Fire Performance of Glass Curtain Wall

A Major Qualifying Project

Submitted to the Faculty of Worcester Polytechnic Institute

in partial fulfillment of the requirements for the Bachelor of Science

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Abstract

For this Major Qualifying Project (MQP) a virtual simulation of the fire-resistance test ASTM E 2307 for an glass curtain wall system was created using computer software ANSYS. Using the software, knowledge was gained on the thermal and structural performance of these structures during a fire. Information from building codes such as the Uniform Building Code, Standards Building Code, BOCA National Building Code, the International Building Code and Underwriters Laboratories also allowed for the understanding of the fire-resistance of a curtain wall. Together, the codes and the virtual simulation support in determining whether there is a need for certain per-requisites such as, a 3-foot spandrel inside a curtain wall or having an automatic sprinkler system installed that are reference in the building codes.

Acknowledgements

We want to give a thank you to all those how helped us in completing this Major Qualifying Project. To Brian Kuhn and Joshua Kivela from Simpson, Gumpertz, and Heger for providing us with the idea for this project. As well as, allotting us with resources to aid in the research portion of this project. A special thank you to both of our advisors Professor Steven Van Dessel and Professor Ali Fallahi, both of whom have been trivial in the completion of project. They provided us with the knowledge and encouragement to do the work necessary. Once again, thank you!

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Executive Summary

Simpson, Gumpertz, & Heger (SGH) is a national engineering firm that designs, investigates and rehabilitates structures and building enclosures[1]. For this Major Qualifying Project (MQP) we worked alongside SGH to investigate glass curtain wall systems. Curtain walls are defined as thin, usually aluminum-framed wall, containing in-fills of glass, metal panels, or thin stone, this framing is then attached to the building exterior[2]. Curtain walls along with many other elements in building construction have regulations set in place by the building code for safety purposes. For instance, steel beams are tested to make sure they can withstand specific wind and gravity loads before they can be used for construction. For the design of curtain wall systems, one regulation is to have a 3-foot spandrel. The spandrel allows for the fire to spread throughout the structure slowly as the fire needs to pass through the empty space provided by the 3 feet of spandrel. However, there is an exception in the building code that can remove the spandrel requirement if there is an automatic sprinkler system installed in the building. Nevertheless, many of the glass curtain wall systems that were looked at in the initial stage of this project had the 3-foot spandrel and automatic sprinkler system. The necessity for the spandrel is investigated in this MQP.

The curtain wall systems examined are Underwriters Laboratories (UL) listed assemblies. All these structures passed building code requirements such as, the fire-resistance testing in compliance with the ASTM E2307 and the time-temperature curve of the ASTM E119. Knowing this various building code editions were looked at to see how the requirements for exterior walls,

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[1] Simpson, Gumpertz, & Heger (website)

[2] Chris Arnold, "Building Envelope Design Guide" *Whole Building Design Guide (WBDG)* (2016)

specifically curtain walls, change over time. Research was put into understanding the function and data provided by ASTM E2307 and ASTM E119.

The goal of this MQP is to study the need for the 3-foot spandrel. To do this a HILTI curtain wall model without a spandrel is used in a virtual simulation of the Intermediate-Scale Multi-Story Apparatus (ISMA) that is utilized in the ASTM E2307: fire resistance test. The creation of this virtual apparatus with computer software such as ANSYS gives understanding to what a curtain wall system goes through first hand when put under the conditions of fire and loading. The thermal and structural performance of the curtain wall is tested to see the failure of materials and the times at which these failures occur. Further testing is put into the apparatus to view the effects fire and wind loads have on the system. For instance, moving the fire closer or further away from the vision glass may influence the failure/deformation of the material. If the apparatus is on the 10^{th} floor and not the 1^{st} floor, the wind loads may be effected and in turn might affect the fire and failure/deformation of the curtain wall materials. The parameters that are questioned are put to the test. The results garnered from the simulation are compared to the actual results from the ASTM E 2307 and ultimately show if the HILTI model used passes the test or requires the 3-foot spandrel.

1. Introduction

The possibility of a fire is a major concern when constructing a building. To protect those who inhabit these structures specific attention is paid to the fire-resistance of the building materials. High-rise buildings that use a glass exterior façade, curtain wall systems have a low fire-resistance rating and as a result, elements such as a 3-foot spandrels and/or automatic sprinkler systems are used to increase the fire-resistance rating. These elements allow the fire to spread slowly throughout the building, giving time for those inside to evacuate before the building materials start to fail and collapse.

If a fire were to break out in a high-rise building the spread of fire would be vertical, going from one floor to the next, following with the flow of air currents. This is because the void between the floor and curtain wall are not properly sealed. The fire will affect both sides of the curtain wall system causing premature failure of the wall and potentially the vision glass (*International Firestop Council, 2004*). To reduce the spread of fire, a properly designed and tested Perimeter Fire Barrier System is used. This system not only protects the perimeter joint, but the wall framing and support components of the wall as well.

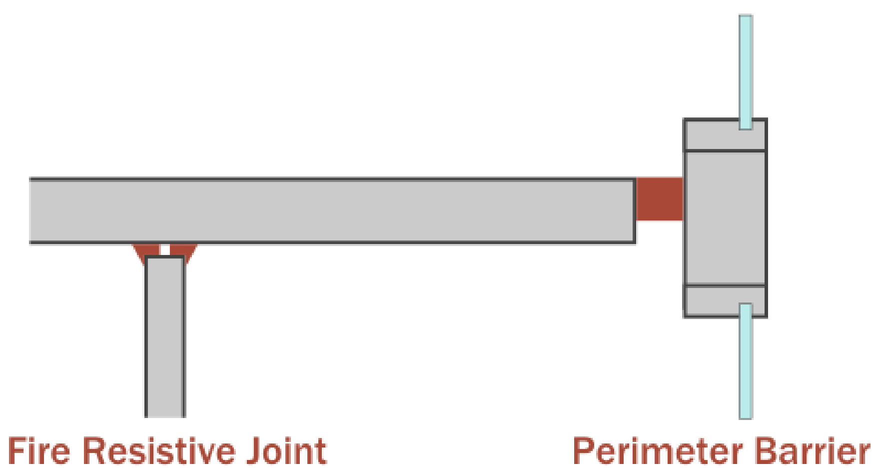

Figure 1.1: Curtain Wall Representation of Fire Resistive Joint and Perimeter Barrier

Protecting the perimeter also requires the extension of the rated floor to the exterior wall surface. The Perimeter Fire Barrier System, the sealing of the perimeter joint, and extension of the rated floor provides structural protection and maximizes the integrity of the wall system. This can keep the wall and window system intact for a longer period of time. Other benefits of these precautions include:

- *Forcing the fire to exit the building*
- *Preventing the movement of flames, hot gases and smoke to the floors above*
- *Protecting the structural elements and helps prevent failure of spandrel system*
- *Maximizing fire protection of non-fire rated walls*
- *Giving time for occupants to evacuate and first responders to secure the building*
- *Providing additional protection if sprinklers or fire alarms fail*

To test the integrity of a glass curtain wall and it's perimeter fire barrier an Intermediate-Scale Multi-Story Apparatus (ISMA) is used. This scheme is referenced in the more recent editions of the IBC and is performed in accordance to ASTM E2307: Fire-Resistance Test. This test determines two ratings: "F"-rating[3], the resistance to fire spread and "T"-rating[4], the temperature on non-fire side. Further understanding of this test permits the knowledge to use and design curtain wall systems that are structurally sound when withstanding loads such as, wind and gravity, and being able to sustain itself during extreme conditions such as fire.

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[3] The "F Rating" is a measure of the perimeter-fire-containment system to limit flame penetration through the system or around its boundaries and the passage of flames and hot gases sufficient to ignite cotton waste as defined in ANSI/ASTM E2307 (*UL Online Certification Directory)*

[4] The "T Rating" is a measure of the ability of the perimeter-fire-containment system to limit the temperature rise on the unexposed surface of the perimeter-fire-containment system and the adjacent supporting construction as defined in ANSI/ASTM E2307 (*UL Online Certification Directory*)

For this Major Qualifying Project, the problem that is to be solved is the inevitability of the 3-foot spandrel to increase the fire-resistance of a curtain wall system. To do this, an initial study of the effects fire has on the thermal and structural performance of a non-spandrel curtain wall model has to be done. Research is put into the different building code requirements, taking into consideration constraints for exterior walls, curtain walls, spandrels, and fire protection.

2. Background

To recognize why certain requirements are put in place during the construction process of a curtain wall system, one should consider the different building codes used. This is to know how these construction constraints might have changed over time and the differences that were made to the erection and/or instillation of that system. The codes that were looked at in this project include the Uniform Building Code, Standard Building Code, BOCA National Building Code, and the International Building Code. With each edition of the different codes the requirements for exterior walls, curtain walls and fire protection change slightly, staying current with any construction/ engineering advancements.

2.1 History of Building Code

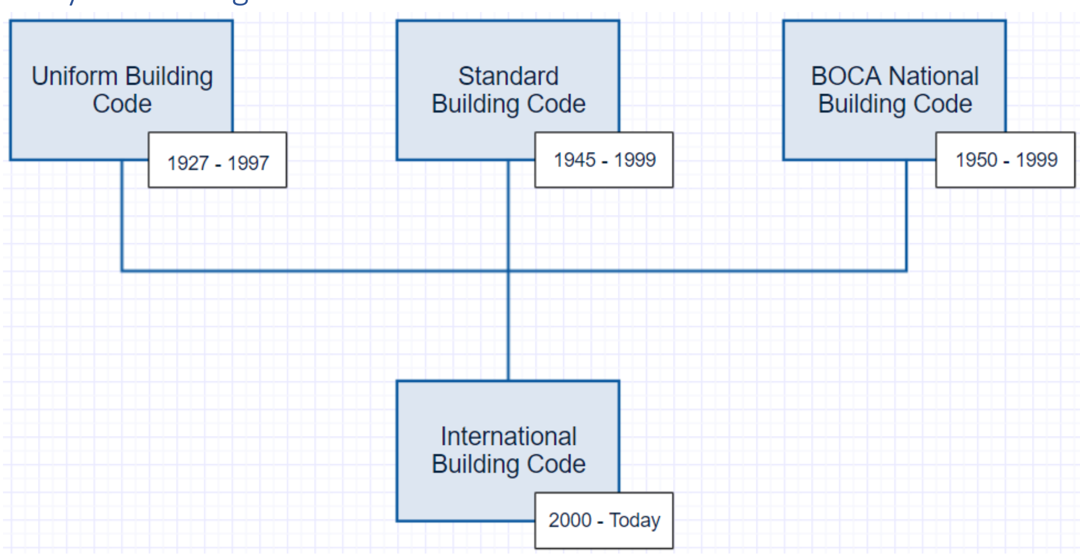


Figure 2.1: Building Code in the United States

The building code for engineers, contractors, and architects goes back about 90 years and went from three individual codes separated by region i.e. Northeast, South, and Midwest to one cohesive code. The first of the building codes were the Uniform Building Codes (UBC), then the Standard Build Codes (SBC), and finally BOCA National Building Codes (BOCA/NBC). The three organizations that created these codes came together to create the International Building Code

(IBC) which meets many the requirements set forth by the codes before them, with the addition of other prerequisites as times have changed and advancements are made.

2.1.1 Uniform Building Code (UBC)

The UBC were codes for the Mid-West part of the United States. The International Conference of Building Official's (ICBO) developed these codes. For these codes, there was mention of exterior walls needing to maintain a fire resistive rating if they were passing through an attic. The UBC provided its own table for these fire resistance rating of exterior walls. Later versions of the UBC also mention construction joints needing to be used in fire resistant walls to protect an opening in the wall. However, the editions of the code looked at by the team had no mention of curtain walls or spandrel requirements.

2.1.2 Standard Building Code (SBC)

The SBC was a set of regulations enacted by the Southern Building Code Congress International (SBCCI) in 1945. These code requirements dealt with southern states such as, Alabama, Georgia, and Florida. The primary focus of these codes was to protect the life, health, and welfare of the building environment. Though these codes played an important role in southern states, a find full versions of the code could not be found to understand how southern states dealt with exterior walls/curtain walls and its thermal and structural performance.

2.1.3 BOCA National Building Code (BOCA/NBC)

BOCA National Building Codes were established in the 1950s for construction in the Northeast and Mid-West by the nonprofit organization Building Official's and Code Administrator International (BOCA), which was established in 1915. The parameters set forth by this organization in accordance to Fire Protection and Curtain wall system requirements include section 902.1.1 Fire resistance Rating.

> ***902.1.1 Fire Resistance-Rating:*** *The fire resistance properties of materials and assemblies must be measured and specified according to a common test standard. For this reason, the fire resistance rating of building assemblies and structural elements shall be determined in accordance to ASTM E 119* [5]*(BOCA, 1990)*

The ASTM E119 is pivotal in building assemblies and is stilled used to determine the fire-resistance rating of materials and structures. The ASTM E119 test provides a time-temperature curve that is used to see when a material in a curtain wall system or any other type of building assembly were to fail. If the material were to collapse before the time and temperature previously established by the curve, then the assembly or material should not be used.

Besides the mention of the ASTM E119, there is no reference to curtain wall systems or spandrel opening in the code editions that were found. There was also no reference to the ASTM E2307 test.

2.1.4 International Building Cod (IBC)

The International Building Code was developed in 2003 and takes into consideration the requirements that were set in place by the previous building codes. The first edition of the code had similar requirements to UBC for exterior wall systems however; later versions of the IBC do mention curtain wall systems and the need for a 3-foot spandrel.

> ***705.8.5 Vertical separation of opening:*** *Openings in exterior walls in adjacent stories shall be separated vertically to protect against fire spread on the exterior of the buildings where the openings are within 5 feet (1524 mm) of each other horizontally and the opening in the lower story is not a protected opening with a fire protection rating of not less than 3/4 hour. Such openings shall be separated vertically not less than 3 feet (914 mm) by spandrel girders, exterior walls or other similar assemblies that have a fire-resistance rating of not less than 1 hour*
>
> ***Exceptions:***

[5] Test method that evaluates the ability of an assembly to contain a fire or to retain its structural integrity, or both, in terms of endurance time during the testing conditions (BOCA, 1990)

1. *This section shall not apply to buildings that are three stories or less above grade plane.*
2. *This section shall not apply to buildings equipped throughout with an automatic sprinkler system in accordance with* Section 903.3.1.1 *or* 903.3.1.2*.*
3. *Open parking garages.*

- IBC, 2015

In this section of the IBC, the 3-foot spandrel is used to allow for a fire-resistance rating [6]of at least an hour. The minimum fire-resistance rating of 1 hour allows for appropriate protection of the system[7] because it gives people enough time to exit a building before the materials start to fail and the structure collapses. The exception to the rule, having a sprinkler system installed, is mentioned in this section of the IBC. The sprinkler system is used as precaution; if a fire were to start in a structure the sprinklers will go off to try to minimize the fire, giving those who inhabit the structure time to exit.

The IBC also references ASTM E2307 in section 715.4: Exterior Curtain Wall/Floor Intersection. The section goes into detail about the different rating provided by the ASTM E2307 as well as, exception to this rule.

> ***715.4 Exterior curtain wall/floor intersection:*** *Where fire resistance-rated floor or floor/ceiling assemblies are required, voids created at the intersection of the exterior curtain wall assemblies and such floor assemblies shall be sealed with an approved system to prevent the interior spread of fire. Such systems shall be securely installed and tested in accordance with ASTM E2307 to provide an F rating for a time period not less than the fire-resistance rating of the floor assembly. Height and fire-resistance requirements for curtain wall spandrels shall comply with Section 705.8.5.*
>
> ***Exception:*** *Voids created at the intersection of the exterior curtain wall assemblies and such floor assemblies where the vision glass extends to the finished floor level shall be permitted to be sealed with an approved material to prevent the interior*

[6] Fire-resistance rating: the duration for which a passive fire protection system can withstand a standard fire resistance test, is quantified as a measurement of time

[7] Arthur J. Parker and Jesse J. Beitel, *Required Fire Resistance Ratings for Structural Building Elements,* SFPE

> *spread of fire. Such material shall be securely installed and capable of preventing the passage of flame and hot gases sufficient to ignite cotton waste where subjected to ASTM E119 time-temperature fire conditions under a minimum positive pressure differential of 0.01 inch (0.254 mm) of water column (2.5 Pa) for the time period not less than the fire-resistance rating of the floor assembly*
>
> *- IBC, 2015*

In this portion of the code, floor or floor/ceiling assemblies such as curtain walls are required to have an approved system that is installed and tested in accordance to ASTM E2307. This test provides an F rating[8] for various time periods; the rating should be at least equal to the fire-resistance rating of the floor assembly (*IBC, 2012*). If the material fails to do so, it cannot be used for the assembly of a curtain wall.

The requirements set in place by these two sections of the code allowed for greater understanding of curtain wall system design. It also provides a stepping-stone for this Major Qualifying Project.

2.2 Modern Code Usage

In addition to researching building codes, other documentation that deemed a curtain wall safe for use were considered. The Underwriters laboratories documentation for certification of safety helped in determining the type of curtain wall modeled for the schematic. Underwriter Laboratories is a company that conducts safety analysis for new technologies such as electrical appliances and curtain wall system. UL provides safety certification through precautions such as testing and inspection. If the system passes the necessary testing and other requirements it receives the UL seal of approval for use. The testing required for curtain wall systems will be discussed in the next few paragraphs.

[8] F-rating: Flame rating - expressed in hours and the number indicates the specific length of time that a barrier can withstand fire before being consumed or before permitting the passage of flame through the opening (*ASTM E814*)

2.2.1 Underwriters Laboratories (UL) Listing

To gain the certification of the Underwriters Laboratory (UL) the curtain walls go through specific test. One of the test contains a perimeter-fire-containment system, Intermediate-Scale Multi-Story Apparatus (ISMA), it is particular to constructions consisting of a floor with an hourly fire-resistance rating, an exterior curtain wall with no hourly fire-resistance rating, and material installed to fill gaps between the floor and the curtain wall to prevent the vertical spread of fire in a building (*Underwriters Laboratories, 2017*). The UL listing uses an hourly rating to determine the strength of the system. When determining, the hourly rating the complete system is considered. The materials and specifications for the perimeter-fire-containment system and the wall assembly are directly related to the established rating.

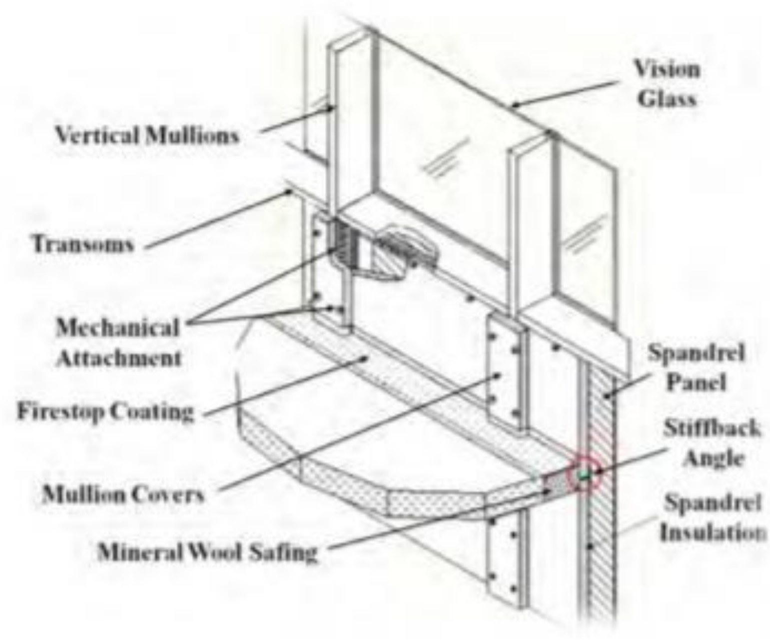


Figure 2.2: Typical Glass Curtain Wall with elements defined

The image above shows a typical curtain wall system with a spandrel that could be UL listed. The F and T rating of the perimeter fire-barrier system fall under all the necessary criteria of the ATSM

E2307 to be certified. It also is in compliance with the UL 2079, an additional criterion for certification that provides the integrity rating and the insulation rating using the same apparatus, ISMA.

These ratings go hand in hand to attest to a structurally sound curtain wall system. The standards for the Integrity Rating complies with the requirements for the "F-rating". It also limits the passage of flams through openings in the curtain wall above the perimeter fire barrier (*UL Online Certification Directory).* For the Insulation Rating it complies with the "T-Rating" and it also limits the temperature rise to 325 F above the starting temperature in the interior surface of the curtain wall (*UL Online Certification Rating*).

The Underwriters laboratories also takes into consideration the Leakage Rating (L-Rating) that measures the amount of air leakage through the perimeter-fire-containment system. Using NFPA 101 "Life and Safety Code" as a parameter to determine the stability of the system to restrict the movement of smoke throughout a building (*UL Online Certification Rating*). However, the virtual simulation created for this MQP is a simplified version of the perimeter-fire-containment system, taking only into consideration the only the "F-Ratings" and "T-Ratings". To take into consideration air leakage would require the knowledge of the fluids parameter in ANSYS which could not be adequately learned in the amount of time required to complete this project.

Nevertheless, the two ratings, F and T, that is given with the HILTI curtain wall model schematic provided a simulation that was able to function and give readings for the thermal and structural performance.

3. Review of Relevant Codes and Standards

Other parameter like the F-Rating and T-Rating were found through the review of relevant codes and standards. The deflection limit for mullion system as well as, maximum wind pressure and other loadings that are applied to a high-rise building when put under conditions of the Fire Resistance Test. These parameters gave further understanding of what to expect when creating and analyzing the virtual simulation of the Fire Resistance Test modeled in ANSYS.

3.1 IBC

The curtain wall modeled for this project uses stainless steel for the mullion system. With stainless steel being a sturdy material the deflection limit that was used is L/360. Looking in the IBC table 1604.3 gave some construction types and deflection limits that were used as a basis for the assumption for the deflection.

