roof coverings be permitted only on dwellings, private garages and barns separated at least 12 feet from other buildings and only when located outside of the fire limits.

PROTECTION OF EXTERIOR WALL OPENINGS - The code requires that all exterior wall openings be protected by either wired glass, fire doors or fire shutters when the wall in question lies within 30 feet of (1) an adjacent wood frame building, (2) an adjacent lower combustible roof, (3) an opening in an adjacent wall. Also, protection is required when the wall lies within 15 feet of an adjacent lot line or when the wall opening lies within 10 feet of an exterior fire escape stair. The only exceptions to these requirements are openings in exterior walls of (1) dwellings, (2) churches, (3) wood frame or unprotected noncombustible buildings, and (4) open air parking garages. The code also specifies certain fire resistance requirements for all exterior bearing walls (except for unprotected non-combustible and wood frame buildings.) In addition, where an exterior building wall is exposed within 30 feet, non-bearing portions also must have a specified fire resistance and the total window area in the wall is limited to 60% of the total wall area (40% of total area if exposure distance is less than 20 feet.)

VERTICAL SEPARATION BETWEEN OPENINGS IN EXTERIOR WALLS - The code requires that there shall be not less than three feet separation between vertically adjacent exterior wall openings provided by an non-combustible material having a fire resistance of at least two hours, or in lieu thereof, the vertical openings shall be separated by a similar assembly extending horizontally outward from the wall at least three feet. The only exceptions to this requirement intended to prevent vertical spread of fire are: (1) ordinary construction located outside of the fire limits, (2) unprotected non-combustible and wood frame construction, (3) when the lower of any two successive wall openings opens into an occupancy of light fire load, i.e. business, educational, residential, etc. and (4) when the exterior openings are protected by wired glass or fire doors.

INTERIOR FINISH - The code classifies interior finish materials on the basis of A.S.T.M. Standard E-84 (N.F.P.A. No. 255-Tunnel Test) as to their flame spread hazard. Interior finish may not have a flame spread greater than 75 in (1) exit stairwells and exit hallways (2) portions of buildings greater than 75 feet in height (except in rooms of 1500 ft.^{2} or less), and (3) in all portions of institutional occupancies. If in any of the above cases, the building is sprinklered, the requirement is reduced to a 200 flame spread. In all other cases except dwellings, the flame spread limitation is 200 (one other exception is allowable 500 flame spread in rooms of 1500 ft.^{2} or less in business, high hazard, industrial and storage occupancies.)

The flame spread limitations also apply to the back face of interior finish materials used in exitways located more than 75 feet above grade, in all rooms or spaces of institutional occupancies and assembly occupancies, or theaters more than 45 feet in height.

MASONRY WALL THICKNESS REQUIREMENTS - The code specifies certain minimum thickness for masonry walls of various types. This represents somewhat of a departure from a performance to a specification type basis. However, the N.B.F.U. justifies this action on the grounds that the standard fire resistance test (ASTM E-119) which is conducted on a 100 ft.^{2} wall sample is not of sufficient magnitude to reproduce the actual stress and expansion effects which occur in larger building walls during a fire. In general, the code requires a minimum of 12" thickness for masonry bearing walls (6" for reinforced concrete) except that 8" is permissible for dwellings and a minimum of 8" thickness for non-bearing exterior masonry walls. Buildings greater than 35 feet in height of course require correspondingly thicker bearing walls (4" for each 35 feet in a downward direction.)

Where walls are utilized to separate portions of a building to conform with the code's area limitations (i.e. fire walls), they must (1) be independently supported so as to allow collapse of construction on either side, (2) have a fire resistance of at least 4 hours, (3) extend through the roof and at least 36" above except for fire resistive roofs, and (4) in the case of hollow masonry walls must be of at least 16" thickness and with reinforced concrete walls, must be at least 9" thick. Openings in fire walls are restricted to 120 ft.^{2} area (with maximum 12' dimension) and the aggregate width of all such openings shall not exceed 25% of the length of the wall. Also, all such openings must be protected on both sides of the wall by approved Class A fire doors.

PROTECTION OF VERTICAL OPENINGS - In general, the code requires that interior stairways, elevator shafts and all other vertical openings be protected. In buildings less than 4 stories in height, the enclosure must be of at least one hour fire resistance and in taller buildings, the requirement is for a fire resistance of at least two hours. In the latter case, only non-combustible materials can be used to construct the enclosure, while with buildings less than four stories high, this requirement applies only to the fire resistive and non-combustible classifications. All openings into stairway enclosures must be protected by approved Class B fire doors except that where one hour fire resistance is required, solid flush type wooden doors of 1-3/4" minimum thickness can be used.

The only exceptions to the general requirement for enclosing all interior stairwells are the following:

(1) where a stairway serves only two floors, is not part of the required exit facilities and is cut-off at one of the two floor levels by a one hour partition.
(2) where stairway serves three floors, is not part of the required exit facilities and is cut-off at both the upper and lower floors by a one hour partition.
(3) stairs leading from a mezzanine or balcony to a floor below where the mezzanine or balcony area doesn't exceed 1/3 of the area of the floor below.

AUTOMATIC SPRINKLER SYSTEMS AND STANDPIPES - The code strongly encourages the use of automatic sprinkler systems by allowing greatly increased permissible areas, more combustible interior finish, wider spacing of exits, etc. when a building is so protected. However, in general, the code recognizes that automatic sprinkler protection goes beyond what could be defined as reasonable minimum safety and therefore does not require sprinkler protection. The only exception to this position is taken in the case of occupancies which manufacture, sell or store large amounts of combustible goods or merchandise. Because of the high combustible fire load involved in such instances, the code requires that when such buildings exceed certain combinations of, heights and areas, both the fire fighting and fire conflagration problems become acute and it is then necessary to provide more positive fire protection. Some of the more important height and area limitations are:

fire resistive - 2 stories and 10,000 ft.^{2}
protected non-combustible - 2 stories and 8,000 ft.^{2}
other construction types - 2 stories and 6,000 ft.^{2}

In addition, sprinkler protection is required in certain cases when the building heights exceed specified limits, irregardless of area, and the building is used for the storage of large amounts of combustible materials.

Also, sprinkler protection is required for parking or repair garages and storage basements of mercantile buildings when certain area and/or height limits are exceeded. The latter requirement arises from the extremely difficult fire fighting problem involved in gaining interior access to basements of mercantile buildings.

The code requires standpipes to be installed only in buildings that are required to be sprinklered under the code (with the exception of open air parking garages.)

SEGREGATION OF HAZARDOUS OCCUPANCIES - The code in certain instances requires that hazardous portions of an occupancy be cut-off by fire resistive partitions, floors, etc. from remaining portions of the occupancy or one adjacent thereto. For instance, bowling alley areas must be separated from other portions of a building by a one hour cut-off. Parking and/or repair garage operations must be cut-off as must mercantile areas from adjoining residential occupancies in the same building. These requirements are principally aimed at reducing the life hazard factor and, to some extent, at reducing possible areas subject to any one fire.

HEATING, VENTILATING, AIR CONDITIONING, ELECTRICAL, ETC. - In the various areas of utilities systems and equipment, the code suggests that other applicable nationally recognized standards be adopted. For instance, the National Electrical Code, the N.B.F.U. Standard on Heat Producing Appliances, Heating, Ventilating, Air Conditioning, Blower and Exhaust Systems, etc.

COMPARISON WITH OTHER THREE NATIONALLY RECOGNIZED CODES

BASIC BUILDING CODE - B.O.C.A. (1955 Edition)

Heights and Areas - Allows greater heights for Type B fire resistive and protected non-combustible buildings in some instances. Also, allows larger areas in both the single and multi-story classifications for the relatively poorer types of construction.

Protection of Exterior Wall Openings - Requires protection only for 4 story or higher buildings.

Fire Walls - Requires only 1½ hour fire door to be installed on each side of wall opening. Also, fire wall requirements are on a performance basis, and in some cases, only 3 or 2 hours fire resistance is required. In addition, requirements for separate ground supports for fire walls are less rigid.

Restrictions Within the Fire Limits - Doesn't restrict the use of unprotected non-combustible construction within the fire limits.

Parapets - Requires only a maximum of 24" parapet height.

Automatic Sprinkler Systems - Require sprinkler protection in certain instances only for 4 story or higher buildings containing a high fire load.

Interior Finish - Uses both A.S.T.M. E-84 (tunnel test) and Federal Specifications Test SS-A-118b to evaluate flame spread hazard. The applicant has the option in this matter.

UNIFORM BUILDING CODE - I.C.B.O. (1955 EDITION)

Heights and Areas - Allows somewhat greater heights for the 3 poorest classes of construction and permits unlimited heights for all Type B fire resistive buildings. Allows somewhat greater areas for all types of construction and for almost all types of occupancies.

Protection of Exterior Wall Openings - Allows closer exposures outside of the fire limits and is generally less restrictive in requiring protection for various types of exposure situation.

Fire Walls - Requirements expressed on performance basis and only two hours fire resistance specified in some cases. In addition, only single 1½ hour fire doors required to protect openings in fire wall which separates unprotected non-combustible or wood frame construction.

Parapets - Requires only 12" height and no parapets are required (1) when roof is non-combustible, (2) when the building is 20 feet or less in height or (3) on fire walls.

Automatic Sprinkler Systems - Doesn't require sprinkler protection for repair or parking garages nor mercantile occupancies over 2 stories in height (unless of very large area.)

Interior Finish - Uses both A.S.T.M. E-84 and Federal Specifications Test SS-A-118b as basis for flame spread hazard.

SOUTHERN STANDARD BUILDING CODE - S.S.B.C.C. (1954 EDITION)

Heights and Areas - Allows greater areas for all one story buildings and also multi-story buildings of heavy timber or poorer types of construction.

Protection of Exterior Wall Openings - Requires protection for buildings less than 3 stories in height only when 8 feet or less from property line.

Fire Walls - Requirements expressed only on performance basis with 4 hours fire resistance specified.

Restrictions Within the Fire Limits - Allows somewhat more liberal use of unprotected non-combustible construction within the fire limits.

Automatic Sprinkler Systems - Allows much larger areas of high occupancy fire load in various construction classes before requiring the provision of an automatic sprinkler system.

Interior Finish - Allows any interior finish material which "will not have a rate of flame spread in excess of that of wood or fiberboard when exposed to heat or flame." The only restriction on the above is that in fire resistive buildings over three stories in height, all fiberboard finish must be installed over a non-combustible base.

FUTURE TRENDS IN BUILDING CODES

It is apparent from analyzing the four nationally recognized building codes that there exists some considerable differences of opinion as to what constitutes reasonable minimum safety requirements. Furthermore, this divergence of opinion is quite naturally more pronounced in those areas in which judgment plays a large part in deriving code standards. Therefore, it follows that any substantial future improvement in writing realistic but adequate building code requirements will necessarily have to be preceded by greatly expanded fundamental research within the area of fire development and behavior within buildings.

The recent work done by the British Joint Fire Research Committee in the area of building separation and ignition by radiation which was supplemented by radiation ignition studies made by Canadian authorities during the "St. Lawrence Seaway Burnout Test Series" offers excellent future promise in developing scientifically realistic standards for protection of exterior wall openings and building separation criteria.

Studies made by the National Bureau of Standards in the early 1940's, which have since been greatly expanded and refined by the British Joint Fire Research Committees' work, in the area of correlating standard fire resistance test ratings (A.S.T.M. E-119) with fire severity as measured by combustible fire loads (i.e. lbs. combustibles/ft.^{2} floor area or B.T.U./ft.^{2} floor area), also offers great promise for a more rational approach to fire resistance code requirements. However, there remains much work to be accomplished before this method can be used in other than the crude indirect fashion presently recognized by the various model codes.

In his publication, "Fire Protection Through Modern Building Codes," B. L. Wood advanced the suggestion that building area code limitations be developed by a somewhat complicated scaling method whereby the maximum permissible area of any particular building is dependent upon (1) its occupancy insofar as it reflects on contents fire loading and life hazard and (2) its construction as it reflects on the additional contributed fire load and on the degree of fire resistance offered. By comparing each basic type of occupancy and construction (as used in the model code classification system) on each of these counts from data available in the National Bureau of Standards fire loading study and exit standards of the N.F.P.A., he developed a series of relative scaling factors for each class of occupancy using a value of unity for wood frame construction. Thus, once a determination is made of the actual maximum permissible area which can be allowed for wood frame construction within each occupancy classification (this would have to be set by the code writing body,) the remaining permissible areas fall into place and the end result is an area table which he claims reflects equivalent fire risks for each case. For instance, the maximum allowable area for a Type A fire resistive building with an institutional occupancy would present the same total fire risk as the maximum allowable area specified for a wood frame building with a business occupancy. As previously noted, he defines the total fire risk as representing the sum of the conflagration risk plus the life hazard risk.

Other areas in which it appears that fruitful research could be undertaken include (1) realistic study of life hazard factors, (2) comprehensive study of conflagration factors and (3) correlation study between the behavior of walls in standard fire tests and in actual building fires.

The recent series of tests conducted on three school buildings in Los Angeles brought out quite forcefully the fact that the present test methods used for evaluating the life hazard characteristics of interior finish materials (i.e. tunnel test, radiant panel test, etc. ...) do not directly provide meaningful quantitative information on their hazard to human occupancy. This is especially true with regard to the development of smoke and toxic gases. In addition, there is some doubt as to whether any of these test methods even places materials in their correct relative hazard position in all cases. There is a definite need to first quantitatively determine the various factors bearing on the life safety problem and then to develop a correlation between these factors and existing test methods or to develop more meaningful tests for interior finish materials.

The present method utilized in codes to retain the potential conflagration hazard within reasonable limits is to prohibit combustible buildings and roof coverings from within the fire limits and to regulate heights, areas and exposed wall openings with regard to all other buildings erected within the congested mercantile districts. This approach, which is based on past experience, directly attacks some of the more important factors bearing on this problem, but again, it represents at its best only a crude attempt to measure and control this problem. An entirely new approach is vitally needed if building codes are to eventually reach a true realistic status.

Both the British and Japanese governments are presently supporting basic research intended to develop the use of small scale model buildings to study the behavior of fire development and mass fires. The initial problem, of course, consists of developing proper "scaling factors" which can take results obtained in model fires and provide meaningful information as to the probable behavior of fires in full scale buildings. If these studies can be carried to a successful conclusion, it will then be possible to apply a mathematical analysis to conflagration hazard on both a block and area basis which can be translated into rational code requirements.

The present shortcoming of specifying minimum thicknesses for masonry exterior and fire walls, irregardless of standard fire resistance test ratings, should be eliminated and a performance approach used. This will necessitate further study into the various structural stress and stability factors present in different sizes and types of walls subjected to actual building fires and the development of a meaningful correlation between these factors and the standard wall fire resistance test. The results will likely result in a revision of the present test method insofar as the application of structural load and test observations are concerned. The end result will be a test which develops a fire resistance rating which is meaningful from a structural stability standpoint.

As new building materials and methods continue to be developed and the rejuvenation and expansion of our cities reaches its full impetus in the next decade or two, the need for a realistic analytical approach to the problem of achieving adequate but not excessive fire protection in building construction will provide one of the great challenges to our profession.

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National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866)

COMMITTEE ON FIRE PREVENTION AND ENGINEERING STANDARDS

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BUILDING CODES—THE NATIONAL BUILDING CODE OF THE NBFU

Communities looking for a good way to modernize their building codes will do well to consider the National Building Code, recommended by the National Board of Fire Underwriters.

The National Building Code is well suited for adoption by reference, and a suggested ordinance for use in adopting the Code by reference is published as Appendix P. Many cities have so adopted it. For communities which feel that their needs can be cared for by a briefer code, the National Board of Fire Underwriters has published an abbreviated edition of the Code.

In its efforts to influence and encourage the introduction of improved and safe methods of building construction, the National Board of Fire Underwriters has published a recommended building code continuously since 1905 when the first edition appeared. The 1955 Code is the seventh major revision, and in commemoration of 50 years since the publication of the country's first model building code by the National Board of Fire Underwriters, it is called the 1955 Golden Anniversary Edition.

The Code has been prepared with the definite objective of meeting the public interest, providing safety to life as well as property, and giving due regard to provisions affecting health and sanitation. The fire insurance companies carry on this activity because that which serves the public interest in these matters also serves their interest.

The Code is a performance code and insofar as practicable, within the limits of public safety, allows the use of any material, type of assembly, method of construction, or style of architecture that meets the required standards of strength, stability and fire resistance.

The Code has been drafted by engineers of the National Board of Fire Underwriters with help and assistance from many sources. Approved American Standards and nationally recognized standards of trade associations have been widely used in the Code.

Safety to life from fire of the kind which a building code should provide, requires more than ample exit capacity. It requires exit ways that will be safe to use under fire conditions, and restrictions on the spread of fire such as limitation of areas, proper enclosure of stairs and elevators, fire walls (and in some cases exterior walls) having stability under fire conditions as well as fire resistance, restrictions on flame spread rating of materials used as interior finish, protection of window openings against fire exposure, and installation of automatic sprinkler systems in certain situations including large area buildings of readily combustible construction or occupancy.

Lack of one or more of the above features has frequently been an important factor in the injury or death of persons from fires in buildings. The requirements of the National Building Code take into account the accumulation of years of study of these factors by men familiar with the phenomena of fires and their spread in buildings.

The National Building Code contains the latest nationally recognized working stresses for steel and lumber, and permits the use of glued laminated lumber provided its use is in accordance with nationally recognized good practice. It recognizes the place of plastics in building construction and covers their use. It recognizes the use of newly developed thin panel wall sections and permits them under certain conditions.

Buildings of unlimited area are covered by stipulating the conditions under which such buildings are permitted.

High hazard occupancies are covered by requiring compliance with nationally recognized good practice where such exists and giving certain requirements for other high hazard occupancies.

Installation of heating appliances, incinerators, and air duct systems, are covered in the Code by a brief section which cites the "Code for the Installation of Heat Producing Appliances, Heating, Ventilating, Air Conditioning, Blower and Exhaust Systems" recommended by the National Board of Fire Underwriters. This is published in one of the appendixes and is also available in separate pamphlet form.

The Code contains 16 appendixes which give supplementary information. In addition, information on the fire-resistance ratings of walls and partitions, column, beam, girder and truss protections, and floor and roof constructions is given at the end of the Code.

One appendix gives supplementary code provisions for resistance to severe wind conditions. Other appendixes give special provisions covering resistance to earthquakes and protection against termites.

This Code should be a valuable reference book for every building official, architect, structural engineer, and fire chief as well as many others. Any person concerned with building construction may obtain a copy without charge.

Any community considering adoption of the National Building Code, or the Abbreviated Edition thereof, will be furnished on request without charge a sufficient number of copies for study, and on the adoption of either edition will be furnished with up to 50 additional free copies of the edition that is adopted, and as many additional copies as may be desired for a nominal charge that partially covers cost of publication.

Any city or town which adopts either code will, on request, be furnished 1 to 3 sets of the Standards of the National Board of Fire Underwriters and the appropriate official of such town or city will be placed on a mailing list to receive future issues of the standards.

F. P. File C8 123

National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866)

COMMITTEE ON FIRE PREVENTION AND ENGINEERING STANDARDS

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85 John Street, New York 38, N. Y.

JOHN A. NEALE, Chief Engineer

January 23, 1956

Special Interest Bulletin No. 11*

BUILDING OFFICIALS, IMPORTANCE OF—ALSO, SUGGESTED ORDER FOR CHECKING PLANS AGAINST BUILDING CODE

The building official's job in any political subdivision is very important and yet, unfortunately, its importance is too often overlooked by local governing bodies and the citizenry.

We are all aware of the important part played by the firemen and policemen in safeguarding our lives and property from fire and theft because we see and hear about their work daily. Yet we either take for granted or are unaware of the official responsible for seeing to it that the homes we live in and the buildings in which we work, play or worship are designed and constructed to be structurally stable, have adequate means of egress and light and ventilation and provide reasonable protection to life and property from fire. The fact that the building official plays an important part in providing reasonable safety to life and property from fire in buildings and structures is probably surprising to many people.

That such a fact is surprising is probably due to the layman's lack of ability to recognize fire protection features that are built into buildings and to understand their purpose. For instance, many people think of doors leading to stairways as being unnecessary obstacles in their path of travel in stores, offices and other buildings and therefore have a tendency to block the doors open. Yet the importance of properly enclosed stairways, including closed doors, has been demonstrated time and again to be of utmost value in preventing the vertical spread of fire up stairways and in providing a means whereby occupants are able to escape from a burning building with reasonable safety. Properly enclosed stairways further provide a means for the fire department to get to upper floors to fight fires.

Proper enclosure of stairways and other vertical openings through floors of buildings is a fundamental fire protection requirement covered in modern building codes. Some of the other fire protection features included in up-to-date codes are limitations of height and area, sprinklers or standpipes required because of area, height or occupancy of a building, fire walls to subdivide large areas, firestopping of walls, floors and suspended ceilings, protection of exterior openings against exposure fires, restrictions on types of construction in the fire limits and construction of chimneys, flues and vents.

In addition to fire protection requirements in building codes, there are many other requirements that are designed to provide safety, health and sanitation for the public. Some of these are provisions for adequate means of egress, light and ventilation, structural stability, plumbing facilities and for the installation of heating equipment.

All of the above matters included in building codes affect each of us and contribute to the general welfare of the community in which we live.

Responsibility for enforcing building codes rests with the building officials. This is indeed an important responsibility as the building official must see to it that the protection contemplated under the code is provided and yet he must be reasonable in applying the code provisions to the multitudinous variations in building design and materials so as not to be accused of being arbitrary. In addition he must have intimate knowledge of building design and construction practices. Such a job certainly requires many skills.

The National Board of Fire Underwriters has long been aware of the importance of building officials and has maintained a policy of providing helpful assistance to them whenever possible. In accordance with this policy there is given below a recommended order to be followed in checking the code in use to determine items which would be applicable to a proposed building. This procedure is designed to facilitate processing plans for building permits.

1. Determine the occupancy classification and then check all special occupancy requirements such as type of construction required, separation from other occupancies, permissible height or area modifications, etc.

2. Determine type of construction proposed.

3. Determine whether proposed building is to be erected within the fire limits and if so check the requirements within such limits.

4. Determine height and area allowed for the type of construction and occupancy proposed taking into account all permitted modifications.

5. Check location of proposed building on the lot to determine requirements for fire-resistance rating of exterior walls and protection of openings in exterior walls.

6. Check means of egress provided—number of exit ways, location, width and other details.

7. Check light and ventilation provided—size of rooms, window area, courts, yards, etc.

8. Check fire protection requirements such as fire walls, parapets, protection of vertical openings, roof covering, sprinklers, standpipes, interior finish, etc.

9. Check structural design details such as design for proper loads, allowable working stresses of materials, miscellaneous requirements for kind of materials to be used, etc.

10. Check design of chimneys, flues, vents and fireplaces and framing around them.

11. Check sanitary features such as water supply, toilet facilities, etc.

12. Check mechanical and electrical installations such as elevators, moving stairways, air conditioning, ventilating and heating systems, electric wiring, plumbing, gas piping, etc.

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* This Bulletin replaces Bulletin No. 11 dated September 9, 1935 entitled "The Need for Gas Masks in Fighting Fires, Their Value and Limitations" which should be discarded.

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National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866)

COMMITTEE ON FIRE PREVENTION AND ENGINEERING STANDARDS

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Special Interest Bulletin No. 219

BUILDING CODES, IMPORTANCE OF PROPER

Almost any fire chief or building official could point out in his community buildings which he would class as fire traps and which he regards as having defects both as to construction and occupancy which would tax the fire department to the utmost with serious danger to life, and which, under unfavorable conditions, might result in a spreading fire involving other buildings.

For many years the National Board of Fire Underwriters and other organizations maintained by the capital stock fire insurance companies have studied these conditions and offered various recommendations for remedying unsatisfactory conditions and thus aid in reducing the enormous destruction of life and property which has taken place over the past years. The increased cost of construction and the attendant increase in taxable values emphasize the importance of reducing these fire losses. The loss in taxable values alone may have a serious impact, and failure of a burned out industry to rebuild may seriously affect a community in a number of ways.

Fire experience has clearly indicated that a large percentage of the serious losses of life and property are due to faults in building construction. The installation of dividing walls to reduce areas, the enclosure of stairways and other vertical openings from floor to floor, the firestopping of walls, and other features necessary to restrict the spread of fire, safeguard life and aid firemen in extinguishing a fire have often been omitted either because of their cost or because of ignorance on the part of the owner or builder as to the need of such safeguards. Even some so-called fireproof or fire-resistive buildings are seriously deficient in some of these important points.

Many years ago the National Board of Fire Underwriters learned that the preparation of a model building code which would protect life and property against fire, permit the use of new materials as they were developed, and provide for freedom of action in the design of buildings by architects, was a matter requiring a large amount of study and the cooperation not only of building officials but also of trade associations representing manufacturers of the materials used as well as other interested parties.

Because of the importance of such work, men of outstanding ability have been employed by the National Board of Fire Underwriters to prepare and edit a model code. Modifications and revisions have been carried on from year to year by men specializing in building construction and fire protection. The result has been a carefully edited, well arranged, concise and complete code. Since the first edition of this code in 1905 up to the present, a large percentage of the cities of America have used it as a guide and many have adopted it as a whole.

If proper codes are not adopted in municipalities of the United States, much future construction will result in buildings little better than those of the past, and a continued high rate of destruction may be expected of the assets of America as represented by buildings and their contents, as well as a continued high loss of life from fire.

Every city and town in the United States should be prepared for future building programs by having a modern up-to-date building code, with provisions for strict enforcement. Where there is need for the adoption of a new code the first step usually is to appoint a building code committee. Such a committee can well expedite its work by using the National Building Code or the National Building Code, Abbreviated Edition, recommended by the National Board of Fire Underwriters. The committee can make comparisons with the existing regulations in the city, and with codes of other cities, and see what changes, if any, are needed to make the code fit local conditions. However, experience has shown that modification of the arrangement or of the provisions of the National Building Code is seldom necessary. To aid in this work the National Board of Fire Underwriters will provide any city or town with free copies of the codes to be used as the basis of study by any committee appointed to prepare a suitable code for the community. In addition, the National Board has on its staff engineers who are available for consultation work, without cost to the community, both in reviewing any code prepared and in explaining the provisions in its National Building Code.

Inasmuch as the cost of preparing and printing a building code is high, a number of cities have adopted the National Building Code or the Abbreviated Edition by title, with such amendments as seemed necessary. A suggested ordinance for use in adopting the National Building Code, or the Abbreviated Edition, is given in an appendix of each code. Where either code is thus adopted it is the policy of the National Board of Fire Underwriters to provide the city with up to fifty free copies of the edition that is adopted without cost, and as many additional copies of the codes as may be desired at a nominal price per copy, which is less than cost of publication. The National Board of Fire Underwriters will also be pleased to furnish any town or city which adopts either code with one to three sets of the Standards of the National Board of Fire Underwriters and to place the appropriate official of such town or city on a mailing list to receive future issues of the Standards.

National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866*)*
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SPECIAL INTEREST BULLETINS
(For Those Interested in Preventing Loss of Life and Property from Fire)

August 1, 1945

Bulletin No. 220

RESTRICTION OF AREAS OF BUILDINGS

The tendency in constructing any building is to provide for operations by the user such as to entail the least amount of waste movement. For most conditions this means having everything on one floor. This is especially true for stores, machine shops, planing mills and many other industries.

It is therefore natural to expect frontier communities to consist largely of one- or, at most, two-story buildings, and when these become overcrowded, additions are made to them. Only where land values increased rapidly did increase in the height of buildings become a factor in providing enough operating space.

In the process of growth every city has gone through the same stages of building construction. Walls have had openings cut through them, turning several buildings into one fire area, and large structures, originally in semi-isolation, have become centers of congested sections.

The result has been that large-area and excess-area buildings exist, of various occupancies and all of a type of construction having little resistance to destruction by fire. In the final analysis it makes little difference whether structural parts of a building are of wood, unprotected steel, cast-iron, glass or many kinds of stone, plaster or tile; a complete burn-out of the contents results in seventy-five to one hundred per cent destruction of the building. Even in a fireproof building the damage to trim, partitions, decorations, etc., has amounted to eighty per cent or more of the total value, where these buildings have been completely involved.

Studies of fires have been the business of the fire insurance engineers and of the fire chiefs of this country. One fact which experience has shown, and on which theory agrees, is that material well involved in a fire cannot be extinguished unless water can be applied directly upon the incandescent mass. Another recognized fact is that there is a limit to the "reach" of a stream from hose lines, and therefore if all parts of a floor area cannot be reached by the water, when applied from doorways and windows, there is little chance of putting out the fire; in fact, if the burning of the contents is sufficient to prevent the firemen from advancing the nozzle, the fire usually causes the roof or floors to collapse and the firemen will have to retire. Even open areas, such as large platforms at a cotton compress, a lumber yard, or a railroad storage yard, may be so big and develop such heat as to practically prevent successful fire fighting.

This matter of combatting a fire involving a large area has been the bane of firemen of all times, and it has proven many times to be beyond the ability of control by hose line and manpower. So long as these conditions exist in a community the demands for large fire departments, with their high cost to the taxpayer, will exist.

Those buildings which were built before the days of building code requirements controlling areas will always remain as a menace. Where located in congested areas they become conflagration breeders. Even where isolated their destruction seriously injures the economic structure of the community. Besides reducing the taxable assets, the loss of such a structure reduces the income of those thrown out of work, and if not rebuilt it may result in an exodus of workers from the community.

It is the business of the legislative body to enact suitable safeguards, and one of the most vital of these is in the restriction of areas of buildings. No one individual should expect treatment favoring his economics at the expense of the community. Too much of this has existed in the past. Recent serious fires have shown that even the expediency of war has not justified the construction of buildings of great area and holding commodities of large value or great scarcity.

The restriction of fire areas in buildings does not impose a serious obstacle to the use of many buildings. It can be separated into sections by fire walls, or by fire partitions in fireproof and semi-fireproof construction, and by providing fire doors on openings, the building's fire areas will be within the requirements and the building serve its purpose without interfering with operations and at no great cost.

Even though the nature of the use may make it disadvantageous to so restrict the area, there are other safeguards. The potential hazard introduced by excess areas can be somewhat reduced by separating or isolating combustible materials and hazardous processes through the erection of suitable partitions. However, there is no assurance of these conditions being maintained; in fact, the varied changes in occupancy and in process in the past few years have resulted in million-dollar fires occurring in magnesium, rubber, on piers, and even in the open.

There can be no panacea for large and excess areas. The nearest approach is to provide some means of getting water onto a fire irrespective of its location within the building.

The problem of large areas was solved in the years following 1880 by the development of automatic sprinklers. These provided means for the discovery of a fire in its early stages and furnished a discharge of water. Thus it became possible to apply water mechanically where manual application would not be possible. Today automatic sprinkler systems are of such reliability and have proven of such adequacy that all modern building codes recognize them as offsetting the hazard produced by excess areas, except that certain limitations must be made where construction is of a type which would introduce considerable danger of injury of the sprinkler system by collapse or the amount of combustible material might be too great for effective sprinkler control.

It must be recognized that hose lines will be most effective on ground floor areas, and as buildings go upward the ability of hitting all portions becomes less. This may appear to justify greater ground floor areas than on upper floors, but here the economics of design comes in, as stepped-in walls are not well adapted to economic construction. And further, the basement area is the most inaccessible part of a building and it will equal the ground-floor area.

Various factors have been introduced in formulas devised to mathematically determine a true permissible area. The complication of these, and especially if the formula attempts to include heat units of contents and resistance value of the construction in terms of minutes and hours of fire, leads those who have tried to evaluate the various factors back where they were before. That is, that there can never be a scientific determination of area limitation, but that reasonable figures, based upon experience, should be set for all new construction, and where it is desired to exceed these figures that conditions shall be corrected through fire wall and fire partition separation and by requiring automatic sprinkler protection. Any building code which does not rigidly restrict unsprinklered building areas, irrespective of the location and type of construction for most occupancies, fails in one of its important functions.

It will be found that the most logical limit to areas is that which best fits in with the usual size of lot. Where the plat map shows the lots as being 20 to 30 feet wide and 100 to 120 feet in depth, a limitation of two lots in width might well be considered as the basis beyond which the building would be considered as so large as to require special consideration. With the common provision of blank party walls between buildings of other than frame construction, and a separation distance of three feet to the lot line for frame buildings, conditions on this basis would not be too bad, and will be found in close harmony with the limitations in the Recommended Building Code of the National Board of Fire Underwriters.

National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866)

COMMITTEE ON FIRE PREVENTION AND ENGINEERING STANDARDS

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November 1, 1945

Bulletin No. 224

BUILDING HEIGHTS

The crash recently of an airplane into the tall tower of the Empire State Building in New York City forcibly emphasizes the fact that the public has an interest in the often debated subject as to the desirability of limiting the height of structures.

This newest hazard, which produced a death list of fourteen, makes it advisable for all cities to review the subject of structure heights and evaluate the matter from all standpoints.

The arguments for high buildings are: Greater use of land of high value; an advertising item of considerable worth; better light and air on upper floors. Against these are several pertinent arguments which are discussed below.

Consider first the item of land value. This is a purely artificial item, which is becoming of less moment with the changes in transportation, especially in places of less than metropolitan size. Where the principal means of travel was by walking or the use of fixed route transportation, the value of land near these arteries of travel reached astounding figures. These conditions are rapidly changing with the advent of the automobile, and may change even more with the greater use of the airplane.

As a final analysis this claim of the need of great height to overcome high land values does not stand up; close to these high buildings are many of less height and often nearby open lots are used for parking.

Obviously existing Building Codes and Zoning Ordinances will have to take cognizance of the danger of high buildings to airplane travel. They must be prohibited in the immediate vicinity of airfields, and should preferably be limited along the principal approaches for a considerable distance.

Adequate light and air can well be assured for all buildings, whether low or high, by requirements for separation, for courts, areaways and yards, and for setbacks. It is true that these were not provided for in many building codes of the past century, but they have now been incorporated in zoning ordinances. It is no longer necessary to go to excessive heights for breezes and sunshine, especially in these days of air conditioning.

The outstanding factors in height of buildings will always be those endangering life by fire. In this connection there are several items which must be considered. It is not only the few excessively tall structures, which the first part of this article may have seemed to apply to, but the broader aspect of relation of height to types of construction. Certain sections of this country, in the days before the automobile, had many multiple-family frame buildings erected three- and sometimes four-stories high, with little separation between individual buildings. Height is always a material factor in life hazard, and height, combined with close grouping, greatly increases the potential danger of conflagrations. The result of this permission for the erection of such structures has been to increase the requirements as to men and apparatus needed in the fire department. In like manner because there were no suitable restrictions in the building code, factory, store, office, hotel and apartment buildings of brick-joisted construction were erected in many cities to heights of six to eight stories; these also are conflagration breeders, but of even greater moment, they are proving to be death traps for their occupants. Not only does the height of these buildings limit life saving and fire extinguishment by the fire department, but it increases the flue action of the commonly found open stairway. Even where such stairways and other vertical openings through floors are protected, the absence of good fire resistance to the floors makes occupancy of higher stories dangerous.

The National Board of Fire Underwriters in its Recommended Building Code has not limited the height of fireproof buildings. This type has a high degree of stability and of resistance to fire spread from floor to floor. However, even this type might well be restricted by the individual city, on the basis of preventing congestion. This congestion may prove very costly to a city. It will require additions to water, sewers, gas and electricity; it overtaxes transportation during certain hours of the day; it provides complications in the parking and garaging of automobiles, and it necessitates vital changes in schools, playgrounds and in delivery of goods.

Many existing buildings, particularly those without elevator service, cannot find tenants for either residence or business occupancy for floors above the third. In every city are areas in which buildings of even three stories have only ground floor occupancy. Under normal conditions the erection of a new and more modern building will always cause vacancies, especially in upper floors, of older buildings, even though the older, as well as the newer, building may be fireproof.

It is very evident that it is one of the obligations of a law-making body of every community to restrict the height of buildings. An engineering study of this subject covering half a century, indicates that limitation covered by Article 403 of the Building Code Recommended by the National Board of Fire Underwriters properly applies to the various occupancies and classes of construction.

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National Board of Fire Underwriters

(A National Organization of Capital Stock Fire Insurance Companies Established in 1866)

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Revised April, 1957

Special Interest Bulletin No. 227

FIRE LIMITS

One of the most important objectives of a building code is to minimize the possibility of fire involving a series of buildings in the closely built commercial districts. Where suitable laws are not enforced and adequate precautions are not taken to prevent spreading fires in closely built commercial districts, experience has shown that there is an ever-present possibility of a sweeping conflagration. Such a conflagration might be ruinous not only to the individual establishments concerned but to the entire community.

That there is a need for some means to lessen the possibility of a major conflagration has long been recognized. In years past the memory of conflagrations and their consequences in such cities as Chicago, Boston, Seattle, Milwaukee, Jacksonville, Baltimore and San Francisco, served as constant reminders of this need. As the memory of these conflagrations has dimmed, there has come a tendency in recent years on the part of some building code writers to relax the controls that are so vital to the prevention of such catastrophes. However, the lessons of these serious fires must not be forgotten for we are not without examples of serious conflagrations in recent years.

The most effective means by which a building code minimizes the possibility of conflagration is in the fixing of limits known as fire limits together with restrictions on the types of building construction permitted within such limits. With minor exceptions buildings of wood frame and unprotected noncombustible construction should be prohibited within these limits. The types of buildings that are permitted within such limits should be those with exterior walls possessing substantial fire-resistive qualities.

For many years building codes required masonry walls for buildings erected within the fire limits. This was based on years of experience showing that of the materials available at the time for constructing exterior walls, brick and stone of sufficient thickness furnished the most dependable barrier to the spread of fire. However, with the development of new materials and methods of construction, modern building codes no longer specify the materials that must be used for exterior walls of buildings within the fire limits, but require the exterior walls to be of noncombustible material and have a fire resistance rating of not less than 2 hours.

Great care must be taken in the delineation of fire limits and the restrictions placed upon construction therein. The idea of including all of the area zoned for mercantile or for industrial use is unwise in most cases as often these include areas in which there are scattered buildings of mercantile occupancy found along certain street fronts or small, somewhat isolated, industrial buildings; such groups do not in general produce conditions which a moderate sized fire department could not readily handle and usually the growth of such areas will be slow. Neither is there need of setting up special fire limits in which buildings are restricted to fire-resistive construction. The adoption of two or more kinds of fire limits, or as is done in some codes as A, B, C or 1st, 2nd and 3rd limits, is an unnecessary degree of refinement.

It is not believed that fire limits should be of an extent such that they would unduly restrict construction, especially of dwellings, and which will not permit good leeway in design. Fire limits are largely to reduce the spread of fire from building to building.

Fire limits should include all closely built districts of predominantly business or commercial occupancy, together with such blocks or portions of blocks surrounding these districts on all sides as constitute an exposure to these districts, including areas where a definite trend toward business or commercial development is manifested. The outer belt of blocks or part blocks surrounding the closely built districts ordinarily should be not less than 200 feet wide.

Where a land use or zoning ordinance has been adopted, it may be desirable to correlate the fire limits with the provision of the zoning ordinance regarding location of commercial occupancies. Some extension of the fire limits to include areas zoned for commercial occupancies may be appropriate; however, as indicated previously, it is seldom necessary or desirable to include all such areas within the fire limits.

The problem of properly delineating fire limits has confronted municipal authorities and others interested in the subject for years. In an effort to meet the need for information on this matter the National Board of Fire Underwriters has published a Recommended Method for Laying Out Fire Limits in booklet form. This booklet gives a procedure for analyzing built-up areas of communities and criteria for determining whether they should be included within the fire limits.

Copies of the Recommended Method for Laying Out Fire Limits may be obtained free by persons having an interest in it. Copies will be supplied on request to the National Board of Fire Underwriters at 85 John Street, New York 38. If you are located in the Middle West write to 222 West Adams Street, Chicago 6, Ill., and if west of the Rockies, write to 465 California Street, San Francisco 4, Calif.

National Board of Fire Underwriters

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COMMITTEE ON FIRE PREVENTION AND ENGINEERING STANDARDS
85 John Street, New York 7, N. Y.
SPECIAL INTEREST BULLETINS
(For Those Interested in Preventing Loss of Life and Property from Fire)

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Bulletin No. 173

OCCUPANCY HAZARDS

Too often a manufacturing concern will introduce a material into its process without looking into the question as to whether this new material is hazardous. This condition may become more prevalent at the present time because of the need of using substitutes for those commonly used materials which are now scarce.

Film Fire.—As an example of a hazard introduced without proper steps being taken to safeguard the material is a fire which occurred in a large plant which originally made photographic dry plates, using glass. For over forty years this relatively low hazard process was carried on, but about ten years ago, the use of nitrocellulose film was introduced and used in the place of glass. The hazard was recognized by the insurance inspector and a recommendation made for a sprinkler system and for safe storage of the large amount of nitrocellulose film on hand.

Apparently there was no adequate fire prevention ordinance in this city, and therefore the fire department could not force the proper safeguards. Also, apparently, the owner of the plant did not appreciate the danger involved, both to life and property, and took no action. That a fire in this material did not occur for a period of ten years was probably due to luck. The fire which made itself known by two explosions, about eleven o'clock at night, was soon out of control with a loss of about $200,000.

Excess Area Building and High Occupancy Hazard.—This fire would be just another case of the inability of any fire department to successfully fight a fire in a building of excess area, where the fire gets under good headway before it is discovered. were it not that it involved today's all important product—rubber.

Any rubber fire is bad enough from the standpoint of fire fighting—the fumes and smoke are a serious handicap—but when to this is added many gallons of rubber cement and a delay in discovery of possibly 4 hours, there is little a fire department can do.

The building was 320 feet by 160 feet, which meant that streams from windows and doors could not reach all parts of the interior.

Here again, it is evident that the community did not have a fire prevention bureau. In fact, it was a small town outside of a large city, and it is probable that this outside location was chosen partly because the owner could not "build as he chose" within the city where there was a building code and a fire prevention code.

Within most cities structures of this area would have to be sprinklered, and there would be periodic inspections to see that common hazards, particularly those of poor housekeeping, were eliminated.

Delay in Discovery.—Preventing the total destruction of a building, with consequent loss of thousands of dollars, is true fire prevention. Repeated examples, occurring in all communities, emphasize that delay in discovery of a fire is one of the outstanding causes of serious fires.

The story of a recent fire in a 3-story and basement building is typical of these delayed-discovery fires. A city patrolman smelled smoke at 11:00 p. m., but was unable to locate it then or later; at 3:45 a. m. flames were coming through the basement windows. Although an alarm was sent in immediately, and a general alarm within six minutes, the fire could not be brought under control until noon.

Fire prevention, if it is to eliminate such fires, must include the education of owners and operators of the need of guarding against a condition where a fire may burn and smolder for hours, filling the building with heated gases, which in turn heat up woodwork and other burnable material to a point where only the introduction of additional air is needed to make the interior of the building a seething mass of flame.

There are cures for such conditions. Enclosing stairways and elevator shafts will be of great value, and should be done in any multi-storied building. To prevent the delay in discovery a watchman will be of value, but preferably an automatic fire detecting system, which will transmit an alarm to the fire department, should be installed, or the building equipped with sprinklers.

Pyroxylin Plastic Fires. — As an indication of the value of knowledge as an aid in fire fighting, the following story is of interest:

It looked like only an ordinary fire, this blaze in a store handling supply for students in one of the State colleges. Four of the firemen fighting the fire on the inside wore gas masks, but others were without them. Those without masks were dropping like flies. It was recognized then that the fumes were those from T squares, triangles, protractors and other engineering drawing materials made of pyroxylin plastic. All the men affected were immediately put to bed. One fireman completely collapsed; forty-five minutes' application of a resuscitator was necessary before normal breathing was obtained. Others were kept in bed, regardless of protests, until danger of collapse had past.

Fumes from pyroxylin plastic, which is known by the various trade names of celluloid, pyralin, fiberloid, xylonite, niscoloid and nixonoid, can sometimes be recognized by the smell of camphor; the smoke is dense, often of a brownish color; men who are gassed generally resent help with physical force. The fumes are very toxic and men without masks should not be allowed inside the building. Water spray tends to wash out some of the toxic properties, therefore automatic sprinkler protection is very desirable.

UL 10.6. 136

D. Standard Tests for Fire Door Assemblies S8, Ch. X-parag. C

  1. purpose
  2. specific performance requirements
  3. significance and application of test ratings

E. Standard Fire Tests for Roof Covering Materials S8, Ch. VI

  1. purpose
  2. specific performance requirements
  3. significance and application of test ratings

IV. BASIC STRUCTURAL COMPONENTS AND CONSTRUCTION TYPES

Read Section 8, Chapters II, III, IV and IX. This material will only be briefly covered in lecture.

EXAM I

V. BASIC STRUCTURAL MATERIALS

A. Rocks and their decomposition products
B. Portland Cement
C. Concrete
D. Gypsum

VI. SURVEY OF NEW BUILDING MATERIALS AND ASSEMBLIES-Sweet's Catalog Bulletins

A. Lightweight aggregate plasters
B. Contact sprayed fireproofing
C. Concrete assemblies

  1. block floor systems
  2. lightweight concrete
  3. precast concrete slabs and joists
  4. prestressed concrete

D. Gypsum roof decks
E. Composite roof decks
F. Cellular steel floors
G. Lightweight partitions
H. Plastics-mimeo. lecture notes

VII. PROTECTION OF INTERIOR STRUCTURAL OPENINGS-S8, Ch. X

A. Basic objectives
B. Horizontal openings
C. Vertical openings
D. Special methods
E. Smoke and heat venting - S8, Ch. XII

VIII. PROTECTION OF EXTERIOR STRUCTURAL OPENINGS-S8, Ch. XIII

A. Scope of problem
B. Types of protection
C. Theoretical calculations of space separation - mimeo. lecture notes

  1. basic theory
  2. derivation of formulas and tables
  3. application of method to specific building problems

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IX. PRINCIPLES AND APPLICATION OF FIRE LOADING THEORY-S8, Ch. I-parag. D and mimeo. lecture notes

- A. Objectives
- B. National Bureau of Standards approach
- C. British approach
- D. Applications and limitations of method

X. STRUCTURAL DESIGN FOR LIFE SAFETY-S8, Ch. XI and Building Exits Code

- A. Basic philosophy
- B. Exit types and details
- C. Influence of construction features
- D. Influence of occupancy features
- E. Analysis of Los Angeles school fire test program - mimeo. lecture notes
- F. Analysis of other life safety testing programs:
  1. Los Angeles Fire Department dwelling fire tests
  2. British dwelling fire tests
  3. Canadian dwelling fire tests

- G. Application to specific building problems

XI. FIRE PROTECTION THROUGH BUILDIND CODES - S8, pp. 22-24, National Building Code and mimeo. lecture notes

- A. Basic objectives
  1. life safety
  2. limitation of interior fire spread
  3. limitation of conflagration potential
  4. regulate causative hazards

- B. Analysis of National Building Code

- C. Comparison with other nationally recognized codes
  1. Basic Building Code (B.O.C.A.)
  2. Southern Standard Building Code (S.B.C.C.)
  3. Uniform Building Code (I.C.B.O.)

- D. Application to specific building problems

XII. ENGINEERING ECONOMICS OF STRUCTURAL FIRE PROTECTION - mimeo. lecture notes

~~A~~ 139

School GROUP A

39000# GROSS

$\frac{39000}{40} \Rightarrow$ 975 people

9.75 units needed

have 8 units =10 since its a requirement and not a credit.

.75 < 10% of 9

need door @ ②

not >125' to exit
need exit @ 3 or 4

Need smoke barrier in hall since > 300' long halls.

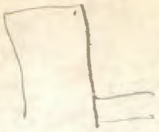
Should have w.g. windows in partns or none.

Should have manual (FA) & adequate illuminated exits

At least 1 window in ea. classroom should open. ¶ 2277

Heating plant O.K. - 1 HR. Cut off.

would advise door ⑤ swing other way or put exit @ ⑥



GROSS AREA

PLACE OF ASSEMBLY (INC (LOBBY)

$$\frac{1200}{15\overline{)18000}}$$
15
30

120 x 150 = 18000 GROSS CLASS A

1400 SEATS $\frac{18000}{15\ \#/p.} \Rightarrow$ 1200 people

NET FLR. AREA = $\frac{12876}{6} \Rightarrow$ 2146 people

REMAINDER

(150)(60) + (80)(300) + 60(100) 39000#

* should NOT have > 14 SEATS betw. aisles.
end aisles shouldn't have > 7 seats./row.

should have exit @ pt. # ① ⅊ 2112 a.

should have exit @ ② (not > 20' allowed)

CLASS B interior finish in assembly hall ok
However, in lobby (exit) not < CLASS A ⅊ 2125 a

$\frac{2146}{100} \Rightarrow$ AT LEAST 21.5 UNITS

They have 11 UNITS

need 10.5 more to outside

should have type 1 emergency illumination
exit lights

Need MANUAL (FA)

Calculating Reg.

3.2 = 3.0 (.2 < .3)
8.3 = 8.0 (.3 < .8)
8.6 = 8.5 (.1 < .8)

$$\frac{\begin{matrix}180\\4\end{matrix}}{720} \qquad \frac{\begin{matrix}16\\80\end{matrix}}{1280}$$

105

$$\begin{matrix}720\\1280\\500\\ \hline 2500\end{matrix}$$

Actual Count:

1st: $(20\times9)(4)+(20\times16)(4)+$ ~~Lobby~~ $\left[\left(\tfrac{1}{2}\right)(30\times100)/3\right]$

$720+1280+$ ~~500~~

$\Rightarrow$ ~~2500~~

$$\frac{\begin{matrix}18\\9\end{matrix}}{\begin{matrix}162\\2\end{matrix}} \quad \frac{}{324}$$

Balcony $(18\times9)(2)+(18\times16)(2)$

$324+576$

$\Rightarrow 900$

$$\begin{matrix}18\\32\\ \hline 36\\54\\ \hline 576\end{matrix} \qquad \begin{matrix}324\\576\\ \hline 900\end{matrix}$$

NET AREA 1st. $\rightarrow$ $\dfrac{115\times100}{6}+\dfrac{15\times100}{3}$

$1917+500$

$\Rightarrow 2417$

$$6\overline{)11500}^{\,1916} \quad \begin{matrix}6\\55\\54\\10\\6\\40\end{matrix} \qquad 3\overline{)50}^{\,16.6} \quad \begin{matrix}3\\20\\18\\20\end{matrix}$$

Balcony $\dfrac{50\times100}{6}$

$\Rightarrow 833$

$$\begin{matrix}1917\\500\\ \hline 2417\end{matrix} \qquad 6\overline{)5000}^{\,833} \quad \begin{matrix}48\\20\\18\end{matrix}$$

$\therefore$ Use Actual count

2500 people main flr

900 people balcony

CLASS A place of assembly

20 UNITS AUDIT
+5 UNITS lobby.

$\dfrac{2500}{100}\Rightarrow$ 25 UNITS of exit for main flr.

$\rightarrow$ NOT more than $\frac{2}{3}(25)=16.5$ may be thru lobby

$\dfrac{900}{75}\Rightarrow$ 12 UNITS of stairs for balcony

$\rightarrow$ MAX 6 UNITS CAN BE F.E.

$$75\overline{)900}^{\,12} \quad \begin{matrix}75\\150\end{matrix}$$

$\frac{3}{4}\times12\Rightarrow$ 9 UNITS exit cap. from stairs.

[illegible] $\rightarrow$ Not $> 9\times\frac{2}{3}=6$ may go thru lobby

or $6\times\frac{4}{3}=8$ stairs thru lobby.

142

How many existing

Main FLOOR

36
22
14

$4\left(\frac{44}{22}\right) = \boxed{8}$

$2\left(\frac{36}{22}\right) = 2(1.5) = \boxed{3}$

$\frac{2}{3} \times 11$
7.3
$3\overline{)22}$
21
10

LOBBY

30
22
8

$5\left(\frac{88}{22}\right) = \boxed{20}$

$2\left(\frac{30}{22}\right) = 2(1) = \boxed{2}$

33

Balcony:

STAIRS

F.E. $2\left(\frac{44}{22}\right) = 4$

$2\left(\frac{66}{22}\right) = 6$

10

Note: $9 - \frac{3}{4}(4) = \boxed{6}$ unit exit cap. now req. in bldg. from stairs

NOT O.K.

look at it another way,
audit has 11 units
∴ lobby needs (20-11) = 9
+ 5 for lobby + 6 from
balcony ⇒ 20 o.k.
(has 22)

Summary:

Main Floor:

Need total 25 units +6 = 31

have 8+3 = 11
+ MAX $\boxed{16.5}$ = 27.5 INADEQUATE
$\frac{2}{3} \times \frac{25}{1}$

31.0
27.5
3.5 Needed in auditorium

Balcony:

Need 12 units stairs, Max 6 of wh. may be F.E.

have 10 units stairs, 4 of wh. are F.E.

since ~~to~~ 6 of these go thru lobby, and $9 \times \frac{2}{3} \times \frac{4}{3} = 8$ stairs ~~[illegible]~~ is max allowable, Need another 2 unit F.E. or 2 unit stair thru lobby.

4.5
$4\overline{)18}$
16
20

$6 \times \frac{3}{4} = 1.5$ units exit req. in lobby for stairs, o.k.

Note: If only had enough for main floor, could they be used for this 4.5?

has. 4 exits remote from ea. other.

not > 100' travel. dist.

Type 1 emergency illumination o.k.

Open stairs to balcony o.k.

Acoustical tile in lobby and other places of exit should be treated → F.S. ≦ 25.

Rows of seats betw. aisles shouldn't have > 14 seats.

end rows shouldn't have > 7 seats

spacing 32" back to back o.k.

width of aisles ok (36" min.) ¶ 3135

80 rows of seats o.k.

Cross aisle width o.k. (min 44")

should have partitions or 42" railings in lobby to keep standing people from obstructing exit.

115
210
1150
230
4 | 24,150
6030

15

BUILDING EXITS PROBLEM (GROUP B TYPE)

1 PERSON / 40# GROSS FLOOR AREA

2ND. FLOOR ; N. Wing 329 people on 6400# gross
S. Wing 289 people on 5600# gross.
618 12000#
N. Wing 329 " " 1800# net
S. Wing 289 " " 1200# net
3000

GROSS $\frac{12000\#}{1} \times \frac{1 \text{ People}}{40\#} \Rightarrow \underline{\underline{300}}$ people on second flr according to gross method.

N. WING: 329
ACTUAL
S. WING: 289 618 people actual

Net $\frac{3000\#}{1} \times \frac{1 \text{ people}}{6\#} = \underline{\underline{500}}$ people net.

1ST FLOOR.

GROSS $\Rightarrow \underline{\underline{300}}$ people

ACTUAL

$$\begin{array}{r} 569 \\ -329 \\ \hline 240 \end{array} \quad \begin{array}{r} 631 \\ -289 \\ \hline 342 \end{array} \quad \begin{array}{r} 342 \\ 240 \\ \hline \end{array} \Rightarrow \boxed{582}$$

N. WING: 240
S. WING: 342

Net

$$\begin{array}{r} 1400 \\ 1200 \\ \hline 2600 \end{array} \quad \frac{2600\#}{1} \times \frac{\text{People}}{6\#} \Rightarrow \underline{\underline{433}}$$

433
6 | 2600
24
20

~~# Stairs Needed to 2nd. Flr.~~

~~$\frac{618 \text{ people}}{1} \times \frac{1 \text{ UNIT}}{60 \text{ people}} = \underline{10}.3$ UNITS stairs REQ'D.~~

~~FIRST FLR. DOORS. $\frac{582}{100} = 6$ units~~

~~2ND. FLR. DOORS: $\frac{618}{100}$ 6.18 $\Rightarrow$ 6 units~~

BUILDING EXITS PROBLEM

EXIT REQ.

N. WING. ~~ANNEX + S. WING.~~

1ST.

$\frac{240}{100} = 2.4$ UNITS

$\Rightarrow$ 2.5 UNITS. DOORS.

FROM 2ND. $\frac{5.5}{1} \times \frac{3}{4} = 4.1 \Rightarrow$ 4 UNITS DOOR.

2ND. $\frac{329}{60} =$ 5.5 UNITS. STAIRS.

S. WING

2ND! $\frac{289}{60} =$ 4.8 UNITS $\Rightarrow$ 5 UNITS STAIRS!

1ST! $\frac{342}{100} = 3.42 \Rightarrow$ 3.5 UNITS DOORS

$\frac{.75 \times 5}{3.75}$ FROM 2ND $3.5 \times \frac{3}{4} = 2.6 =$ 3 UNITS DOORS

EXITS AT HAND

N	east. stairway	52/22	= 2.36 .14	= 2	UNITS	STAIR	7
	west stairways	2x 56/22	= 5.1	= 5	"	"	
S	east stair	30/22 =	1.36	= 1	UNIT	STAIR	3.5
	middle Stair	30/22 =	1.36	1	"	"	
	F.E.	36/22 =	1.64	1.5	"	"	
N	W. 4-44" doors			8	UNITS	DOOR	10
	E. 1-44" "			2	"	"	
S	E. 1-44" door			2	UNITS	DOOR	3
	middle 1-28" door			1	"	"	

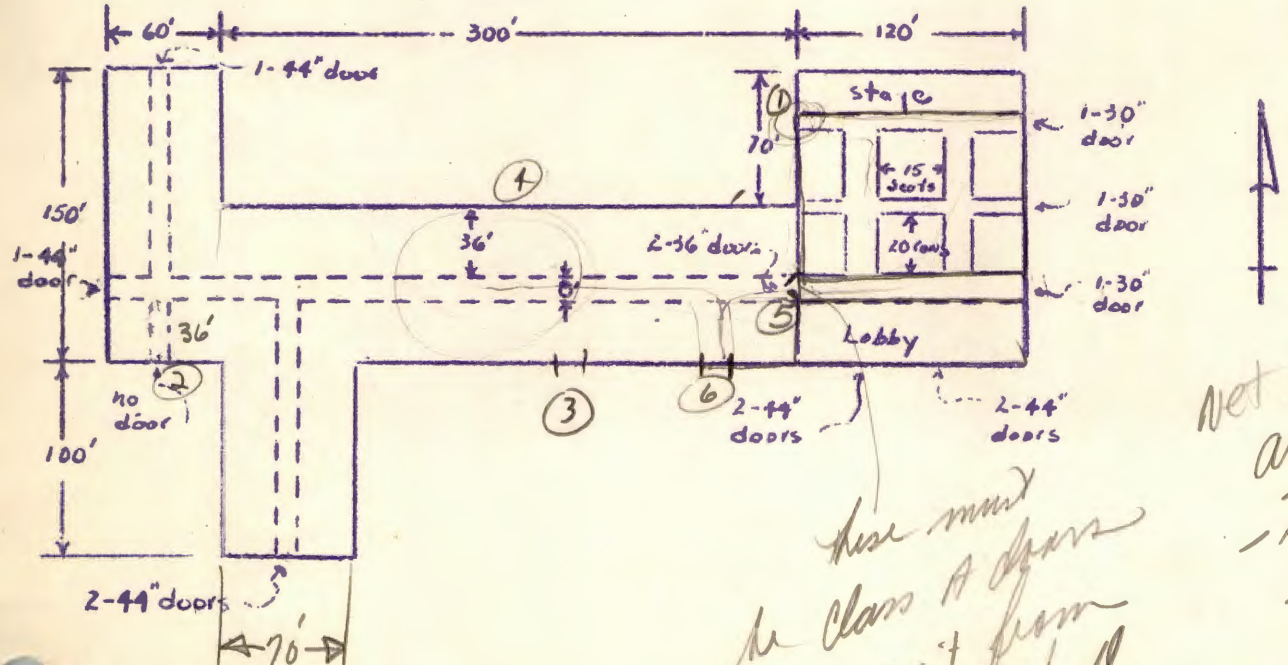
F.P.E. 307 - BUILDING EXIT PROBLEM

Evaluate the following proposed one story without basement school building with reference to the various applicable requirements of the Building Exits Code. Include in your answer each instance when this building does or does not meet the Code. Use only the Gross Area Method except for the Assembly Hall.

Building consists of 8" brick bearing walls with concrete floor on ground and with tectum roof slabs on steel bar joists. Ceiling consists of 3/4" gypsum-perlite plaster on metal lath attached directly to the bottom of the bar joists throughout the building. Ceiling of assembly hall and of corridors throughout remaining portion of the building have acoustical tile attached directly to the underside of the plaster. This tile has been listed by U.L. as having a flame spread rating of 40.

The stage in the assembly hall has an approved fire resistive curtain and no scenery of any type. Assume that the assembly hall will be used on occasion by outside groups after school hours. Also, assume that the lobby will not be utilized for standing room during performances. Both longitudinal aisles are 8 feet wide and the cross aisles are 4 feet wide except at the rear of the hall which has a 6 foot aisle. There are 10 seats in each side aisle and 15 seats in the center aisle. There are 20 rows of seats between cross aisles. There is 28 inches spacing back to back between rows.

In the classroom sections of the building, corridors are 8 feet wide. Classroom doors are solid wood flush type. A large ordinary glass panel is to be provided in the corridor wall adjacent to each classroom door. The classroom section of the building is to be air-conditioned and therefore the windows of the classrooms will not be movable. The heating plant for the entire building is to be cut off from the remainder of the building by a one-hour cutoff. No emergency exit lighting or fire alarm system is contemplated.



these must be class A doors for exit from assembly hall.

Net area - assembly hall - stage - lobby

Solution

Population Calculation

Classroom Section:

$$\text{Area} - \begin{array}{l} 150'\text{x}60' = 9{,}000 \text{ ft.}^2 \\ 100'\text{x}70' = 7{,}000 \text{ ft.}^2 \\ 300'\text{x}80' = 24{,}000 \text{ ft.}^2 \\ \hline 40{,}000 \text{ ft.}^2 \end{array} \qquad 40{,}000 \text{ ft.}^2 \text{ x } \frac{P}{40 \text{ ft.}^2} = 1000 \text{ P}$$

Assembly Hall:

$$\text{Area} - 150'\text{x}120' = 18{,}000 \text{ ft.}^2 \qquad 18{,}000 \text{ ft.}^2 \text{ x } \frac{P}{15 \text{ ft.}^2} = \boxed{1200 \text{ P}}$$

Actual Count - 2x20x (15+10+10) = 1400 P

Exit Requirements

Classroom Section

$$1000 \text{ P x } \frac{\text{Unit}}{100\text{P}} = 10 \text{ units}$$

Assembly Hall

$$1400 \text{ P x } \frac{\text{Unit}}{100\text{P}} = 14 \text{ units}$$

Available Exits

2-44" doors (south)	2x2 = 4 units
1-44" doors (west)	1x2 = 2 units
1-44" door (north)	1x2 = 2 units
	8 units
4-44" doors (south)	4x2 = 8 units
3-30" doors (east)	3x1 = 3 units
	11 units
2-36" doors (division wall)	$2\text{x}1\frac{1}{2}$ = 3 units

(1) **Exit Capacity**

Classroom Section - require 10 units of street door capacity and have 8 units. ~~However, because assembly hall would not have simultaneous occupancy, the two doors in the division wall can be utilized for a total of 8+3 = 11 units of exit capacity - satisfactory~~.

Assembly Hall - require 14 units of street door capacity and have 11 units. However, as stated above, total exit capacity is 11+3 = 14 units of exit capacity - satisfactory. Aisle capacity - satisfactory.

(2) **Exit Arrangement**

(a) independent exits - require 2 in classroom section and 4 in assembly hall - satisfactory.

(b) maximum distance to exits - require ≤ 125' in classroom section and ≤ 150' in assembly hall. In east portion of classroom section, maximum travel distance would be at least 36'+1/2(360) = 216 feet - inadequate. Assembly hall - satisfactory. In addition, classroom section has a 36' blind corridor at the west end (limit of 20' permiss.)-inadequate.

(c) balanced exit capacity - classroom section - satisfactory. Assembly hall has 8 units through public lobby and 2+3 = 5 units elsewhere - satisfactory (not greater than 2/3 capacity through public lobby.)

(d) seating arrangement
  (1) ≤ 14 seats between aisles - have 15 seats - inadequate.
  (2) ≤ 7 seats between aisles and walls - have 10 seats - inadequate.
  (3) ≤ 20 rows between aisles - have 20 rows - satisfactory.
  (4) ≥ 30" between rows, back to back - have 28" - inadequate.
  (5) ≥ 3' aisle width - satisfactory.

(3) Construction Features

(a) Interior Finish - require Class B in corridors and assembly hall, Class A in lobby, and Class C elsewhere - satisfactory except for lobby where proposed Class B acoustical tile can not be used.
(b) 300' corridor length - have approximately 646' of open corridor - inadequate. Therefore, must provide two smoke barriers to reduce open corridor length below 300'.
(c) classroom-corridor partitions-require wired glass windows - have ordinary glass wall panels adjacent to classroom doors - inadequate.
(d) minimum 6' corridor width - have 8' wide corridors - satisfactory.
(e) minimum 1 hour boiler room cut-off - satisfactory.
(f) window access from classrooms - none provided account of air conditioning system, inadequate - provide one movable window per classroom of adequate size and not more than $2\frac{1}{2}$ ft. above the floor.
(g) stage in assembly hall - fire resistive curtain - satisfactory.

(4) Protection Features

(a) emergency exit illumination - account of possibility of night-time occupancy, a type 1 or 2 emergency lighting system is required - none provided - inadequate.
(b) manual fire alarm system - required but not provided - inadequate.

F.P.E. 307 - BUILDING EXITS PROBLEM

Two story with basement brick ordinary joist school. (Evaluate as Group B Type.)

Actual school population

north wing-569 (329 on 2nd floor)
annex and south wing-631 (289 on 2nd floor)

Floor areas

north wing-6400 ft.^{2} (net classroom areas; 1800 ft.^{2} on 2nd floor
and 1400 ft.^{2} on 1st floor)
annex and south wing-5600 ft.^{2} (~~net classroom areas~~; 1200 ft.^{2} area available for seating
on each floor)

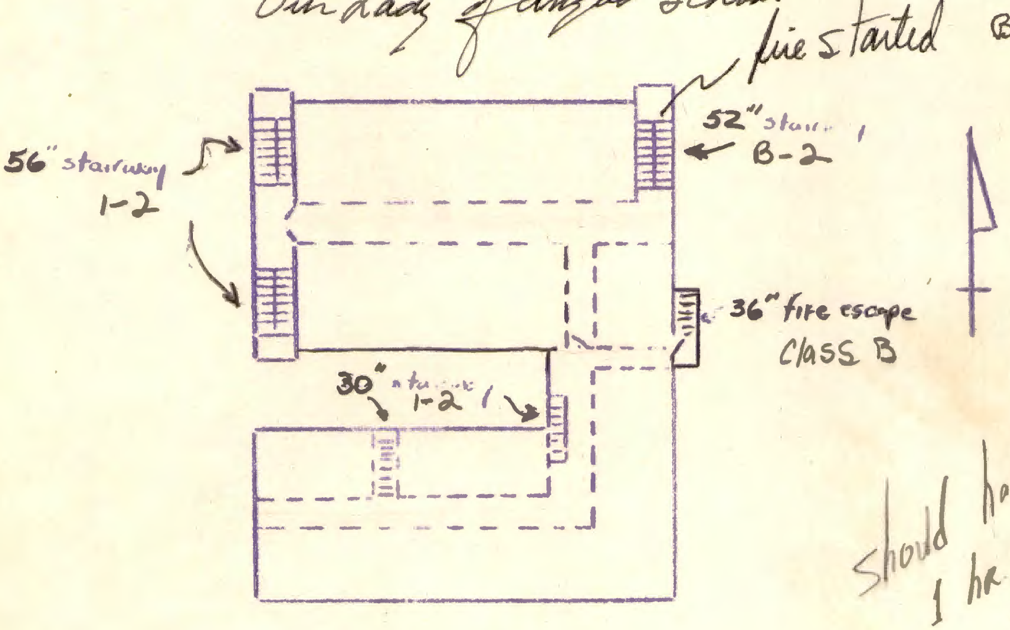
Exit facilities in north wing include a stairwell enclosure at west end with 2-56" stairways from 1st to 2nd floors and with 4-44" doors at street level. Doors into corridors at both floors are wood and plain glass. Stairway at east end is 52" wide and extends from basement to 2nd floor. Door protection into corridor is as follows: Basement-wood door, first floor-Class B fire door, second floor-open. Door at street level to outside is 44" wide.

Exit facilities in annex and south wing include two-30" open stairways from first to second floors (44" street level door on east stair and 28" street level door on middle stair) and a 36" outside Class B fire escape stair at the east end.

Doors separating the two sections of the building are of unapproved wooden type.

Interior finish consists of wood lath and plaster with combustible acoustical tile (estimated flame spread rating in excess of 200) fastened to ceilings of all classrooms and to the ceilings of the first and second floor corridors of the north and annex sections. Doors to classrooms are wooden with ordinary glass transoms above. Windows of classrooms are located with bottom sill 3½ feet above floor level. All outside street level doors are equipped with panic hardware. All interior corridors are 10 feet wide.

Our Lady of Angels School



all 95 killed on 2nd. No F.D. but class "B" F.D. 1ST.

Should have 1 hr prot. stairs.

had plenty of exits in N. Section but NO PROT.

Questions P 2202-3

Solution

Population Calculation

Gross Area Method	**North Wing**	**Annex and South Wing**
Second Floor:	$6400\ ft.^2 \times \frac{P}{40\ ft.^2} = \boxed{160\ P}$	$5600\ ft.^2 \times \frac{P}{40\ ft.^2} = \boxed{140\ P}$
First Floor:	same $= \boxed{160\ P}$	same $= \boxed{140\ P}$
Net Area Method		
Second Floor:	$1800\ ft.^2 \times \frac{P}{6\ ft.^2} = \boxed{300\ P}$	$1200\ ft.^2 \times \frac{P}{6\ ft.^2} = \boxed{200\ P}$
First Floor:	$1400\ ft.^2 \times \frac{P}{6\ ft.^2} = \boxed{233\ P}$	same $= \boxed{200\ P}$
Actual Count Method		
Second Floor:	= 329 P	= 289 P
First Floor:	= 240 P 569 P	= 342 P 631 P

why 6?

Exit Requirements

2nd floor-North Wing

$329\ P\ \frac{Unit}{60P} = 5.5$ units ✓

2nd floor-Annex and South Wing

$289\ P\ \frac{Unit}{60P} = 4.8 = 5$ units

1st floor-North Wing

$240\ P\ \frac{Unit}{100P} = 2.4 = 2.5$ units ✓

plus street door capacity
for 2nd flr. stair capacity
3/4 (5.5) = 4.1 = 4.0 units ✓
6.5 units

1st floor-Annex and South Wing

$342P\ \frac{Unit}{100P} = 3.4 = 3.5$ units

plus street door capacity
for 2nd floor stair capacity
3/4 (3.5) = 2.6 = 3 units
(5.0-1.5 = 3.5) 6.5 units

Available Exits

east stairway 52"/22" = 2.3 units = 2 units
west stairways 2x56"/22" =2 x 2.5 = 5 units
7 units

east stairway 30"/22" = 1.2 = 1 unit
middle stairway 30"/22" = 1.2 = 1 unit
outside fire escape-36"/22" = 1.5=1.5 units
3.5 units

west end 4-44" doors 4x2 = 8 units
east end 1-44" door 1x2 = 2 units
10 units

east end 1-44" door 1x2 = 2 units
middle stair 1-28" door 1 x 1 = 1 unit
3 units

165

(1) Exit Capacity

North Wing - require 5.5 units of stairway capacity and have 7 units available - satisfactory. Require 6.5 units of street door capacity and have 10 units available - satisfactory.

Annex and South Wing - require 5 units of stairway capacity and have 3.5 units available - inadequate. Require 6.5 units of street door capacity and have 3 units available - inadequate.

Bldg. considered as a whole - require 10.5 units of stairway capacity and have 10.5 units available. Require 13 units of street door capacity and have 13 units available. Total exit capacity is satisfactory but it is poorly balanced as between the two sections of the building.

(2) Exit Arrangement

(a) two independent exits - two exits are available from each floor of each section of the building. However account of open stairways, these exits are not independent.
(b) maximum 125' travel distance to exits - satisfactory.
(c) protection of stairwells - west stairwells have unapproved doors and the remaining stairwells are open except for a Class B fire door at the first level in the east stairwell in the North Wing. This is inadequate for Type B school. Either the stairwells must all be properly enclosed, or in lieu thereof, the building must be sprinklered and a separate outside access provided from the basement (Type C-Section 2230.)
(d) balanced exit capacity-An additional 1.5 units of stairway capacity and 3.5 units of street door capacity should be provided in the Annex and South Wing. This can be achieved most economically by providing a 44" exterior fire escape and by widening the doorway opposite the middle stairway to 66" width.

(3) Construction Features

(a) Interior Finish - require at least Class B in corridors and exitways and Class C elsewhere. Combustible acoustical tile must therefore be treated in classrooms to reduce flame spread below 200 and in corridors to below 75. (Assuming an existing building.)
(b) Classroom doors - require wired glass in any windows. Have ordinary glass transoms - inadequate.
(c) Other features - panic hardware - satisfactory; minimum 6 foot corridor width-satisfactory. Maximum height to window sill - inadequate.

F.P.E. 307 - BUILDING EXITS PROBLEM

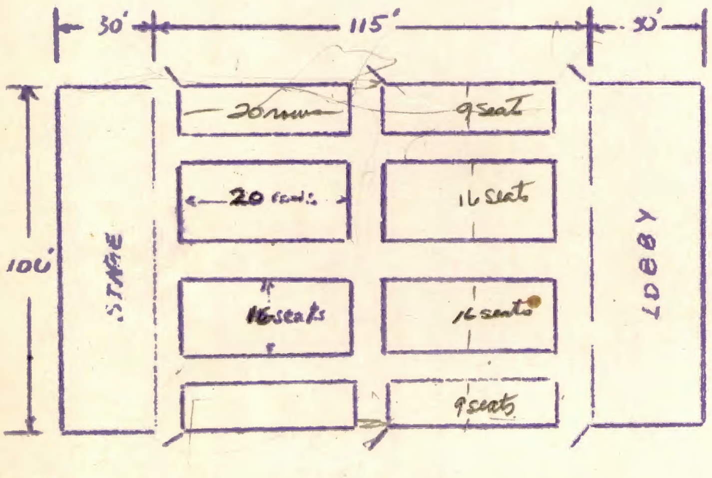
Problem: Evaluate the adequacy of the exit facilities and associated features provided in the following exisiting 1 - 2 story movie theater with balcony which is of fire resistive construction. Use the Net Area and Actual Count Methods.

Main floor - provided with 4-44" doors and 2-36" doors (nominal width) on the side walls opening directly to the outside. All doors are equipped with panic hardware. Longitudinal aisles consist of a 132" center aisle and 2-88" side aisles and 3-66" transverse aisles (as shown on sketch). There are 16 seats between the center and side aisles and 9 seats between the side aisles and the walls. There are 20 rows between cross aisles and spacing between rows is 32" back to back.

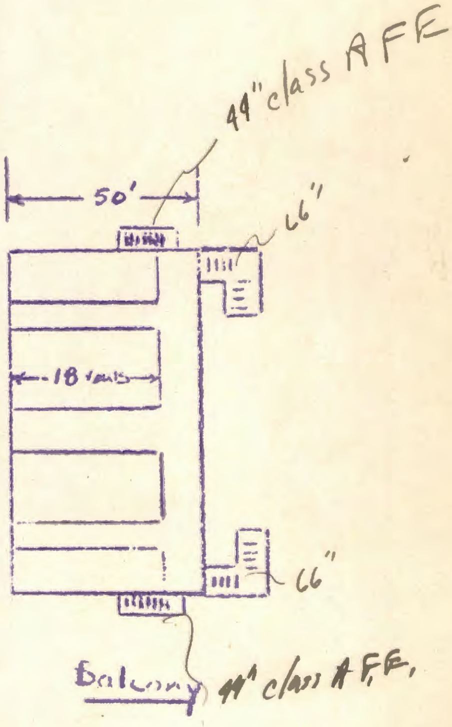
Balcony - provided with 2-44" Class A exterior fire escapes. There are also 2-66" interior open stairways leading from the back of the balcony down to the first floor lobby. Arrangement of aisles is the same except single 132" transverse aisle at rear. Seating arrangement is identical with first floor except that there are 18 rows of seats.

Lobby - Assume 1/2 of area is available for standing room. Street doors consist of 5-88" double door openings (2-40" clear openings each) and 2-30" single doors (nominal width).

In General - Entire auditorium is equipped with a Type I emergency illuminating system. Interior finish on auditorium and lobby ceilings is acoustical tile (U.L. rating of 40).



Main Floor



Balcony

169

Solution

Population Calculation

Net Area Method

main floor - $115' \times 100' = 11{,}500 \text{ ft.}^2 \times \frac{P}{6 \text{ ft.}^2} = \boxed{1917 \text{ P}}$

balcony - $50' \times 100' = 5{,}000 \text{ ft.}^2 \times \frac{P}{6 \text{ ft.}^2} = \boxed{833 \text{ P}}$

lobby - $1/2\,(30' \times 100') = 1{,}500 \text{ ft.}^2 \times \frac{P}{3 \text{ ft.}^2} = 500 \text{ P}$

Actual Count Method

main floor - 2x20x (16 + 16 + 9 + 9) = 40 × 50 = 2000 P

balcony - 18 (16 + 16 + 9 + 9) = 18 × 50 = 900 P 2

Total 3400 P

Exit Requirements

Balcony

$900 \text{ P} \times \frac{\text{unit}}{75\text{P}} = 12 \text{ units}$

Main Floor

Audit. - $2000 \text{ P} \times \frac{\text{Unit}}{100\text{P}} = 20 \text{ units}$

Lobby - $500 \text{ P} \times \frac{\text{Unit}}{100\text{P}} = 5 \text{ units}$

25 units

street door capacity
for balcony stairs 3/4(12-4) = 6 units

31 units

Available Exits

2-44" Class A ext. fire escapes 2x2 = 4 units
2-66" stairways 2x3 = 6 units
10 units

4 - 44" doors 4x2 = 8 units
2 - 36" doors $2 \times 1\frac{1}{2}$ = 3 units
5 - 88"(2-40" clear opn'gs.) 5x2x2 = 20 units
2 - 30" doors (nom. width) 2x1 = 2 units
33 units

(1) Exit Capacity

Balcony - require 12 units; have only 10 units - inadequate

Main Floor - require 31 units; have 33 units - satisfactory. However, auditorium provides 11 units directly; therefore, 9 units must be provided in form of lobby doors plus 5 units for lobby standing area plus 3/4 (12-4) = 6 units to evacuate occupants coming from balcony or a total of 20 units - also satisfactory.

2, (2) Aisle Capacity - 132"/22 + 2(88"/22) = 14 units. Although main floor requires 20 units, consider as adequate because of egress in various directions to the several auditorium exits.

9/2

16.5

$2\overline{)49.5}$

2

(3) Exit Arrangement

(a) 4 independent exits for Class A assembly hall - satisfactory.
(b) maximum of 2/3 required exit capacity thru public lobby - have 22 units - satisfactory.
20 + 5 + 3/4(12) = 34 total required; 2/3x34 = 22.7 units allowable.
(c) maximum 150' travel distance to exit - satisfactory.
(d) protection of interior stairways - waived as per section 2123.
(e) seating arrangement

(1) max. of 14 seats between aisles - have 16 seats - inadequate.
(2) " " 7 seats " " and wall - have 9 seats - inadequate.
(3) " " 20 rows between cross aisles - satisfactory.
(4) minimum of 30" between rows, back to back - satisfactory.
(5) minimum width of aisles - satisfactory in all cases.

(4) Interior Finish - require Class A interior finish in exitways and Class A or B interior finish in general assembly areas. Have Class B acoustical tile in both auditorium and lobby ceilings - inadequate in lobby.

(5) Emergency Illuminating System - require Type I system for Class A assembly hall - have Type I system installed - satisfactory.

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME David Lucht

SUBJECT

CLASS DATE

INSTRUCTOR

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9		19	
10		20	

83

1. a. these hold-open devices found inadequate since untenable smoke conditions usually preceed temperatures which are high enough to actuate device.

b. effective in reducing temperatures to small degree, but had no effect on smoke cond.

c. adequate in certain cases, but it is unknown as to if some of the test fires would <u>ever</u> have been dangerous.

-4 ? d. Weren't found to actuate fast enough to do any good as far as ~~t~~ giving occupants time to evacuate.

2. 1. giving building structural integrity (won't collapse)

2. Providing adequate exits – (Allows firemen to enter bldg with more safety)

3. Venting reqmts. – (vents out smoke + dangerous gasses)

4. Sprinkler Reqmt's. (esp. bsmts) firemen don't have to take as many chances fighting bsmt fires

-3 5. ? Fire Escapes ~~esp.~~ existing bldgs. – provides good access.

3. 1. More research on performance characteristics of fire walls.

2. More research on exposure problems.

-5 3. More research on possibility of correlating model building performance with actual.

4. 1. Concentration of Population - more people requires more exit capacity

2. Adequacy of Fire Dept. (Esp. ladder equipment) - how well exits can be replaced or aided by ladder work

3. Mental & Physical condition of occupants - how able are occupants to use the exits provided?

4. Combustibility of Interior finish materials - must keep fire out of exits

5. Height and area of bldg. this governs how far people must travel to reach safety

$4\overline{)2240}$ = 560; 20; 24

230 × 80 = 18400

80 × 50 = 4000

5, TFA - GROSS 80 × 50 + 80 × (150 + $\overset{80}{}$80)

80 × 50 80 × 230

✓ 18400 + 4000 = 22400 = GROSS Area.

✓ $\frac{22400\#}{40\#/p}$ = 560 people / floor.

REQ.

1ST floor: ✓ $\frac{560}{100}$ = 5.6 ⇒ 5.5 units exit doors

9.33 = $6\overline{)56}$; 54; 20

2ND ✓ $\frac{560}{60}$ = 9.33 = 9 UNITS. STAIRS.

6 ✓ $\frac{3}{4} \times \frac{9.33}{1}$ = ~~7~~ 6.75 ~ 6.5 STREET EXITS REQ FOR STAIRS

~~10 [illegible]~~

∴ need TOTAL ~~12.5~~ 12.0 exit UNITS 1ST

✓ AND. 9 UNITS stairs.

AVAILABLE EXITS:

$3 \times \frac{28}{22}$ = 3
$3 \times \frac{28}{22}$ = 3
$3 \times \frac{28}{22}$ = 3
$1 \times \frac{40}{22}$ = ~~1.5~~ 2.0
} ~~10.5~~ 11.0

STAIRS:

$1 \times \frac{66}{22}$ = 3
$1 \times \frac{66}{22}$ = 3
$1 \times \frac{44}{22}$ = 2
} 8 ✓

∴ need 2 more door exit units
and one stair unit.

✓ ~~Probably~~ should install stair
in N. end to balance exits
and eliminate dead end. ?
GROUP B school
arrange so that
ea. stairwell has door cap at least = $\frac{3}{4}$ stair cap;
✓ Stairs should have 1 HR. enclosure
and adequate means to keep doors
closed.

✓ Bsmt. should have access only
from ~~to~~ outside.

✗ It doesn't appear that anyone should
have to travel > 125' ∴ o.k.

north end of 2nd flr. (incl. 50' travel dist. inside of classrm.)

✓ Cmt. Acoustic tile should be
replaced with tile with
F.S. at least < 75 in corridors
+ exits. and < 200 elsewhere.
Except bsmt should be replaced with

ceiling which would yield a 1 HR. fire resistance to the floor assembly above it. (storage area)

✓ transoms should have w.g.

✓ Exterior doors and doors in any room with >100 persons should be equipped with panic hardware.

✓ Corridor width O.K.

✓ height to bottom of windows shouldn't be > 2'6" and at least one should be able to be opened from inside.

✓ Boiler Room cut-off O.K.
Since bsmt is for storage, it must be 1 HR too.

✓ Should have adequate exit illumination

✓ Should have manual F.A. and plan fire drills.

X Vertical opng. protect. S/B 1 hr.

F.P.E. 309

Important F.P. & Related Organizations

1. NFPA a-f
2. NBFU a-d
3. FIA
4. F.M.

Codes, Laws, & legislation:

Advisory Standards: 1-6
Federal Laws: 1-4 Dpts.
State
County
Municipal Govern: 1-2

F.P.E. v. ARCHITECT.

Hazards of Interior Finish Matls.

Reasons for death in Cocoanut Grove, School etc.

1.
2.
3.

Cocoanut Grove → U.L. WORK → TUNNEL

UL. 723, NFPA 255
ASTM E-84

Steiner Tunnel measures 1.
2.
3.

Variables to be controlled

1.
2.
3.

3 FORMULAE ?

Calculation of Smoke & Fuel Cont ?

OTHER TEST METHODS
1. Federal Specifications Test SS-A-118(b)
2. RADIANT PANEL TEST. NBS
3. Small Tunnel Test FPL
4. Schlyter Test - Sweden
5. F.M. Calorimeter test
6. Spread of Flame Test BS. 476
7. New British Bldg. Bd. test
8. Pilot Ignition Test - Austrailian

TESTING IMPREGNATED MATL:
1. UL 723
2. ASTM E-160

TESTING FOR COMB OR NONCOMB.
1. NFPA Defn.
2. ASTM E-136-T
3. F.M. CALORIMITER
4. N.B.S. OXYGEN CALORIMITER BOMB TEST
5 BRITISH

TESTING METAL DECK.
1. F.M.
2. U.L.

Methods of Reducing Comb.
1.
2.
3.
4.

Types of Surface Coating

1.
2.
3.
4.

Impregnation - how?

How does wood burn?

- decomp. products?
- make up. - give off?

theories of how impreg. works:

1. Coating theory -
2. Thermal ~~[illegible]~~ theory
    A.
    B.
    C.
3. Gas theories
    A.
    B.
4. Chemical theories

Advantages & disadvantages of Impreg. lbr.

Sangamon & Superior
S&B.
932 W 732 N

Metal Roof Decks.

Standard Fire Severity Tests

ASTM E-119 }
NFPA 251 } fire endurance Test.
UL 263 }

Measures 1. - A.

Natural Aggregates:

1.
2.
3.
4.

Artificial Aggregate:

1.
2.
3.

Two Types Pre-stressed Conc.

1.
2.

British Results: concerning RFC

1.
2.
3.
4.

N.B.S. Methods of Estimating F-R periods

$R = (CV)^n$

V = vol. solid mat'l/unit area exposed wall surface.

$R = (c_1V_1 + c_2V_2, \ldots)^n$

$R = (R_1^{.59} + R_2^{.59} + \ldots)^{1.7}$

of plast $R = (R_1^{.59} + R_2^{.59} \ldots + K)^{1.7}$

Menzel's Formula
Niesel's Formula.
Harmathy's Formula.

Read TESTING FIRE DOORS. U.L. 10b., NFPA 252, ASTM E 152
To retard passage of fire
ASTM T-T curve
LABLED: A, B, C, D, E, F
& if ≤ 250° or ≥ 650°F label

Read Testing Roof Covering Mat'ls UL 790, NFPA 256
3 types test 1.
2.
3.

Construction of Earth Surface

Clay =
BRICK =
H.T. =
Portland Cement =
limestone =
Gypsum = ? calcined gypsum
limeplaster =
how does it set?
? hydrated lime?

3 COATS NOW USED - made of what?

Perlite & Vermiculite ?

— CONTACT SPRAYED FIRE Proofing
made of ?
advantages?
disadvantages?

— Concrete Assemblies
Two types? 1.
2.
Advantages of L.W. conc. ? three L.W. agg.

"CELLUFLOR"?

Advantages of Composite Roof. e.g. tectum:
1.
2.
3.

PARTITIONS

advantages of gyp. F.R. partns.

PLASTICS - Def.

thermoplastic ?

Thermosetting ?

General qualities of plastics
1-8.

PROBLEM with Plastics W.R.T. F.P. ?

Types fillers OR aggregate commonly used:

1.
2.
3.
4.
5.

Tests available ?

How can we reduce fire hazard of Plastic ?

1.
2.
3.

— Fire walls ______ req? 12" upper 35' + inc 4" ea. 35'

Basic requirements of. Fire Wall.

1.
2.
3.
4.

CONSTRUCTION TYPES OF FIRE DOORS.

1. COMPOSITE TYPE
2. HOLLOW METAL
3. KALAMEIN
4. TIN CLAD
5. SHEET METAL
6. ROLLING STEEL

} CONST. & QUALITIES

Selection of F.D. depends on: 1.
2.
3.

PROTECTION OF EXTERIOR OPENINGS

Factors which have bearing on intensity of exp.
1-11.

BRITISH JOINT FIRE RESEARCH ORG. METHOD.
3 methods of transfer of heat
1.
2.
3.

British Concerned with

$$I = \phi e T^4$$

$$\phi = \frac{Sd^2}{\pi l^4}$$ 11 Bldgs.

Exposed Surface reaches max value when:

IGNORE: Setbacks < 5'
Openings < 120 # is none within 5'
Encl. stairs

Separate ~~[illegible]~~ radiators is > 4 (B.D) apart
check. concentration of exposure.

Compare NBS & BRITISH METHODS FOR
CORRELATING FIRE LOAD W. STD. FIRE SEVERITY.

· effect of venting?

How do they do it?

Need for exits governed by:
1-5

Psycological Problems
1-4

Basic Philosophy of Code 1-7.

What is an exit?

Two speeds exit travel?

MAX-MIN Door Width?
Revolving DOORS:

Building Code:
3 Basic Provisions
Providing safety to 1-4

Book #1

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME D. LUCHT

SUBJECT F.P.E. 309 FINAL

CLASS ____ DATE ____

INSTRUCTOR ____

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discussion of direct vs. indirect fire exposure

1. Today, the major evaluation of interior finish materials is based on flame spread, as in the ASTM E-84 tunnel test etc. However, the major cause of death due to fire is the smoke, toxic vapors, (CO) and deficient O_2 developed during a fire. This flame spread evaluation has been accepted by building code authorities etc. as a basis for their requirements. It seems that the potential use of smoke + toxic vapor ratings would be most valuable in life safety design problems. Though ASTM E 84 measures this, the "science" requires more research.

2. a. Plastics have ~~been~~ been increasingly used in building const. because; 1. good strength to weight ratio.

2. high corrosion resistance

3. good light diffusion properties

4. Can be formed into good insulation matls.

5. good possibilities in asthetic uses.

from an FPE standpoint, the problems arise when manfrs, etc. add such things as fillers, pegments, hardiners, plastiszers,

catalysts etc. which change
the ~~fire~~ burning qualities
greatly from the original
properties, thus making contemplation
of burning characteristics difficult.
Also plastics usually give off
a lot of smoke.

b. the artificial agregates, popularly
perlite, vermiculite, foamed slag,
have very low densities and
require less structural steel.
This saves money. These
aggregates yield very good
F. R. qualities.

c. Prestressed Conc. has ~~the~~
become popular since it
requires less vertical columns
etc to give assemblies
~~so~~ structural integrity.

When subjected to fire,
the assemblies are very
good, since the steel
makes up for the weakness
of ord. conc. as far
as tensil stress is
concerned. (all provided
the steel is properly prot.)

&. these are very good
as it takes much less
time + ∴ less money
to construct bldgs. However
the stresses and reactions
in the joints etc. of
these assemblies is difficult
to predict from a fire
resistance stand point.

3. 1. there is the possibility that the field const. will not duplicate the sample tested, and ∴ will give different results.

2. A 2 HR. etc. rating will not necessarily guarantie the field assembly will maintain the requirement, due to difference in fire load etc.

3. The rating was based on a relatively severe test, and ~~con~~ the field assembly may be in such an occy which would never have this severe of a fire.

-½

(3) ??

4. a. fire wall req. (specifications)
relative heights / + areas of bldgs,
protection of exterior openings, ppts,
roof covering req., interior
finish, separation distance
b. ~~[illegible]~~ fire limit requirement,
roof covering req., ppt. req.
exterior opg. prot.-req.
separation distance.
c. Requiring standard hourly
fire resistance ~~req.~~ for
building walls and
structural elements, prot.
vertical openings, venting
req. sprinkler requirements

5. the technical factors would be with reference to life safety and property preservation they would include application of various required codes such as the building code, exits code, and advisory standards; fire protection codes etc.

-3

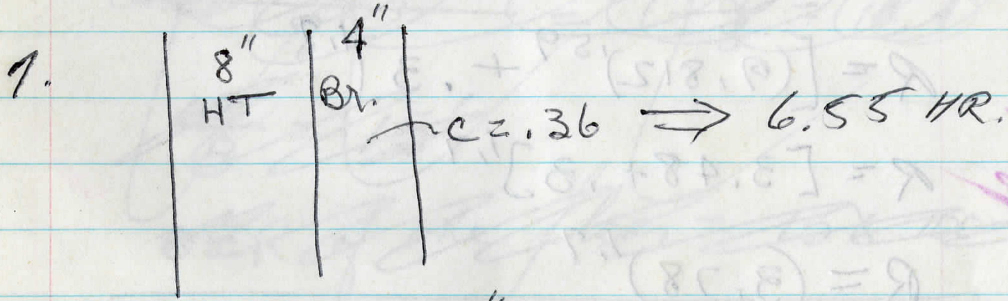
the economic factors would be such things as maintainance costs to installed devices, depreciation, insurance values. Questions such as is a certain type protection worth the cost? etc.

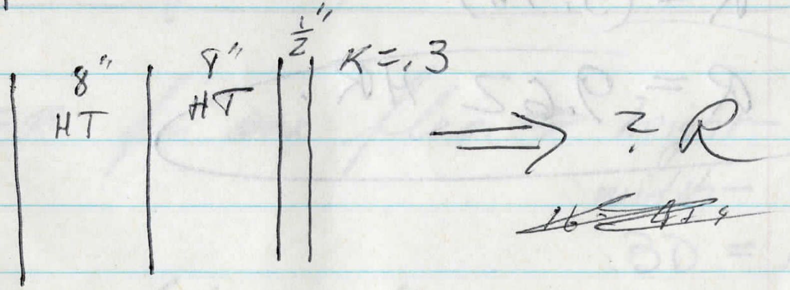
6. According to the chemical theory, flaming combustion is retarded in three ways:

1. the temperature at which decomposition of th material begins is reduced.
2. the temperature at which the reaction becomes exothermic is raised.
3. the reaction is directed towards formation of Charcoal and water rather than combustible tars + vapors.

The Glowing combustion is retarded due to the fact that the reaction is directed from formation of CO_2 to formation of CO; this CO formation reaction is 80% less exothermic.

1.





.364
1.34

$$R_{brick} = \left[(.36)(4)\right]^{1.7} = (\overset{1.44}{\cancel{1.34}})^{1.7} = \overset{1.86}{\cancel{1.644}}$$

$$6.55 = \left[(\overset{1.86}{\cancel{1.64}})^{.59} + R_{HT}^{.59}\right]^{1.7}$$

$$(6.55)^{.59} = (\overset{1.86}{\cancel{1.64}})^{.59} + R_{HT}^{.59}$$

$(6.55)^{.59} = (1.64)^{.59} + R_{HT}^{.59}$?

take .59 root

$6.55 = 1.644 = R_{HT}$

math

$$\begin{array}{r} 6.550 \\ -1.644 \\ \hline 4.906 \end{array}$$

$$\begin{array}{r} 4.906 \\ 4.906 \\ \hline 9.812 \end{array}$$

$R_{HT} = 4.906$

$R_{\text{new wall}} = \left[R_{HT_{8''}}^{.59} + R_{HT_{8''}}^{.59} + K \right]^{1.7}$

$R = \left[(9.812)^{.59} + .3 \right]^{1.7}$

-5

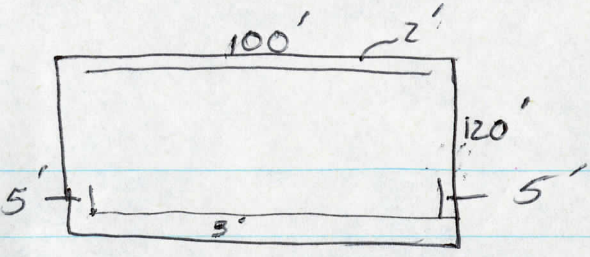
$R = \left[3.48 + .3 \right]^{1.7}$

$R = (3.78)^{1.7}$

$R = 9.62$ HR.

$d = 28'$

8. BD = 14'



all windows 10 x 5

Each floor will be a separate radiator.

~~distance between floors will be~~

~~$\frac{120-(2+3)}{8} = \frac{115}{8} = 14.4'$~~

~~$\frac{120}{8} = 15'$~~

~~OER of one floor = 15 x 100-10~~

OER for one floor ⇒ height - 10'
width - 90'
BD = 14'

-4

frome table ⇒ % opening
not to exceed 50%
on any floor.

this would give 15' bldg. dist or 30' separation dist.

Book #2.

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME D. Lucht

SUBJECT F.P.E. 309 Final

CLASS DATE

INSTRUCTOR

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8
15)12000
00

26
15)4000
30
100
90

150
80
12000

80
50
4000

9. TFA = Gym: 150 X 80 = 12000 #

✓ Classroom: 280 X 100 28000 #

✓ Cafeteria: 80 X 50 4000 #

7
4)2800

Gym - Place of Assembly ✓ $\frac{12000}{15}$ ⇒ 800 people

Classrooms $\frac{28000}{40}$ = 700 people ✓

13

Cafeteria: Place of Assembly $\frac{4000}{15}$ ⇒ 267 ✓

First Floor: Req.

~~Assume Gym & classrooms won't be used simultaneously.~~

✓ Gym - $\frac{800}{100}$ ⇒ 8 units exit width.

1.16
6)7.00
6
10
9.0

Cafeteria - $\frac{267}{100}$ ⇒ 2.67 = 2.5 units ✓

Classroom $\frac{700}{100}$ ⇒ 7[illegible] units ✓

Second: Classrooms: ~~[illegible]~~ $\frac{700}{60}$ = 11.67 = ~~12~~ 11.5 Stairs

$\frac{3}{4}$ x 12 = 9 exit units at street

1,5
4

need { Gym – 8
Caf. – 2.5
1st Classrms. – [illegible] 7
Street exits [illegible] 9
stairs [illegible] 12

have! Gym! O.K. $\cancel{4}\,6 \times \left(\frac{36}{22}\right) = \cancel{3}\ \cancel{6}\ 9$ (front)
~~$2 \times \left(\frac{36}{22}\right) = 3$~~

Cafeteria! $4\left(\frac{36}{22}\right) = 6$ ✓

Classrooms; $2\left(\frac{36}{22}\right)$
$2\left(\frac{36}{22}\right)$
$2\left(\frac{36}{22}\right)$ } 9 ✓

1,5
6
9,0

Street units $2\left(\frac{36}{22}\right) = 3$

Stairs – $2\left(\frac{66}{22}\right) = 6$

6.11

the stairs are insufficient. They would need a total of 5 stairs in order to prevent the existence of dead end hallways 720'. Since they need 12 units, each stair could be 3 units wide, or could have ~~# 2 unit~~ ~~stairs and~~ combination of different sized stairs such that total units = 12 with 3/4 stair unit capacity at top and bottom of stairs, with "B" fire doors (kept closed) at top of stairs, and bottom of those which do not empty out side. All panic hardware. The additional stairs emptying into first floor would create a situation where ~~[illegible]~~ a minimum of 4.5 more units of exit would be required, or if they all emptied into classroom section a new total of 4.5 + 7 = 11.5 now req. we only have 9, so would have to put in 2.5 more exit units from classroom sect.

Could use smoke barrier, as an "L" shape of hall => 300'

~~Each~~ Interior finish should be Class A or B in assembly hall + hallways and Class C elsewhere.

✓ Should have w.g. in doors.

X ? Not > 125' exit travel O.K.

At least 2 exits required in ~~them~~ Gym + Cafeteria as remote from ea. other as possible.

✓ Gym exits could be relocated somewhat + Cafeteria needs one in W. wall

✓ Corridors 10' wide OK.

✓ Each room should have at least 1 window 2'6" off floor + <u>openable</u>.

✓ Heating equip. cut off OK.

All cooking equipment ~~should~~

✓ air cond. etc. should accord to Sect 47.

If Gym. used at night
→ ✓ type 1 or 2 emergency illumination.

✓ Should have ~~at least~~ manual (F.A.) system

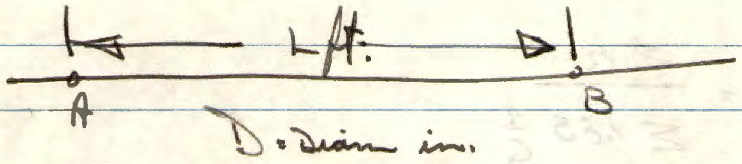
After re-examining the dead end ~~sta~~ halls, it appears that some of them will be exactly 20' long, and the allocation of a total of 5 stairs may be a judgement factor rather than a requirement.

9-21-64

FPE 420

HARDY CROSS METHOD

Hazen Williams Formula



$$H_f = (2.31)\underline{\underline{(452.4)}}\left(\frac{Q^{1.85}}{C^{1.85}\,D^{4.87}}\right)$$

Q = gpm.

h_f = ft. H_2O/100' pipe

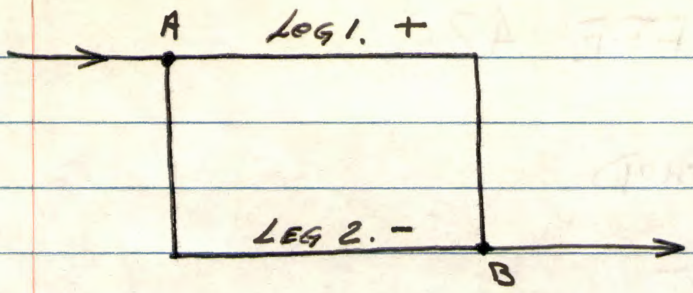
~~not~~ 457.6

* correct in data Manual

$$* \quad h_{f\,A-B} = \frac{L}{100}\, h_f \,\frac{\text{ft}\,H_2O}{100'\,\text{pipe}} = \underbrace{\frac{L}{100} \times \frac{2.31}{1} \times \frac{452.4}{1}\,\frac{Q^{1.85}}{C^{1.85}\,D^{4.87}}}$$

used in calculations in hydraulic data manual @ C=100 of Old CIP

Nomograph in manual for converting to 8" pipe and different C values



LEG 1. FLOWS CLOCKWISE (+)

LEG 2. FLOWS COUNTERCLOCKWISE (−)

EQ. #8 $q = \frac{\Sigma h}{\Sigma 1.85 \frac{h}{Q}}$

Read Article up to middle pg 74

WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	LINE NUMBER	L FT.	PIPE SIZE IN.	EQ.L. 8" FT.	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.
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WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	LINE NUMBER	L FT.	PIPE SIZE IN.	Eq. L. 8" FT.	Q G. P. M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G. P. M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G. P. M.	h FT. OF WTR.	$n\frac{h}{Q}$	CORRECTION	Q G. P. M.	h FT. OF WTR.
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WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	LINE NUMBER	L FT.	PIPE SIZE IN.	Eq.L. 8" FT.	Q G.P.M.	h FT. OF W'TR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'TR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.
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WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	LINE NUMBER	L FT.	PIPE SIZE IN.	Eq.L. 8" FT.	Q G.P.M.	h FT. OF W'TR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'TR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.
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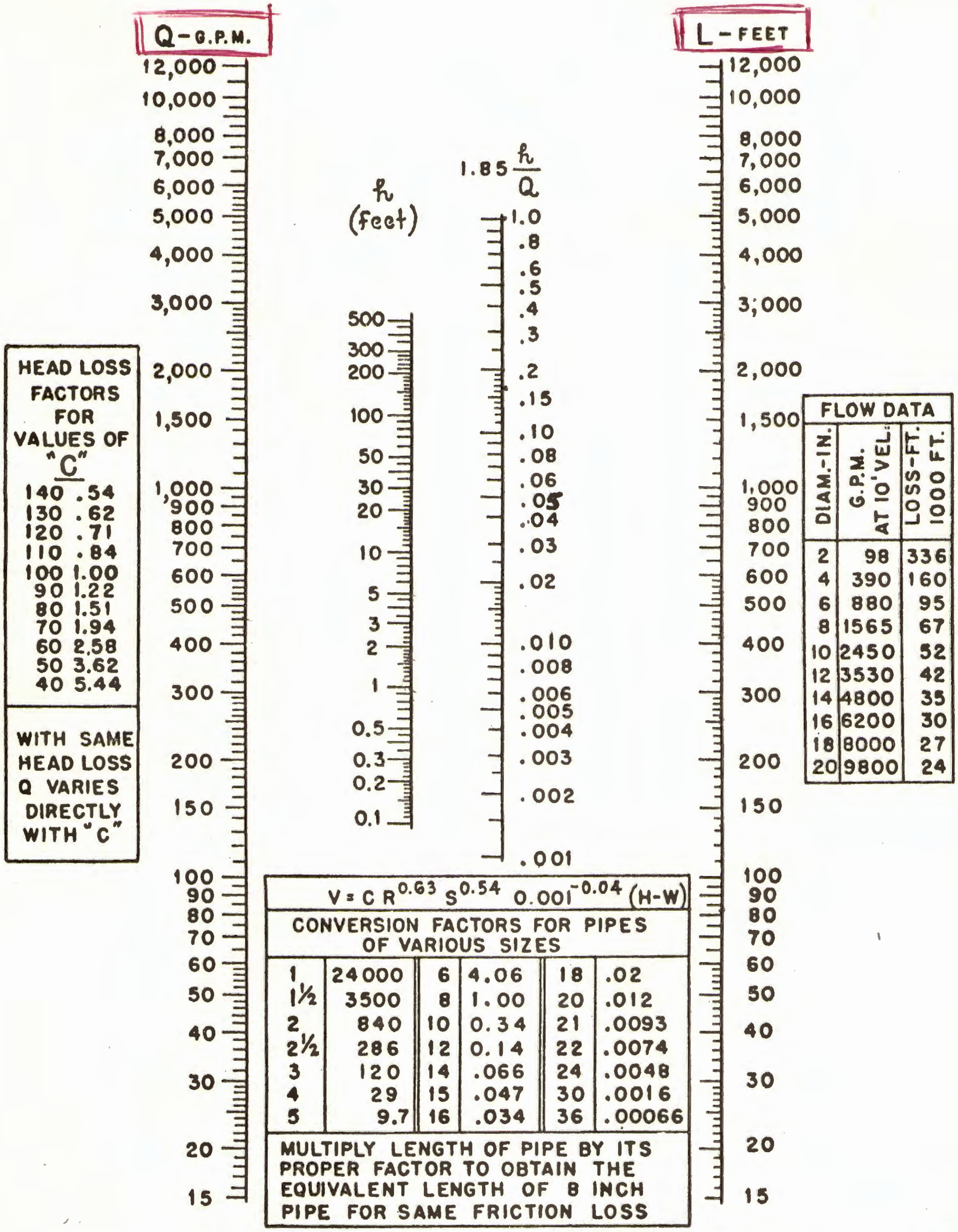


HEAD LOSS FACTORS FOR VALUES OF "C"	
140	.54
130	.62
120	.71
110	.84
100	1.00
90	1.22
80	1.51
70	1.94
60	2.58
50	3.62
40	5.44

WITH SAME HEAD LOSS Q VARIES DIRECTLY WITH "C"

FLOW DATA

DIAM.-IN.	G.P.M. AT 10' VEL.	LOSS-FT. 1000 FT.
2	98	336
4	390	160
6	880	95
8	1565	67
10	2450	52
12	3530	42
14	4800	35
16	6200	30
18	8000	27
20	9800	24

$$V = C\,R^{0.63}\,S^{0.54}\,0.001^{-0.04}\ \text{(H-W)}$$

CONVERSION FACTORS FOR PIPES OF VARIOUS SIZES

1	24000	6	4.06	18	.02
1½	3500	8	1.00	20	.012
2	840	10	0.34	21	.0093
2½	286	12	0.14	22	.0074
3	120	14	.066	24	.0048
4	29	15	.047	30	.0016
5	9.7	16	.034	36	.00066

MULTIPLY LENGTH OF PIPE BY ITS PROPER FACTOR TO OBTAIN THE EQUIVALENT LENGTH OF 8 INCH PIPE FOR SAME FRICTION LOSS

FIGURE 1 by T. FRANCIS O'CONNOR

Nomograph for the Rapid Calculation of Loss of Head in Pipes.

9-21-64

PRIVATE FIRE MAIN SYSTEMS AND WATER SUPPLIES

I. UNDERGROUND FIRE MAIN SYSTEMS

A. Hydraulic Characteristics of Various System Layouts

1. Single and Compound Pipe Systems
2. Single and Multiple Looped Systems
    - a. Hardy Cross Method

B. Analysis of Performance of An Entire Private Fire Protection Water Supply and Distribution System

1. Supplies Flowing Individually
2. All Supplies in Service and Flowing

Note: Solutions obtained by use of hydraulic slide rule, nomographs, charts and graphs and special graph paper ruled with Head versus Flow Rate$^{1.85}$.

9-23-64

FPE 420

Assume req. F.F. of 1500 gpm. @ B considering the indicated domestic flows; C.I. pipe, C=100; neglecting valve + fitting losses; Calculate water flow dist. in the grid system. Calculate resid. pressure req. at C to produce a min. resid. pressure of 20 psi @ A.

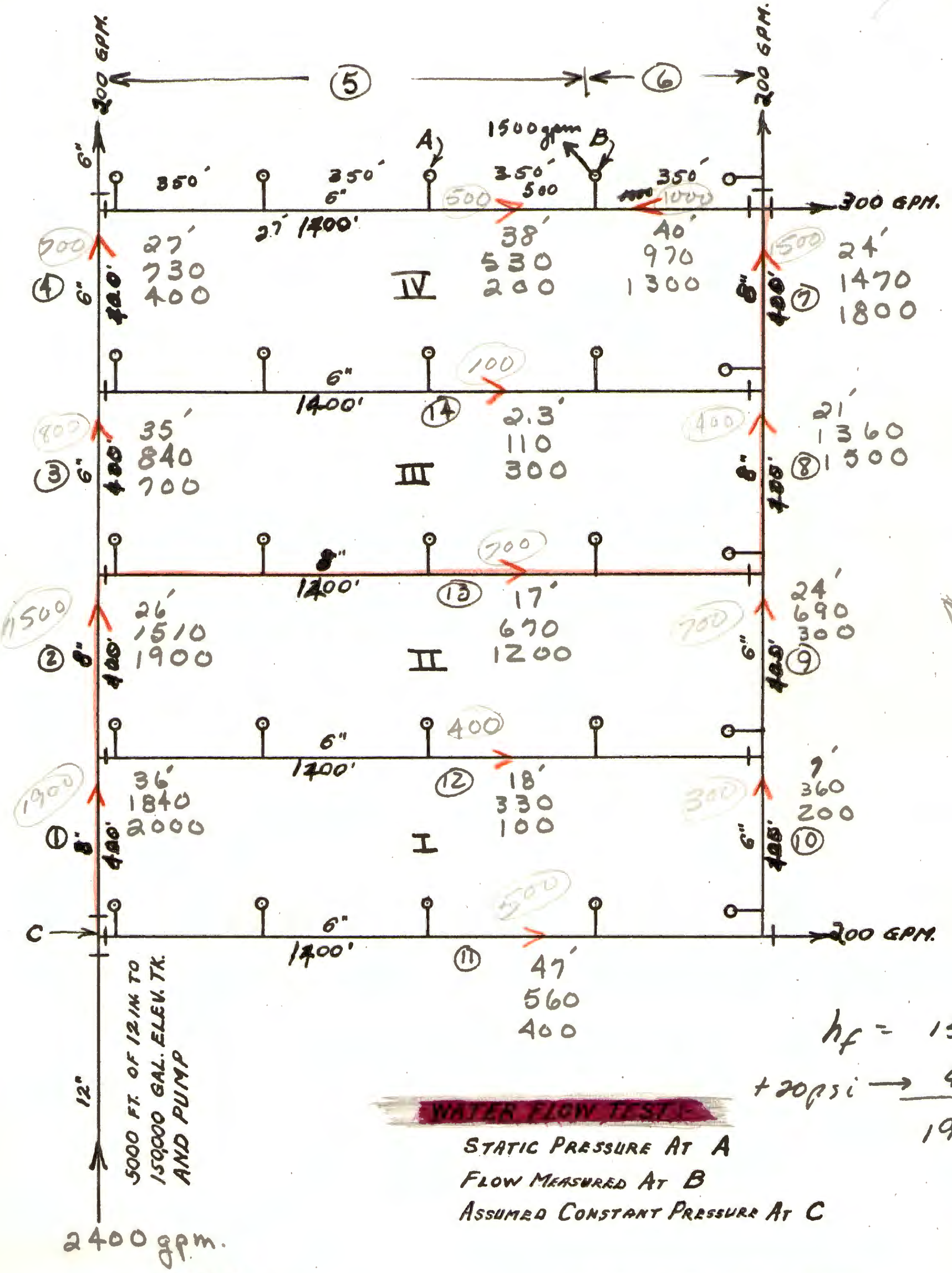
Work on ↑ 9-25-64

Read CH 17 FM 9-28-64
For 9-30-64

159.30
6.70
152.60

HEAD LOSS 38'
FINAL FLOW 530
FIRST TRIAL 200

How to calculate equivalent pipe?



h_f = 15'1 C to A
+20psi → 46
197 req. at C

WATER FLOW TEST:-
STATIC PRESSURE AT A
FLOW MEASURED AT B
ASSUMED CONSTANT PRESSURE AT C

KEY
┼ —VALVE
○ —HYDRANT

REQUIRED FIRE FLOW
PUBLIC WATER SYSTEM
SCALE:- 1"=300'

12-7-58 W. G. L.

WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
	LINE NUMBER	L FT.	PIPE SIZE IN.	Eq.L. 8" FT.	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF WTR	$\frac{nh}{Q}$
I	1	400	8.	400	+2000	43	.04	-70 0	+1930	40.0	.038	-130 0	1800	35.0	.035	50	1850	37	.037
	12●	1200	6	4900	+100	2	.04	-70 +520	+550	46.0	.160	-130-160	260	13.0	.100	50+50	360	21	.110
	10	400	6	1620	-200	-2.4	.023	-70 0	-270	-4.2	.030	-130- 0	-400	-8.3	.040	50	-350	-7	.037
	11	1200	6	4900	-400	-26	.120	-70 0	-470	-35.0	.140	-130 0	-600	-54.0	.170	50	-550	-46	.160
						16.6/	.223	= 74.4		46.8/	.368	127		-14.3/	.345	= -41.5		5/	.344
																			= 14
II	2	400	8	400	+1900	+40.0	.038	-520 0	+1380	21.0	.028	160	1540	26.0	.031	-50	1490	25.0	.030
	13●	1200	8	1200	+1200	+48.0	.075	-520-130	+ 550	11.0	.040	160+30	740	20.0	.040	-50-50	640	15.0	.040
	9	400	6	1620	-300	-5.0	.031	-520 0	-820	-35.0	.078	160	-660	-22.0	.062	-50	-710	-26.0	.068
	12□	1200	6	4900	-100	-2.0	.040	-520 0	-620	-46.0	.160	160		-13.0	.100	-50		-21.0	.110
						95.0/	.184	= 516		-49/	.306	= -160		11.0/	.233	= +47.2		-7/	.248
																			= -28
III	3	400	6	1620	+700	26.0	.068	130 0	+830	35.0	.090	-30	800	32.0	.075	50	850	35.0	.080
	14●	1200	6	4900	+300	15.0	.090	130-330	+100	2.0	.040	-30+0	70	1.0	.030	50	120	2.8	.040
	8	400	8	400	-1500	-25.0	.030	130 0	-1370	-20.0	.028	-30	-1400	-22.0	.030	50	-1350	-20.0	.028
	13□	1200	8	1200	-1200	-48.0	.075	130 0	-1070	-11.0	.040	-30		-20.0	.040	50		-15.0	.040
						-32/	.263	= -122		6/	.198	= 30.3		-9/	.175	= -51.3		2.8/	.188
																			= 14.9
																	730	0	
IV	4	400	6	1620	+400	+8.5	.040	330	+730	22.0	.070	-0	730	27.0			530	0	
	5	1050	6	4260	+200	+6.0	.060	330	+530	38.0	.130	0	530	38.0			-970	0	
	6	350	6	1420	-1300	-69.0	.100	330	-970	-40.0	.090	0	-970	-40.0			-1470	0	
	7	400	8	400	-1800	-35.0	.035	330	-1470	-24.0	.030	0	-1470	-24.0				-2.8	
	14□	1200	6	4900	-300	-15.0	.090	330	+30	-2.0	.040	0		-					
						-104.5/	.325	-322		-1/	.350	= -2.86							

12-26-57 W.G.L.

WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
LINE NUMBER	L FT.	PIPE SIZE IN.	Eq.L. 8" FT.	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.
1			400	1840	36	.038	0	1840	36	.038	0	1840	36	.038	0	1840	36
12°			4900	340	19	.110	0 -20	320	17	.100	0 +10	330	18	.100	0	330	18
10			1620	-360	-7	.038	0	-360	-7	.038	0	-360	-7	.038	0	-360	-7
11			4900	-560	-47	.165	0	-560	-47	.165	0	-560	-47	.165	0	-560	-47
					1/	.351	=2.85		-1/	.341	-2.93		0/	.341	=0		
2			400	1500	25	.030	20	1520	27	.032	-10	1510	26	.031	0	1510	26
13°			1200	620	14	.040	20+40	680	17	.040	-10+0	670	17	.040	0	670	17
9			1620	-700	-25	.065	20	-680	-24	.065	-10	-690	-24	.065	0	-690	-24
12□			4900		-19	.110	20		-17	.100	-10		-18	.100	0		
					-5/	.245	=-20.4		3/	.237	=-12.7		1/	.236	=4.24		
3			1620	880	38	.080	-40	840	35	.078	0	840	35.0	.078	0	840	35
14°			4900	150	4	.045	-40	110	2.3	.040	0	110	2.3	.040	0	110	2.3
8			400	-1320	-20	.028	-40	-1360	-21	.029	0	-1360	-21.0	.029	0	-1360	-21.0
13□			1200		-14	.040	-40		-17	.040	0		-17.0	.040	0		
					8/	.193	=41.5		-.7/	.187	=-3.74		-.2/	.187	=-3.74		

12-26-57 W.G.L.

CITY WATER FLOW TEST DATA:

Alpha Street: Static Head-75 psi (175 ft of water)
Residual Head - 48 psi (111 ft of water) with
1500 gpm flowing past Point A.

Beta Street: Static Head-100 psi
(231 ft of water)
Residual Head-63 psi (146 ft of water)
with 1200 gpm flowing past Point B.

FIRE PUMP DATA:

For simplicity, the following fire pump data is based upon recommended curves for Horizontal Shaft Centrifugal Fire Pumps:

Rated Capacity and Head - 1000 gpm @ 125 psi (289 ft of water).

Other points along the characteristic curve are,

Churn (zero flow) = 125 x 1.2 = 150 psi (347 ft of water).
500 gpm @ 140 psi (322 ft of water).
1320 gpm @ 104 psi (240 ft of water).
1500 gpm @ 81 psi (188 ft of water).
1600 gpm @ 52 psi (120 ft of water).

Note: Pump has 8" suction and discharge flanges.

DETERMINE THE FOLLOWING INFORMATION FROM THE ABOVE DATA AND THE SKETCH:

NOTE: For purposes of this problem, friction head losses in valves and fittings may be neglected.

1. Based upon the City Water flow test data,

   a. Determine the Alpha Street City Water Supply Curve effective at Point C.

   b. Determine the Beta Street City Water Supply Curve effective at Point C.

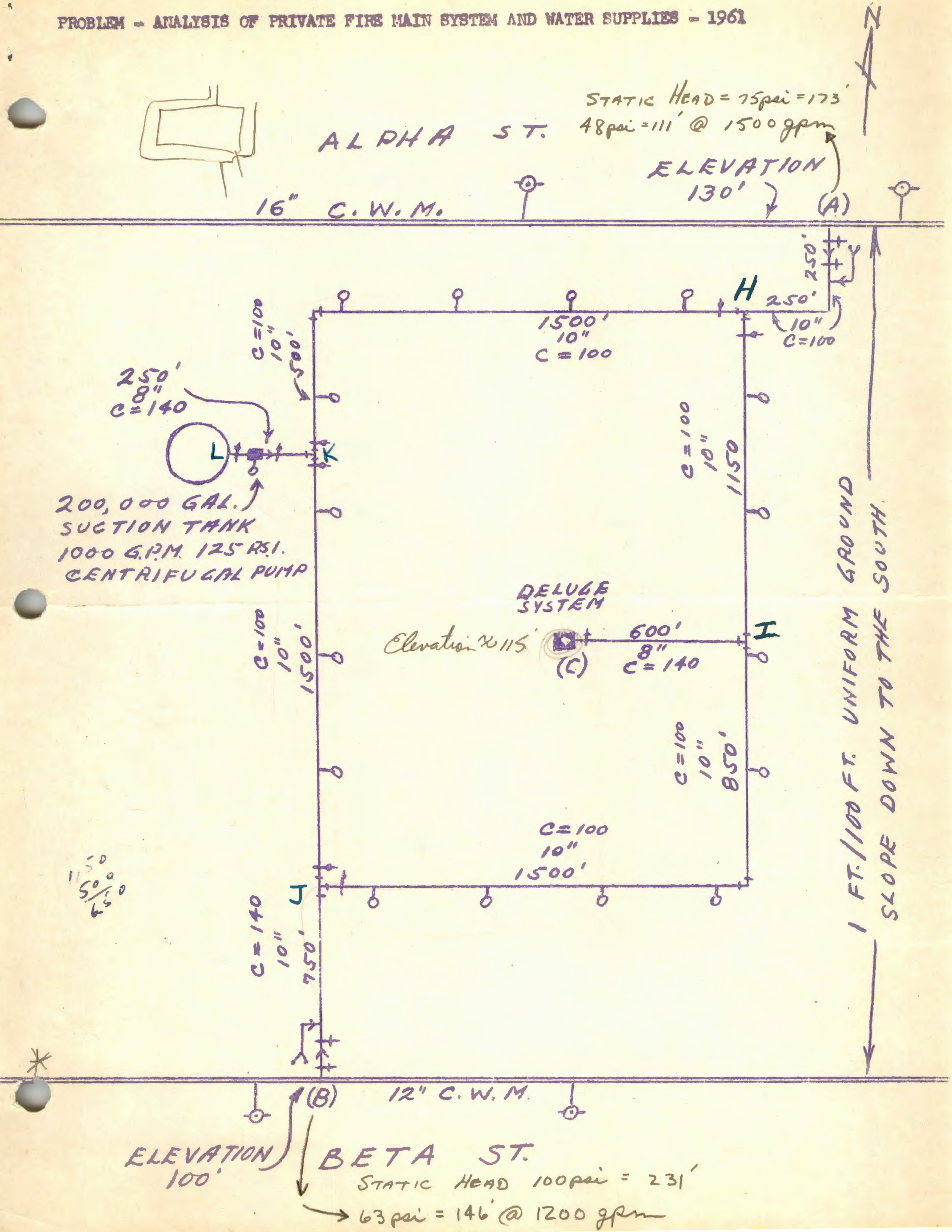
2. Based upon the Centrifugal Fire Pump Data,

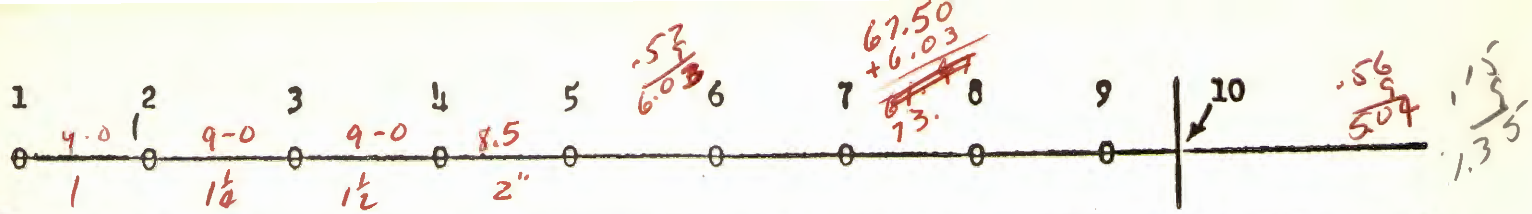
   a. Determine the curve representing the effective XXXX Fire Pump Supply Curve at Point C.

3. Based upon all available data,

   a. Determine the curve representing the combined operation of all supplies effective at Point C.

PROBLEM - ANALYSIS OF PRIVATE FIRE MAIN SYSTEM AND WATER SUPPLIES - 1961



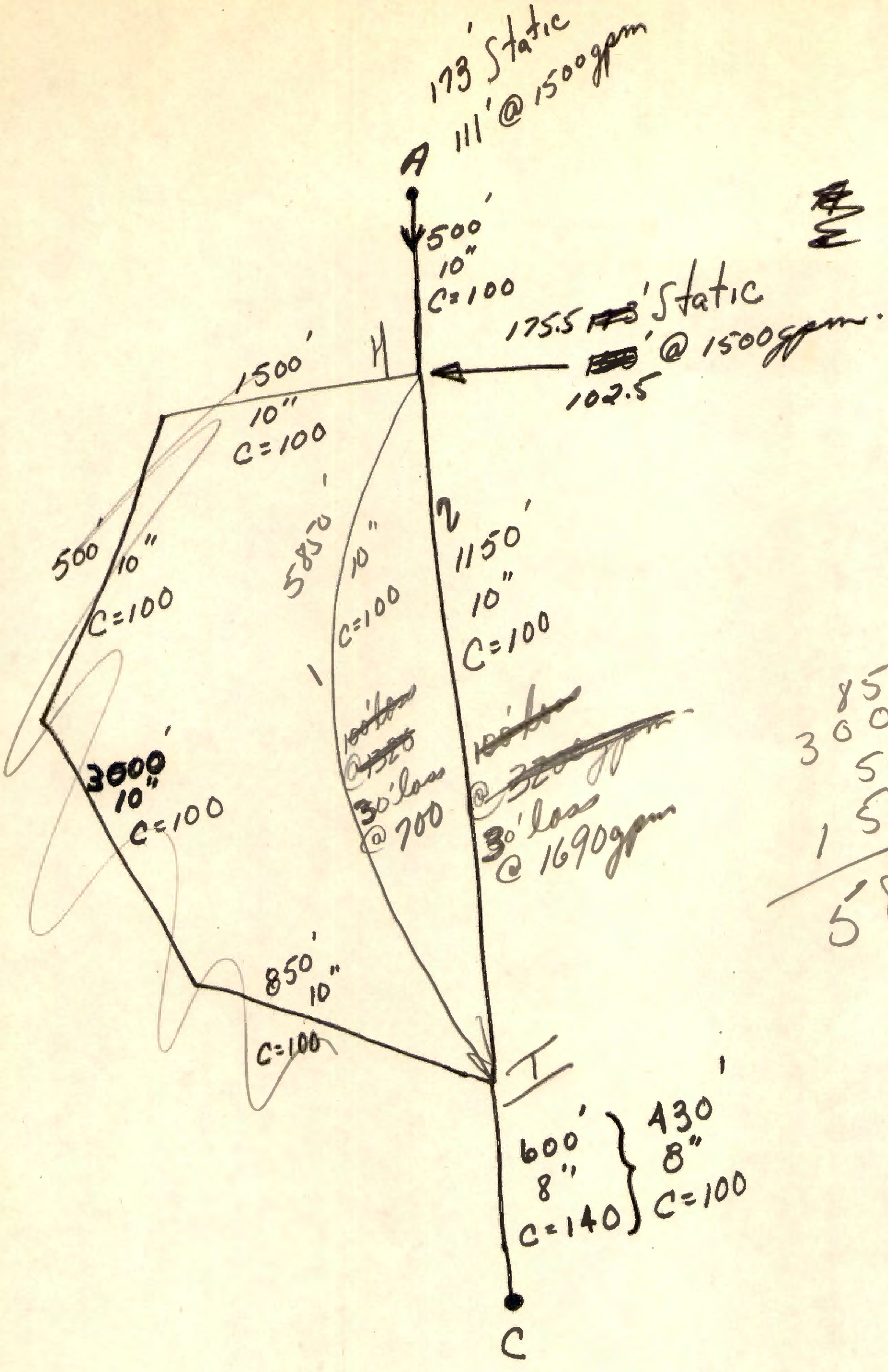


No.	SEQUENCE OF CALCULATIONS 1.05	16.50	Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	~~67.80~~	Q(1) ~~30.1~~ 15.0	~~30.1~~ 15.0
2	hf(2-1)....(9 Ft. 1 In. Pipe) +	6.03		
3	Z (2-1).............................. +	+5.85		
4	H(2) 18.0	67.67	15.7	30.7
5	hv(2-1)....(1 In. Pipe) .... −	-~~1.05~~	~~31.8~~	~~61.9~~
6	hn(2) .... ~~67.67~~ .73.53	~~55.02~~	Q(2) ~~46.0~~	~~[illegible]~~
7	hv(3-2)....(In. Pipe).......... +	73.53		
8	hf(3-2)....(.85 Ft. In. Pipe) +	5.04 78.57		
9	Z (3-2) .... +	- .3		
10	H(3) 19.01	78.27	16.2	46.9
11	hv(4-3) T.&E. (In. Pipe) .... −	→		
12	hn(3)	78.27	Q(3) 32.8	94.7
13	H(3) .... From Above	78.27		
14	hf(4-3) ...(5 Ft. 1½ In. Pipe).+	6.10 84.37		
15	Z (4-3) .... +	20.06		
16	H(4)	84.07	16.6	63.5
17	hv(5-4) T.&E. (In. Pipe) .... −			
18	hn(4)	84.07	Q(4) 38.0	132.7
19	H(4) .... From Above	84.07		
20	hf(5-4) ...(8.5 Ft. 2 In. Pipe)+	15.30		
21	Z (5-4) .... +	20.12		
22	H(5)	99.37		
23	hv(6-5) T.&E. (In. Pipe) .... −			
24	hn(5)		Q(5)	
25	H(5) .... From Above			
26	hf (6-5)..(Ft. In. Pipe)+			
27	Z (6-5) .... +			
28	H (6)			
29	hv (7-6)T.&E. (In. Pipe) .... −			
30	hn(6)		Q(6)	
31	H(6) .... From Above			
32	hf (7-6)..(Ft. In. Pipe)+			
33	Z (7-6) .... +			
34	H(7)			
35	hv(8-7) T.&E. (In. Pipe) .... −			
36	hn(7)		Q(7)	
37	H(7) .... From Above			
38	hf(8-7) ..(Ft. In. Pipe)+			
39	Z (8-7) .... +			
40	H(8)			
41	hv (9-8) T.&E.(In. Pipe) .... −			
42	hn (8)		Q(8)	
43	H(8) .... From Above			
44	hf (9-8) .....(Ft. In. Pipe)+			
45	Z (9-8) .... +			
46	H(9)			
47	hv (10-9)T.&E.(In. Pipe) .... −			
48	hn (9)		Q(9)	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe)+			
51	Z ( ) .... +			
52	hv ( ) ......(In. Pipe) .... +			
53	H ( )			

11-7-55 W.G.

1. a.

231
173
58



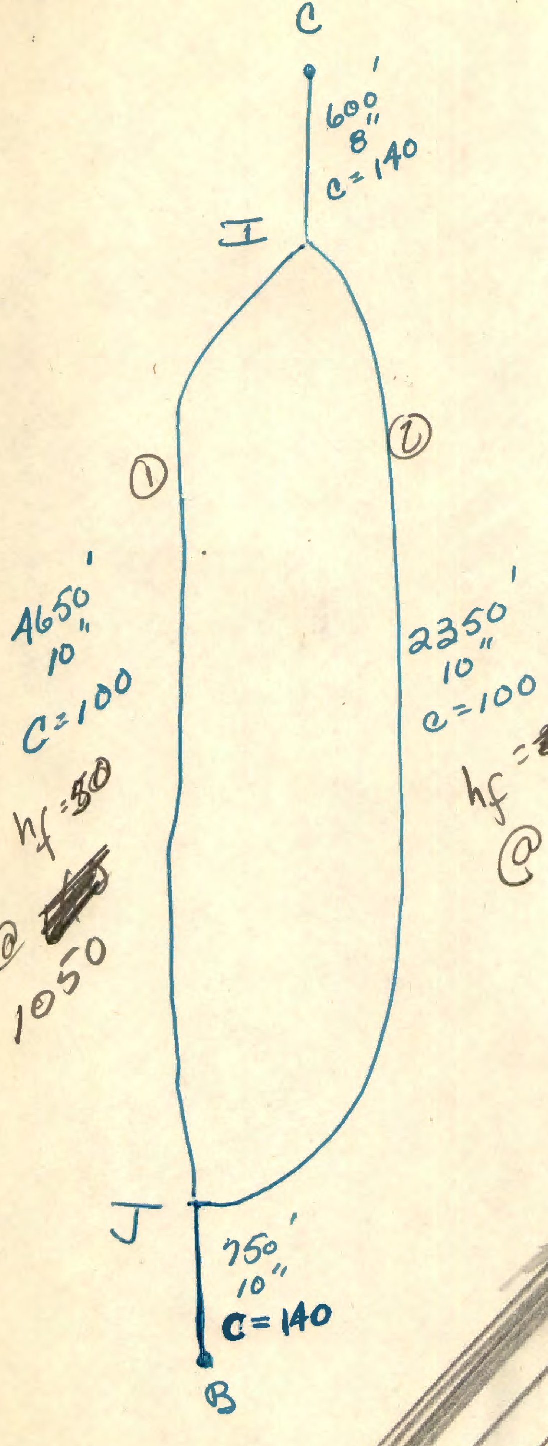
850
3000
500
1500
5850

11.50

1690
700
2390 @ 30' loss.

or 1600 @ 14.5' loss

1.b



hf = 50
@ 1050

hf = 50
@ 1520

1500
850
2350

2000
1500
1150
4650

600'
8"
C = 140 = C = 100
1600 gpm   1150

23'

1040
720
1760

1600 gpm = 1150 gpm
C = 140   C = 100

hf = 9.75'

850
750
1600

2.a.

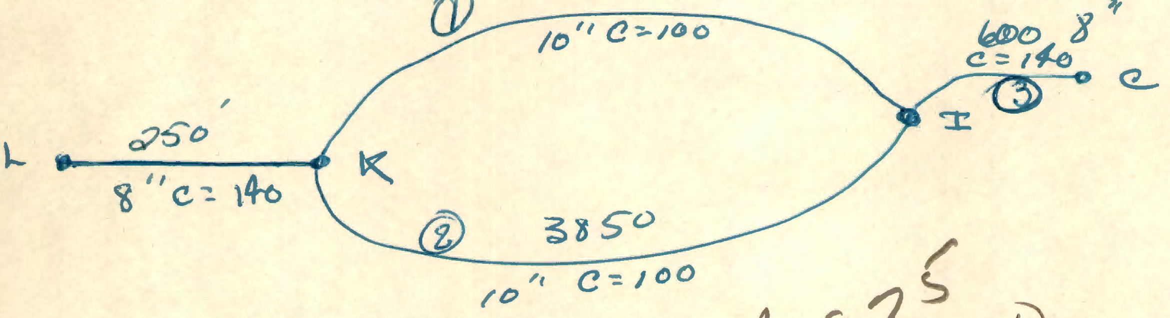
250'
8"
c = 140 = c = 100
1600 gpm = 1040

hf = 8

hf = [redacted] 75
Q = [redacted] 1600

600' 8"
c = 140 = c = 100
1600 gpm = 1040 gpm

hf = 19



hf = 75
Q = 1420
1600
3020

19
23
42

14
18
32

1240 ✓

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME LUCHT

SUBJECT

CLASS DATE

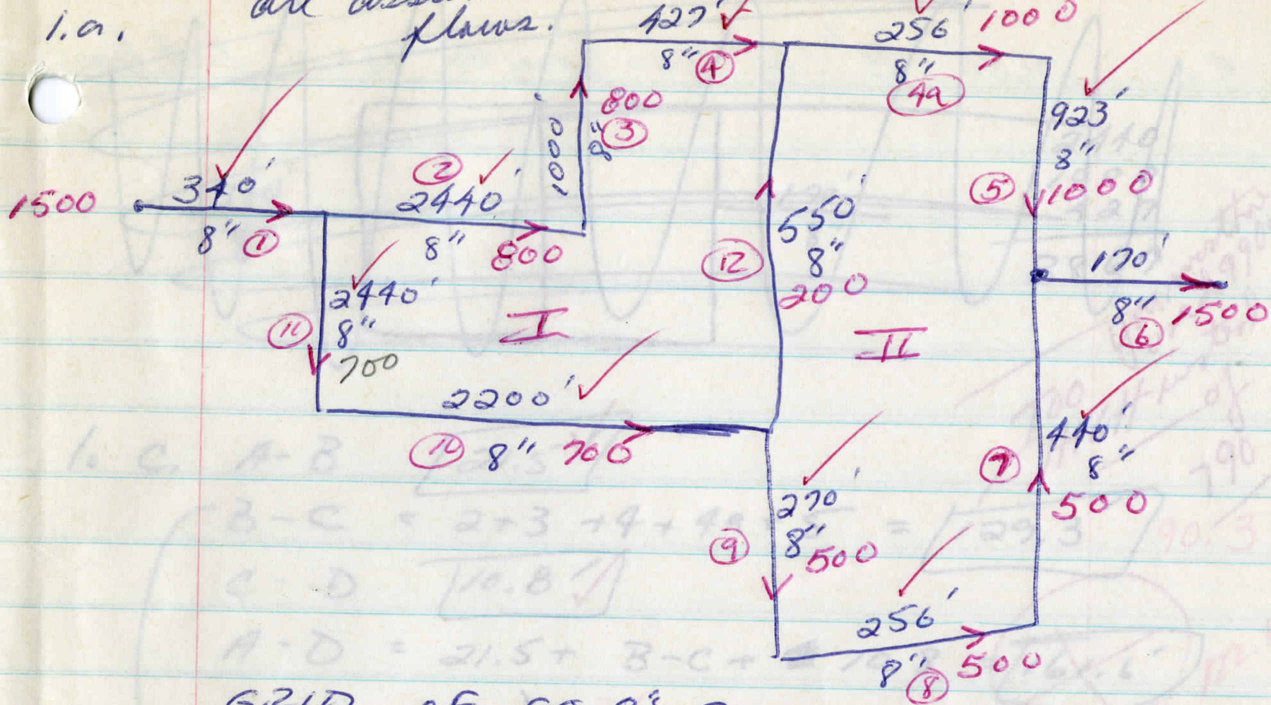
INSTRUCTOR

a ~~1~~	✓	11	
b ~~2~~	-5	12	
c ~~3~~	✓	13	
d ~~4~~	✓	14	
e ~~5~~	✓	15	
6		16	
7		17	
8		18	
9		19	
10		20	

-5 / 95

1.a.

RED #'s are assumed flows.



GRID OF EQ. 8" PIPE C=100

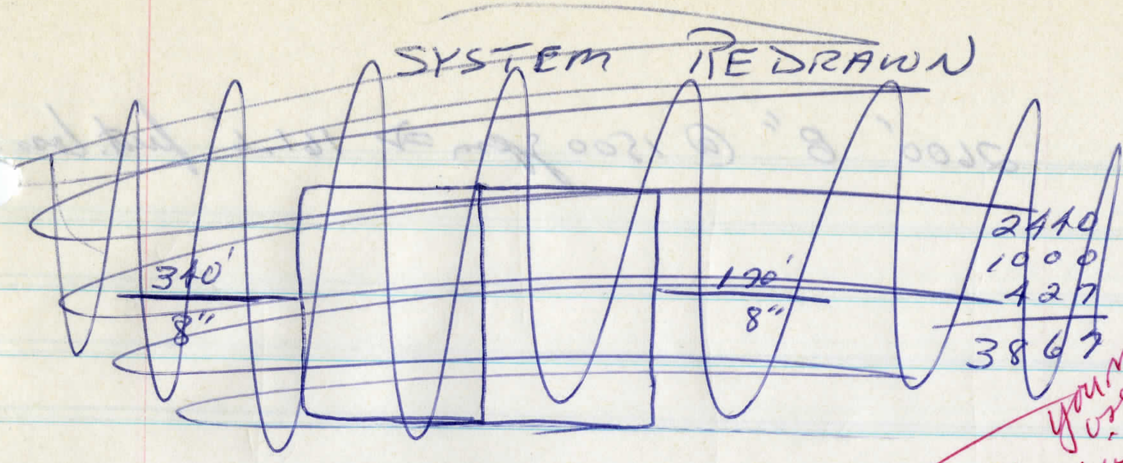
4.06
600
2436.00

2500
2
50

(2500)(.14)(1.22) = 427
(1500)(.14)(1.22) = 256
(1100)(.84) = 923
(3100)(.71) = 2200

} all other conversions done on slide rule

SYSTEM REDRAWN



TOO HIGH you must have used 990 gpm instead of 790

1. c. A-B $\boxed{21.5'}$ ✓

B-C = 2+3+4+4a+5 = $\boxed{129.3'}$ 90.3

C-D $\boxed{10.8'}$ ✓

A-D = 21.5 + B-C + 10.8 = ~~161.6'~~ 122.6

		122.6
		90.3
70	45.0	21.5
29	19.0	10.8
12	8.0	~~129.3~~
3.3	3.3	~~161.6~~
15	15.0	
~~129.3~~	90.3	

~95 ft.

from worksheet

~127 ft.

---

1. d. A-D loss ~~161.6'~~ ~127 122.6

@ 1500 gpm ⇒ $\boxed{2600'\ 8"}$

(2600' 8")

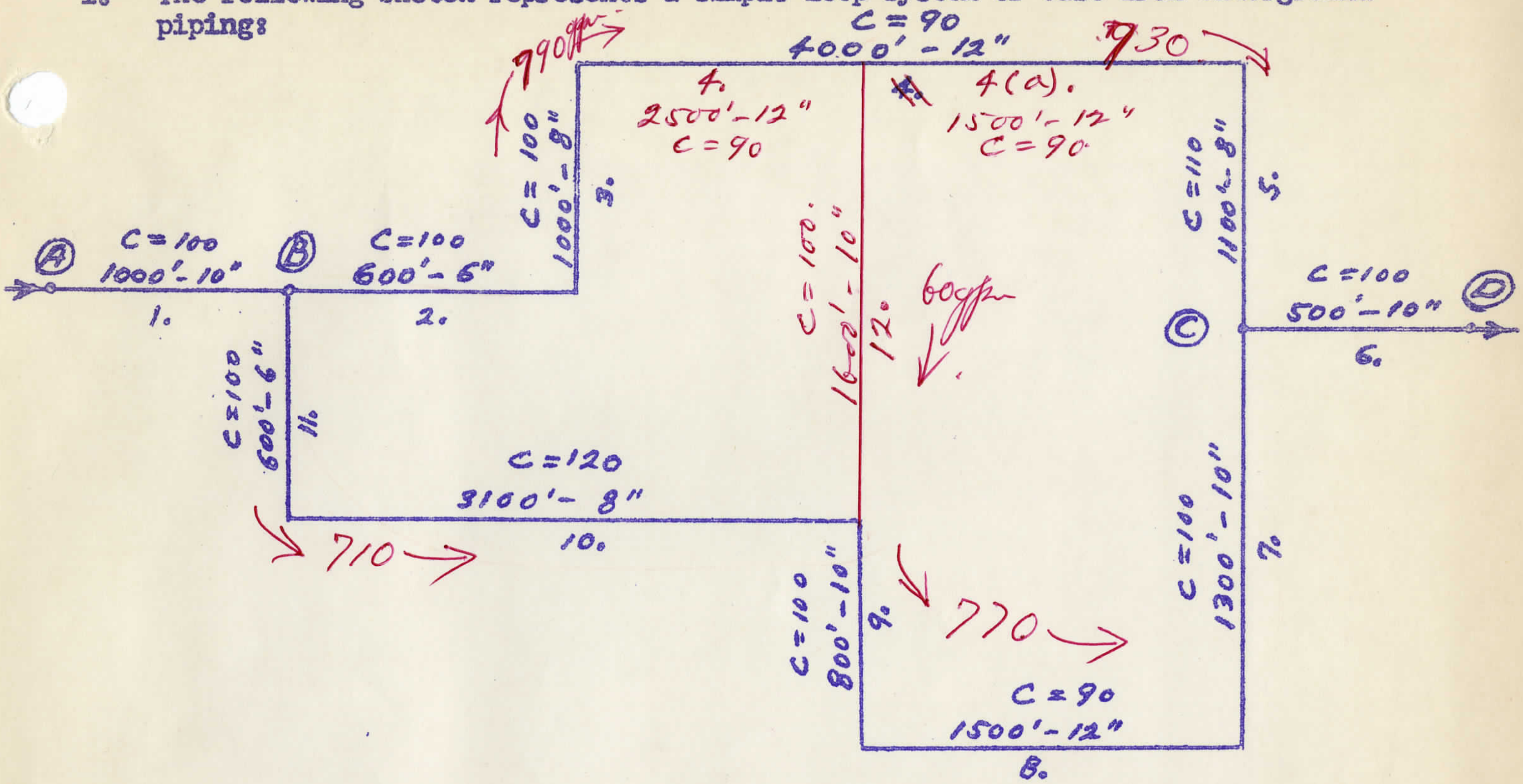
~ 2000' correct

e. 2600' 8" @ 1500 gpm ⇒ 161.6' frict. loss.

Exam No. 4 F.P.E. 420 January 7, 1963

LUCHT

1. The following sketch represents a simple loop system of Cast Iron Underground piping:



(a) Convert all piping to its equivalent in feet of 8" Cast Iron Pipe, C = 100.

(b) Assuming a total flow through the system of 1500 gpm, calculate the flow rate through each leg of the loop, (B) - (C).

Note: Assume negligible elevation head and neglect fitting losses.

(c) For the same assumptions as Item (b), determine the loss due to friction in feet of water from (A) to (B), (B) to (C), (C) to (D) and (A) to (D).

21.5 ft ← → 10.8' Slide rule

(d) Calculate the equivalent length of 8" pipe, C = 100 which could be used to replace the system (A) to (D).

(e) Point (A) of the system is connected to a water supply for which the following test data, with respect to Point (A), is available:

Head ft.	Flow Rate gpm.
280 (121 psi)	0
260	1200
230	2000

Using a graphical method:

(1) Draw the supply curve for the water available at Point (A).
(2) Draw the friction loss curve for the system between Points (A) and (D).
(3) Draw the yield curve representing the water available at Point (D), assuming no change in elevation (A) to (D).
(4) How much water would be available at Point (D) at a Head of ~~80~~ 50 feet of water?