Table 3.1: IBC 2015 Table 1604.3 Deflection Limits

TABLE 1604.3
DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	*L*	*S* or *W*[f]	*D* + *L*[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	*l*/360	*l*/360	*l*/240
Supporting nonplaster ceiling	*l*/240	*l*/240	*l*/180
Not supporting ceiling	*l*/180	*l*/180	*l*/120
Floor members	*l*/360	—	*l*/240
Exterior walls and interior partitions:			
With plaster or stucco finishes	—	*l*/360	—
With other brittle finishes	—	*l*/240	—
With flexible finishes	—	*l*/120	—
Farm buildings	—	—	*l*/180
Greenhouses	—	—	*l*/120

3.2 Standards

In the structural component of building construction various types of loading can be applied. For this project simuation typical forces are placed on curtain wall, i.e. wind and gravity loads.For the wind pressure being applied to the curtain wall the system was theoretically placed in Boston, Massachusetts taking on 105 mph wind speed. In this situation, the wind pressure being utilized on the structure is 8.35 psf. The number was calculated by using the Cornell University Wind Pressure Calculator by Jonathan Ochshorn. This calculator took into account the city, giving a constant wind speed of 105 mph, and the roof height. Other parameters in the calculator remained unchanged resulting in a wind pressure of 8.35 psf. This calculator though not intended for actual design purposes did give understanding of design principals. As for the gravity load the standard value for gravity, 386 in/s^2 is used. The parameters found through research allows for the simulation to mimic that of the real world.

3.3 ASTM E2307

ATSM E2307 is a fire-resistance test that measures the performance of the perimeter fire barrier[9] and its ability to maintain a seal to prevent fire from spreading among an exterior wall assembly and floor assembly. Through this test the deflection and deformation of material that compose the curtain wall can be seen.

This fire test simulates an indoor fire located near a window. Time is considered in this test, as the flame burns for longer periods of time the effects on the exterior wall assembly and floor assembly can be seen as fire travels through the structure. The goal of this test is to find the period of time elapsing before the first condition of compliance is reached. During this test, the fire barrier perimeter is subjected to time and temperature dependent fire exposer.

[9] The perimeter joint protection in building construction provides fire resistance to prevent passage of fire from floor to floor within the building at the opening between the exterior wall assembly and the floor assembly. The boundaries are the edge of the floor assembly and the interior face of the exterior wall assembly in contact with the perimeter joint protection (*ASTM E 2307*)

Conditions of compliance include:

- Movement Cycling Test[10]
  Perimeter joint[11] protection completes at least the minimum movement cycle for the movement type selected
- Fire-Resistance Test
  T-Rating of perimeter fire barrier should be determined when conditions such as, the temperature unexpectant rises more than 375F from its original temperature, first occurs
- Integrity Test
  The perimeter fire barrier should not allow for fames or hot gases to pass and ignite insulation
- Load Application
  The perimeter joint of protection should be able to withstand the load being applied during the rating period

The fire exposer conditions used for this test are specified in the first 30 minutes of fire exposer.

Then the time-temperature curve from ASTM E119, which will be discussed later, is used for the remained of the test.

Figure 3.1: Actual Performance of ASTM E 2307 Test

[10] Movement cycle – the change between the minimum and the maximum joint width
[11] The linear void located between a juxtaposed exterior wall and assembly and floor assembly to accommodate various movements of the floor and wall during construction (ASTM E 2307)

3.3.1 Test Set Up

The testing apparatus should be a two-story test structure having a test room and observation room (Figure 3.2). Each room has an inside length and width dimension of 120 ± 0.5 in. and a height of 84 ± 0.5 in. The floor and roof should be supported by columns and beams sized to support the loads from the floor and roof. The floor should have a thickness of 8 ± 0.5 in. and the walls that make up the test apparatus should be insulated.

To create the controlled fire for the test there should be two gas-fired burners. The test room burner is a nominal 2 in. OD steel pipe, u-shape with holes drilled in the pipe to allow for fire to expand though out the structure. The window burner should be rectangular shape made with a 60 ± 0.5 in nominal 2 in OD pipe.

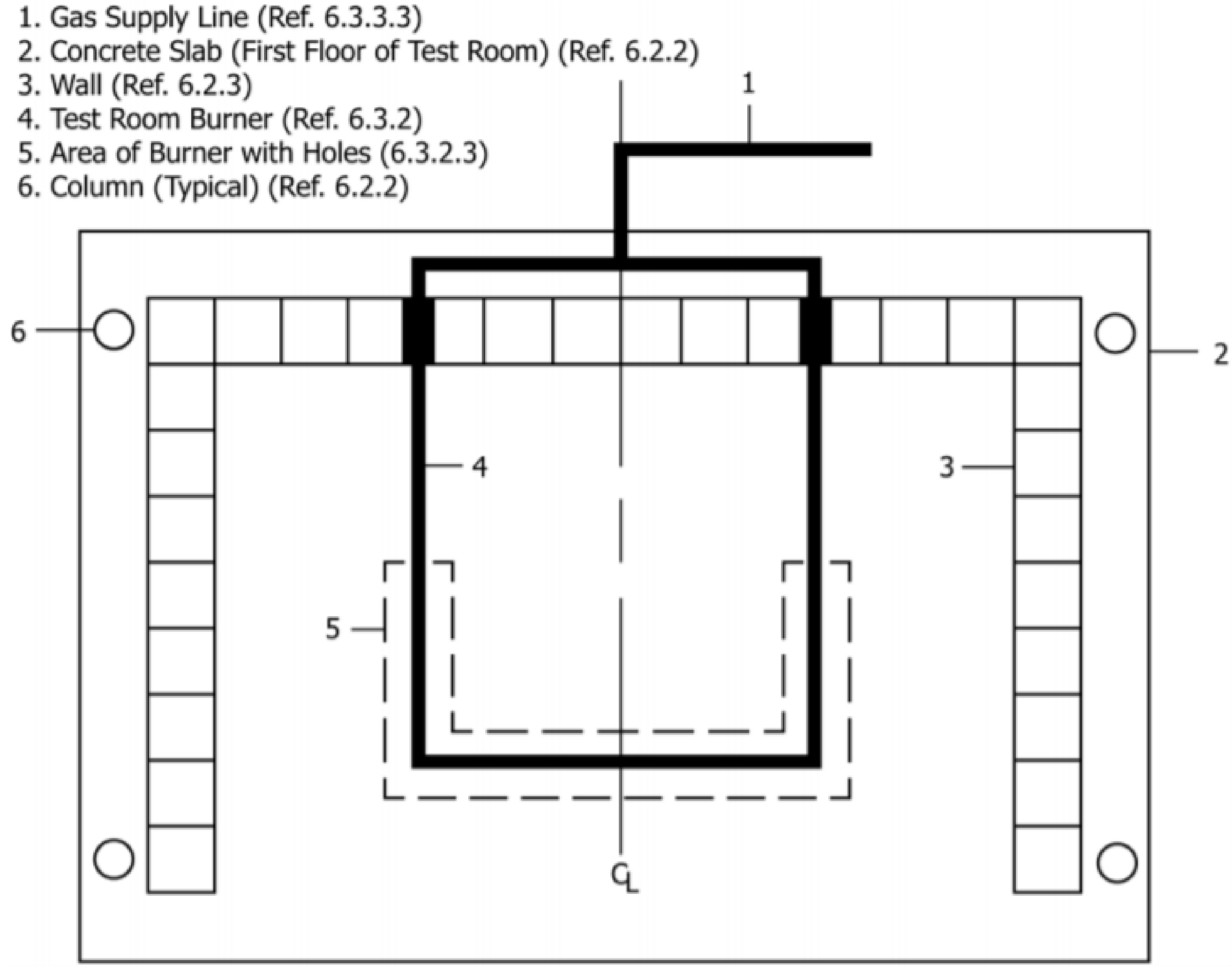


Figure 3.2: Plan View of Test Room Burner Positioned in Test Room

1. Window Burner
2. Slot in Burner
3. Gas Supply Line
4. Perimeter Joint Protection
5. Window
6. Test Room in Test Apparatus
7. Observation Room in Test Apparatus
8. Horizontal Centerline of Burner
9. Vertical Centerline of Burner
10. Window Burner Location During Test
11. Exterior Wall Assembly
12. Test Apparatus
13. Floor Assembly5
14. Floor of Observation Room
15. Roof Slab
16. Floor of Test Room
17. Window Sill Height

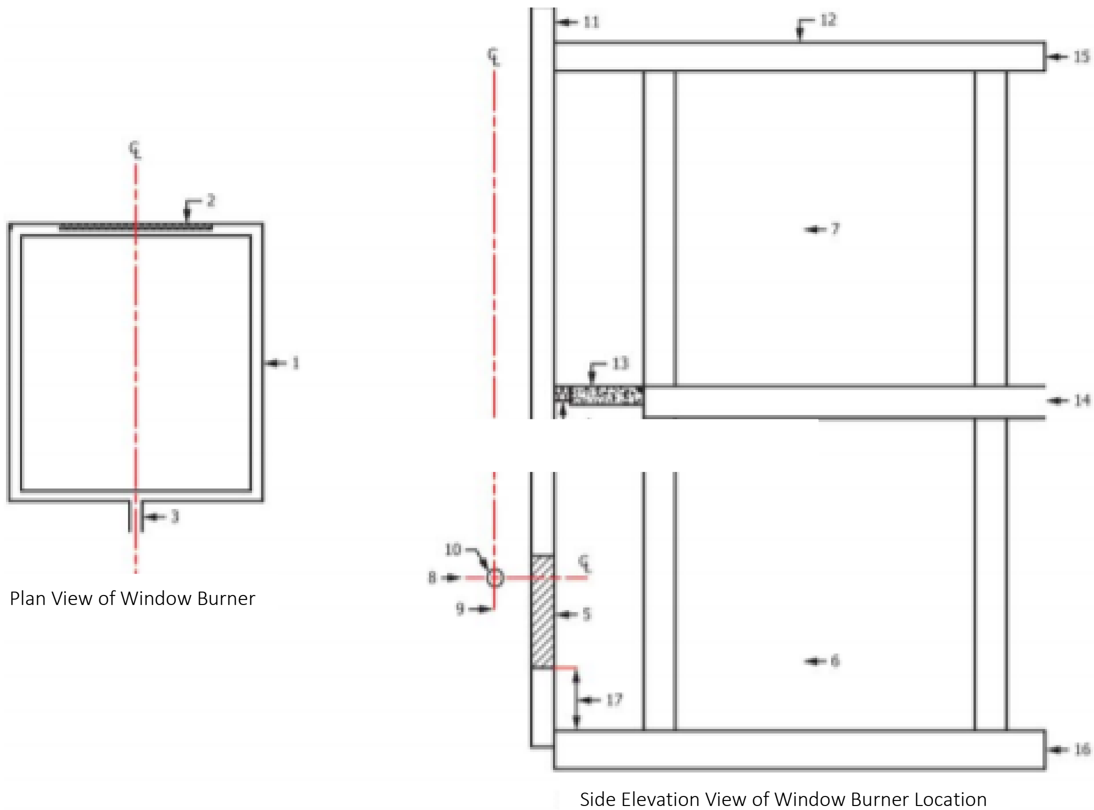
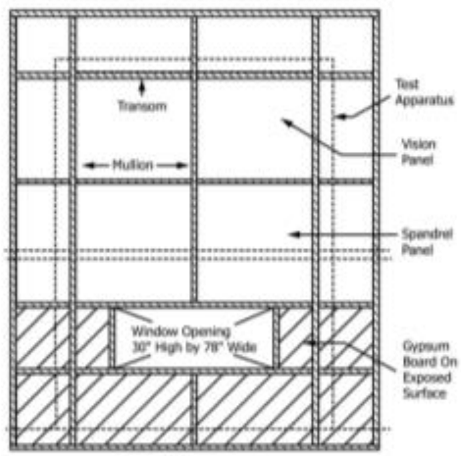
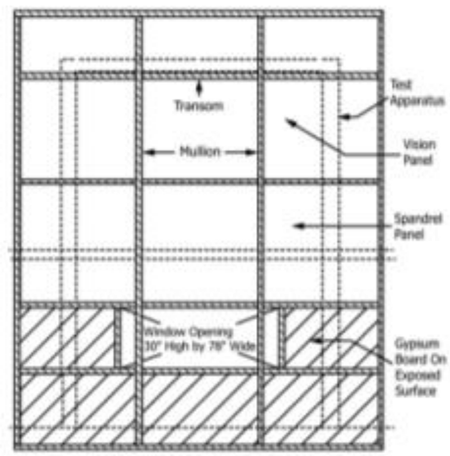


Figure 3.3: Plan View of Window Burner and Side Elevation View of Window Burner Location

The exterior wall assembly used during these test is determined by the test sponsor and laboratory and should be secured to the testing apparatus. The minimum height and width of the exterior wall assembly should be 17.5 by 13.33 ft. For the floor assembly of this structure it should have a width of at least 12 in and have a length of 13ft. The window placed in the exterior wall assembly should have a height and width of 30 by 78 in. Figure 3.4 below shows examples of exterior wall assemblies and their attachment to the test apparatus.



Center Mullion Configuration



Center Spandrel Configuration

Figure 3.4: Examples of Exterior Wall Assembly with Window Openings

3.3.2 Results:

When the test set up is completed, the test can now be performed. From this test method a variety of exterior wall assemblies such as curtain walls can be examined. This allows for the understanding of exterior wall assembly performances during a fire, which can be used during the selection and construction process. The results that are garnered are in relation to time and temperature and can determine the failure of material and/or assembly. To aid in determining when and at what temperature a material is to fail the ASTM E119 Time vs. Temperature curve is used a reference.

3.4 ASTM E 119

The ASTME 119 test the performance of wall, columns, floors and other building elements when in a fire. This test measures the ability of a wall, partition, floor or roof to be able to stop flames or hot gases from going thru an assembly[12]. The assemblies tested are put under the conditions of a temperature of at least 2400F and a time of at least 8 hours. The information

[12] Firefree Coating Inc. (2017)

gathered from this test are put into a graphical representation of a time vs. temperature curve (Figure 3.5).

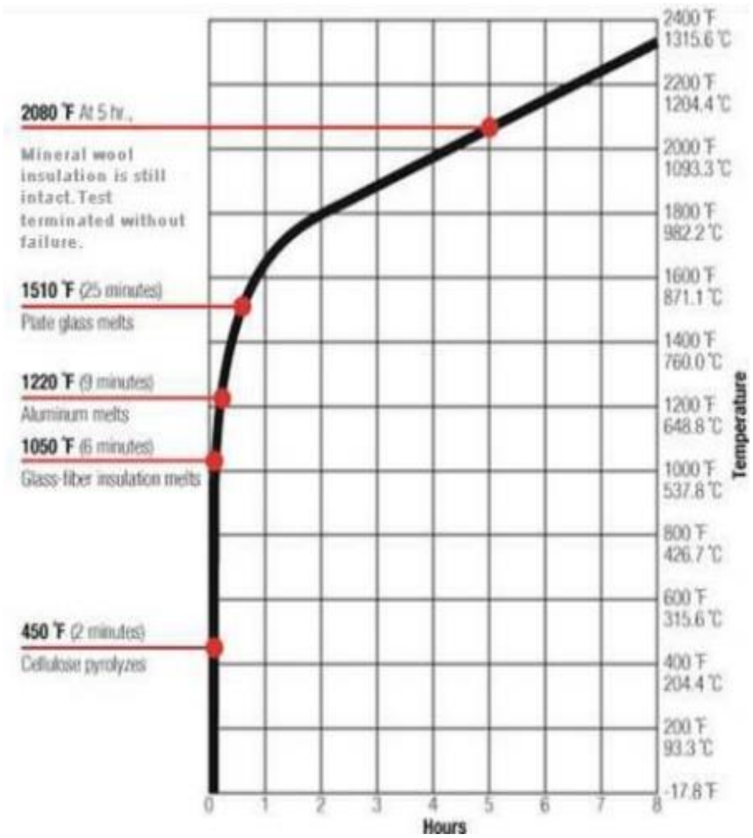


Figure 3.5 Time vs Temperature curve with examples of material failure

With the requirements for the ASTM E2307 understood and the parameters for ISMA detailed the project continued. The team worked towards the next phase of the project, understanding and using the computer software ANSYS.

4. Methodology

The goal of this project was to develop computerized simulation of the ASTME 2307: Fire Resistance Test. Using the computer software ANSYS, the Intermediate Scale Multistory Apparatus, used to test the Fire Resistance of a curtain wall was modeled. It gave a visual representation of how the curtain wall selected for this project is effected when simulating the fire of ASTME 2307 test. For instance, specific material will have varying strength, which will in turn effect the thermal and structural performance of that material. For this project, the deflection of materials, specifically the mullion was analyzed.

4.1 ANSYS

To understand the structural and thermal performance of a curtain wall the computer software ANSYS was used. ANSYS is a general-purpose software, used to simulate interaction of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers[13]. In this project, ANSYS was used to simulate the thermal and structural performance of a curtain wall system when under the condition of the ASTME 2307 test. Simple problems were used to first understand how the software dealt with different structural and thermal conditions.

4.1.1 Structural Performance

To comprehend the structural performance of a system, a test on a simple fixed beam was conducted. In the figure below the fixed beam has, a pressure being applied downward is shown. Using ANSYS this problem was simulated to show the deformation of the beam, which can be seem in Figure 4.6.

[13] Figes Engineering, “What is ANSYS” (2017)

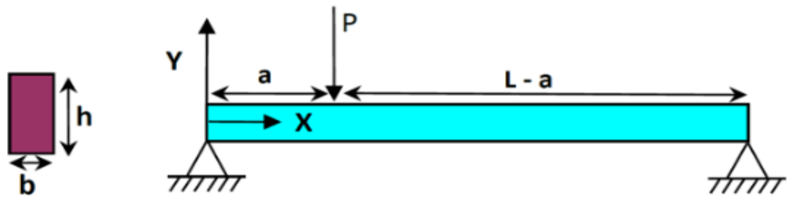


Figure 4.1: Fixed Beam

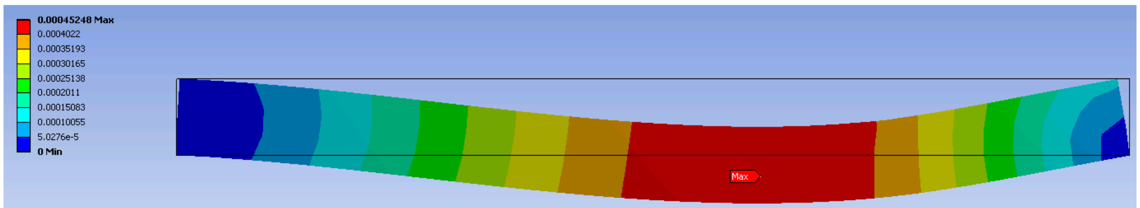


Figure 4.2: Deformation of the Fixed Beam

This theory of deformation when loading is applied can be used in a curtain wall system. The loads being applied to the system are wind loads (applied longitudinally) and gravity loads (applied latitudinal downward). These loads will cause a slight deformation to the curtain wall. This structural performance was examined further in the test of the HLTI curtain wall system.

4.1.2 Thermal Performance

To understand the thermal performance of a curtain wall, a case showing the radiation of an object was looked at. In this problem of very cold specimen is placed in the center of a shell at room temperature. ANSYS simulations the radiation exchange between the surface of the shell and the specimen. From the results seen below from the shell and the specimen, one can note that some radiation emitted by the shell is being absorbed and stored within the specimen. With the initial temperature of the specimen, being close to absolute zero it emits very small amounts of radiation. However, the specimen's emitted radiation gradually increase, as it gets warmer with time.

This type of thermal reaction can be used when looking at a fire within a curtain wall system. For instance, the glass will absorb the heat being emitted from the fire. As the fire grows hotter over time, the glass will absorb more of the heat which can then cause a reaction within the glass, the glass can fail and combust. This theory is looked into further in the model of the HILTI curtain wall system.

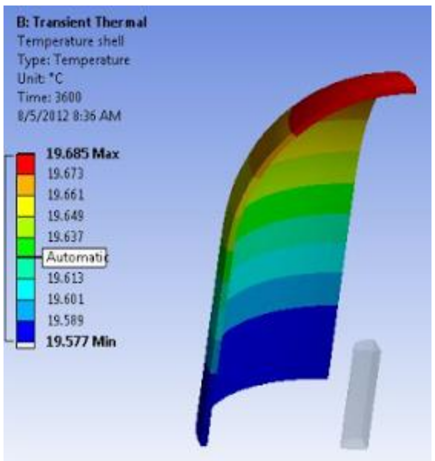


Figure 4.3: Thermal Reading of Shell

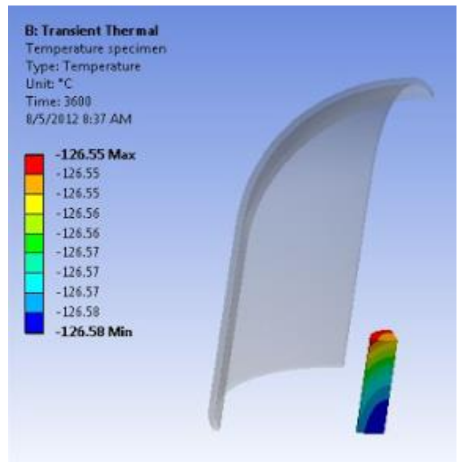


Figure 4.4: Thermal Reading of Specimen

4.1.3 Combination of Structural and Thermal Performance

Examining the structural and thermal performance together of a building can allow for understanding of how these properties work together. In the example below there is a simply fixed beam place between two walls and the temperature on the bar with an initial temperature of 22C and is increased to 100C. With the increase in temperature on the beam will cause a deformation of the beam, either expanding or contracting.