[redacted]

800 − 10 = 790

1.b. flow thru each leg of loop B-C – for direction see diagram of system. Except #12

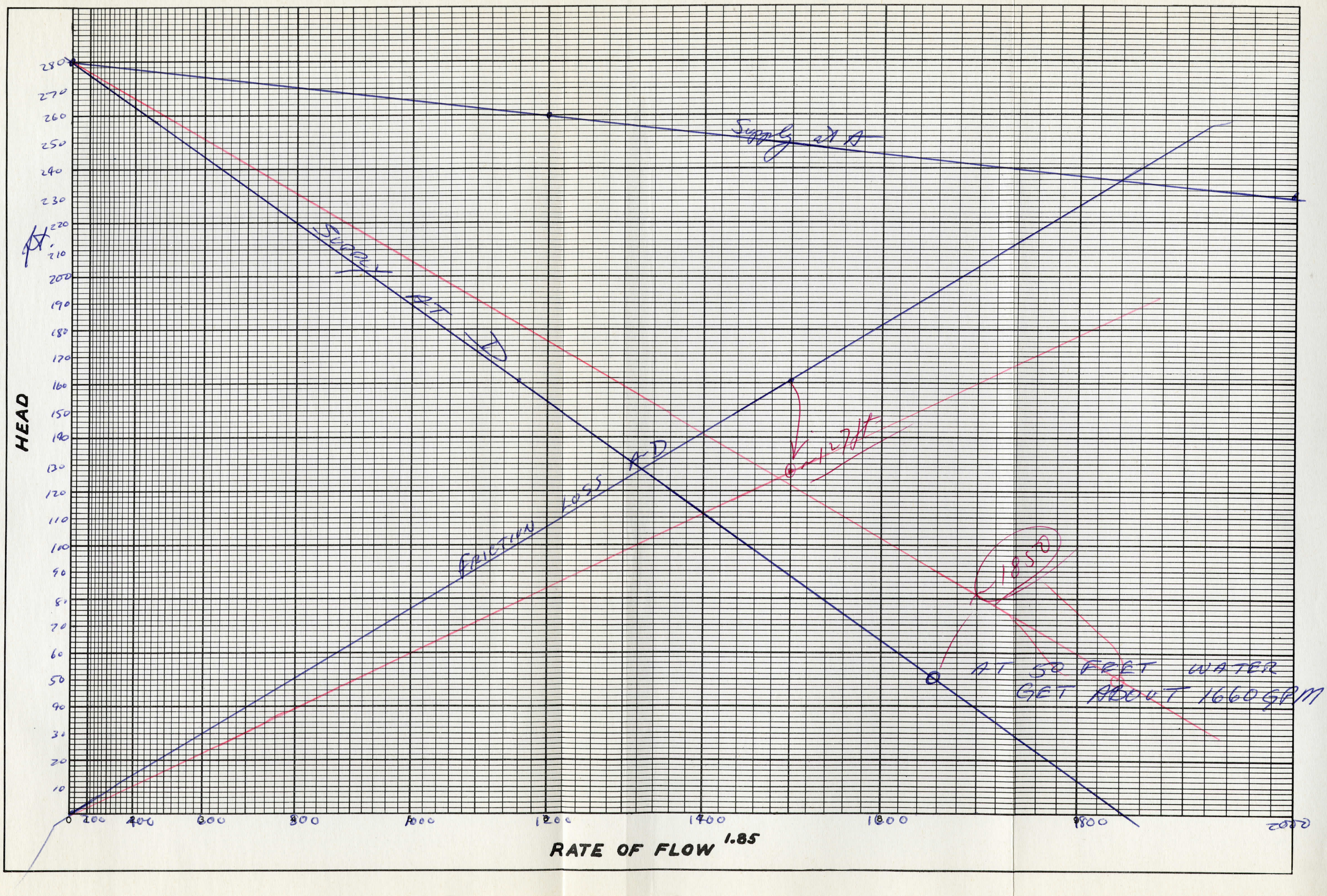
WORK SHEET FOR ANALYSIS OF FLOW IN WATER DISTRIBUTION SYSTEMS

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
LINE NUMBER	L FT.	PIPE SIZE IN.	Eq.L. 8" FT.	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R.	$n\frac{h}{Q}$	CORRECTION	Q G.P.M.	h FT. OF W'T'R
2		8	2440	800	46	.110	−10	990	45 70	.110 .136	0						
3			1000	800	19	.045	−10	990	19 29	.045 .055	0						
4			+430	800	8.5	.020	−10	990	8 12	.02 .023	0						
12°			550	−200	−0.8	.008	−10 +270	60	.02 0.1	.028	0						
10			2200	−700	−32.0	.083	−10	−710	−30.4	.090	0						
11			2440	−700	−36.0	.098	−10	−710	−40.0	.100	0						
				46	4.7	/.364	=12.9	111.0	40.6	/.426	=9.5						
		32		19 8.5				−70.4	2.4	/.426	≅0						
		36		+73.5		29 70		40.6									
		68.8		−68.8	4.7	12 111			3.3								
4a			260	1000	6.8	.013	−270	730	[illegible]	.040	0						
5			920	1000	27.0	.050	−270	730	15.0	.040	0						
7			440	−500	−3.6	.013	−270	−770	−8.0	.020	0						
8			256	−500	−2.0	.008	−270	−770	−3.6	.010	0						
9			270	−500	−2.2	.008	−270	−770	−4.0	.010	0						
12			550	+ 200	0.8	.008	−270	−60	−0.1	.028	0						
				−5.6	26.8/	.100	=268		2.6/	.158	≅0						
				−7.8	34.6												
					−7.8												
					26.8												

ok Assumed wrong direction for #12

LUCHT

12-26-57 W.G.L.

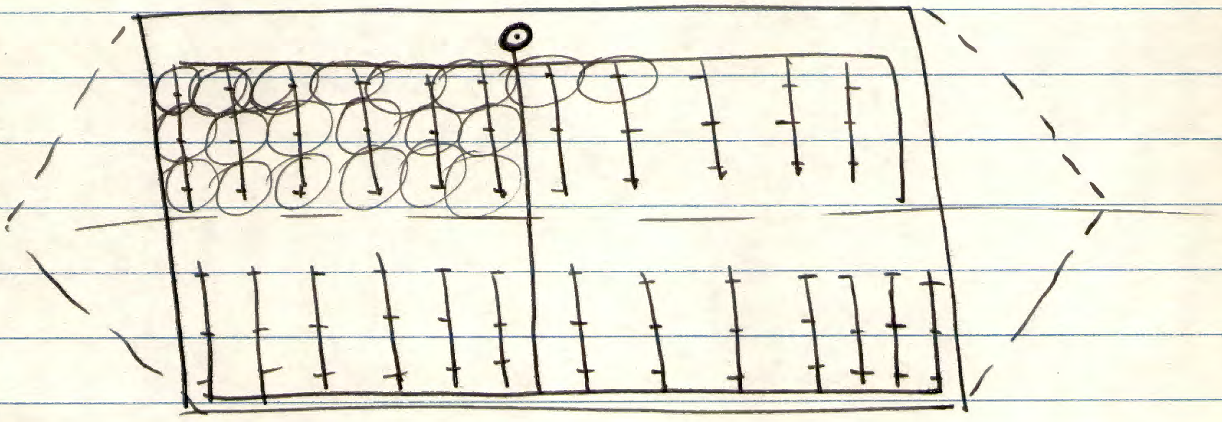


AT 50 FEET WATER GET ABOUT 1660 GPM

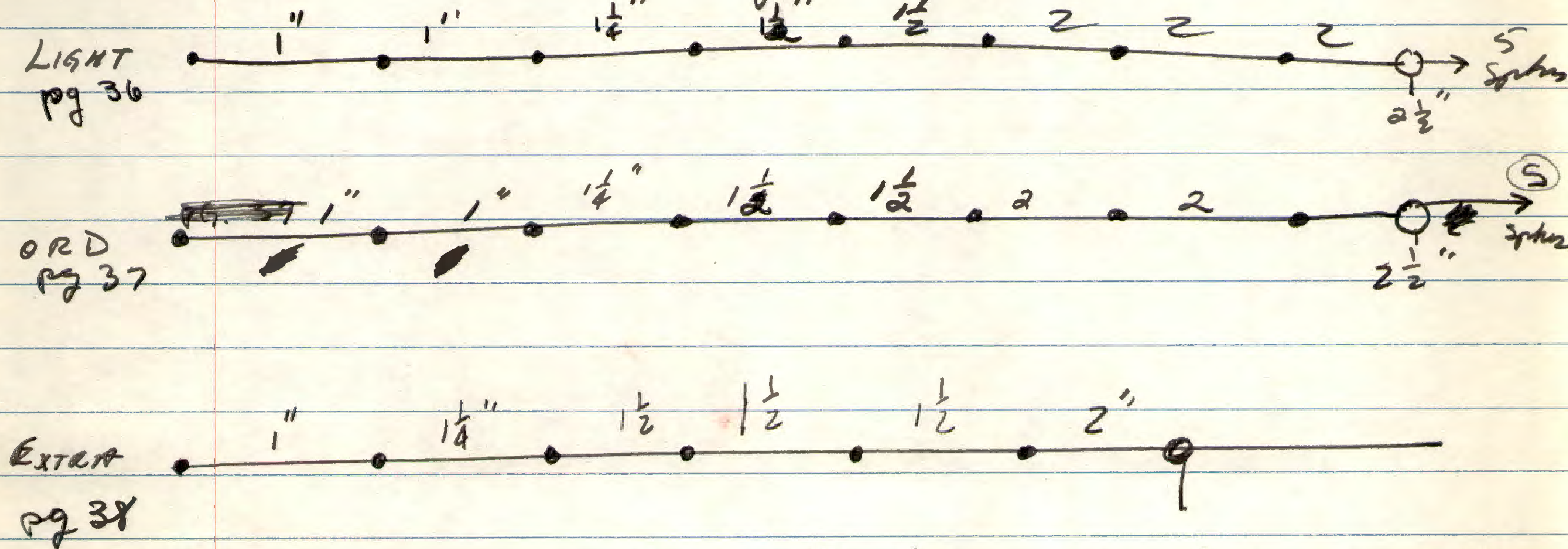
FPE 420 10-7-64

Sprinkler Systems WBFU #13

Pg. 34 + Fig. 3010



3 different kinds of piping schedules



Read Section 3 Components

FPE 420

NBFU 13

pg 34

ʃʃ 3001

ASA schedule 40, 80, 30, ~~#~~ etc. designate pipe wall thickness req.

refers only to PIPE

Schedule 40 = "Standard wall" Pipe
Schedule 30 = acceptable in 8" + larger.

Dimensions for all pipe must meet ASA B-36.10 1959 – can use for pressures up to 300 psi.

FITTINGS

Pg. 54

~~2~~ ʃʃ 3300

working pressure not < 175 psi COLD H_2O
↓
not same as steam pressure.

Small fittings up to 2" – can use CI <175#
>2" CI >175# must use heavy CI pattern

Ductile Iron = CI + alloys ⇒ not as brittle

SS3317 Malleable Iron OK up to + incl. 6" < 300#

§§ 3315 Valves.

pressure rating stamped on valve.
certified by mfr.

§§ 3316 JOINTS

FPE 420

10-12-64

pg 56 §§ 3321 Couplings + Unions
see also pg. 14+15 CRANE "Piping Pointers)

Pg. 56 Reducers + Bushings Pg 16 CRANE

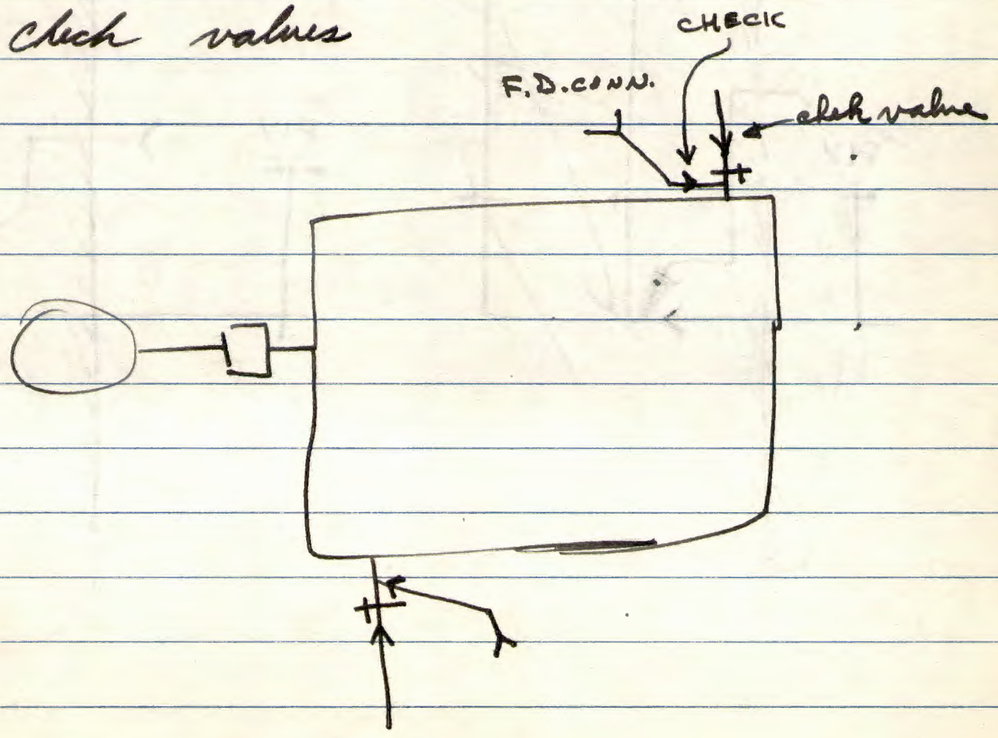
pg. 56 VALVES

§§3420 Pg 56 Valves Controlling Water Supplies
3421 - no valve on F.D. connection
but must have ① valve to control all of
rest of supply. (see fig. 3424)
→ to each system

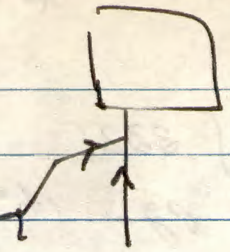
3422 Also ① valve in EACH source

3423 check valves

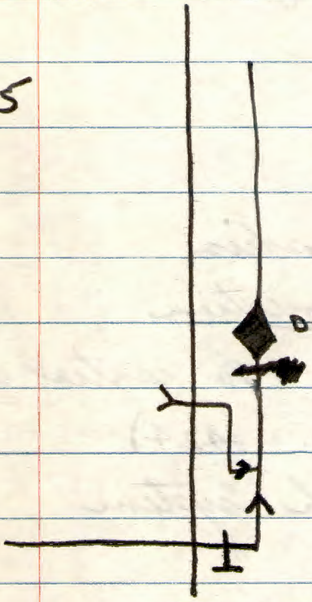
e.g.



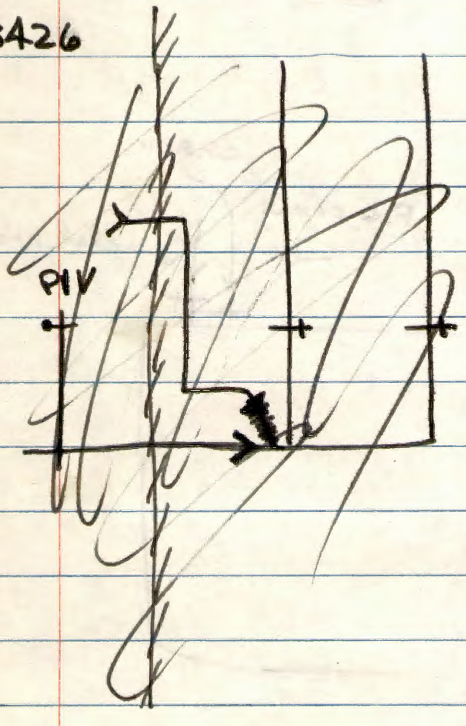
3424 one Water Supply
must still check

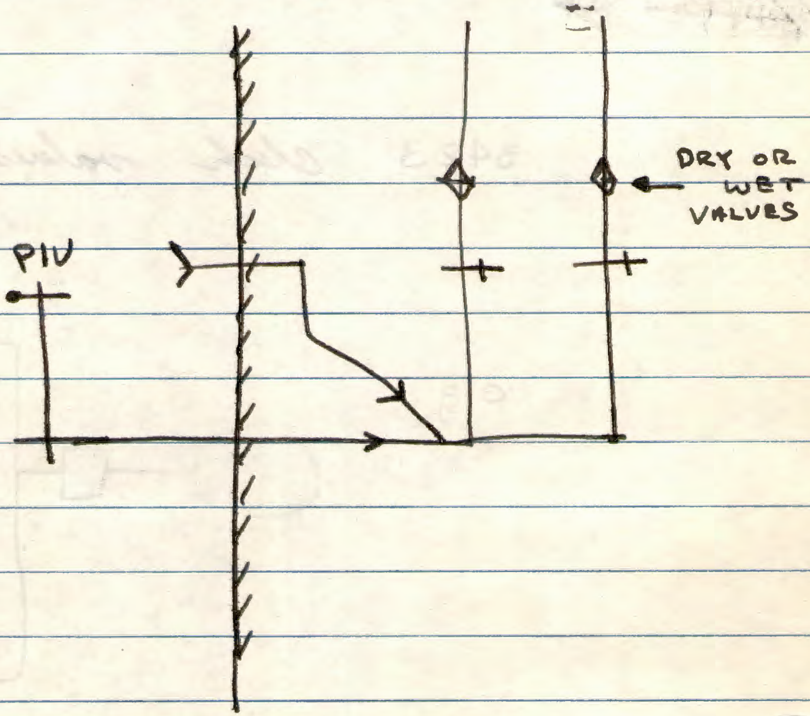


3425

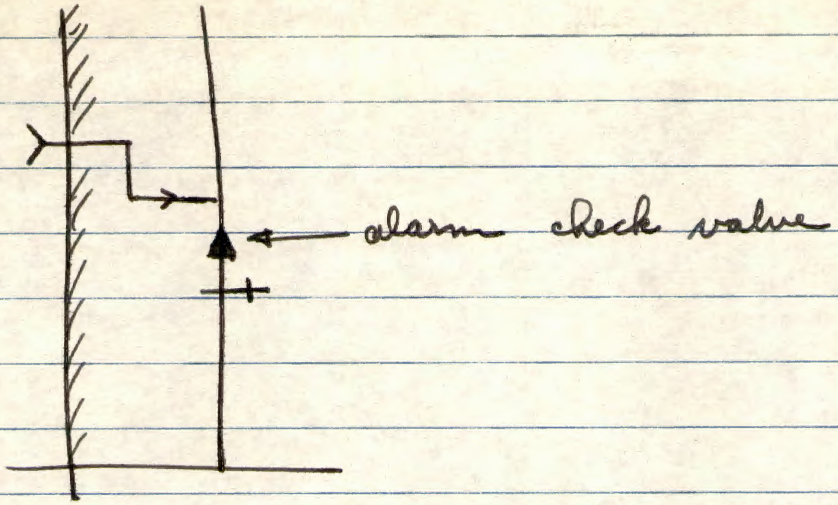


3426



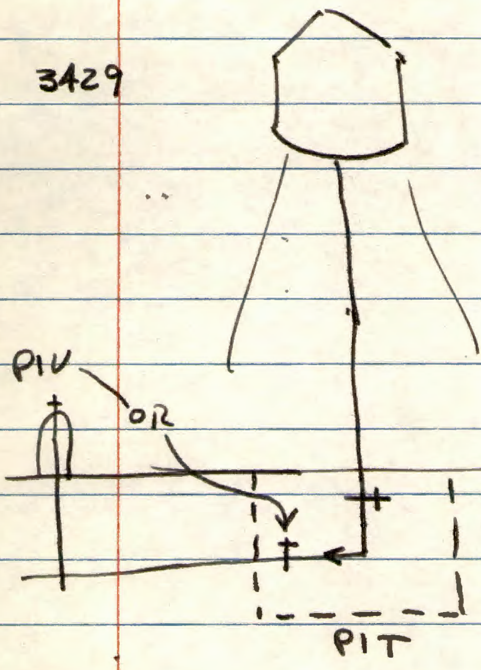


3427



3428

3429



FPE 420

Pg 58

§§ 3431 You don't put a supply of water into bldg w/o a way to shut it off!

3432

Don't want other supply going into broken pipes + pumps & all over the place in the bldg.

3433

If check is overhead @ lower level it is vulnerable - not so important if one fire area however.

3434 Control valves must be accessible

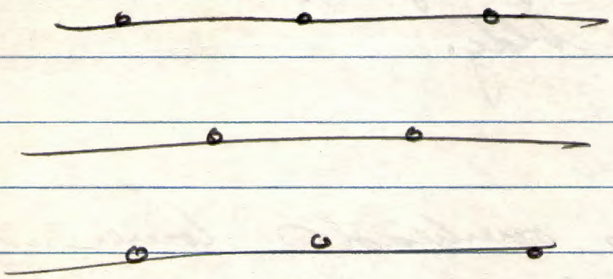
3440 Large yard ~~sections~~ systems are sectioned by valves.

HANGARS - Pg. 61 Be careful to choose proper hangar.

pg. 82.

4040 DEFINITIONS
4041 - 4044 Types Construction.
~~4040~~

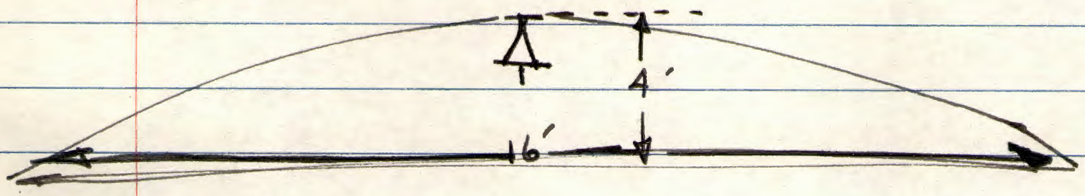
pg 84 Staggered Spacing



Pg. 84

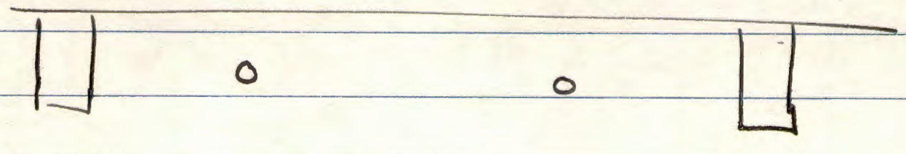
§ 4130 Protection Area Limitation

Max. Area covered by ea. spkr.
Max distance between spkrs.
Max distance between branch lines



1. Decide type Const.
2. Get Max area
   Max spkr. dist.
   Max branch dist
3. Layout

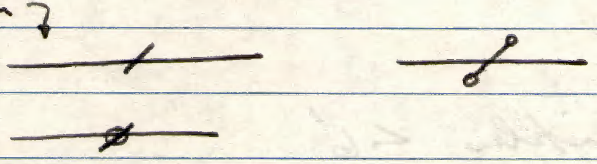
e.g.



if girders are wide enough ⇒ lines will be betw. them, may have to put 2 lines betw. if one won't cover.

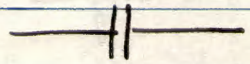
Sprinkler on Branch Line

Pipe hanger

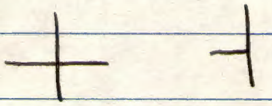


or whatever you want & key it.

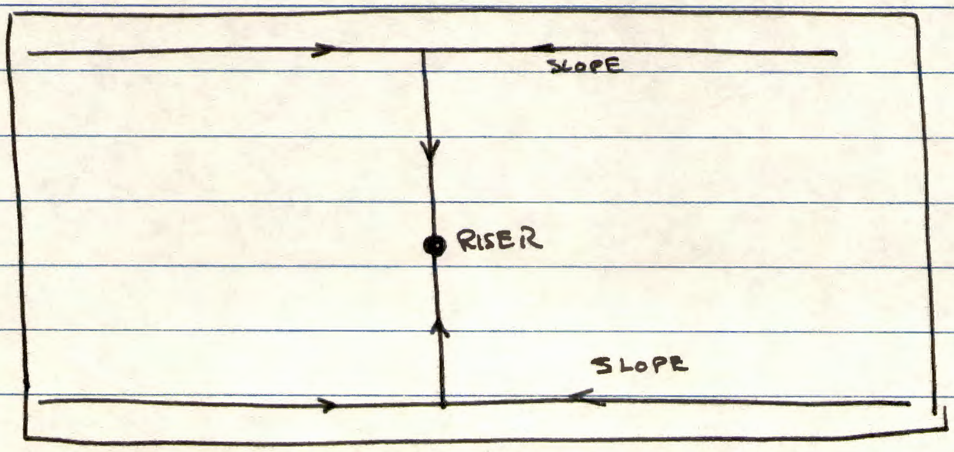
Flanged Joints

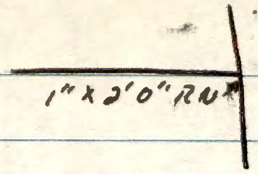


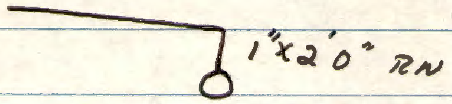
Intersection



At each end of each pipe must show elevation of ℄ of pipe for slope.







RISER NIPPLE

Don't put sprinkler < 6'

Read article [illegible] By Art Guys
fire ext
& Extinction of fire by Water Sprays

RE: "Chemical Aspects of Fire Extinguishment"

FPE 420 10-26-64

Can:

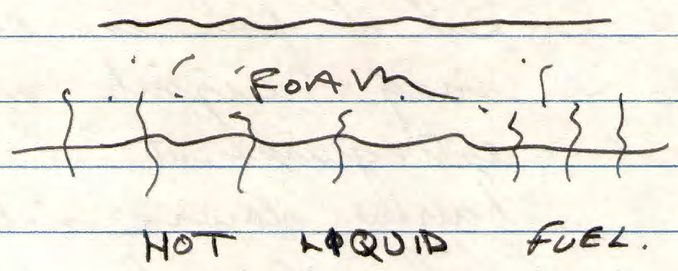
1. Cool fuel ∋ sufficient gases aren't given off to support comb.
2. Space occupied by flame.
   a. mix inert gas with it to dilute O_2 + comb. gases. But if fuel is hot enough may reignite after initial extinguishment. If fire can burrow down into fuel, the fuel will cool very slowly and CO_2 etc. aren't very effective. unless applied for long period of time.

   b. Chain Breaking method applied to space occupied by flame.
   e.g. Dry Chemical
   Some CO_2 + H_2O formed, but not sufficient to extinguish. Extinguishment is primarily obtained by chain breaking process. (Capture free radicals)

__Water__ — Plain water 1. + 2.

Cools and Steam acts as inert gas in flame.

Foam.

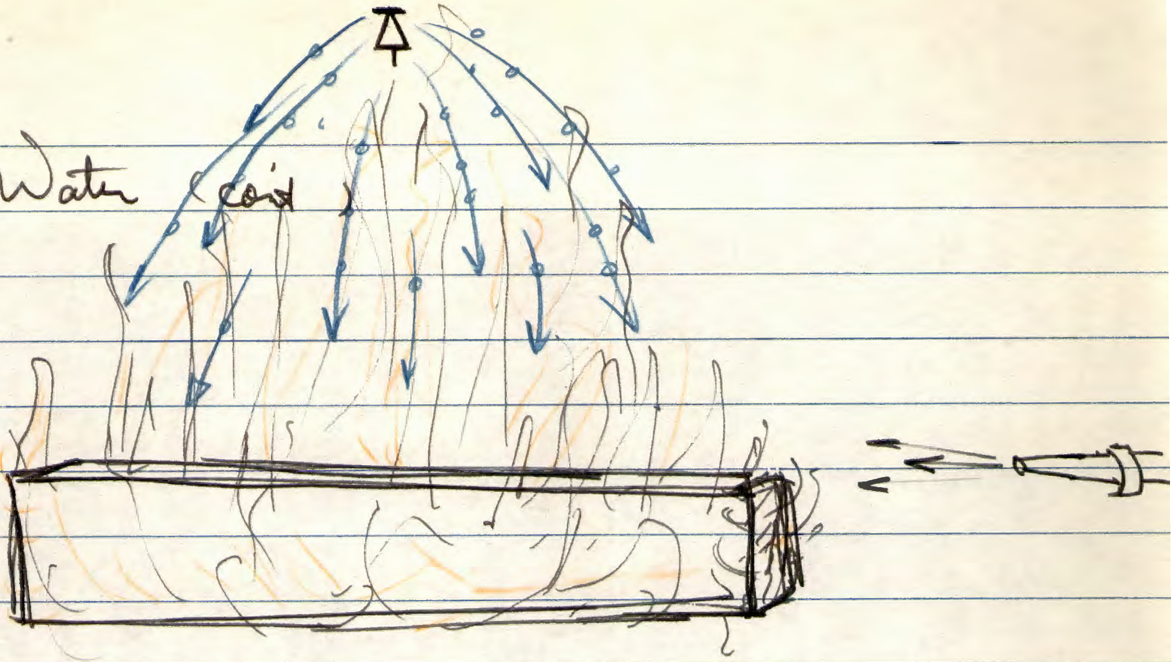


Absorbs heat + cuts of O_2
reduce temp below fire point
∋ can't give off vapors to support flame.

Note: gasoline + ethyl ether etc. is above fire pt. at ordinary temperatures. ∴ must rely on restriction of O_2 only, + cover ∋ vapors can't get thru foam.

Wetting Agents:
Reduce run off time ∋ more water will stay on fuel to evaporate.

Plain Water (cont)



On open fire, most of spray cools fule only, as steam is carried away + doesn't effect flame area.

If fire area is somewhat enclosed cooling + steam are both effective.

In most of our cases, we will have the effect of both.

Note, with hose stream you can get to the seat of fire + cool fuel + still get steam dilution of O_2 + fuel gases even in open fire.

FPE 420 10-30-64

(AS) PROBLEM DUE DEC. 11 - LATEST DEC. 14

What we should get out of these [redacted] papers
Write down firm conclusions from these papers. - How we might use them.

A

420

I/EC
uidebook for
chnical Management

Man 10-26-64

Chemical Aspects of Fire Extinguishment

Concepts of fire and fire extinguishment must be revamped because recent findings add a fourth dimension to the fire triangle

by A. B. Guise, Ansul Chemical Co.

As a result of fairly recent and not too widely publicized research, our understanding of how fire extinguishing agents work has increased greatly. This may lead to more effective provision for the control and extinguishment of fires.

The old familiar fire triangle concept which postulates that fire can exist only when heat, fuel, and oxygen are present, is an oversimplification. In the light of new findings it must be refined to a square. A new factor, a chemical chain reaction in the flame itself, is the fourth essential. Consequently, in fire extinguishment a new factor has been added: "interrupt the flame chain reaction." This action may be extremely important as an explanation of the effectiveness of certain extinguishing agents.

Water. The most common—oldest, cheapest, and most plentiful of all—is water, applied to a fire as a liquid stream or spray. With one exception, the extinguishing action of water and water solutions is purely physical. Steam acts as a smothering agent by displacement of oxygen, and the mechanical and chemical foams act as blanketing agents to separate the fuel from the air. Wetting agents and viscosity-increasing agents increase the effectiveness of the cooling action of water by retarding runoff.

Water includes foam, loaded stream etc.

The first indication of true chemical action in extinguishment where water is concerned is the "loaded stream," a solution of potassium carbonate in water with other additives to reduce the freezing point to -40° F., used in hand portable and wheeled extinguishers. It is more effective than plain water on fires in ordinary combustibles such as wood, cloth, or paper and is approved for use on flammable liquid fires where water would not be effective even as a spray.

Early work in this area was described by Thomas and Hochwalt in 1928. They concluded that water solutions of metallic salts based on elements in Group I of the Periodic Table (lithium, sodium, potassium, rubidium, or cesium) were more effective as the atomic weights of the cations increased. Alkali metal salts with anions containing oxygen and halogens were most effective and they ascribed the action to a "negative catalytic" effect on the combustion reaction. It is probable that the effectiveness of these solutions is due to a chemical chain-breaking action. This is also indicated by practical experience with the loaded stream extinguisher, which is most effective on flammable liquid fires when the solution is applied to produce a spray.

Carbon Dioxide. Carbon dioxide is essentially as simple in its action as water. When introduced into the combustion zone, it dilutes the reactants—oxygen and fuel vapors—below the concentration necessary to support combustion. Carbon dioxide may be used on any type of fire, regardless of the type of fuel involved or the presence of electrical hazards. However, confinement is required in fires involving ordinary combustibles to assure effective exclusion of oxygen long enough to cool to below reignition temperatures.

(**Halogenated Hydrocarbons.**) Much research has been carried out on the extinguishing effectiveness of a large variety of halogenated hydrocarbons. At one time it was thought that their action was due to cooling by vaporization and smothering by vapor dilution of air and fuel vapors. It is now believed that the major extinguishing mechanism is a chemical chain-breaking action and that the halogens inhibit continuation of the combustion reaction by combining with hydrogen atoms and removing them.

not used in normal Industrial Install.

Carbon tetrachloride is an inexpensive extinguishant, but its application is declining because of its toxicity and the toxicity of the products of thermal decomposition. Chlorobromomethane, developed

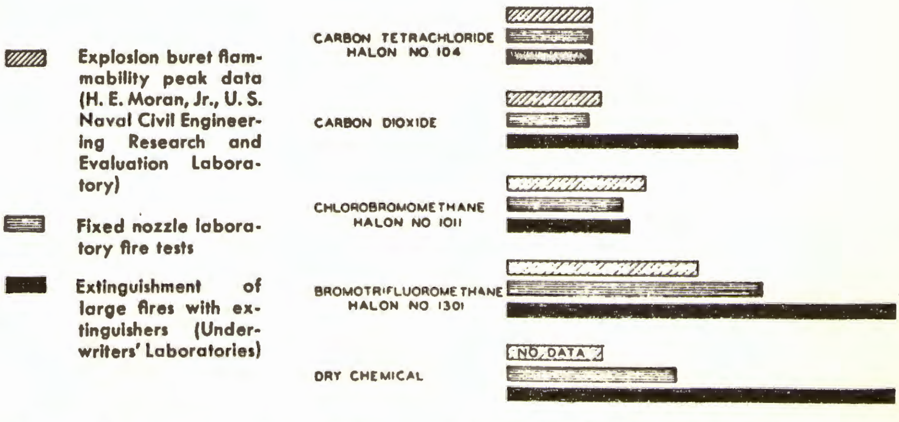


Figure 1. Comparative effectiveness of extinguishing agents on weight basis

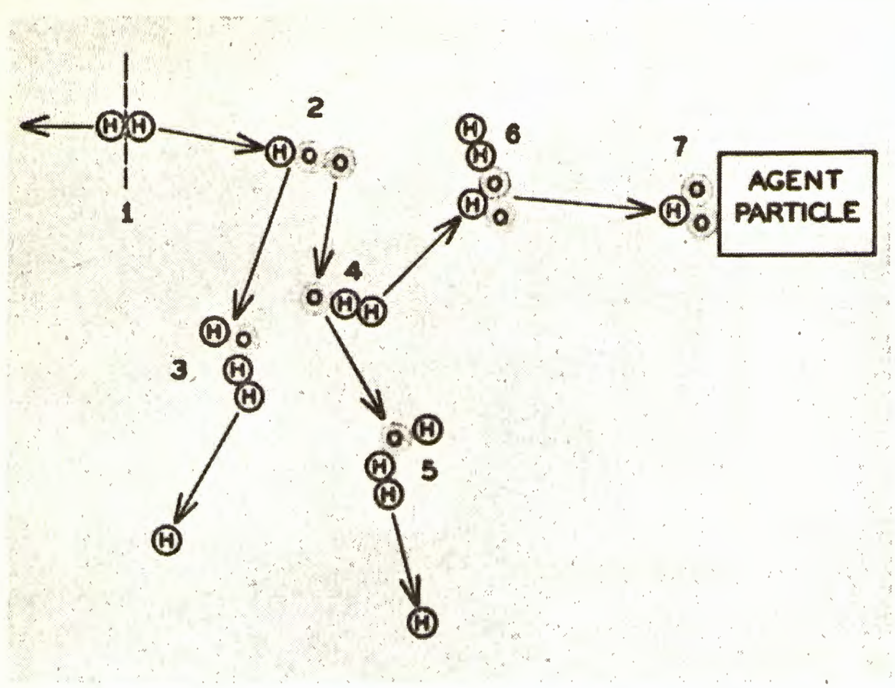


Figure 2. Branched-chain combustion reaction of hydrogen and oxygen

by the Germans during World War II, has slightly less toxicity and is a more effective extinguishing agent.

Methyl bromide gained wide acceptance in foreign countries but has never been widely used in the United States. Its use abroad has also declined, because of toxicity.

New halogenated agents of considerable effectiveness are fluorobromo compounds. Bromotrifluoromethane (Halon 1301) is receiving concentrated attention from the military, but its cost, about $4 per pound, has delayed commercial application despite excellent extinguishing effectiveness and low toxicity.

Limited use for aircraft

Laboratory evaluation of halogenated compounds must be carefully weighed in the light of field application. There is considerable discrepancy between practical extinguishing results and laboratory evaluation, especially by the explosion buret method.

Although the explosion buret method is a convenient way of carrying out preliminary evaluations in the laboratory, it does not represent actual conditions of fire extinguishment, because the values are obtained under conditions where combustion is not already proceeding. Laboratory evaluations on a larger scale by the use of fixed nozzles may be converted to practical applications, where properly engineered piped systems with fixed nozzles are used. Where streams from extinguishers or hose lines must be used, the physical characteristics of the halogenated compounds do not allow the theoretical effectiveness of the extinguishing agent to be obtained. This is shown by Figure 1.

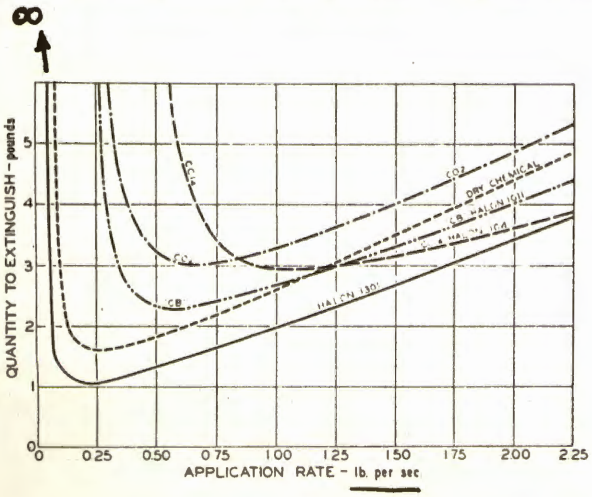


Figure 3. Effect of application rate

Dry Chemical. Dry chemical consists of finely divided sodium bicarbonate with additives used primarily to enhance flowing action and water repellency.

Potassium bicarbonate is under consideration, but is not yet commercially available. Both laboratory and practical evaluations indicate greater extinguishing effectiveness than sodium bicarbonate dry chemical.

The finely divided chemical is expelled from its container by dry gas (air, carbon dioxide, or nitrogen) under pressure through a nozzle which controls the pattern of application much as water is controlled. Dry chemical is believed to extinguish primarily by chemical chain-reaction interruption. Cooling or dilution of reactants is believed to be a relatively minor factor. Many chemicals not readily decomposed by heat, such as sodium chloride, are effective extinguishing agents when applied as a powder.

The chain reaction involves the presence of free radicals in the flame zone. These interact with fuel and oxygen to produce a continuing or increasing supply of free radicals to continue the flame reaction (Figure 2). A simple hydrogen flame reaction illustrates this point. The free radicals are self-propagating unless captured by condensation on or interaction with some inerting substance. The fine particles introduced to the flame area are believed to capture sufficient free radicals to interrupt the chain reaction, and flame suppression is nearly instantaneous.

A cloud of dry chemical therefore is similar to a flame arrester, in that a flame cannot pass through a cloud of particles, when in proper concentration; conversely, when the cloud of particles is produced while the combustion reaction is proceeding, extinguishment takes place.

It takes about 200,000,000 particles of dry chemical per cubic

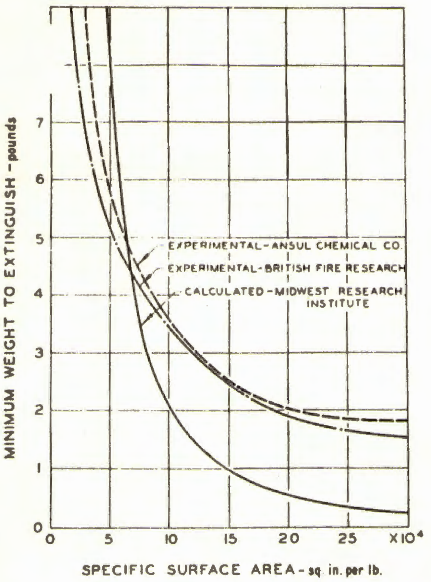


Figure 4. Relation of particle size to extinguishing effectiveness of dry chemicals

foot of flame to extinguish a gasoline fire and approximately 2,000,000,000 particles to extinguish a hydrogen fire.

All extinguishing agents may be generally compared for effectiveness in terms of the quantity required for extinguishing a given fire. Each curve in Figure 3 is derived from extinguishing data and all illustrate an important factor in the effectiveness of any type of agent—rate of application.

In the case of dry chemical extinguishing one more factor is vital—particle size (Figure 4). Attachment of free radicals to a surface is apparently a basic factor in chain-reaction interruption. The dry chemical particles in the flame zone provide such a surface and the finer the powder the greater the effective surface for a given quantity of agent and the shorter the distance of diffusion of a free radical.

Division of Industrial and Engineering Chemistry, 136th Meeting, ACS, Atlantic City, N. J., September 1959.

420

Mon

The Extinction of Fires by Water Sprays

D. J. Rasbash

Joint Fire Research Organization, Boreham Wood, England

Introduction

Water spray has long been widely used for the extinction of fires in both liquid and solid fuels. Although there have been numerous *ad hoc* investigations on the effect of sprays from various nozzles on fires of different types, it is only in recent years that any systematic study has been made using sprays and fires with controlled and measured properties. Work of this nature has been carried out for about ten years at the Joint Fire Research Organization. In this work attention has been paid in particular to the ability of spray to penetrate to the seat of a fire, the mechanism of extinction, and the properties of sprays required to extinguish fires of various types. To some extent the work has also permitted an approach to be made to defining critical heat transfer criteria for extinguishing fire. In this paper these aspects of the problem will be discussed and illustrated by experimental results obtained at the above organization and elsewhere. The results of the experiments also suggest certain broad principles on which fire-fighting operations should be based, and these will be outlined.

Penetration of Spray to the Seat of a Fire

In order for a spray to be able to exert a useful effect on a fire, it is usually necessary for the spray to penetrate to the seat of the fire, particularly to the burning fuel. To do this the spray must be either formed near the fuel or it must have sufficient forward force to prevent too much of the spray being either deflected by or evaporated in the flame and hot gases associated with the fire.

The factors which control the penetration of spray to the seat of a fire are the drop size and thrust of the spray, the thrusts of the flames and wind, gravity, and the evaporation of spray in the flames. When sprays are applied to fires by hand the effects of the thrust of the flames and the wind, and the evaporation of spray in the flames are usually minimized by applying the spray directly through the base of the flames to the fuel from the upwind side of the fire; the reach of the spray, which is determined mainly by gravity and the forward thrust of the spray, usually controls the penetration to the seat of the fire under these conditions. When spray is applied downward to a fire, all the above factors are of importance but particularly the relative thrusts of the spray and the flames. Little information is available from the literature on either of these two factors but work carried out at the Joint Fire Research Organization indicates that they may be estimated from readily measured properties of the spray and the flame. The thrust within a spray is a function of the reaction at the nozzle and the width of the spray; there is also evidence that at some distance from the nozzle it is approximately equal to the thrust of the entrained air current. The latter depends on the flow rate of spray per unit area and the pressure at the nozzles. The thrust of flames is proportional to the buoyancy head. Further information on these relationships is given in the appendix.

Experimental information on the penetration of sprays to burning fuel is available for fires in kerosine burning in a 30 cm diameter vessel using downward application of spray.[1] The results were scattered mainly because the penetration was very sensitive to the pattern of the spray at the fire area, a factor which was very difficult to control experimentally. Broadly, however, the penetration decreased as the pattern of the spray became more peaked in the centre of the vessel and as the thrust and the drop size of the spray decreased. The effect of the latter two factors is illustrated in Figure 1 which refers to sprays in which 2

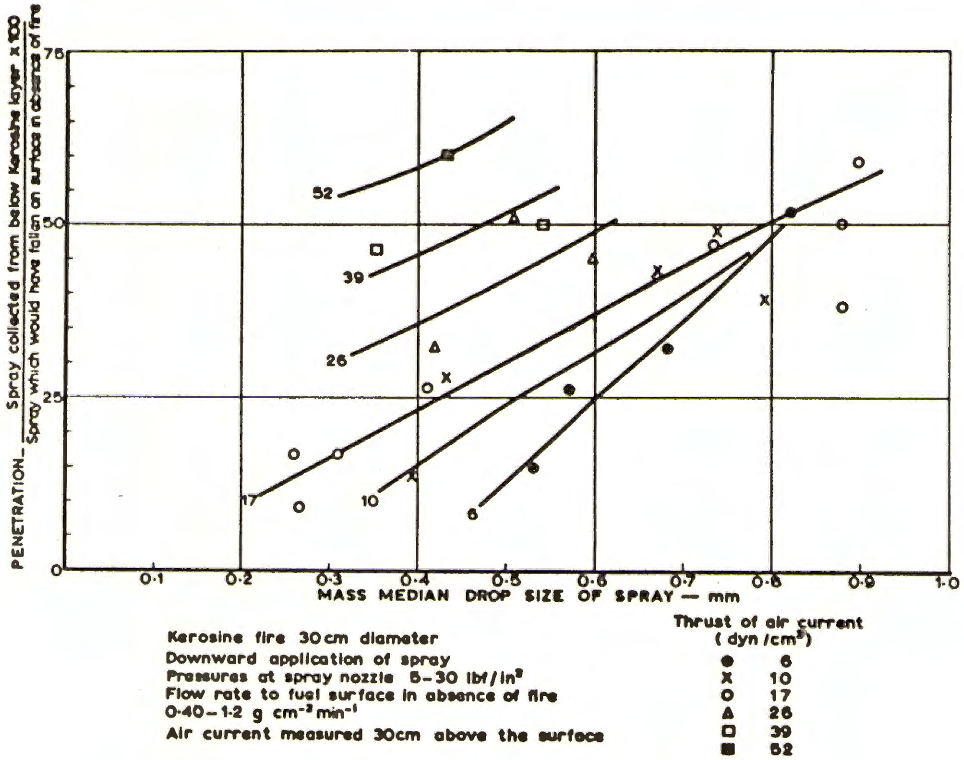


Figure 1. Penetration of spray to the fuel of a fire.

the peak of the spray distribution was contained in the central half of the vessel but in which not more than one-fourth of the area of the vessel was covered by a flow rate less than one-half of the peak value. In spite of the scatter of the points, the effect of spray thrust, as calculated from the entrained air current, and the drop size on the penetration is clearly seen. There is, however, an indication that at drop sizes greater than about 0.8 mm the penetration was independent of the thrust. If the peak was outside the central area of the vessel the penetration was usually considerably greater. 2

In the tests referred to in Figure 1 the height of the flame as judged visually was 150 cm before the application of spray and was reduced to mean values between 80 and 140 cm during the application of the spray. These heights correspond to upward flame thrusts of 34 and 18–30 dynes/cm² (see appendix). It will be

→ N LB/IN²

seen from Figure 1 that the thrusts of the spray required to give a 50 per cent penetration for the finer sprays is comparable to these values.

how measured ?
see Appendix

It was observed during the tests that as the thrust of the spray was increased above 20 dynes/cm^2 the flames became increasingly unstable. Sprays with higher thrusts than represented in Figure 1 often caused stabilization of the flame as a relatively flat flame above the vessel after a period of instability. The minimum spray thrust at which this phenomenon occurred was 77 dynes/cm^2. It would be expected that under these conditions the bulk of the spray, even if it were fine and of a peaked pattern at the fire area, would penetrate to the burning fuel; this might also be inferred by extrapolation of the results in Figure 1. This critical thrust, T_c might be related to x, the height of the flames as judged visually prior to the application of spray, by equation (1).

$$T_c = 0.5\,\rho_0\, g\, x \tag{1}$$

ρ_0 = density of air, g = acceleration due to gravity.

It would be expected that since equation (1) represents the thrust in the air current of the spray required to overcome the buoyancy head of the flames, T_c should scale with flame height for larger sizes of fire than the fire tested.

For a given flow rate of spray in the absence of fire, and for a given pressure, the thrust of the spray in these experiments was approximately independent of the drop size. Therefore, as the drop size decreased the penetration decreased. However, as the drop size decreased the efficiency of ~~unit~~ mass of spray in reducing the rate of burning increased since the finer spray cooled the liquid more efficiently. As a result of these two phenomena a drop size occurred at which there was a minimum rate of burning for a given flow rate and pressure. This drop size depended on the spray thrust, and decreased from 0.8 to 0.33 mm as the thrust increased from 6 to 26 dynes/cm^2.

Mechanism of Extinction

There are two main ways of extinguishing a fire with water spray: (1) cooling the burning fuel and (2) cooling the flame. The mechanism of smothering the flame with steam is one aspect of cooling the flame and will be dealt with under that heading.

Cooling the Fuel

To reduce the temperature of the fuel the spray must be capable of abstracting heat from the fuel at a rate greater than the rate at which the fuel will take up sensible heat. Heat will normally reach the fuel by heat transfer from neighbouring hot bodies and from the flame. Information on heat transfer from bodies may be obtained from texts on heat transfer although there are many important cases, for example, on the flow of films of fluid over hot surfaces where information is lacking. There is evidence, which will be given later, that radiation from the flame to the fuel that is being cooled does not normally play a large part in determining critical conditions for extinction, although if only a part of the fire is being extinguished at any one time, radiation from the rest of the flames might become an important factor. In this paper, therefore, particular attention will be paid to estimating critical conditions when the surface receives heat mainly by convective or conductive transfer from the flame. Such estimates may be obtained from known relationships between the rate of burning and the heat

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transferred from the flame to the surface. The method used may be best illustrated by an example. Equation (2) was found by Spalding to give the rate of burning of liquid fires flowing over surfaces with a vertical dimension (d).[2]

$$\dot{m}'' = \frac{0.45k}{dc} B^{\frac{3}{4}} \sqrt[4]{\frac{gd^3}{\alpha^2}} \tag{2}$$

where

$\dot{m}''$ is the average rate of vaporization per unit surface area,
d is the linear dimension of the surface,
k, c α^2 are thermal conductivity, specific heat and thermal diffusivity of air at room temperature,
g is the acceleration due to gravity,
B is a transfer number equal to

$$\frac{M_{og} H/r + c\,(T_g - T_s)}{Q}$$

where

Q is the heat transfer to the fuel surface per unit mass of fuel vaporized,
M_{og} is the concentration of oxygen in air (by weight),
H is the heat of combustion of the fuel,
T_g is the ambient gas temperature and T_s the surface temperature,
r is the stoichiometric ratio (weight of oxygen/weight of fuel).

Normally, under steady conditions, the value of Q in the transfer number is equal to λ_f, the heat required to vaporize unit mass of fuel. However, when a spray is acting on the fuel and heat is being removed from the fuel, Q will be greater than λ_f.

For most liquid hydrocarbons equation (2) may be reduced with little error to

$$\dot{m}'' = \frac{0.17}{d^{0.25}\, Q^{0.75}} \tag{3}$$

($\dot{m}''$ in g cm^{-2}s^{-1}; d in cm; Q in cal/g.)

The rate at which heat reaches unit area of the burning liquid from the flame is Q $\dot{m}''$; the rate at which heat needs to be transferred to vaporize the fuel is $\lambda_f\,\dot{m}''$. Therefore, a steady condition as expressed in equation (3) will be maintained if the spray removes from the liquid a quantity of heat γ given by

$$\gamma = (Q - \lambda_f)\,\dot{m}'' \tag{4}$$

Combining equations 3 and 4 gives either

$$\gamma = \frac{0.17}{d^{0.25}\, Q^{0.75}}\,(Q - \lambda_f) \tag{5}$$

or

$$\gamma = \left(\left(\frac{0.17}{d^{0.25}\,\dot{m}''}\right)^{\frac{4}{3}} - \lambda_f\right)\dot{m}'' \tag{6}$$

-then

If the spray is capable of removing heat at a greater rate than the temperature of the fuel will be reduced. This will result in a smaller value of $\dot{m}''$ and a correspondingly larger value of Q and γ. The reduction in temperature will also bring about a reduction in the rate at which spray can remove heat from the fuel.

In a burning fuel in which the temperature of the fuel has reached steady conditions, $Q = \lambda_f$ and $\gamma = 0$. The application of spray with a lower temperature than the fuel will therefore result in the fuel being cooled. This will continue until

$$\cancel{\gamma = \left[\left(\frac{1}{\frac{4}{3}\,Q^{.25}}\right)^{\frac{4}{3}} - Q\right]\left(\frac{.17}{d^{.25}\,Q^{.75}}\right)}$$

$$\cancel{\gamma = \left(Q^{-\frac{3}{4}}\right)\xi - Q \qquad \frac{1}{Q} = \frac{Q^2}{Q} = \left(\frac{1-Q^2}{Q}\right)}$$

either a steady burning condition is established at a particular temperature or one of the two following critical conditions for extinction is reached.

heat transfer to fuel

1) The value of Q may reach the maximum value, Q_c, which the flame is capable of imparting to the surface without becoming extinguished.
2) The value of ṁ″ may reach a minimum value, $\dot{m}_c''$ below which a flame cannot continue to exist above the surface.

rate of vaporization

The rate γ_c at which the spray must abstract heat from the fuel at the particular fuel temperature at which these critical conditions occur will be given by one of the equations (5) and (6), and if Q_c and $\dot{m}_c''$ are assumed independent of the linear dimension of the burning surface, then γ_c will be expected to decrease slowly as this dimension increases.

"d"

By a similar argument to that developed above, it is possible to put forward equations giving γ_c for a wide range of conditions, indeed for all conditions for which there is a known relationship between the Nusselt number for heat transfer from a gas and other relevant dimensionless groups, e.g., the Reynolds, Grashof, and Prandtl numbers. By these means it may be shown that above a certain dimension of the surface γ_c will cease to decrease with increase in d, and if the wind is sufficiently strong γ_c will be proportional to the square root of the wind velocity and inversely proportional to the square root of d.

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γ_c heat from fuel by spray

flammable liq. is simpler to handle than wood.

A certain amount of information is available for the critical value of Q. Thus for flame quenching in channels[3] and in flame arresters[4] it has been found that for stoichiometric hydrocarbon flames the maximum amount of heat a flame can impart to a surface before it is extinguished is 23 per cent of the heat of combustion of the fuel, i.e., about 2500 cal/g. Spalding[2] carried out experiments on the circulation of kerosine burning on the surface of a sphere and here again it was found that the fire was extinguished when the heat transferred to the burning surface by the flame was 2500 cal/g of fuel vaporized. Spalding's experiment is analogous to extinguishing a fire by cooling with water spray, the only difference being that heat was removed by excess fuel rather than by water spray. It would be expected that the conditions under which the maximum fraction of the heat of combustion can reach the surface of the burning fuel would occur when a stoichiometric mixture burns very close to the liquid surface. The temperature of the surface should, therefore, be near to the value corresponding to equilibrium with a stoichiometric mixture. For kerosine this temperature is 15°C higher than the temperature at which the surface is in equilibrium with the lower limit mixture and is approximately equal to the fire point.

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heat abstraction Rate from fuel by Spray

Using 2500 cal/g as the value for Q_c the following values for γ_c may be calculated for fires burning under conditions of natural convection.

$\gamma_c = \frac{.6}{2.34}$

$\gamma_c = .256$ cal. $cm^{-2} sec^{-1}$ for d = 30cm (pg. 35)

Pool or spill fires $\gamma_c = 0.6/d^{0.25}$ (7)
Fires on tubes $\gamma_c = 1.2/d^{0.25}$ (8)
Fires on vertical surfaces $\gamma_c = 1.2/l^{0.25}$ for $l < 100$ cm (9)
$= 0.4$ for $l > 100$ cm (10)

γ_c is in cal/cm²/sec; d, l characteristic dimension in cm.

$\frac{0.256}{45} = .0057 gm. cm^{-2} sec^{-1}$

$(.0057)(60) = .342 gm. cm^{-2} min^{-1}$

There is little information on the minimum value of ṁ″ below which a flame will not be sustained. It might be postulated that $\dot{m}_c''$ should be not less than the value required to sustain a lower limit flame at its appropriate burning velocity over the whole surface; this would give $\dot{m}_c''$ equal to about 1.5×10^{-4}

fig 2 shows .3 to .35 mm drop. size

g/cm²/sec for fires in hydrocarbon liquids. On the other hand experiments on the extraction of heat from laminar propane-air flames[5] indicate that a stoichiometric mixture may continue to burn close to a surface to which it is imparting heat at a rate similar to Q_e when the combustion rate is as low as 2.6×10^{-4} g/cm²/sec. The above figures for m_e'' are about one-tenth of the rate of combustion of pool fires under steady conditions; they imply that γ_e may depend on critical rate of vaporization when the dimension of the fire is greater than 30 cm, for fires burning in a natural draught.

The analysis so far has dealt only with burning liquids. There are difficulties in applying a similar analysis to wood. The main difficulty as far as the extinction of flaming combustion is concerned is that the heat required to produce unit mass of volatiles is not known. The slow decomposition of wood is an exothermic process, i.e., λ_f is negative, but Klason[6] showed that as the rate of decomposition increases the process changes from being exothermic to endothermic. There is evidence that for the rates of decomposition required to sustain a flame over a wood surface, the decomposition is indeed highly endothermic. For the extinction of glowing combustion the analysis would have to be modified to take into account the loss of heat from the surface by radiation and the effect of surface temperature on the combustion rate.

?

The above considerations are concerned with the rate at which heat must be removed from the fuel in order that the fire may be extinguished by cooling the fuel. The ability of the spray to remove this heat will depend on the properties of the spray and the fuel; this aspect of the problem will be referred to when experimental results are discussed.

Extinction of the Flame

The criterion of extinction of a flame by heat abstraction inside the flame is that the combustion products as they leave the reaction zone should not exceed the temperature they would have for lower limit flames; this temperature is about 1580°K for a wide range of flammable vapours and gases. A decrease in temperature approximately to this value is obtained when extinction is obtained by adding nitrogen, water vapour, carbon dioxide, or inert dust to flames in stoichiometric mixtures.[7]

2380°F
1307 C.

? what about dilution and chain breaking as per Ansul?

The amount of heat which it is necessary to remove from the flame to accomplish this is the difference in heat of combustion of stoichiometric and lower limit mixtures. For most flammable organic compounds and probably also for the volatiles from some common dry woods this is about 45 per cent of the heat of combustion of the fuel. Since with diffusion flames it would be expected that there would be a zone between the fuel and the atmosphere where the stoichiometric mixture occurs, the heat which has to be removed from the flame as a whole is 45 per cent of the heat of combustion of the fuel. It is important, however, that this heat be removed either from the reactants or the reaction zone. If the heat is removed from the combustion products the heat removal will not substantially affect the temperature of the products leaving the reaction zone. In a turbulent diffusion flame it is very difficult to differentiate between the reactants, the reaction zone and the combustion products. However, it would be expected that if a spray is capable of removing all the heat of combustion from the flame, then the flame will be extinguished.

It is interesting to note that the heat removal required to extinguish the flame by cooling the flame is twice as great as the heat which an extended surface on the reactant side of the flame may abstract from the flame before the flame is extinguished. This might be explained by a different balance of heat release and heat loss rates for a vitiated flammable mixture and a stoichiometric flammable mixture close to an extended surface.[8] Owing to the intractability of defining the position and properties of the reaction zone in a turbulent diffusion flame the approach to estimating critical conditions for extinction of the flame by water spray has been made on the basis of heat transfer taking place within the whole flame. If V is the volume of the flame, Z the mass rate of burning, and H the heat of combustion of the fuel, then I, the mean rate of the heat production per unit volume of flame, assuming complete combustion of the fuel, is $\frac{ZH}{V}$. If the capacity for heat transfer of the spray within the flame is defined as X, the rate of heat transfer per unit volume of flame to the spray, then three critical criteria for X may be put forward.

1) Removal of all the heat in the flame neglecting the production of steam as a result of heat transfer to the spray

$$X_1 = I \tag{11}$$

2) Removal of heat only from the reaction zone and the reactants, but also neglecting steam formation

$$X_2 = 0.45\ I \tag{12}$$

3) Removal of heat only from the reaction zone and the reactants, but assuming that all the heat transfer for the drops result in steam formation. This will only be the case if the drops enter the flame at the wet bulb temperature (about 75°C). It may be assumed that the steam formed will contribute to the cooling of the flame a quantity β per unit mass of steam equal to the whole of the sensible heat of steam from 370–1580°K. The ratio of β to λ, the latent heat of steam, is 1.23. This gives

$$X_3 = \frac{\lambda}{\beta + \lambda}\, 0.45\ I = 0.195\ I \tag{13}$$

A fourth criterion may also be put forward if steam is formed outside the flame either at the burning surface or at surrounding hot bodies. Under these conditions the latent heat of vaporization does not contribute to cooling the flame but the sensible heat of steam up to 1580°K does. If the steam is formed at or sufficiently near to the burning surface to accompany the reactants into the flame then the critical flow rate, W, of water required would be

$$W = 0.45\, \frac{ZH}{\beta} \tag{14}$$

If the steam is formed well away from the burning surface and is heated by the combustion products, then W may rise to values equal to $\frac{ZH}{\beta}$.

The quantity I in equations (11) through (13) is an intensity of combustion and depends on the conditions of combustion, particularly the air current in which the flame is burning. For petrol, kerosine, benzole and alcohol fires 30 cm diameter burning under conditions of natural draught, I was found to be independent of the fuel or the rate of burning and equal to 0.45 to 0.50 cal cm^{-3}sec^{-1}.[9]

The entrained air current in a spray not only affects the intensity of combustion but also affects the critical heat transfer rate required to extinguish flame. There is very little information to allow the assessment of this factor on a quantitative basis, but an indication of what might be expected may be obtained from work on the blowout of flame at obstacles. For example, if the assumption is made that the fundamental burning velocity of the flame decreases in proportion to the heat transfer capacity of the spray, then on the basis of relationships between the blowout velocity and the fundamental burning velocity[10] it may be expected that

$$V_{BO} = a_3 - bX^{1.5 \text{ to } 2}d^{0.5 \text{ to } 1} \qquad (15)$$

where V_{BO} is the velocity of the entrained air current that will cause a blowout when the spray has a flame heat transfer capacity X, d is a characteristic dimension of the system and a_3 and b are constants.

It is of interest to compare critical heat transfer rates for extinction by cooling the flame and cooling the fuel. It follows from equations (11) to (14) that the critical heat transfer rate for cooling the flame is greater than 20 per cent of the total heat of combustion of the fire. Equation (4) and subsequent remarks indicate that for cooling the fuel the critical heat transfer is less than 25 per cent of the much smaller rate of combustion that would occur under critical conditions. On this basis much lower critical flow rates would be expected for extinguishing the fire by cooling the fuel than by cooling the flame. As opposed to this, however, it is feasible that unit mass of water can, under critical conditions, be the sink of a much greater amount of heat from the flame (about 1300 cal/g) than it can from a solid or liquid fuel (45 cal/g for kerosine and 750 cal/g for wood).

Experimental Investigations on the Extinction of Fire

In order to examine the relevance of the above analyses of extinction mechanism, experimental investigations have been divided into two groups covering investigations in which there is substantial evidence that extinction was by cooling the fuel and the flame, respectively. For investigations on the extinction of fires in rooms, however, there has not usually been sufficient evidence to decide on the mechanism of extinction and these investigations will be dealt with separately.

Cooling the Fuel

Critical flow rate of spray for extinction of pool fires. Evidence has been obtained from experiments with pool fires that the critical heat transfer rate for extinction of the fire by cooling the fuel is controlled mainly by convection from the flame to the liquid rather than by radiation from the flame. This evidence may be summarised briefly as follows:

1) With sprays at less than the critical rate a steady fire condition could be established with a temperature near the liquid surface not greatly in excess of the fire point, with a flame size very much less than the size of the flame if no spray were applied, and with the flame reaching down to the surface of the liquid.[1] In these fires the predominant mechanism of heat transfer to the fuel surface was by convection.

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2) The effect of scale on the critical flow rate was what was expected if convection controlled the critical heat transfer rate rather than radiation.

The reason for the above phenomenon is that when radiation is the predominant mechanism of heat transfer from the flame to the surface, the bulk of the heat reaching the surface is taken up as latent and sensible heat of the vapour leaving the surface and does not manifest itself as sensible heat in the remaining fuel. There is thus little resistance to the cooling of the fuel by water spray. The temperature of the surface is also much higher than the fire point and the capacity of the water spray for taking up heat is correspondingly much greater. Figure 2

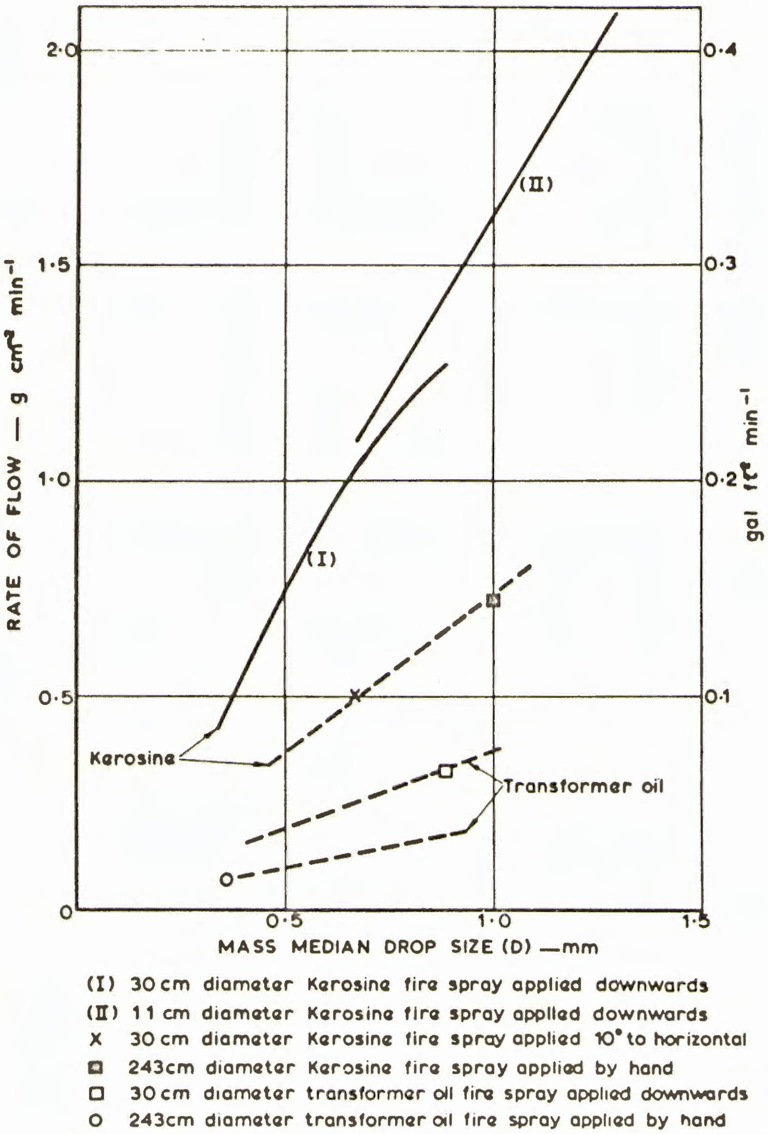

Figure 2. Critical flow rates for extinction of pool fires by cooling the liquid.

50% of drops < mass median size
50% of drops > mass median size

shows critical rates to extinguish kerosine and transformer oil fires by cooling the fuel plotted against the mass median drop size for fires burning in vessels 11, 30, and 243 cm diameter. The curves for the 30 and 11 cm diameter kerosine fires were obtained by extrapolating to the fire point relationships between the flow rate of spray reaching the fuel and the resulting steady temperature near the fuel surface for sprays of different drop size; the spray was applied in a downward direction.[11] The curves obtained separate tests in which extinction took place by cooling from tests in which no extinction occurred. Although for both fires the critical rate was approximately proportional to the drop size, for a given drop size the rate was slightly less for the 30 cm diameter fire than for the 11 cm diameter fire. If radiation controlled the critical heat transfer rate, the critical flow rate for extinction would be expected to be 100 per cent greater for the 30 cm diameter fire but, if convection controlled, about 15 per cent smaller. The difference between the points for tests with horizontal application of spray to a kerosine fire 30 cm diameter and for hand application of spray to a fire 243 cm diameter may be accounted for by the different drop sizes of the spray. If radiation controlled the critical heat transfer rate, a ratio of 2.5 would be expected in the critical rate. After taking into account the probable effect of drop size there was in fact no difference in the critical rates. However, the critical rate for horizontal application for the 30 cm diameter fire was about half that for vertically downward application. A possible reason for this difference is that the spray pushed the flame sideways; as a result the drops did not become heated in the flame and had a greater cooling capacity when they reached the liquid.

The effect of radiation is likely to be much greater with pool fires in which the burning surface can "see" all the flame than with other fires. Since radiation from the flame of the fuel being extinguished has a minor effect on the critical rates for extinguishing pool fires by cooling, it is reasonable to neglect it for other fires.

The effect of drop size on the critical rate follows from the fact that the drops are in the liquid for only a limited time and their size is a controlling factor in the rate at which heat is transferred. It would be expected [11] that the heat transfer from the body of the liquid to the drops would be proportional to $D^{-1/3}$. However, the transfer of heat from the surface of the liquid to the interior would be expected to increase as the eddy conductivity caused by the turbulent eddies set up by the motion of the drops on the liquid; this is estimated to increase as $D^{1/3}$. The actual effect of drop size results from a combination of these two factors.

The driving force for heat transfer in the liquid may be represented by ΔT, the difference in temperature between the surface of the liquid under critical conditions (for practical purposes the fire point) and the temperature of the drops (for practical purposes the ambient temperature). It would, therefore, be expected that for a given drop size the critical rate should be inversely proportional to ΔT. Measurements of critical rate indicated in Figure 2 for downward application of spray to a 30 cm diameter transformer oil fire and hand application of spray to a 243 cm diameter fire support this.

Extinction Time for Pool Fires

As long as the flow rate of spray is greater than the critical value, then extinction will take place in a time which depends on the amount of heat present in the burning fuel which must be removed by the spray to reduce the surface temperature to the fire point. With most pool fires this heat content increases as the preburn time increases up to about 10 to 20 minutes but for hot zone forming liquids, e.g., heavy fuel oils, this heat content may increase indefinitely. Experiments [12, 13] on extinction of pool fires using fixed nozzles sited vertically above the burning liquid (see Plate 1) and for hand extinction of an 8 ft diameter fire gave the following relationships:

Fixed nozzle

$$t = 6800\ (D/M)(Y/\Delta T^{1.75}) \qquad (16)$$

Hand application for 8 ft diameter vessel

$$t = 121{,}600\ D^{0.85}\ F_1^{-0.68}\ Y^{0.39}\,\Delta T^{-1.67}\ L^{-0.33} \qquad (17)$$

where

D is the mass median drop size of the spray in mm
M is the flow rate of spray in gallons $ft^{-2}min^{-1}$ *
Y is the preburn time in minutes
ΔT is the difference between fire point and ambient temperature °C
F_1 is the total flow to the fire in gallon/min
L is the total number of tests carried out by the operator
t is the extinction time, sec

The influence of drop size and of flow rate of spray are as may be expected from considerations of heat transfer between the liquid and the drops. The influence of ΔT, however, is greater than may be expected from a heat transfer basis alone. A reason for this may be that the higher the value of ΔT the greater was the temperature of the surface of the liquid in excess of 100°C, particularly when application of water spray commenced, and the greater was the steam formation in the liquid during the extinction process. This steam probably accelerated the cooling of the liquid surface by stirring the bulk liquid. An increase in the preburn time increased the extinction time, although to a lesser extent for hand application than for fixed application. The experience of the operator as expressed by the factor L in equation 17 was also an important factor in the extinction of fire by hand application.

Both the equations (16) and (17) presume that the bulk of the spray reaches the burning liquid. If the downward thrust of the spray was less than the upward thrust of the flames and if the flames could burn vertically upwards against the spray, then the extinction time was prolonged. In this connection it is noteworthy that the size of the flames in the first few seconds of application were usually considerably greater than the size before application of spray, as indicated in Plate 1. This was due to the sputtering of fuel into the flame. However, for tests on fires 3 ft and 4 ft diameter in a large roofless structure, the ambient wind was usually sufficient to blow the flames away from the upright position and the force of the spray was not a significant factor in extinction of the fire, if the spray was much wider than the fire. With hand application of spray to an 8 ft diameter fire there was no difficulty in enabling even fine sprays of low thrust to reach the burning liquid, since the fire could be approached on the upwind side and the spray applied directly to the base of the flames. A complicating factor in all these tests was the occurrence of splash fires with coarse sprays; burning fuel was splashed into the flame by the spray and a vigorous flame maintained even though the liquid was cooled well below the fire point. If, when a splash fire was established, the spray were taken away the fire often went out.

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* "gallon" refers to imperial gallon in this paper—1 imp. gal.=1.2 U.S. gal.

1 gm./min/cm² = 0.246 gpm/ft²

1gpm/ft² = 4.07 gm./min/cm²

Fires in Oil Running Over Metal Work

When sprays are applied to a pool fire which has been burning for some time, there is an initial upsurge of flame and the flames then reduce in size gradually within the extinction time. When burning liquids are flowing over a surface the liquid layer is very thin and the sensible heat in the liquid which needs to be removed is very small. Providing the flow rate of water spray is near the critical rate the flames are reduced in size almost immediately after turning on the water spray and thereafter are reduced in size much more slowly. This is illustrated in Plate 2 which shows a fire in transformer oil flowing over a test rig consisting of a bank of tubes 5 cm diameter. The rate of flow required to extinguish the fire in a given time depended on the preburn time in this case, since during the preburn period the tubes themselves were heated and acted as a reservoir of heat during the application of spray. The effect of the temperature of the tubes on the rate

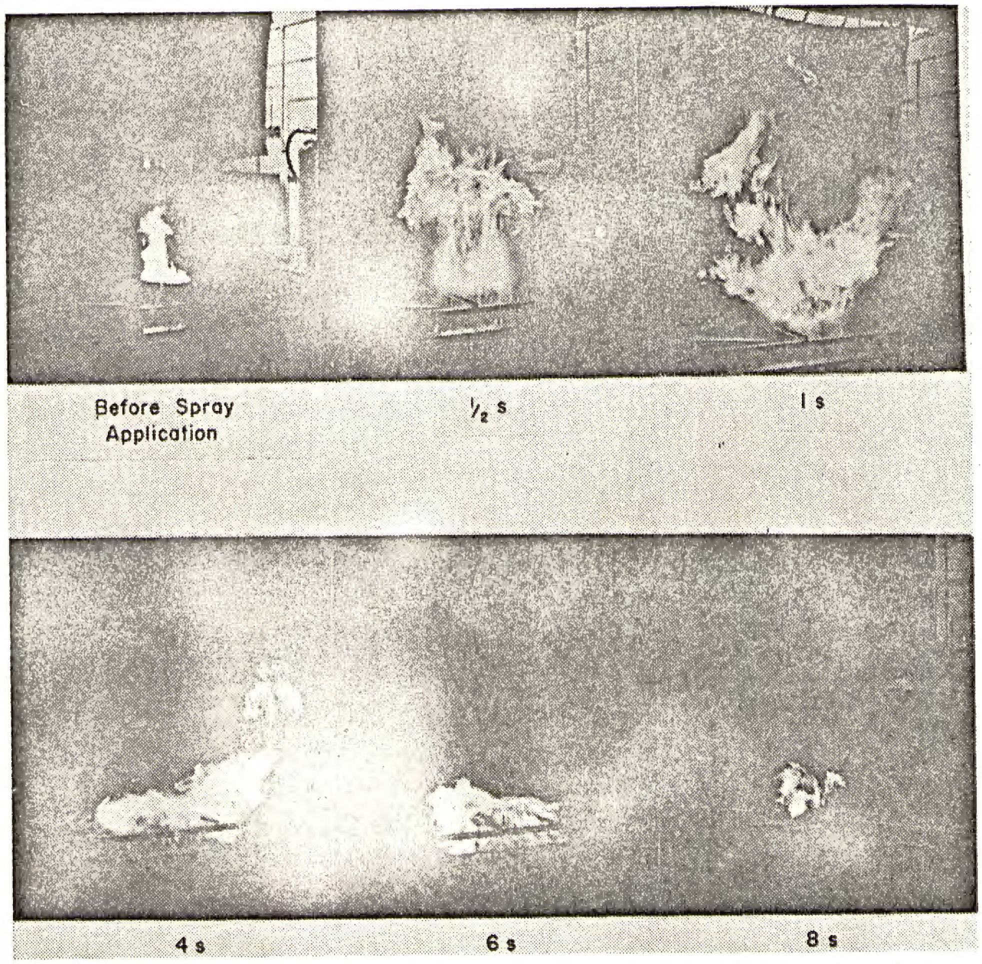
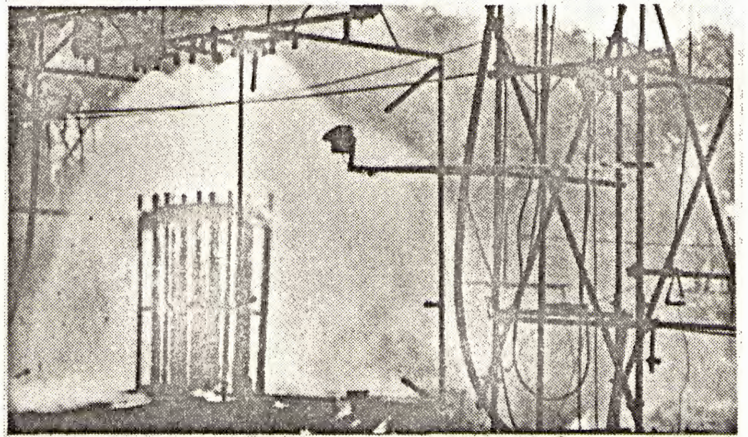
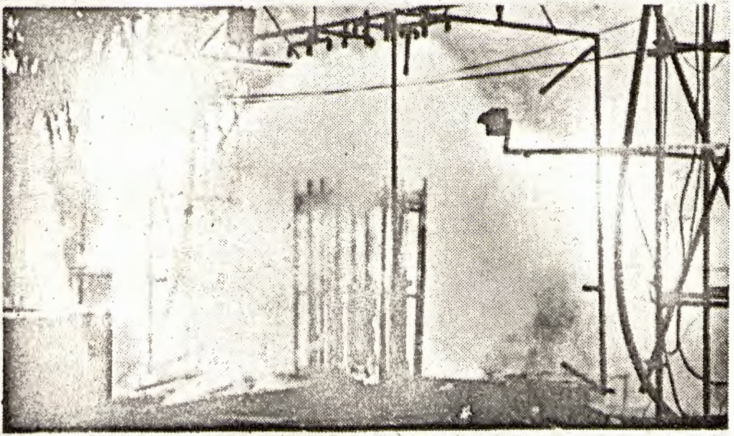


Plate 1. Extinction of fire in transformer oil by downward application of spray from fixed nozzle (extinction time 8.8 sec).

Application



5 s



30 s

Plate 2. Control of fire in transformer oil on a bank of tubes.

of flow required to control and extinguish the fire is given in Figure 3. The relationships in Figure 3 were obtained for sprays projected directly downwards from 5 ft above the point in the tube rig where oil was injected (6 in below the top), but tests in which the sprays were projected from a similar distance from the side of the

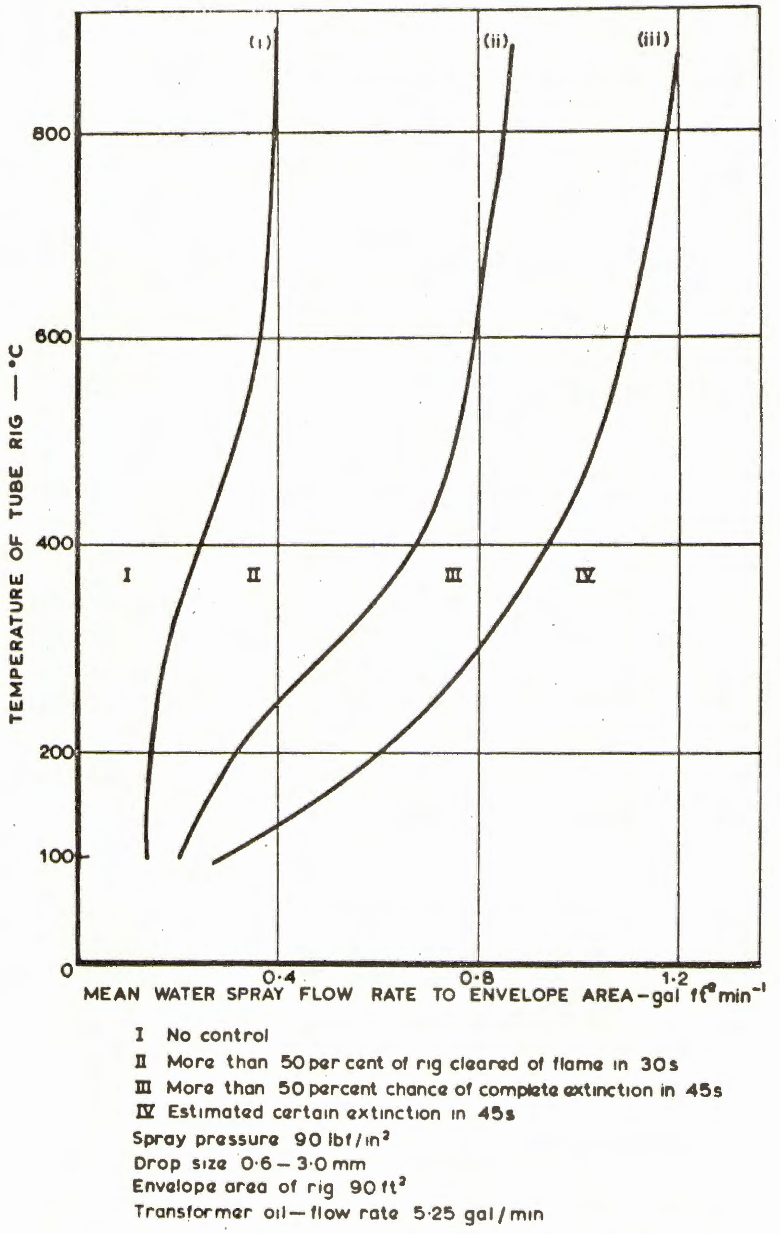


Figure 3. Control and extinction of oil fires on tube rig.

rig did not give significantly different results, nor was there any difference if the tube bank was horizontal rather than vertical. The drop size of the spray was found to have no significant effect in the range tested (mass median 0.6 to 3.0 mm); there was evidence, however, that an increase in drop velocity increased the efficiency of the spray [14] and the effect of the drop size may have been masked by the fact that the ratio of drop size to drop velocity was constant for the sprays referred to in Figure 3. The tests covered a wide range of ambient wind conditions. However, Figure 3 indicates that the critical rate for these varying conditions increased as the temperature of the tubes increased. These critical rates may be taken as lying between curves (1) and (3) in Figure 3.

A large number of tests have been carried out in the United States in which water spray has been applied to oil fires on sheet metal structures simulating transformers.[15, 16] A comparison between the results of these tests and those carried out on the tube rig in England has indicated that to obtain a given extinction performance under given conditions of nozzle pressure, oil fire point and preburn time, a mean flow to unit area of the envelope of the tube rig on the average 2.3 times as great as that to the large sheet metal simulated transformers was required. Equations (8) and (10) indicate that the ratios of critical heat transfer rates to the surface would be about 1.8, the expected ratio of flow rates to the envelopes of the two risks would be between 1.8 and 2.8. If the wind velocity controlled the critical heat transfer rate the expected ratio would be greater. It is unlikely that the condition for heat transfer to the drops in the oil would differ between the oil running down tubes and a vertical surface although it would be expected that the accessibility of spray to the surfaces would be easier for a flat surface than for a nest of tubes. Broadly, however, the comparison does support the theoretical approach.

Critical Rate for Extinction of a Wood Fire

Bryan [17] has measured the critical rate for a wood fire consisting of 2 inch square pieces with a total surface area of 80 ft^2. The minimum rate at which he obtained extinction with water was 0.16 g/min corresponding to a rate of 0.01 $\text{g/cm}^2\text{/min}$. Bryan concluded from other observations that extinction was by cooling the wood. Under the conditions he used it may be assumed that the water was entirely vaporized; this would correspond to a heat transfer of 0.1 $\text{cal/cm}^2\text{/sec}$ at the wood surface. From information on the heat of combustion of wood volatiles and assuming that critical criteria as described above may be applied to burning wood, it may be estimated that 0.8 $\text{cal/cm}^2\text{/sec}$ would have been transferred from the flame to the wood surface under critical conditions. The difference between the measured and estimated values might be taken to indicate that a substantial heat transfer, of the order of 800 cal/g, was required to cause the evolution of sufficient volatiles for combustion.

Direct Extinction of Flame

To examine the relevance of the theory developed above it is necessary to have an estimate for X, the heat transfer capacity for the sprays. These estimates were obtained using equation (18), a modification of the Ranz and Marshall relationship for heat transfer from gases to drops [18] which was found to hold for water drops evaporating in a bunsen flame.[19]

$$\frac{hD}{k}=\frac{1}{1+0.4\beta/\lambda}\left[2+0.6\left(\frac{c\mu}{k}\right)^{0.33}\left(\frac{V_D D\rho}{\mu}\right)^{0.5}\right] \qquad (18)$$

c, μ, k, ρ specific heat, viscosity, thermal conductivity, density in boundary layer;
D drop size, V_D drop velocity relative to gas stream;
h heat transfer coefficient;
β enthalpy increase per unit mass of vapour between surface and flame temperature;
λ heat required to vaporize unit mass of the liquid.

In estimating X it was assumed that the concentration and velocity of the drops in the flame were the same as in the approaching spray, and that the contribution of the individual fractions of the different drop sizes could be added. Since the surface area of drops of size D present per unit volume of space through which the drops are passing is proportional to $M_D/V_D D$ where M_D is the flow rate per unit area, it follows from equation 18 that

$$X \propto M D_r^{-(1.5 \text{ to } 2.0)} V_r^{-(0.5 \text{ to } 1.0)} \qquad (19)$$

where M is the total flow rate per unit area, D_r and V_r are a representative drop size and drop velocity.

The extinction of fire by water spray by extinguishing the flame has been studied with fires in kerosine, petrol, and benzole is a vessel 30 cm diameter.[20, 1] Extinction of the flame differed from extinction by cooling the fuel in that there was a sudden clearance of a comparatively large volume of flame which led to extinction.

When the spray was applied in a downward direction the flames of the petrol and kerosine fires were not extinguished unless the downward thrust of the spray was greater than 60 and 40 dynes/cm², respectively. These forces are comparable with the upward force of the flames before the spray was applied. With sprays of greater downward force the flames were extinguished as long as the heat transfer capacity of the spray was greater than about 0.15 cal/cm²/sec, and as long as the preburn time was not very short. The above value is intermediate between those expected from equations (12) and (13), if I is taken to refer to the upward moving flames before spray application.

For a given type of spray the most important factor in the heat transfer capacity is the drop size of the spray (equation (19)) and in the thrust of the spray the rate of flow per unit area of the fire. If the drop size of the spray is plotted against the critical rate of flow for extinction at that drop size, the above phenomenon of critical thrust manifests itself as a flow rate below which the fire is difficult to extinguish with sprays of any drop size. Critical flow rates for extinction of a flame have been plotted in this way in Figure 4 for the kerosine and petrol fires; points for extinction and nonextinction are shown for the petrol fire. For comparison critical flow rates for the extinction of the kerosine fire by cooling the liquid have been included. Similar relationships obtained by the author for sprays produced by hypodermic needles acting on a kerosine fire 11 cm diameter,[21] and by the National Board of Fire Underwriters for sprays acting on a petrol fire 15 cm diameter [22] have been given elsewhere. The critical flow rate below which extinction was difficult was smaller in both cases than those shown in Figure 4 for the 30 cm diameter fires. This may be mainly attributed to the smaller dimension of the fires and the resulting smaller upward force of the flames, but different conditions of test and different patterns of spray at the fire area also probably played a part. Extinction of the flame has been found to be easier if the peak concentration of the spray is near or even outside the edge of the vessel, since after a clearance of part of the flame, the remnants of flame from which a flash back may occur are at the edge.[20] This phenomenon may account also for comparatively low flow rates for extinction of flame reported by Y. Yazi.[23]

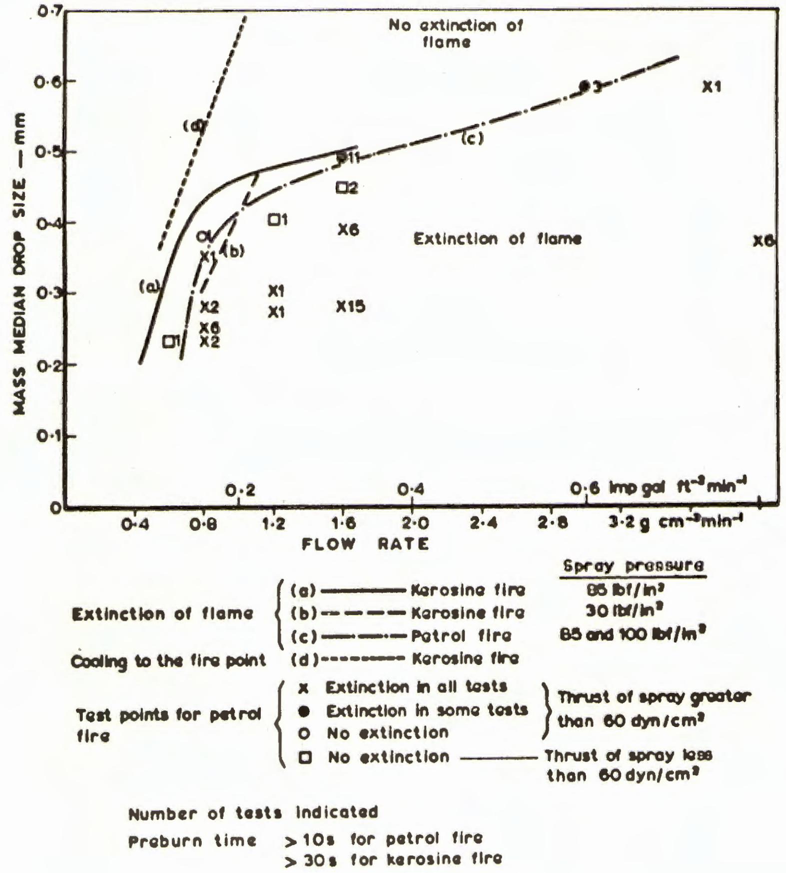


Figure 4. Critical flow rates for extinction of kerosine and petrol fires 30 cm diameter, downward application of spray.

During the tests the flames were usually wild with frequent partial clearance and flash backs. However, with petrol and benzole fires when the preburn time was very short (less than 10 sec) and when sprays with high downward thrust were used, the spray pushed the flame immediately into a flat flame close to the liquid surface which was very difficult to extinguish. The appearance of the flame depended on the drop size and heat transfer capacity of the spray. A spray with a value of X equal to 0.44 cal/cm^3/sec gave thin blue flames near the inside edge of the vessel; with a value of X of 0.14 cal/cm^3/sec, a belt of yellow flame covered the whole vessel. Flames stabilized close to the liquid surface were also obtained if spray were applied to the surface at an angle less than 30° to the horizontal. It was estimated that the value of I for flames stabilized in this way was about 2.5 cal/cm^3/sec. It would, therefore, be expected that value of X equal to about 0.5 to 1 cal/cm^3/sec would have been required to extinguish these flames reliably.

Regression analyses on the extinction time for the kerosine and petrol fires [20] indicated that for sprays with a given value of X the entrained air current had a powerful effect on the extinction time. This effect was much more powerful than might be expected from a relation such as is given in equation (15). This may be attributed to two reasons. Firstly, the entrained air current helped to present the spray to all parts of the flame; associated with this reason it also helped the spray penetrate to the burning liquid, cooling the latter and thus reducing the size of the flame. Secondly, the entrained air current tended to blow away the thick vapour zone which was usually established after burning for about 10 seconds and thus rendered the flames unstable.

Extinction of Fires in Rooms

Tests have been carried out by many authorities on the extinction of solid fuel fires in rooms. It is not yet clear, however, whether these fires are more efficiently controlled by cooling of the fuel or by the formation of steam which cools the flames.

Kawagoe [24] has found that the rate of burning in room fires is, on the average, directly proportional to the ventilation, and the constant of proportionality indicates that the ratio of air to fuel volatiles is the stoichiometric ratio. When fires in rooms are attacked with sprays from an opening in the wall, then additional air would be entrained into the room comparable with the normal ventilation rate through the opening. Under these conditions it may, therefore, be expected that the fire is burning with excess air when extinction is commenced. The critical amount of steam required to smother the flames would then be governed by equation (14). It may be estimated using equation 14 that if steam is obtained by the impact of spray on the burning surface, the critical flow rate of water to form sufficient steam to extinguish the flames is 10 to 15 times greater than that found by Bryan [17] to be necessary to extinguish a wood fire by cooling. However, conditions in practical fire fighting may still frequently be such that steam extinction would require the use of a smaller total quantity of water.

From the intrinsic nature of extinction of the flame by steam and extinction by cooling the fuel, the qualitative effect of various factors on the efficiency of control (i.e., critical flow rate and quantity of water required) may be deduced. These effects are compared in Table 1.

Available test results have been summarised by Hird *et al.*[25] but owing to the lack of a systematic investigation of the above factors, at least on the full scale, it is not possible to give a firm opinion on the extinction mechanism. The amounts of water used to control the fires varied from 2 to 15 gal/1000 ft^3. The above workers also carried out a comprehensive series of tests in which sprays of varying pressures from 80 to 500 lb/in^2 and with flow rates from 5 to 25 gal/

7GAL. 17GAL.

min were used against a standard fully developed fire in a room of volume 1750 ft^3. The quantity of water required to control and extinguish the fire was 7 and 17 gallons, respectively, and within the variance of the results, was independent of the pressure, the flow rate and whether jets or sprays were used.

TABLE 1

EFFECT OF VARIOUS FACTORS ON CONTROL OF ROOM FIRES BY COOLING AND BY STEAM FORMATION

Factor	Cooling the Fuel	Steam Formation
1. Increase in preburn time.	Critical flow rate increased somewhat. Quantity increased approximately in proportion to preburn time.	No effect.
2. Decrease in ease of access of water spray to burning surfaces.	Quantity increased.	No substantial effect if walls are hot.
3. Increase in the fraction of incombustible surface present; total area of combustibles remaining the same.	Critical flow rate increased (due to radiant heat falling onto burning surfaces).	No substantial effect if incombustible surfaces are hot.
4. Increase in ventilation.	No effect.	Critical flow rate and quantity increased.
5. Linear dimension d.	Critical rate proportional to d^2.	Critical rate proportional to $d^{5/2}$.

Use of Water Sprays in Practical Fire Fighting

The following broad principles may be put forward on the basis of the experimental work carried out at the Joint Fire Research Organization and elsewhere.

1) In general the best way of putting a fire out is that spray should be made to reach and cool the burning fuel. The rate at which the spray need absorb heat in doing this is generally far less than the rate of production of heat by the fire. Experimental results are available giving information on critical rates for a few systems. On the basis of equations (7) to (10) or other relationships developed in similar manner, it is possible to extrapolate these results to other systems as long as heat transfer between the spray drops and the fuel behaves in a similar way. Perhaps the most important consequence of equations (7) to (10) is that critical flow rates per unit area for a given type of system should not increase as the scale increases; under some conditions they may in fact decrease.

2) If sprays are applied downwards to a fire with a flame moving steadily upwards, then for the bulk of the water to reach the burning fuel the downward thrust of the spray should be comparable to the upward thrust of the flame. These two thrusts may be calculated as indicated in the paper. If the sprays are applied laterally or by hand from the windward side of a fire, a much smaller thrust is necessary.

3) Water sprays in current use are unreliable in extinguishing a fire that cannot be extinguished by cooling the fuel. However, extinction may frequently be obtained with available fire sprays produced by pressure nozzles (mass median

drop size 0.2–0.4 mm) particularly if there is no change to stable burning in the air current of the spray. When extinction is not obtained, a large reduction in the size of flame may be achieved.

4) For most of the fires for which water sprays are useful, e.g., fires in solids and fires in high boiling liquids flowing over solid surfaces, the drop size of the spray is not usually an important practical factor. However, for fires in deep pools of high boiling liquids the efficiency of the spray increases as the drop size is reduced.

5) The pressure at a nozzle influences a number of factors that affect the extinction of fire. However, where sprays may be reliably used for extinction of fire, an increase in pressure about 100 lb/in^2 with a given flow rate of spray has not been found to confer any extra efficiency on the spray, providing that the water can reach the seat of the fire. The choice of pressure for a pump, therefore, depends rather on operational factors, in particular the length and diameter of hose line and the flow rate which it is desired to give the operator, than on intrinsic efficiency of the spray in fighting the fire. It should be added here that an increase in flow rate, or a decrease in cone angle, has a greater effect on increasing the throw of a spray [26, 27] than an increase in pressure, and that an increase in pressure has a smaller effect on reducing the drop size of a spray when the pressure is above 100 lb/in^2 than when it is below 100 lb/in^2.

Finally, it is instructive to compare quantities of water which have been found necessary to extinguish experimental fires with those actually used in practical fire fighting. For fires in rooms it has been found experimentally that about 10 gallons per 100 ft^2 of floor area is required and, according to the drop size of the spray, from 5 to 15 gallons may be used to extinguish a gas oil pool fire of the same size. According to information provided by Mobius [28] the minimum quantity of water to extinguish fully developed room fires under operational conditions is about 100 gallons. Thomas [29] made an analysis of the amount of water used at large fires based on the number of pumps called to the fire. It may be estimated from this analysis that for large fires approximately 1000 gallons of water are used for 100 ft^2 of the fire. Thus, either wastage or operational difficulties in applying water to fires is by far the most important factor governing the amount of water used, and this would appear to be a direction where a substantial research effort is worthwhile.

APPENDIX

Thrust of Flames and Sprays

Thrust of Flames

A complete analysis of the movement of flame has not yet been made, but as this movement is controlled by the buoyancy of the flame, it would be expected that the upward thrust would be proportional to the flame height. Analysis of buoyant columns rising from small heat sources indicate [30, 31] that the thrust at the centre of the column is given by

$$\rho_z V_z^2 = 1.5 \text{ to } 2.0(\rho_0 - \rho_z)gz \qquad (20)$$

where ρ_z is the density of the column at a point z above the source and ρ_0 is the density of the ambient air.

In Figure 5 some calculated thrusts based on measurements of the upward velocity of flames and the flame temperature [9] are plotted against the buoyancy

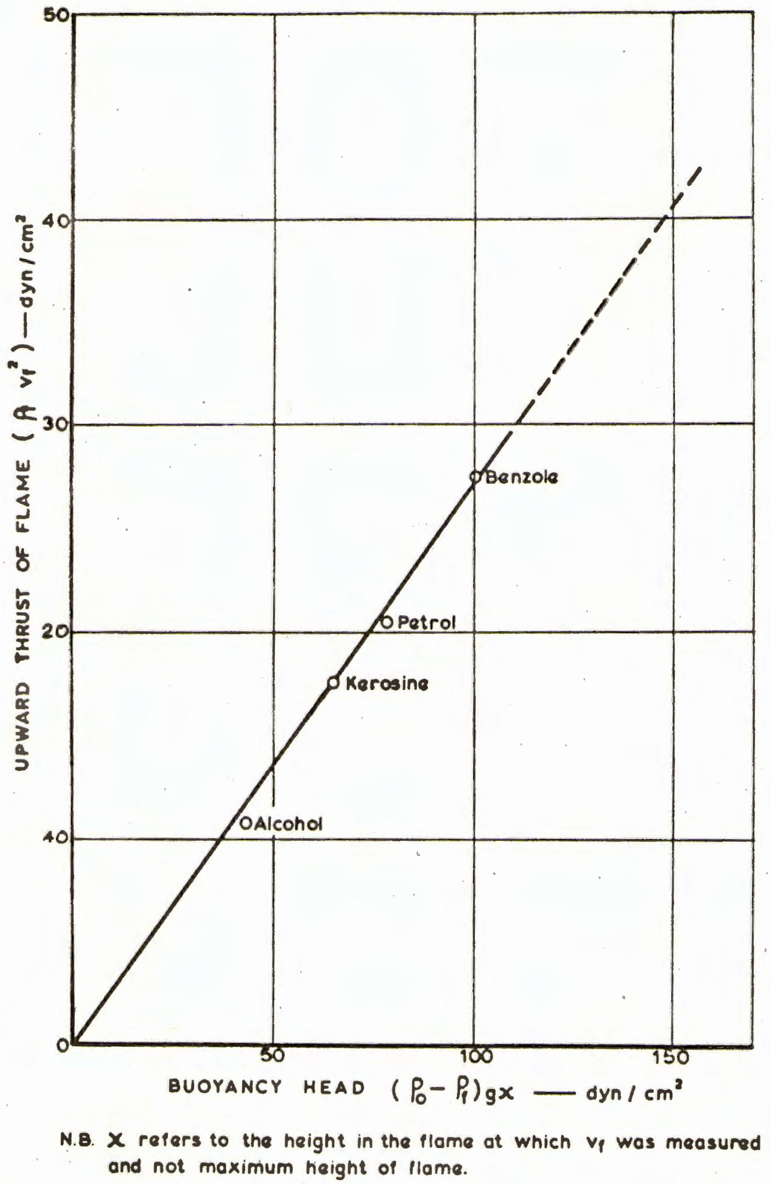


Figure 5. Relation between upward thrust of flames and buoyancy head—freely burning liquid fires 30 cm diameter.

head $(\rho_o - \rho_f)gx$ for fires in different liquids burning in a vessel 30 cm diameter; ρ_f is the density of the flame and x the height of the point in the flame for which the thrust was estimated. The velocity measurements were made by observing the upward motion of the top of the flame and eddies at the side of the flame as recorded by a cine camera; the calculation of the thrust was made for the mean time of burning and the mean height of the flame at which measurements were made. The temperature on which ρ_f was based was a mean temperature across the flame as measured by the Schmidt method. The straight line relation (equation 21) obtained

$$\rho_f v_f^2 = 0.27(\rho_o - \rho_f)gx \tag{21}$$

confirms the proportionality expected and indicates that thrust is independent of the nature of the burning fuel. The constant, however, is considerably less than would be expected from equation (20).

On the basis of equation (21) it is possible to calculate the upward thrust of the flame knowing the flame heights. The latter has been related by Thomas to the rate of burning and the main dimension of the fuel layer for solid fuel fires.[32]

Thrust of a Spray

A spray after leaving a nozzle very soon becomes a suspension of drops moving in an air stream. The air stream is generated by the transfer of momentum from the drops and is of importance in determining the velocity of the drops and the motion of the spray as a whole. The total forward thrust of a spray may be measured by the reaction at the nozzle. Measurements of the entrained air current of sprays directed downward from a number of nozzles[33] have shown that for sprays of mass median drop size less than 1.0 mm, the bulk of the thrust is transferred into momentum of the airstream by the time the spray has reached a plane 6 ft below the nozzle; most of the remaining thrust may be accounted for by momentum of the drops moving at the velocity of the air stream. For very coarse sprays (mass median drop size 1.5–3.5 mm) about 50 per cent of the initial thrust is converted into momentum of the air current.

The reaction of a jet is the product of the flow rate and the velocity at the nozzle, both these factors being proportional to the square root of the pressure. The reaction of a spray nozzle, however, is less than the product mentioned above due mainly to the presence of lateral motion in the spray. Figure 6 shows the ratios of the reaction of a number of spray nozzles to that of corresponding perfect jets and indicates the extent to which the reaction is reduced as the cone angle increases and as the spray pattern becomes less peaked in the centre. Knowing the reaction at the nozzle, an approximate estimate of the mean forward thrust in a plane is given by R/A, where A is the cross-sectional area of the spray in the plane, and if the assumption is also made that the thrust has been entirely converted into movement of the entrained air stream then the air velocity v_a may be given by:—

$$\rho_0 v_a^2 = \frac{R}{A} = a_1 \rho^{0.5} \frac{F}{A} \tag{22}$$

where

a_1 is a constant depending on the nozzle
P is the nozzle pressure
F is the flow rate

Equation (22) gives, of course, a mean value of v_a. There is evidence, however, that the distribution of entrained air velocity in a plane perpendicular to the spray axis, when both entrained air velocity and distance from the axis are expressed in dimensionless terms, is approximately independent of the distribution of flow rate within the spray. In addition the distribution of the entrained air

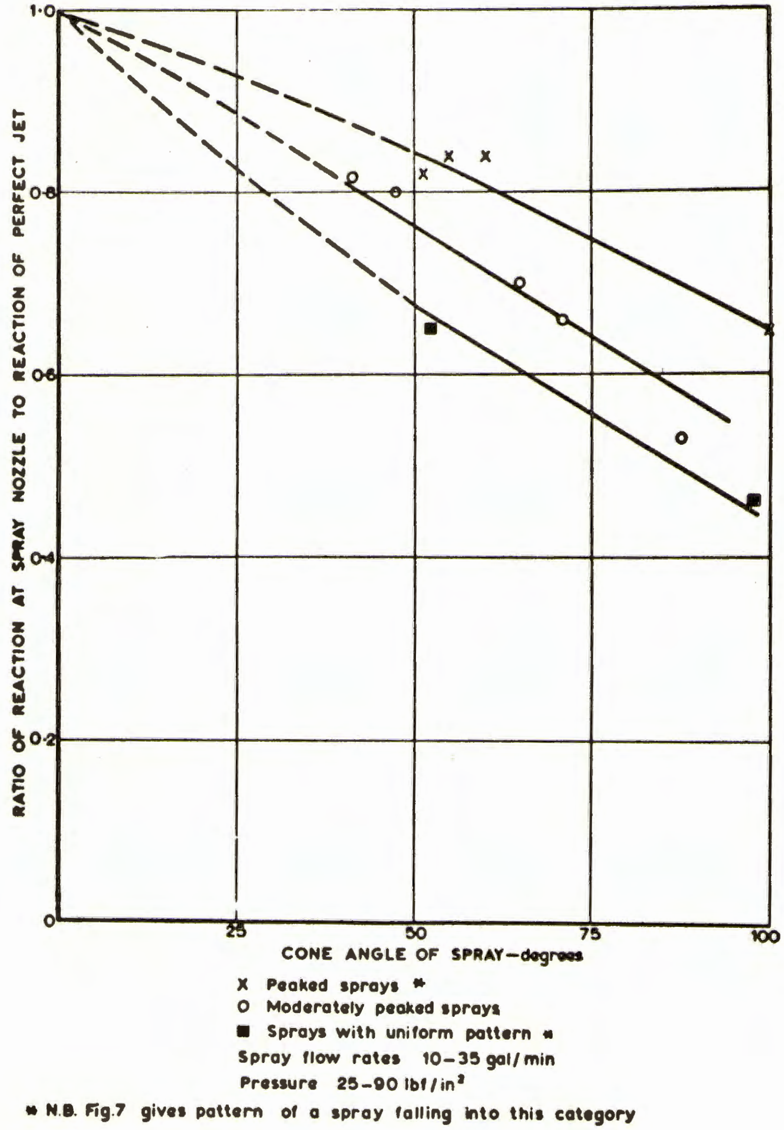


Figure 6. Reaction of spray nozzles.

velocity is similar to the distribution found in a turbulent air jet. These points are illustrated in Figure 7 which shows an almost identical distribution of the entrained air for sprays with widely different spray pattern. The radii of the sprays referred to in this figure are those radii where the entrained air velocity and water flow rate were respectively 1/100 of the values in the centre of the spray.

For sprays with a similar pattern over a given area it follows from equation 22 that for a given part of the spray

$$v_n \ \alpha \ P^{0.25}M^{0.5} \qquad (23)$$

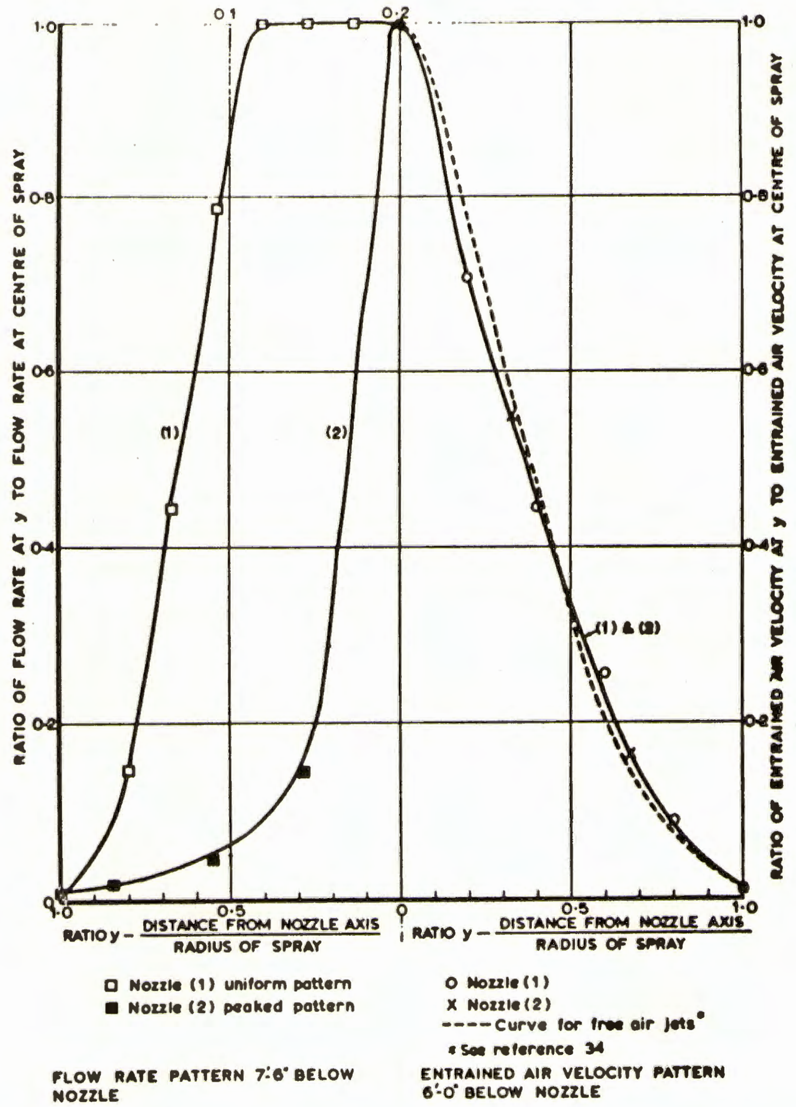


Figure 7. Comparison of distribution of entrained air current and water flow in sprays from given nozzles.

where M is the local flow rate per unit area. A relation similar to this has been found to hold for a wide range of values of P and M for sprays projected downward from a battery of impinging jet nozzles.[26]

Symbols

a_1 a_2 a_3 b	Constants
c	Specific heat in gas boundary layer
d	Linear dimension
g	Acceleration due to gravity
h	Heat transfer coefficient
k	Thermal conductivity
l	Linear dimension
M_{og}	Concentration of oxygen in the air
$\dot{m}''$	Rate of burning per unit area per unit time
r	Stoichiometric ratio (weight of air/weight of fuel)
t	Time
v_a, v_D, v_{BO}	Velocity of entrained air, of spray drops, and velocity to blow out flame
v_f, v_z	Upward velocity in flame, in buoyant hot column
x	Height of flame
z	Height of buoyant column
A	Cross sectional area of spray
B	Transfer number (after Spalding)
D	Drop size
F	Total flow rate of spray
H	Heat of combustion
I	Intensity of combustion in flame
M, M_D	Total flow rate of spray per unit area, flow rate of drop size D
L	Number of tests carried out by operator
P	Pressure to produce spray with pressure nozzles
Q, Q_c	Heat transfer to fuel surface per unit mass of fuel vaporized, critical value of Q
R	Reaction of nozzle
T_g, T_s	Gas temperature, surface temperature
ΔT	Difference in temperature between fire point and ambient
V	Volume of flame
W	Critical flow rate of water to extinguish flame by steam formation
X_1, X_2, X_3	Critical values of X
X	Heat transfer to spray within unit volume of flame in unit time
Y	Preburn time
Z	Rate of fuel consumption in fire
α	Thermal diffusivity
β	Sensible heat of steam or vapour
γ	Heat taken up as sensible heat in fuel per unit area of surface per unit time
λ, λ_f	Heat required to vaporize unit mass of liquid, of fuel
μ	Viscosity in boundary layer
$\rho, \rho_f, \rho_0, \rho_2$	Density in boundary layer, in flame, ambient air, in buoyant column
T_c	Thrust of spray
γ_c	Critical value of γ

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Basic Conclusions of Rashbash paper.

Liq. pool fires

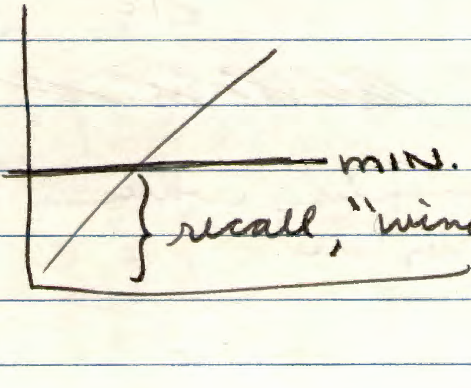
Must be heat transfer from flame to liq. ∋ vaporization sufficient to sustain Comb.

Radiation predominates in lq. pool fires. As containers get larger, hot container walls giving heat as ~~Radiation~~ convection + conduction mean less and less.

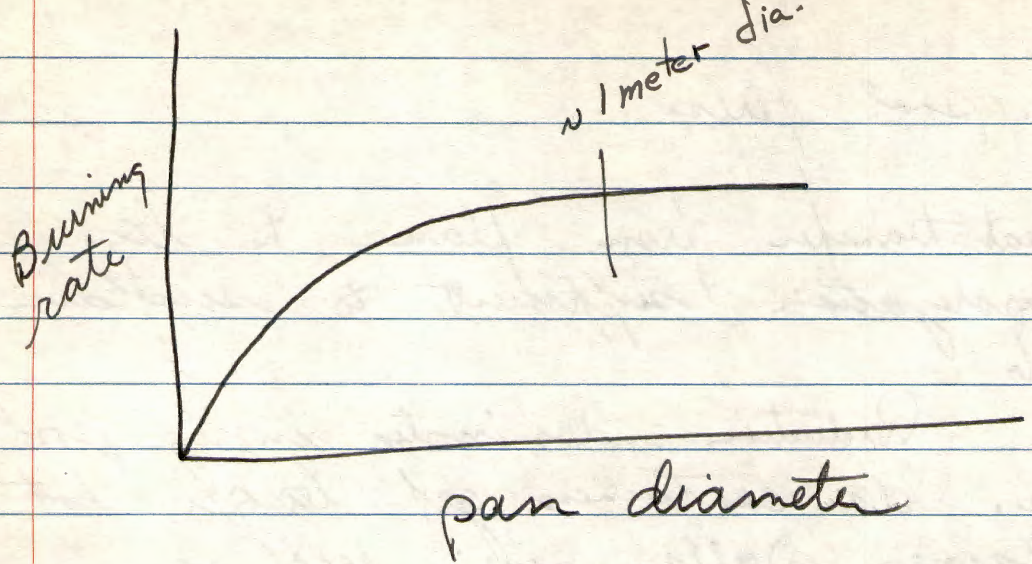
PG 30 But As you cool, convection takes over ??
↳ middle last ¶

PG 32

$$\gamma_c \propto \frac{\sqrt{v_w}}{\sqrt{d}}$$



} recall, "wind isnt sufficiently strong" to effect



PG. 32. 23%

can perform heat balance of flame

heat goes: back to fuel
up hot gas col.
radiation
etc.

eg. 7, 8, 9, + 10 ~~should be~~
→ remember where + what they are.

PG. 35 Item #1, cooling the fuel.

German Paper - Redusch Water Drops

Eq. 9

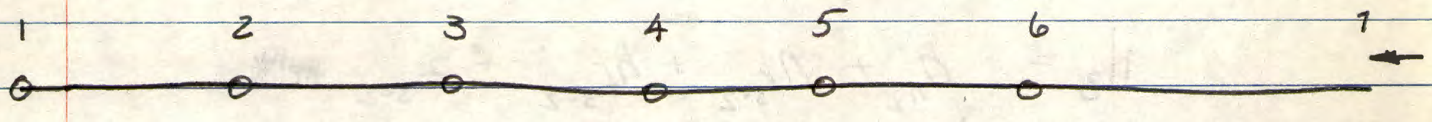
Says. .35 mm most favorable drop size.

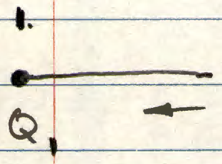
Compares well with eq. # 7 of Rasbash.
↳ + FIG. # 2 giving .345mm.

Also NBFU came up with .3mm.

→ read

Ch A — hydraul. calc. of Sprk. sys.
+ ditto — Inter. & hyd. of Sprk. sys.
↳ look over





All of energy after pt 2. will be expended, completely into velocity head out of orifice # 1.

e.g. assign 15 gpm from # 1
find it would take certain pressure to get 15gpm. e.g. ~ 18.48 ft water.

assign Q_1
$H_1 = 18.48'$ = TOTAL HEAD from table

$h_{f_{2-1}}$

$H_2 = H_1 + h_{f_{2-1}} + Z$

h_{n_2} = head causing flow at 2 = (static pressure head)
also = h_p
later notation

$h_{n_2} = H_2 - h_{v_{2-1}}$

Eq. 3

$$H_3 = \underbrace{h_{n_2} + h_{v_{3-2}}} + h_{f_{3-2}} + z_{3-2}$$

$$h_{n_3} = H_3 - h_{v_{4-3}}$$

~~#~~ To find pressure head @ 9

TOTAL HEAD = $H(9) = 76.74'$

#41 $h_v(9-8) = 5.89'$

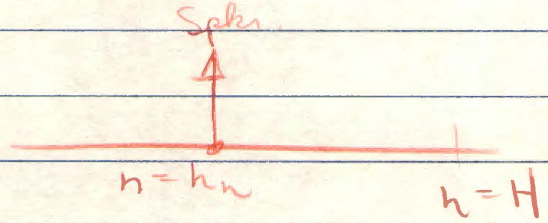
$\therefore h_{p(9)} = 76.74' - 5.89'$

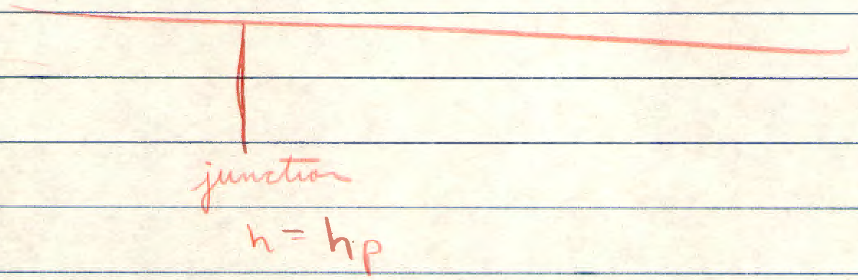
Problem

1. Br. Line
Ord. Haz. schedule for pipe
8 heads
$Z = 0$
$L = 10$ ℄ to ℄.
$Q_1 = 30$

A20

$Q = k\sqrt{h}$





if (1) + (2) are two different conditions

$$Q_{(9)_1} = K_{(9)_1} \sqrt{h_{p(9)_1}}$$

$$Q_{(9)_2} = K_{(9)_2} \sqrt{h_{p(9)_2}}$$

$$\frac{Q_{(9)_2}}{Q_{(9)_1}} = \frac{K_{(9)_2} \sqrt{h_{p(9)_2}}}{K_{(9)_1} \sqrt{h_{p(9)_1}}}$$

$$K_{(9)_2} = K_{(9)_1} = 24.3$$

$$K = \frac{Q}{\sqrt{h}} = \frac{gpm}{(Ft_{H_2O})^{1/2}}$$

Say we know from calculation of sample problem pg. 5

$$K = \frac{204.36}{\sqrt{70.85}} = \frac{Q_9 \text{ (Total)}}{\sqrt{h_9}}$$

$$K = 24.3$$

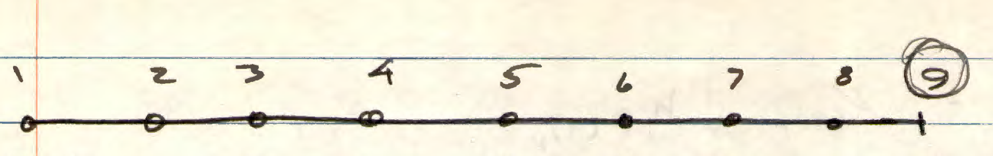
Can find out values of Q (demand) for different supply pressures.

Can Calculate K or use Ratio

$$\sqrt{\frac{157.29}{70.85}} \cong 1.5$$

note $\frac{30}{20} \cong 1.5$ also

∴ can apply ratio to each sprinkler - don't have to recalculate for each cond.



$$Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8 \cancel{+Q_9} = Q_9$$

or $$1.5(Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8) = Q_9 (1.5)$$

$$\frac{Q_{9(2)}}{Q_{(9)1}} = 1.5$$

(the K remains const. + cancells)
But Can't change physical PIPING

Can use pieces of an already calculated line for other lines to save time.

PROBLEM #2
Same 8 hd. br. line.
20 gpm @ sphr. #1.
slope positive @ 30°
(pushing water uphill)

PROBLEM #3
Q_1 = 15 gpm.
@ 10° slope. positive

420

$Q = K\sqrt{h}$ may be used on all HORIZONTAL lines (no slope) or on lines with insignificant slope.

① Orifice Equation

$$Q_{gpm} = \frac{\overset{19.54}{29.83}}{\sqrt{2.31}} C_d d^2 \sqrt{h_n}$$

$$Q_{gpm} = K_{orifice} \sqrt{h_n}$$

h_n = head causing flow

② Velocity Head.

$$h_{v_{ft.}} = Q_{gpm}^2 / 385 D^4$$

$$Q^2 = 385 D^4 h_v$$

$$Q = \underbrace{\sqrt{385 D^4}}_{K_v} \sqrt{h_v}$$

③ Friction Loss:

$$h_f = f \frac{L}{D} h_v$$

$$h_f = f \frac{L}{D}\left(\frac{Q^2}{385 D^4}\right)$$

$$Q^2 = \frac{385 D^4}{f\left(\frac{L}{D}\right)} h_f$$

$$Q = \underbrace{\sqrt{\frac{385 D^4}{f\left(\frac{L}{D}\right)}}}_{K_f} \sqrt{h_f}$$

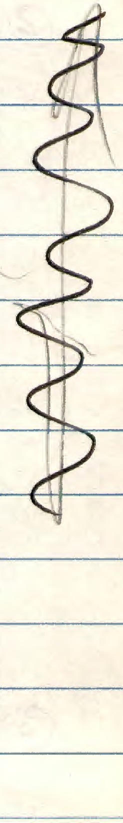
④ ELEVATION HEAD

~~$H_{ft} \Rightarrow$~~

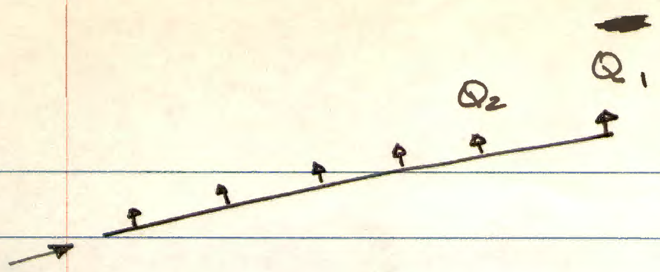
$Z_{ft} \propto$ change in elevation

Does NOT follow the general law as do other pressure calculations.

$$Q = K\sqrt{h}$$



Ordinary drainage requirements are not significant slopes.



$H_2 = h_f(2-1) + Z_{(2-1)}$

Z is here

$h_{w_2} = H_2 - (H_{v(2-1)})$

this accumulates all the way down the line.

PROBLEMS $\overset{\text{DUE}}{\wedge}$ MON.

Do the

problem #④ → 8 head la. line with $Q_1 = 15$ 0° slope
apply Ratios

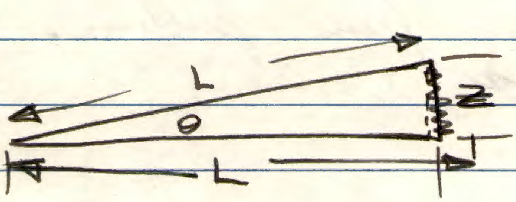
PROB #⑤ → $Q_1 = 15$ 20° slope.

PROB #⑥ → $Q_1 = 15$ 30° slope.

FPE 420

Problem #7 $10°$ neg. slope. } 15 gpm = Q_1
Problem #8 $20°$ neg. slope }

Flow from sloping Branch line



Same Length of line

Subscript l refers to level line
" s " " sloping "

$$\Delta Q = Q_s - Q_l$$

$$\Delta H = H_s - H_l$$

$$\frac{\Delta Q}{Q_l} = \frac{Q_s - Q_l}{Q_l} = \left(\frac{Q_s}{Q_l} - 1\right)$$

$$\frac{\Delta H}{H_l} = \frac{H_s - H_l}{H_l} = \left(\frac{H_s}{H_l} - 1\right)$$

$$Q_s = \left[1 + \left(\frac{\Delta Q}{Q_l}\right)\right] Q_l$$

$$H_s = \left[1 + \left(\frac{\Delta H}{H_l}\right)\right] H_l$$

$$K_l = \frac{Q_l}{\sqrt{H_l}}$$

$$K_\ell = \frac{\sqrt{\left[1+\left(\frac{\Delta H}{H_\ell}\right)\right]}}{\left[1+\left(\frac{\Delta Q}{Q_\ell}\right)\right]} \cdot \frac{Q_s}{\sqrt{H_s}} = \frac{1}{C} \cdot \frac{Q_s}{\sqrt{H_s}}$$

$$Q_s = C K_\ell \sqrt{H_s}$$

~ Knowing Q_s + H_s + K_ℓ from problems, find values of **C** ~

$Q_s = C K_\ell \sqrt{H_s}$

$K_\ell = 23.28$

Slope	$C = \frac{Q_s}{K_\ell \sqrt{H_s}}$
0	1.000
5	0.970
10	0.947
15	0.929
20	0.914
25	0.903
30	0.892

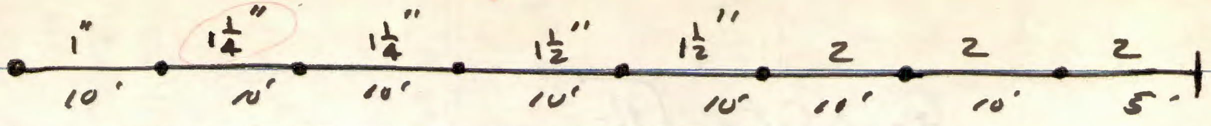
$Q_s = C K_\ell \sqrt{H_s}$

	5°	10°
$\frac{H_s(9)}{H_\ell(9)}$ =	1.189	1.37
$\frac{Q_s(9)}{Q_\ell(9)}$ =	1.060	1.111

It can be seen that slope makes lg. difference

Modified Pipe Schedule

changed this length



Problem

\# 9 $Q_1 = 15$ gpm 0° slope

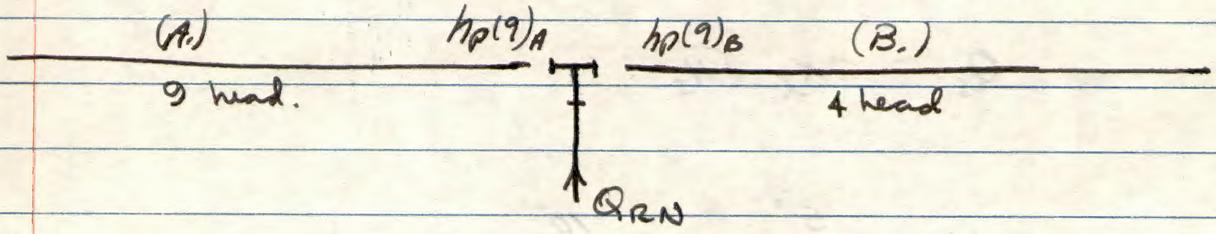
\# 10 $Q_1 = 15$ gpm 20° positive slope

Pg. 6 Ditto sheet Example # 2

line 9 from Bottom

$H(9) \Rightarrow$ should be $h_p(9)$

86 should be 70.5 feet of H_2O



Calculate A + B + find $h_p(9)_A \neq h_p(9)_B$

$\therefore$ hold $h_p(9)_A$ const + adjust B

$\Rightarrow h_p(9)_B = h_p(9)_A$ which MUST BE

GET:

$Q_{(9)A}$ $Q_{(9)B}$

corrected

$Q_{RN} = Q_{(9)A} + Q_{(9)B}$

$Q_{(9)A} = 209.4$

$h_{p(9)A} = 70.85$

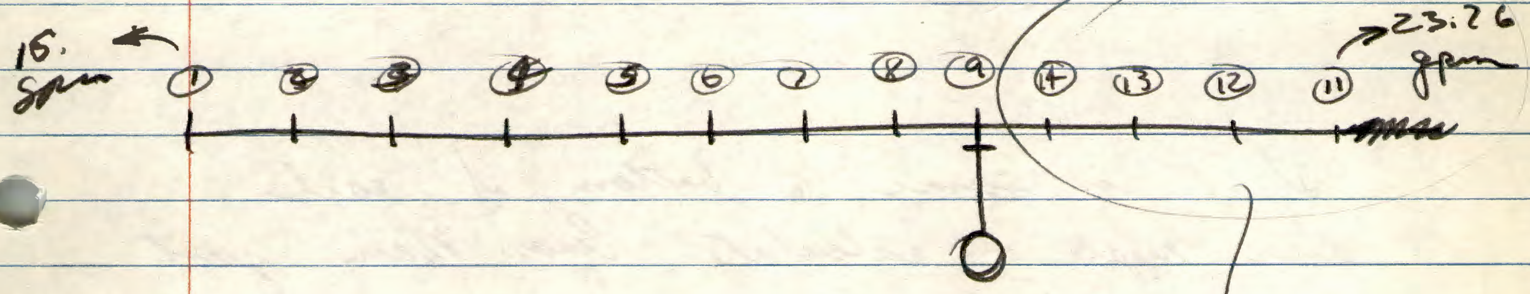
spacing 10' { Extra Hazard pipe Schedule
problem # 11 $Q_1 = 15$ gpm 0° slope
problem # 12 $Q_2 = 15$ gpm. 20° + slope

[illegible]

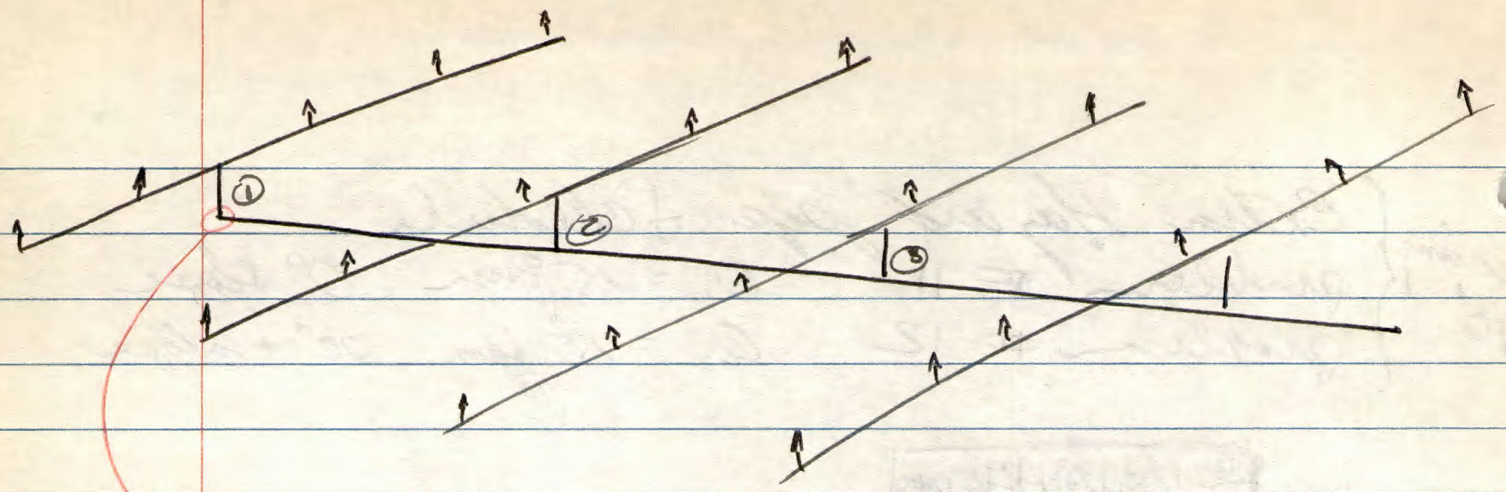
Joining Branch Lines

Pg. 6 of Ditto

(make corrections given in last class)



may want to re design for better Balance.



can find Q + H (TOTAL) + find K value at this point

$$K = \frac{Q}{\sqrt{H}}$$

If K is same @ bottom of each riser nipple — calculate Cross Main just as branch line -

get h_{n_2} + $Q_2 = K\sqrt{h_{n_2}}$

Go over pg. 7
also corrections

Item 23 — mult. 14.13 by 2 since there are 2 tees

Item 35 — 198.34 = 212.47
↑ should be

Bottom 85.9 now = 92

$$\frac{212.47 - 3.10}{2.31} = \frac{209.37}{2.31} = 90.6$$

Pg. 8 add.

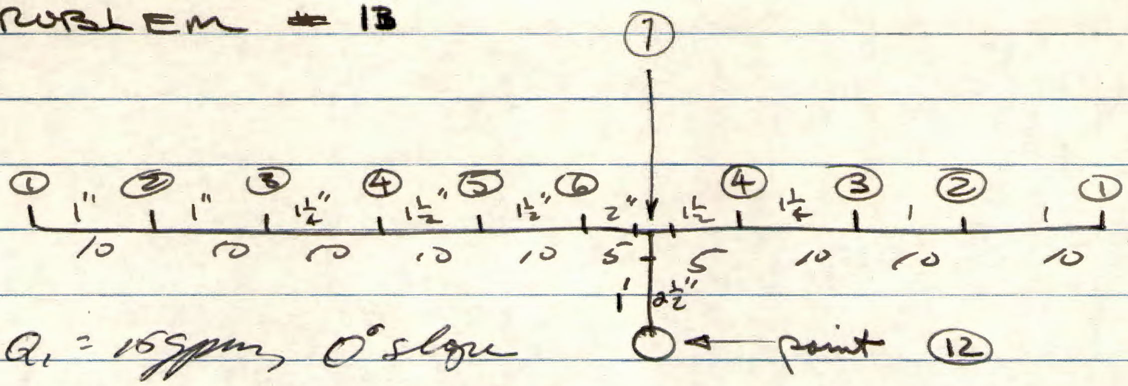
H = Total head = $h_p + z + h_v$

$N_R = LV/\nu$

ν = kinematic viscosity (last item)

ϵ = roughness factor

PROBLEM # 13



Q_1 = 15 gpm, 0° slope

Determine 1. total flow rate
2. total head at point (12)
3. K_{12} value

h_f (fittings) = $k\ h_v$

k: fitting resistance coeff.

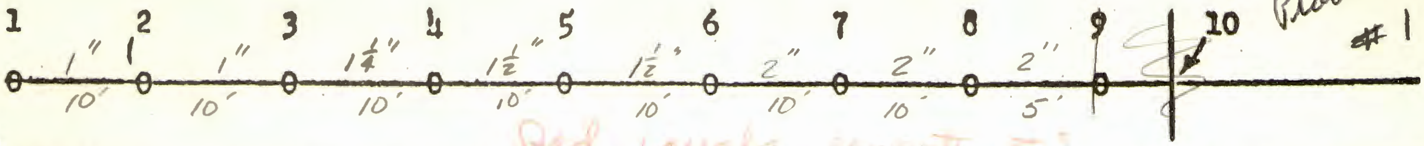
h_v: vel. hd. upstream of fitting

k's are listed in hydraulic Data manual table 32 a. pg 28

Use Inlet diameter + Inlet Velocity

17.5
$\sqrt{305.18}$
~ v/10

Problem #1

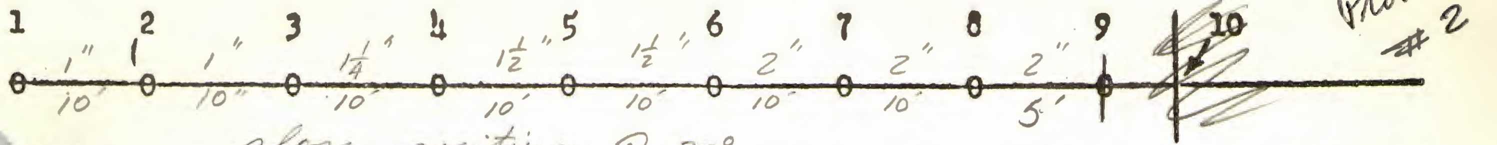


Red equals computer = 5

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
		66.46		
1	H(1) = hn(1)	65.00	Q(1)	
2	hf(2-1)....(10 Ft. 1 In. Pipe) +(.565)	5.65	30.00	30.00
3	Z (2-1)..................................+	0.00		
4	H(2)	70.65		
5	hv(2-1)....(1 In. Pipe) ....- 1.92	1.95		60.81
6	hn(2)	68.70	Q(2) 30.40	60.40
7	hv(3-2)....(1 In. Pipe)..........+	7.90	~~32.6~~ ~~35.1~~	93.00 95.50
8	hf(3-2)....(10 Ft. 1 In. Pipe) +(2.16)	27.60	~~33.8~~ ~~35.6~~	94.20 96.00
9	Z (3-2) ....+	0.00	34.7	
10	H(3)	98.20	35.0	95.4
11	hv(4-3) T.&E. (1¼ In. Pipe) ....-	6.50		96.36
12	hn(3)	91.70	Q(3) 35.00	95.40
13	H(3) .... From Above	98.20	34.6 37.7	130.00
14	hf(4-3) ...(10 Ft. 1¼ In. Pipe).+(1.31)	13.10	36.6 37.8	132.00
15	Z (4-3) ....+	0.00	37.6 37.8	133.00
16	H(4)	111.30	37.8	133.20
17	hv(5-4) T.&E. (1½ In. Pipe) ....-	6.90	37.92	133.28
18	hn(4)	104.40	Q(4) 37.80	133.20
19	H(4) .... From Above	111.30	39.8 41.5	173.00
20	hf(5-4) ...(10 Ft. 1½ In. Pipe)+(1.13)	11.30	41.3 37.0	174.5
21	Z (5-4) ....+	0.00	39.0 38.8	~~172.1~~
22	H(5)	122.60	38.9	172.1
23	hv(6-5) T.&E. (1½ In. Pipe) ....-	11.30	39.1	173.38
24	hn(5)	111.30	Q(5) 38.8	172.0
25	H(5) .... From Above	122.60	40.0 43.0	212.0
26	hf (6-5)..(10 Ft. 1½ In. Pipe)+1.85	18.90	42.0 42.9	214.0
27	Z (6-5) ....+	0.00	42.9	214.9
28	H (6)	141.50		
29	hv (7-6)T.&E. (2 In. Pipe) ....-	6.60	43.02	216.6
30	hn(6)	134.90	Q(6) 42.9	214.9
31	H(6) .... From Above	141.50	44.1 43.5	259.0
32	hf (7-6)..(10 Ft. 2 In. Pipe)+	7.90	43.4	258.3
33	Z (7-6) ....+	0.00		
34	H(7)	149.40		
35	hv(8-7) T.&E. (2 In. Pipe) ....-	9.50	43.10	260.20
36	hn(7)	139.90	Q(7) 43.5	258.4
37	H(7) .... From Above	149.40	44.2 45.0	302.6
38	hf(8-7) ..(10 Ft. 2 In. Pipe)+	11.20	44.6	303.2
39	Z (8-7) ....+	0.00	44.8	303.2
40	H(8)	160.60		
41	hv (9-8) T.&E.(2 In. Pipe) ....-	13.00	44.98	305.18
42	hn (8)	147.60	Q(8) 44.8	303.2
43	H(8) .... From Above	160.60		305.0
44	hf (9-8) .....(5 Ft. 2 In. Pipe)+(1.51)	7.55		
45	Z (9-8) ....+	0 00		
46	H(9) 9-8	168.15		
47	hv (10-9)T.&E.(In. Pipe) ....-	13.00		
48	hn (9)	155.15	Q(9) → hp	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe)+			
51	Z ( ) ....+			
52	hv ( ) ......(In. Pipe) ....+			
53	H ( )			

11-7-55 W.G.L.

Problem #2

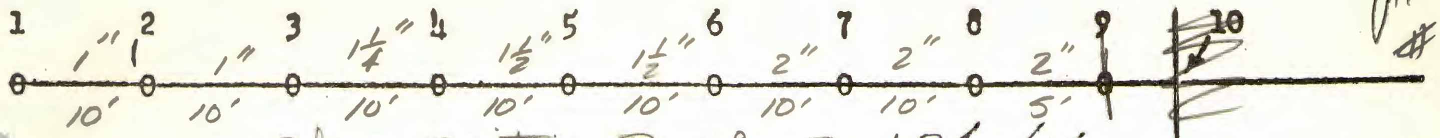


slope positive @ 30°

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	29.54	Q(1) 20.00	20.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +	2.55		
3	Z (2-1).......... +	5.00		
4	H(2)	37.09		
5	hv(2-1)....(1 In. Pipe) ....−	0.85	[illegible]	
6	hn(2)	36.24	Q(2) 22.25	42.25
7	hv(3-2)....(1 In. Pipe)..........+	3.85	25	67.25
8	hf(3-2)....(10 Ft. 1 In. Pipe) +	10.80		
9	Z (3-2) .... +	5.00	26.6	68.85
10	H(3)	55.89		
11	hv(4-3) T.&E. (1 1/4 In. Pipe) ....−	3.35	26.64	
12	hn(3)	52.54	Q(3) 26.60	68.85
13	H(3) .... From Above	55.89	28.15	97.00
14	hf(4-3) ...(10 Ft. 1 1/4 In. Pipe).+	7.00	29.70	
15	Z (4-3) .... +	5.00		
16	H(4)	67.89		
17	hv(5-4) T.&E. (1 1/2 In. Pipe) ....−	3.79	29.41	
18	hn(4)	64.10	Q(4) 29.70	98.55
19	H(4) .... From Above	67.89	31.50	129.55
20	hf(5-4) ...(10 Ft. 1 1/2 In. Pipe)+	6.30	31.30	31.3
21	Z (5-4) .... +	5.00		
22	H(5)	79.19		
23	hv(6-5) T.&E. (1 1/2 In. Pipe) ....−	6.50	31.29	
24	hn(5)	72.69	Q(5) 31.30	160.85
25	H(5) .... From Above	79.19		196.85
26	hf (6-5)..(10 Ft. 1 1/2 In. Pipe)+	17.80	36	
27	Z (6-5) .... +	5.00	36.1	
28	H (6)	101.99		
29	hv (7-6)T.&E. (2 In. Pipe) ....−	5.50	35.01	
30	hn(6)	96.49	Q(6) 36.1	196.95
31	H(6) .... From Above	101.99	38	134.95
32	hf (7-6)..(10 Ft. 2 In. Pipe)+	6.65	38.8	
33	Z (7-6) .... +	5.00		
34	H(7)	113.64		
35	hv(8-7) T.&E. (2 In. Pipe) ....−	2.82	36.48	
36	hn(7)	110.82	Q(7) 38.8	135.75
37	H(7) .... From Above	113.64	40.25	176.00
38	hf(8-7) ..(10 Ft. 2 In. Pipe)+	3.28	40.00	175.75
39	Z (8-7) .... +	5.00		
40	H(8)	121.92		
41	hv (9-8) T.&E.(2 In. Pipe) ....−	4.40	38.20	
42	hn (8)	117.52	Q(8) 40.00	175.75
43	H(8) .... From Above	121.92		239.18
44	hf (9-8) .....(5 Ft. 2" In. Pipe)+	2.68		
45	Z (9-8) .... +	2.50		
46	H(9)	127.10	hp(9)	
47	hv ~~(10-9)T.&E.(2 In. Pipe)~~ (9-8)....−	4.40	122.70	
48	hn (9)	122.70	~~Q(9)~~	
49	hn ( )		115.0	
50	hf ( ) .....(Ft. In. Pipe)+			
51	Z ( ) .... +			
52	hv ( ) ......(In. Pipe) ....+			
53	H ( )			

11-7-55 W.G.T.

Problem #3



Slope positive @ 10° Z = 1.74/10'

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	16.50	Q(1) 15.00	15.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +	1.50		
3	Z (2-1) +	1.74		
4	H(2)	19.74		
5	hv(2-1)....(1 In. Pipe) −	.48		
6	hn(2)	19.26	Q(2) 16.25	31.25
7	hv(3-2)....(1 In. Pipe) +	2.10	18.75	50.00
8	hf(3-2)....(10 Ft. 1 In. Pipe) +	6.10	19.25	50.50
9	Z (3-2) +	1.74		
10	H(3)	29.20		
11	hv(4-3) T.&E. (1¼ In. Pipe) −	1.85		
12	hn(3)	27.35	Q(3) 19.25	50.50
13	H(3) From Above	29.20	22	72.50
14	hf(4-3) ...(10 Ft. 1¼ In. Pipe) +	3.84	21.1	71.60
15	Z (4-3) +	1.74		
16	H(4)	34.78		
17	hv(5-4) T.&E. (1½ In. Pipe) −	2.00		
18	hn(4)	32.78	Q(4) 21.10	71.60
19	H(4) From Above	34.78	23	94.60
20	hf(5-4) ...(10 Ft. 1½ In. Pipe) +	3.35	22.25	93.85
21	Z (5-4) +	1.74		
22	H(5)	39.87		
23	hv(6-5) T.&E. (1½ In. Pipe) −	3.40		
24	hn(5)	36.47	Q(5) 22.25	93.85
25	H(5) From Above	39.87	24.15	118.00
26	hf (6-5)..(10 Ft. 1½ In. Pipe) +	5.65		
27	Z (6-5) +	1.74	24.90	118.75
28	H (6)	47.26		
29	hv (7-6) T.&E. (2 In. Pipe) −	2.02		
30	hn(6)	45.24	Q(6) 24.90	118.75
31	H(6) From Above	47.26	27	145.75
32	hf (7-6)..(10 Ft. 2 In. Pipe) +	2.50	25.7	144.45
33	Z (7-6) +	1.74		
34	H(7)	51.50		
35	hv(8-7) T.&E. (2 In. Pipe) −	2.99		
36	hn(7)	48.51	Q(7) 25.7	144.45
37	H(7) From Above	51.50	26.5	170.95
38	hf(8-7) ..(10 Ft. 2 In. Pipe) +	3.75		
39	Z (8-7) +	1.74		
40	H(8)	56.99		
41	hv (9-8) T.&E.(2 In. Pipe) −	4.15		170.58
42	hn (8)	52.84	Q(8) 26.7	171.15
43	H(8) From Above	56.99		
44	hf (9-8) .....(5 Ft. 2 In. Pipe) +	2.55		
45	Z (9-8) +	.87		
46	H(9)	57.12 60.41		
47	hv (~~10-9~~) T.&E. (~~2 In. Pipe~~) (9-8) −	4.11 4.15		
48	hn (9)	55.81 56.26	Q(9)	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe) +			
51	Z ( ) +			
52	hv ( ) ......(In. Pipe) +			
53	H ( )			

hp9 = 56.26

55.81

.51/5

2.55

11-7-55 W.G.D.