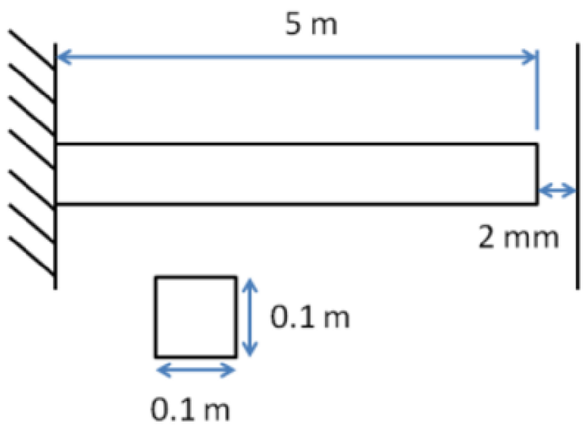


Figure 4.5: Simply fixed beam between two walls

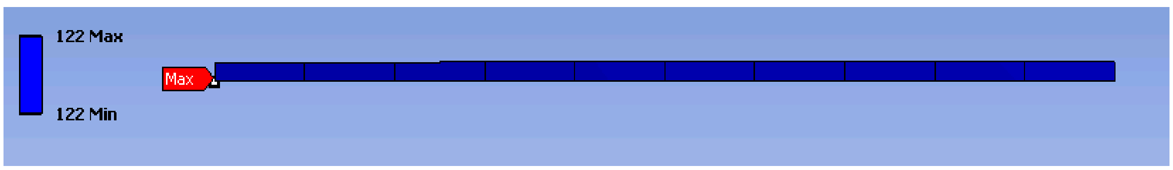


Figure 4.6: Thermal Result - temperature remains at 122C

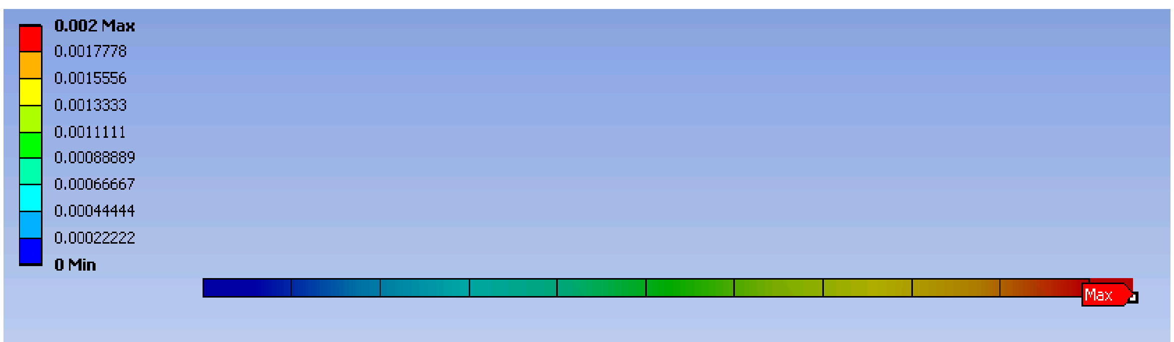


Figure 4.7: Structural Result - total deformation of beam is 0.002m

The results of the jointed thermal and structural analysis of beam can be seen above in figures 4.6 and 4.7. The thermal results show that with the beam in steady state that the beam has a constant temperature of 122C, going from initial temperature of 22C increasing 100C to have a final temperature of 122C. With the temperature increasing, the material of the beam is affected. In this example, the beam experiences a stretch, causing an elastic change in the beam, increasing 0.002m.

Comparing this model to the curtain wall system looked at, the temperature increase from the fire will cause the material such as, the glass and mullion system to deform. Also, the loads being applied to the to the system simultaneously with temperature change will result in addition deformation of the system because wind loads, gravity loads, and self-weight of the system are being applied.

4.2 Curtain Wall Model

In selecting a curtain wall to test in the simulation the team chose a curtain wall that had already gone through the ASTM E2307 test giving the team values for the F and T-Ratings. Knowing that the system had passed the Fire Resistance test allows for the assumption that this system should also pass the simulation created.

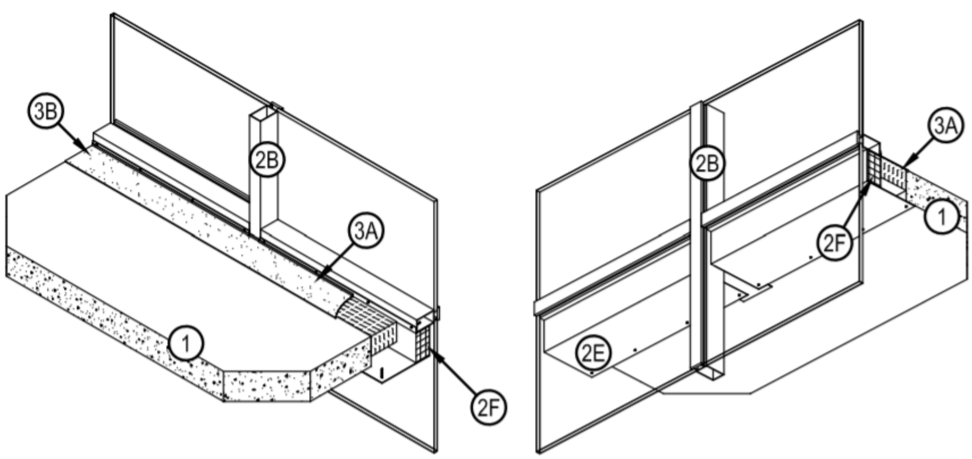


Figure 4.8: HILTI CAD Curtin Wall drawing

The model that was chosen was the HILTI curtain wall model without the recommended 3-foot spandrel. As mentioned previously, the spandrel is a 3-foot opening in a curtain wall used to slow down the spreading of fire up a curtain wall. Using this model gives an understanding of what occurs in a curtain wall when that opening is not available. The HILTI model uses materials such as, aluminum mullions, concrete slab floor and roof, wool insulation, silicone fire stop spray, and glass paneling. To fully understand this system, it is modeled in Auto CAD and then in ANSYS, defining each element of the system including connections and parts of the curtain wall not seen in the 3D CAD image provided by HILIT (figure 4.8). This model can then be examined through the conditions required for thermal and structural analysis, which will be discussed further in the methodology section of this report.

To perform the Fire Resistance Test, the curtain wall system had to follow the requirements for the ISMA detailed in the ASTM E2307. The height of the curtain wall system had to be at least 17-feet with a width of 13.33-feet. The floor slap had to have a thickness of at most 8 inches. Also, the simulated fire had to be a certain size and be raised a certain amount off the ground. The fire had to be at least 30 inches in height and 78 inches in width because of the window size. The exact height of the fire was not specified in the test and as a result, some assumptions were made to garner the best outcome. Nevertheless, following these criteria allowed for a more precise result in ANSYS.

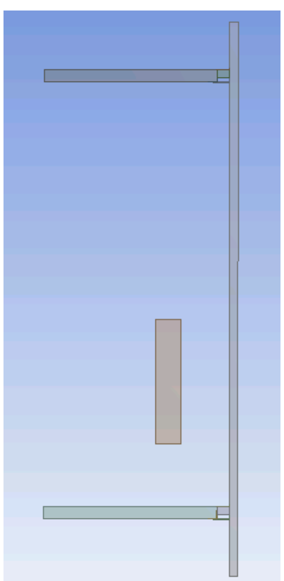


Figure 4.9: 2D ANSYS of Glass Curtain in ISMA

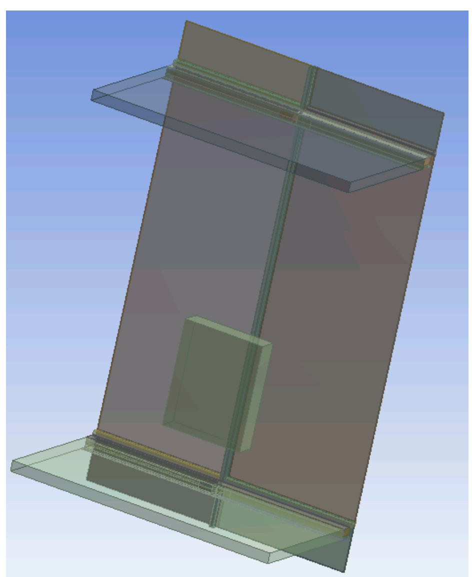


Figure 4.10: 3D ANSYS pf Glass Curtain Wall in ISMA

4.2.1 2D Auto CAD

The Auto CAD drawing of the non-spandrel curtain wall was the first step in being able to design this virtual simulation of the Fire Resistance Test. This drawing details elements of the curtain wall system not readily seen in figure 4.8. Using the CAD drawings provided by HILTI gave a general idea of the elements that make up the curtain wall. The model was expanded upon to meet the stipulations given by the ASTM E2307. A 2D elevation of the curtain wall was created in Auto CAD and this elevation aided in conductimg the joint thermal and structural analysis of a curtain wall.

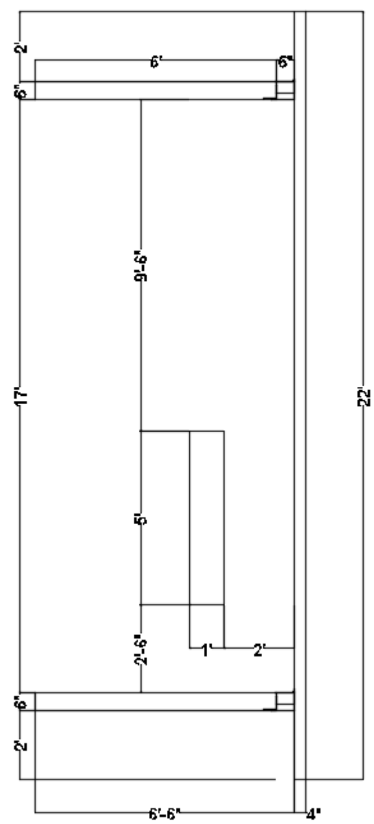


Figure 4:11 2D Auto CAD of Glass Curtain Wall

The 2D Auto CAD model seen in figure 4.11 has the fire placed at the proper distance away from the glass/mullion, 2 feet and the specified height above the floor, 2.5 feet, as the window that holds the burners for the fire was 2.5 feet above the ground. For the simulation, the fire is considered to be a rectangular shape to allow for properties such as temperature and boundary conditions to be implemented later on in ANSYS. The height of the system from floor to ceiling is 17 feet as detailed in the ASTM E2307 for the ISMA. The floors and ceiling slabs have a thickness of 6 inches which does not exceed the recommended 8 in. thickness. However, for the flooring and length of the floor slab was only 6 feet and not the recommended 13 feet. This is because for the analysis portion in ANSYS the team wanted to create a simpler model of the ISMA to garner results. The team did not treat the ISMA as a room as detailed in the ASTM E2307 but instead as portion of the ISMA, theoretically continuing on but only taking into consideration the portion of the curtain wall greatly affected by the fire, at the mullion between to glass panels.

Other considerations that were taken into account when modeling the HILTI curtain wall, is that the ISMA is a closed system, but in the CAD drawing it is an open system with only a floor slab, to meet the specifications of the ASTM E2307 a ceiling was added. The CAD drawing also provides the details for a window, however, since the 2D Auto CAD will be used for analyzing the deflection of the mullion and not window the thickness mullion is defined as ½ in. Other elements that are implement in the Auto CAD drawing is the “L” shape bracket connections between the concrete slabs and wool insulation. Small elements such as the “L” bracket do effect the ANSYS model and as a result must be detailed in Auto CAD drawing. The “L” bracket is not readily found in the CAD drawing provided by HILTI so it should be drawn in manually. The wool insulation and air are details already found in the modeled so do not need to be manually implemented but are necessary to detail. Once the 2D model is completed in Auto CAD save file as an “stl.” to allow for easy import into ANSYS.

4.2.2 2D ANSYS: Set-Up

The 2D curtain wall model will be used for the analysis for the combined thermal and structural. To create this type of analysis a "custom system" is chosen in the project page of ANSYS, specifically a "Thermal-Stress: Custom System". ANYSY will generate two tables once "Thermal-Steady State" and the other "Structural-Steady State", changing the automatic tables ANSYS generates from "Steady-State" to "transient". Having transient conditions for the thermal and structural analysis allows for a progression of change in for instance, the fire, allowing for the fire to gradyally increase over a period of time rather than in steady state condition where the fire would have is a constant value. To assure that the simulation stays true to the real world conidition

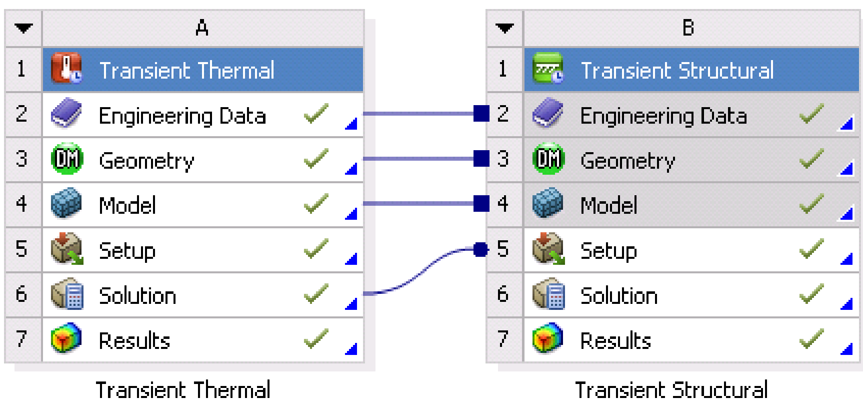


Figure 4.12: Custom System - Thermal-Structural

For the general setup of the 2D model, the materials of each element of the curtain wall is defined as well as the connections between the elements. Using the Engineering Database provided by ANSYS selecting the materials that will be used and importing them into the projects own Engineering Database.

- Materials Used:
    - Structural Steel – Given Material
    - Stainless Steel – Found in General Materials
    - Concrete – Found in General Materials
    - Resin Polyester – Found in Composite Materials

- Silicone Anisotropic – Found in General Materials

With the materials defined the 2D AutoCAD can be imported into the ANSYS geometry. In the geometry portion of ANSYS the materials for each element was applied, the table below has the elements of the curtain wall, the material, and the properties of the material which includes density, isotropic conductivity, and specific heat.

Table 4.1: 2D Geometry Materials and their Thermal Properties

Elements of Curtain Wall	Material	Density ($kg.m^{-3}$)	Isotropic Conductivity ($W.m^{-1}.C^{-1}$)	Specific Heat ($J.kg^{-1}.C^{-1}$)
Mullion	Stainless Steel	7750	15.1	480
Floor Slab	Concrete	2300	0.72	780
Ceiling Slab				
Firestop Spray	Silicon	2330	148	712
Sheet Metal Pans	Structural Steel	7850	60.5	434
In-Concrete Steel Angles				
Curtain Wall Insulation	Resin Polyester	1044	0.033	1500

When the geometry and materials are defined the ANSYS modeling of the curtain wall is to follow. In the modeling portion of ANSYS connections between elements of the curtain wall are specified. For the 2D model only bonded connections are considered. Bonded elements act between contacting faces of structurally supporting bodies, as a result, there is no movement between the elements. The table below shows the contacts that are made in ANYS. A more detailed explanation of the general 2D ANSYS setup can be found in the Appendix: User's guide.

Table 4.2: 2D Geometry Connection between Elements

Bonded	
Sheet Metal Pan	In-Concrete Steel Angle
	Mullion
	Wool Insulation
	Silicone Firestop Spray
Concrete	Wool Insulation
	In-Concrete Steel Angle
	Silicone Firestop Spray
Wool Insulation	Silicone Firestop Spray
	In-Concrete Steel Angle

With the contacts characterized the system is meshed. For the 2D geometry face sizing is used, giving the nodes the connection necessary for ANSYS to later run the simulation.

Table 4.3: Number of Faces and Node Sizes for Meshing

Elements	# of Faces	Size (in.)
In Concrete Steel Angel	6	0.0625
Bracket		
Silicone		
Mulion	5	0.5
Concrete slab		
Wool Insulation		

After the general setup is complete the model was generate in ANSYS with all its properties to then begin the setup for the different analysis that is conducted.

4.2.3 2D ANSYS: Combined Thermal and Structural Set-Up

When the geometry and model are completed in Transient Thermal, ANSYS will automatically transfer the model to geometry. In the setup of transient thermal the boundary conditions need to be defined. For this system radaiation applied to the fire and interior elements of the curtain wall were considered. Since this analysis is not steady (constant) but trasient (steps) the data for radiation is in tablular data form, broken into 6 steps going from an initial time of 0s to a final time of 7200s. The properties of the boundary conditions are as followed:

Table 4.4: 2D Radiation – Tabular Data

Element	Boundary	Emissivity	Ambient Temperature (F)
Fire (Rectangle)	Radiation	0.8	71.6 F
Interior elements of Curtain Wall	Radiation	0.8	71.6 F

Another condition applied to this system is the temperature of fire, similar to radiation it will gradually increase over time. The temperature starts at 71.6 F, for an average room temperature and ends 1800 F, the start of melting of the mullion system as defined in the ASTM E119 Time vs. Temperature curve. The breakdown of the temperature for the fire can be found in the table below.

Table 4. 5: Fire Temperature – Tabular Data

Steps	Time (s)	Temperature (F)
1	1	71.6
2	120	450
3	360	1050
4	540	1220
5	1500	1510
6	7200	1800

Once the boundary conditions the solution type was chosen to run the simulation. In the thermal setup, the solution necessary is the temperature. Run the simulation and the results for temperature can be found in section 5.

For structural analysis setup, boundary conditions such as, gravity and wind pressure are taken into consideration. Gravity load is defined in ANSYS as 386.09 in/s^2 in the y-axis and it is applied to the whole system. Pressure is also defined in this analysis however, not as a constant but tabular data detailed in Table 4.6 below.

Table 4.6: Wind Pressure – Tabular Data

Steps	Time (s)	Pressure (Psi)
1	1	8.35
2	120	8.35
3	360	8.35
4	540	8.35
5	1500	8.35

Also, to assure that the structural analysis is performed correctly the elements in the curtain wall is defined as a fixed support, resulting in no movement of curtain wall. When the setup is completed the solution for structural in determined, for this simulation total deflection is taken into consideration. After the individual set up are completed and the solutions are finalized the simulation can be run giving results of the total deflection of the mullion based on the pressure, wind load and fire temperature.

4.2.4 3D Auto CAD

The 3D Auto CAD of the curtain wall is used for the individual analysis of the individual thermal and structural performance of the system. The image below (figure 4.17) shows two-pane glass panels that were elongated to the proper height for the ASTM E2307 test, 17 feet. It was made to be a closed system like in the 2D Auto CAD, thus, there is concrete flooring and concrete roof held in place by a two steel/aluminum mullions that create an "I" shape. Another element that was placed in the CAD drawing is a rectangular prism again, it will act as heat source/fire when performing the thermal and structural test in ANSYS.

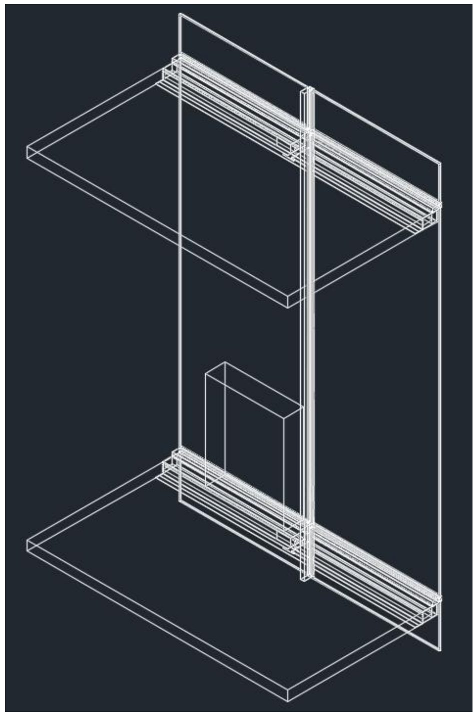


Figure 4.13: 3D Auto CAD of Model

The rectangular prism has a height of 5 feet, a width of 1 foot, and length of 6.5 feet. The length of the fire was given by the ASTM E2307 standards for the window size for the burner, however the height and width of the prism are assumed sizes to fit what is known about indoor fires. The prism is lifted 2.5 feet above the concrete floor slab and is placed about 2 feet away from the glass panels. The height at which the prism is lifted is another given measurement from the ASTM E2307 test while the distance away from the glass panel is assumed. The placement of the fire is a parameter of the test that will eventually be analyzed to see the effects the fire placement has on the deflection of the system.