.87
2)1.74

PROBLEM # 4

Same 8 head branch.
with $Q_1 = 15$ GPM
0° Slope.

from problem ①

$Q_1 = 30.00$	$h_{n_1} = 66.50$
$Q_2 = 30.81$	$h_{n_2} = 70.09$
$Q_3 = 35.55$	$h_{n_3} = 91.70$
$Q_4 = 37.92$	$h_{n_4} = 104.40$
$Q_5 = 39.10$	$h_{n_5} = 111.30$
$Q_6 = 43.02$	$h_{n_6} = 134.90$
$Q_7 = 43.80$	$h_{n_7} = 139.90$
$Q_8 = 44.98$	$h_{n_8} = 147.60$
	$H(9) = 168.15$
$Q_1' = 15.00$	$h_{n_1}' = 16.62$
$Q_2' = 15.40$	$h_{n_2}' = 17.52$
$Q_3' = 17.77$	$h_{n_3}' = 22.92$
$Q_4' = 18.96$	$h_{n_4}' = 26.10$
$Q_5' = 19.55$	$h_{n_5}' =$
$Q_6' = 21.51$	$h_{n_6}' = 33.72$
$Q_7' = 21.90$	$h_{n_7}' =$
$Q_8' = \underline{22.49}$	$h_{n_8}' =$
$Q_T' = 153.47$	$H(9) = 41.68$

$$\frac{Q}{Q'} = \sqrt{\frac{h}{h'}} = 2$$

$$Q' = \frac{Q}{2}$$

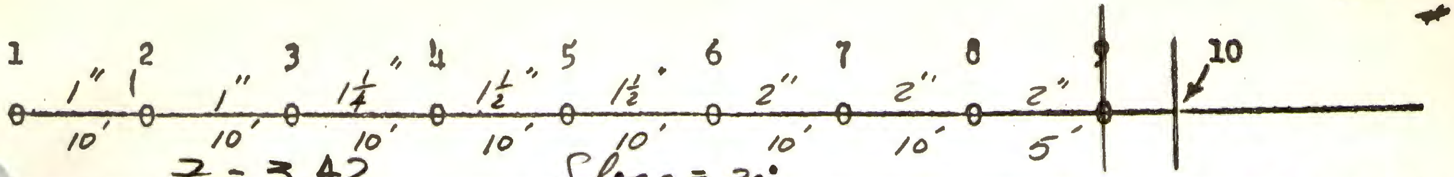
$$h' = \frac{h}{4}$$

$$4\overline{)134.90}^{\,33.725}$$

12
14
12
29
28
10

$$4\overline{)104.4}^{\,26.1}$$

Problem #5

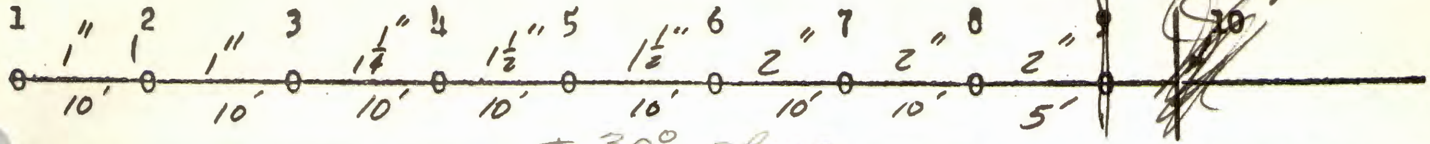


Z = 3.42 Slope = 20°

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	16.50	Q(1) 15.00	15.00
2	+ hf(2-1)....(10 Ft. 1 In. Pipe) +	1.50		
3	+ Z (2-1) +	3.42		
4	H(2)	21.42		
5	− hv(2-1)....(1 In. Pipe) −	.48		
6	hn(2)	20.94	Q(2) 17.00	32.00
7	+ hv(3-2)....(1 In. Pipe) +	2.20	19.5	51.50
8	+ hf(3-2)....(10 Ft. 1 In. Pipe) +	6.40	20.6	52.60
9	+ Z (3-2) +	3.42		
10	H(3)	32.96		
11	− hv(4-3) T.&E. (1¼ In. Pipe) −	2.00		
12	hn(3)	30.96	Q(3) 20.5	52.50
13	H(3) From Above	32.96	23.00	75.50
14	+ hf(4-3) ...(10 Ft. 1¼ In. Pipe) +	4.06	22.80	75.30
15	+ Z (4-3) +	3.42		
16	H(4)	40.44		
17	− hv(5-4) T.&E. (1½ In. Pipe) −	2.23		
18	hn(4)	38.21	Q(4) 22.8	75.30
19	H(4) From Above	40.44	25.2	~~100.5~~
20	+ hf(5-4) ...(10 Ft. 1½ In. Pipe) +	3.78	24.4	99.7
21	+ Z (5-4) +	3.42		
22	H(5)	47.64		
23	− hv(6-5) T.&E. (1½ In. Pipe) −	3.90		
24	hn(5)	43.74	Q(5) 24.4	99.70
25	H(5) From Above	47.64	27.00	126.70
26	hf (6-5)..(10 Ft. 1½ In. Pipe) +	6.44	27.60	127.30
27	Z (6-5) +	3.42		
28	H (6)	58.50		
29	hv (7-6) T.&E. (2 In. Pipe) −	2.30		
30	hn(6)	56.20	Q(6) 27.60	127.30
31	H(6) From Above	58.50	30.00	157.30
32	hf (7-6)..(10 Ft. 2 In. Pipe) +	2.87	28.90	156.20
33	Z (7-6) +	3.42		
34	H(7)	64.79		
35	hv(8-7) T.&E. (2 In. Pipe) −	3.50		
36	hn(7)	61.29	Q(7) 28.90	156.20
37	H(7) From Above	64.79	32.00	188.20
38	hf(8-7) ..(10 Ft. 2 In. Pipe) +	6.15	30.60	186.80
39	Z (8-7) +	3.42		
40	H(8)	74.36		185.00
41	hv (9-8) T.&E. (2 In. Pipe) −	5.00		
42	hn (8)	69.36	Q(8) 30.60	186.80
43	H(8) From Above	74.36		
44	hf (9-8) (5 Ft. 2 In. Pipe) +	3.00		
45	Z (9-8) +	1.71	hp(9)	
46	H(9)	75.49 79.07	74.07	
47	hv ~~(10-9)T.&E.(2 In. Pipe)~~ 9-8 −	4.83 5.00		
48	hn (9)	74.07	Q(9)	
49	hn ( )			
50	hf ( ) (Ft. In. Pipe) +			
51	Z ( ) +			
52	hv ( ) (In. Pipe) +			
53	H ( )			

11-7-55 W.G.L.

problem #6



+ 30° slope

No.	SEQUENCE OF CALCULATIONS	Z = 5.00	Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	16.50	Q(1) 15.00	15.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +	1.50		
3	Z (2-1).... +	5.00		
4	H(2)	23.00		
5	hv(2-1)....(1 In. Pipe) .... −	.48		
6	hn(2)	22.52	Q(2) 17.60	32.60
7	hv(3-2)....(1 In. Pipe).... +	2.27	20.00	52.60
8	hf(3-2)....(10 Ft. 1" In. Pipe) +	6.60	21.60	54.20
9	Z (3-2) .... +	5.00		
10	H(3)	36.39		
11	hv(4-3) T.&E. (1¼ In. Pipe) .... −	2.13		
12	hn(3)	34.26	Q(3) 21.60	54.20
13	H(3) .... From Above	36.39	23.00	77.20
14	hf(4-3) ...(10 Ft. 1¼ In. Pipe). +	4.70	24.40	78.60
15	Z (4-3) .... +	5.00		
16	H(4)	46.09		
17	hv(5-4) T.&E. (1½ In. Pipe) .... −	2.40		
18	hn(4)	43.59	Q(4) 24.40	78.60
19	H(4) .... From Above	46.09	27.00	105.60
20	hf(5-4) ...(10 Ft. 1½ In. Pipe) +	4.07	26.20	
21	Z (5-4) .... +	5.00		
22	H(5)	55.16		
23	hv(6-5) T.&E. (1½ In. Pipe) .... −	4.32		
24	hn(5)	50.84	Q(5) 26.2	104.8
25	H(5) .... From Above	55.16	28.00	132.8
26	hf (6-5)..(10 Ft. 1½ In. Pipe) +	7.02	29.50	134.3
27	Z (6-5) .... +	5.00		
28	H (6)	67.18		
29	hv (7-6)T.&E. (2 In. Pipe) .... −	2.57		
30	hn(6)	64.61	Q(6) 29.5	134.3
31	H(6) .... From Above	67.18	31.00	165.3
32	hf (7-6)..(10 Ft. 2 In. Pipe) +	3.20	31.00	
33	Z (7-6) .... +	5		
34	H(7)	75.38		
35	hv(8-7) T.&E. (2 In. Pipe) .... −	3.91		
36	hn(7)	71.47	Q(7) 31.00	165.3
37	H(7) .... From Above	75.38	32.7	198.0
38	hf(8-7) ..(10 Ft. 2 In. Pipe) +	4.80	33.0	
39	Z (8-7) .... +	5.00		
40	H(8)	85.18		197.43
41	hv (9-8) T.&E.(2 In. Pipe) .... −	5.6		
42	hn (8)	79.58	Q(8) 33.0	198.3
43	H(8) .... From Above	85.18		
44	hf (9-8) .....(5 Ft. 2 In. Pipe) +	3.40	85.48 hp(9)	
45	Z (9-8) .... +	2.50		
46	H(9)	88.09 91.08		
47	hv (10-9)T.&E.(In. Pipe) 9-8 .... −	5.50 5.60		
48	hn (9)	82.59 85.48	Q(9)	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe) +	.685 3.40		
51	Z ( ) .... +			
52	hv ( ) ......(In. Pipe) .... +			
53	H ( )			

11-7-55 W.G.T.

$Q_1 = 15$ gpm

problem 7

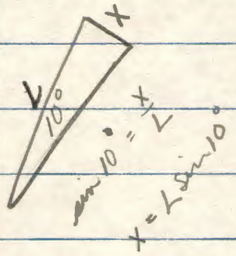
10° negative slope

1.74
2
3.

19.74
3.48
16.26

16.50
1.50
18.00
−1.74
H_2 16.26
$-h_{v_{2-1}}$ − .48
h_{n_2} → 15.78
h_v 3-2 1" 1.85
5.55
23.18
−1.74
H(3) 21.44
1¼" $h_{v_{4-3}}$ − 1.55
h_n 3 = 19.89

15.78
3.45
.26



21.44
hf(4-3) 1¼" 2.20
24.64
− 1.74
H(4) = 22.90
hv 5-4 1½" 1.57
21.33

22.90
hf (5-4) 1½" 2.67
25.57
− 1.74
H(5) = 23.83
h_v (6-5) 1½" 2.51
21.32

23.83
hf (6-5) 1½" 3.79
27.62
− 1.74
H(6) = 25.88
2" h_v (7-6) = 1.39
24.49

	TOTAL Q
Q_1 = 15.00	15.00
14.8	~~13.00~~
Q_2 = 14.70	29.70
13.00	42.70
16.60 16.00	45.70
15.20	44.90
16.50 16.6	46.20
Q_3 16.50	46.20
15.00	61.20
17.10	63.30
17.00	63.20
17.2	
Q_4 = 17.00	63.20
18.00	81.20
17.00	80.20
17.1	80.3
17.3	
Q_5 = 17.1	80.3
17.7	98.0
18.3	98.6
18.5	
Q_6 = 18.3	98.6

~~TH~~

Q_6 = 18.3	18.8 98.6
18.50	117.1
18.10	106.7
18.3 Q_7 = 18.10	18.3 116.7
18.30	135.0
18.09	134.7
18.4 Q_8 = 18.00	136.0 134.7

H(6) 25.88

$h_f(7-6)$ 2" 1.76

27.64

− 1.74

H(7) = 25.90

$h_v(8-7)$ 2" 1.95

23.95

H(7) 25.90

h_f (8-7) 2" 2.45

28.35

− 1.74

.325/1.50

H(8) → 26.61

h_v (9-8) 2" 2.60

h_n 24.01

H(8) = 26.61

h_f (9-8) 5' of 2" 1.60

28.21

.87

H(9) → 27.34

− h_v (9-8) − 2.60

$h_p(9)$ = 24.74

26.27

Q_1 = 15 gpm
slope = −20°
z = −3.42

problem # 8

$H(1) = h_{n1}$ =	16.50	Q_1 15.00	Q_T = 15.00
h_f	1.50		
	18.00		
$-z(2-1)$	3.42		
$H(2)$ →	14.58		
$h_v(2-1)$ 1" →	.48	14.0	15.10
$h_n(2)$ →	14.10	Q_2 = 13.90	Q_T = 28.90
$h_v(3-2)$ 1" →	1.80	15.10	44.00
$h_f(3-2)$ 1" →	5.25		
	21.15		
	−3.42		
$H(3)$ →	17.73		
$h_v(4-3)$ 1¼" →	−1.40	15.2	
$h_n(3)$	16.33	Q_3 = 15.00	Q_T = 43.90
H_3	17.73	14	57.90
$h_f(4-3)$ 1¼"	2.88	14.2	
	19.61		
	3.42		
$H(4)$	16.19		
$h_v(5-4)$ 1½"	1.30	14.8	
	14.89	Q_4 = 14.2	58.10
		13.4	71.5
$H(4)$	16.19		
$h_f(5-4)$ 1½"	2.30		
	18.49		
	3.42		
$H(5)$ →	15.07		
$h_v(6-5)$ 1½"	2.00	14.1	
	13.07	Q_5 = 13.3	Q_T = 71.4
$H(5)$	15.07	13.6	85.0
$h_f(6-5)$ 1½"	3.40		
	18.47		
	3.42		
$H(6)$ →	15.05		
$h_v(7-6)$ 2"	1.03	14.5	
	14.02	Q_6 = 13.8	85.2

H(6) 15.05

$h_f(7-6)$ 2" 1.33

16.38

− 3.42

H(7) → 12.96

$h_v(8-7)$ 2" 1.38

11.58

H(7) 12.96

$h_f(8-7)$ 2" 1.73

H(8) → 14.69

$h_v(9-8)$ 2" 1.75

12.94

H(8) → 14.69

$h_f(9-8)$ 2"(5') 1.10

15.79

1.71

H(9) → 14.08

− $h_v(9-8)$ − 1.75

$\boxed{h_p(9) \rightarrow 12.33}$

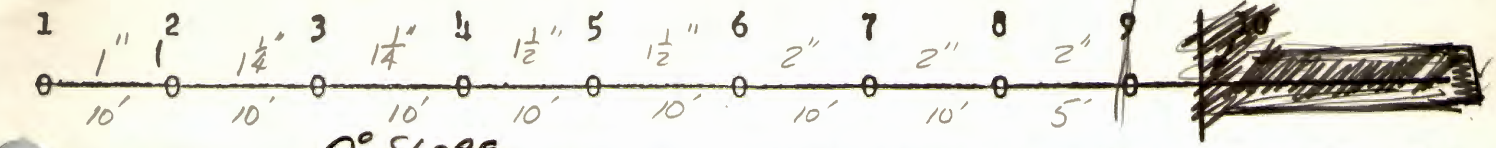
10.45

1.22

1.10

$Q_6 = 13.8$	$Q_T = 85.2$
12.8	98.0
12.6	97.8
13.3	
$Q_7 = 12.6$	$Q_T = 97.8$
13.2	111.0
12.3	113.2
$Q_8 = 13.3$	111.1

Problem # 9



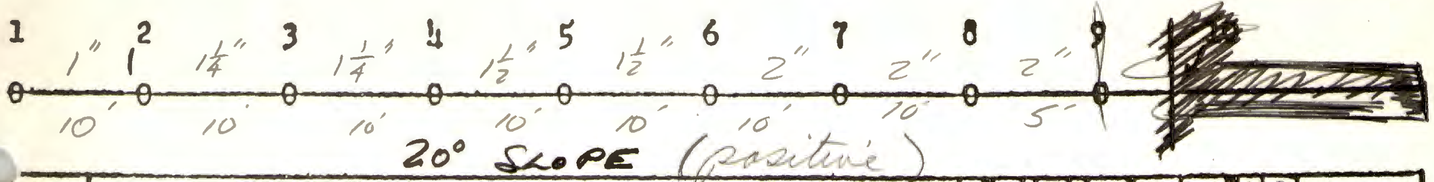
O° SLOPE

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	16.50	Q(1) 15.00	15.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +	1.50		
3	Z (2-1)..................................+	0.00		
4	H(2)	18.00		
5	hv(2-1)....(1 In. Pipe) ....-	.48	15.5	
6	hn(2)	17.52	Q(2) 15.50	30.50
7	hv(3-2)....(1¼ In. Pipe)..........+	.68		
8	hf(3-2)....(10 Ft. 1¼ In. Pipe) +	1.43	16.00	46.50
9	Z (3-2) ....+	0.00	15.70	46.20
10	H(3)	19.63		
11	hv(4-3) T.&E. (1¼ In. Pipe) ....-	1.55	15.8	
12	hn(3)	18.08	Q(3) 15.70	46.20
13	H(3) .... From Above	19.63		
14	hf(4-3) ....(10 Ft. 1¼ In. Pipe).+	1.47	16.00	62.20
15	Z (4-3) ....+	0.00	16.40	62.60
16	H(4)	21.10		
17	hv(5-4) T.&E. (1½ In. Pipe) ....-	1.53	17.0	
18	hn(4)	19.57	Q(4) 16.40	62.60
19	H(4) .... From Above	21.10		
20	hf(5-4) ....(10 Ft. 1½ In. Pipe)+	2.67	17.00	79.60
21	Z (5-4) ....+	0.00	17.10	79.70
22	H(5)	23.77		
3	hv(6-5) T.&E. (1½ In. Pipe) ....-	2.47	17.8	
24	hn(5)	21.30	Q(5) 17.10	79.70
25	H(5) .... From Above	23.77	18.0	97.70
26	hf (6-5)..(10 Ft. 1½ In. Pipe)+	4.15	19.0	98.70
27	Z (6-5) ....+	0.00		
28	H (6)	27.92		
29	hv (7-6)T.&E. (2 In. Pipe) ....-	1.38	19.7	
30	hn(6)	26.54	Q(6) 19.0	98.70
31	H(6) .... From Above	27.92		
32	hf (7-6)..(10 Ft. 2 In. Pipe)+	1.77	20.00	118.70
33	Z (7-6) ....+	0.00	19.50	118.20
34	H(7)	29.69		
35	hv(8-7) T.&E. (2 In. Pipe) ....-	2.00	20.0	
36	hn(7)	27.69	Q(7) 19.50	118.20
37	H(7) .... From Above	29.69		
38	hf(8-7) ..(10 Ft. 2 In. Pipe)+	2.50	20.2	138.40
39	Z (8-7) ....+	0.00	20.0	138.2
40	H(8)	32.19		
41	hv (9-8) T.&E.(2 In. Pipe) ....-	2.75	20.7	141.5
42	hn (8)	29.44	Q(8) 20.0	138.2
43	H(8) .... From Above	32.19		
44	hf (9-8) .....(5 Ft. 2 In. Pipe)+	1.70		
45	Z (9-8) ....+	0.00	hp(9) 31.14	.134 5.0 1.7
46	H(9)	33.89		
47	hv ~~(10-9)T.&E.(~~ 2 ~~In. Pipe~~ (9.8)........-	2.75		
8	hp(9)	31.14	Q(9)	
	hn ( )			
50	hf ( ) .....(Ft. In. Pipe)+			
51	Z ( ) ....+			
52	hv ( ) ......(In. Pipe) ....+			
53	H ( )			

Note — getting
just as good
spray w/o modification
w. less supply
+ pressure
req.

11-7-55 W.G.L.

Problem # 10



20° SLOPE (positive)

No.	SEQUENCE OF CALCULATIONS Z = 3.42		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	16.50	Q(1) 15.00	15.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +	1.50		
3	Z (2-1).................... +	3.42		
4	H(2)	21.42		
5	hv(2-1)....(1 In. Pipe) .... –	.48	17.0	
6	hn(2)	20.94	Q(2) 17.00	32.00
7	hv(3-2)....(1¼ In. Pipe)........ +	.74		
8	hf(3-2)....(10 Ft. 1¼ In. Pipe) +	1.57	17.5	49.50
9	Z (3-2) .... +	3.42	18.4	50.40
10	H(3)	26.67	18.4	
11	hv(4-3) T.&E. (1¼ In. Pipe) .... –	1.85		
12	hn(3)	24.82	Q(3) 18.4	50.40
13	H(3) .... From Above	26.67		
14	hf(4-3) ...(10 Ft. 1¼ In. Pine).+	3.80	20.0	70.4
15	Z (4-3) .... +	3.42	20.8	
16	H(4)	33.89		
17	hv(5-4) T.&E. (1½ In. Pipe) .... –	1.95	20.9	
18	hn(4)	31.94	Q(4) 20.8	71.2
19	H(4) .... From Above	33.89	22.0	93.2
20	hf(5-4) ...(10 Ft. 1½ In. Pipe)+	3.38	22.5	93.7
21	Z (5-4) .... +	3.42		
22	H(5)	40.69	22.7	
23	hv(6-5) T.&E. (1½ In. Pipe) .... –	3.38		
24	hn(5)	37.31	Q(5) 22.5	93.7
25	H(5) .... From Above	40.69	24.3	118.0
26	hf (6-5)..(10 Ft. 1½ In. Pipe)+	5.70	25.5	119.2
27	Z (6-5) .... +	3.42		
28	H (6)	49.81	25.7	
29	hv (7-6)T.&E. (2 In. Pipe) .... –	2.03		
30	hn(6)	47.78	Q(6) 25.5	119.2
31	H(6) .... From Above	49.81	26.3	145.5
32	hf (7-6)..(10 Ft. 2 In. Pipe)+	2.65		
33	Z (7-6) .... +	3.42	26.7	
34	H(7)	55.78	26.8	
35	hv(8-7) T.&E. (2 In. Pipe) .... –	3		
36	hn(7)	52.78	Q(7) 26.7	145.9
37	H(7) .... From Above	55.78	28.1	174.0
38	hf(8-7) ..(10 Ft. 2 In. Pipe)+	3.71		
39	Z (8-7) .... +	3.42		
40	H(8)	62.91	28.3	174.8
41	hv (9-8) T.&E.(2 In. Pipe) .... –	4.3		
42	hn (8)	58.61	Q(8) 28.2	174.1
43	H(8) .... From Above	62.91		
44	hf (9-8) .....(5 Ft. 2 In. Pipe)+	2.65	62.97 = hp(9)	63.18
45	Z (9-8) .... +	1.71		
46	H(9)	67.27		
47	hv (~~10-9~~)T.&E.(~~In. Pipe)~~ (9-8)........ –	4.36		
48	hp (9)	62.97	Q(9)	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe)+			
51	Z ( ) .... +			
52	hv ( ) ......(In. Pipe) .... +			.53
53	H ( )			5

2.65

look at all these [illegible] to get an idea of how change in variable effects answer

11-7-55 W.G.L.

Extra Hazard Schedule - 8 heads, - $Q_1 = 15$ gpm

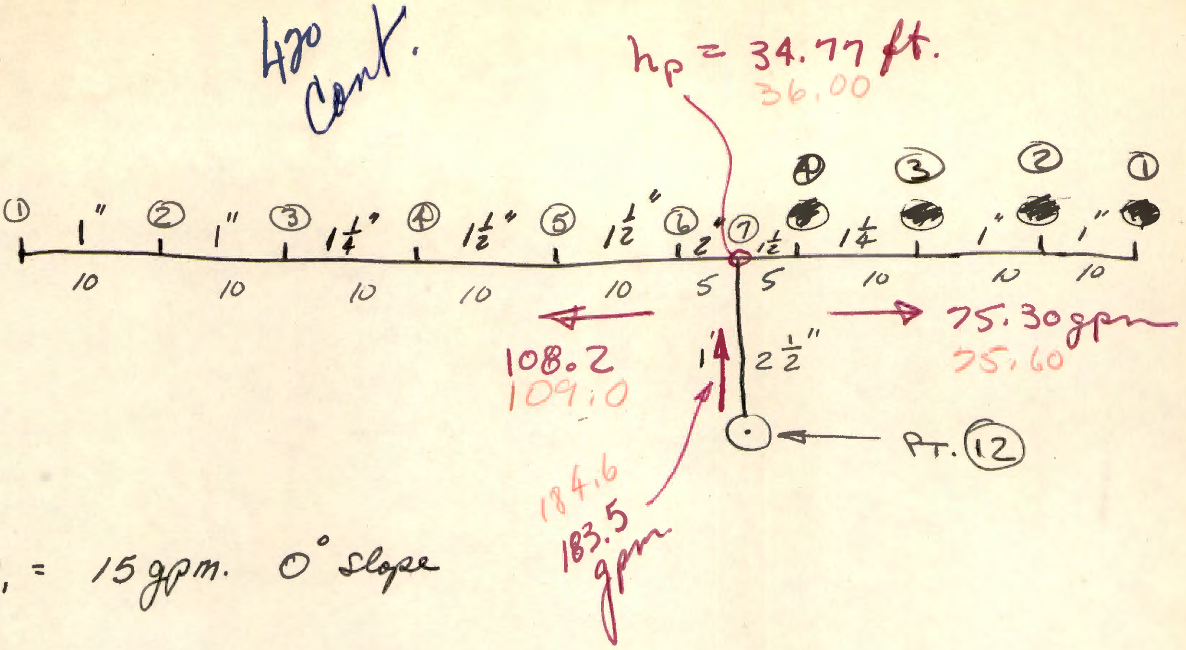
Answers { problem # 11 } 0° slope Q_T = 138. 34 gpm. hp(9) = 31. 27

problem # 12 } 20°+slope Q_T = ~~162. 34~~ gpm. hp(9) = ~~55.69~~

171.80 60.80

PROBLEM # 13

420 Cont.



$Q_1 = 15$ gpm. 0° slope

From problem # 1 + # 4.

$$Q_{TOTAL} \text{ at } ⑥ = \frac{216.4}{2} = 108.2 \text{ gpm.}$$

$$H(6) = h_{n(6)} + h_v(7-6)$$

$$H(7) = H(6) + h_f(7-6)$$

~~.21 5 1.05~~

$$\begin{array}{r} 67.14 \\ 2\overline{)134.28} \\ 12 \\ 14 \end{array}$$

$$h_{n(7)} = H(7) - h_v(7-6)$$

$$h_{n(7)} = \overbrace{H(6) + h_f(7-6)} - h_v(7-6)$$

$$h_{n(7)} = \overbrace{h_{n(6)} + \cancel{h_v(7-6)}} + h_f(7-6) - \cancel{h_v(7-6)}$$

$$h_{n(7)} = h_{n(6)} + h_f(7-6)$$

$$h_{n(7)} = 33.72 + (.21)(5) = 33.72 + 1.05 =$$

$$\boxed{h_{n(7)} = 34.77}$$

Q_{TOTAL} @ ④ from problem #1 & #4:

$Q_T = 67.14$

67.50

$h_{n(7)}$ for 67.14 gpm:

$h_{n(7)} = h_{n(4)} + h_{f(7-4)}$

$h_n(7) = 26.10 + .3(5) = 26.10 + 1.50$

$h_n(7) = 27.60$

28.5

36.00

But it must equal 34.77

∴ find new flow in Right Branch:

$$\frac{Q_1}{Q_2} = \left(\frac{h_1}{h_2}\right)^{\frac{1}{2}}$$

.7

$$\frac{67.14}{Q_2} = \left(\frac{27.60}{34.77}\right)^{\frac{1}{2}}$$

$$Q_2 = \frac{67.14}{\left(\frac{27.60}{34.77}\right)^{\frac{1}{2}}} = \frac{67.14}{.892} = 75.3 \text{ gpm.}$$

75.6

∴ Total flow thru RN will be:

75.30

108.20

$\boxed{183.50 \text{ gpm.}}$

184.60

$h_{p(7)}$ = → 34.77 36.00

$h_{(v)}$ (12-7) 2½" pipe → 2.37

h_f (2" x 1½" x 2½" tee →

(K = 1.3)(h_v = 2.37) 3.08

↑ inlet Dia ? → always use inlet Dia + inlet h_v

h_f RN 1' 2½" pipe .24

Z RN 1.00

H(12) → 41.46 = $h_{(n)12}$

TOTAL HEAD @ ⑫ = 41.46 feet H_2O 42.83

TOTAL FLOW @ ⑫ = 183.50 gpm 184.6

$$K_{⑫} = \frac{Q}{\sqrt{h}} = \frac{183.5}{\sqrt{41.46}} = \frac{183.5}{6.44} = 28.5$$

AN INTRODUCTION TO THE HYDRAULICS OF SPRINKLER SYSTEMS

by
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I. PURPOSE

The purpose of this paper is to present a basic understanding of the calculation of pressure and flow distribution in sprinkler systems designed for the control and extinguishment of fires. The basic mathematical relationships are described. Calculations associated with the solution of a simple sprinkler system are presented to explain the method.

II. BASIC EQUATIONS (See Page 8 for notation)

A. Material Balance - $Q(\text{total}) = Q_1 + Q_2 + Q_3 \cdots\cdots Q_x$ Eq. 1

B. Energy Balance - At any cross-section in a flowing pipe system,

$$H = h_p + z + h_v \qquad \text{Eq. 2}$$

Between any two points in a pipe system,

$$H_1 = H_2 + h_f \qquad \text{Eq. 3}$$

C. Other useful equations -

$$h_v = \frac{V^2}{2g} = \frac{Q^2}{385\ D^4} \quad \text{(velocity head)} \qquad \text{Eq. 4}$$

$$h_f = f\ \frac{L}{D/12}\ \frac{V^2}{2g} \quad \text{(friction head loss)} \qquad \text{Eq. 5}$$

$$f = 0.0055 \left[1 + (20{,}000\ \frac{\varepsilon}{D/12} + \frac{10^6}{N_R})\right]^{1/3} \qquad \text{Eq. 6}$$

$$Q = 19.62\ C_d\ d_o^2\ \sqrt{h_n} \quad \text{(nozzle flow)} \qquad \text{Eq. 7}$$

$$Q = K\ \sqrt{h} \qquad \text{Eq. 8}$$

$$N_R = \frac{V\ D/12}{\nu} \quad \text{(Reynolds Number)} \qquad \text{Eq. 9}$$

For water at $60^\circ F$, $\nu = 1.216 \times 10^{-5}$ ft^2/sec
and Reynolds Number becomes,

$$N_R = 6850\ V D = 2810\ Q/D \qquad \text{Eq. 10}$$

$$V = \frac{Q}{2.44\ D^2} \quad \text{(pipe velocity)} \qquad \text{Eq. 11}$$

D. By combining various equations and solving for Q, the relations for nozzle flow, velocity head and friction head loss may be put into the form of Eq. 8, as follows:

Nozzle flow, from Eq. 7:

$$Qn = Kn \sqrt{hn} \qquad \text{Eq. 12}$$

in which, for a particular nozzle

$$Kn = 19.62\ C_d\ d_o^{\ 2} \qquad \text{Eq. 13}$$

Velocity head, from Eq. 4:

$$Q = K_v \sqrt{hv} \qquad \text{Eq. 14}$$

in which, for a particular cross-section in a flowing system

$$K_v = D^2 \sqrt{385} \qquad \text{Eq. 15}$$

Friction head loss, from Eqs. 4 and 5:

$$Q = K_f \sqrt{h_f} \qquad \text{Eq. 16}$$

in which, for a particular cross-section in a flowing system

$$K_f = D^2 \sqrt{385}\ \left(\sqrt{\frac{D/12}{fL}} \right) = K_v \sqrt{\frac{D/12}{fL}} \qquad \text{Eq. 17}$$

III. BRANCH LINE CALCULATIONS IN EQUATION FORM - Following the sequence of calculations on the form used for branch line calculations, Example No. 1, equations for TOTAL HEADS at each sprinkler are written below:

1. $H(1) = hn(1)$
2. $H(2) = H(1) + hf(2-1) + z(2-1)$
3. $H(3) = hn(2) + hf(3-2) + z(3-2) + hv(3-2)$
4. $H(4) = H(3) + hf(4-3) + z(4-3)$
5. $H(5) = H(4) + hf(5-4) + z(5-4)$
6. $H(6) = H(5) + hf(6-5) + z(6-5)$
7. $H(7) = H(6) + hf(7-6) + z(7-6)$
8. $H(8) = H(7) + hf(8-7) + z(8-7)$

Equations for the head causing flow from each sprinkler may be written as follows:

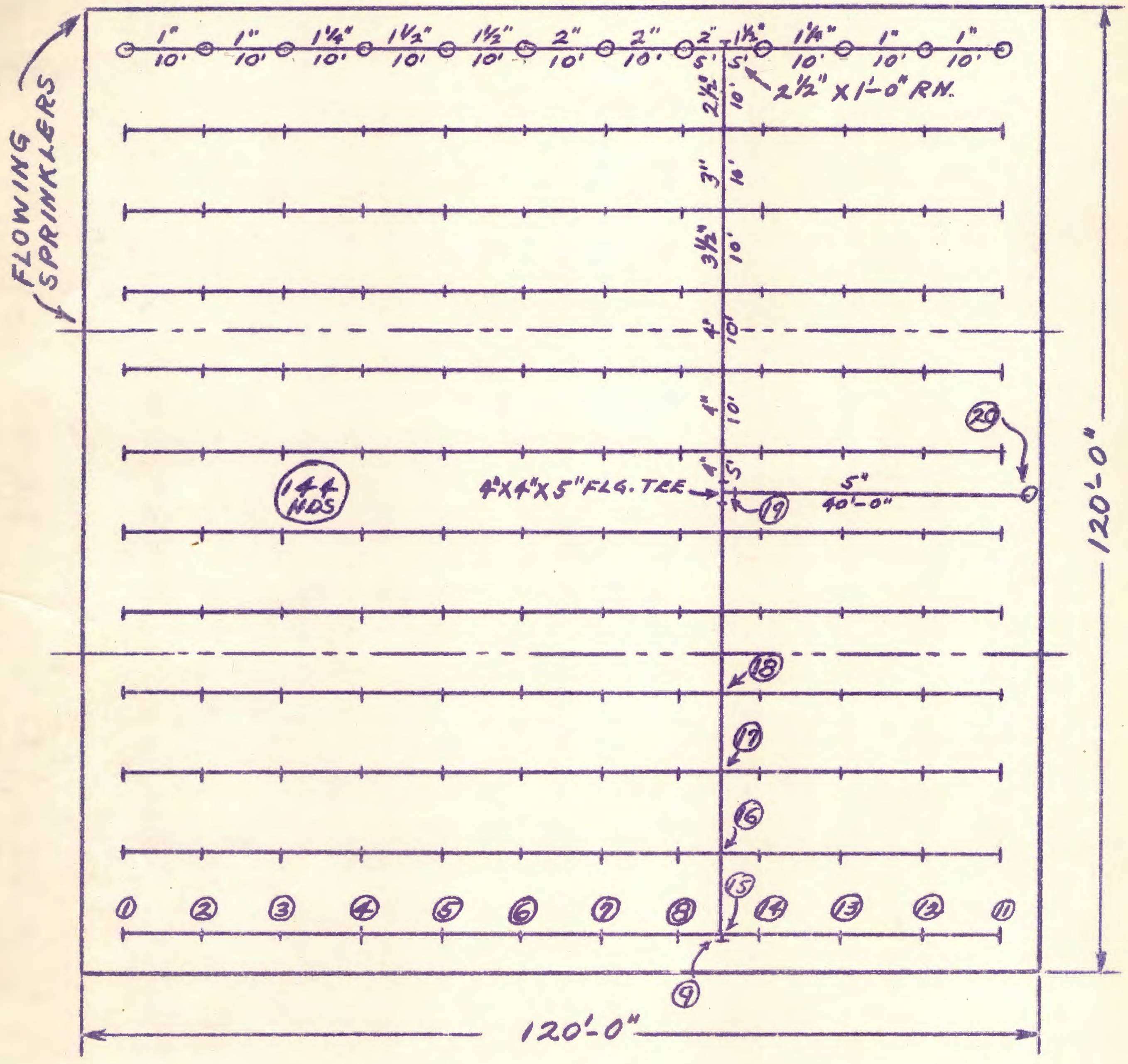
Memorize

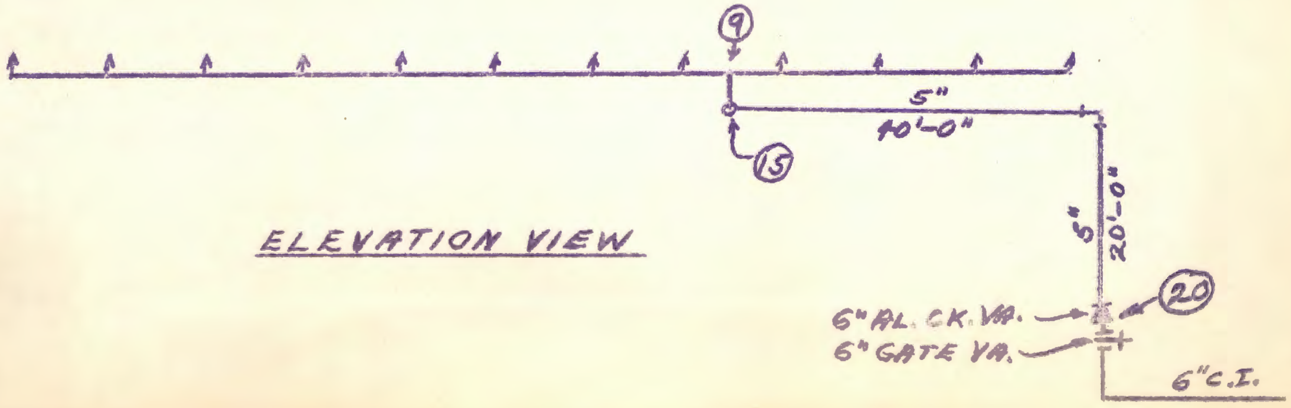
1. $hn(1) = H(1)$
2. $hn(2) = [H(1) + hf(2-1) + z(2-1)] - hv(2-1)$
3. $hn(3) = [hn(2) + hf(3-2) + z(3-2) + hv(3-2)] - hv(4-3)$
4. $hn(4) = [H(3) + hf(4-3) + z(4-3)] - hv(5-4)$
5. $hn(5) = [H(4) + hf(5-4) + z(5-4)] - hv(6-5)$
6. $hn(6) = [H(5) + hf(6-5) + z(6-5)] - hv(7-6)$
7. $hn(7) = [H(6) + hf(7-6) + z(7-6)] - hv(8-7)$
8. $hn(8) = [H(7) + hf(8-7) + z(8-7)] - hv(9-8)$

Please Note: Elevation head z has been included as a separate term in the above equations as a matter of convenience, and is not implied as having been included in the Total Head H, as shown in Eq. 2, page 1.

IV. CALCULATIONS FOR A SIMPLE SYSTEM

The following sketch represents a simple layout of building and sprinkler system, as a basis for demonstrating the hydraulic calculations involved: (SCALE:- 1/2 inch = 10 ft.)



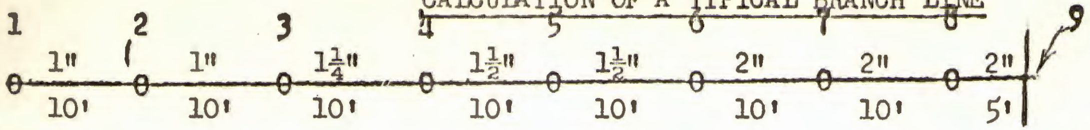


ELEVATION VIEW

Z = 0.00
Q(1) = 20 gpm

EXAMPLE NO. 1

CALCULATION OF A TYPICAL BRANCH LINE



Example Problem.

No.	SEQUENCE OF CALCULATIONS		Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	29.54	Q(1) 20.00	20.00
2	hf(2-1)....(10 Ft. 1 In. Pipe) +(0.255)	2.55		
3	Z (2-1) +	0.00		
4	H(2)	32.09		
5	hv(2-1)....(1 In. Pipe) −	0.85		
6	hn(2)	31.24	Q(2) 20.57	40.57
7	hv(3-2)....(1 In. Pipe) +	3.51		
8	hf(3-2)....(10 Ft. 1 In. Pipe) +(0.997)	9.97		
9	Z (3-2) +	0.00		
10	H(3)	44.72		
11	hv(4-3) T.&E. (1¼ In. Pipe) −	2.96		
12	hn(3)	41.76	Q(3) 23.78	64.35
13	H(3) From Above	44.72		
14	hf(4-3) ...(10 Ft. 1¼ In. Pipe) +(0.599)	5.99		
15	Z (4-3) +	0.00		
16	H(4)	50.71		
17	hv(5-4) T.&E. (1½ In. Pipe) −	3.11		
18	hn(4)	47.60	Q(4) 25.39	89.74
19	H(4) From Above	50.71		
20	hf(5-4) ...(10 Ft. 1½ In. Pipe) +(0.518)	5.18		
21	Z (5-4) +	0.00		
22	H(5)	55.89		
23	hv(6-5) T.&E. (1½ In. Pipe) −	5.18		
24	hn(5)	50.71	Q(5) 26.20	115.94
25	H(5) From Above	55.89		
26	hf (6-5)..(10 Ft. 1½ In. Pipe) +(0.853)	8.53		
27	Z (6-5) +	0.00		
28	H (6)	64.42		
29	hv (7-6)T.&E. (2 In. Pipe) −	2.96		
30	hn(6)	61.46	Q(6) 28.85	144.79
31	H(6) From Above	64.42		
32	hf (7-6)..(10 Ft. 2 In. Pipe) +(0.361)	3.61		
33	Z (7-6) +	0.00		
34	H(7)	68.03		
35	hv(8-7) T.&E. (2 In. Pipe) −	4.28		
36	hn(7)	63.75	Q(7) 29.38	174.17
37	H(7) From Above	68.03		
38	hf(8-7) ..(10 Ft. 2 In. Pipe) +(0.517)	5.17		
39	Z (8-7) +	0.00		
40	H(8)	73.20		
41	hv (9-8) T.&E.(2 In. Pipe) −	5.89		
42	hn (8)	67.31	Q(8) 30.19	204.36
43	H(8) From Above	73.20		
44	hf (9-8) .....(5 Ft. 2 In. Pipe) +(0.707)	3.54		
45	Z (9-8) +	0.00		
46	H(9) GET PRESSURE HEAD @ 9	76.74	hp9 = 70.85	
47	hv (10-9)T.&E.(In. Pipe) −	5.89		
48	hn (9)	70.85	Q(9)	
49	hn ( )			
50	hf ( ) .....(Ft. In. Pipe) +			
51	Z ( ) +			
52	hv ( ) ......(In. Pipe) +			
53	H ( )			

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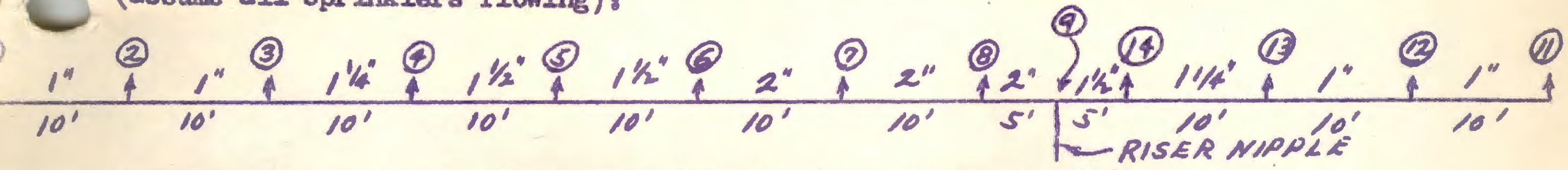
EXAMPLE NO. 2 - Applying the information available in Example No. 1, calculate the flow of water into a 12-head branch line, having 8 sprinklers on one side and 4 on the other side of the junction, as shown in the following sketch (assume all sprinklers flowing):



From Example No. 1, the Total Flow from the 8 sprinklers = 204.4 gpm.

Also, the Total Head at Point 9 H(9) has been calculated to be 76.74 ft. of water; the Static Pressure Head at Point 9, hp (9) = H(9) - hv (9-8) = 76.74-5.89 = 70.85

The Total Flow through Sprinklers 11, 12, 13 and 14, with 70.85 ft. of water at Point 9 will now be calculated:

It is seen by inspection of the sketch that the right-hand side of the branch line is similar to a part of the left-hand side, consisting of Sprinklers 1, 2, 3 and 4 to the midpoint between Sprinklers 4 and 5. Referring to Item 18 (see arrows) of Example No. 1,

(a) The total flow from Sprinklers 1, 2, 3, 4 = 89.74 gpm

(b) The Static Pressure Head at the midpoint between Sprinklers 4 and 5 may be calculated by adding the Friction Head Loss through 5 ft. of $1\frac{1}{2}$" pipe to the Static Pressure Head at Point 4, hn(4), as follows:

$$47.60 + (5 \text{ ft.} \times 0.518) = 47.60 + 2.59 = \underline{50.19 \text{ ft. of water.}}$$

Since there can be only one head acting at the junction, Point 9, the Total Flow into Sprinklers 11, 12, 13 and 14 may be calculated as follows:

$$Q(\text{total}) = 89.74\sqrt{\frac{70.85}{50.19}} = 89.74 \times 1.188 = 106.6 \text{ gpm.}$$

The individual flows from the sprinklers may be calculated similarly:

Q(11) = 20 x 1.188 = 23.76 gpm.
Q(12) = 20.57 x 1.188 = 24.44 "
Q(13) = 23.78 x 1.188 = 28.25 "
Q(14) = 25.39 x 1.188 = 30.16 "
Q(total) = 106.61 gpm.

The Total Flow into the junction at Point 9, with all sprinklers flowing under an inlet head H(9) of 86 ft. of water, is then

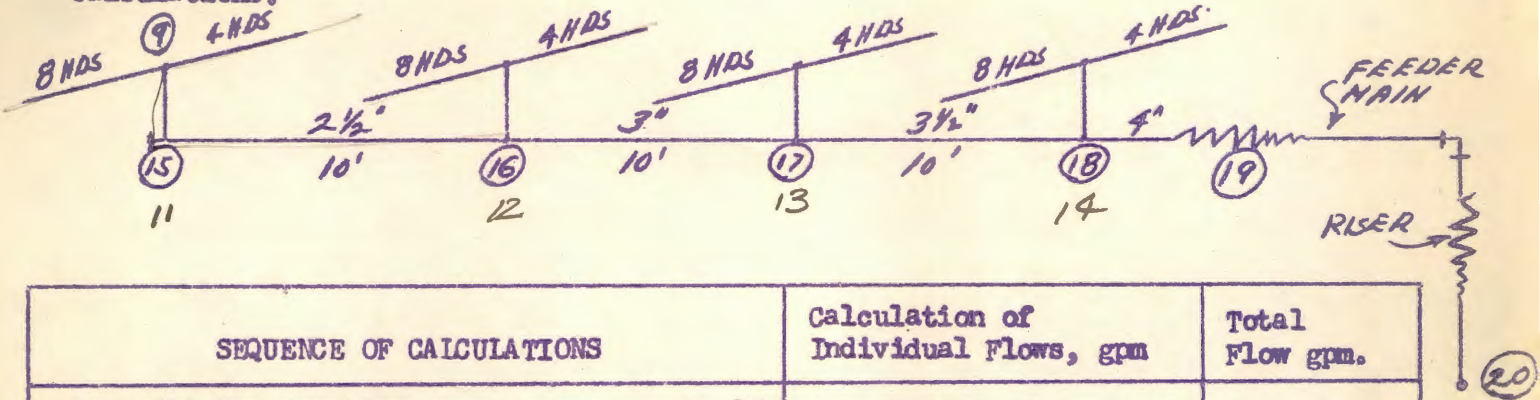
$$204.4 + 106.6 = \underline{311.0 \text{ gpm.}}$$

Referring once more to Example No. 1, Item 30, if the 12 sprinklers in the above branch line were supplied at the midpoint,

(a) The Total Flow from all sprinklers would be 289.58 gpm., a decrease of about 6.9% from the previously calculated unbalanced supply point.

(b) The Static Pressure Head hp at the midpoint has been calculated to be 63.26 ft. of water, a decrease of about 10.7 from the previously calculated unbalanced supply point.

EXAMPLE NO. 3 - Applying the information available from Example No. 2, calculate the total flow of water necessary to supply 48 sprinklers (4 12-head branch lines, 1/3 of the 144 sprinklers in the building); also calculate the Total Head at Point 20 H(20), as well as the Static Pressure Head h_p necessary to supply the 48 flowing sprinklers. The following sketch represents part of the cross-main involved in the calculations:



	SEQUENCE OF CALCULATIONS		Calculation of Individual Flows, gpm	Total Flow gpm.
1	hp(9) (at junction	70.85	$K = \frac{311}{\sqrt{88.14}} = \frac{311}{9.39}$	311.0
2	hv(15-9) 2½" pipe	6.80		
3	hf(1½ x 2 x 2½ Tee)		K = 33.12	
4	(k = 1.3) (hv = 6.80)	8.84		
5	hf(RN) 1 ft. 2½" pipe (0.65)	0.65	may be advisable	
6	Z (RN) (15-9)	1.00	to add in at end	
7	H (15)	88.14		
8	hf (16-15) 2½" pipe (0.65)	6.50		
9	H (16)	94.64	$Q(16) = 33.12\sqrt{87.84}$	
10	hv (16-15) 2½" pipe	-6.80	$= 33.12 \times 9.37$	
11	hn (16)	87.84	= 310.33	621.3
12	hv (17-16) 3" pipe	11.30		
13	hf (17-16) 10' of 3" (0.81)	8.10		
14	H(17	107.24	$Q(17) = 33.12\sqrt{93.04}$	
15	hv (18-17) T & E 3½" pipe	-14.20	$= 33.12 \times 9.65$	
16	hn (17)	93.04	= 319.6	940.9
17	H(17)	107.24		
18	hf(18-17) 10' of 3½" (0.88)	8.80		
19	H(18)	116.04	$Q(18) = 33.12\sqrt{100.34}$	
20	hv (19-18) T & E 4" pipe	15.70	$= 33.12 \times 10.02$	
21	hn (18)	100.34	= 331.9	1272.8 gpm
22	H(18)	116.04		Total
23	hf (two 4x4x2½ Tees)			Flow
24	(k = 0.9) (hv = 15.7) ....2×	14.13 = 28.26		
25	hf (19-18) 25' 4" pipe (0.81)	20.25		
26	hf (4x4x5 Tee, flgd.)			
27	(k = 0.65) (hv = 6.4)	4.16		
28	hf (5" flgd. Ell)			
29	(k = 0.3) (hv = 6.4)	1.92		
30	hf (20-19) 60' of 5" pipe (0.255)	15.30		
31	Z (Riser height)	20.00		
31	hf (6" flgd. ck. va.)			
32	(k = 2) (hv = 3.1)	6.20		
33	hf (6" flgd. gate va.)			
34	(k = 0.11) (hv = 3.1)	0.34		
35	H (20) 212.47	~~198.34~~ ft. of water		

212.47
~~198.34~~/2.31 ft. of water per psi = ~~85.9~~ psi (TOTAL HEAD AT POINT 20) 92

212.47 − 3.1 209.37

$$h_p = \frac{198.34 - 3.1}{2.31} = \frac{\cancel{195.24}}{2.31} = \cancel{84.5}\ \text{psi}$$ (STATIC PRESSURE HEAD) (AT POINT 20)

90.6

NOTATION USED IN EQUATIONS

Unless otherwise stated, the notation used is as follows:

C_d = Coefficient of discharge, orifices and nozzles.

D = Internal pipe diameter, inches.

d_o = Orifice or nozzle diameter, inches.

f = Friction factor for pipe flow, dimensionless.

g = Acceleration of gravity, ft/sec^2

H = Total Head = $h_p + z + h_v$, ft. of water.

h = Any fluid head, ft. of water.

h_f = Head lost in friction, ft. of water.

h_n = Head causing flow at a nozzle or orifice, ft. of water.

h_p = Static pressure head, ft. of water.

h_v = Velocity head, $V^2/2g$, ft. of water.

K = Constant in the equation $Q = K \sqrt{h}$

k = Loss coefficient for pipe fittings and other parts of a system, where h_f (fitting, etc.) = $k\ h_v$.

L = Length of pipe, feet.

N_R = Reynolds Number = $L\ V/\nu$, dimensionless.

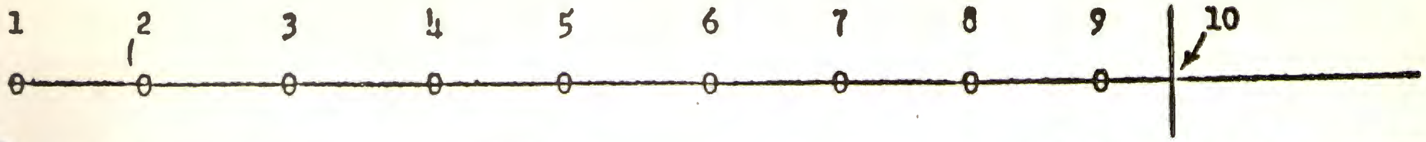
Q = Volume flow rate, gallons per minute (gpm).

V = Mean fluid velocity, ft/sec.

z = Elevation head above an arbitrary datum plane, ft. of water.

ϵ = Absolute pipe roughness factor, feet.

ν = Kinematic viscosity, sq. ft/sec.



No.	SEQUENCE OF CALCULATIONS	Individual Flow G.P.M.	Total Flow G.P.M.
1	H(1) = hn(1)	Q(1)	
2	hf(2-1)....(Ft. In. Pipe) +		
3	Z (2-1)............................+		
4	H(2)		
5	hv(2-1)....(In. Pipe) ....−		
6	hn(2)	Q(2)	
7	hv(3-2)....(In. Pipe)..........+		
8	hf(3-2)....(Ft. In. Pipe) +		
9	Z (3-2) ....+		
10	H(3)		
11	hv(4-3) T.&E. (In. Pipe) ....−		
12	hn(3)	Q(3)	
13	H(3) .... From Above		
14	hf(4-3) ...(Ft. In. Pipe).+		
15	Z (4-3) ....+		
16	H(4)		
17	hv(5-4) T.&E. (In. Pipe) ....−		
18	hn(4)	Q(4)	
19	H(4) .... From Above		
20	hf(5-4) ...(Ft. In. Pipe)+		
21	Z (5-4) ....+		
22	H(5)		
23	hv(6-5) T.&E. (In. Pipe) ....−		
24	hn(5)	Q(5)	
25	H(5) .... From Above		
26	hf (6-5)..(Ft. In. Pipe)+		
27	Z (6-5) ....+		
28	H (6)		
29	hv (7-6)T.&E. (In. Pipe) ....−		
30	hn(6)	Q(6)	
31	H(6) .... From Above		
32	hf (7-6)..(Ft. In. Pipe)+		
33	Z (7-6) ....+		
34	H(7)		
35	hv(8-7) T.&E. (In. Pipe) ....−		
36	hn(7)	Q(7)	
37	H(7) .... From Above		
38	hf(8-7) ..(Ft. In. Pipe)+		
39	Z (8-7) ....+		
40	H(8)		
41	hv (9-8) T.&E.(In. Pipe) ....−		
42	hn (8)	Q(8)	
43	H(8) .... From Above		
44	hf (9-8) .....(Ft. In. Pipe)+		
45	Z (9-8) ....+		
46	H(9)		
47	hv (10-9)T.&E.(In. Pipe) ....−		
48	hn (9)	Q(9)	
49	hn ( )		
50	hf ( ) .....(Ft. In. Pipe)+		
51	Z ( ) ....+		
52	hv ( ) ......(In. Pipe) ....+		
53	H ( )		

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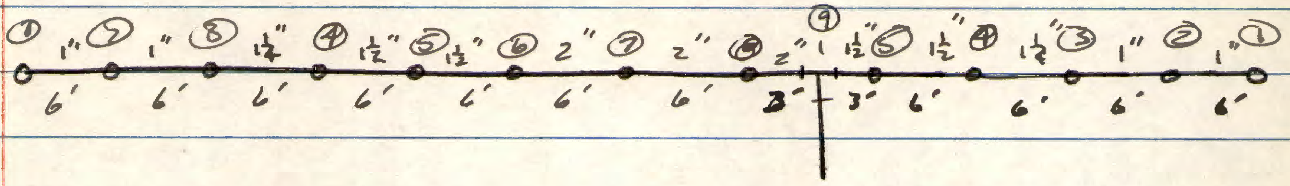
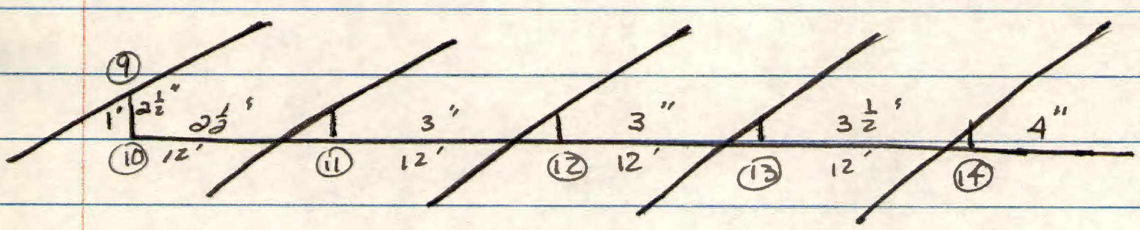
420 11-30-64

PROBLEM:



$Q_1 = 15\,GPM$

$Z = 0$



TOTAL FLOW IN?

+ head Causing flow

.26

$\frac{.35 \times 3}{1.05}$

$\frac{.26 \times 6}{1.56}$

$\frac{.33 \times 6}{1.98}$

$\frac{.185 \times 6}{1.110}$

$\frac{.28 \times 6}{1.68}$

$\frac{.57 \times 6}{3.42}$

$\frac{.15 \times 6}{.90}$

$\frac{.45 \times 6}{2.70}$

$Q_{TOTAL} = 140.7$ GPM
$h_m(9) = 29.53$ FT. H_2O } 8 head Side

$Q_{TOTAL} = 82.4$ GPM
$h_m(9) = 25.96 - 2.70 = 23.26$ FT H_2O } 5 head Side

$$\frac{Q_1}{Q_2} = \sqrt{\frac{h_1}{h_2}}$$

.7
.8

$$\frac{82.4}{Q_2} = \sqrt{\frac{23.26}{29.53}} = .888$$

$$Q_2 = \frac{82.4}{.888} = \boxed{92.7 \text{ GPM}}$$

$$\begin{array}{r} 92.7 \\ 140.7 \\ \hline 233.4 \end{array}$$

Q_{TOTAL} INTO BRANCH = 92.7 + 140.7
= 233.4 GPM 230

Pressure head at tee = 29.53 FT. H_2O

$h_m(13) = 48.9$
944 gpm into (13)

$H(3) \cong 64$

944 gpm thru $3\frac{1}{2}$" pipe
1000 is limit for $3\frac{1}{2}$" pipe – beyond this not economical

Itm. No.	Sequence of Calculations	Calculation of Individual Flows		Total Flow G.P.M.
1	$H(1) = h_n(1)$	16.50	$Q_1 = 15$	15
2	$h_f(2-1)$ 6' of 1"	.90		
3	$H(2)$	17.40		
4	$h_v(2-1)$ (1")	- .49		
5	$h_n(2)$	16.91	$Q_2 = 15.2$	30.20
6	$h_v(3-2)$ (1")	1.97		
7	$h_f(3-2)$ 6' of 1"	3.42		
8	$H(3)$	22.30		
9	$h_v(4-3)$ T+E 1¼"	- 1.53		
10	$h_n(3)$	20.77	Q_3 16.8	47.0
11	$H(3)$ from above	22.30		
12	$h_f(4-3)$ 6' of 1¼"	1.98		
13	$H(4)$	24.28		
14	$h_v(5-4)$ T+E 1½"	- 1.63		
15	$h_n(4)$	22.65	Q_4 17.6	64.6
16	$H(4)$ from above	24.28		
17	$h_f(5-4)$ 6' 1½"	1.68		
18	$H(5)$	25.96		
19	$h_v(6-5)$ T+E 1½"	- 2.70	Q_5 17.8	
20	$h_n(5)$	23.26		82.4
21	$H(5)$ from above	25.96		
22	$h_f(6-5)$ 6' 1½"	2.70		
23	$H(6)$	28.66		
24	$h_v(7-6)$ T+E 2"	- 1.46		
25	$h_n(6)$	27.20	Q_6 19.2	101.6
26	$H(6)$ from above	28.66		
27	$h_f(7-6)$ 6' 2"	1.11		
28	$H(7)$	29.77		
29	$h_v(8-7)$ T+E 2"	- 2.20		
30	$h_n(7)$	27.57	Q_7 19.4	121.0
31	$H(7)$ from above	29.77		
32	$h_f(8-7)$ 6' 2"	1.56		
33	$H(8)$	31.33		
34	$h_v(9-8)$ T+E 2"	- 2.85		
35	$h_n(8)$	28.48	Q_8 19.7	140.7
36	$H(8)$ from above	31.33		
37	$h_f(9-8)$ 3' 2"	1.05		
38	$H(9)$	32.38		
39	$h_v(9-8)$ from above	2.85		
40	$h_n(9)$	29.53		
41				
42				
43				
44				
45				
46				
47				
48				
49				

Itm. No.	Sequence of Calculations		Calculation of Individual Flows	Total Flow G.P.M.
	$h(P)$ 9	29.53	$Q_T(9)$	233.4
	h_f (1½" x 2" x 2½") tee			
	$k = 1.3$, $h_v = 3.85$	5.00		
	$h_f (10-9)$ 1' 2½" pipe (.38)	.38		
	$Z (10-9)$	1.00		
	$h_n (10)$	35.91	$K_{10} = \frac{233.4}{\sqrt{35.91}} = 39.6$	
	$h_f (11-10)$			
	$H(11)$			
	$h_v (11-10)$			
	$h_n (11)$			
	$h_v (12-11)$			
	$h_f (12-11)$			
	$H(12)$			
	$h_v (13-12)$ T+E			

5.88

$Q_{TOTAL} = K_{INLET} \sqrt{H_{INLET}}$

increase H_{inlet} by X to account for ageing

to $X H_{inlet}$

$\therefore Q_{TOTAL}$ will increase by $\sqrt{X}$

+ distribute its self.

h_f will increase along lengths of pipe

$h_f \text{ ft} = y \, h_f' \text{ ft/ft water } L$

we don't know what y is

$h_{f_{OLD}} = y \, h_f' L$

K <u>may</u> change too

Darcy Wethor $h_f = f \frac{L}{D} h_v$

$f = f\left(\frac{\varepsilon}{D/12}\right)$

Selection of proper pipe size

Curve C-8 Hydraulic Data Manual.

e.g. 1" pipe ~60 gpm, $h_v \cong 20-22$ is about limit

Try + keep well under 30, preferably close to 20 or 20-25 for h_v.

P

Itm. No.	Sequence of Calculations		Calculation of Individual Flows	Total Flow G.P.M.
1	$H(1) = h_n(1)$ ($K_n = 4.8$)	27.15	$Q(1) = 25.0$	25.0
2	h_f (1" 90° ell) $k = 1.4$ $h_v = 1.35$	+1.89		
3	$H(2)$	29.04	$K_2 = 25/\sqrt{29.04} = 4.65$	
4	$h_f(3\text{-}2)$ 6'-0" 1" PIPE (0.40)	2.40		
5	h_f (1" 90° ell) RE: ITEM 2	1.20		
6	$H(3)$	32.64		
7	$h_v(3\text{-}2)$ 1" pipe	−1.35		
8	$h_n(3)$	31.29	$Q_3 = 4.65\sqrt{31.29} = 26.0$	51.0
9	$h_v(4\text{-}3)$ 1¼" pipe	1.87		51.2
10	$h_f(4\text{-}3)$ 6' 1¼" pipe (.385)	2.31		
11	h_f (1¼" 90° ell) $K = 1.3$ $h_v = 1.87$	2.43		
12	$H(4)$	37.90		
13	$h_v(5\text{-}4)$ 1½" pipe T & E	2.40		
14	$h_n(4)$	35.50	$Q_4 = 4.65\sqrt{35.5} = 27.7$	78.7
15	$h_f(5\text{-}4)$ 2' 1½" pipe (.405)	.81		78.9
16	$h_P(5)$ (JUNCTION POINT 5)	$\boxed{36.31}$		
17	Branch lines symmetrical about pt 5			
		36.31	∴ $Q_5 = 78.7 \times 2 = 157.4$	157.4
18	h_f (1½" × 1½ × 2" tee)			157.8
	$k = 1.35$ $h_v = 3.54$	4.77		
19	$h_f(6\text{-}5)$ 5' 2" pipe (.432)	2.16		
20	$Z(6\text{-}5)$	1.00		
21	$h_n(6)$	45.24		
	Calculation of Branch line ABC to point 6			
22	$H(a) = h_n(a)$ ($K_n = 4.8$)	27.15	$Q(a) = 25.0$	25.0
23	$h_f(b\text{-}a)$ 3' 1" pipe (.40)	1.20		
24	$H(b)$	28.35		
25	$h_v(b\text{-}a)$ 1" pipe	1.35		
26	$h_n(b)$	27.00	$Q_b = 4.8\sqrt{27} = 24.9$	49.9
27	$h_f(b\text{-}c)$ 1'6" 1¼" pipe (.369)	.55	24.9	49.9
28	$h_P(C)$	27.55		
	Branch lines symmetrical about Junction pt C			
29	$h_P(C)$ (Item 28)	27.55	$Q_c = 49.9 \times 2 = 99.8$	99.8
30	h_f (1¼ × 1¼ × 2" tee)			99.8
	$k = 1.35$ $h_v = 1.42$	1.92		
31	h_f (RN) 1' 2" pipe ( )	.18		
32	h_v (RN) 2" pipe	1.42		
33	Z (RN)	1.00	17.6	
34	$H(6)$ (Inlet to RN @ point (6))	32.07	$K_6 = 99.8/\sqrt{32.07} = 17.5$	
	Continuation from Item 21 @ pt. 6			157.4
35	$h_n(6)$ (Item 21)	45.24	$Q(6) = 17.5\sqrt{45.24} = 117.5$	117.5
				274.9
36	Note: Increase flows in Sprinklers		A & B above	
	point (6) by			

Itm. No.	Sequence of Calculations	Calculation of Individual Flows	Total Flow G.P.M.

F. P. E. XXXX 420

Problems No. 1 XXXXXXXXXXX 20 Page 1.

COUNTS 1 EXAM

OCCUPANCY: Sketches represent a portion of a light metalworking plant, with alkali and acid treating and plating vats on the second floor.

CONSTRUCTION: Two stories, with full basement; concrete foundation supporting brick walls; basement floor concrete. Construction of first and second floors are exactly the same, as shown on Page 2; roof construction is as shown on Second Floor Ceiling Plan, Page 3.

Open elevator shaft extends through all floors and roof; 3' elevator pit in basement, below finished floor; 18" draft curtains around elevator and adjoining stairway floor openings at allXXX ceiling levels. Stairway extends through all floors.

Heat provided by steam coils along walls.

Elevations are as follows:

(a) Finished basement floor to finished first floor ---- 10 feet.

(b) Finished basement floor to grade ---- 6 feet.

(c) Underground water supply piping buried 4'-6" below grade.

(d) Finished first floor to finished second floor ---- 13'-1½". 13.125'

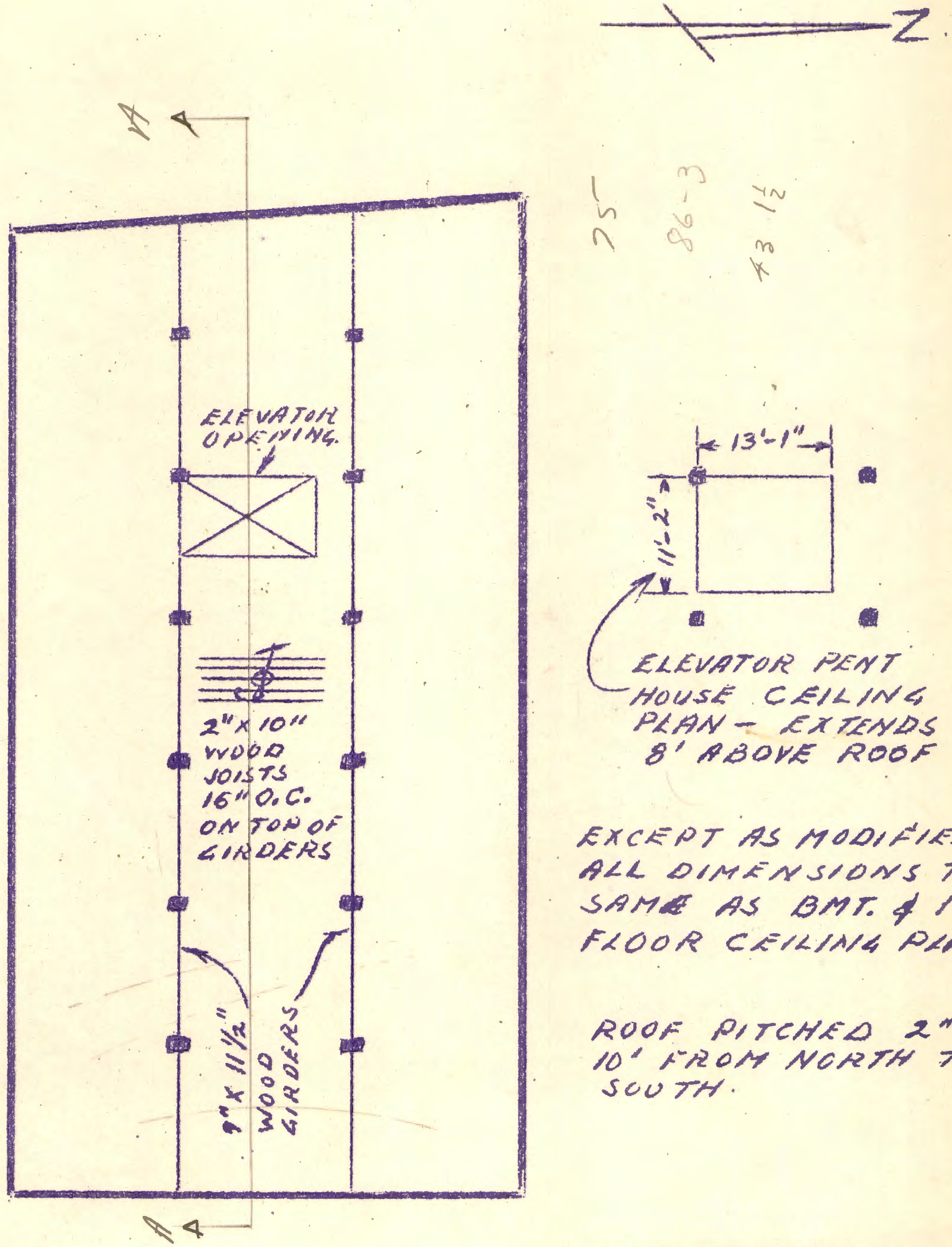
(e) Finished second floor to underside of roof joists at north wall of building ---- 12 feet. @ South wall of bldg — 11' 2"

(f) Roof pitched 2" in 10' from north to south.

PROBLEM: PART A - Prepare working plans for sprinkler installation in this building drawn to a scale of 1/8" equals 1 foot. Include plan views and necessary elevations to show details, together with water supply connection, fire department connection, and other essentials.

PART B - It has been decided to design the sprinkler system to deliver water at a minimum application rate of 0.25 gpm/sq ft. Calculate the gage pressure at the riser in the basement necessary to supply approximately 25% and 50% of the sprinklers on each floor, including basement; also calculate the total water demand to supply XXXX these sprinklers.

6



ELEVATOR PENT HOUSE CEILING PLAN - EXTENDS 8' ABOVE ROOF

EXCEPT AS MODIFIED, ALL DIMENSIONS THE SAME AS BMT. & 1ST FLOOR CEILING PLAN.

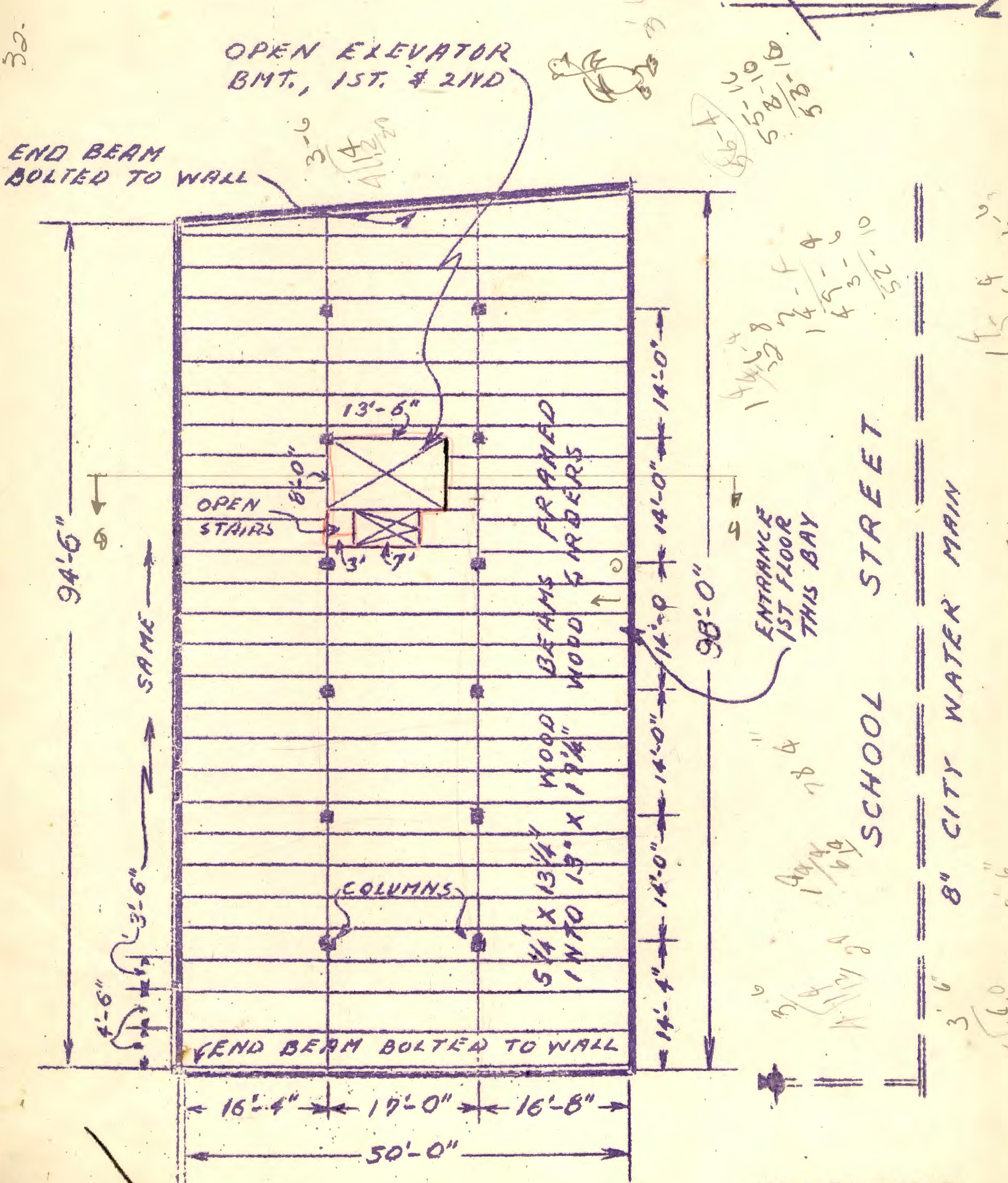
ROOF PITCHED 2" IN 10' FROM NORTH TO SOUTH.