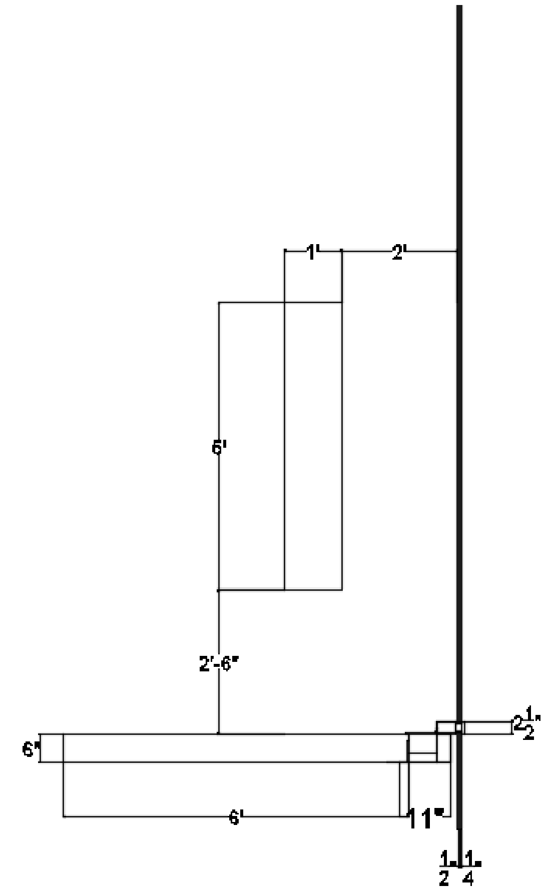


Figure 3Figue 4.14: 2D HILTI Model with Dimension

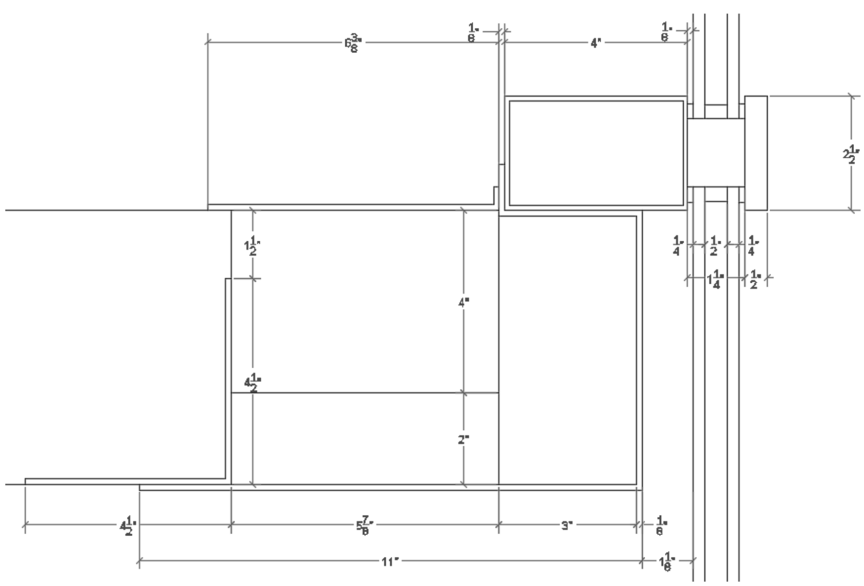


Figure 4.15: Zoomed in on the mullion and concrete connection

The mullions and connections to the floor and roof slabs are elements of the curtain wall that are detailed to express the internal fixtures within the system. Figure 4.15 shows a zoomed in version of the connections as well as the glass panels for the window. To connect the concrete slab to the insulation in the mullion a reinforced metal L-bracket is placed into the 3D AutoCAD model. In an actual curtain wall, the L-bracket prevents the movement of the floor/ceiling slab and insulation. This detail though not specified in the HILTI CAD drawing it is a necessary element to add to correctly simulate the performance of a curtain. Another connection not detailed in the HILTI CAD drawing but necessary to add is are two smaller bracket connections in the mullion to create the "I" shape, shown in figure 4.16. These connections prevent the movement of the mullions and keep the curtain wall intact.

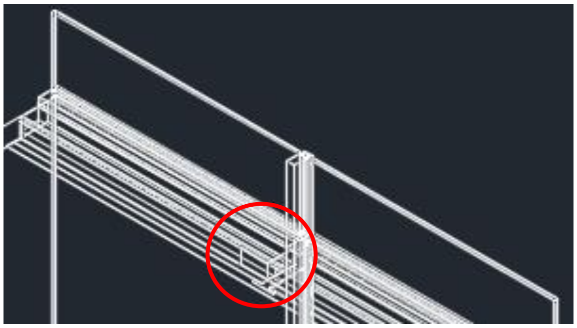


Figure 4.16: L-bracket connection between mullions

Other smaller elements that were added to the model incude rubber spacers that fit inbetween the mullion. This element will provide thermal insulation when preforming the analysis later on in the project. The small details drawin into the orginal CAD will aid in thermal and structural performance of the system in ANSYS. When the geometry and model are finalized the setup for the two analysis can be completed.

4.2.5 3D ANSYS: Set-Up

To complete the thermal and structural analysis of the 3D model in ANSYS, consider the general setup of the model, meaning having the correct curtain wall system imported into the software and understanding what details need to be specified in the model for instance, the material used and/or the connections between elements in the system. Once the geometry solidified and the materials and connections are identified, the specialized set up for each type of analysis can start.

Table 4.7: 3D Geometry Materials and their Thermal Properties

Elements of Curtain Wall	Material	Density ($Kg.m^3$)	Isotropic Conductivity ($W.m^{-1}C^{-1}$)	Specific Heat ($J.kg^{-1}.C^{-1}$)
Mullion	Stainless Steel	7750	15.1	480
Transoms ***Caps***	Aluminum Alloy	2770	Tabular Value	875
Floor Slab ***Ceiling Slab***	Concrete	2300	0.72	780
Vision Glass	Glass	2400	1.4	750
Curtain Wall Insulation	Resin Polyester	1044	0.033	1500
Rubbers ***Spacers***	Rubber Hard	1190	0.16	1
Firestop Spray	Silicon	2330	148	712
Sheet Metal Pans ***T-Shape Steel Plates*** ***Brackets*** ***In-Concrete Steel Angles***	Structural Steel	7850	60.5	434

Table 4.8: Tabular Data - Alumium Alloy

Temperature (C)	Thermal Conductivity ($W\ m^{-1}\ C^{-1}$)
-100	114
0	144
100	165
200	175

Once each element of the curtain wall has its own material the connections between elements are made. The purpose of defining these connections are to show how these elements acted with one another. In a real-world scenario elements, such as, a T-shape Steel Plate and an in concrete steel angle would be bolt to each other. This would prevent movement of that specific section of the model. With the simplified version of the curtain wall model connections were defined as either bonded or no separation. For bonded elements, they act between contacting faces of structurally supporting bodies, as a result, there is no movement between the elements. For no separate elements, they act between contracting face of thermal insulation bodies and those of other bodies, these elements are connected but can move laterally (up and down). Making these connections give for a more realistic telling of how the curtain wall would act and also makes the meshing of the whole system easier. Table 4.9 below shows the connection of materials either bonded or no separation.

Table 4.9: 3D Geometry Connection between Elements

Bonded		**No Separation**	
Rubber	Glass	**Curtain Wall**	Sheet Metal Pan
	Mullion		Brackets
	Transom		Transoms
	Caps		Mullions
T-Shape Steel Plate	In-concrete steel angle		Wool Insulation
	Mullion	**Wool Insulation**	Sheet Metal Pans
Sheet Metal Pans	In-Concrete Steel angle		Brackets
	Transoms		Concrete floor slab
Brackets	In-concrete steel angle		Silicone Firestop spray
	Mullion		Mullion
In-concrete Steel angle	Concrete Floor Slab	**Silicone Firestop Spray**	Sheet Metal Pan
	Wool Insulation		Concrete Floor Slab
Mullions	Transoms		Mullion
Vertical Caps	Horizontal Caps		
Glass	Spacers		

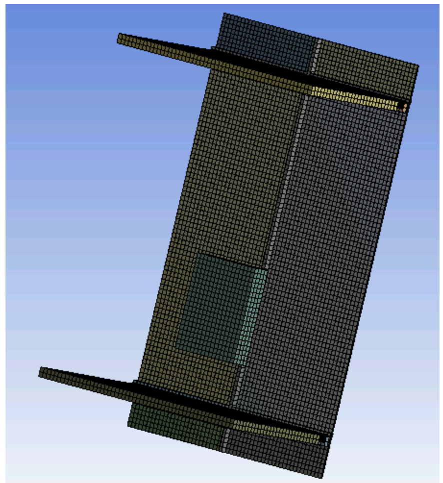


Figure 4.17: Meshing of Curtain Wall

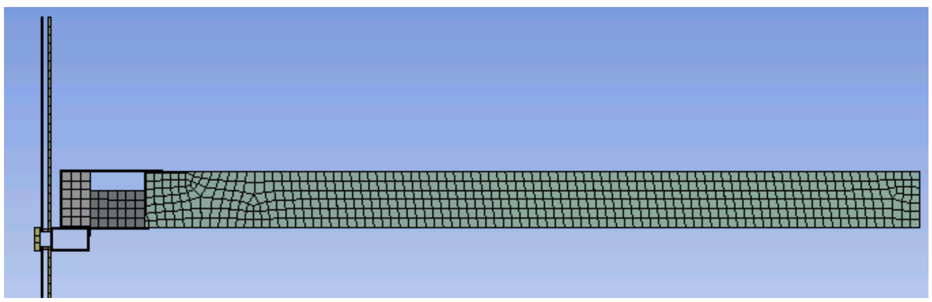


Figure 4.16: Zoomed in Meshing of Joint Connect of Curtain Wall

The meshing of the geometry is the next step before defining what is to be and running the simulation. The meshing for this system was more defined, using the connections that were defined previously, as well as, size meshing smaller elements in the system i.e. T-shape, cap, rubber, and wool insulation allowed for a more conscience meshing. Figure 4.19 below shows the complete ANSYS model with materials and connections defined. The geometry, materials, and meshing remains the same with each analysis conducted.

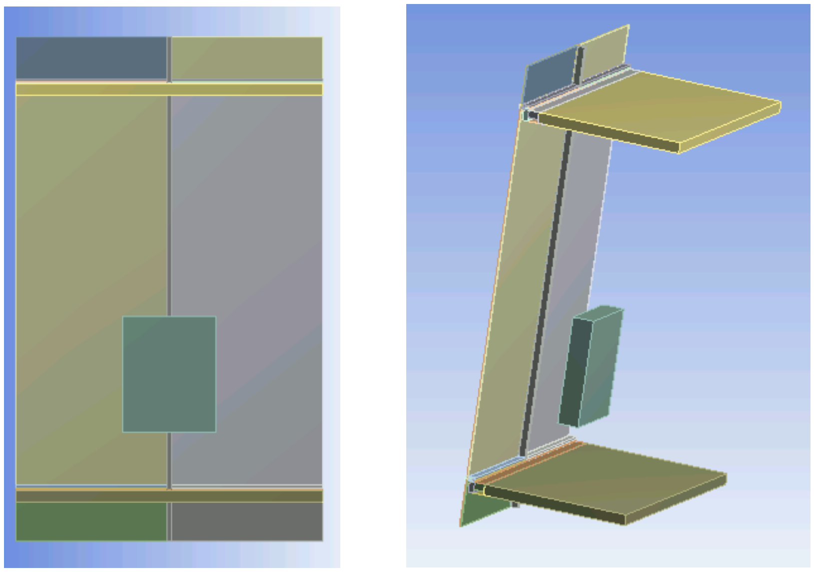


Figure 4.19: 3D Model of Curtain Wall

4.2.6 3D ANSYS: Thermal Set-Up

Thought the general set up for ANSYS differ slightly from 2D to 3D the thermal set up remains constant. To complete the thermal analysis, characterized the conditions for transient heat transfer. For instance, stating the boundary conditions that will be using. For this system, take into account radiation that would occur as a result of the fire, specifically use surface to surface radiation that emits an emissivity of 0.8.

Table 4.10: Defined Boundaries in Surface to Surface Radiation

Surface to Surface Radiation	
Fire	Interior Surface
Inside glass	Outside glass

Another condition that was defined was fire. Using the ASTM E 119 Time vs. Temperature curve precise values to how the temperature changed over a time. Showing the steps of temperature increase in a period of two hours, giving us an estimated temperature of the fire at every step. The two-hour range is in direct correlation with the actual ASTM E 2307 and the UL listed table provide with the curtain wall system. Over the two-hours aluminum is assumed to start melting

(9 minutes, temperature 1220 F). This condition is one that can be tested in the simulation to see if the model is accurate.

4.2.7 3D ANSYS: Structural Set-Up

For structural 3D analysis, the project type is defined as static structural ANSYS. Having a static protect type results in specifications being constant and not changing over time. The set-up for structural analysis take into consideration the boundary conditions, loading being applied to the system both laterally and longitudinally, as well as wind pressure.

Table 4.11: 3D Geometry Structural Boundary Conditions and Properties

Geometry	Boundary	Value	Applied by
11 faces	Pressure	0.11 psi	Surface Effect
All Bodies	Gravity	-386.09 in/s^2 (z-direction)	

Similar to the structural setup for 2D the type of supports need for the curtain wall was defined, in this simulation, the floor and ceiling, as well as the glasses are fixed supports. Once the setup is complete the solutions for the analysis are define. For this simulation the Total Deformation, Equivalent Elastic Strain, and Equivalent Stress are take into consideration.

5. Results

The results garnered from the simulation are split into three analysis, thermal, structural and combination of thermal-structural. For the individual thermal analysis the effects of temperature of fire was examined, as well as the heat flux in the curtain wall caused by the fire. In the individual analysis of the structural aspect of the curtain wall the total deformation caused by the loads being applied to the curtain wall. Additional information garnered from the structural analysis is the equivalent stress and strain applied to the curtain wall. For the combined Thermal-Structural analysis total deformation caused by loading and fire temperature over a period of two hours. The results of each analysis is detailed further in the following few paragraphs.

5.1 Thermal Results

In the analysis of the thermal performance of the curtain the max heat sources is the fire which increased from 0 seconds to 7200 seconds (hours) from an ambient temperature of 71.6 F to a max temperature of 1800F. The heat is radiating out to elements such as, inside and outside glass, and interior surfaces of the curtain wall. Checking the mullion of the curtain wall the applied by the fire is about 1402 F. This shows that the element that gets most of the heat from the fire is the mullion system. With the placement of the fire and its proximity to mullion that result garnered from the test is true.

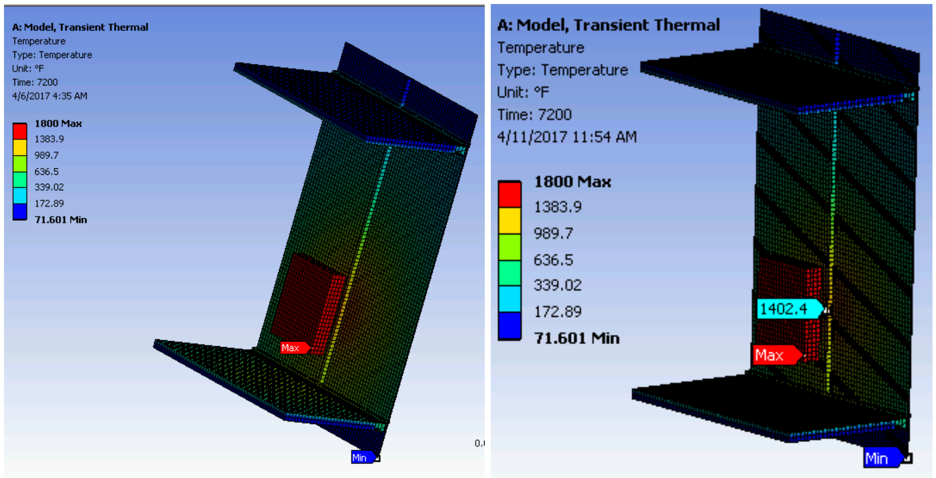


Figure 5.1: Transient Thermal Results: Temperature

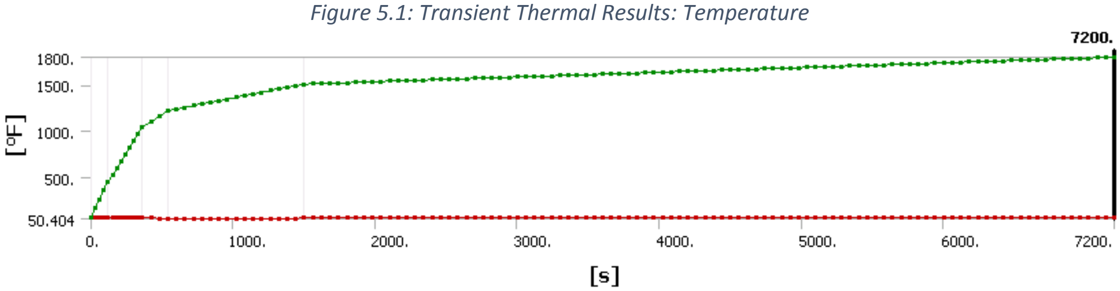


Figure 5.2: Graphical – Transient Thermal Results: Temperature

The heat flux helped to exam the rate of heat energy transfer through the surface over a period of time. For the simulation, most the curtain wall has a heat flux of 8.93×10^{-18} BTU/s in^2. The small value of heat flux shows that there is not a major transfer of energy as a result, did not have a huge impact on the deflection of the material in the curtain wall.

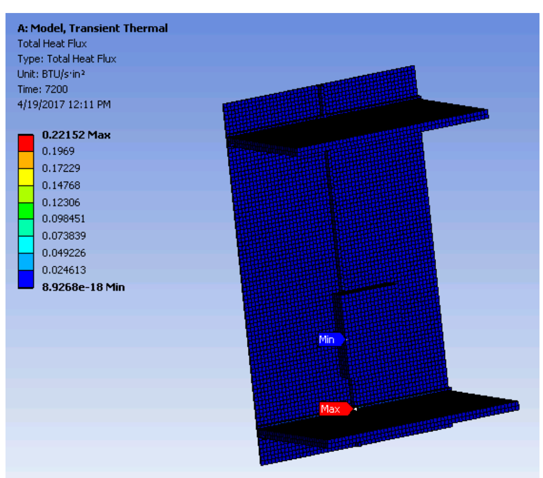


Figure 5.3: Transient Thermal Results: Heat Flux

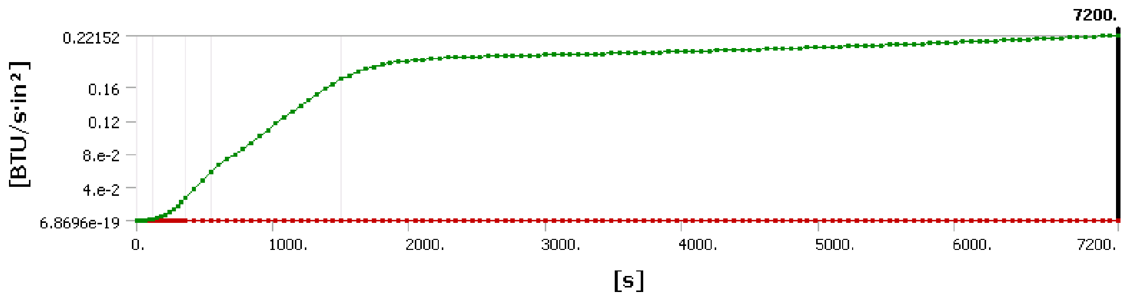


Figure 5.4: Graphical – Transient Thermal Results: Heat Flux

In the actually ASTM E2307 convection and air are factors which affect the fire and in turn affects the material of the curtain wall. For the virtual simulation, these factors couldn't be taken into consideration and as a result the heat radiating from the fire and on to the materials isn't as high as it could be. Also, because the fire is treated as hot box with material properties of structural steel and was not treated as a natural element there are restrictions to the thermal properties of fire. With the need to heat up that material of the curtain wall first, the radiation bouncing off of the fire box again isn't the highest it could have been. Nevertheless, examining the radiation that occurs between the fire and the materials of the curtain wall allows for the understanding of the effects of fire over time.

5.2 Structural

In the structural analysis of the curtain wall boundary conditions of pressure and gravity loads are considered. These loads when applied affect the deflection of the material. In an actual curtain wall system, the maximum deflection occurs at the middle edge of the glass. This is because glass is a weaker material in comparison to that of the mullion. However, in the simulation the maximum deflection occurs in the middle, center of the glass curtain wall. The reason for this might be because of the how the supports in the curtain wall were defined. Though the results are not what is assumed, the deflection of the whole system is examined.

Using the parameter for the deflection of stainless steel “L/360” the assumption for the deflection of the steel mullion is about 0.5 in. in the simulation, the deflection garnered for the mullion was about 0.37908 in. which is less than the max deflection calculated. Showing that though the maximum deflection is not where expected the simulation does exceed the max deflection

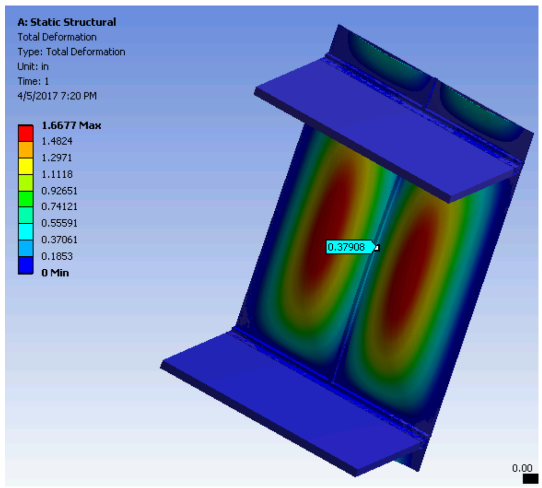


Figure 5.5: Static Structural Results: Total Deformation

Another aspect of static structural that is looked at is the Equivalent Elastic Strain and Equivalent Stress caused by the loading. Having these two results helped in understanding the strength in material. The Equivalent Elastic Strain shows the strain in which the element under loading and deformation returns to its original shape and size when the loading is removed. For most of the curtain wall has the same value of Equivalent Stress Strain as shown in figure 5.6.

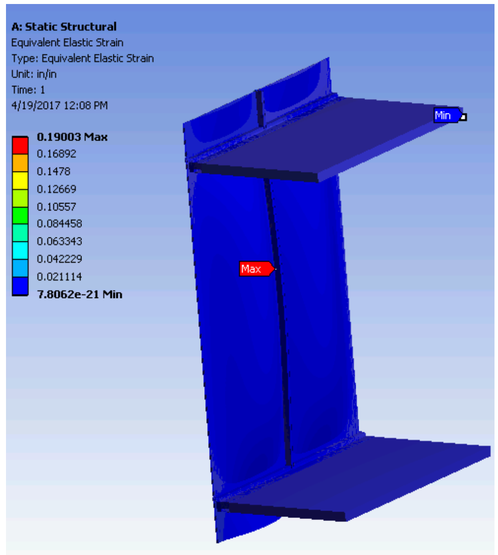


Figure 5.6: Static Structural Results: Equivalent Elastic Strain

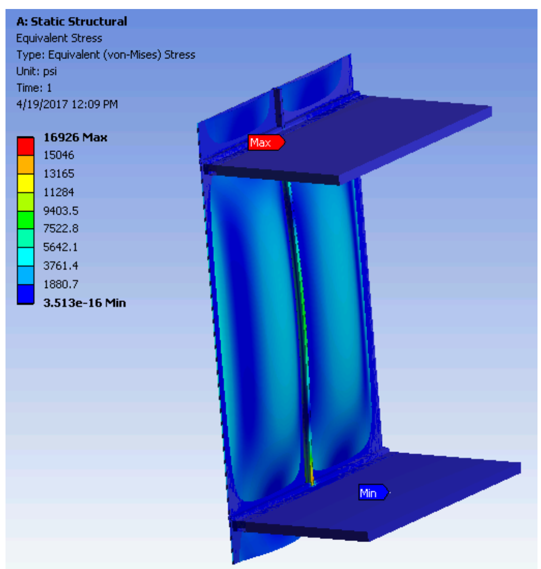


Figure 5.7: Static Structural Results: Equivalent Stress

The Equivalent Stress shows the yielding[16] of material, providing a value for the deformation of a material when it does not return to its normal shape after the loading is removed. Unlike the Equivalent Elastic Strain the value of Equivalent Stress varies with each material. This is because

[16] Yield Strength – the material property defined as stress at which the material begins to deform plastically, non-reversible change in shape when forces are applied.

the strength in material is different for each. These additional tests though do not affect the total deformation of the materials do provide background to how the materials are influenced by the loading be applied.

5.3 Thermal & Structural

The Thermal and Structural analysis took into consideration the temperature of fire and the loading being applied to the curtain wall showing the deformation. For this analysis only the deflection of the mullion was studied. The results of the simulation show that maximum deflection of 0.28831 in. at the end of 1500s with a total max deflection of 0.351 in. at the end of 540s. The deflection resulting from this analysis differs slightly from the deflection found in the individual structural analysis. This might be because this simulation is taking into consideration fire and wind pressure, with wind pressure in one direction and the fire in the other the corresponding deflections cancel each other out giving a smaller value. The deflection shown in figure 5.8 is not one that is expected. When a load is being applied to a mullion the deflection usually bows out but the in the simulation the maximum deflection bows in toward the fire. This result might have again been because of the whole system being a fixed support, in an actual curtain wall there is slight movement between materials giving a different shape for deflection.

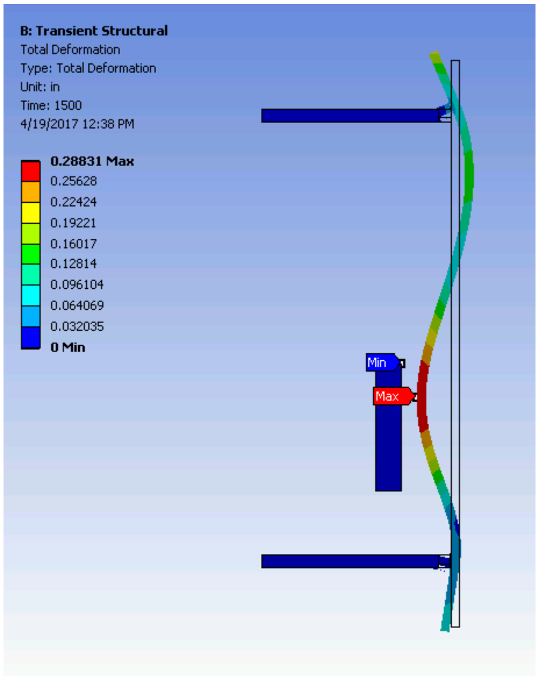


Figure 5.8: Combined Thermal and Structural: Total Deformation

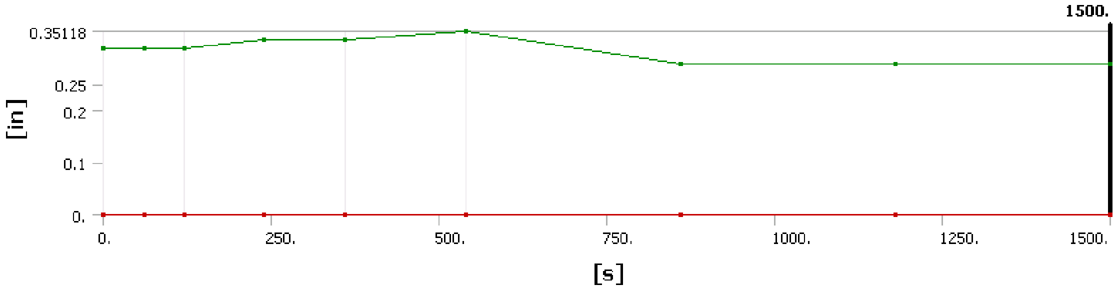


Figure 5.9: Graphical – Max and Min Total Deformation

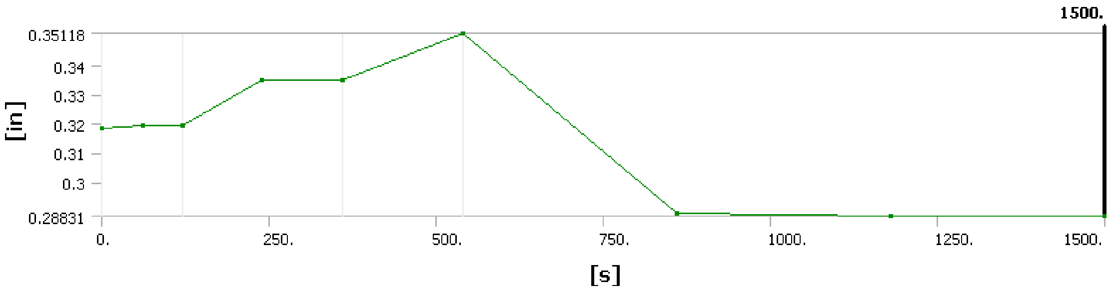


Figure 5.10: Graphical – Max Total Deformation

Table 5.1: Time vs Deflection: Max and Min

Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.31841
60.5	0.	0.31958
120.	0.	0.31947
240.	0.	0.33496
360.	0.	0.33491
540.	0.	0.35118
860.	0.	0.28931
1180.	0.	0.28847
1500.	0.	0.28831

Through the individual thermal and structural analysis to the combined analysis the performance of the curtain wall is seen. The simulation provides a visual aid to see the effects of fire and wind load. Though the results were not always what was expected did give the team a better understanding of the thermal and structural performance of a curtain wall when put under the condition of fire. It also, gave an understanding to the ASTM E2307: Fire Resistance Test and why curtain wall are put to the test.

Usiing the result gained from the individual analysis parametric testing was completed testing the placement of the fire and the amount of wind loads being applied to the system. Garnering a greater understanding of the thermal and structural performance of a curtain wall.

6. Parametric Test

With the results gathered from the thermal and structural analysis the wind pressure and fire placement was tested. These two elements affect the deflection of curtain wall over a period of time and their placement should effect the value of deflection. In the original simulation, the fire is placed on the first floor and the fire is placed 2 feet away from the mullion. For the parametric testing the fire was moved from 1 foot to 6 feet, expanded the length of the concrete floor slab and the wind pressure was change to reflect if the curtain wall was on the first through tenth floor.

6.1 Wind Loads

For the wind loads the total deformation of the mullion was looked at. As a comparsion the team first looked at what happens if only wind pressure is being applied with no fire. In the test the mullion bows out. This is not what is expected because when loading is applied on the outside of the mullion the expectation is for it to bow inward toward the fire. But from previous test, from the combined thermal and structural the team assumed this type of deflection occurs because the mullion boundary conditions being applied to the system. Further test was completed with the wind pressure but this time taking into consideration the effects of fire. The wind pressure increases as the curtain wall is moved higher in a high rise building. With the greater wind pressure the deflection also increases, which is what is to be expected. Results from the parametric test can be found in the appendix of the report.

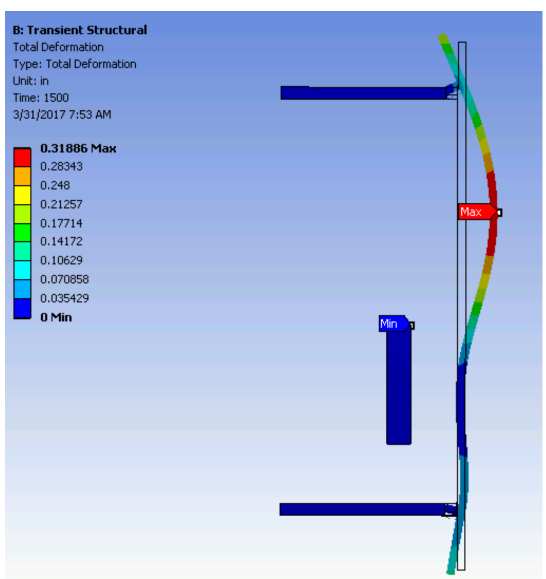


Figure 6.1: Total Deformation – 1st Floor, No Fire, Only Wind Pressure

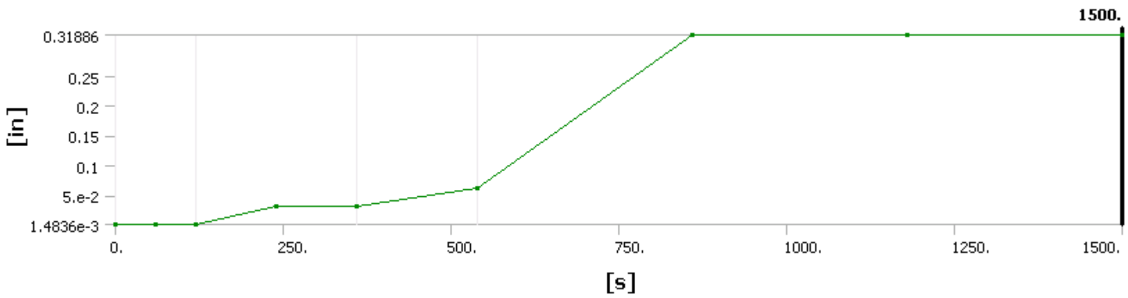


Figure 6.2: Graphical – Max Total Deformation caused by Wind Pressure

Table 6.1: Time vs Deflection: Max and Min Wind Pressure

Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.4837e-003
120.	0.	1.4836e-003
240.	0.	3.2807e-002
360.	0.	3.2807e-002
540.	0.	6.125e-002
860.	0.	0.31841
1180.	0.	0.31881
1500.	0.	0.31886

Table 6.2: Max Deflection from 1st to 10th Floor

Floor	Deflection (in)
1	0.28831
2	0.35933
3	0.40969
4	0.45015
5	0.48462
6	0.51447
7	0.54166
8	0.56652
9	0.58896
10	0.61025

6.2 Movement of Fire

For the fire a similar approach was taken, the team took into account a curtain wall system with noly fire and no wind as the bases of the parametic testing. In this situation the mullion deflects inward toward the fire. The expectation for this mullion is the closer the fire gets to the mullion the greater the deflection causing the mullion to expand due to the higher temperatires. As a result, the mullion should bow out and not in. Similar to the structural analysis the deflection garnered is not the expectation. The reasoning behind this again, might be the boundary conditions that were applied to the system.

Further testing is completed taking into consideration both the fire and wind pressure. The results from this parametric testing show that the further the fire gets from the curtain wall the lower the deflection. This result is what is to be expected because the mullion will expand less if the heat is further away from it. The complete results from the parametric testing of fire can be found in appendix of this paper.

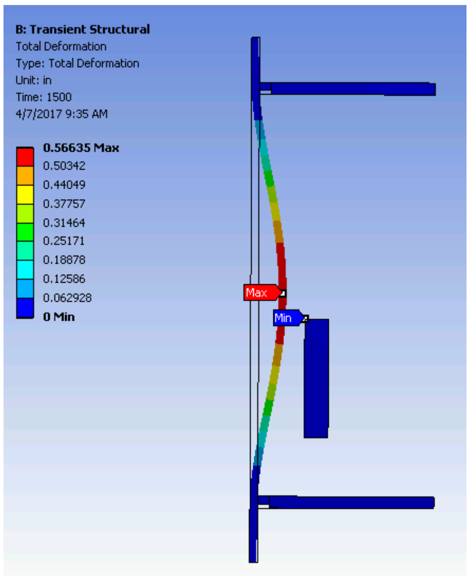


Figure 6.3: Total Deformation caused by Fire Temperature

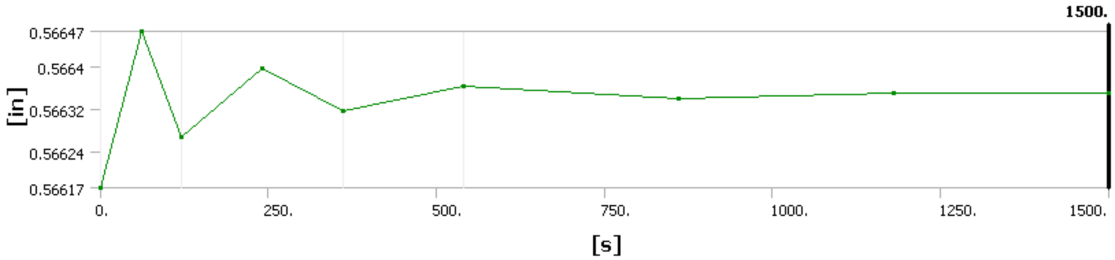


Figure 6.4: Graphical – Max Total Deformation caused by Fire Temperature

Table 6.3: Time vs Deflection caused by Fire Temperature

Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.56617
60.5	0.	0.56647
120.	0.	0.56627
240.	0.	0.5664
360.	0.	0.56632
540.	0.	0.56636
860.	0.	0.56634
1180.	0.	0.56635
1500.	0.	0.56635

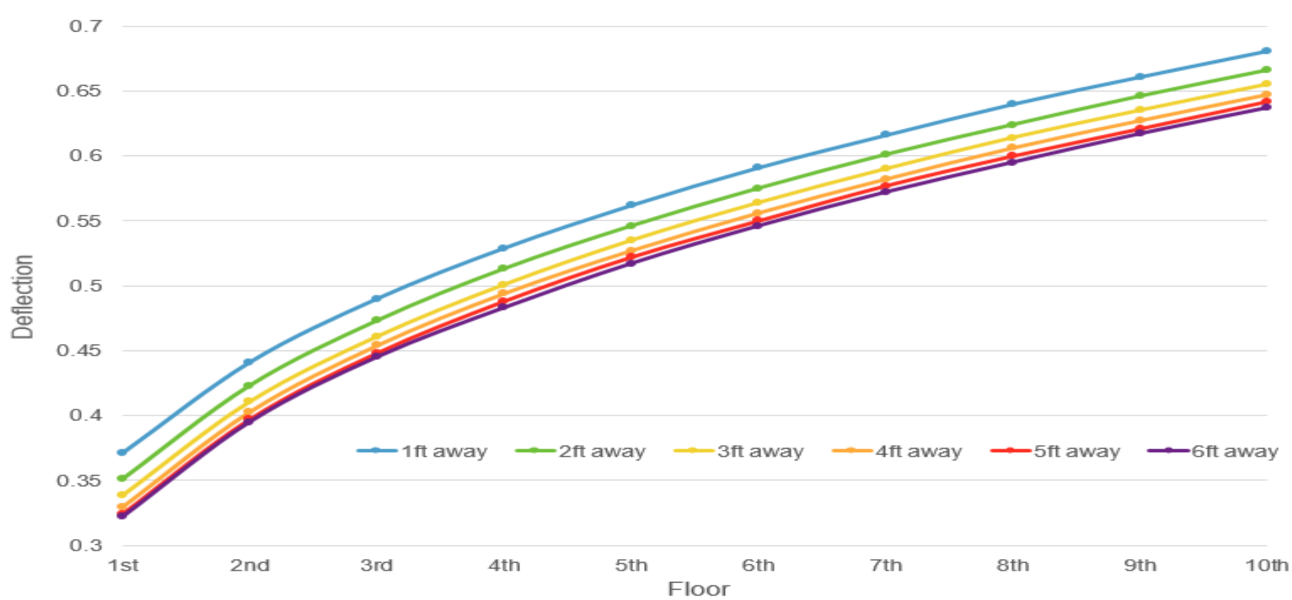
Table 6.4: Max Deflection from 1 to 6 feet Away

Feet Away from Curtain Wall	Deflection (in)
1	0.345
2	0.319
3	0.293
4	0.27
5	0.25
6	0.234

6.3 Results

The results from the parametric testing shows the effect of the placement of fire and curtain wall. When the curtain wall is on the first floor the deflection is the lowest and when he fire is moved further and further away from the curtain wall it continues to decrease which is what to be expected. The deflection of the mullion on the 10th floor is greater, it has the highest wind pressure but similar to the first floor the further the fire got from the curtain wall the deflection decreases. Through the parametric testing the effect of the fire and wind pressure could readily be seen.

Floor	Wind Pressure (psi)	Deflection (in.)					
		1 ft. away	2 ft. away	3 ft. away	4 ft. away	5 ft. away	6 ft. away
1st	8.35	0.371	0.351	0.339	0.330	0.324	0.322
2nd	10.18	0.441	0.423	0.411	0.403	0.397	0.395
3rd	11.43	0.490	0.473	0.461	0.454	0.448	0.445
4th	12.41	0.529	0.513	0.501	0.494	0.488	0.483
5th	13.23	0.562	0.546	0.535	0.527	0.522	0.517
6th	13.93	0.591	0.575	0.564	0.556	0.550	0.546
7th	14.56	0.616	0.601	0.590	0.582	0.577	0.572
8th	15.13	0.640	0.624	0.614	0.606	0.600	0.595
9th	15.64	0.661	0.646	0.635	0.627	0.621	0.617
10th	16.12	0.681	0.666	0.655	0.647	0.642	0.637



7. Conclusion

All in all, the virtual simulation of the ASTM E2307: Fire Resistance Test detailed the performance of the curtain wall. Through the thermal and structural analysis, the deflection caused by the loading and fire temperature are visible. Though the results for the deflection are not what was expected the general idea behind the fire resistance test, which is to see if the curtain wall is structural and thermally sound for contstruction purposes can be garnered from the results with gathered. From our individual thermal and structural and even the combined analysis the deflection max for the mullion is not reached.

Through the parametric testing we saw that the curtain wall is able to handle the fire, wind and gravity loads being applied to it from level 1 to 10. Beyond that point the deflection of the mullion exceeds is yield strength. Nevertheless, being able to simulate the fire resistance test gave a better understanding to the effects of fire and the importantace of the thermal and structural strength of material. With fire being a major concern when constructing a building attention has to be paid to every detailed and element being used.

7.1 Future Consideration

If this project were to continue future teams should consider the following, continuing with the parametric testing and analyszing a different type of curtain wall. In continuing with the parametric testing the materials of the curtain wall could be changed. The materials used for this simulation were readily available in the ANSYS database and might not meet requirements thermal and structural requirements set forth by the building code. For instance, for the simulation created float glass was used however, most curtain walls uses insulated glass. The insulated glass could improve the thermal properties of the curtain wall changing the results gained from the analysis. Making changes to the material properties to meet the proper thermal requirements for a curtain wall could better simulate the actual results from the Fire Resistance Test.

To get a better understanding of the effects of fire has on a curtain wall a comparison of different curtain walls would be useful. Simulating a curtain wall with a 3-foot spandrel can show the effects fire has on the opening provided by the spandrel. Being able to analyze the thermal and structural performance of the system. All in all, continuing to gain knowledge about the ASTM 2307 and being able to test the ffects of the ASTM E2307 can give more knowledge to the fire performance of a curtain wall.

HI/BPF 120-09

Design No. HI/BPF 120-10

PERIMETER FIRE BARRIERS

Firestop Joint Spray CFS-SP WB

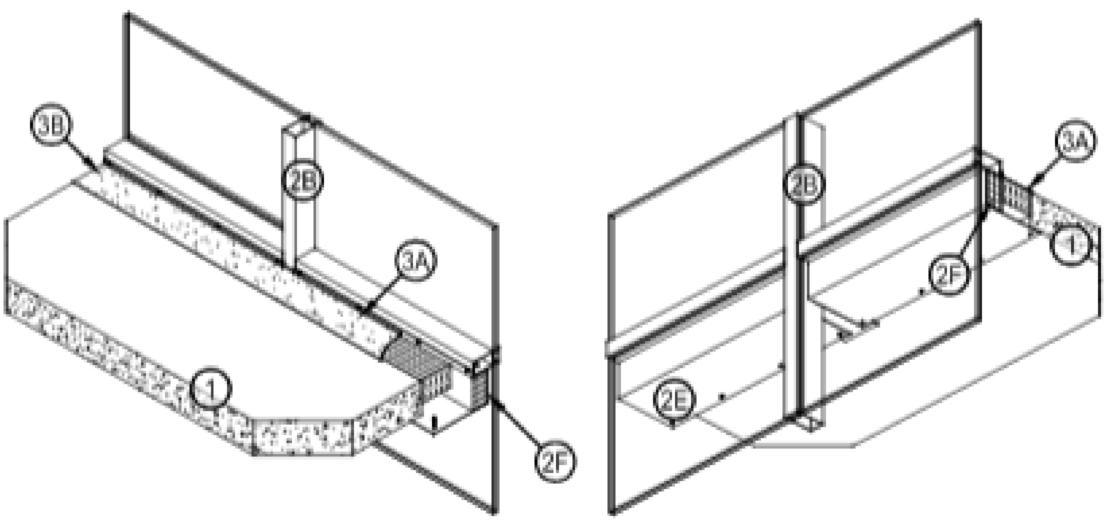
ASTM E 2307

Table 1.