SECOND FLOOR CEILING PLAN (ROOF)

~~[illegible], 1937~~

W. G. LABES

SCALE: 1/16" = 1'



BASEMENT & FIRST FLOOR
CEILING PLAN

W. G. LABES
SCALE:- 1/16" = 1'

420

Exam Jan. 6

Q_T = [illegible] $\boxed{Q_T = 843}$ for the water spray problem.

$h_m(6)$

[redacted]

$Q_6 = 280.6$?

$Q_5 = 157.8$

Q_{ABC} 99.72 → 122.8

$\alpha\ 1.23 \cong 1.25 = \frac{25}{20}$

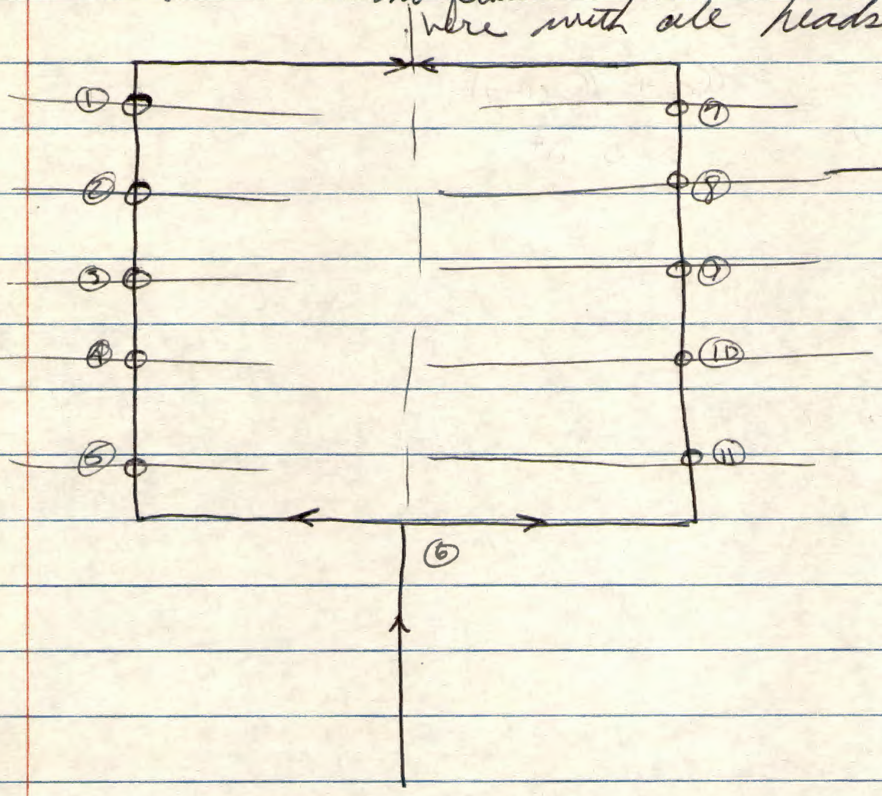
Pg. 39 ~~of~~ pamphlet 15

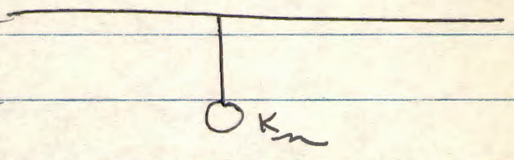
Item b. etc. which fittings to include + neglect in calculations

FPE 420

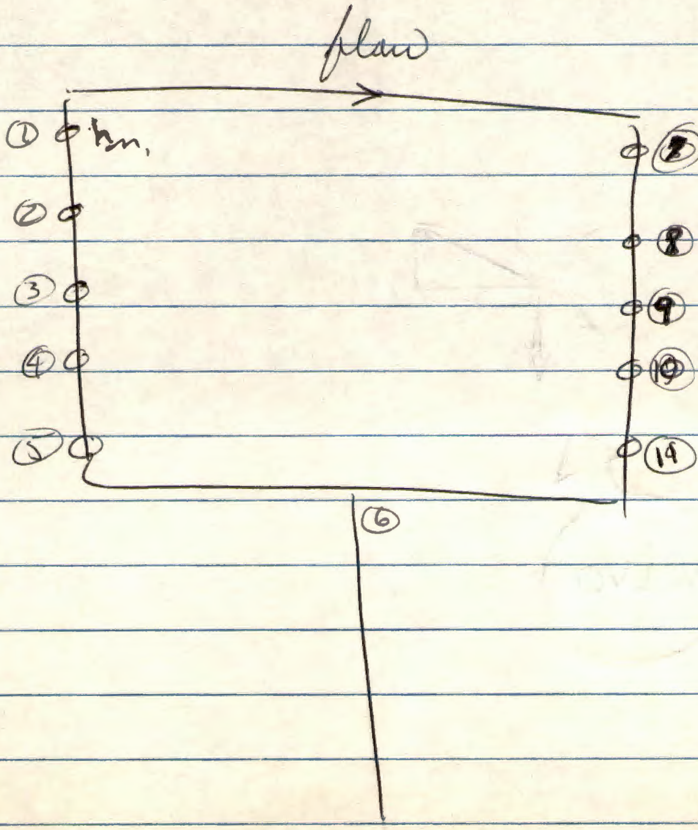
12-14-64

If perfectly Balanced no flow here with all heads open.





$$Q = K_n \sqrt{h_n}$$



if there is flow

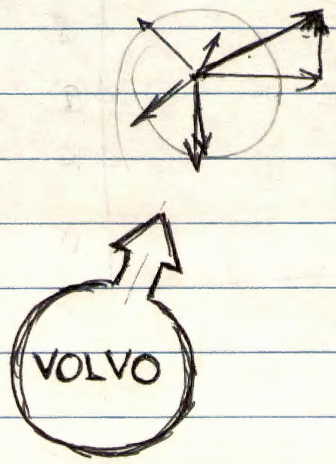
$$h_{n_1} = \frac{Q^2}{K_n}$$

$$H_1 = h_{n_1} + h_{v(2-1)}$$

↑

may be $h_{v_{1-7}}$ but must test experimentally & find out for sure we can get h_{m}, knowing Q_1 + h_m

$$h_{v(2-1)} = \frac{Q_1 + Q_{(1-7)}}{385\ D^4}$$



420

Fall
1964

ILLINOIS INSTITUTE OF TECHNOLOGY
CHICAGO

FPE **DEPARTMENT**

TITLE SPRINKLER SYSTEM DESIGN **EXP. No.**

Name LUCHT - FPE 420 Group No.

12-14-64

Laboratory Day

Grade 93

Instructor LABES

Dates Performed

Date Presented

Returned for Correction

Returned After Correction

F.P.E. 420 ave 81 93 **LUCHT**

1. Plans are usually drawn with NORTH at the top or right.

D ✱ 2. Provide flushing connections at the ends of cross mains

3. Indicate underground supply main as cast iron - 6" C.I.

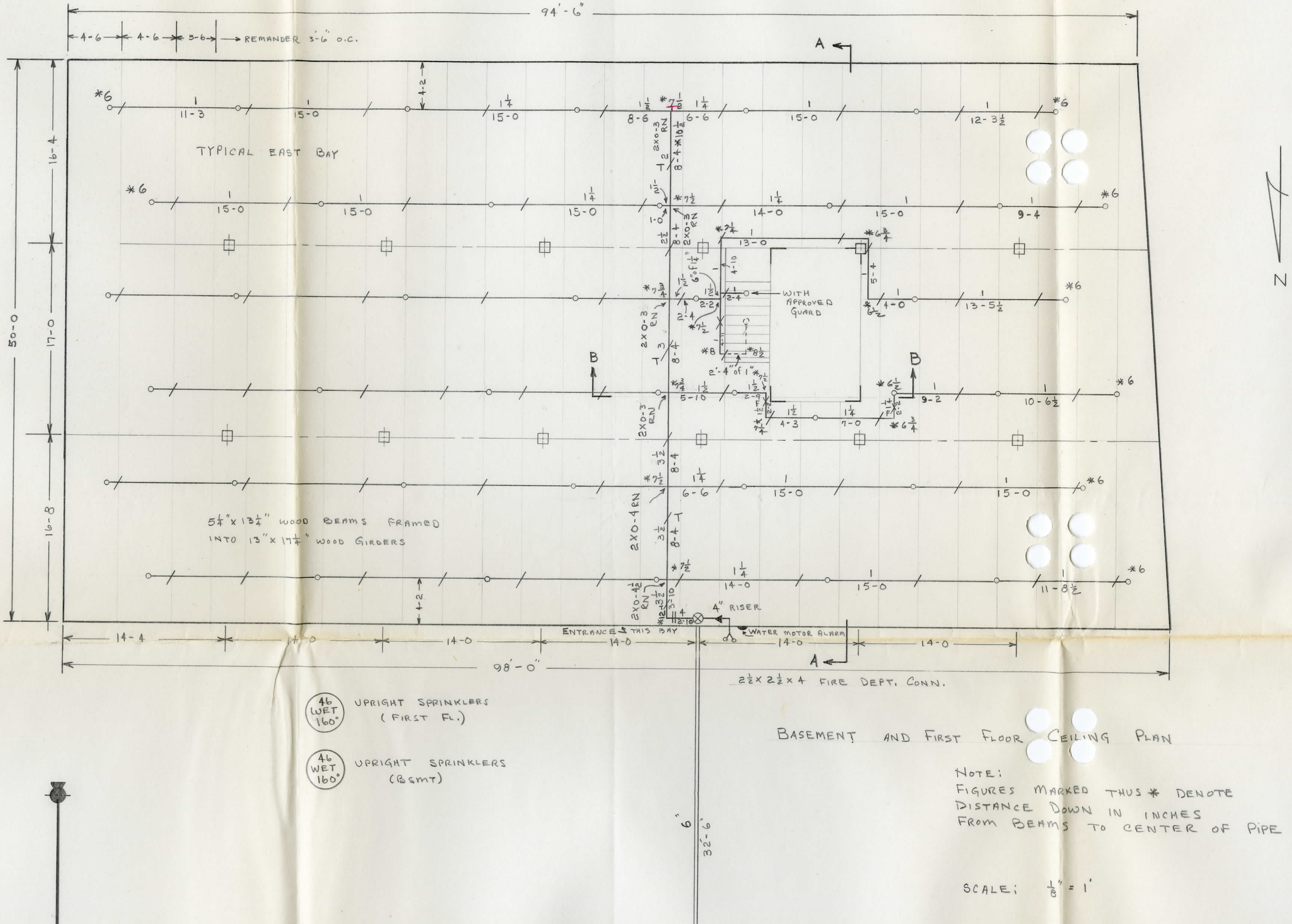
D ✱ 4. Provide check valve in F.D. Conn equipped with ball drip.

D ✱ 5. RE: 1st Story and Bsmt Plan, believe you may have difficulty with trapped pipe because branch line crosses under girder.

6. Indicated heated pent ~~house~~ house or provide for cold weather protection

B 7. Label elevator, stairway and elevator pit.

8.



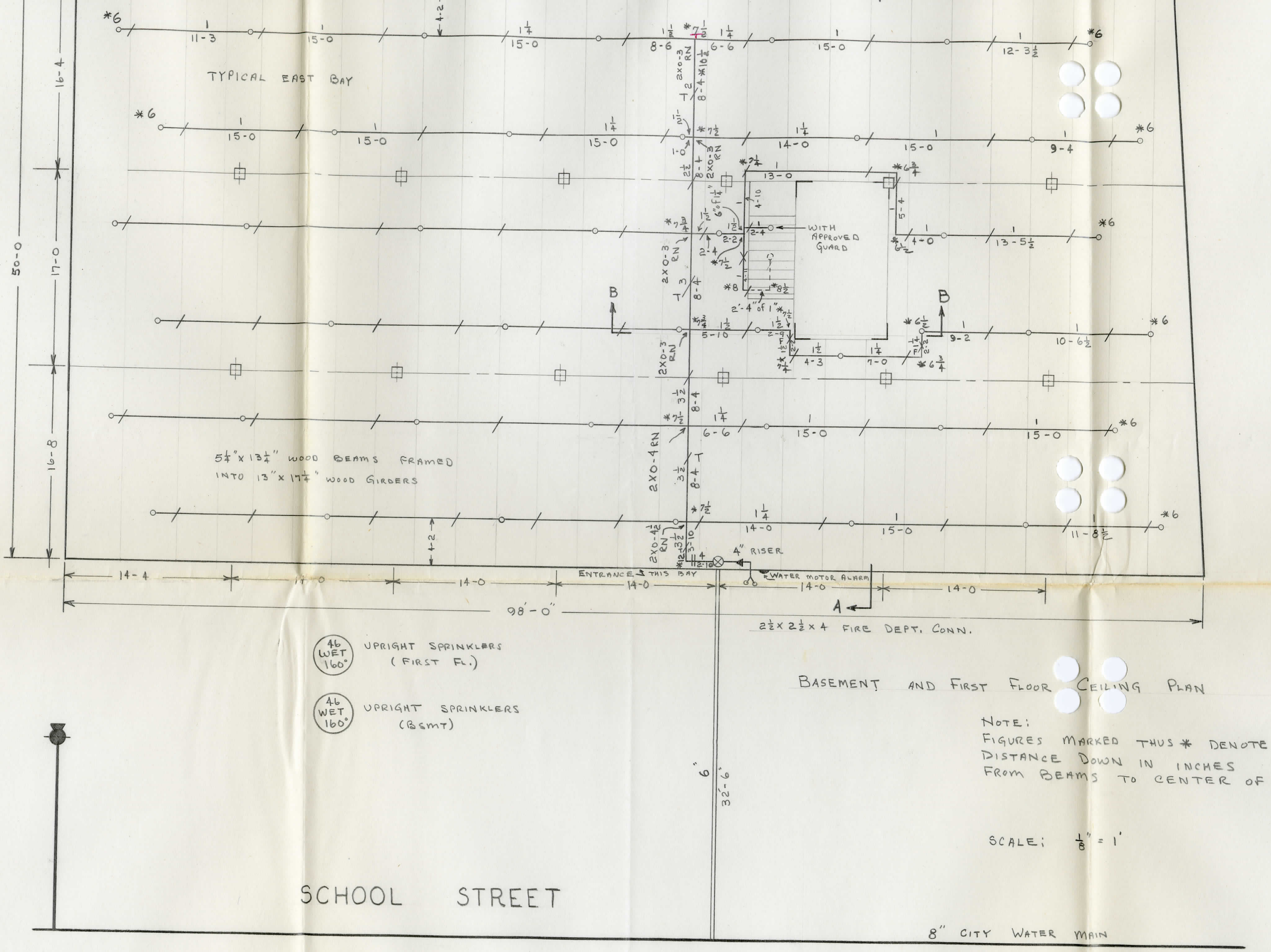
46 WET 160° UPRIGHT SPRINKLERS (FIRST FL.)

46 WET 160° UPRIGHT SPRINKLERS (BSMT)

BASEMENT AND FIRST FLOOR CEILING PLAN

NOTE:
FIGURES MARKED THUS * DENOTE
DISTANCE DOWN IN INCHES
FROM BEAMS TO CENTER OF PIPE

SCALE: ⅛" = 1'



46 WET 160° UPRIGHT SPRINKLERS (FIRST FL.)

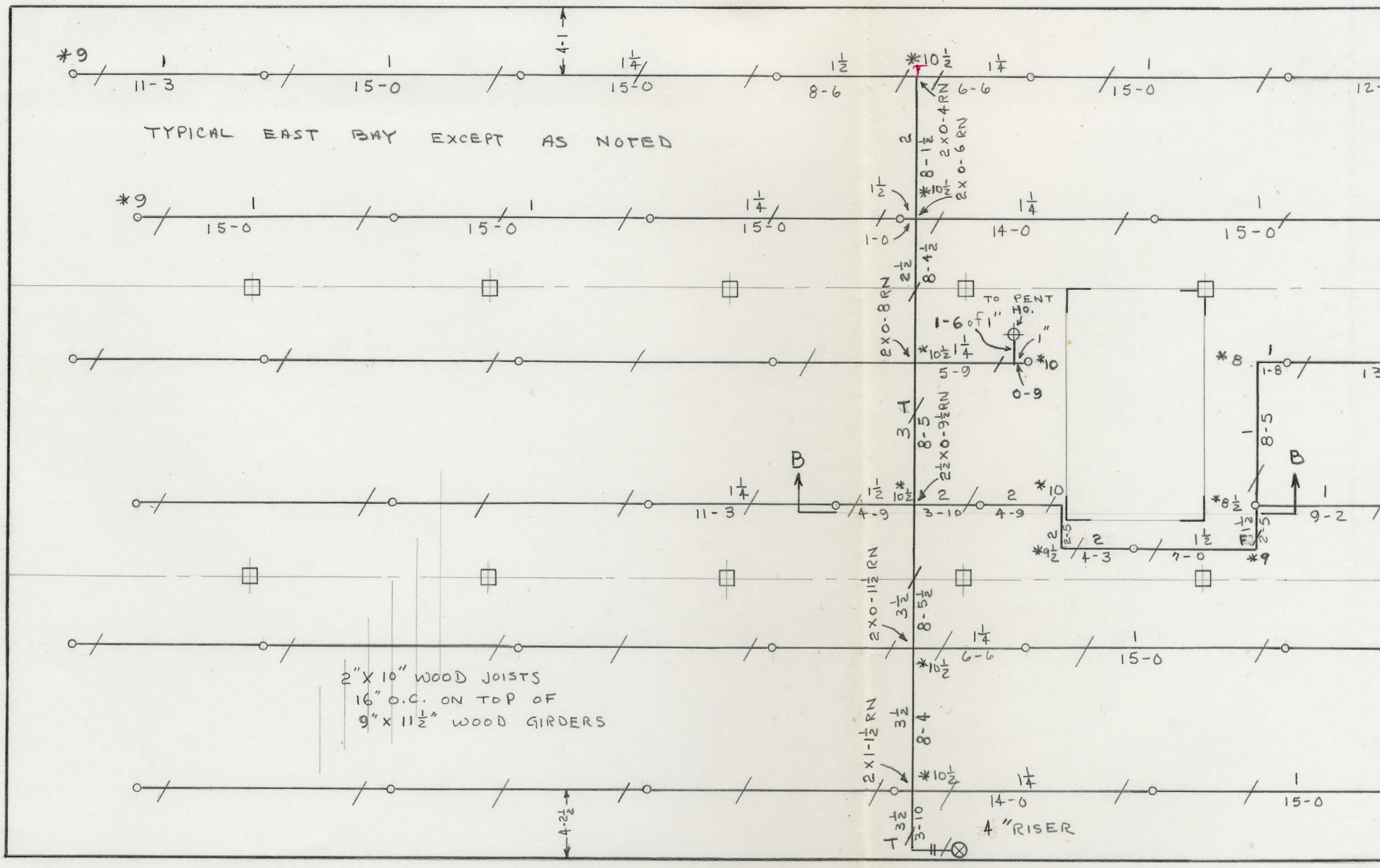
46 WET 160° UPRIGHT SPRINKLERS (BSMT)

BASEMENT AND FIRST FLOOR CEILING PLAN

NOTE:
FIGURES MARKED THUS * DENOTE
DISTANCE DOWN IN INCHES
FROM BEAMS TO CENTER OF PIPE

SCALE: ⅛" = 1'

D. LUCHT
F.P.E. 420

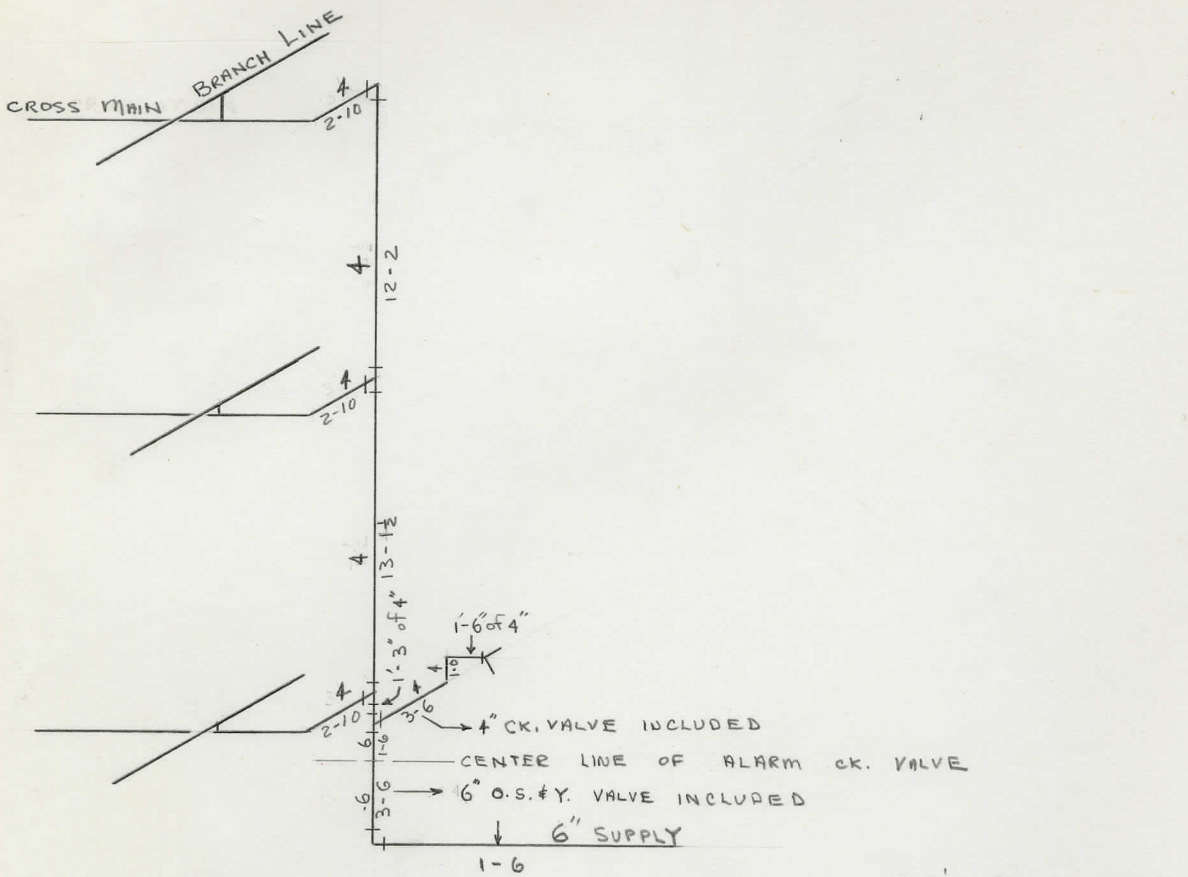


SECOND FLOOR OR ROOF PLAN

NOTE:
FIGURES W
DISTANCE
OF JOISTS

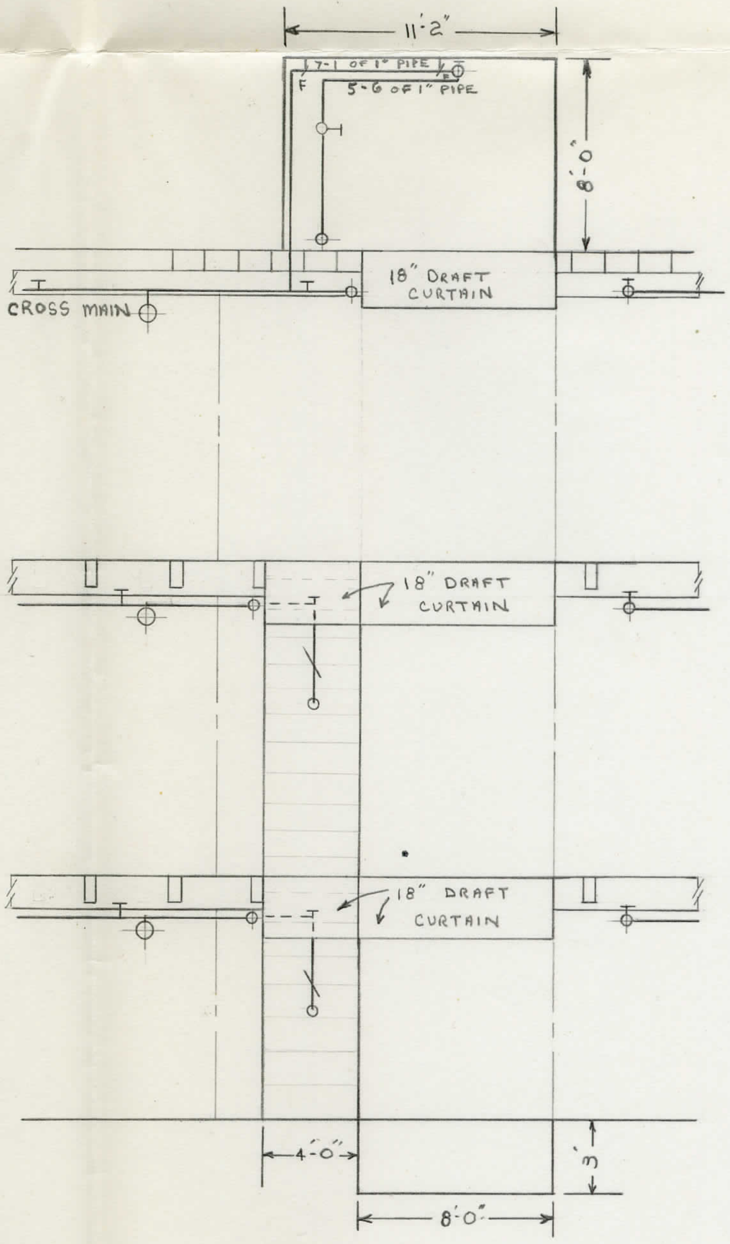
46
WET
160°

UPRIGHT SPRINKLERS
CORR. RESISTANT

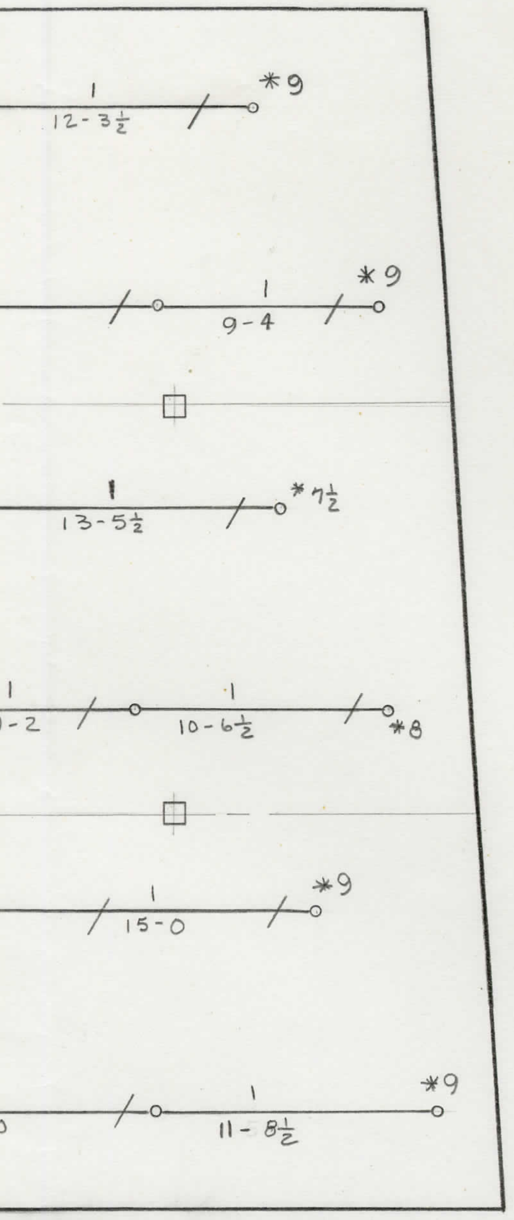


ISOMETRIC VIEW OF RISER CONNECTIONS

₵ TO ₵ LENGTHS AND FLANGED JOINTS INDICATED



ELEVATION "B-B"



:
ES MARKED THUS * DENOTE
ANCE IN INCHES FROM BOTTOM
JOISTS TO CENTER OF PIPE.

NOTE:

APPROVED CORROSION-RESISTANT OR SPECIAL COATED SPRINKLERS TO BE INSTALLED TO WITHSTAND CORROSIVE VAPORS ON SECOND FLOOR AND ELEVATOR HOUSE. ALL UPPER STORY PIPING ALSO TO BE PROPERLY PROTECTED.

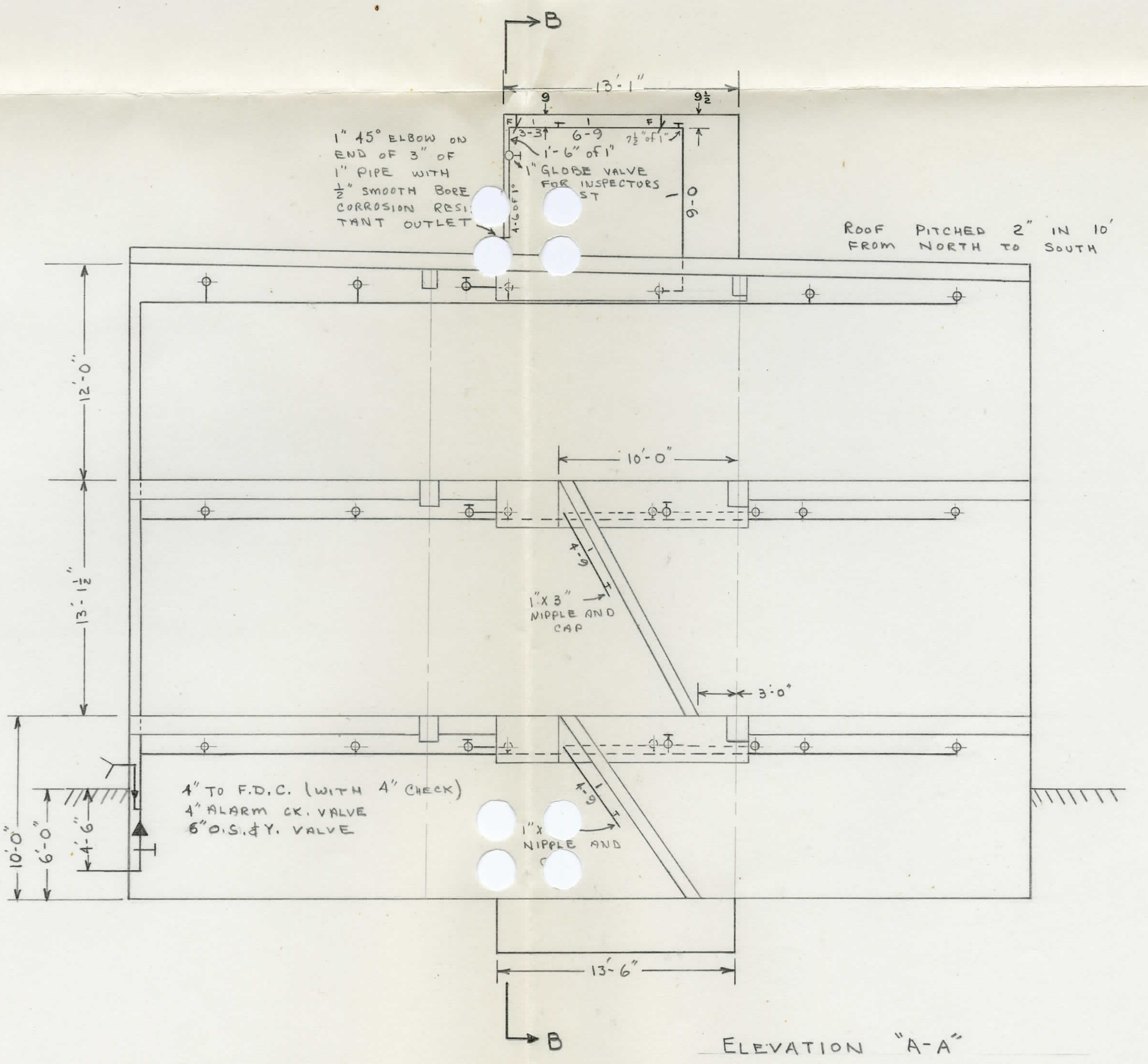
ALL HANGERS ARE STANDARD U-TYPE FOR THE RESPECTIVE SIZE PIPE AND APPLICATION EXCEPT THOSE OTHERWISE MARKED AS FOLLOWS:

T TRAPEZE HANGER
F CEILING FLANGES

HANGERS LOCATED CLOSE TO SPRINKLERS ARE APPROXIMATELY 18" FROM SPRINKLERS

ASSUME 5" FROM DEFLECTOR TO ℄ OF BRANCH LINE

SCALE: ⅛" = 1'



ELEVATION "A-A"

ILLINOIS INSTITUTE OF TECHNOLOGY

NAME D. LUCHT

SUBJECT

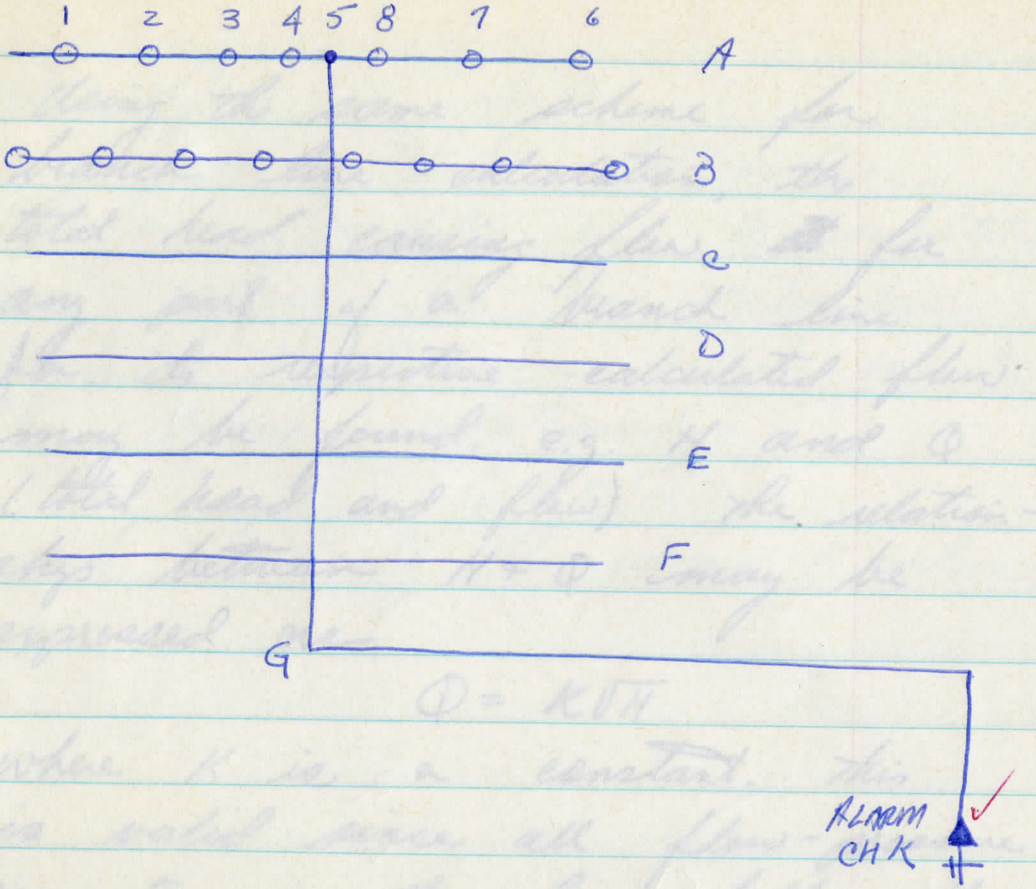
CLASS DATE

INSTRUCTOR

1	-5	11	
2	✓	12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	

-5

95



h_f = friction loss } obtain from curves
h_v = vel. head

Q_A, Q_B etc = total flow into Riser

Q_1, Q_2, etc = flow in head 1, 2, etc.

Nipple

✓ 2. Using the same scheme for branch line calculation, the total head causing flow ~~at~~ for any part of a branch line for its respective calculated flow may be found. e.g. H and Q (total head and flow) the relationships between H & Q may be expressed as

$$Q = K\sqrt{H}$$

where K is a constant. this is valid since all flow-pressure parameters in the line follow the same relationships, i.e.

$$Q = K_v \sqrt{H_v}$$ for vel. head

$$Q = K_f \sqrt{H_f}$$ for friction loss

It must be noted that elevation head does not follow the same relationships, but for ordinary drainage requirements, the effect is negl.

Knowing this relationship therefore, enables one to substitute an orifice for the particular part of the branch which exibits the same relationship

$$Q = K\sqrt{H}$$

with identically the same K value.

LUCHT

①

Itm. No.	Sequence of Calculations	Calculation of Individual Flows	Total Flow G.P.M.
	- Branch Lines A -		
1. ✓	Assume a flow in head # 1 and find h_n from curves or knowing K value of sprinkler		
		Q_1 ✓	Q_1 ✓
2 ✓	$H(1) = h_n(1)$		
✓	$+ h_f(2-1)$		
	+ 0 (elevation diff. negl.)		
✓	$H(2)$		
✓	$- h_v(2-1)$		
✓	$h_n(2)$	Q_2 ✓	$Q_1 + Q_2$ ✓
✓	$+ h_f(3-2)$		
✓	$+ h_v(3-2)$		
✓	$H(3)$		
✓	$- h_v(4-3)$ T+E ✓		
✓	$h_n(3)$	Q_3 ✓	$Q_1 + Q_2 + Q_3$ ✓
✓	$H(3)$ from above		
✓	$+ h_f(4-3)$		
✓	$H(4)$		
✓	$- h_v(5-4)$ T+E ✓		
✓	$h_n(4)$	Q_4 ✓	etc. ✓
	~~H(4) from above~~		
✓	$+ h_f$ 5-4		
✓	$h(P)5$		
✓	now Calculate Right Branch line of A same as left and get another $h(P)5'$		
	since $h(P)5 \neq h(P)5'$ multiply the flow into the lower pressure line by $\cancel{X}\sqrt{\frac{h(P)5'}{h(P)5}}$ (which it will be assumed in 71)	Assume $h_{P_5} > h'_{P_5}$ ∴ $\sqrt{\frac{h_{P_5}}{h'_{P_5}}}$	
✓	To this product add the flow in the other branch and get total flow into RN A		Q_A ✓
✓	$h(P)5$		
✓	$+ h_f$ in Tee at Top of RNA		
✓	$+ h_v$ in RNA		
✓	+ length of RNA		

eg. chose a Q_3, get h_v from $Q_1+Q_2+Q_3$, get $h_n(3)$ + see if this ~~matches~~ corresponding flow ~~[illegible]~~ matches Q_3

-5

✓ $+ h_f$ in RNA

✓ H (at bottom of RNA)

Itm. No.	Sequence of Calculations	Calculation of Individual Flows	Total Flow G.P.M.
✓	$K(RN)A = Q_A / \sqrt{H(\text{bottom RN A})}$		
✓	H(bottom of RN A)		
✓	$+ h_f(B-A)$		
✓	$H(B)$		
✓	$- h_v(B-A)$		
✓	$h_n(B) \Longrightarrow Q_B = K_B\sqrt{h_n(B)}$ ✓	(Must adjust flows in heads in lines B)	$Q_A + Q_B$ ✓
	(calculate K_B same as K_A ✓		
✓	$h_n(B)$		
✓	$+ h_v(C-B)$		
✓	$+ h_f(C-B)$		
✓	$H(C)$		
✓	$- h_v(D-C)$ T+E ✓		
✓	$h_n(C)$ Q_C ✓ $= K_A\sqrt{h_n(C)}$		$Q_A + Q_B + Q_C$

Follow this same procedure which is identical to the Branch line calculation using
✓ $K_A = K_C = K_E$
✓ $K_B = K_D = K_F$
until $h_n(F)$ is obtained (head causing flow at bottom of RN F.

See pg 2A

to $h_n(F)$ add h_f from RNF to the alarm check valve plus the elevation difference and obtain the pressure head at the valve at the calculated total flow, Q_T

where $Q_T = Q_A + Q_B + Q_C + Q_D + Q_E + Q_F$

Suggest you start with H_F instead of $h_n(F)$.
and then subtract h_v(4" Riser) from H(4" Riser)
to get h_P(4" Riser). You can visualize ~~that~~
$h_v(G-F) \geqslant h_v$(4" RISER).

Itm. No.	Sequence of Calculations	Calculation of Individual Flows	Total Flow G.P.M.
✓	$H(C)$ from above		
✓	$+h_f\ (D-C)$		
✓	$H(D)$		
✓	$-h_v\ (E-D)$ T+E ✓		
✓	$h_n\ (D)$ $Q_D = K_B \sqrt{h_n(D)}$	Q_D	
✓	$H(D)$ from above		
✓	$+h_f\ (E-D)$		
✓	$H(E)$		
✓	$-h_v\ (F-E)$ T+E		
✓	$h_n(E)$ ✓ $Q_E = K_A \sqrt{h_n(E)}$	Q_E	
✓	$H(E)$ from above		
✓	$+h_f(F-E)$		
✓	$H(F)$		
✓	$-h_v\ (G-F)$		
✓	$h_n\ (F)$ ✓ $Q_F = K_B \sqrt{h_n(F)}$	Q_F	Q_T

PHYSICAL PROPERTIES OF CARBON DIOXIDE

Courtesy
Cardox Corporation
Bell Building
Chicago, Illinois

Table 9
Solid and Saturated Carbon Dioxide

(Values from Plank and Kuprianoff (6) converted by G. C. Hodsdon (7), arranged by Editor)

atm

Temp.	Pressure	Volume		Total Heat from −40°			Entropy from −40° plus 1.0	
°F t	Abs. lb./in.^{2} p	Solid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Solid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Solid Btu./lb.°F s_f	Vapor Btu./lb.°F s_g
−140	3.18	0.01008	24.320	−121.5	250.7	129.2	0.6847	1.4690
−130	5.39	0.01012	14.740	−118.8	249.4	130.6	0.6932	1.4500
−120	8.90	0.01018	9.179	−116.0	248.0	132.0	0.7014	1.4418
−115	11.31	0.01021	7.279	−114.6	247.3	132.7	0.7055	1.4231
−110	14.22	0.01024	5.848	−113.2	246.4	133.2	0.7096	1.4145
−109	14.88	0.01025	5.597	−112.9	246.2	133.3	0.7105	1.4128
−108	15.57	0.01026	5.358	−112.6	246.0	133.4	0.7114	1.4111
−107	16.29	0.01027	5.129	−112.3	245.8	133.5	0.7123	1.4085
−106	17.04	0.01027	4.911	−112.0	245.6	133.6	0.7132	1.4079
−105	17.82	0.01028	4.703	−111.6	245.4	133.8	0.7141	1.4063
−104	18.63	0.01029	4.505	−111.3	245.2	133.9	0.7150	1.4045
−103	19.48	0.01030	4.316	−111.0	245.0	134.0	0.7159	1.4029
−102	20.36	0.01031	4.138	−110.7	244.8	134.1	0.7168	1.4013
−101	21.27	0.01031	3.967	−110.4	244.6	134.2	0.7177	1.3997
−100	22.22	0.10132	3.804	−110.1	244.4	134.3	0.7185	1.3981
−99	23.20	0.01033	3.648	−109.8	244.1	134.3	0.7194	1.3965
−98	24.22	0.01033	2.499	−109.5	243.9	134.4	0.7203	1.3949
−97	25.28	0.01034	3.357	−109.2	243.6	134.4	0.7212	1.3933
−96	26.39	0.01035	3.222	−108.9	243.4	134.5	0.7221	1.3917
−95	27.54	0.01035	3.093	−108.5	243.2	134.7	0.7231	1.3901
−94	28.73	0.01036	2.970	−108.1	242.9	134.8	0.7241	1.3905
−93	29.97	0.01037	2.852	−107.8	242.7	134.9	0.7251	1.3969
−92	31.26	0.01038	2.738	−107.4	242.4	135.0	0.7261	1.3953
−91	32.69	0.01039	2.629	−107.0	242.1	135.1	7.7271	1.3937
−90	33.98	0.01040	2.525	−106.7	241.8	135.1	0.7281	1.3821
−89	35.41	0.01040	2.425	−106.3	241.5	135.2	0.7291	1.3806
−88	36.89	0.01041	2.330	−105.9	241.1	135.2	0.7302	1.3790
−87	38.43	0.01042	2.240	−105.5	240.8	135.3	0.7313	1.3774
−86	40.02	0.01043	2.153	−105.1	240.4	135.3	0.7323	1.3758
−85	41.67	0.01044	2.070	−104.6	240.1	135.5	0.7333	1.3742
−84	43.38	0.01045	1.995	−104.2	239.7	135.5	0.7344	1.3727
−83	45.15	0.01046	1.913	−103.8	239.3	135.5	0.7355	1.3711
−82	46.98	0.01047	1.839	−103.4	238.9	135.5	0.7366	1.3695
−81	48.88	0.01048	1.768	−103.0	238.6	135.6	0.7377	1.3679
−80	50.85	0.01048	1.700	−102.5	238.2	135.7	0.7399	1.3663
−79	52.89	0.01049	1.636	−102.0	237.7	135.7	0.7400	1.3648
−78	55.00	0.01050	1.575	−101.5	237.3	135.8	0.7412	1.3632
−77	57.19	0.01051	1.516	−101.1	236.9	135.3	0.7424	1.3616
−76	59.45	0.01052	1.460	−100.5	236.4	135.8	0.7436	1.3600
−75	61.79	0.01053	1.407	−100.2	236.0	135.8	0.7447	1.3584
−74	64.21	0.01054	1.356	−99.8	235.6	135.8	0.7458	1.3568
−73	66.72	0.01055	1.306	−99.3	235.1	135.8	0.7469	1.3553
−72	69.33	0.01057	1.257	−98.9	234.8	135.9	0.7481	1.3538
−71	72.03	0.01058	1.209	−98.4	234.3	135.9	0.7493	1.3523
−70	74.82	0.01059	1.162	−98.0	233.9	135.9	0.7506	1.3508
−69.9	75.10	0.01059	1.157	−97.9	233.8	135.9	0.7507	1.3506

Table 10
Saturated Carbon Dioxide

TRIPPLE POINT.

Temp.	Pressure	Volume		Total Heat from −40°			Entropy from −40° plus 1	
°F t	Abs. lb./in.^{2} p	Liquid ft.^{3}/lb. v_f	Vapor ft.^{3}/lb. v_g	Liquid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Liquid Btu./lb.°F s_f	Vapor Btu./lb. °F s_g
−69.9	75.1	0.01360	1.1570	−13.7	149.6	135.9	0.9677	1.3506
−68.0	78.6	0.01365	1.1080	−12.9	148.9	136.2	0.9688	1.3490
−66	82.4	0.01369	1.0589	−11.9	148.1	136.2	0.9711	1.3474
−64	86.4	0.01374	1.0125	−11.0	147.3	136.0	0.9734	1.3459
−62	90.5	0.01379	0.9686	−10.1	146.6	136.5	0.9757	1.3444
−60	94.7	0.01384	0.9270	−9.2	145.8	136.6	0.9777	1.3429
−58	99.1	0.01389	0.8875	−8.3	145.0	136.7	0.9802	1.3414
−56	103.7	0.01393	0.8502	−7.4	144.2	136.8	0.9824	1.3399
−54	108.4	0.01398	0.8149	−6.5	143.4	136.9	0.9847	1.3384
−52	113.2	0.01404	0.7812	−5.6	142.7	137.1	0.9869	1.3369
−50	118.2	0.01409	0.7492	−4.7	141.9	137.2	0.9892	1.3354
−48	123.4	0.01414	0.7188	−3.8	141.1	137.3	0.9913	1.3340
−46	128.7	0.01420	0.6899	−2.9	140.3	137.4	0.9935	1.3326
−44	134.2	0.01425	0.6624	−2.0	139.5	137.5	0.9957	1.3312
−42	139.9	0.01431	0.0362	−1.0	138.7	137.7	0.9978	1.3298
−40	145.8	0.01437	0.6113	.00	137.8	137.8	1.0000	1.3285
−38	151.8	0.01442	0.5876	+.9	136.9	137.8	1.0021	1.3271
−36	158.0	0.01448	0.5649	1.8	136.2	138.0	1.0043	1.3257
−34	104.4	0.01454	0.5433	2.7	135.4	138.1	1.0064	1.3244
−32	171.0	0.01460	0.5227	3.6	134.5	138.1	1.0085	1.3231
−30	177.8	0.01466	0.5029	4.5	133.7	138.2	1.0107	1.3218
−28	184.8	0.01472	0.4841	5.4	132.9	138.3	1.0127	1.3206
−26	192.0	0.01479	0.4661	6.3	132.0	138.3	1.0148	1.3193
−24	199.4	0.01485	0.4489	7.2	131.2	138.4	1.0169	1.1380
−22	207.0	0.01491	0.4325	8.1	130.3	138.4	1.0190	1.3167
−20	214.9	0.01498	0.4168	9.1	129.4	138.5	1.0212	1.3154
−18	223.0	0.01504	0.4092	10.1	128.5	138.6	1.0232	1.3140
−16	231.2	0.01511	0.3872	11.1	127.6	138.7	1.0252	1.3127
−14	239.6	0.01518	0.3666	12.0	126.7	138.7	1.0272	1.3115
−12	248.3	0.01525	0.3600	12.9	125.8	138.7	1.0283	1.3103
−10	257.3	0.01532	0.3472	13.9	124.8	138.7	1.0314	1.3091
−8	266.5	0.01540	0.3349	14.9	123.9	138.8	1.0334	1.3078
−6	275.9	0.01547	0.3231	15.9	122.9	138.8	1.0355	1.3065
−4	285 4	0.01555	0.3118	16.9	122.0	138.9	1.0376	1.3053
−2	295.3	0.01563	0.3009	17.9	121.0	138.9	1.0397	1.3041
0	305.5	0.01570	0.2904	18.8	120.1	138.9	1.0418	1.3029
2	315.9	0.01579	0.2803	19.8	119.0	138.8	1.0439	1.3017
4	326.5	0.01588	0.2707	20.8	118.0	138.8	1.0460	1.3006
6	337.4	0.01596	0.2614	21.8	116.9	138.7	1.0481	1.2994
8	348.7	0.01605	0.2526	22.9	115.8	138.7	1.0520	1.2982
10	360.2	0.01614	0.2437	24.0	114.7	138.7	1.0536	1.2980
12	371.9	0.01623	0.2354	25.0	113.6	138.6	1.0558	1.2967
14	383.9	0.01632	0.2274	26.1	112.5	138.6	1.0580	1.2955
16	396.2	0.01642	0.2197	27.2	111.3	138.5	1.0602	1.2943
18	408.9	0.01652	0.2121	28.3	110.1	138.4	1.0625	1.2931

Saturated Carbon Dioxide (concluded)

Temp.	Pressure	Volume		Total Heat from −40°			Entropy from −40° plus 1	
°F t	Abs. lb./in.² p	Liquid ft.³/lb. v_f	Vapor ft.³/lb. v_g	Liquid Btu./lb. h_f	Latent Btu./lb. h	Vapor Btu./lb. h_g	Liquid Btu./lb.°F s_f	Vapor Btu./lb.°F s_g
20	421.8	0.01663	0.2049	29.4	108.9	138.3	1.0648	1.2919
22	434.0	0.01673	0.1979	30.5	107.7	138.2	1.0672	1.2907
24	448.4	0.01684	0.1912	31.7	106.4	138.1	1.0696	1.2595
26	462.2	0.01695	0.1846	32.9	105.1	138.0	1.0720	1.2883
28	476.3	0.01707	0.1783	34.1	103.8	137.9	1.0744	1.2871
30	490.8	0.01719	0.1722	35.4	102.4	137.8	1.0768	1.2859
32	505.5	0.01731	0.1663	36.7	101.0	137.7	1.0792	1.2844
34	502.6	0.01744	0.1603	37.9	99.5	137.4	1.0875	1.2830
36	536.0	0.01759	0.1550	39.1	98.1	137.2	1.0838	1.2816
38	551.7	0.01773	0.1496	40.4	96.5	136.9	1.0873	1.2801
40	567.8	0.01787	0.1444	41.7	95.0	136.7	1.0884	1.2786
42	584.3	0.01801	0.1393	42.9	93.4	136.3	1.0907	1.2771
44	601.1	0.01817	0.1344	44.3	91.8	136.1	1.0932	1.2756
46	618.2	0.01834	0.1297	45.6	90.1	135.7	1.0958	1.2741
48	635.7	0.01851	0.1250	47.0	88.4	135.4	1.0996	1.2725
50	653.6	0.01868	0.1205	48.4	86.6	135.0	1.1010	1.2709
52	671.9	0.01887	0.1161	49.8	84.7	134.5	1.1036	1.2700
54	690.6	0.01906	0.1117	51.2	82.7	133.9	1.1064	1.2674
56	709.5	0.01927	0.1075	52.6	80.8	133.4	1.1075	1.2657
58	728.8	0.01948	0.1034	54.0	78.7	132.7	1.1104	1.2638
60	748.6	0.01970	0.0994	55.5	76.6	132.1	1.1145	1.2618
62	768.9	0.01994	0.0956	57.0	74.4	131.4	1.1174	1.2597
64	789.4	0.02020	0.0918	57.6	72.0	130.6	1.1202	1.2575
66	810.3	0.02048	0.0880	60.2	69.5	129.7	1.1230	1.2552
68	831.6	0.02079	0.08422	61.9	66.8	128.7	1.1260	1.2526
70	853.4	0.02112	0.08040	63.7	63.8	127.5	1.1292	1.2497
72	875.5	0.02150	0.07657	65.5	60.7	126.2	1.1324	1.2466
74	898.2	0.02192	0.07269	67.3	57.2	124.5	1.1360	1.2432
76	921.3	0.02242	0.06875	69.4	53.4	122.8	1.1399	1.2396
78	944.8	0.02300	0.06473	71.6	49.3	120.9	1.1441	1.2357
80	968.7	0.02370	0.06064	73.9	44.8	118.7	1.1486	1.2314
82	993.0	0.02456	0.05648	76.4	40.2	116.6	1.1532	1.2271
84	1017.7	0.02553	0.05223	79.4	34.5	113.9	1.1582	1.2215
86	1043.0	0.02686	0.04789	83.3	27.1	110.4	1.1646	1.2143
87.8	1066.2	0.03454	0.03454	97.0	0.0	97.0	1.1890	1.1890

Table 11. Superheated Carbon Dioxide

(Transcribed from data of Plank and Kuprianoff (6) by graphical means.)

Temp. °F.	Abs. Pressure one atmosphere (Sat'n. Temp. = −110.02°F.)			Abs. Pressure 20 (Sat'n. Temp. = −103.3°F.)			30 (Sat'n. Temp. = −92.6°F.)			40 (Sat'n. Temp. = −85.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
at sat'n	*6.39*	*133.3*	*1.414*	*4.70*	*133.5*	*1.403*	*2.70*	*134.5*	*1.387*	*1.99*	*136.0*	*1.375*
−100	6.41	134.7	.419	4.71	133.7	1.405						
−90	6.50	136.7	1.424	4.77	135.8	1.411						
−80	6.60	138.7	1.429	4.84	137.9	1.417	2.80	137.1	1.395	2.01	136.3	1.380
−70	6.70	140.7	1.434	4.92	140.0	1.423	2.90	139.2	1.400	2.08	138.4	1.386
−60	6.82	142.7	1.438	5.00	142.1	1.429	3.00	141.3	1.405	2.15	140.5	1.392
−50	6.96	144.7	1.442	5.10	144.2	1.435	3.10	143.4	1.410	2.22	142.6	1.398
−40	7.10	146.7	1.446	4.20	146.3	1.440	3.20	145.5	1.415	2.30	144.7	1.404
−30	7.26	148.7	1.450	4.36	148.4	1.445	3.30	147.6	1.420	2.38	146.8	1.410
−20	7.45	150.7	1.454	4.55	150.5	1.450	3.40	149.7	1.425	2.46	148.9	1.415
−10					152.6	1.455	3.50	151.8	1.430	2.52	151.0	1.420
0					154.7	1.460	3.60	153.9	1.435	2.60	153.1	1.425
10					156.8	1.465	3.74	156.0	1.440	2.69	155.2	1.430
20					158.8	1.470	3.90	158.2	1.445	2.79	157.4	1.435
30										2.89	159.5	1.440
40										3.00	161.6	1.445
50										3.10	163.7	1.450
60										3.20	165.8	1.455
70										3.30	167.9	1.460
80										3.40	170.0	1.465
90										3.52	172.1	1.470
100										3.65	174.4	1.475
110										3.79	176.5	1.480

Temp. °F.	50 (Sat'n. Temp. = −79.9°F.)			60 (Sat'n. Temp. = −75.2°F.)			70 (Sat'n. Temp. = −71.1°F.)			80 (Sat'n. Temp. = −66.9°F.)		
t	V	H	S	V	H	S	V	H	S	V	H	S
at sat'n	*1.70*	*135.5*	*1.365*	*1.42*	*136.0*	*1.359*	*1.22*	*136.3*	*1.360*	*1.09*	*136.5*	*1.345*
−70	1.77	137.8	1.370	1.50	137.2	1.363	1.23	136.5	1.353			
−60	1.81	139.7	1.377	1.52	139.4	1.370	1.25	138.7	1.360			
−50	1.85	142.2	1.384	1.54	141.6	1.376	1.27	140.9	1.367	1.14	140.3	1.362
−40	1.90	144.5	1.391	1.58	143.8	1.382	1.30	143.1	1.373	1.16	142.5	1.369
−30	1.95	146.7	1.398	1.62	146.0	1.388	1.33	145.3	1.379	1.18	144.7	1.376
−20	2.00	148.9	1.404	1.66	148.2	1.394	1.37	147.5	1.385	1.20	146.9	1.383
−10	2.05,	151.1	1.410	1.70	150.4	1.400	1.41	149.7	1.391	1.22	149.1	1.390
0	2.10	153.3	1.416	1.74	152.6	1.406	1.45	151.9	1.397	1.25	151.3	1.396
10	2.15	155.5	1.421	1.76	154.8	1.412	1.50	154.1	1.403	1.28	153.5	1.402
20	2.20	157.7	1.426	1.80	157.0	1.418	1.55	156.3	1.409	1.32	155.7	1.408
30	2.25	159.9	1.431	1.84	159.2	1.424	1.60	158.5	1.415	1.37	157.8	1.414
40	2.30	162.1	1.436	1.88	161.4	1.430	1.65	160.7	1.421	1.43	160.0	1.420
50	2.35	164.3	1.441	1.92	163.6	1.435	1.70	162.9	1.427	1.50	162.3	1.425
60	2.40	166.5	1.446	1.96	164.8	1.440	1.75	164.1	1.433	1.58	163.5	1.435
70	2.45	168.7	1.451	2.00	167.0	1.445	1.80	166.3	1.439	1.66	165.7	1.435
80	2.50	170.9	1.456	2.04	169.2	1.450	1.85	168.5	1.445	1.74	167.9	1.440
90	3.55	173.1	1.461	2.08	171.4	1.455	1.90	170.7	1.450	1.82	170.1	1.445
100	2.60	175.3	1.466	2.12	173.6	1.460	1.96	172.9	1.455	1.90	172.3	1.450

Superheated Carbon Dioxide (continued)

Temp. °F.	100 (Sat'n. Temp. = −57.0°F.)			150 (Sat'n. Temp. = −39.0°F.)			200 (Sat'n. Temp. = −26.5°F.)			250 (Sat'n. Temp. = −13.37°F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
at sat'n	*.86*	*137.3*	*1.357*	*.59*	*1.332*	*1.327*	*.476*	*133.8*	*1.320*	*.378*	*139.2*	*1.312*
−50	0.890	138.7	1.342									
−40	0.945	141.0	1.349									
−30	0.995	143.3	1.356	0.605	140.1	1.334						
−20	1.045	145.6	1.363	0.640	142.6	1.341						
−10	1.095	147.9	1.369	0.670	145.1	1.348	0.51	142.4	1.331	0.38	140.0	1.317
0	1.14	150.2	1.375	0.700	147.6	1.355	0.53	144.8	1.338	0.40	142.5	1.324
10	1.18	152.5	1.881	0.725	150.1	1.362	0.55	147.3	1.345	0.42	145.0	1.330
20	1.22	154.8	1.386	0.750	152.4	1.368	0.57	149.8	1.351	0.44	147.5	1.335
30	1.26	157.1	1.391	0.775	154.8	1.373	0.59	152.3	1.356	0.46	150.0	1.340
40	1.30	159.4	1.396	0.800	157.2	1.379	0.61	154.8	1.361	0.48	152.5	1.345
50	1.33	161.7	1.401	0.825	159.6	1.384	0.63	157.3	1.366	0.49	155.0	1.350
60	1.36	164.0	1.406	0.850	162.0	1.389	0.65	159.8	1.371	0.50	157.5	1.355
70	1.39	166.3	1.411	0.877	164.4	1.394	0.67	162.3	1.376	0.51	160.0	1.360
80	1.42	168.6	1.416	0.905	166.8	1.398	0.69	164.8	1.381	0.52	162.5	1.365
90	1.45	170.9	1.420	0.928	169.2	1.402		167.3	1.386	0.53	165.0	1.370
100	1.48	173.2	1.424	0.950	171.8	1.410	0.71	169.8	1.391	0.55	167.3	1.375
120	1.52	177.6	1.432	0.992	176.3	1.417	0.75	174.6	1.401	0.57	172.3	1.384
140	1.56	182.0	1.440	1.030	180.8	1.424	0.78	179.4	1.410	0.59	177.3	1.393
160	1.60	186.4	1.447	1.066	185.3	1.431	0.81	184.2	1.418	0.61	182.3	1.401
180	1.630	190.8	1.454	1.100	189.8	1.437	0.84	188.0	1.425	0.63	187.3	1.409
200	1.660	195.3	1.461	1.130	194.3	1.443	0.87	193.3	1.430	0.65	192.3	1.417

Temp. °F.	300 (Sat'n. Temp. = −2.0°F.)			350 (Sat'n. Temp. = 7.2°F.)			400 (Sat'n. Temp. = 15.7°F.)			450 (Sat'n. Temp. = 24.0°F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
at sat'n	*.30*	*139.4*	*1.305*	*.250*	*139.4*	*1.298*	*.215*	*139.3*	*1.292*	*.18*	*138.6*	*.286*
0	0.31	139.9	1.308									
10	0.33	142.5	1.315	0.26	140.5	1.300						
20	0.35	145.1	1.324	0.28	143.5	1.307	0.22	140.5	1.295			
30	0.36	147.7	1.326	0.30	146.5	1.313	0.24	143.5	1.301	0.18	141.0	1.288
40	0.37	150.3	1.331	0.31	148.3	1.318	0.25	146.3	1.307	0.19	144.3	1.294
50	0.38	152.9	1.336	0.32	151.0	1.323	0.26	149.0	1.313	0.20	147.4	1.300
60	0.39	155.5	1.344	0.33	153.7	1.328	0.27	151.7	1.318	0.21	150.2	1.306
70	0.40	158.1	1.346	0.34	156.4	1.333	0.28	154.4	1.323	0.22	153.0	1.312
80	0.41	160.7	1.351	0.35	159.1	1.338	0.29	157.1	1.328	0.23	155.8	1.318
90	0.42	163.3	1.356	0.36	161.8	1.343	0.30	159.8	1.333	0.24	158.6	1.324
100	0.43	165.9	1.361	0.37	164.5	1.348	0.31	162.5	1.338	0.25	161.4	1.330
110	0.44	168.5	1.366	0.38	167.2	1.353	0.32	165.2	1.343	0.26	164.2	1.335
120	0.45	171.1	1.371	0.39	169.9	1.358	0.33	167.9	1.348	0.27	167.0	1.340
130	0.46	173.7	1.376	0.40	172.6	1.363	0.34	170.6	1.353	0.28	169.8	1.345
140	0.47	176.3	1.381	0.41	175.3	1.368	0.35	173.3	1.358	0.29	172.6	1.350
150	0.48	178.9	1.386	0.42	177.9	1.373	0.36	176.0	1.363	0.30	175.4	1.355
160	0.49	181.5	1.390	0.43	180.5	1.378	0.37	178.7	1.368	0.31	178.1	1.360
170	0.50	184.0	1.394	0.44	183.1	1.383	0.38	181.4	1.372	0.32	180.8	1.365
180	0.51	186.5	1.398	0.45	185.7	1.387	0.39	184.1	1.376	0.32	183.5	1.370
190	0.52	189.0	1.402	0.46	188.3	1.391	0.40	186.8	1.380	0.34	186.2	1.375
200	0.53	191.4	1.406	0.47	190.5	1.395	0.41	189.6	1.384	0.35	188.7	1.380

Superheated Carbon Dioxide (continued)

Temp. °F.	700 (Sat'n. Temp. = 55.6°F.)			800 (Sat'n. Temp. = 65.0°F.)			900 (Sat'n. Temp. = 73.8°F.)			1000 (Sat'n. Temp. = 82.1°F.)		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
at sat'n	*.100*	*133.8*	*1.263*	*.087*	*130.4*	*1.250*	*.070*	*124.0*	*1.240*	*.05*	*114.8*	*1.216*
60	0.11	137.3	1.270									
70	0.12	142.5	1.281	0.112	134.5	1.264						
80	0.130	146.2	1.291	0.120	140.1	1.274	0.082	132.0	1.246			
90	0.14	149.3	1.300	0.127	144.5	1.283	0.093	138.5	1.256	0.064	130.5	1.227
100	0.150	153.5	1.308	0.127	148.0	1.291	0.101	143.0	1.265	0.086	138.5	1.252
110	0.16	157.0	1.315	0.134	151.9	1.298	0.108	148.5	1.273	0.100	143.5	1.267
120	0.17	160.0	1.320	0.141	155.5	1.304	0.114	153.0	1.290	0.107	149.5	1.277
130	0.18	162.8	1.325	0.141	159.0	1.310	0.121	157.0	1.296	0.112	154.0	1.284
140	0.19	166.0	1.330	0.153	163.4	1.315	0.128	160.9	1.301	0.117	158.5	1.290
150	0.197	169.0	1.335	0.159	166.4	1.320	0.134	164.4	1.308	1.112	162.0	1.296
160	0.204	172.0	1.339	0.165	169.4	1.325	0.140	167.7	1.314	0.127	165.2	1.302
170	0.211	175.0	1.343	0.171	172.4	1.330	0.145	170.9	1.320	0.132	168.4	1.308
180	0.218	178.0	1.347	0.177	175.4	1.335	0.150	173.9	1.326	0.136	171.6	1.314
190	0.225	181.0	1.351	0.183	178.4	1.340	0.155	176.9	1.331	0.140	174.8	1.320
200	0.231	184.0	1.355	0.190	181.4	1.345	0.160	179.9	1.336	0.144	178.0	1.326
210	0.237	187.0	1.359	0.196	184.4	1.350	0.165	182.9	1.341	0.148	181.3	1.332
220	0.243	190.0	1.363	0.202	187.4	1.358	0.170	185.9	1.346	0.152	184.4	1.338
230	0.249	192.8	1.367	0.208	190.4	1.359	0.175	188.9	1.351	0.156	187.6	1.349
240	0.255	195.6	1.371	0.214	193.4	1.363	0.180	191.9	1.356	0.160	190.8	1.349
250	0.260	198.1	1.375	0.219	196.5	1.367	0.185	195.0	1.361		193.5	1.354

Superheated Carbon Dioxide (concluded)

Temp. °F	1100			1200			1300			1400		
t	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*	*V*	*H*	*S*
at sat'n	—	—	—	—	—	—	—	—	—	—	—	—
0												
20												
40												
60												
80												
100	0.060	129.0	1.252	0.05	111.0	1.240						
120	0.090	143.5	1.266	0.077	137.5	1.255	0.064	131.0	1.244	0.050	124.5	1.234
140	0.100	153.8	1.280	0.09	150.0	1.270	0.074	144.0	1.260	0.070	140.5	1.252
160	0.109	161.5	1.293	0.096	158.0	1.284	0.083	155.3	1.275	0.080	152.0	1.269
180	0.118	168.5	1.306	0.104	166.3	1.298	0.090	164.3	1.289	0.087	162.5	1.285
200	0.127	176.0	1.318	0.112	174.0	1.313	0.089	172.0	1.303	0.094	170.0	1.300
220	0.136	182.0	1.320	0.120	180.2	1.325	0.107	178.3	1.317	0.101	176.5	1.314
240	0.144	188.0	1.342	0.128	186.4	1.336	0.115	184.6	1.331	0.108	183.0	1.326
260	0.152	194.0	1.354	0.138	192.6	1.347	0.124	190.9	1.343	0.115	189.5	1.336
280		200.0	1.363	0.143	198.8	1.357	0.132	196.2	1.352	0.122	196.0	1.346
300	0.160	206.0	1.372	0.150	204.8	1.367	0.140	203.6	1.361	0.129	202.5	1.355

CARBON DIOXIDE FLOW IN PIPE LINES

PART NO.	DESCRIPTION	EQUIVALENT LENGTH (FEET)*
1	Cylinder Valve Assembly	110 ft. 1/2" Schedule 40 Pipe
2	Time Delay	20 ft. 1/2" Schedule 40 Pipe
3	1/2" Selector Valve	20 ft. 1/2" Schedule 40 Pipe
4	3/4" Selector Valve	25 ft. 3/4" Schedule 40 Pipe
5	1" Selector Valve	30 ft. 1" Schedule 80 Pipe
6	1-1/4" Selector Valve	45 ft. 1-1/4" Schedule 80 Pipe
7	1-1/2" Selector Valve	60 ft. 1-1/2" Schedule 80 Pipe
8	2" Selector Valve	75 ft. 2" Schedule 80 Pipe
9	2-1/2" Selector Valve	125 ft. 2-1/2" Schedule 80 Pipe
10	3" Selector Valve	145 ft. 3" Schedule 80 Pipe
11	1/2" Check Valve	10 ft. 1/2" Schedule 40 Pipe
12	3/4" Check Valve	20 ft. 3/4" Schedule 40 Pipe
13	1" Check Valve	15 ft. 1" Schedule 80 Pipe
14	1-1/4" Check Valve	30 ft. 1-1/4" Schedule 80 Pipe
15	1-1/2" Check Valve	55 ft. 1-1/2" Schedule 80 Pipe
16	2" Check Valve	60 ft. 2" Schedule 80 Pipe
17	2-1/2" Check Valve	70 ft. 2-1/2" Schedule 80 Pipe
18	3" Check Valve	100 ft. 3" Schedule 80 Pipe

Note:

Adjustment can be made for a small difference in Pipe Diameter (Such as from Schedule 80 to Schedule 40) by the formula:

$$L_1 = \frac{D_1}{D_2}^{5.25}$$

*Values to be used in class problem calculations until other values are officially published.

NOTES ON CARBON DIOXIDE FLOW THROUGH PIPES AND ORIFICES

LIQUID-GAS FLOW IN PIPES

See pg 2

"The simultaneous flow of liquids and gases in pipes is complicated by the fact that the action of gravity tends to cause settling and slip of the liquid with the result that the gas flows at a different velocity in the pipe than does the liquid. The pressure drop is greater in liquid-gas flow than that for the single phase flow of either gas or liquid for several reasons. Some of the reasons are the irreversible work done on the liquid by the gas and that the effective cross-sectional area of flow for either fluid is reduced by the flow of the other fluid." The above quotation was taken from Lapple (1).

As explained by Hesson, page 3 (2), "Liquid carbon dioxide is discharged rather than vapor (in a fire extinguishing system) because the discharge rate is greater for a given piping system, the fire extinguishing action is better, and withdrawal of vapor would cause too large a pressure recession in the storage vessel."

Hesson continues, "When the saturated liquid carbon dioxide is discharged through the pipeline, a reduction of pressure occurs due to flow friction loss and the conversion of pressure head to velocity head. This reduction in pressure causes a flashing or boiling of the liquid to form a vapor phase and also causes a reduction in temperature of the mixture of liquid and vapor. This formation of vapor causes a progressive decrease in density and increase in velocity of the mixture of liquid and vapor as it flows down the pipeline. This decrease in density and increase in velocity causes a progressive increase in the rate of pressure drop per unit of pipe length as the two-phase mixture flows farther down the pipeline. Because of this change in density and velocity which result in a variable rate of pressure drop per unit length of pipeline, the usual formulae and tables for determining pressure loss and flow rates can not be used."

wt. rate of flow const. but density decreases + ∴ vel. increas

Assuming continuous flow of carbon dioxide in a pipeline (steady state conditions), for a system in which the change in elevation dZ is zero or can be neglected, equations for a material balance and mechanical energy balance can be written as follows:

$$G = U\rho = \text{Constant} \quad \text{wt. rate of flow} \qquad \text{(Eq. 1)}$$

$$\frac{144\,dP}{\rho} + \frac{W\,U\,dU}{g} + f\,\frac{U^2}{2g\,D/12}\,dL = 0 \qquad \text{(Eq. 2)}$$

Review terms.