	Firestop Joint Spray CFS-SP WB	Silicone Joint Spray CFS-SP SIL
F-Rating	2 Hour	2 Hour
T-Rating	45 Minute	45 Minute
Application Thickness	1/8 in. wet film (1/16 in. dry)	2 mm (0.08 in.) wet film

Static Joint

L-Rating <1.0 SCFM/LF at Ambient Conditions



Hilti Firestop Systems

Page: 1 of 2

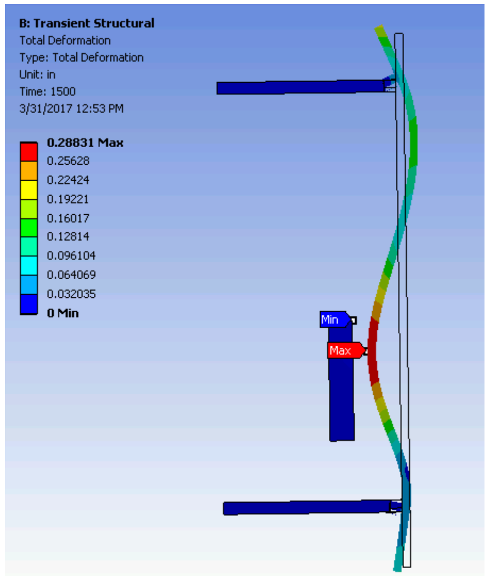
Design No. HI/BPF 120-10

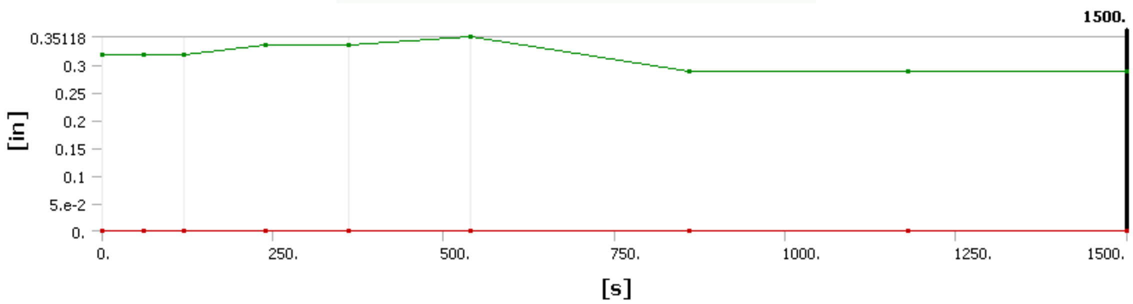
HI/BPF 120-10

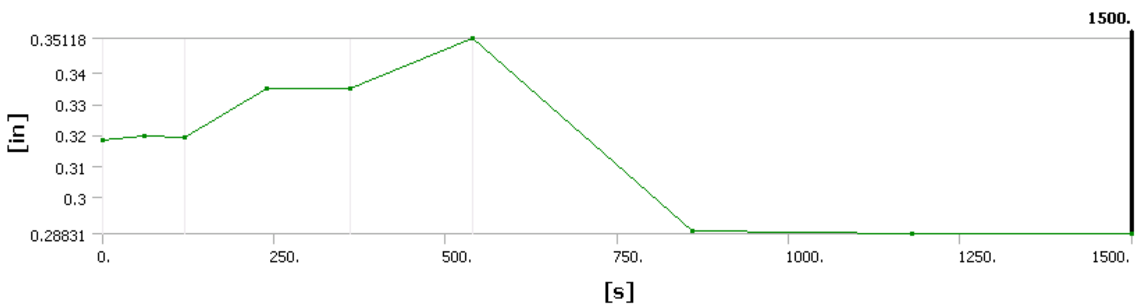
1. CONCRETE FLOOR ASSEMBLY: 2 hour rated concrete floor assembly made from either lightweight or normal weight concrete with a density of 100 to 150 pcf, having a min. thickness of 6 in. at the joint face. When a longitudinal recess (blockout) is required to contain an architectural joint system, increase concrete floor assembly thickness to maintain a min. thickness of 6 in. and accommodate depth of blockout formed in the concrete: blockout width unrestricted.
2. CURTAIN WALL ASSEMBLY: The curtain wall assembly shall incorporate the following construction features:
   A. Mounting Attachment (Not shown): Attach aluminum framing (Item 2B) to the structural framing according to the curtain wall manufacturer's instructions. Connect the mounting attachments to the joint face of the concrete floor assembly (Item 1) according to the curtain wall manufacturer's instructions.
   B. Aluminum Framing: Use hollow rectangular aluminum extruded tubing with min. overall dimensions of 0.100 in. thick, 4 in. high and 2-1/2 in. wide. Locate mullions (vertical aluminum framing) min. 60 in. oc. Locate the transom (horizontal aluminum framing) such that the bottom surface of the transom is at the same height as the top surface of the floor assembly.
   C. Glass Panels: Sized and installed into aluminum framing (Item 2B) in accordance with the curtain wall manufacturer's instructions. Use min. 1/4 in. thick, clear, heat strengthened (HS) or tempered glass with a max. width and height less than the aluminum framing (Item 2B) oc spacing. OC spacing shall allow glass to be secured to the aluminum framing (Item 2B) between the notched shoulders. Secure glass panels with a thermal break (rubber extrusion), pressure bar (aluminum extrusion), min. 1/4-20 by 5/8 in. long screws, and a snap face (aluminum extrusion).
   D. Aluminum Anchor Brackets (Not shown): Use min. 1/2 in. thick aluminum anchor brackets to serve as part of the mounting attachment (Item 2A) rigidly secured to the aluminum framing (Item 2B) and the concrete floor assembly (Item 1).
   E. Galvanized Sheet Metal Pan: Attach 18 GA galvanized steel section to the aluminum framing with No. 10 self-drilling sheet metal screws at 12 in. oc and to the concrete slab with Hilti Kwik HUS-EZ 1/4 in. x 1 7/8 in. steel concrete anchors, also 12 in. oc. The galvanized steel pan shall be formed such that it has a min. 1 in. lip for which to secure the pan to the aluminum framing, can contain min. 3 in. thick min. 6 in. tall curtain wall insulation (Item 2F), and a bottom leg long enough to overlap the concrete floor assembly min. 1 in. to secure the pan to the floor assembly (Item 1). Install 18 GA galvanized steel plates min. 4-1/2 in. in width, centered at the aluminum mullions such that there is continuous coverage below the joint. Install Hilti CFS-S SIL GG Firestop Silicone along the edges of the metal pan that are in contact with the aluminum members of the curtain wall assembly.
   F. Curtain Wall Insulation: Fill the cavity of the metal pan (Item 2E) with nominal 3 in. thick, min 6 in. tall, 8 pcf density, mineral wool batt insulation. Tightly fit, compress at least 1/8 in. in all directions. Use only Intertek certified products meeting the above min. requirements.
3. PERIMETER JOINT PROTECTION: Do not exceed a 4 in. nominal joint width (joint width at installation). Incorporate the following construction features for the perimeter joint protection (also known as perimeter fire barrier system):
   A. Packing Material: Use only mineral wool bearing an Intertek certified product label and meeting the following min. requirements. Insert min. 12 in. long, min. 2 in. tall, 4-pcf density, mineral wool batt insulation packing material compressed into the joint to 25% into bottom of pan centered at each mullion. Use min. 4 in. tall, 4-pcf density, mineral wool batt insulation and cut packing material width to achieve 25% compression when installed in the nominal joint width and use no more than two adjacent strips. Install insulation with the fibers running parallel to the edge of concrete floor assembly (Item 1) and curtain wall assembly (Item 2A). Tightly compress together splices (butt joints) in the lengths of packing material by using min. 1/4 in. compression per piece of packing material. Use only Intertek certified products meeting the above min. requirements. Locate the top surface of the packing material flush with the top surface of the concrete floor assembly (Item 1).
   B. CERTIFIED MANUFACTURER: Hilti Corporation
   CERTIFIED PRODUCT: Firestop Joint Spray CFS-SP WB or Silicone Joint Spray CFS-SP SIL
   Fill, Void, or Cavity Material: Apply over the packing material (Item 3A) as discussed below.
   Apply at the thickness specified in Table 1 and overlap the material 1/2 in. onto the adjacent curtain wall assembly and concrete floor slab assembly. When the spraying process is stopped and the applied liquid cures to an elastomeric film before application is restarted, overlap the edge of the cured material at least 1/8 in. with the spray. Reference Product Section of the Intertek Directory for more details on the Listed product.

Parametric Data: Wind loads

1st Floor(old):







Time [s]	Minimum [in]	Maximum [in]
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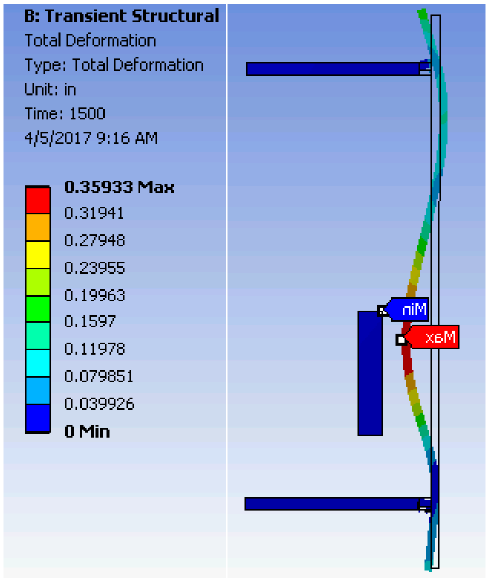
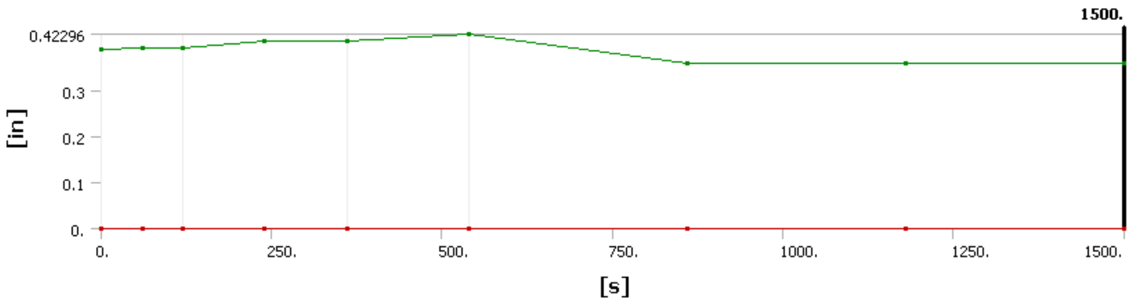
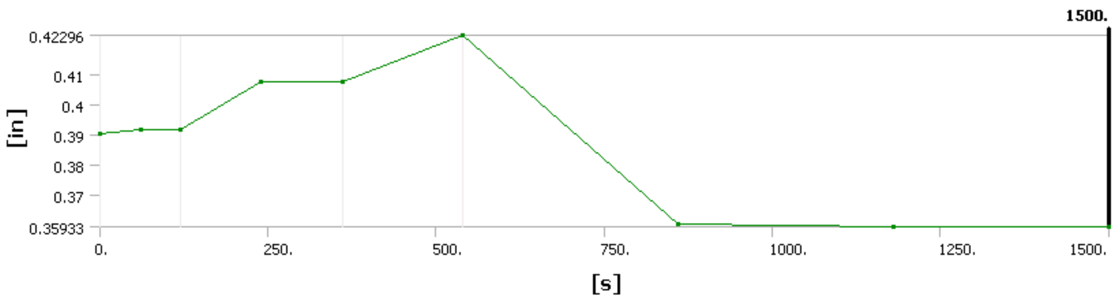
120.	0.	0.31947
240.	0.	0.33496
360.	0.	0.33491
540.	0.	0.35118
860.	0.	0.28931
1180.	0.	0.28847
1500.	0.	0.28831

2nd Floor:

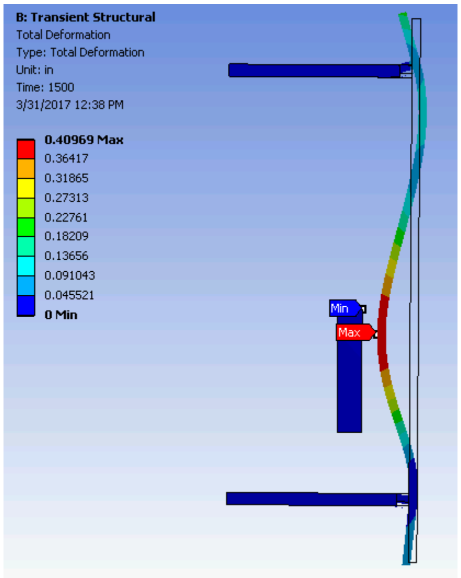


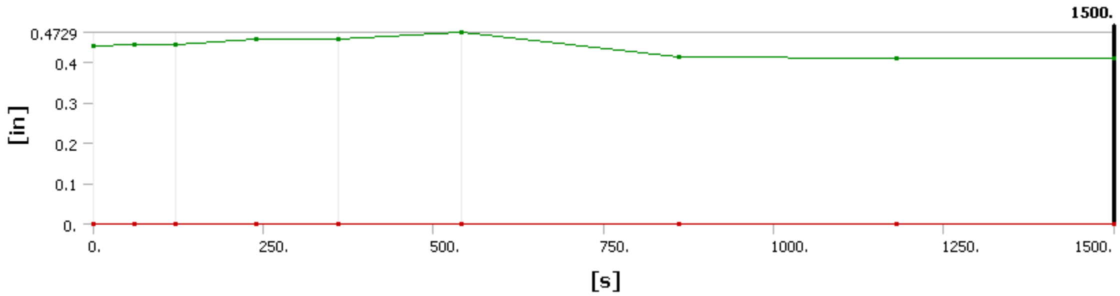


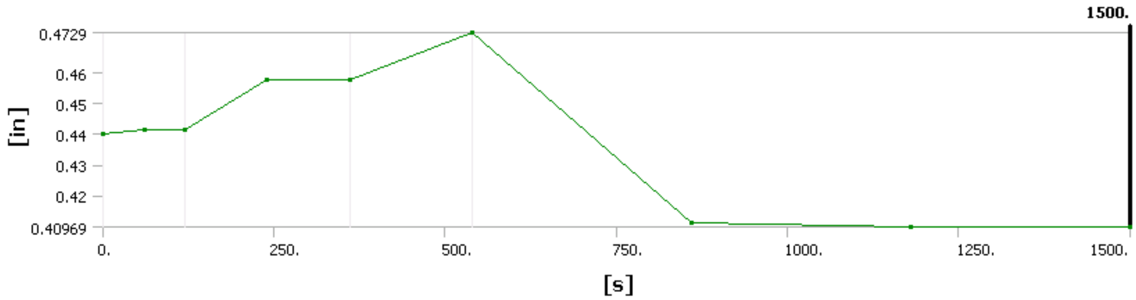


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.39045
60.5	0.	0.3917
120.	0.	0.39157
240.	0.	0.40735
360.	0.	0.4073
540.	0.	0.42296
860.	0.	0.36046
1180.	0.	0.35952
1500.	0.	0.35933

3rd Floor:

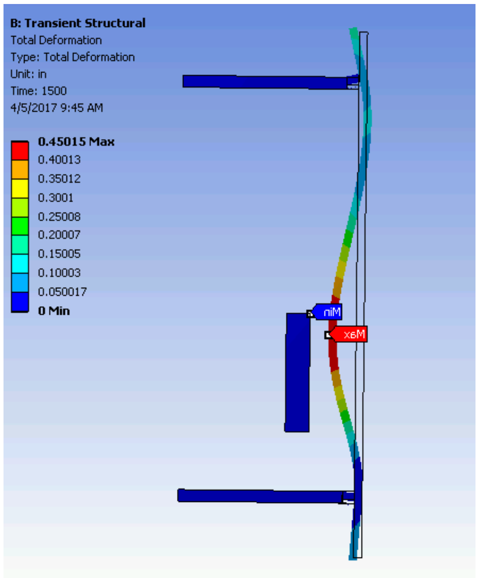


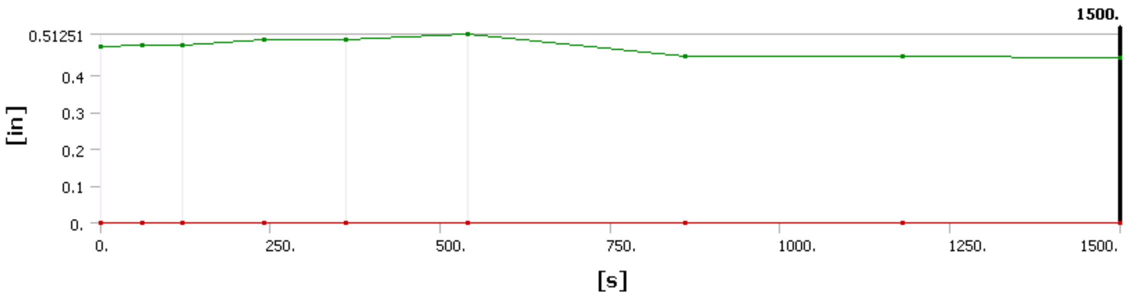


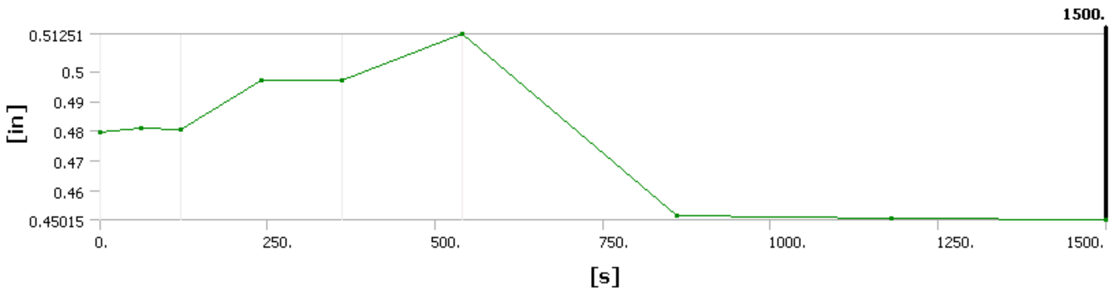


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.44013
60.5	0.	0.44144
120.	0.	0.44129
240.	0.	0.45739
360.	0.	0.45733
540.	0.	0.4729
860.	0.	0.41091
1180.	0.	0.4099
1500.	0.	0.40969

4th Floor:

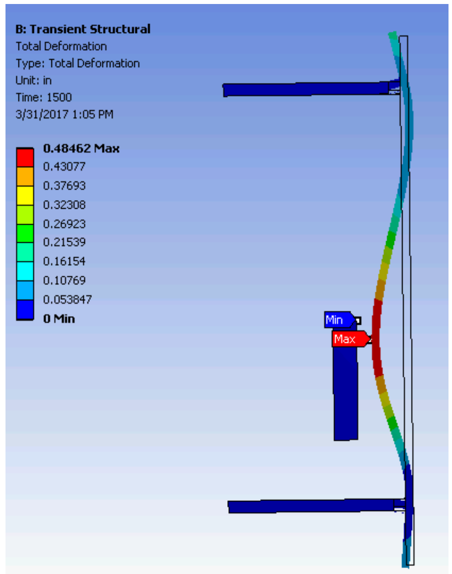


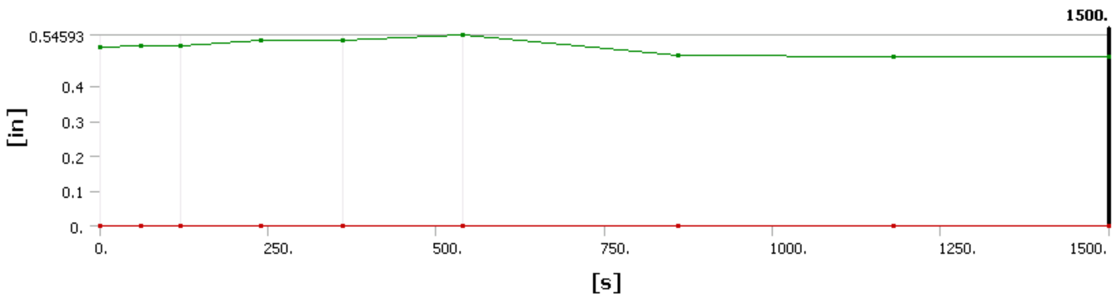


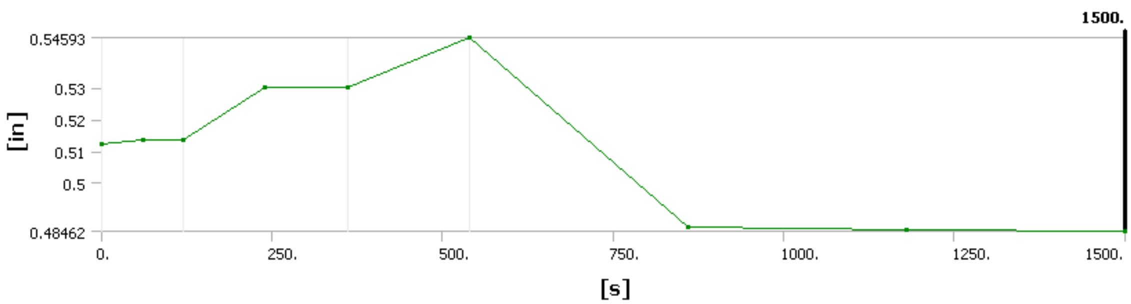


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.47934
60.5	0.	0.48069
120.	0.	0.48053
240.	0.	0.49694
360.	0.	0.49687
540.	0.	0.51251
860.	0.	0.45144
1180.	0.	0.45038
1500.	0.	0.45015

5th Floor:

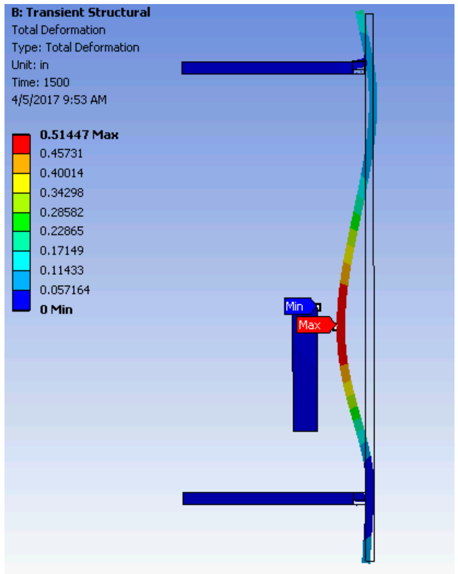


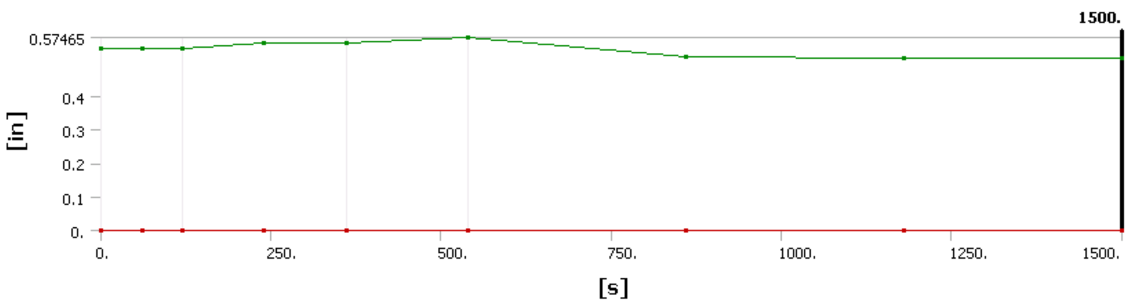


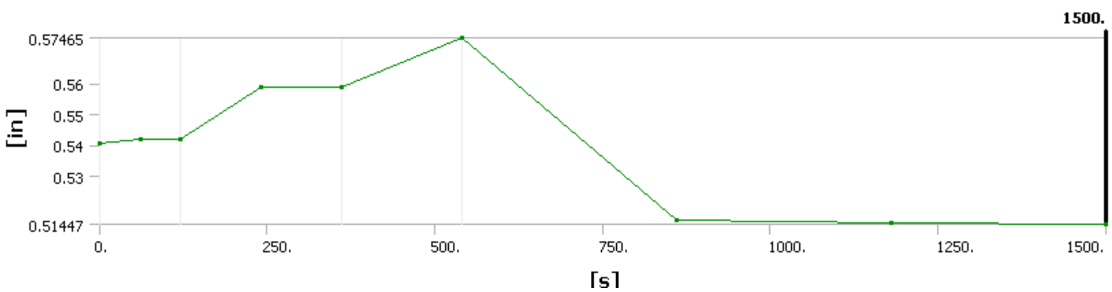


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.51233
60.5	0.	0.51372
120.	0.	0.51354
240.	0.	0.53023
360.	0.	0.53016
540.	0.	0.54593
860.	0.	0.48597
1180.	0.	0.48487
1500.	0.	0.48462

6th Floor:

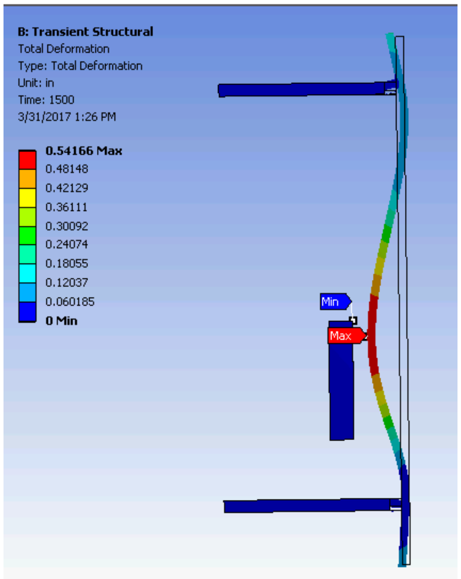


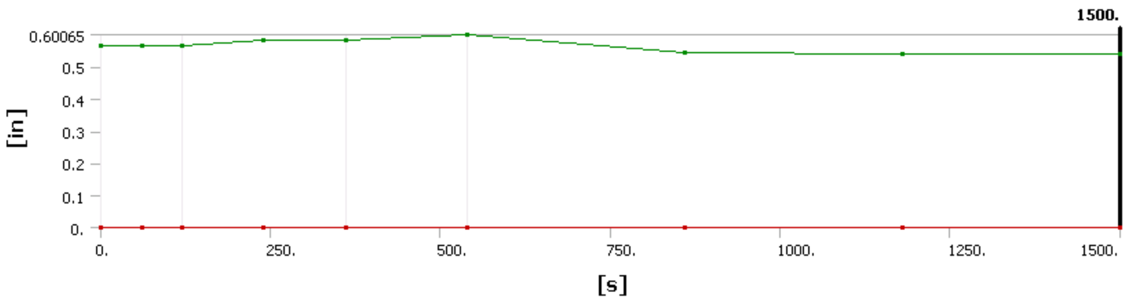


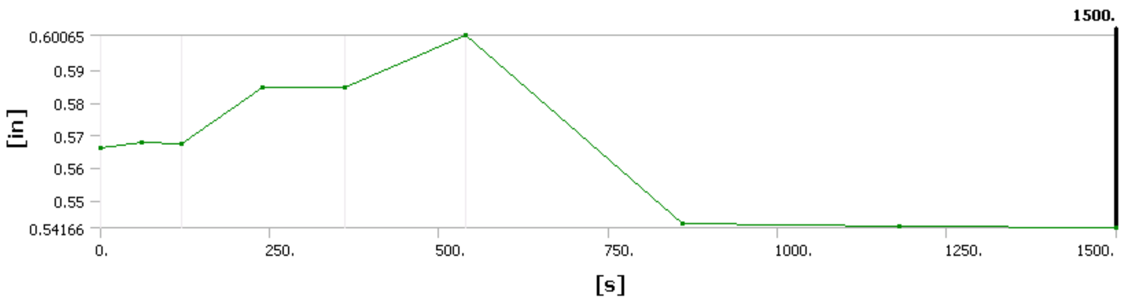


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.54061
60.5	0.	0.54204
120.	0.	0.54185
240.	0.	0.5588
360.	0.	0.55872
540.	0.	0.57465
860.	0.	0.51588
1180.	0.	0.51474
1500.	0.	0.51447

7th Floor:

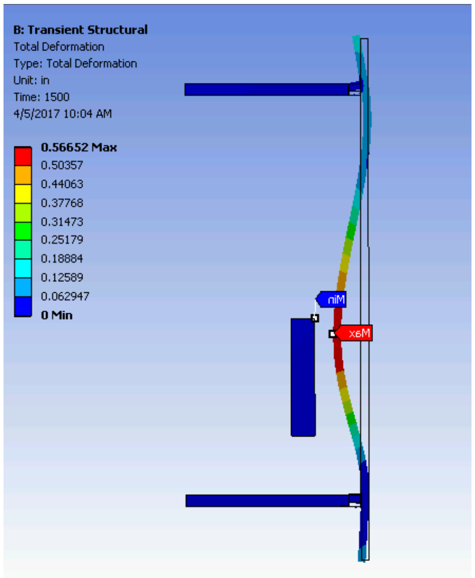


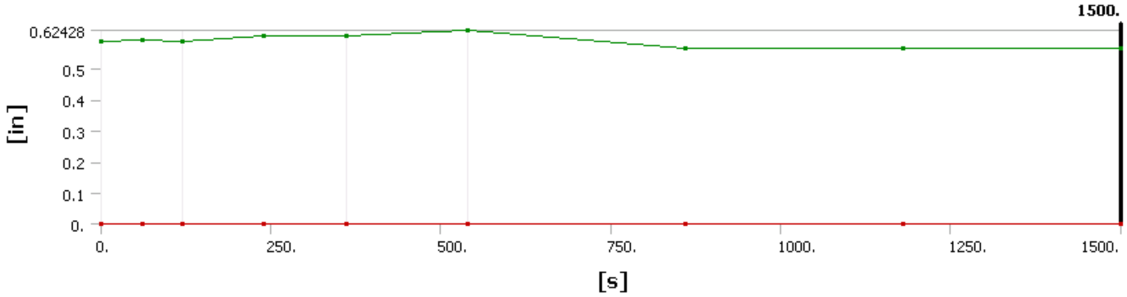


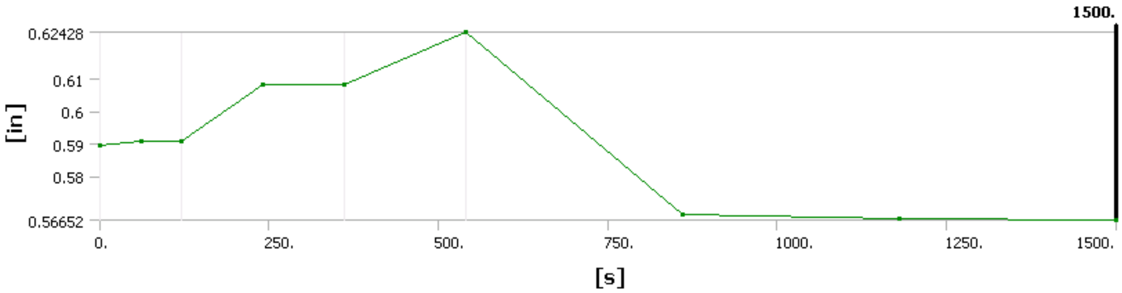


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.56617
60.5	0.	0.56763
120.	0.	0.56743
240.	0.	0.58462
360.	0.	0.58454
540.	0.	0.60065
860.	0.	0.54313
1180.	0.	0.54195
1500.	0.	0.54166

8th Floor:

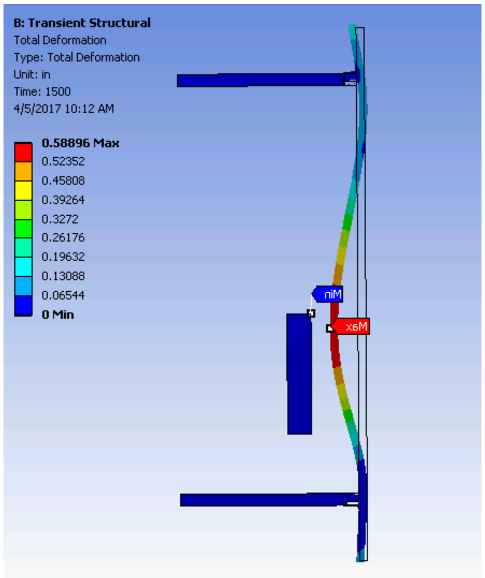


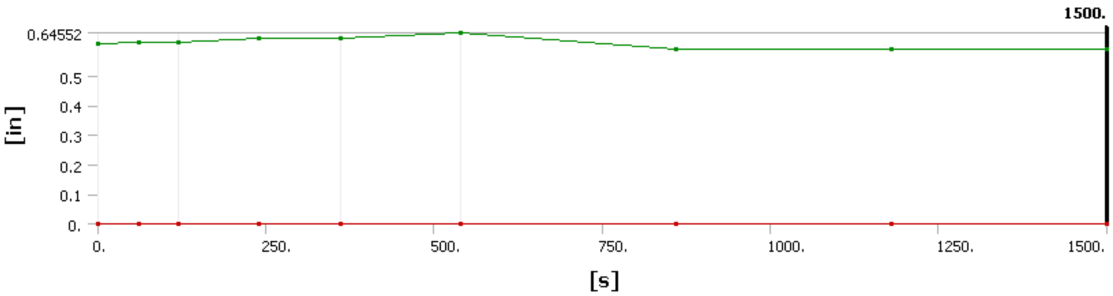


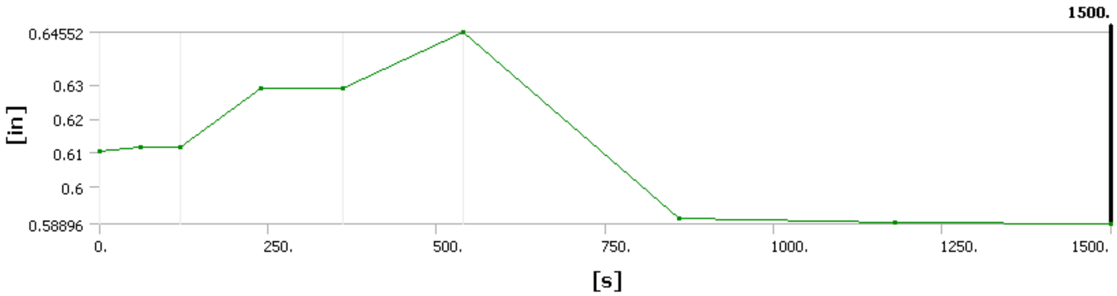


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.58938
60.5	0.	0.59086
120.	0.	0.59065
240.	0.	0.60807
360.	0.	0.60799
540.	0.	0.62428
860.	0.	0.56804
1180.	0.	0.56683
1500.	0.	0.56652

9th Floor:

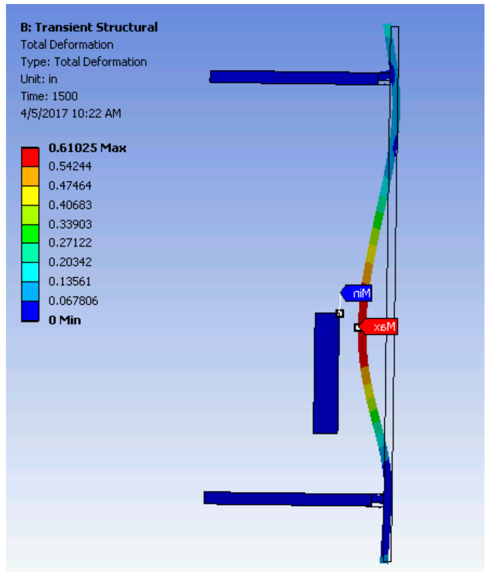


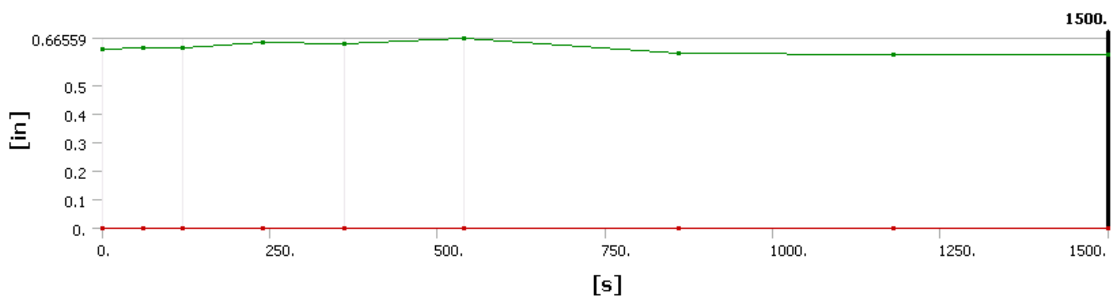


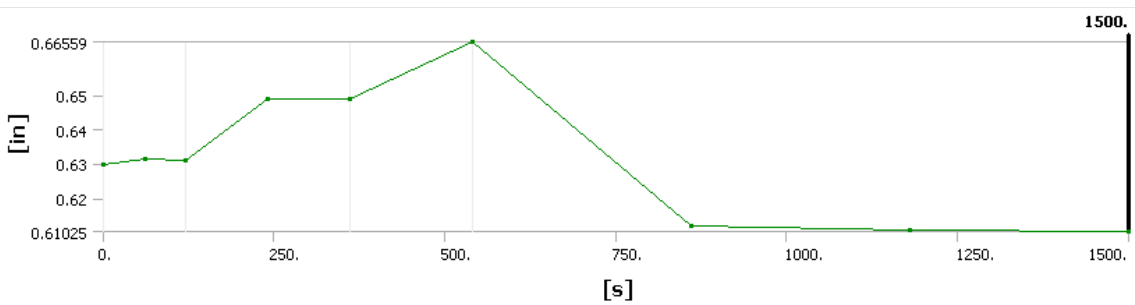


Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.61021
60.5	0.	0.61172
120.	0.	0.6115
240.	0.	0.62913
360.	0.	0.62904
540.	0.	0.64552
860.	0.	0.59053
1180.	0.	0.58929
1500.	0.	0.58896

10th Floor:



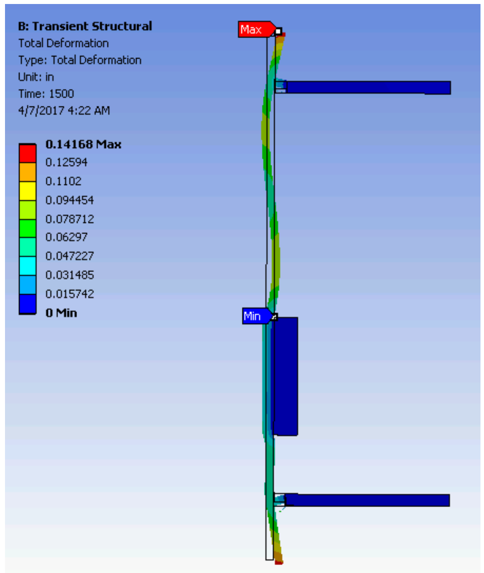


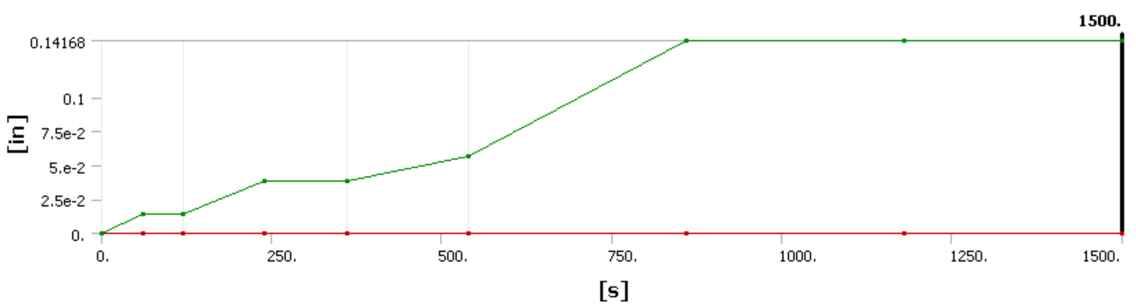


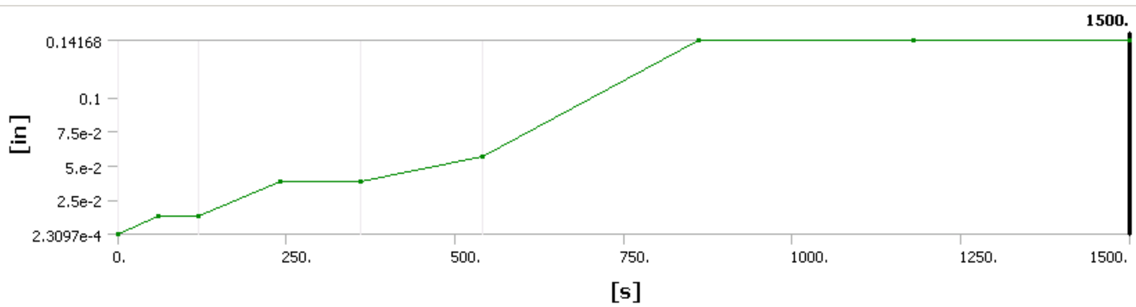
Time [s]	Minimum [in]	Maximum [in]
1.	0.	0.62987
60.5	0.	0.6314
120.	0.	0.63118
240.	0.	0.64901
360.	0.	0.64892
540.	0.	0.66559
860.	0.	0.61187
1180.	0.	0.6106
1500.	0.	0.61025

Parametric Data: Fire Movement

0 Feet Away from Curtain Wall

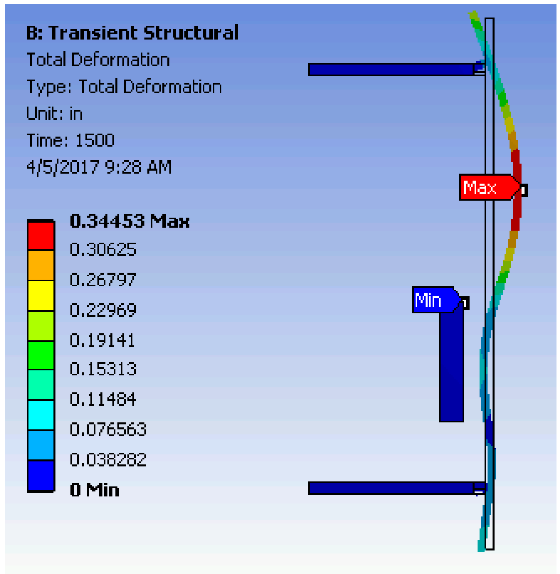


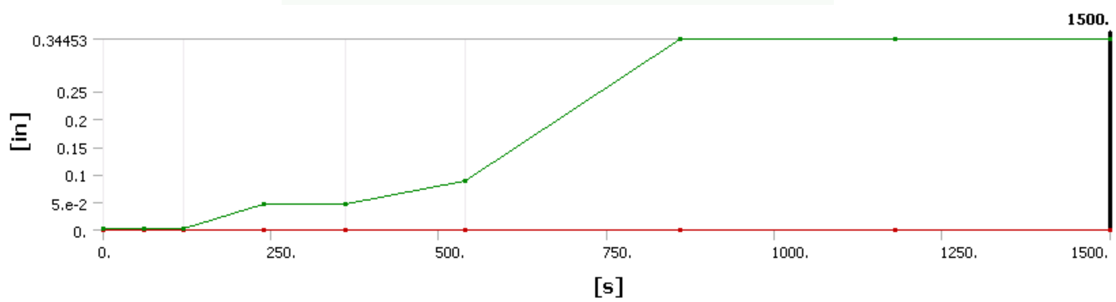


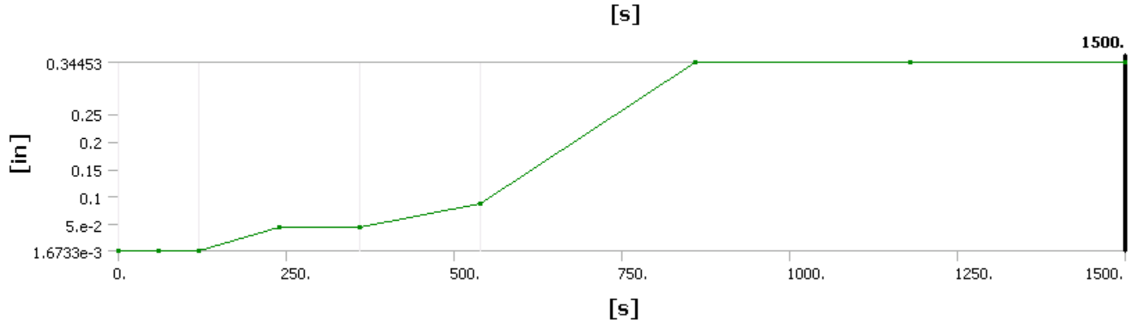


Time [s]	Minimum [in]	Maximum [in]
1.	0.	2.3097e-004
60.5	0.	1.3864e-002
120.	0.	1.3864e-002
240.	0.	3.8863e-002
360.	0.	3.8863e-002
540.	0.	5.6497e-002
860.	0.	0.14168
1180.	0.	0.14168
1500.	0.	0.14168