In Equation 2, the first term represents the change in pressure or head energy, the second term represents the change in velocity energy, and the third term represents the change in friction energy.

Certain aspects of the thermodynamics of the fluid system under discussion is considered by Hesson (2), page 11, "If there were no change in velocity energy, the flow would take place at constant enthalpy, or $\Delta H = 0$. If there were no change in friction energy, the flow would take place at constant entropy, or $\Delta S = 0$. Since both velocity and friction terms are not zero, the actual flow takes place somewhere between the conditions $\Delta H = 0$ and $\Delta S = 0$. However, since for all ordinary pipeline conditions the friction term is much greater than the velocity term, the condition will be much nearer $\Delta H = 0$ than $\Delta S = 0$. In addition, there will usually be heat added to the carbon dioxide during flow, since it will be below zero Fahrenheit.

This addition of heat will cause the flow condition to be nearer the isoenthalpic. In addition, under the conditions involved, the results are nearly the same for either $\Delta H = 0$ (isoenthalpic) or $\Delta S = 0$ (isoentropic). <u>The isoenthalpic condition will be used.</u>"

Assuming the above flow conditions, together with extensive flow tests of carbon dioxide in pipes, Hesson (2) concluded that his results could best be represented by the following equation:

$$L = \frac{3647\, D^{5.25}\, Y}{Q^2} - 8.08\, D^{1.25} Z \qquad \text{(Eq. 3)}$$

length or eq length of pipe

where

$$Y = \frac{100\,i}{\ln j}\left\{ j^{P_0/100} - j^{P/100} \right\} = \int_{P_0}^{P} \rho\, dP \qquad \text{(Eq. 4)}$$

and

$$Z = \ln j \left(\frac{P_0}{100} - \frac{P}{100} \right) = \int_{\rho_0}^{\rho} \frac{d\rho}{\rho} = \ln \frac{\rho_0}{\rho} \qquad \text{(Eq. 5)}$$

The last terms (the integrals) in Eq. 4 and Eq. 5 are included here to clarify the meaning of Y and Z, as described in the Progress Report of the Committee on Carbon Dioxide (3). A table of values of Y and Z taken from (3) are included in these notes.

→ parameters depending on stge pressure + line pressure

For convenience in application, Eq. 3 can be rearranged as given below:

$$\frac{L}{D^{1.25}} = \frac{3647\, Y}{(Q/D^2)^2} - 8.08\, Z \qquad \text{(Eq. 6)}$$

Be familiar with workings of this eq. *

A table of values of $D^{1.25}$ and D^2 for various pipes (3) is also included in these notes.

Q is a weight rate of flow.

LIQUID-GAS FLOW THROUGH ORIFICES

The flow of a two-phase mixture of carbon dioxide liquid and vapor through orifices has been investigated by Hesson and Peck (5). The following information is taken from that work:

"The following are the basic equations used to compute the flow rates through an ideal nozzle for negligible approach velocity U_1.

$$Q = 60\,(A/144)\,(U_2/V_2) \qquad \text{(Eq. 9)}$$

$$Q = 60\,(A/144)\,(1/V_2) \cdot \left[2g\,(144) \int_{P_2}^{P_1} V\, dP \right]^{1/2} \qquad \text{(Eq. 10)}$$

$$Q = 60\,(A/144)\,(1/V_2) \cdot \left[2g\, J\, (-)\, \Delta H_{12} \right]^{1/2} \qquad \text{(Eq. 11)}$$

A = orifice area
U = ave. vel
V = specific volume? FT^3/lb

press @ throat

For critical flow, $P_2 = P_t$, $U_2 = U_t$, and $V_2 = V_t$. **For subcritical flow**, $P_2 = P_3$

'In this investigation it was found that saturated carbon dioxide vapor can flow through a nozzle or orifice in a supersaturated condition. When flowing in a supersaturated condition, it behaves as superheated vapor with an expansion coefficient n, defined by the equation: $PV^n = P_1V_1^n$. When this equation is substituted into Eq. 10 and the integration is performed, the results for the nozzle are:

$$Q = \frac{60A\left[2g/144\right]^{1/2}\left\{(P_1/V_1)\left[n/(n-1)\right]\left[1-(P_2/P_1)^{\frac{(n-1)}{n}}\right]\right\}^{1/2}}{(P_2/P_1)^{-1/n}} \qquad \text{(Eq. 12)}$$

When P_3 is greater than P_t, $P_2 = P_3$. <u>When</u> P_3 <u>is less than</u> P_t, $P_2 = P_t$, <u>and critical flow results</u>,

$$Q = 60A\left[2g/144\right]^{1/2}\left[(P_1/V_1)\right]^{1/2}\cdot\left[n/(n+1)\right]^{1/2}\left[2/(n+1)\right]^{\frac{1}{(n-1)}} \qquad \text{(Eq. 13)}$$

and

$$(P_t/P_1) = \left(2/(n+1)\right)^{\frac{n}{(n-1)}} \qquad \text{(Eq. 14)}$$

VALUES OF n AND P_t/P_1 FOR SATURATED VAPOR

Pressure P_1 psia	n	P_t/P_1
0 to 600	1.30	0.55
700	1.22	0.56
800	1.17	0.57
900	1.07	0.59
1000	0.94	0.62

It will be noted that one of the effects of supersaturation is to increase the density for an expansion to a given pressure. Thus the actual flow rate is greater than that computed from the usual Mollier diagram for thermodynamic equilibrium.

'In this investigation it was found that saturated carbon dioxide liquid can flow through a nozzle in a superheated or metastable condition and that it behaves as a nonvolatile liquid between the limits of the initial pressure and a lower pressure. On the assumption that the liquid is incompressible in Eq. 10, the following results:

$$Q = 60A\left[2g/144\right]^{1/2}\cdot\left[(P_1 - P_2)/V_{f1}\right]^{1/2} \qquad \text{(Eq. 14a)}$$

This equation agrees with experimental results for values of P_2 from P_1 down to near the critical throat pressure P_t."

"An equation which covers the saturated liquid, saturated vapor, and two-phase region for the nozzle was developed by making the following assumptions:

1. The initial vapor fraction of the mixture expands without heat or mass interchange with the remainder of the mixture according to the relationship

$$PV^n = P_1V_{g1}^{m} .$$

2. The initial liquid fraction of the mixture may undergo some evaporation, but the vapor thus formed is considered part of the volume due to the initial liquid fraction, which expands according to the relationship

$$PV^{\alpha} = P_1V_{f1}^{\alpha} .$$

3. The velocity of both phases is the same.

The equation is:

$$Q = \frac{5A\left[2g\,\frac{P_1}{V_{f1}}\,\frac{1}{x}\right]^{1/2}\left[\frac{\alpha}{\alpha-1}\left\{1-\left(\frac{P}{P_1}\right)^{\frac{(\alpha-1)}{\alpha}}\right\}+\frac{1-x}{x}\,\frac{V_{g1}}{V_{f1}}\,\frac{m}{m-1}\left\{1-\left(\frac{P}{P_1}\right)^{\frac{(m-1)}{m}}\right\}\right]^{1/2}}{\left(\frac{P}{P_1}\right)^{-1/\alpha}+\frac{1-x}{x}\,\frac{V_{g1}}{V_{f1}}\left(\frac{P}{P_1}\right)^{-1/m}} \quad \text{(Eq. 15)}$$

VALUES OF α FOR EQUATION 15

x	α
0 to 0.80	1.0
0.90	1.1
0.95	1.3
0.975	3.0

Note: Values of n given in previous table also apply to Eq. 15.

For flow rates less than the critical, P is equal to the back pressure, P_3. For critical flow P/P_1 is evaluated for a maximum value of Q, in which case $P = P_t$, the throat pressure.

'When the initial fraction of liquid → 0, $x \rightarrow 0$, and Eq. 15 reduces to Eq. 16 and 17 which further reduce to Eqs. 12 and 13 for saturated vapor,

$$Q = \frac{60A[2g/144]^{1/2}\left[1/(1-x)\right]^{1/2}\left\{\frac{P_1}{V_1}\,\frac{m}{m-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{(m-1)}{m}}\right]\right\}^{1/2}}{\left(\frac{P_2}{P_1}\right)^{-\frac{1}{m}}} \quad \text{(Eq. 16)}$$

and for critical flow,

$$Q = 60A[2g/144]^{1/2}\left(\frac{P_1}{V_1}\right)^{1/2}\cdot\left[\frac{1}{(1-x)}\right]^{1/2}\left[\frac{m}{(m+1)}\right]^{1/2}\cdot\left[\frac{2}{(m+1)}\right]^{\frac{1}{(m+1)}} \quad \text{(Eq. 17)}$$

When the initial fraction of liquid is 1.0, $x = 1.0$ and Eq. 15 reduces to Eq. 14 for saturated liquid."

The discharge rate per square inch of equivalent orifice area for Low Pressure Storage (300 psia) and for High Pressure Storage (750 psia), as given in Reference (3), are included in these notes.

NOTATION

A = Orifice area, in^2.
A_p = External surface area of pipe, ft^2.
C_p = Specific heat at constant pressure, BTU/lb/°F.
d = Differential operator.
D = Pipe internal diameter, inches.
D_o = Orifice diameter, inches.
f = Friction factor, dimensionless.
g = Acceleration due to gravity. (32.17 $ft/sec.^2$
G = Mass flow, $lbs/sec/ft^2$.
h_f = Enthalpy of liquid, BTU/lb.
h_g = Enthalpy of vapor, BTU/lb.
H_f = Enthalpy of liquid at initial pressure, BTU/lb.
ΔH = Change in enthalpy.
i and j = Constant depending upon storage pressure.
J = Mechanical equivalent of heat, 778 ft lbs/BTU.
L = Length or Equivalent length of pipe, feet.
n = Vapor expansion coefficient, dimensionless, where $PV^n = P_1V_1^n$.
P = Pressure, psia. (P_o = Storage pressure, psia.)
P_1 = Pressure at nozzle inlet conditions, psia.
P_2 = Pressure at nozzle throat conditions, psia.
P_3 = Pressure at nozzle downstream conditions, psia.
P_t = Pressure at nozzle throat conditions at critical flow rate, psia.
q = Liquid evaporation rate due to heat input, lbs/min.
Q = Flow rate; also corrected flow rate, lbs/min.
S_f = Entropy of liquid, BTU/lb/°R.
S_g = Entropy of vapor, BTU/lb/°R.
ΔS = Change in Entropy.
t = Temperature, °F; also average room temperature, °F; or average pipe temp., °F.
U = Average velocity, ft/sec.
V = Specific volume, ft^3/lb; subscripts 1, 2 and 3, same as nozzle press. cond.
V_f = Specific volume of liquid, ft^3/lb; V_{f1}, refers to nozzle inlet conditions.
V_g = Specific volume of vapor, ft^3/lb; V_{g1}, refers to nozzle inlet conditions.
V_t = Specific volume of mixture of liquid and vapor, ft^3/lb.
V_p = Internal volume of piping, ft^3.
W = Ratio of actual energy in the flowing fluid to the energy as computed by $U^2/2g$ per unit mass. A good average value for turbulent flow is 1.1, where Reynolds Number = 2×10^4.
W = Weight of pipe and valves in the time delay Eq. 8.
x = Fraction, by weight, of mixture which is liquid.
$(1 - x)$ = Fraction, by weight, of mixture which is vapor.
Y and Z = Parameters depending upon storage pressure and line pressure.
α = Liquid expansion coefficient, dimensionless, where $PV^{\alpha} = P_1V_{g1}^{\alpha}$.
ρ = Density of mixture, lbs/ft^3.
ρ_1 = Density at pressure P_o, lbs/ft^3.
τ = Time; also time delay, seconds.
ln = Natural logarithm.

TABLE A-1
A.S.A. SCHEDULE 40 (STD. WT.) PIPE

NOM. PIPE SIZE	INT. DIA. Din.	$D^{1.25}$	D^2	TRANS AREA in^2	SURFACE AREA ft^2/ft	VOLUME $ft^3/ft.$	WEIGHT LBS/FT
1/2	0.622	0.5521	0.3869	0.304			
3/4	0.824	0.7850	0.679	0.533	0.275	0.0037	1.13
1	1.049	1.0615	1.100	0.864	0.344	0.0060	1.68
1¼	1.380	1.4960	1.904	1.495	0.435	0.0104	2.27
1½	1.610	1.8130	2.592	2.036	0.497	0.0141	2.72
2	2.067	2.4750	4.272	3.355	0.622	0.0233	3.65
2½	2.469	3.0900	6.096	4.788	0.753	0.0332	5.79
3	3.068	4.06	9.413	7.393	0.916	0.0513	7.58
4	4.026	5.71	16.21	12.730	1.178	0.0884	10.79
5	5.047	7.54	25.47	20.006	1.456	0.1390	14.62
6	6.065	9.50	36.78	28.891	1.734	0.2006	18.97

A.S.A. SCHEDULE 80 (X WT.) PIPE

NOM. PIPE SIZE	INT. DIA. Din.	$D^{1.25}$	D^2	TRANS AREA in^2	SURFACE AREA ft^2/ft	VOLUME $ft^3/ft.$	WEIGHT LBS/FT
1/2	0.546			0.234			
3/4	0.742			0.433	0.275	0.0030	1.47
1	0.957	0.9465	0.9158	0.719	0.344	0.0050	2.17
1¼	1.278	1.359	1.633	1.283	0.435	0.0089	3.00
1½	1.500	1.660	2.250	1.767	0.497	0.0123	3.63
2	1.939	2.288	3.760	2.953	0.622	0.0205	5.02
2½	2.323	2.865	5.396	4.238	0.753	0.0294	7.66
3	2.900	3.79	8.410	6.605	0.916	0.0459	10.25
4	3.826	5.34	14.64	11.497	1.178	0.0799	14.98
5	4.813	7.14	23.16	18.194	1.456	0.1263	20.78
6	5.761	8.92	33.19	26.067	1.734	0.1810	28.57

TABLE A-2. VALUES OF Y AND Z FOR 300 PSIA STORAGE PRESSURE

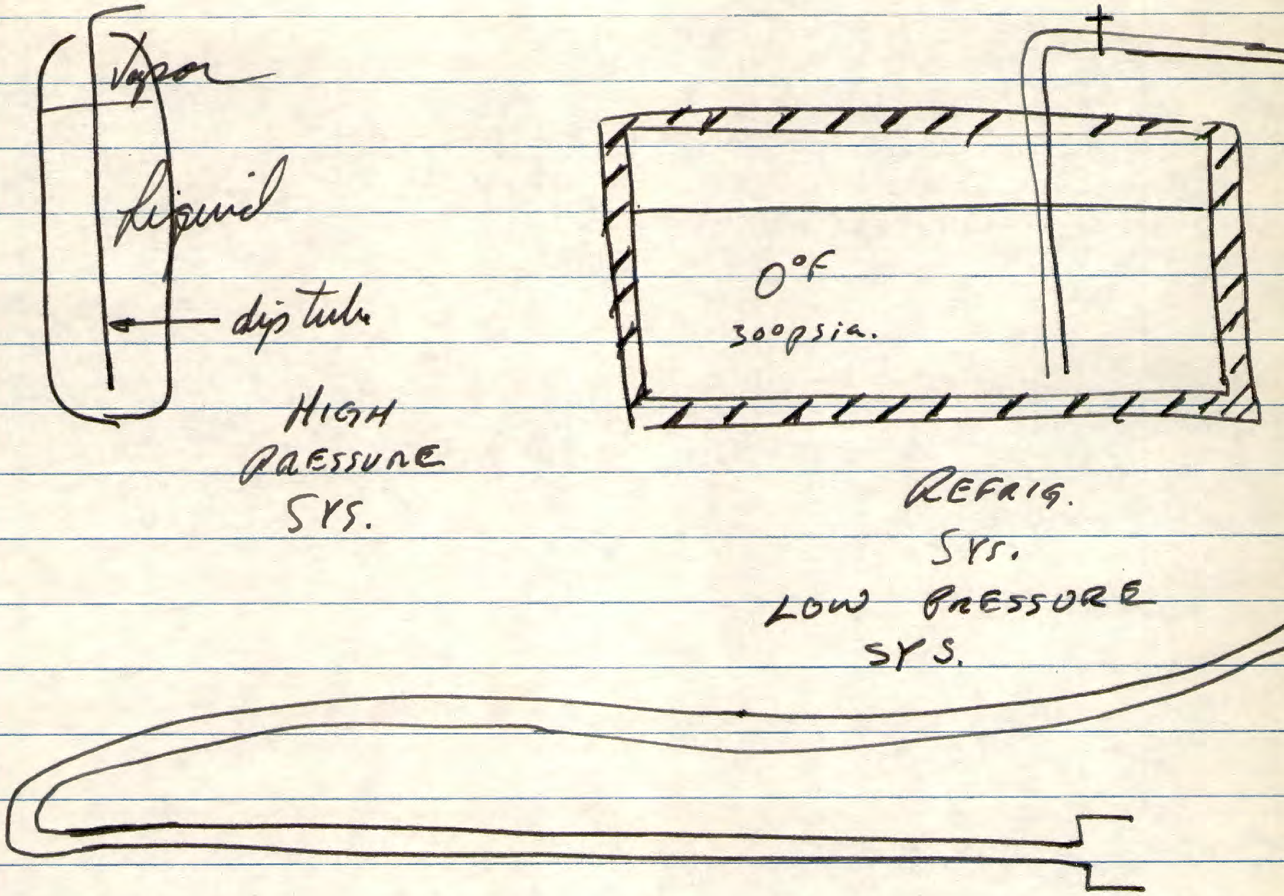
PSIA	Y	Z
300	0	0
290	603	0.12
280	1138	0.24
270	1613	0.36
260	2033	0.48
250	2406	0.60
225	3163	0.90
200	3723	1.20
175	4137	1.50
150	4443	1.80
125	4670	2.11
100	4837	2.41

TABLE A-3. VALUES OF Y AND Z FOR 750 PSIA STORAGE PRESSURE

PSIA	Y	Z
750	0	0
725	1200	.0825
700	2300	.165
675	3320	.249
650	4280	.333
625	5130	.417
600	5960	.501
575	6710	.585
550	7370	.672
525	7980	.760
500	8530	.849
475	9060	.939
450	9530	1.033
425	9970	1.132
400	10400	1.237
375	10740	1.350
350	11020	1.479
325	11410	1.629
300	11560	1.844
250	11950	2.164
200	12150	2.623

@ 70°F
853.4
psia

@ 80°F
968.7



Liquid gas flow in piping:

May start out as a liq., but as some energy is used to overcome friction loss + maintain h_v, pressure drops + you get some vapor.

TABLE A-5. EQUIVALENT ORIFICE SIZES

Orifice Code No.	Equivalent Single Orifice Diameter - Inches	Equivalent Single Orifice Area-Sq. In.
-	.026	.00053
-	1/16	.00307
-	.070	.00385
-	.076	.00454
-	5/64	.0048
-	.081	.00515
-	.086	.00581
3	3/32	.0069
3 +	7/64	.0094
4	1/8	.0123
4 +	9/64	.0155
5	5/32	.0192
5 +	11/64	.0232
6	3/16	.0276
6 +	13/64	.0324
7	7/32	.0376
7 +	15/64	.0431
8	1/4	.0491
8 +	17/64	.0554
9	9/32	.0621
9 +	19/64	.0692
10	5/16	.0767
11	11/32	.0928
12	3/8	.1105
13	13/32	.1296
14	7/16	.1503
15	15/32	.1725
16	1/2	.1964
18	9/16	.2485
20	5/8	.3068
22	11/16	.3712
24	3/4	.4418
32	1	.785
48	1 1/2	1.765
64	2	3.14

Note: The orifice code number indicates the equivalent single orifice diameter in 1/32 inch increments. A plus sign following this number indicates equivalent diameters 1/64 inch greater than that indicated by the numbering system (e.g., No. 4 indicates an equivalent orifice diameter of 4/32 of an inch; a No. 4+ , 9/64 of an inch).

TABLE A-6. DISCHARGE RATE PER SQUARE INCH OF EQUIVALENT ORIFICE AREA FOR LOW PRESSURE STORAGE (300 PSIA)

ORIFICE PRESSURE PSIA	DISCHARGE RATE LBS./MIN./SQ. IN.
300	4220
290	2900
280	2375
270	2050
260	1825
250	1655
240	1525
230	1410
220	1305
210	1210
200	1125
190	1048
180	977
170	912
160	852
150	795
140	741
130	689
120	638
110	589
100	542

TABLE A-7. DISCHARGE RATE PER SQUARE INCH OF EQUIVALENT ORIFICE AREA FOR HIGH PRESSURE STORAGE (750 PSIA)

ORIFICE PRESSURE PSIA	DISCHARGE RATE LBS./MIN./SQ. IN.
750	4630
725	3845
700	3415
675	3090
650	2835
625	2615
600	2425
575	2260
550	2115
525	1985
500	1860
475	1740
450	1620
425	1510
400	1400
375	1290
350	1180
325	1080
300	980
250	780
200	595

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2. HESSON, J. C., "Pressure Drop For Two-Phase Carbon Dioxide Flowing In Pipe Lines," Master of Science Thesis in Chemical Engineering (unpublished), Illinois Institute of Technology, January 1953.

3. Report of the Committee on Carbon Dioxide, Progress Report Containing Proposed Revisions to Standard for Carbon Dioxide Extinguishing Systems, N.F.P.A. Pamphlet 12, Advanced Reports, N.F.P.A. (1960).

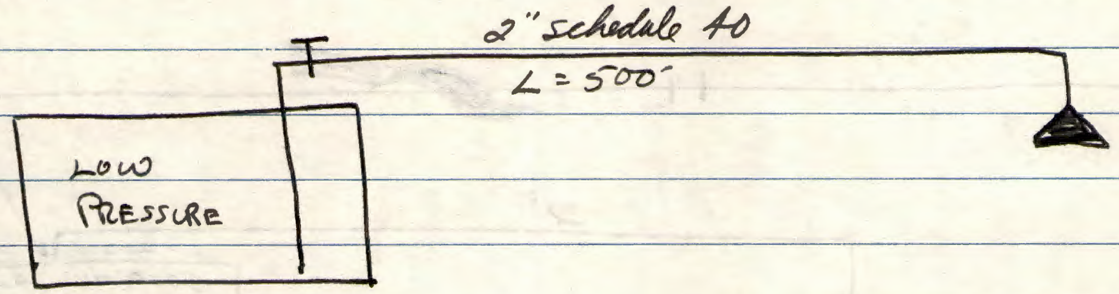
4. "Carbon Dioxide Flow In Pipe Lines," Cardox Division of Chemetron Corporation, Chicago, Illinois (1956).

5. HESSON, JAMES C. AND PECK, RALPH E., "Flow of Two-Phase Carbon Dioxide Through Orifices," A.I. Ch.E. Journal, Volume 4, No. 2, June 1956, pp 207-10.

FPE 420 1-4-65

Pg. 44 NBFU #12
Example problem

go over



FLOW RATE = 1000 #/MIN.

$$\frac{Q}{D^2} = \frac{1000}{4.27} = \frac{1000}{(\text{I.D. } 2''\text{ pipe})^2} = \frac{1000}{4.272}$$

↑ from Table A-4 pg 46

$$\frac{Q}{D^2} = \underline{\underline{234}}\ \text{lb./min}/D^2$$

$$\frac{L}{D^{1.25}} = \frac{500}{2.48} = 201.6$$

↑ from Table A-4

Go to Fig A-4 pg 49

⇒ Terminal pressure = 228 psia

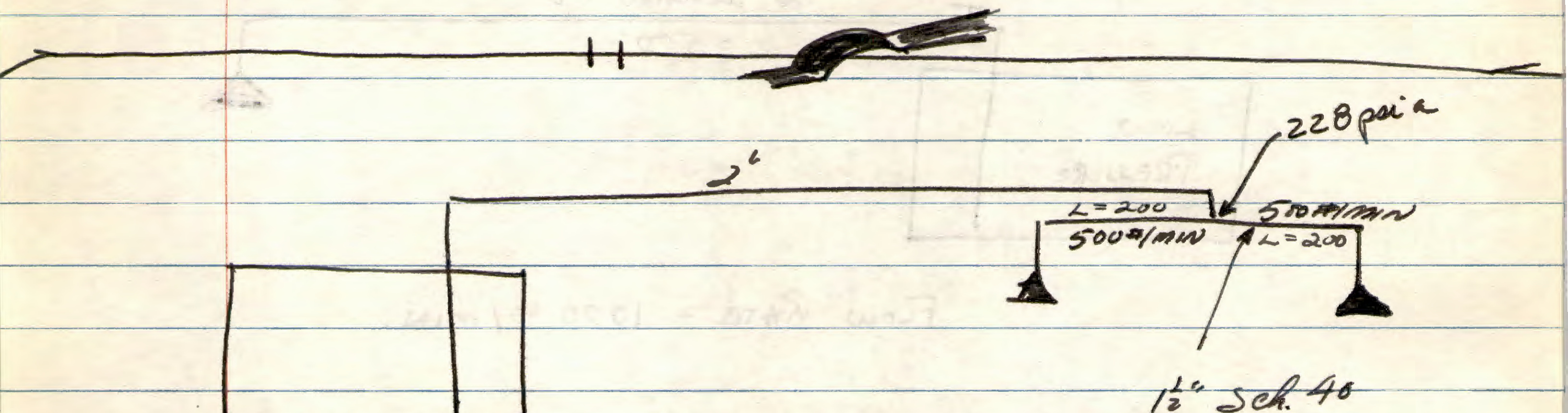
Pg. 18 Table 2

Orifice Pressure psia ~ 230 → Discharge 1410 lb/min/in²

$$\frac{1000}{1410} = .709$$

Pg. 17 find eq. orifice size

.709 ~ .785 ∴ use 1" single ORIFICE
(#32 orifice)



WITH TWO NOZZLES

$$\frac{Q}{D^2} = \frac{500}{2.59} = 192.9$$

$$\frac{L}{D^{1.25}} = \frac{200}{1.81} = 110$$

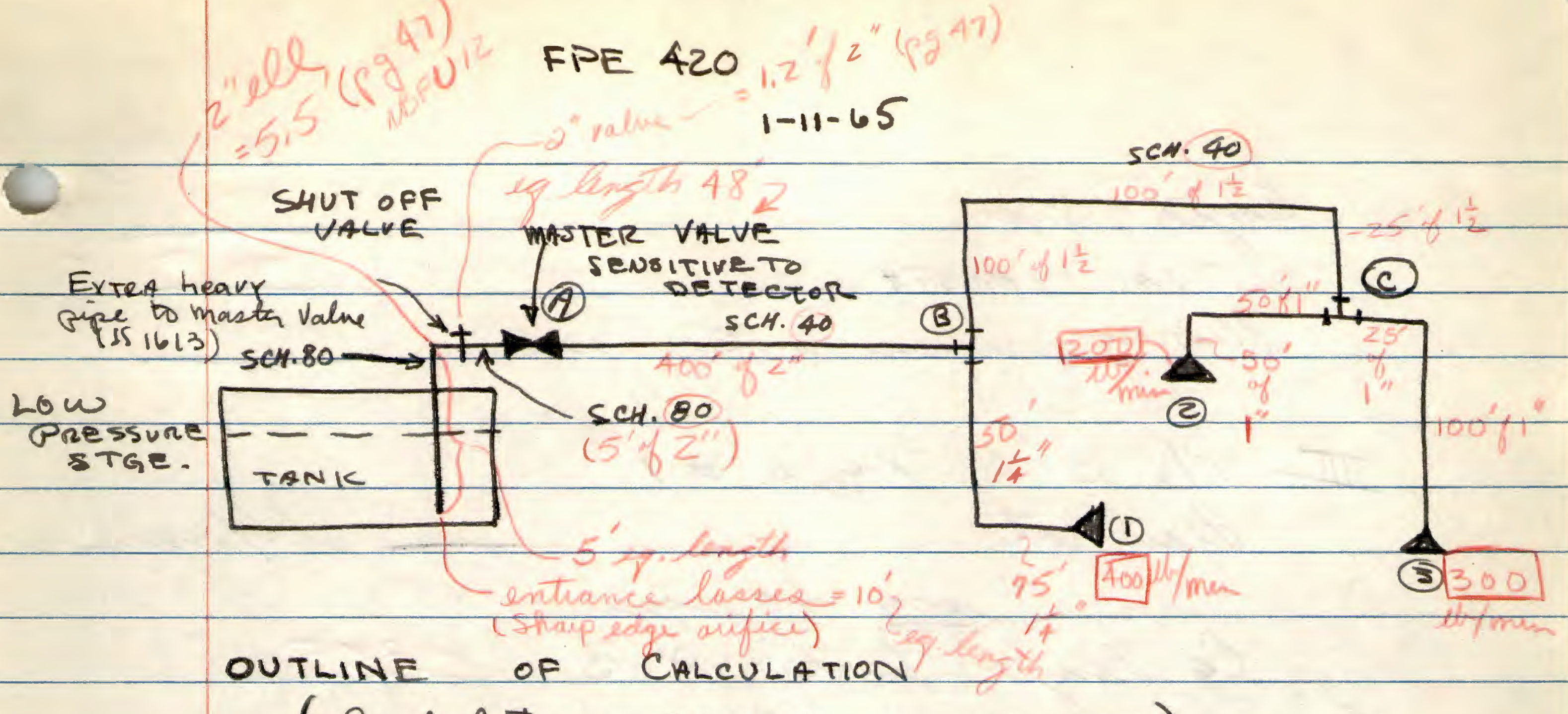
Replace 2" pipe w. eq. length of 1½" ⇒ will still get 228 psia @ junction.

Table A-4 ⇒ $\frac{L}{D^{1.25}}$

other table ⇒ 300' = L

FPE 420

1-11-65



OUTLINE OF CALCULATION

(Read Intro. + CH. 1 In NBFU # 12)
+ Appendix A

Item 1613

I Tank to point A (Master Valve)

FLOW RATE ——————— 900 lb./min

_______ " Sch. 80 pipe

Dip Tube ——————— 15.0 feet long

90° ELL — eq. length ——————— 5.5' eq. length

Shut off valve - eq. length ——— 1.2'

Master valve - eq. length ——— 48.0'

Length of pipe ——— 5.0'

TOTAL EQ. LENGTH TO A ——— 74.7'

Flowing PRESSURE at POINT (A) 291.7 psia

Pg. 12-47 Table A-5 + A-6

II Point A - Point B

Flow Rate ——————— 900 lb/min

40 2" sch. 40 pipe

Eq. length Tank to A ——————— 102.0'

Length of Pipe — — — — — — 102 400 '

TOTAL LENGTH — — — — — — — 502 '

flowing pressure @ B psia 248

III Pt. B to Nozzle # 1

Flow rate — — — 400 lb/min

_____ " sch. 40 pipe.

Eq. length - tank - pt B. 305 '

Eq. Length of pipe, 1 tee side flow 11.2 '

~~Total~~ EQ. LENGTH 90° ell 3.7 '

~~Flowing pressure @~~ 319.9

pipe length — — 125 '

TOTAL EQ. LENGTH 444.9

Flowing pressure @ 1 200 psia → get nozzle size which will produce desired flow

\#22 nozzle

IV pt B to pt C.

Flow Rate — — 500 lb/min

1½ " sch. 40 pipe

Eq. length tank - pt B (may be diff than in III) 450.0 ~~245~~

" " tee 8.7

" " 2 ells 8.6

pipe length 225.0

TOTAL EQ. LENGTH ~~487.3~~ ' → 692.3

450.0
8.7
8.6
225
692.3

flowing pressure @ Ⓒ 188 psia

V point C to pt. #2

Flow Rate ______200______ lb./min.

__1¼__" sch 40 pipe

Eq. length tank - pt C. 1900

" " tee 7.5

" " 90° ell 3.7

pipe length ______100______

TOTAL EQ. LENGTH ______2011.2

flowing pressure @ 2 175

VI point C to pt. # 3

Flow Rate ____________ lb/min

__1¼__" sch. 40 pipe

Eq length Tank - pt C

" " tee

" " 90° ll

pipe length ____________

TOTAL LENGTH

flowing pressure @ 3

1-13-66

Working With Numbers

Use Cardox Equip

Go to FP list

eq. length of Master Valve = 48'

Handling elevation diff on CO_2 systems

pg. 47-48 pamphlet 12

negl. for nominal changes in elevation

Calculate all as horizontal pipe

Find "ave pressure") in leg concerned

(density of CO_2 varies with pressure, ∴ use ave pressure

Elevation correction psi/ft (from chart or
table on basis of "ave pressure") times h, ft,
gives psia correction.

TABLE A-7 pg 48 pamphlet 12

Final — may use pamphlet #12

INTRODUCTION

CH-1

how CO_2 works (generally)

portions of Appendix A

properties of CO_2

flowing

Pipe + orifice size

determinations

Sample problems + charts

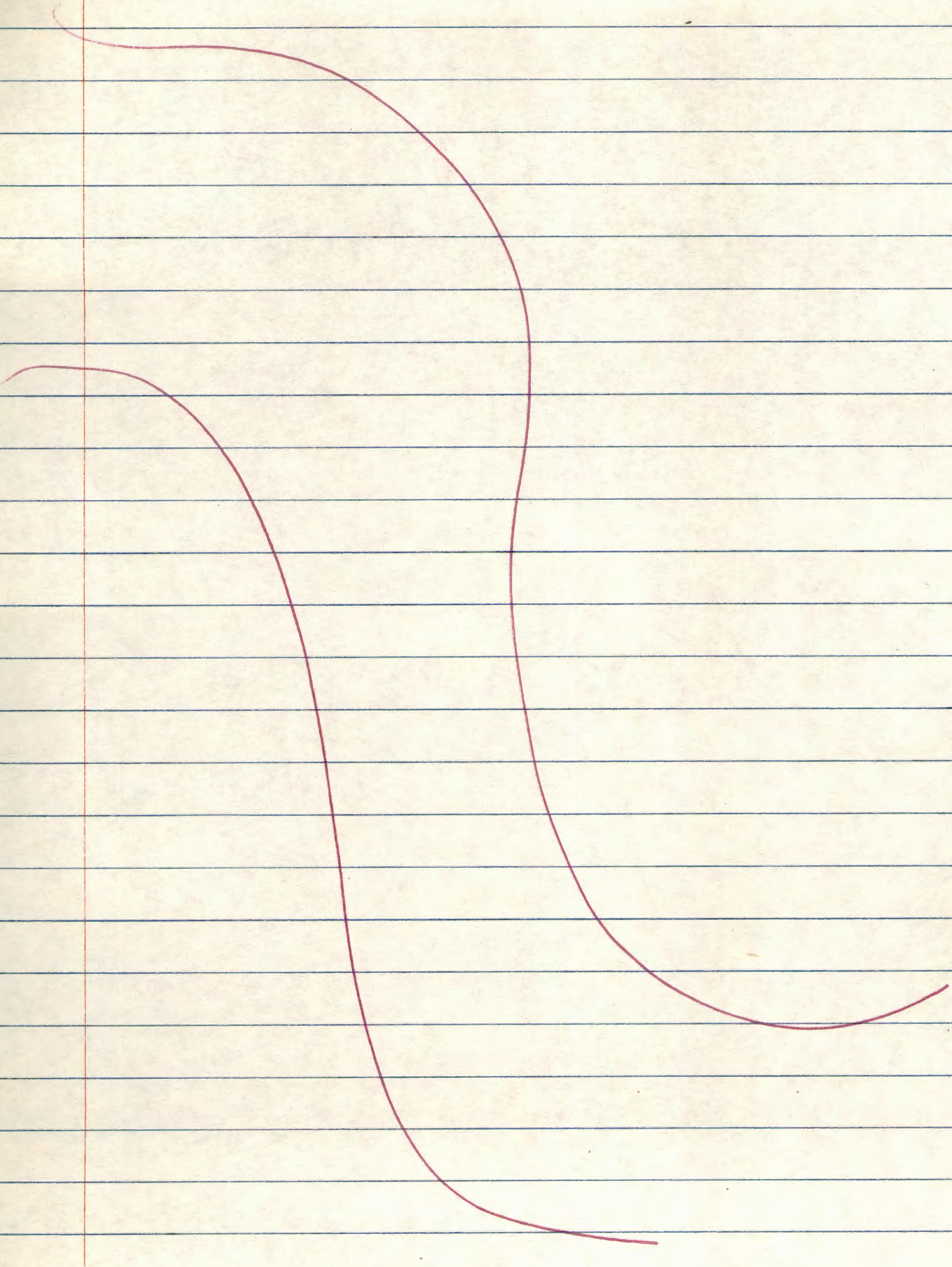
Exclude later part after pg 51

hydraulic data manual

hardy-cross nomograph

Conclusions from droplet size article

General knowledge



Rasbash, D. J., and Rogowski, Z. W. (Joint Fire Research Organization, Boreham Wood, England) "Extinction of Fires in Liquids by Cooling with Water Sprays," Combustion and Flame, 1, 453-466 (1957) 420

Water sprays can be used to extinguish fires in burning liquids by a number of techniques. The most reliable methods are those which depend upon the reduction of evolution of vapor from the burning liquid to a value lower than that quantity which is required to sustain a flame. A particular method of extinction which falls into this category is the cooling of the burning liquid to the fire point. To extinguish a liquid fire by cooling, it is necessary that the flow rate of the coolant be above a certain critical value. At lower rates cooling occurs at a temperature which is higher than the fire point and is, therefore, ineffective.

From a practical point of view, it is important to predict the extinction time of a fire. This feature is particularly important when designing protective installations where rapid fire extinction is quite essential. Rasbash and Rogowski have conducted tests with water sprays on burning liquid fires. They show that, for sprays which extinguish fires by cooling the liquid, there is a correlation between the extinction time and the properties of the sprays and the fires. All of their experiments were conducted with the sprays projecting downward from fixed nozzles to a horizontal surface of the burning liquid.

Liquid fires on transformer oil, kerosene, and gas oil in circular open vessels having diameters ranging from 4.3 to 47.2 in. were utilized in the experiments. Sprays were produced by single nozzles of various types or by a battery of impinging jets. The single nozzles were employed in an investigation to determine the best type of spray for the protection of factories containing oils having high boiling temperatures such as those found in stations generating electricity. The other type of spray was produced from impinging jet nozzles and from swirl nozzles. Both directional and nondirectional sprays were utilized. The nozzles were located at heights above the burning surfaces ranging from 69 to 180 in. Mean flow rates of spray to the combustion vessels were varied from 0.06 to 1.2 gal/sq ft/min. Mass median drop sizes of the spray were altered from 0.012 to 0.12 in. Nozzle pressures from 10 to 100 psi were utilized.

The main evidence used by the authors to decide whether an extinction of the fire occurred by cooling was that the temperature shown by a thermocouple placed near the liquid surface is reduced to the fire point of the liquid prior to extinction. In some instances the fire continued to burn after the indicated temperature was lower than the fire point. This deviation was ascribed partly to uneveness in the spray pattern giving rise to different degrees of cooling at various parts of the liquid surface. In addition, however, some evidence indicated that the flames under these conditions consisted of burning oil droplets that were splashed upwards by the water spray.

When the flames were extinguished by cooling, it was characteristic that after an initial upsurge, the size of the flames was reduced gradually, until in the last stages the flames were about 6 in. high and were usually present only at the edge of the test vessel. A lighted taper placed near the liquid surface did not give immediate re-ignition after the initial extinction. Time-temperature records showed that the liquid continued to cool for a considerable time after the spray was terminated, which was within several seconds after fire extinction.

The nature of liquid burning, the time of initial burning, and the diameter of the burning vessel were the main properties of the fires that were varied during the tests. To obtain an estimate of the effect of the burning liquid, experiments were conducted in which extinctions took place under conditions wherein only the liquid itself was changed.

A comparison was obtained by plotting the extinction time against the temperature difference between the fire point of the liquid under test and the ambient atmospheric temperature. The results show that there was a rapid decrease in extinction time as the temperature difference (defined above) increased; the extinction time was approximately proportional to the temperature difference raised to the -1.75 power. Despite a wide scatter of results, the extinction time was approximately proportional to the initial burning time of the liquid. There appeared to be no significant difference between the extinction time for vessels having diameters of 35 or 47 in.

Rabash and Rogowski found that, in general, it was not possible to ascertain directly from their results the effect of the various spray properties on the extinction time, since over a major portion of conditions in which extinctions by cooling occurred it was not possible to control these properties independently. In some instances a direct estimate was possible. A coarse spray took longer to extinguish the fires tested than did a fine spray. A direct indication of the effect of difference in the velocity of the entrained current of two sprays was obtained. These two sprays had nearly the same drop size and flow rate. When the spray with the low entrained air velocity was applied to the fire, the flames moved upwards against the spray. With a spray of high entrained air current, the spray pushed the flames downwards and there was a smaller extinction time. Within the residual error the extinction time was shown to be directly proportional to the drop size and inversely proportional to the rate of flow of water spray to the fire area. A significant decrease in the extinction time was noted as the entrained air velocity increased.

The extinction times in all tests where extinction was by cooling were plotted against a parameter A, where

$$A = (D/M)\ (Y/\Delta T^{1.75})$$

where D(mm) is the mass median drop size of the spray, $M(g \cdot cm^{-2} \cdot min^{-1})$ is the rate of flow of spray to the fire area, $\Delta T(^{\circ}C)$ is the difference between the fire point of the liquid and ambient temperature, and Y (min) is the initial burning time. The resultant curve showed that, except for two groups of tests, the data fall fairly well about a straight line having a positive slope of unity. All of the data for the groups of tests not falling on the straight line were obtained during experiments wherein the entrained air velocity was less than 8 ft/sec (the approximate upward velocity of the flame gases) and it was characteristic of these tests that the flames moved upwards against the sprays. In general, it was shown that the deviation from the straight line increased as the entrained air velocity decreased.

The equation of the straight line having unit slope is $t = 34{,}000\ A$ where t denotes the extinction time in seconds. All extinction times obtained in the tests, except for those extinction times associated with sprays having low entrained air velocities, fell within a distance of this line that was generally within the range of reproducibility of the tests. From the empirical expression for extinction time, it can be seen that under given conditions liquids with high fire points are extinguished much more rapidly than those with low fire points. Also, the efficiency of the spray, as measured by the reciprocal of the extinction time, is proportional to the flow rate of spray to the liquid surface. The efficiency of the spray increases as the drop size of the spray is reduced. This factor can be expected to hold only if the spray drops have a momentum sufficiently large to penetrate the flame and reach the burning liquid.

The size (diameter) of the fire, which varied from 4.3 to 47 in., was not an important factor in determining the extinction time. Also, the method of spray production, whether accomplished by impinging jets or swirl nozzles or even air atomization, did not affect the extinction time noticeably. Factors like the pressure at which the spray was produced and the cone angle at which the spray was directed from the nozzles affected the extinction times only insofar as they affected the properties of the spray reaching the fire, that is, the drop size, the flow rate, and the entrained air velocity in the spray.

Three mechanisms may be suggested to account for the cooling of the burning liquid: (1) heat transfer from the hot oil to the water drops, (2) mixing of hot oil near the surface with cold oil well below the surface, and (3) the formation of an oil-in-water emulsion followed or accompanied by heat transfer from the hot oil drops to the continuous water phase. The manner in which the extinction time depends upon the factors of the parameter A is most consistent with the view that the cooling to the fire point of the surface layers of the oil was due to the abstraction of heat from the liquid by water drops within the liquid. Thus, the amount of heat which had to be removed increased as the initial burning time increased; the ability of the spray drops to remove this heat increased as the flow rate of the spray increased, as the drop size decreased, and as the temperature difference between the fire point and the ambient temperature increased.

The derived empirical equation gives an estimate of the extinction time for a liquid fire burning from a horizontal layer when the spray is projected vertically downwards from a fixed system with the requirement that the water spray drops should be able to reach the liquid surface. Splash fires are not covered by this empirical equation. It is unlikely for most liquids that an increase in initial burning times beyond 10 to 20 min. will give the increase in extinction time predicted by the empirical equation since the sensible heat in the liquid above the fire-point temperature does not increase significantly after this time.

Subject Headings: Extinguishment by water sprays; Water sprays, flame extinguishment; Fires of liquids.

L. E. Bollinger

Note:

The above abstract was taken from "Fire Research Abstracts and Reviews," Volume 1, No. 1, September, 1958, Committee on Fire Research and Fire Research Conference, National Academy of Sciences, National Research Council, Washington, D.C.

Rhodes, J. M. "Temperature Rating & Sprinkler Performance" Quarterly NFPA 57, 25-30 (1963)

420

When fire occurs in a sprinklered building, only those sprinklers directly above or very near the fire can act to control it. While control is taking place, hot gases can travel far beyond the flame envelope. Within these wide spreading gases, temperatures can be high enough to open sprinklers with "ordinary" operating temperature rating (135-165 °F), but not high enough to damage the structure or other exposed materials. As a result, sprinklers that are not needed operate. Quick operation of sprinklers - an advantage over a fire - may be a disadvantage elsewhere, wasting water and wetting down materials that might otherwise be unaffected.

This paper discusses the results of a program of 130 tests statistically designed to relate the variables of sprinkler temperature rating, ceiling temperature, number of sprinklers opened, opening time, and material burned. Two basic fire types were used, both sized to open more than five sprinklers of ordinary temperature rating: (1) a fire involving a stack of wood pallets 8 feet high, representative of the broad class of fires whose burning rate is greatly affected by sprinkler water; (2) a fire involving gasoline spray discharged at the rate of 1.5 gpm, representative of the class fire that is fixed in location and relatively unaffected by sprinkler water. Sprinklers used in the tests were of the solder type of various makes and temperature ratings ranging from ordinary (160 °F), intermediate (212 °F), high (286 °F) and extra high (360 °F). The full range of heat sensitivity and distribution effectiveness was covered.

The data show that, for the types of fires considered, there are advantages to be gained from more general use of sprinklers of higher operating temperature ratings, especially the intermediate rating. For fast, intense fires, the differences in opening time among the various ratings are negligible. For slower fires where operating time differences are noticeable, the time delay is unimportant.

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Illinois Institute of Technology

Radusch, R. (Research Division for Technique of Extinguishing Fires, Karlsruhe Polytechnical Institute, Germany) "Observations on the Most Favorable Size Drops for Extinguishing Fires with Atomized Water and on the Range of a Stream of Water Spray," VFDB Zeitschrift Forschung und Technik im Brandschutz 2, 47-54 (1953)

428

I. The most favorable size drops

Water has a very high heat capacity which enables its cooling action to play a predominant part in the extinguishment of fires. The rate of heat absorption depends on the extent of the exposed surface. The first part of this report discusses the possibility of improving the fire-fighting ability of water to its maximum by increasing the speed of vaporization by means of very fine atomization. In practice it is required that water be discharged at a distance from and be brought to the surface of the burning object in sufficient quantities per unit of time to absorb the heat generated within that unit of time. Very fine droplets cannot be easily focused at an object from a distance to give proper coverage and they do not have sufficient energy to resist the upthrust of the combustion gases when entering the combustion zone.

It is possible theoretically to determine the most favorable size drops on the basis that the speed of vaporization for a drop of water is a function of its surface area and the heat transfer coefficient. In still air—a condition which prevails at the burning surface itself—this coefficient is inversely proportional to the diameter of the drop and heat will be absorbed in proportion to the extent of the exposed surface. However, when a relative motion exists between the drops of water and the surrounding air, as when water is used mainly to quench the flames, to reduce heat radiation, and to curtail the spreading of fire by cooling of the hot gases, then the heat transfer coefficient is greater and the speed of vaporization is increased. To determine the most favorable size drops under these conditions, the author makes use of Edeling's* equation of the heat transfer to small drops of water in motion:

$$h = 0.75 \frac{k}{\sqrt{\alpha}} \sqrt{\frac{v}{d}} \qquad (1)$$

in which the heat transfer coefficient h is shown to be a function of the ratio of the velocity "v" of the drop to its diameter "d," k is the thermal conductivity and α the thermal diffusivity $\left(\frac{k}{\rho c_p}\right)$. At a constant velocity, the heat transfer coefficient will depend only on "d" and by assuming that the heat quantity "dQ"

$$dQ = h \cdot 4\pi r^2 \cdot \Delta t \cdot d\tau \qquad (2)$$

transmitted within unit time "$d\tau$" to the surface of the drop of radius "r" under a temperature difference "Δt" is made to vaporize a quantity "dW" of water, a vaporization equation can be obtained relating time of vaporization τ to the radius of the drop "r":

$$\tau = \frac{L \cdot \rho w \cdot \sqrt{2\alpha}}{1.5 \cdot 0.75\, k \Delta t \cdot \sqrt{v}} \cdot \sqrt{r^{1.5}} \qquad (3)$$

where L is the heat of vaporization of water, and ρw its density.

A series of tests aimed at measuring the vaporization time of a drop of water in a current of air at constant values of air velocity and temperature led to the conclusion that the exponent of d must be larger than 0.5 and should lie between 0.8 and 1.0. The influence of the air velocity could be analyzed in a similar manner by keeping temperature and diameter of the drop constant. No results were available as yet and the author makes use of results reported by Schmidt † on the transfer of heat from heated pipes, to infer that the exponent of v would have to correspond to, if not exceed, that of "d."

Assuming equal exponents for both "v" and "d," the influence of the quotient "v/d" on the heat transfer coefficient can be analyzed to determine for what value of "d" heat absorption will be maximum. For a drop of a given diameter, neglecting the loss of substance through evaporation during flight, the value of the heat transfer coefficient will be a function of the speed of the drop relative to the surrounding air. The horizontal component of this speed will decrease very rapidly to zero against the resistance of the air although there continues to exist a horizontal component of the absolute speed because of the air current created by the stream of water spray. On the other hand, the vertical component of the relative speed increases toward a limit value, the terminal speed of fall, which is unequivocally defined for any size drop and which determines the balance between the weight of the drop and the air resistance.

The author introduces this terminal speed of fall as the lower limit for the relative speed of the drop and, substituting its value for v in Edeling's equation of the heat transfer, he finds that the coefficient of heat transfer is maximum for a drop diameter of 0.35 mm. This is compared with optimum values of 0.4 to 0.6 mm. obtained in England* during tests on the extinguishment of liquid fires.

II. The range

The range of a solid stream of water is a function of the velocity of the stream at the nozzle which in turn is dependent on the pressure at that point. In the case of a stream of water spray, a certain quantity of energy "A" must be used to overcome the surface tension 'σ' of the water during the atomization process:

$$A = \frac{6\sigma}{10d} \quad kg/cm^2 \qquad (4)$$

It is calculated that the production of drops with a 0.35 mm. diameter at an absolute pressure of 5 atmospheres consumes only 0.24 per cent of the water pressure.

If this energy required for atomization is taken into account in the pressure equation, the initial velocity (or nozzle velocity) "v_0" of a drop of water of a diameter "d" (in mm.) is equal to:

$$V_0 = \sqrt{\frac{2}{\rho_W}\left(P_0 - \frac{6\sigma}{10d}\right) + v_1^2} \qquad (5)$$

where "P_0" is the pressure within the pipe line and "v_1" the speed of water in the line. Assuming a water flow of 100 l/min through a hose of 52 mm. diameter, "v_1" would be equal to 0.79 m/sec. Water drops of 0.35 mm. diameter would have a velocity of about 30 m/sec for a nozzle pressure of 5 atmospheres, providing friction losses within the nozzle are kept low.

To determine the range of the water spray, consideration must be given to the air resistance which is a function of the diameter of the drops and of the dynamic pressure of the air. For a sufficiently short time interval $\Delta\tau$, the deceleration $-\Delta V_0$ of the drop would be

$$-\Delta V_0 = -b_0 \cdot \Delta\tau \qquad (6)$$

where "b_0" is the retardation factor. After $\Delta\tau$ seconds, the speed "v_1" of the drop would be:

$$V_1 = V_0 - \Delta V_0 \qquad (7)$$

and the corresponding distance travelled amounts to:

$$s_1 = \frac{V_0 + V_1}{2} \cdot \Delta\tau \qquad (8)$$

The speed variations and the corresponding distances travelled can be integrated step by step to give the range "S" of the drop:

$$S = \sum_{i=1}^{i=n} s_i \qquad (9)$$

This range is found to be about 1.50 m. for 0.35 mm. drops at an initial velocity of 30 m/sec. Loss of mass by the drop during flight would tend to reduce this value. If attempts were made to extend the range, say to 6 m., by increasing the pipe pressure, it would be found that very high pressures outside the range of practical possibilities would be required since range increases with the 4th root of the pressure. Furthermore, owing to its low mechanical stability, a drop of water is incapable of opposing very high dynamic air pressures. Whenever the dynamic pressure resulting from the speed of the drop exceeds a certain value, the drop is flattened and broken down into smaller drops. The condition of stability which exists between the upper speed limit "$v_{max.}$" and the diameter d of a drop is:

$$v_{max.} = \sqrt{\frac{8\sigma}{d \cdot \rho_L}} \qquad (10)$$

where σ is the surface tension of the drop and ρ_L the specific density of the air. From this, it is found that a drop of 0.35 mm. diameter would become unstable and break down at velocities greater than 36.2 m/sec.

In practice, it is observed that, in a stream of water spray, the drops travel much farther than could be expected on the strength of the theoretical findings above. In a steady-state stream, only the very first drops encounter static air. They create in their path a current of air which rapidly attains a stationary state and reduces the air resistance for the following drops. For an examination of the range of a stream of water spray, the stationary state is, therefore, the determining factor.

Assuming very fine atomization of the water, a stream of water spray can be compared to a stream of air and would be expected to expand quite accurately and independently of the nozzle velocity as a cone having a vertex angle of 14° at the nozzle opening, provided the Reynold's number is sufficiently large. If the drops are not infinitely small, and assuming steady conditions of water flow, the total free surface of the water would be smaller, friction would be reduced, and a smaller amount of air would be forced along. The reduction in the amount of air to be accelerated means that the volume of the cone becomes smaller. It is concluded that in a stream of water spray, the vertex angle which is a function of drop size would lie between the limits of 0° (solid stream) and 14° (fine atomization), providing all drops are emitted at the same speed and direction.

It is found that, in practice, the nonuniformity of drop sizes complicates the dynamics of the stream since small and large drops tend to collide in flight. It would be most important to develop atomizing nozzles which produce drops of uniform sizes, regardless of pipe pressure. With a properly designed nozzle, it would be possible for 50 per cent of the water to arrive at a vertical circular surface of 1 square meter area at a distance of 8 m. from the nozzle. This corresponds to an 11.4° vertex angle of spray. It is also concluded that, for a water flow of 100 l/min and an initial velocity of the drops of 30 m/sec, the absolute velocity of the drops at a distance of 8 m. would be of 4.2 m/sec which is presumed to be sufficiently high to allow the drops to reach the focal point of the fire against the upthrust of the combustion gases. The time of flight would be 0.45 sec. Gravity would make drops having a 0.35 mm. diameter fall a distance of 0.68 m.

Subject Headings: Water, sprays for flame extinguishment; Water, sprays,
range of; Extinguishment, by water sprays.

J. R. Jutras

*Edeling: Investigation of Atomization Drying (Untersuchunger zur Zerstaeubungstrocknung): Diss. 1949, Karlsruhe, Verlag Chemie, Weinheim, Germany.

Schmidt: Introduction into Thermo-Dynamics (Einfuehrung in die Thermodynamik) Berlin 1944.

*Rasbash, Rogowski, Skeet: "Some tests on the effect of water sprays on a hexane fire." F. C. Note #45/1951. Rasbash: "The effect of water sprays in burning kerosene." F. C. Note #41/1951.

<u>Note:</u> The above abstract was taken from "Fire Research Abstracts and Reviews," Committee on Fire Research and Fire Research Conference, National Academy of Sciences - National Research Council, Washington, D.C., Volume I, Number 2, January, 1959.

U.L.

ROBERT BRADER

303

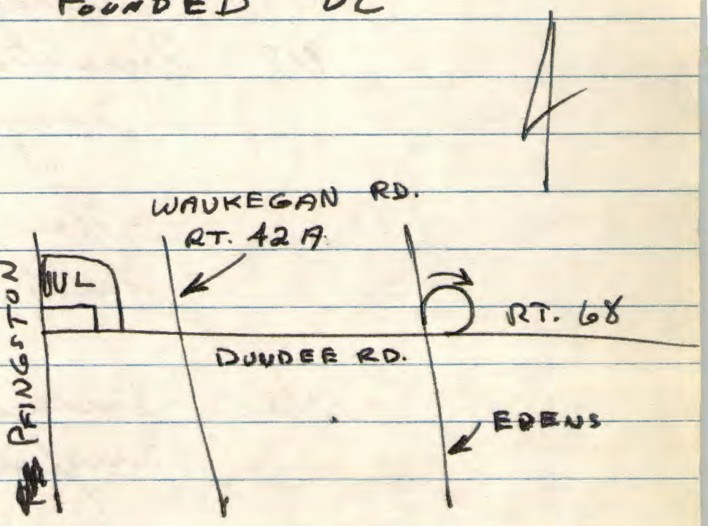
DANGER SLEWS
(DETECTIVES)

ALBUM OF PUBLIC SAFETY

WLM. HENRY MERRILL FOUNDED UL

I BEGINNING

A. ELECTRICAL	1893	
B. FIRE PROT	1893-98	(?)
C. LABEL SERVICE	1905	
D. CHEMICAL	1900-1920	(?)
E. GASES & OILS	1906	(?)
F. CASUALITY	1915	
G. AUTOMOTIVE	1918	
H. BURGLARY PROT.	1921	



HISTORY

OUTCROPPING OF WORLD COLOMBIAN EXPOSITION

Western Union League sent merril to Exposition to see why the displays were burning. Started in 1893 his own "U.L." & test new fangled. merril $350.00 first pres. ⇒ Electrical Bureau for NBFU

Fire prot → Robinson first VP

1904 they were approached by Insurance & codes to label. He said he would if he had inspectors. So Label Service Dept. started in 1905. first label was rigid conduit

Now have 1. Elec. Dept.
2. Fire prot Dept
3. Label. Dept.
then comes Chem Dept.
then abt. 1906-1910 oil burner dept

1915 Casuality Dept. (Refrig, air cond etc)
1918 - Requested to test Autos
prompted use of safety glass
" safer carbs.
Now ~~most~~ mainly - concerned with lift trucks.

1921 - Insurance, safe makers requested Burglary dept.

Started in one area & expanded at request

In 1905 Merrill got Idea to be Independent + in 1917 UL.

& NBFU donated $250,000 equipment they had purchased for UL.
Started charging Mfgr.

+ Service Chge for each label issued to cover inspectors expenses etc.

Excess $ refunded at end of yr.

Unique QUALITIES OF U.L.

1. Non PROFIT
2. ~~•~~ follow up service
3. Create own stds. of safety
   a. Industry & many diff people come to comment.
   b. Councils vote on stds & comment but U.L. decides on its adoption.
   - a.e. go to people for help.

4. Own Engrs.
   Own Test Equipment

Government of U.L.

1906 charter drawn up & stocks issued in ILL.
1936 ~~B~~ found out ILL. didn't have provision for non profit orgs.
So chartered in Delaware.

NBFU

So now have CHARTER

CHARTER

SET UP NBFU AS TRUSTEES (BOARD OF DIRECTORS)

PRES.

ENGINEERING PROBLEMS NOT HANDLED BY NBFU
LONG RANGE BUSINESS " HANDLED BY NBFU

NBFU
CHARTER
PRES.

open AUG 26.

MEVILLE. L.I. - NORTH BROOK - SANTA-CLARA
V.P. V.P. V.P.

EACH DEPT. HAS. MANAGING ENGR. answering to pres.
each dept broken into assoc. managing Engrs.

Label Service works out of Chgo.

Starting to work on some Atomic

Non Profit - No DIVIDENDS.

1955 first Billion mark for labels.

9,200 factories visited / yr.

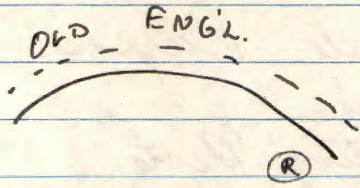
RE-EXAMINATION SERVICE
FLAT RATE
& INSPECTOR
VISITS HIM 1-4
times/yr.
little change
in product

LABEL SERVICE
Inspectors visit W.R.T.
volume of production.

SPECIAL PROBLEMS.

Identification 1. LIST.
2. LABEL.

Under
Label Service Characteristics.



Under Re-examination
Service
In Book gives
~~of~~ [illegible]
or identification.

DIE ~~CAST~~ LABELED UND. LAB. INC.

R

Write Paper on U.L.

UL 723

1. Overall Purpose ✓
2 History ✓
3. Operating Depts. ✓
4. Financial (Income) ✓
5. Follow up Services
6. Idintification of Listed Products
7. Method(s) of submittal of Prod. ✓
8- Usefullness to you as an F.P.E.

+ ??

UNDERWRITERS' LABORATORIES, INC.

DAVID LUCHT

OCT. 5, 1963

F.P.E. 303A

purpose - Testing for Public Safety

Underwriters' Laboratories, Inc. is a nonprofit corporation organized to determine the relative hazards of various devices, materials, and construction methods with respect to life, fire, and casualty loss. Further, having determined the relative hazards of these items, it is the purpose of Underwriters' Laboratories to classify, identify and list those which may reduce and prevent loss of life and property from fire, crime and casualty.

paragraphing

The seed of Underwriters' Laboratories, Inc. was sowed in 1893 by the Western Union League which sent Mr. William Henry Merrill to the World Columbian Exposition in Chicago for the purpose of determining the causes of the frequent fire losses incurred at the Exposition. After surveying the problem, Mr. Merrill saw the need for an organization which could test the safety of the new electrical devices such as those which seemed to be causing the fires at the Exposition. Thus, in 1893 Mr. Merrill formed his own "Electrical Bureau" in connection with the National Board of Fire Underwriters. Next, some time between 1893 and 1898, a Mr. Robinson entered the Bureau as Vice President, and brought with him the Fire Protection Department of the Electrical Bureau. Later, in 1904, the men were approached by insurance companies and building codes people who urged them to label and identify the products which the Bureau had tested. Hence, in 1905, the Label Department of the Electrical Bureau was formed. This expansion continued -- next a Chemical Department was formed, then an Oil Burner Department, and in 1915 a Casualty Department. In 1917 the Bureau became an independent nonprofit corporation, with the National Board of Fire Underwriters donating $250,000 worth of equipment which they had purchased for the work of the Bureau. This was Underwriters' Laboratories, Inc. In 1918 the Automotive Department was formed, and in 1921 the Burglary Department. Working with all of the above departments, Underwriters' Laboratories has grown until today it has four testing stations across the United States with representatives around the world.

Underwriters' Laboratories, Inc., as previously mentioned, is a nonprofit organization. The corporate income is received in the form of fees charged to the manufacturer for examinations, tests, reports, and follow-up service on his product. This income is then used to finance testing expenses and facilities, salaries, and clerical services, and the remainder (except for any lay-away for future or emergency use) is returned to the people for whom services were performed.

The submittor who is interested in obtaining a report, test, and listing of his product writes to Underwriters' Laboratories and gives a complete description of the product in order that its character, purpose, size, rating and other features may be evaluated and the product may be classified as close as possible as to the extent of tests and examinations necessary. After this classification, an application form is sent to the submittor giving in detail the limitations and responsibilities of Underwriters' Laboratories, the amount of deposit necessary, the type examination and test to be performed, and the type follow-up service to be employed if and when the product is found acceptable. Final Listing is contingent upon acceptance of actual production samples only. Further, some products may be tested and examined on the site of production in some instances where shipment to the Laboratories is impractial.

If and when the product is accepted under Laboratories' standards or requirements, it is identified as being Listed. Further, a follow-up service is employed by the Laboratories as a check to insure that all listed products are produced to conform with standards or requirements.

One type of follow-up service is known as the Reexamination Service, which constitutes continued Listing of a product together with visits to the factory one or more times yearly, by a member of the Laboratories' staff, for the selection, examination, and test of representative samples of the most recent production of the Listed product. If this product fails to meet the Laboratories' requirements upon Reexamination, it must be corrected by the manufacturer on further production as a condition of continued Listing. These products Listed under the Reexamination Service are marked with the manufacturers identification and catalog numbers which correspond with identification in the Laboratories' published records. Only those products which actually bear the Listed identification are covered by the Reexamination Service.

Another type of follow-up service is the Label Service. Here the manufacturer conducts his own tests and examinations to insure that his product complies with Underwriters' Laboratories requirements, and attaches registed labels to them. However, as in the Reexamination Service, the Laboratioies' representatives make frequent visits to the factory to check the efficiency of the manufacturers inspection program. Should the representative find the program substandard, the manufacturer must correct defective items or remove labels from the product. Often products purchased by Underwriters' Laboratories in the open market are tested in the Laboratories as a countercheck on the factory inspection. The label of Underwriters' Laboratories, Inc. attached to the product is the only way to identify products produced under the Label Service. This label bears the Label Service Symbol together with the classification of the product involved.

A limited number of products are Listed under the Die-Label Service whereby the Label Service Symbol is stamped, cast, or moulded in the product. Also, a Certificate may be signed by both manufacturer and the Laboratories, which lists definate quatities of material intended for specific job sites, under the Certificate Service.

The services of Underwriters' Laboratories are very valuable to the Fire Protection Engineer, as well as the manufacturer. Underwriters' Laboratories is quite diversified as to the various fields into which it extends, as is the Fire Protection Engineer; in this respect both can often work hand in hand. The results arrived at by Underwriters' Laboratories can be used by the Fire Protection Engineer as a basis of standard upon which he can solve various engineering problems with confidence. Listed materials, devices, and construction methods may be employed without the engineer having to go into a large amount of personal research on the hazards involved. Further, as Underwriters' Laboratories Listed products are so widely accepted by insurance organizations and building codes authorities etc., the engineer can be assured that his client will receive the most appropriate service in this aspect.

Howard Engerman

La Salle Hotel fire created much interest in Hazard classif. People wanted a way of measurement. Had to choose 2 matls - one incomb & 1 comb. for basis.

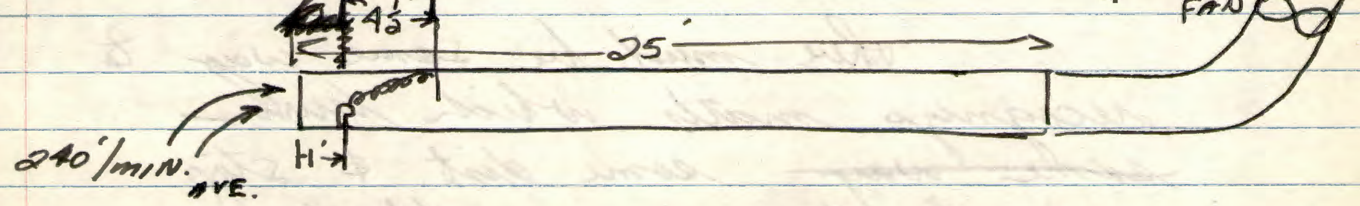
CLASSIFICATION

1. Flame Spread most important - observed

2. Fuel Cont. - recorded

3. Smoke Developed - recorded

25 window ⇒ all of sample can be seen.



40 ± 5% rel. Humidity
70 ± 5 °C

Methane gas used.

the 240'/min established using R.O.
⇒ flame goes 19½' in 5½ min. ±15 sec. ⇒ F.S. 100

10 min test

See 3 formulae.

Majority of matls based on distance formula since most don't reach end.

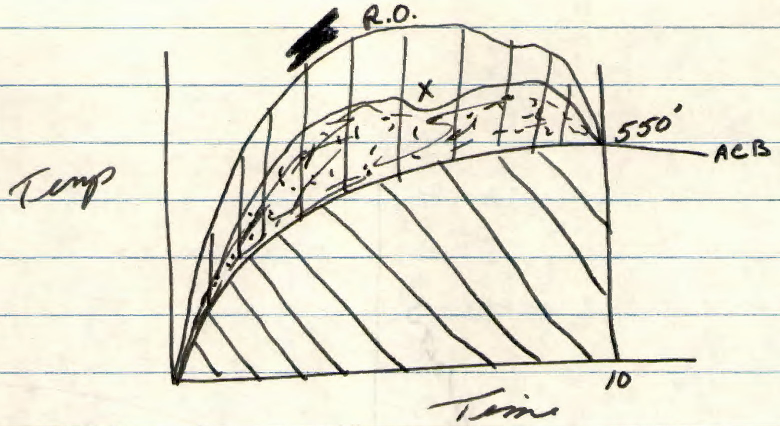
MEASURE FROM Burner and subtract 4½' for calculations.
DATA IS 4½ too big.

Ambiguity in formulae

[redacted] $$F.S. = \frac{5.5}{T} + \frac{1}{2}\left[100 - \frac{5.5(100)}{T}\right]$$

there must be some way to recognize matls which burn ~~some way~~ some dist. & stop
& also to recognize flash over & then recede. this formula set up takes it into account.

Fuel Cont: At 23' TC 1-2" below ℄ ACB



ACB is incomb, so T T curve results from fuel of burner.

$$\frac{\text{Time}}{\text{Temp}} \propto \Rightarrow \text{BTU}$$

$$F.C._{ACB} \Rightarrow 0$$

$$AREA_{RO} - AREA_{ACB} \Rightarrow 26.6\ IN^2 - 14\ IN^2 = 12.6\ IN^2$$

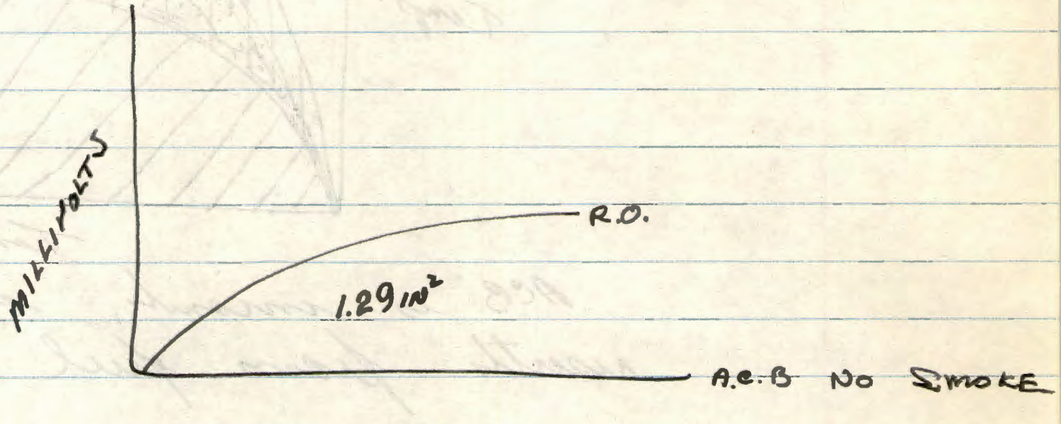
$$\Downarrow$$

100

$$A_x - 14\ IN^2 = 6.3\ IN^2 \quad (ARB)$$

$$\frac{6.3}{12.6} \times 100 \Rightarrow F.C. \text{ of } 50$$

$$S.D. = \frac{A_x}{1.29}$$



* Readings aren't absolute

* Furnace calibrated ⇒

$F.S. \Rightarrow 0_{ACB} \Rightarrow 100_{RO}$

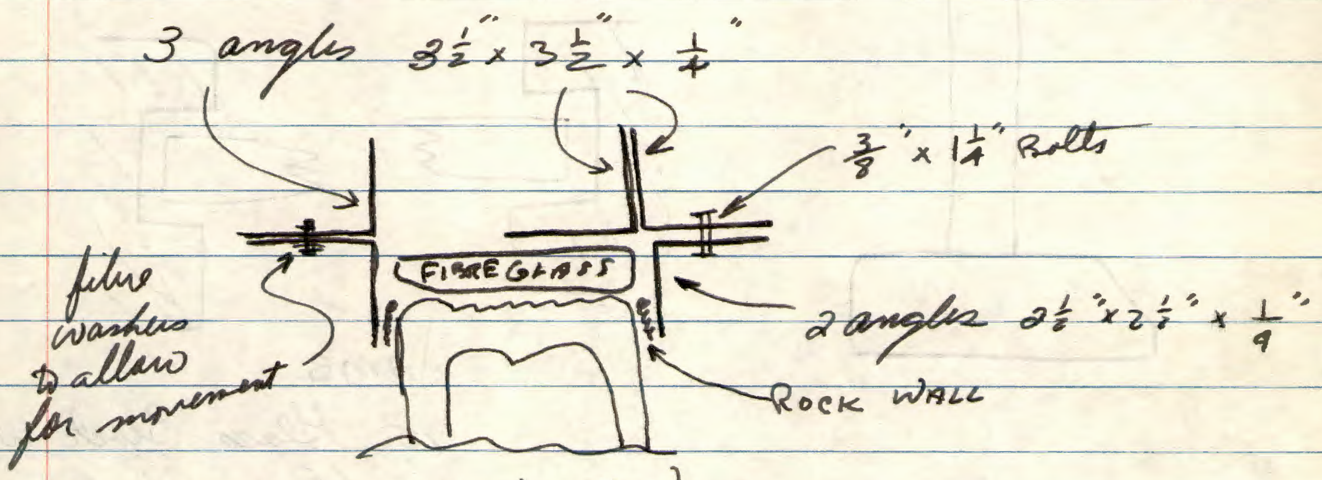
$F.C. \Rightarrow 0_{ACB} \Rightarrow 100^{RO}$

$S.D. \Rightarrow 0_{ACA} \Rightarrow 100_{RO}$

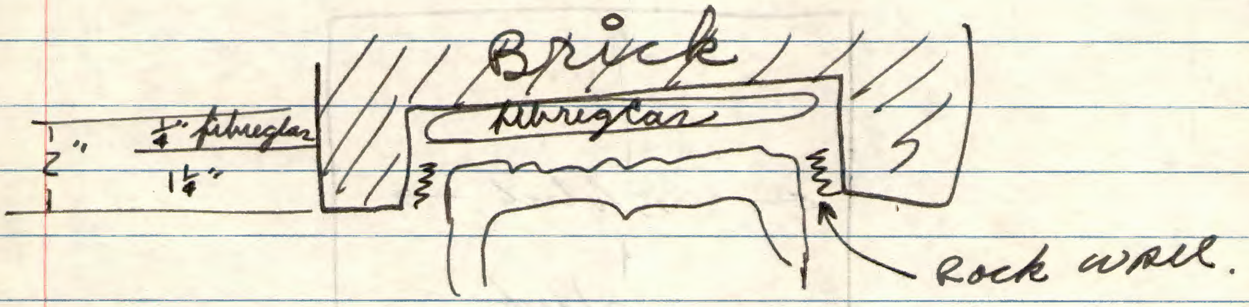
Walter Haas. Glass Block U.L. 9

Glass blocks suitable for 3/4 h. F exterior openings.

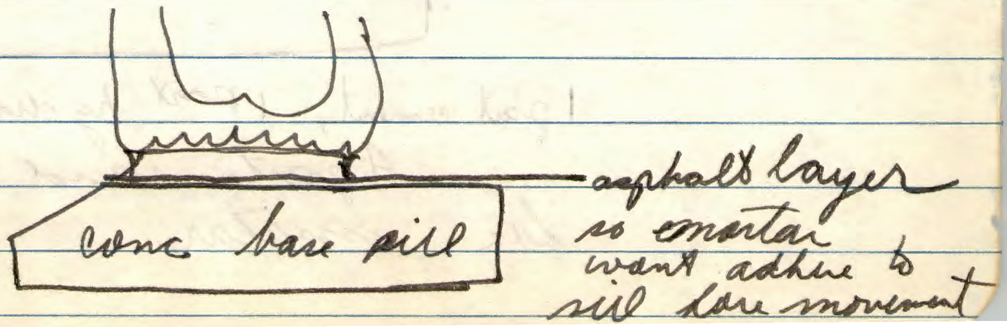
Cannot exceed 120 ft² opening nor 12' max dimension

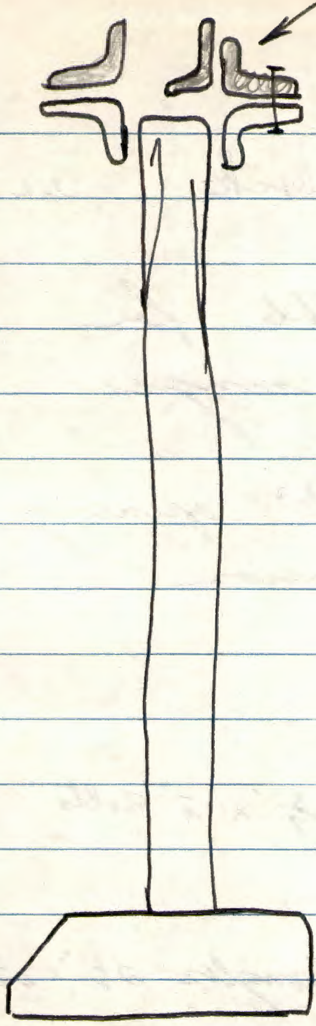


Head Section.

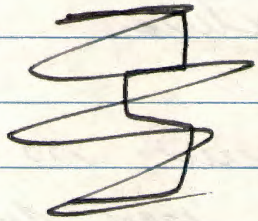


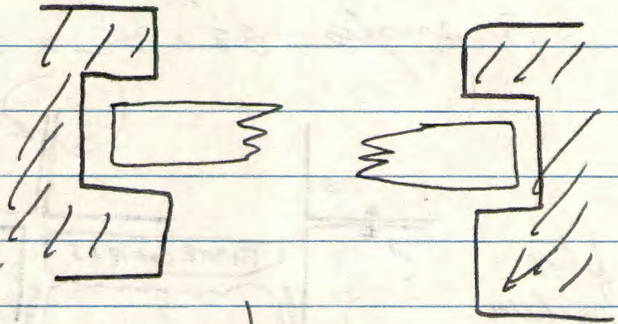
Jamb (side)





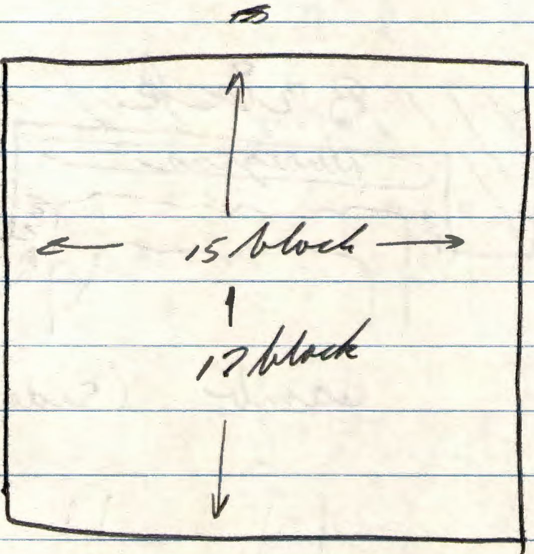
lintel (3 top angles)
(Shaded) carries load
above window





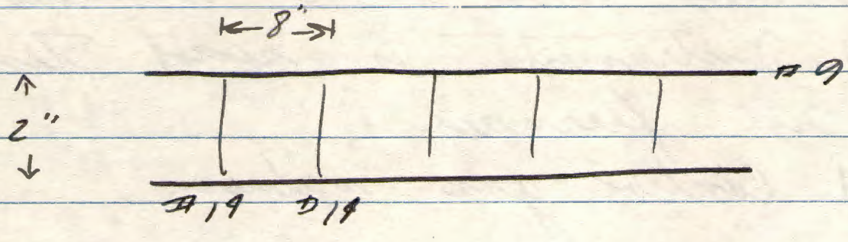
JAMB.

15 Glass Block wide
17 block high



1 part cement, 1 part hydrated lime
4 parts sand (by volume)
for mortar

Reinforcing #9 gauge wires ~~mesh~~.
with 14 ga. mesh. 8" apart
2" apart with #14 wire



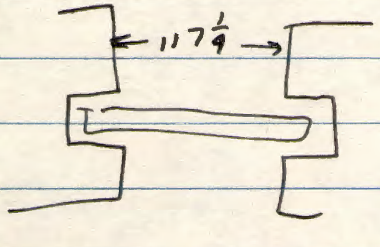
every 3rd row of block starting
at bottom

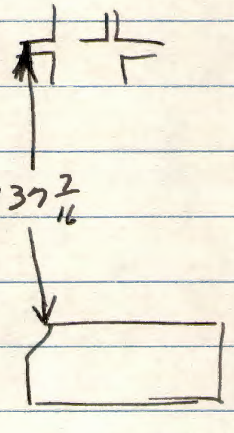
Hose Stream Test

137 7/16" hight

based on area
you can hit with stream.

117 1/4" width





$$\underbrace{\frac{137\frac{7}{16}}{12} \times \frac{117\frac{1}{4}}{12} \times .6}_{\text{time in seconds to be applied}}$$

175/85 137 high

A — check

$9\overline{)137}$ 34
12/14

Observations–

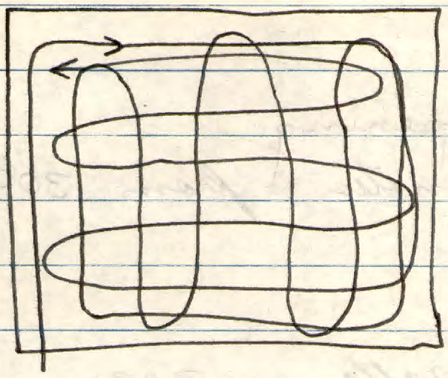
1. Exposed side
2. unexposed side– deflection ~~the~~ meas with wire stretched across.
3. Instrument to read temp in furnace.
4. Control gas valves.

shattering of glass?

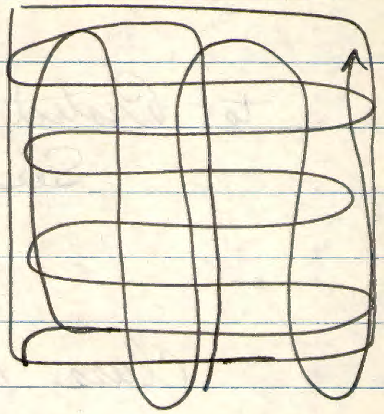
No limitation on temp transmission

Hose Pattern

Glass Block.



Fire Door



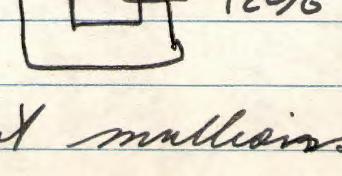
Discoloration
Openings - where
when
Joints breaking
glass breakage.

FIRE DOORS

to Protect a wall opening
See mimeo notes from 309

Class A. - fire walls 3 HR.
usually one door on ea. side
B- vert shafts - stair cases.
rubbish chutes etc.
$1\frac{1}{2}$ or 1 HR.
100 in^2 VISION PANEL PER OPENING.
MAX 12" dimension
↓
if 2 doors
not >100 in^2
total

C- corridors & room partitions
NOT LABLED FIRE DOORS.
1296 in^2 MAX
could have 1296 in ea
of a pair of doors.
OR

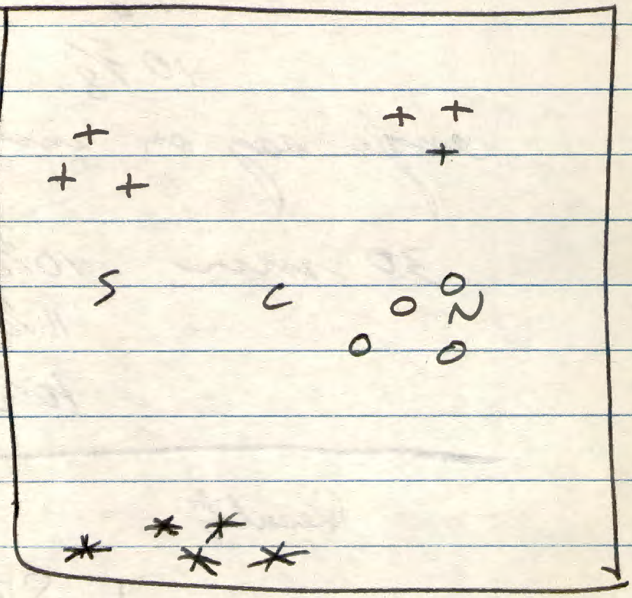


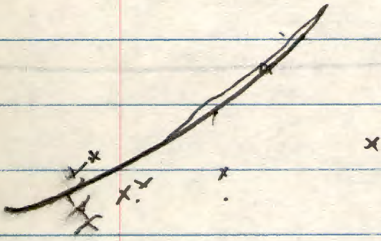
OK.

except not mullions for
ne

Why Jets in rear? Kimble GLASS

2 min cracking o
3 min " +
" " flying glass.
4 " blocks exploding
" " all blocks cracked
except *





5 min meas defl. 10" S
$10\frac{1}{4}$" C
10" N

6 min observed pin holes in exposed side colored block, can't tell on clear

10 min - defl 10" S
$10\frac{1}{2}$" C
$10\frac{1}{4}$ N

15 min framing secure
18 " defl $10\frac{5}{8}$ S
11 C
$10\frac{5}{8}$ N

×

25 min 11" S
11¼ C
10⅝ N
angle sag on inside

30 min 10¾ S
11¼ C
10½ N

Results.

1. Stayed in frame.
2. ?

Doors Cont

"D" ext wall 1½ hr.
"E" door + window
not > 720 in^2 glass
"F" ¾ HR. 1296 in^2 window

34 HOLES

8:30 NORTH BROOK

Deflections

Time	S	C	N
0	$9\frac{1}{4}$	$9\frac{1}{4}$	$9\frac{1}{4}$
5	10	$10\frac{1}{4}$	10
10	10	$10\frac{1}{2}$	$10\frac{1}{4}$
15	$10\frac{5}{8}$	11	~~[illegible]~~ $10\frac{5}{8}$
20	11	$11\frac{1}{8}$	~~[illegible]~~ $10\frac{3}{4}$
25	11	$11\frac{1}{8}$	~~[illegible]~~ $10\frac{5}{8}$
30			
35	$10\frac{3}{4}$	11	$10\frac{1}{2}$
40			

why deflect inward

inner surf exp
until outer side
gets hot

FPE 303

D. LUCHT

igniting flame be adjusted so that

1. the primary requirement for calibration of the tunnel as set forth by the U.L. 723 is that the flame will spread on red oak lumber is 19½ feet in 5½ min ± 15 sec. [(also preheat using ACB.)]

-3

Major Controls:

1. DRAFT 240 ± 5 ft/min
2. AMBIENT TEMP: 70 ± 5°F
3. REL. HUMIDITY 30-40%
4. PREHEAT - Thermocouple reading 105 ± 5°F
5. FUEL - METHANE GAS @ 5000 Btu/min
6. 3" x 17½" DRAFT OPENING

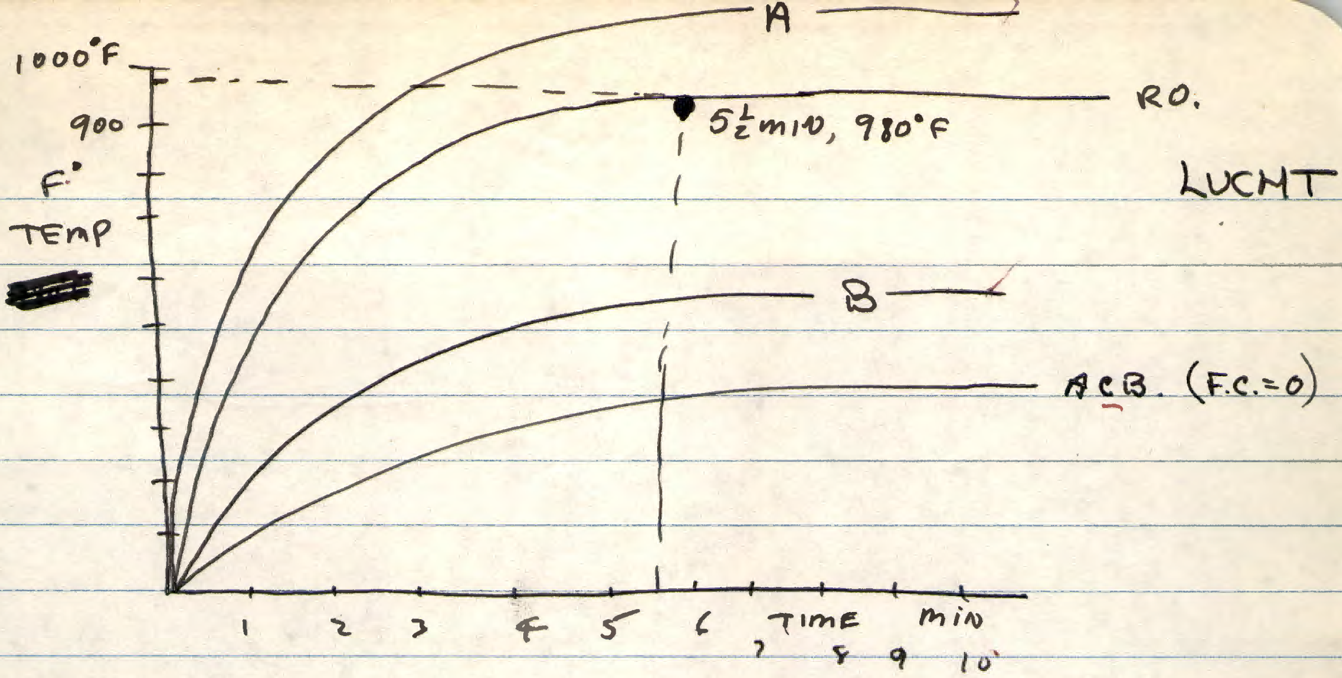
2. not necessarily, the flame may spread very rapidly or flash and will exibit very low smoke and fuel contributed characteristics.

-1

ok.

LUCHT

3.



$$F.C. = \frac{A_u - A_{ACB}}{A_{RO} - A_{ACB}} \times 100$$

where A_u = AREA UNDER UNKNOWN CURVE ("A" or "B")

A_{RO} = AREA UNDER RED OAK "

A_{ACB} " " ASBESTOS CEM. BRD. CURVE

4.

1. MOISTURE CONTENT OF SAMPLE
2. AIR VELOCITY OF DRAFT
3. INTENSITY OF IGNITION FLAME.
4. AMBIENT ROOM TEMP.
5. STRUCTURAL CHARACTERISTICS OF THE MAT'L ITS SELF

1/2

?

D. LUCHT

$$\text{F.S.} = (100)\left(\frac{5.5}{T}\right) \quad \text{for } t \leq 5\tfrac{1}{2}$$

5. TIME: $$\text{F.S.} = (100)\left(\frac{5.5}{T}\right) + \frac{1}{2}\left(100 - \frac{550}{t}\right) \quad t = 5\tfrac{1}{2} \text{ to } 10 \text{ min.}$$

DISTANCE: $$\text{F.S.} = (100)\left(\frac{L}{19\frac{1}{2}}\right)$$

$$\frac{100L}{19.5} = 90$$

$$L = .9(19.5) \cong 17.6'$$

$$\begin{array}{r} 19.5 \\ .9 \\ \hline 17.55 \end{array}$$

~~$\frac{550}{T} = 90$~~

~~$90T = 550$~~

~~$T = \frac{550}{90}$~~

~~$\frac{275}{2}$ 550~~

$$\begin{array}{r} 6 \\ 5 \\ 9\overline{)55} \\ 54 \\ \hline 100 \end{array}$$

$$\begin{array}{r} 250 \\ 25 \end{array}$$

$$\frac{550}{T} + 50 - \frac{275}{T} = 90$$

$$\begin{array}{r} 550 \\ 275 \\ \hline 275 \end{array}$$

$$\frac{275}{T} = 40$$

$$40T = 275$$

$$T = 6.87 \text{ min.}$$

$$\begin{array}{r} 6.87 \\ 40\overline{)275} \\ 240 \\ \hline 350 \\ 320 \\ \hline 300 \end{array}$$

(-1) * So, which burns faster.
F.S. of 90 determined by time indicates that the flame has spread over the end of the sample ($19\frac{1}{2}'$ FS) in about 6.9 min. Determined with respect to distance, the flame has only spread 17.6 feet in 10 min. ✓

6. The material may ~~[illegible]~~ provide a very irregular time temperature curve or exhibit very peculiar burning characteristics. -10 X
e.g. styrofoam board - This mat'l melted before it burned

FPE 303
D. LUCHT

83

6th. Semester.

F.P.E. 304 - Class Session No. 1

A DISCUSSION OF FLUID PRESSURE

1. GENERAL

The purpose of this session is to discuss the theory of fluid pressure, fluid pressure measurement and to familiarize the student with instrumentation used for fluid pressure measurement.

The discussion includes a review of the definition of fluid pressure, the common units for expressing both absolute and gauge pressure, variation of pressure in a fluid, Pascal's Law, etc. Discussion of instruments for measuring pressure includes the piezometer, the simple manometer, the differential manometer and the Bourdon Gauge, as well as the location and connection of these instruments to actual systems. Since these instruments will be used in subsequent laboratory work, the students are expected to familiarize themselves with the design and construction of this equipment.

The calibration of a Bourdon Gauge by means of a dead-weight gauge tester is discussed, demonstrated and performed by the students.

2. References

A. Chapter 1 and Sections 2.1, 2.2 and 2.3, Hydraulic Systems for the Fire Protection Engineer.

3. Discussion Session

A. See Item 1 above.

4. Tests

One or more Bourdon Gauges are provided the students for calibration by means of a dead-weight gauge tester.

5. Report

No report is required on the work done during this class session.

F.P.E. 304 - Class Session No. 2

FLOW MEASUREMENT I - A STUDY OF THE VENTURI METER AND THE ORIFICE PLATE METER

1. GENERAL

SHORT FORM REPORT

The purpose of this session is to provide an understanding of the techniques and instrumentation for the measurement of fluid flow, with emphasis on the theory and calibration of the Venturi Meter and the Orifice Plate Meter.

A combination of material balance and energy balance is applied to a water system in steady flow to determine the calibration coefficients of a Venturi Meter and an Orifice Plate Meter. Differential manometers are used to determine the pressure drop across each meter. Since the meters are installed in series in the same pipe system, the measurement of flow rate at any condition of adjustment applies simultaneously to both meters. Flow rate is determined by collection of water in either a volume tank, or a weight tank for a known period of time. As the work proceeds by varying the pressure drop across the meters, and measuring the flow rate for each adjustment, the data is checked by plotting flow rate versus pressure drop on log-log graph paper. Reruns are made to correct unsatisfactory data. The equations of the curves representing the data are determined.

2. References

A. Sections 2.4, 2.5, 3.1, 3.2 and 3.3, Hydraulic Systems for the Fire Protection Engineer.

3. Discussion Session

A. General discussion of flow measurement and fluid metering in most engineering problems, and fire protection engineering in particular.

B. Classification of fluid flow meters.

C. General discussion of calculations, graphs and report.

4. Tests

A. Adjust the flowing system to produce a number of suitable pressure drops across the flow meters. For each adjustment determine the flow rate by collecting the water in either a volume tank, or a weight tank for a suitable length of time. Calculate the flow rate in gallons per minute and the pressure drop across each meter in pounds per square inch and feet of head of water. The points should lie on a straight line when plotted on log-log graph paper. Check unsatisfactory data. Determine the equations of the curves which describes the data for each meter. Calculate the average calibration coefficient for each meter.

5. Report

A. Prepare a report as assigned by the instructor.

B. Conclusions should include a comparison of the behavior of the two meters, as well as the behavior of the meters as individuals of a class of meters.

F.P.E. 304 - Class Session No. 3

FLOW MEASUREMENT II -
~~A STUDY OF~~ THE FLOW NOZZLE METER AND THE PITOT TUBE METER

1. GENERAL

The purpose of this session is to provide an understanding of the techniques and instrumentation for the measurement of fluid flow, with emphasis on the theory and calibration of the Flow Nozzle Meter and the Pitot Tube Meter.

A combination of material balance and energy balance is applied to a water system in steady flow to determine the calibration coefficients of a Flow Nozzle Meter and a Pitot Tube Meter. The nozzle is arranged to discharge downward into the atmosphere, while the pitot tube inlet is fixed in the nozzle stream. Bourdon Gauges are used to measure the pressure upstream of the nozzle, as well as the pitot tube pressure, both gauges being arranged in the same reference plane at the level of the nozzle outlet. Since the meters are in effect installed in series in the same flow system, the measurement of flow rate at any condition of adjustment applies simultaneously to both meters. Flow rate is determined by collection of water in either a volume tank, or a weight tank for a known period of time. As the work proceeds by varying the pressure upstream of the nozzle, and measuring the flow rate for each adjustment, the data is checked by plotting flow rate versus pressure on log-log graph paper. Reruns are made to correct unsatisfactory data. The equations of the curves representing the data are determined.

2. References

A. Sections 3.4 and 3.5, Hydraulic Systems for The Fire Protection Engineer.

3. Discussion Session

   A. A continued discussion of flow measurement and fluid metering in engineering problems, and fire protection engineering in particular.

   B. General discussion of calculations, graphs and report.

4. Tests

   A. Adjust the flowing system to produce a number of suitable pressures, as measured by the Bourdon Gauge upstream of the nozzle. For each nozzle pressure a pitot tube pressure is measured and recorded. For each adjustment, determine the flow rate by collecting the water in either a volume tank or a weight tank for a suitable length of time. Calculate the flow rate in gallons per minute and convert the gauge pressures from pounds per square inch to feet of head of water. The points should lie on a straight line when plotted on log-log graph paper. Check unsatisfactory data. Determine the equations of curves which describes the data for each meter. Calculate the average calibration coefficient for each meter.

   B. Repeat the above procedure for at least three nozzles of different types.

5. Report

   A. Prepare a report as assigned by the instructor.

   B. Conclusions should include a comparison of the behavior of the two meters, as well as the behavior of the meters as individuals of a class of meters.

F.P.E. 304 - Class Session No. 4

A Study of Friction Head Loss in Pipe

1. GENERAL

The purpose of this session is to provide an understanding of the techniques and instrumentation for the determination of the friction head loss in pipe and to demonstrate the applicability of the Darcy-Weisbach and Hazen-Williams equations to the flow of water in pipes.

D-W

H-W

A combination of material balance and energy balance is applied to a water system in steady flow to determine the pressure drop between two points a measured distance apart on a pipe. The inside pipe diameter listed in the appropriate ASA Specification is assumed to apply for new pipe. Flow rate is determined by collection of water in either a volume tank, or a weight tank for a known period of time. As the work proceeds by varying the pressure drop across a known length of pipe, and measuring the flow rate for each adjustment, the data is checked by plotting flow rate versus pressure drop on log-log graph paper. Reruns are made to correct unsatisfactory data. A comparison is made between the measured friction loss and the calculated friction loss for new pipe. For each run a calculation is made of the Friction Factor (f) in the Darcy-Weisbach equation and of the Roughness Coefficient (C) in the Hazen-Williams equation.

2. Reference

   A. Section 2.8 Calculation of Friction Head Losses in Pipes and Fittings, and Section 2.9 Williams and Hazen Formula: An Empirical Equation for Pipe Flow, Hydraulic Systems for the Fire Protection Engineer.

2232 N. Sawyer

S4B

3. Discussion Session

   A. General discussion of pipe friction and the ageing of pipe.

   B. Discussion of the use of the Darcy-Weisbach and Hazen-Williams equations.

   C. General discussion of calculations, graphs and report.

4. Tests

   A. Adjust the flowing pipe system to produce a number of suitable pressure drops across a known length of pipe. For each adjustment, determine the flow rate by collecting the water in either a volume tank, or a weight tank for a suitable length of time. Calculate the flow rate in gallons per minute and the pressure drop in pounds per square inch and feet of head of water. The points should lie on a straight line when plotted on log-log graph paper. Check unsatisfactory data. Compare the results with the friction loss for new pipe and calculate the per cent change in friction loss based on new pipe. For each run calculate the Friction Factor (f) in the Darcy-Weisbach equation and the Roughness Coefficient (C) in the Hazen-Williams equation.

   B. Repeat the above procedure for at least three pipes of different sizes.

5. Report

   A. Prepare a report as assigned by the instructor.

   B. Conclusions should include a comparison of the results with that of new pipe, as well as the applicability of the Darcy-Weisbach and Hazen-Williams equations to the experimental results.

F.P.E. 304 - Class Session No. 6

Automatic Sprinkler Systems II -

A Study of Dry Pipe Systems, Dry Pipe Valves and Quick-Opening Devices

I. GENERAL

The purpose of this session is to acquaint the student with the characteristics of dry pipe systems and with the performance of dry pipe valves and quick-opening devices.

NFPA Standard No. 13 outlines the requirements for the design and installation of automatic sprinkler systems. Only the general features of the design and installation of dry pipe sprinkler systems are considered in this work; the details of design, installation and hydraulic calculation of sprinkler systems is treated in another course.

A dry pipe sprinkler system is a special purpose system to be used only in unheated buildings subject to freezing temperatures. The layout of sprinklers and piping arrangement for a dry pipe system is similar to a wet-pipe system; the water flow into the piping system is controlled by a dry pipe valve (protected from freezing.) Compressed air in the piping above the valve holds the dry pipe valve closed, preventing water from entering the sprinkler piping until the air pressure has dropped below a predetermined value.

Dry pipe systems are subject to a time delay in application of water on the fire and are, therefore, restricted in size and under certain conditions dry pipe valves are required to be equipped with a quick-opening device to reduce the time delay. The behavior of dry pipe valves is studied when installed on systems of various sizes, with and without a quick-opening device.

2. Referencea

   A. Read Chapter IX, and Part B of Chapter III, Section 16, Fire Protection Handbook, NFPA, Twelfth Edition.

3. Discussion Session

   A. General discussion of dry pipe sprinkler systems

   B. Discussion of differential and mechanical type dry pipe valves; and accelerator and exhauster type quick-opening devices.

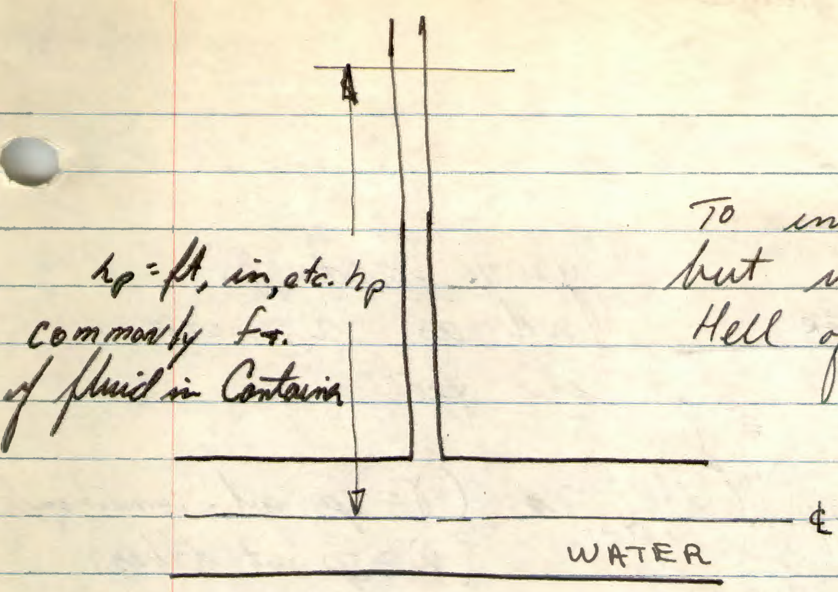
4. Tests

   A. For various water supply pressures determine the air pressure at the trip point of a dry pipe valve and the time from the opening of a sprinkler until the valve trips and until the simulated application of water upon the fire. Perform these tests with the dry pipe valve equipped with and without an accelerator and exhauster.

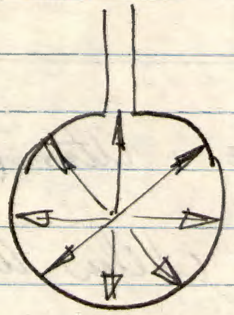
5. Report

   A. Prepare a report as assigned by the instructor.

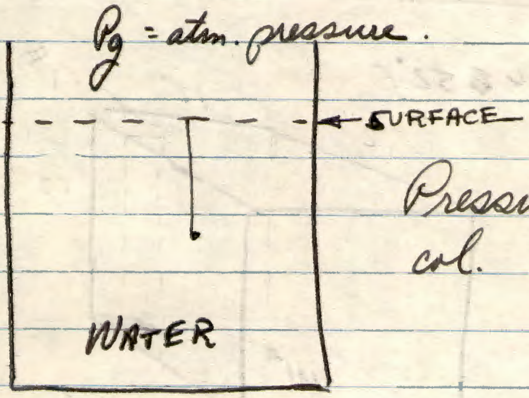
   B. Conclusions should include a comparison of the results with and without a quick-opening device, for the various sizes of dry pipe systems.



To indicate pressure but would req. a Hell of a tall pipe or tube.

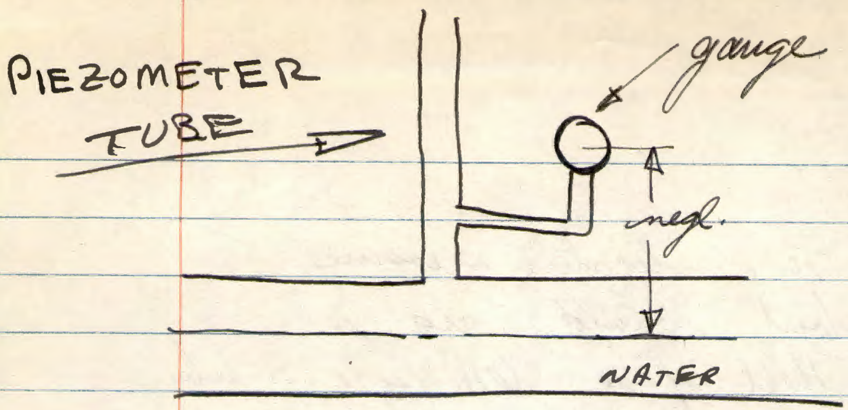


Pascal's Law Says pressure @ a pt in fluid is transmitted in all dir. & ⊥ to surface. a.c. STATIC PRESSURE HEAD



Pressure @ a pt = height of col. H_2O above. times w (sp. wt.)

ABSOLUTE vs. GAUGE?
Here, all gauges read zero @ atm. pressure.



gauge reads psi whereas h_p read in feet.

sp. wt.

Pressure* psf $= (h_{p\,ft})(\gamma\ lb/ft^3)$ ■ (γ = sp. wt. conventional)
(w = sp. wt Dakes)

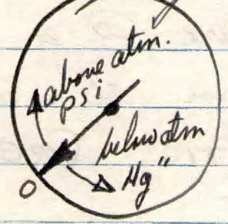
$P^* = psf$

$P = psi$ $\quad P^* = h_p w$

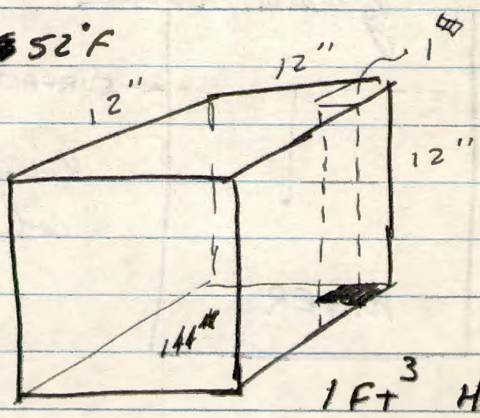
ABSOLUTE PRESSURE = GAUGE + Atm. (Barometer)

Vacuum Gauges read "Hg (below Atm.)

Some Gauges



Sp. Wt.$_{H_2O}$ = 62.4 LB./FT^3 @ ~ 52°F



1 FT^3 H_2O

? pressure on ~~□~~ 1 sq." ?

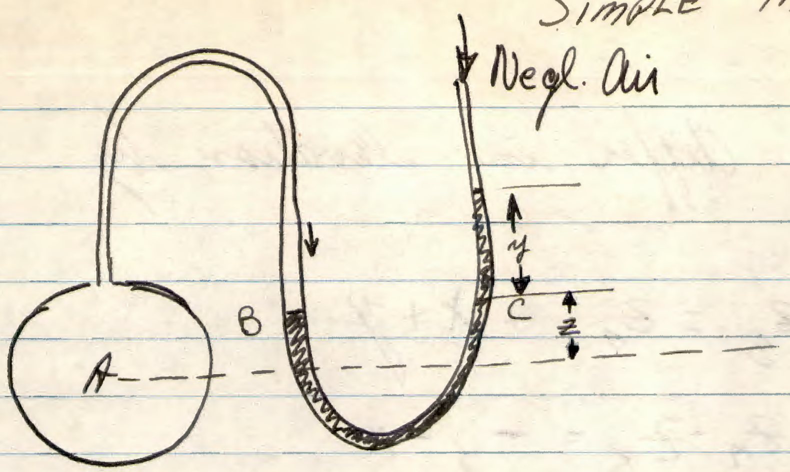
$$P = \frac{62.4\ LB.}{144\ IN^2} = .433\ psi/ft.$$

i.e. a col. of H_2O 1 FT high ⇒ $\underline{\underline{.433}}$ psi

$$\frac{.433}{12} = \underline{\underline{.0361\ psi/IN_{H_2O}}}$$

$$\frac{1}{.433} = \underline{2.31}\ FT_{H_2O}/PSI$$

SIMPLE MANOMETER



Sp. gravity

$$h_A = \frac{P_A}{w} = 0(\text{gauge}) + Sy + z$$ only if A is water.

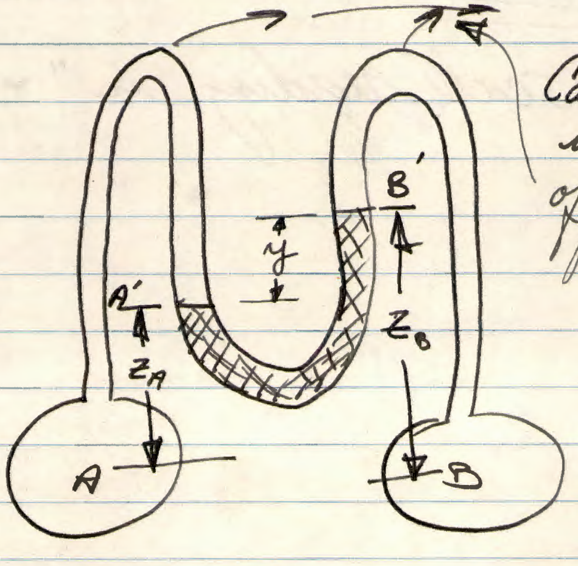
Sp. grav. Hg.

Hg – Sp. grav = $\underline{\underline{13.6}}$

~~[illegible]~~ $\underline{\underline{.0361}}$ psi/in. water

$(13.6)(.0361) = \underline{\underline{.49}}$ psi/in Hg.

DIFFERENTIAL MANOMETER



Can't be any Bubbles in H_2O ∴ Bleed it off

$$\frac{P_A}{w} - z_A - Sy + z_B = \frac{P_B}{w}$$

$z_A - z_B = -y$

$$\frac{P_A}{w} - \frac{P_B}{w} = Sy - y = y(S-1)$$

If A + B differ in elevation by x,

$$z_B = z_A + x + y$$

Now $$z_A - z_B = -y - x$$

"Hg. to psi = .491

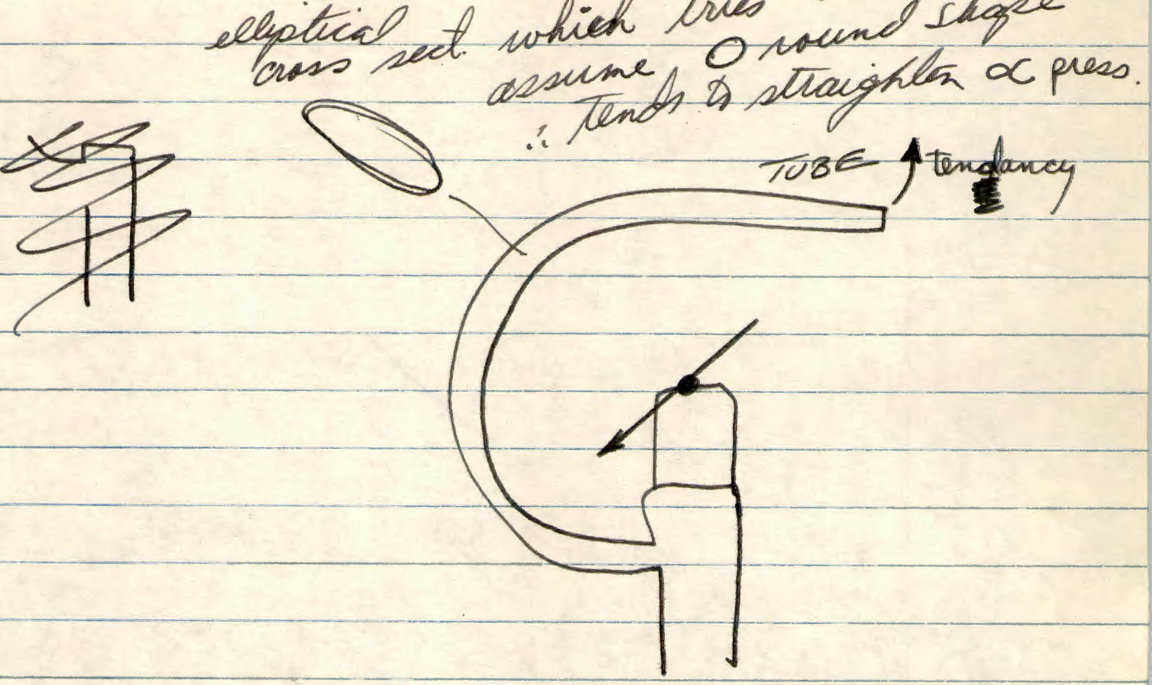
But in this Manometer have to take into account fact that water is on top of Hg.

Now "Hg to psi = .491 - .036 = .455

Can't call it "Hg on differential Manometer since it Has water on it.
<u>must convert</u>-

Take ~~sc~~ scale reading in " + mult by .455

Bourdon Gage

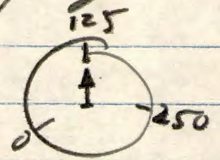

elliptical cross sect. which tries to assume O round shape ∴ tends to straighten ∝ press.

Calibration

Dead wt.

Usually calibrated at centre of Dial

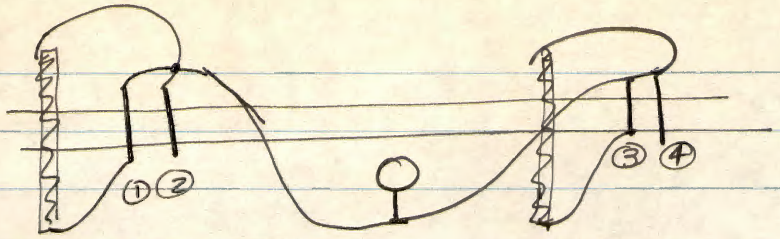
a.e. 250 psi gauge set @ 125



most accurate in middle or near middle of ~~scale~~ scale.

∴ Choose a gauge that will read desired pressure in middle.

Data:



1. Manometer Reading - in.
2. Δh - psi = Manometer level (.455)
3. Gage Readings
   a. upstream
   b. downstream

4. Gal. Collected H_2O
5. time (min)
6. gpm
7. K

$$Q = K\sqrt{\Delta h}$$

Differential

1. 3"

		#1	#2	#3	#4
3"	1.4"	73	70	72	71
7	3.2	71 [illegible] 72	67 68	71 70	69 68
11	5.2	69 [illegible]	64	68	66
15	1.1	67	60	66	63
19	9	66	[illegible] 57	64	61 [illegible]
26		64	52	[illegible] 63	[illegible] 56

Short form report

Convert " + psi Hg.

Readings 1, 2, 3

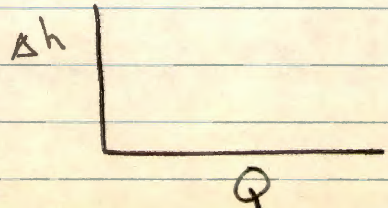
Venturi pressure recovers well
but does have pressure
loss –
5' of 3" pipe after
venturi to next pressure
meas.
i.e. 5' from outlet of Venturi
to inlet of orifice

∴ $\Delta h_f - h_{frict}$ = loss due to Venturi

* V

Hydraulic Data Manual — Q vs. h_f chart
@ 65 = Q → .011' head / ft of pipe
.055' head lost due
to frict after outlet of Venturi

Good Graphs

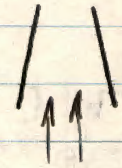


Different kinds of Sprinkler Nozzles.

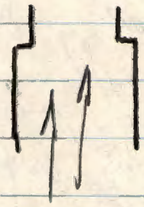
descending efficiency

~~1. Grinnell~~

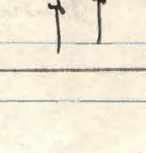
1. **Grinnell B** - Smooth Tapered Nozzle 0.432" dia.



2. **Rockwood D** - Shoulder Type 0.500" dia.



3. Grinnell A (Mfg. 1932) - Thin Plate Nozzle 0.495" dia

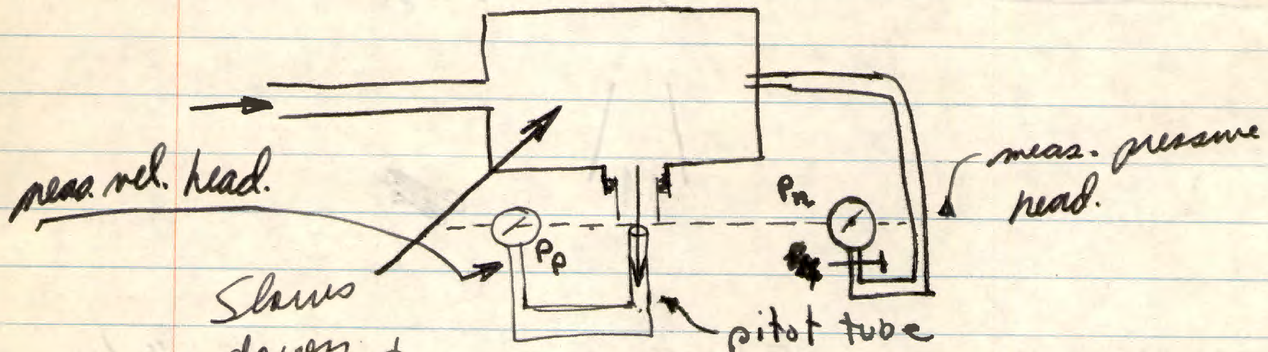


Calculate C_d

EQ. 3-15

C_d = flow coeff. for nozzle or orifice

~~$Q = 29.83$~~



Slows down water to convert vel. head to pressure head (meas.) which is all converted back to vel. head at the orifice in free space.

EQ. 3-15 $$Q_{gpm} = 29.83 \underset{\substack{\uparrow \\ \text{dimensionless}}}{C_d} \, d_{o_{in.}}^2 \sqrt{\Delta P_{psi}} = Q_{gpm} = K \sqrt{\Delta P_{psi}}$$

$K = 29.83 C_d d_o^2$

Can use C_d to compare to other nozzles.

→ find C_d besides K

measure Q
" ΔP

Short
FORM.

at zero psi reads +½ lbs/in²

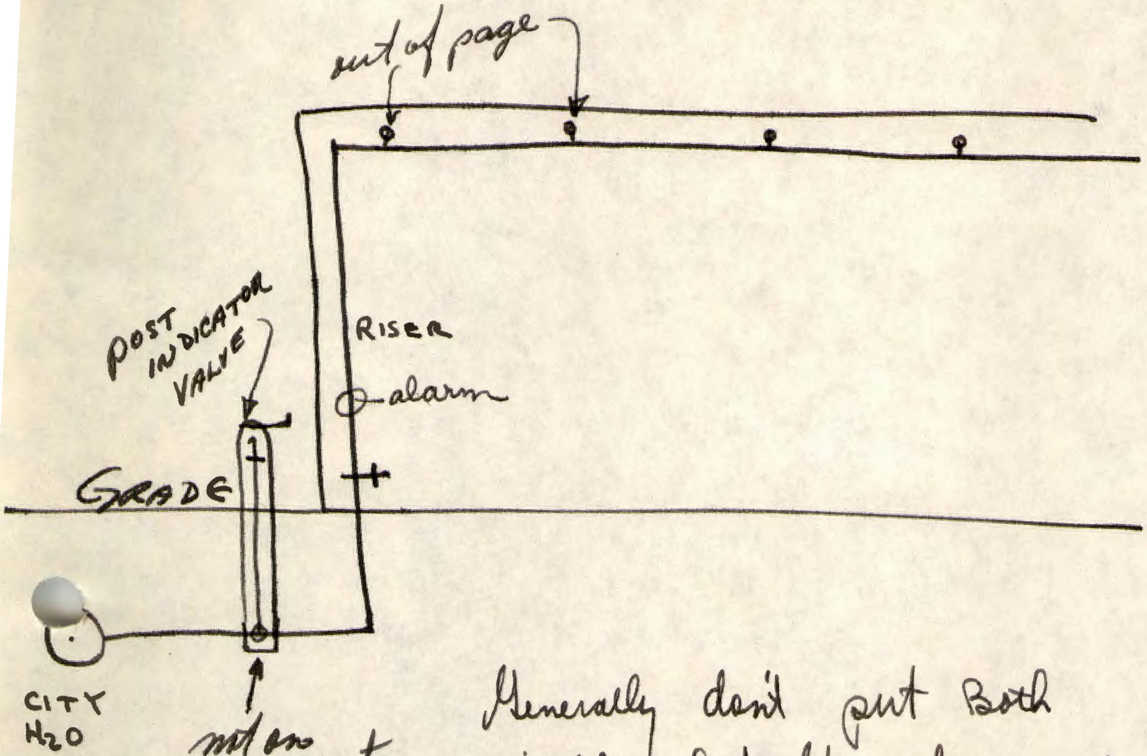
Set known pressure on pressure head gauge & let vel. head follow.

PLOT ΔP v. Q

	Set. Pressure Head	Pitot head.	Q	T
Grinnell B	8 psi	7.8	100 gal	6:40
	12 psi	11.0	100 gal	5:26
	[illegible]		~~100~~	
	22 psi	22.0	100 gal	3:55
	30 psi	29.0	150 gal	5:11
Rockwood A	8 psi	8 psi	100 gal	5~~1~~:52
	12 psi	11 psi	100 gal	4:51
	22	22	150 "	5:22
	30	30	150 "	4:36
Grinnell A	8 psi	7.5 psi	100 gal	6:10
	12	11.5 psi	100 gal	5:01
	22	22	150 "	5:34
	30	29	150 "	4:45

9 Wet Pipe Systems have been found to require fewer heads than dry! See Pg 16-16 - HANDBOOK

WET SYSTEM



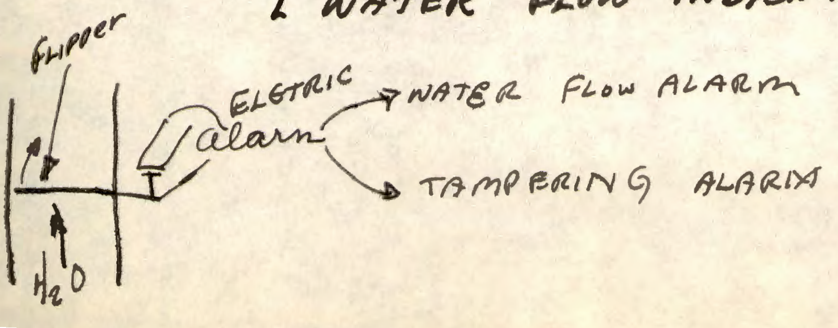
not on public property - don't want it tampered with

Generally don't put Both inside shut off valve AND Post Indicator Valve.

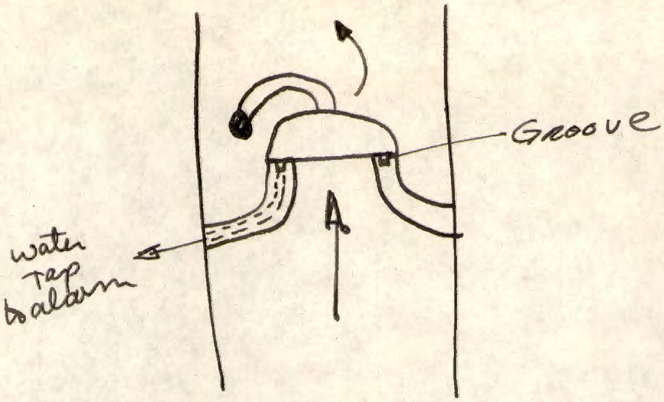
Install alarm System ∋ people know when system is in operation for some reason.
People must be taught what to do when the alarm does go

ALARMS

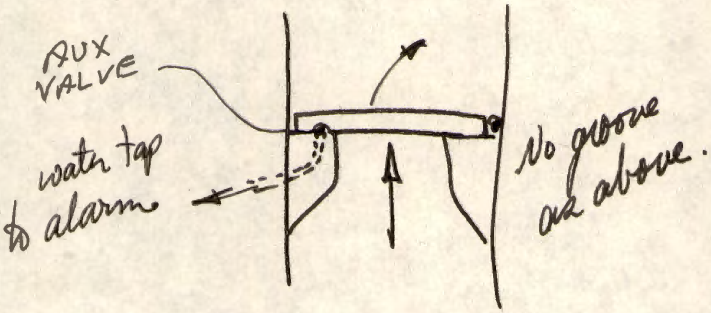
1 WATER FLOW INDICATOR



2. ALARM CKECK VALVE



Alarm Check Valve with auxiliary valve seat



All alarms must be desensitized → water surges won't send Alarm.

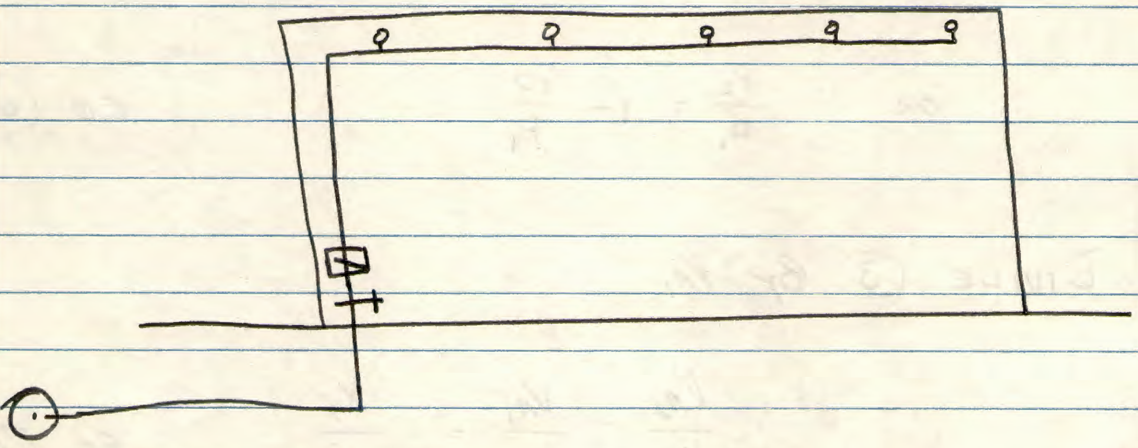
Water Taps

Wet Pipe Systems

"Flexibility" of Wet Pipe System –

At a given Initial pressure P_1, measured at the alarm check valve, the system flexibility, X_f, is defined as the quantity of water, in gallons, which must be drained out of the system to reduce the initial pressure by 10 psi.

$P_1 - P_2 = 10$ psi EQ. ①



GAL. = TOTAL VOLUME $= V_T = V_W + V_A$ EQ. ②

WATER + AIR

@ P_1 $V_T = V_{W_1} + V_{A_1}$

@ P_2 $V_T = V_{W_2} + V_{A_2}$

@ $P_1 - P_2$ $V_{W_1} - V_{W_2} = X_f = V_{A_2} - V_{A_1}$ EQ. ③

BY GAS LAWS: (Pressures in ABSOLUTE)

$$\frac{P_1 V_{A_1}}{T_1} = \frac{P_2 V_{A_2}}{T_2}$$ EQ. ④

CONSIDER $T_1 = T_2$ for short time interval

$$P_1 V_{A_1} = P_2 V_{A_2}$$ EQ. ⑤

$$\frac{P_2}{P_1} = \frac{V_{A_1}}{V_{A_2}}$$ EQ. (5-A)

DIVIDE ① BY P_1:

$$\frac{P_1}{P_1} - \frac{P_2}{P_1} = \frac{10}{P_1}$$ EQ. ⑥

OR $$\frac{P_2}{P_1} = 1 - \frac{10}{P_1}$$ EQ. (6A)

DIVIDE ③ BY V_{A_1}

$$\frac{V_{A_2}}{V_{A_1}} - \frac{V_{A_1}}{V_{A_1}} = \frac{X_f}{V_{A_1}}$$ EQ. ⑦

$$\frac{V_{A_2}}{V_{A_1}} = 1 + \frac{X_f}{V_{A_1}}$$ EQ. (7A)

COMBINE (6A), (7A) & (5A)

$$\frac{X_f}{V_{A_1}} + 1 = \frac{P_1}{P_1 - 10}$$

Solve for X_f

$$X_f = V_{A_1}\left(\frac{10}{P_1 - 10}\right)$$

Max Size of System - Pg. 104 - Pamphlet 13
(Max size ∋ there won't be too much time delay)

max 600 heads OR 750 GAL. CAP.
↑
volume of Pipes

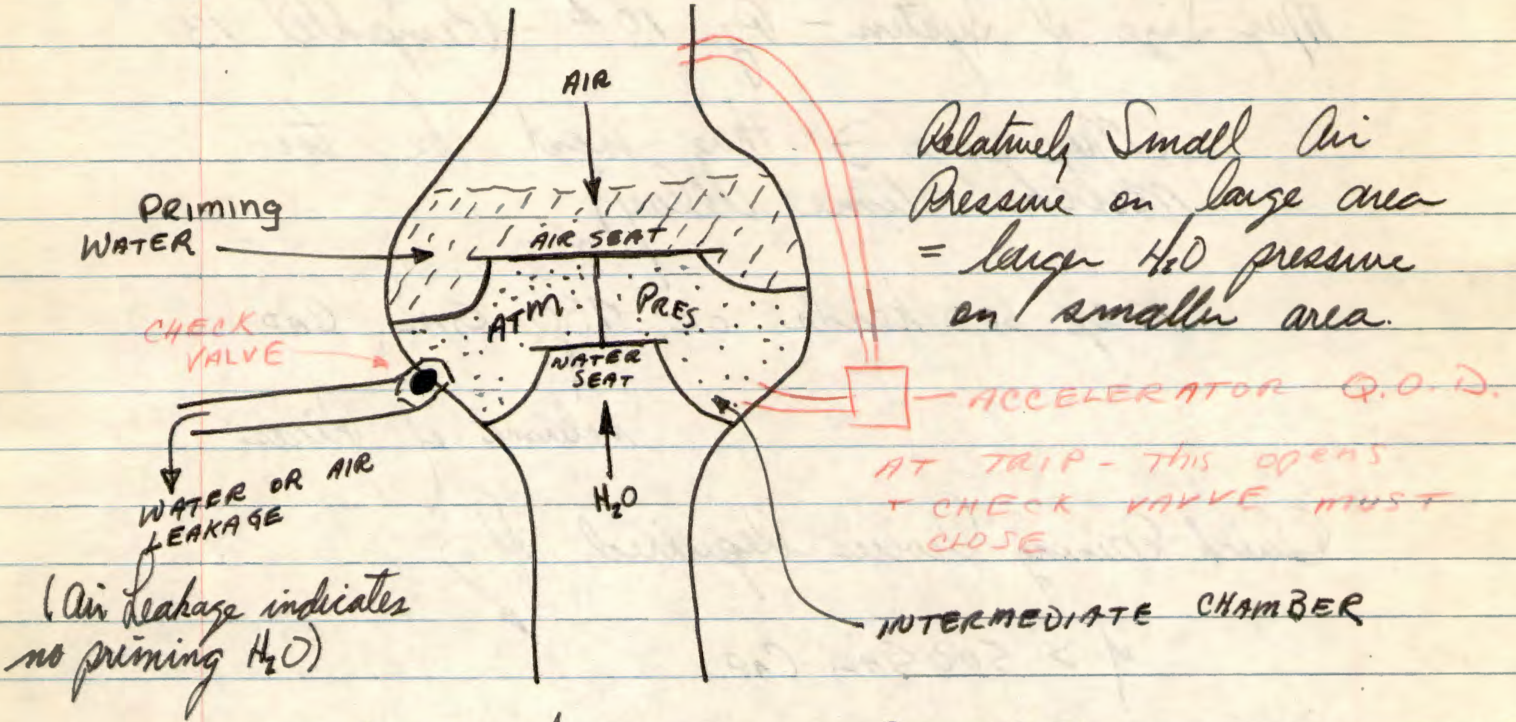
Quick Opening Devices Required if →
if > 500 GAL. CAP.

DRY PIPE VALVE
1. DIFFERENTIAL DPV

2. OLD MECHANICAL DPV

3. NEW MECHANICAL DPV

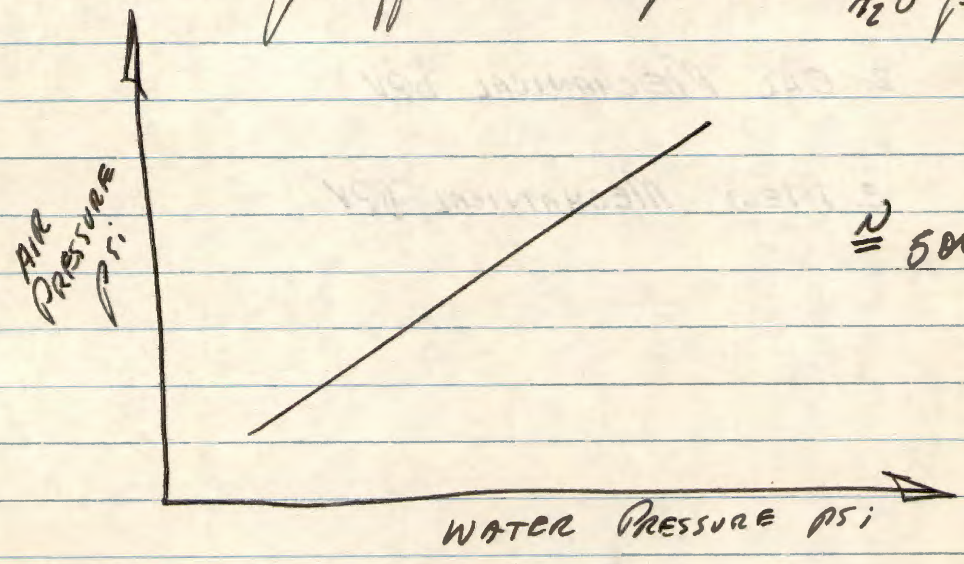
1. DIFFERENTIAL DPV



Relatively Small Air Pressure on large area = large H_2O pressure on smaller area.

THEOR ~~Air~~ → Differential ≅ $\frac{\text{AIR SEAT AREA}}{H_2O \text{ SEAT AREA}}$ e.g. 6 to 1

Working Differential @ trip pt. $\frac{\text{air pressure}}{H_2O \text{ pressure}}$



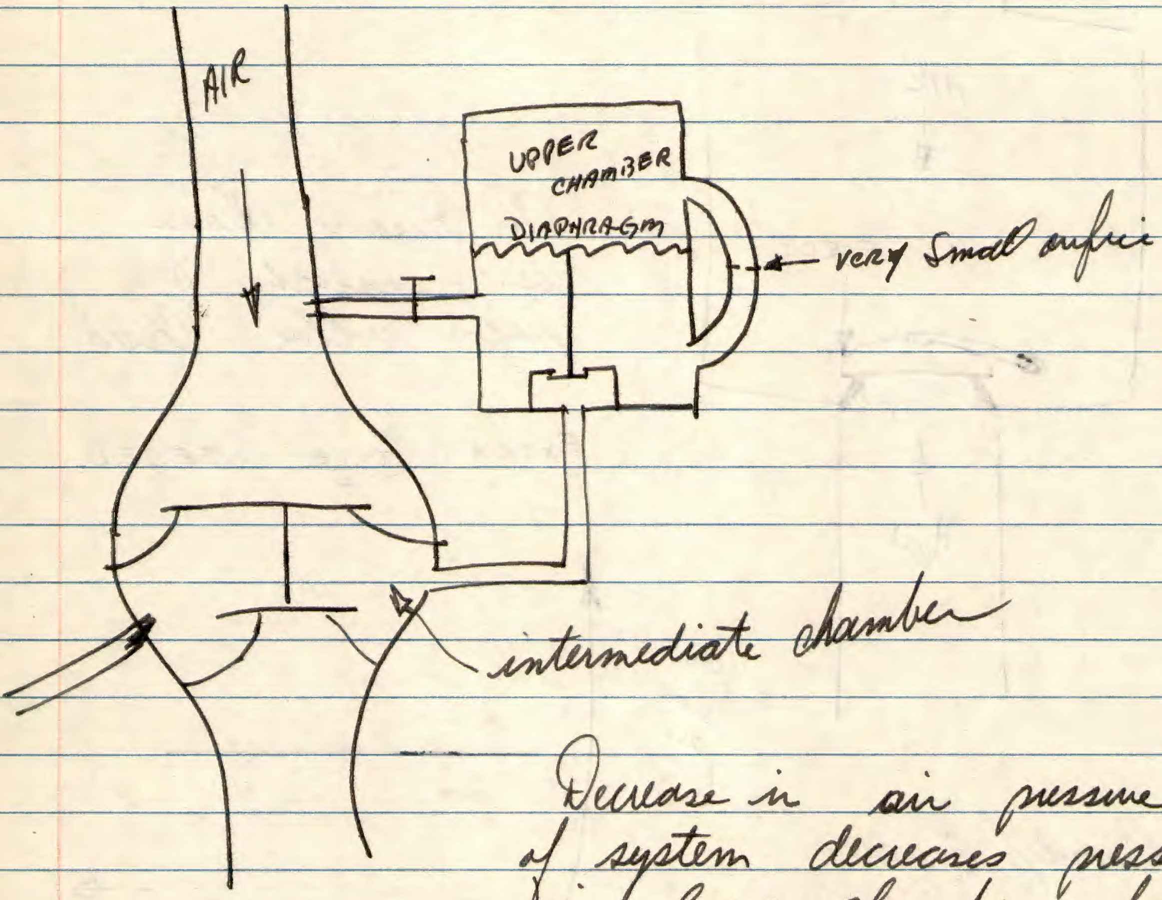
$\frac{H_2O \text{ pressure}}{\text{AIR pressure}}$ ≅ 5 or 6 to 1

Working Differential = SLOPE

Mainly interested in plot so we can check older valves with original plot + see how it compares if it (needs new valve etc.

Quick Opening Device useable ONLY with Differential DPV.

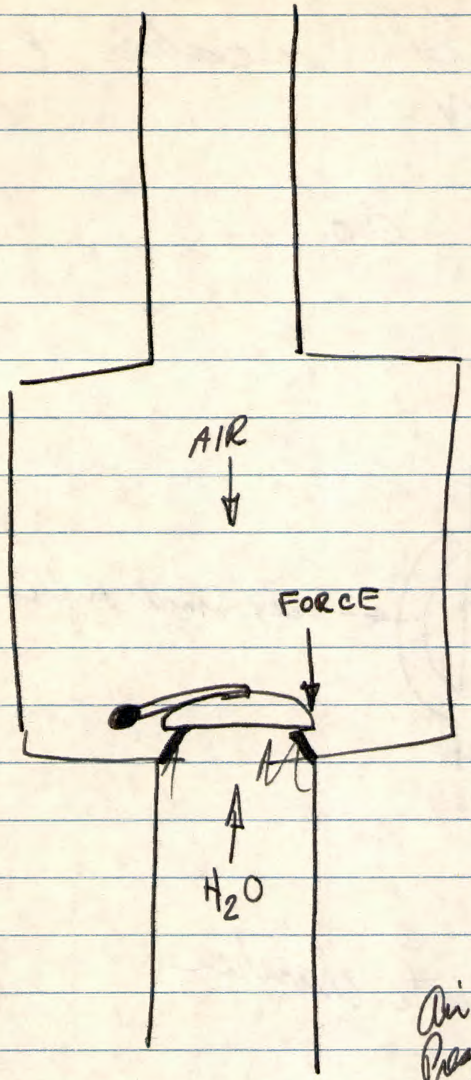
ACCELERATOR Q.O.D.



Decrease in air pressure of system decreases pressure in lower chamber faster than it can leak out of upper chamber ∃ diaphragm lowers and allows pressure into intermediate chamber

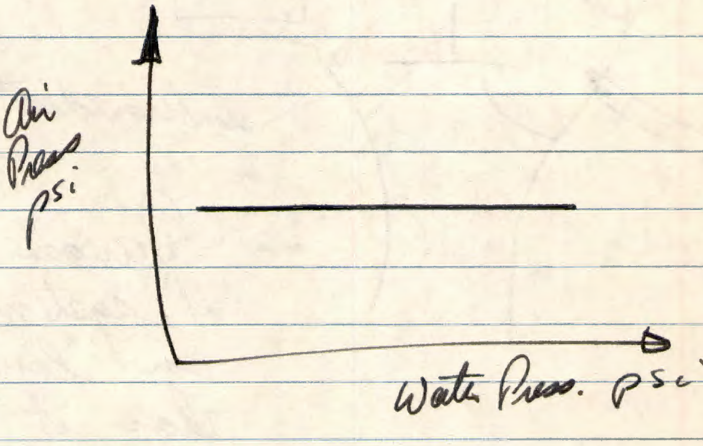
now air is pushed out by H_2O rather than just expanding out.

NEW MECH. DPV.



Air Pressure Alone isn't enough to hold valve Closed.

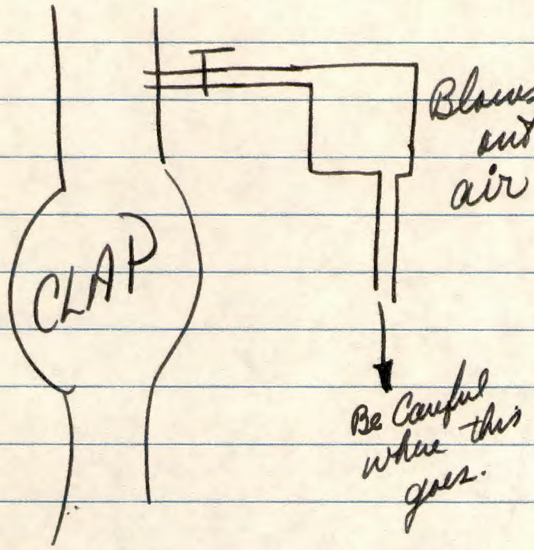
EXTRA <u>FORCE</u> NEEDED.



Force indep of air pressure – A GIVEN air pressure will trip

Clapper usually latched + released with drop of air pressure.

EXHAUSTER - WORKS ON ANY VAULE.



Exhauster must Close when water comes -

SEE PG. 16-151

EXPT. ---

START WITH 750 GAL CAP.

Build up 35 psi air each time
Open "sprinkler" to bleed air pressure
Time when: 1. Open sprinkler
2. DPV TRIPS
3. WATER BUILDS UP TO CERTAIN LEVEL (EACH TIME SAME Level)
(≈ WATER ON FIRE)

4. AIR PRESSURE @ TRIP
INITIAL AIR PRESSURE.

F.P.E. 304 - Class Session No. 7

Automatic Sprinkler Systems III -

A Study of Deluge and Preaction Systems and Deluge and Preaction Valves

1. GENERAL

The purpose of this session is to acquaint the student with the characteristics of deluge and preaction systems and with the performance of deluge and preaction valves.

NFPA Standard No. 13 outlines the requirements for the design and installation of automatic sprinkler systems. Only the general features of the design and installation of deluge and preaction sprinkler systems are considered in this work; the details of design, installation and hydraulic calculations of sprinkler systems is treated in another course.

Deluge and preaction sprinkler systems are special purpose systems; a deluge system is designed to wet down an entire fire area by admitting water to sprinklers that are open at all times; a preaction system is designed primarily to protect properties where there is danger of serious water damage as a result of damaged automatic sprinklers or broken piping. The behavior of deluge and preaction valves are demonstrated in this work.

2. References

   A. Read Chapter X, and Parts C, D and E of Chapter III, Section 16 Fire Protection Handbook, NFPA, Twelfth Edition.

3. Discussion Session

   A. General discussion of deluge and preaction systems.

4. Tests

   A. Demonstration of the operation of a deluge and preaction system.

5. Report

   A. Prepare a report as assigned by the instructor.

Preaction & Deluge Systems

DELUGE SYSTEM

All sprinklers flow at once
no links
Special control valve in riser
- need strong water supply.
Max. size allowable for one valve
pg. 116 pamphlet 13
not > 150 heads on 6" riser
consider min 15-20 gpm/head = 2250 gpm. Total
If more than one system opens = lot of H_2O
By proper arrangement, can reduce # systems which would open for one fire.

Used where conventional type system would be too slow & overtaxed if all heads did open.

Heat detection devices -
e.g. rate of rise ~~dector~~ detector
very fast - 30 sec. is long time for deluge response.

pg 16-162-3 Handbook.
Mechanical Valve

Fig. 16-165
HAD = Heat Actuated Device
Air Chamber - heats & builds up air pressure in tubes to sensitive diaphragm.

Compensating Vent in diaphragm
is calibrated leak ∃ normal temp
pressure won't actuate.
Calibrated to suit occup + desires
Must be careful —— / False actuation
would be costly.

HAD usually located 50' on centre
& 25' from wall.

FIG 16-166
map of HAD's / GROUP

FIG 16-182 B upstairs

FIG 16-180

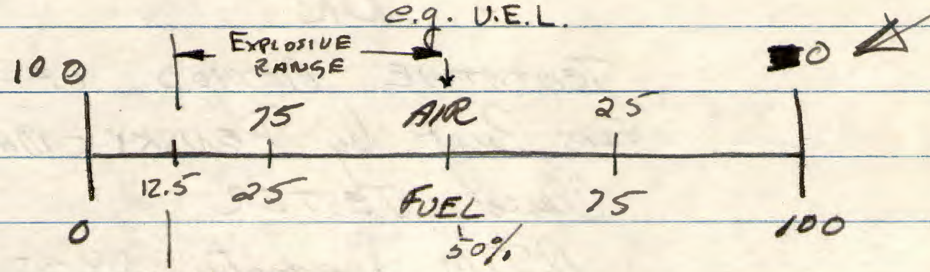
FLASH POINTS

DEF. Pg. 4-8 NFPA Handbook

Mat'l must be at certain temp ⇒ vapor Pressure will give off vapor @ mixture in explosive range.

Below flash point temp, vapors will still come off a.e. will still be vapor pressure

Must be sufficient to attain lower explosion limit.



e.g. LOWER
LEL. EXPLOSION LIMIT 12.5% fuel by volume

Total mixture must be 100%

IGNITABLE MIXTURE = mixture capable of propagating flame away from source.

Will be a reaction below LEL & above UEL, but won't be a prop. of flame away from source of ignition

Not enough fuel in one case, not enough air in other case

FIRE Pt. - temp @ wh. flame
begins + remains.

ASTM 1916 Race St., Phila 3

STD. METHOD OF TEST for
Flash & Fire Points By Cleveland
Open Cup.
ASTM Designation D92-57

OR

TENTATIVE METHOD OF TEST for
FLAS Point by PENSKY-MARTENS
Closed TESTER
ASTM Designation D93-58T

F.P.E. 304