1 Foot Away from Curtain Wall:

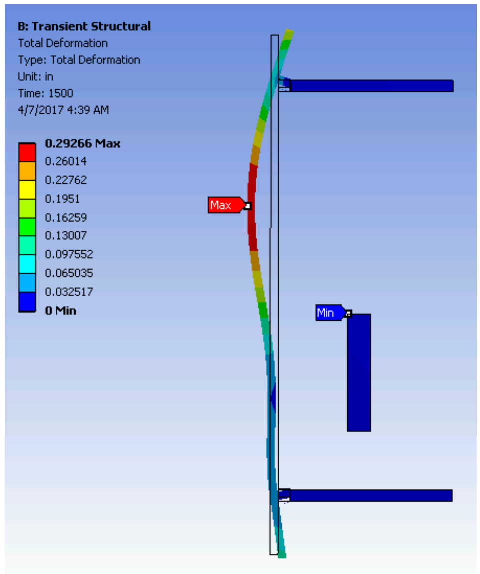


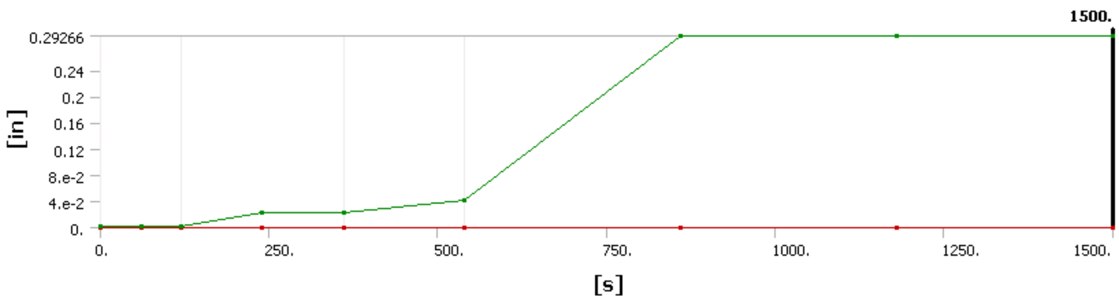


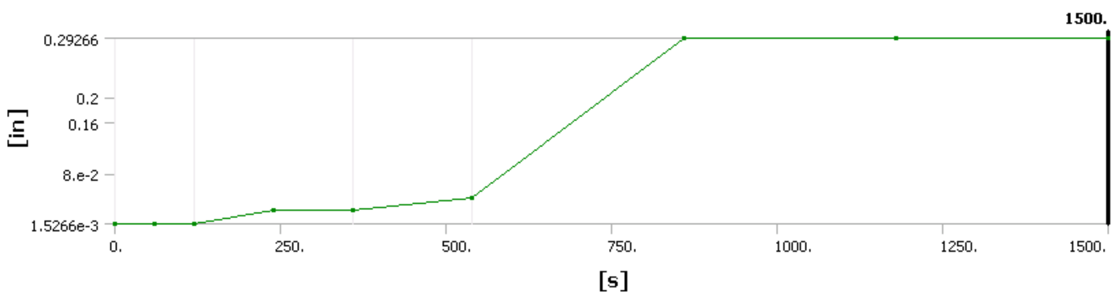


Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.9796e-003
120.	0.	1.9797e-003
240.	0.	4.577e-002
360.	0.	4.577e-002
540.	0.	8.8207e-002
860.	0.	0.34409
1180.	0.	0.34452
1500.	0.	0.34453

3 Feet Away from Curtain Wall

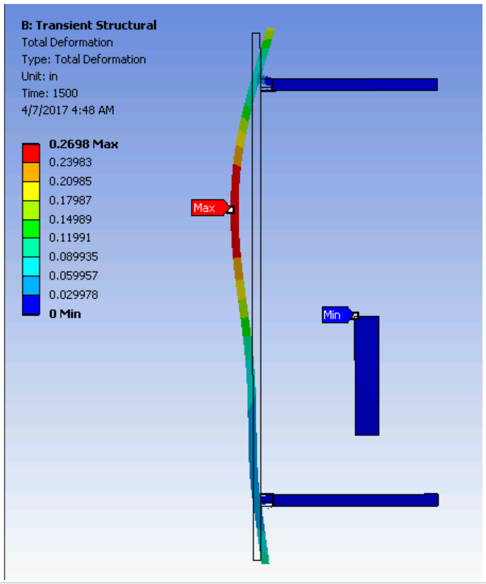


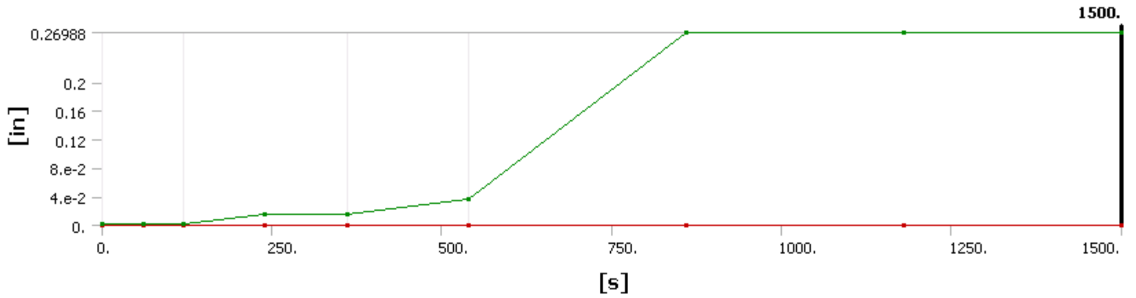


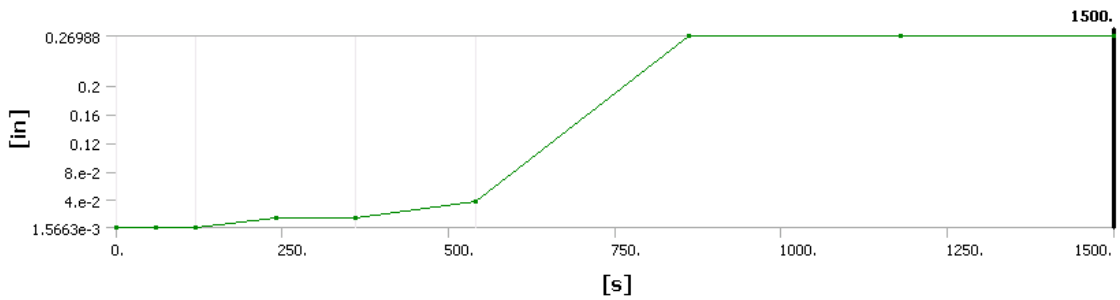


Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.5266e-003
120.	0.	1.5266e-003
240.	0.	2.3011e-002
360.	0.	2.3011e-002
540.	0.	4.1954e-002
860.	0.	0.2922
1180.	0.	0.29258
1500.	0.	0.29266

4 Feet Away from Curtain Wall

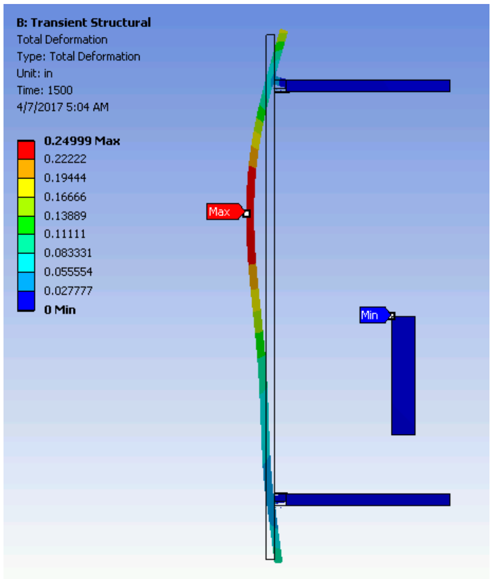


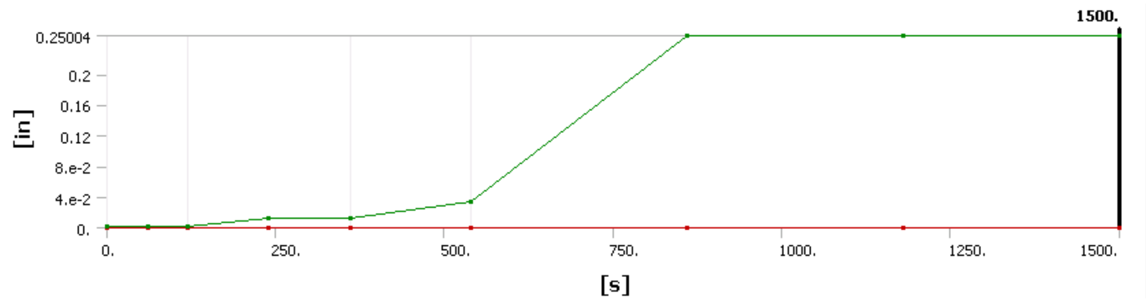


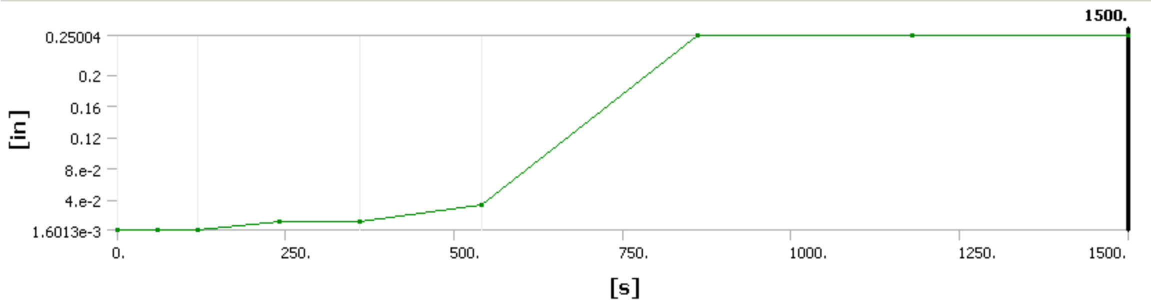


Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.5663e-003
120.	0.	1.5663e-003
240.	0.	1.5877e-002
360.	0.	1.5877e-002
540.	0.	3.732e-002
860.	0.	0.2695
1180.	0.	0.26988
1500.	0.	0.2698

5 Feet Away from Curtain Wall

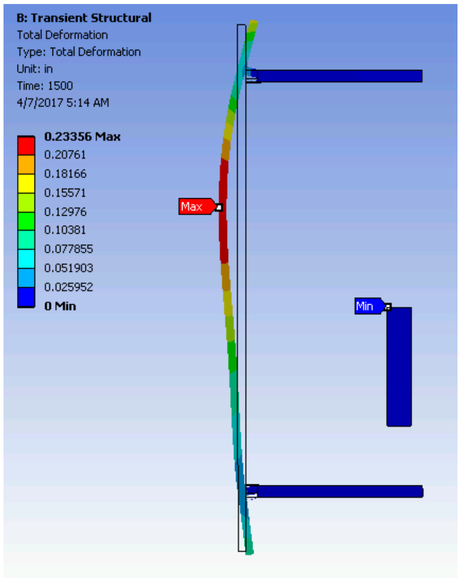


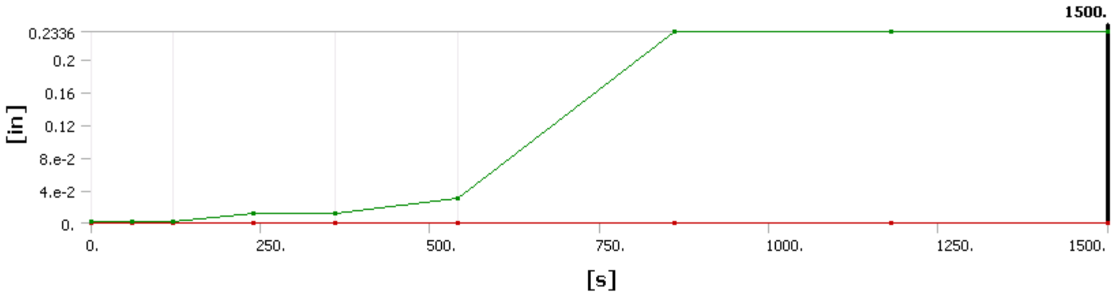


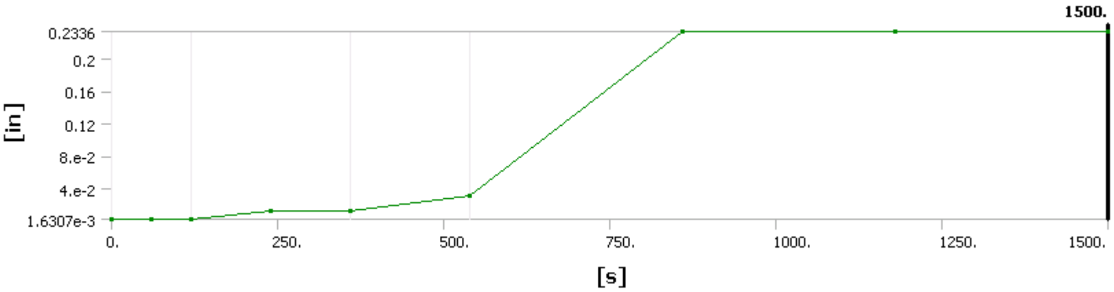


Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.6013e-003
120.	0.	1.6013e-003
240.	0.	1.2105e-002
360.	0.	1.2105e-002
540.	0.	3.3483e-002
860.	0.	0.24969
1180.	0.	0.25004
1500.	0.	0.24999

6 Feet Away from Curtain Wall





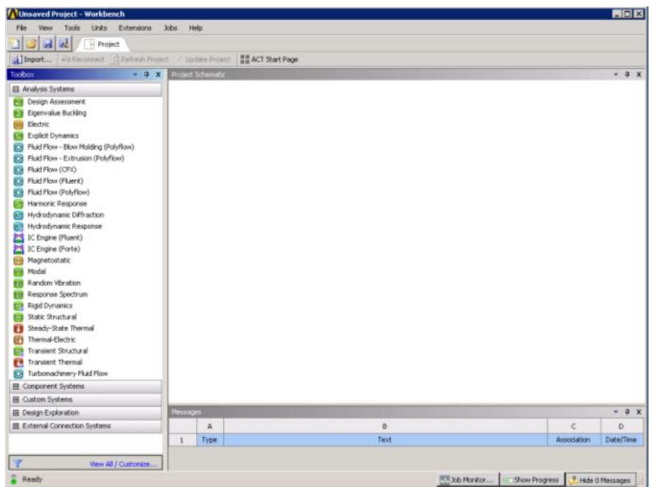


Time [s]	Minimum [in]	Maximum [in]
1.	0.	1.6733e-003
60.5	0.	1.6308e-003
120.	0.	1.6307e-003
240.	0.	1.1069e-002
360.	0.	1.1069e-002
540.	0.	3.0414e-002
860.	0.	0.23326
1180.	0.	0.2336
1500.	0.	0.23356

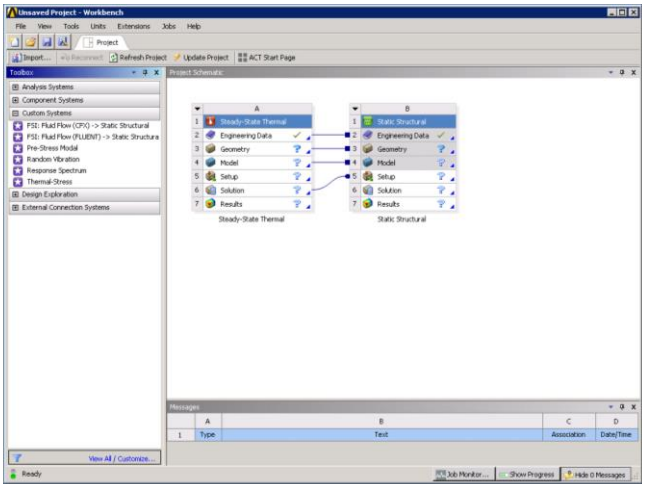
Appendix B: User's Guide

To create this simulation ANSYS 17.0 Workbench was used, other versions of ANSYS can be used however, the button/command tabs might be different. Nevertheless, the same results should be given if the following steps are followed.

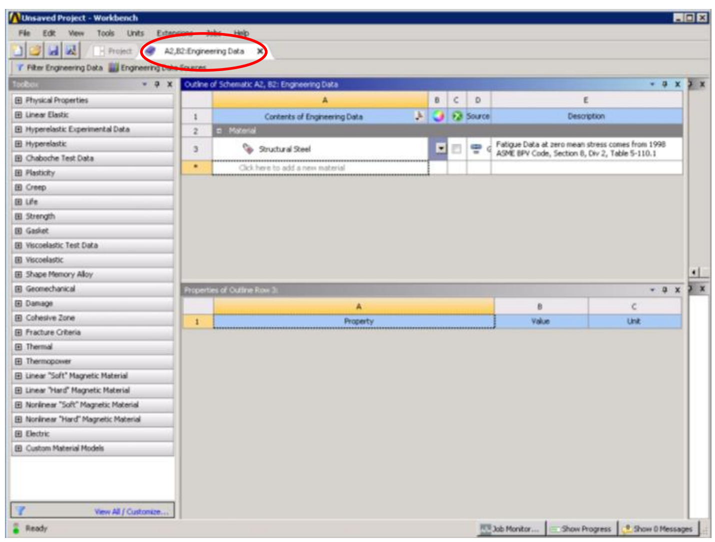
First, open the ANSYS software tab on your computer. The image below is what you should see when ANSYS finishes loading and opens.



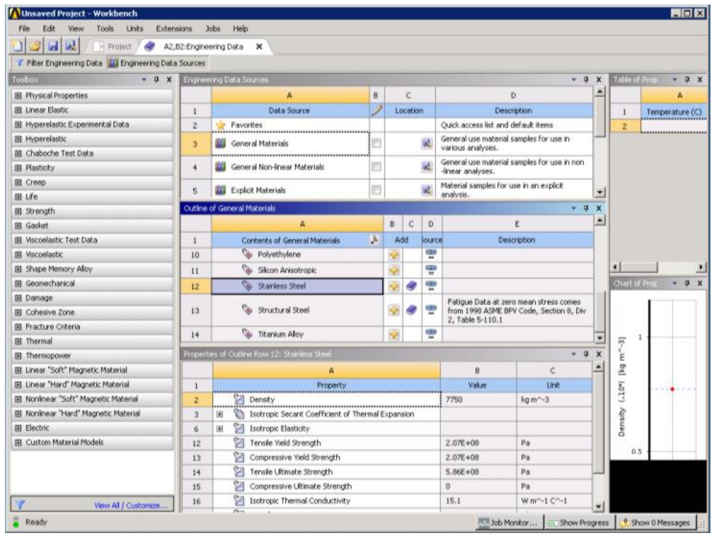
Once open on the left-hand side "Toolbox" tab click the tab "Custom Systems" selecting "Thermal-Stress", the following two tables should appear on your project page. You then want to change the tables property from "Steady-State" to "Transient". To do this you right-click the tab "Steady-State Thermal" or the "Steady State Structural" highlighted in blue, in the image below. A list of options will be given to you and you want to select the option "Replace with" and select the "transient". You do the same procedure with the table that was not chosen.



When those changes are made, you will then go down the list of properties in the table making the necessary alterations to each. Double click the “Engineering Data” tab, in this section you will be choosing the materials that will be used for your model.

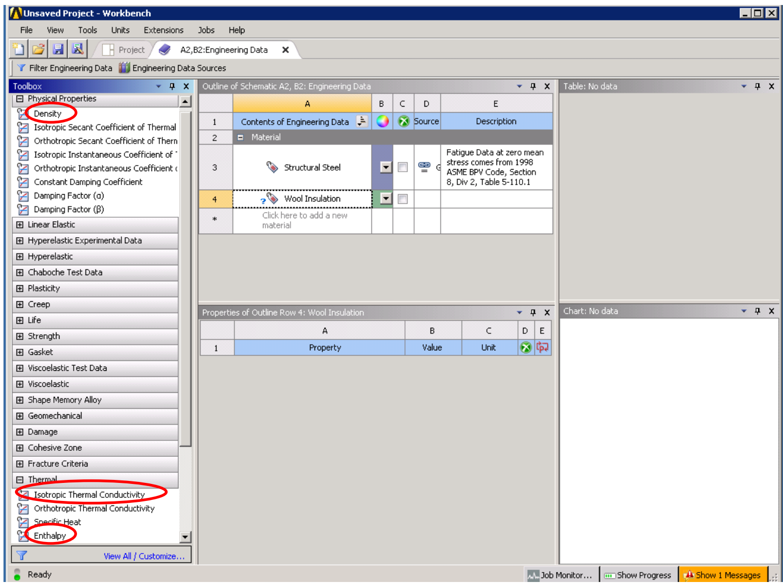


All materials used for curtain wall system can be found in the Engineering database of ANYS. To gather those materials, click the tab “Engineering Data Sources” and choose the necessary materials. For instance, when the “Engineering Data Source” is open click on “General Material” tab which will then open a table of all materials filed under that category, scroll through and click the material you are looking for i.e. stainless steel, then click the “+” to add to your Engineering Data list.



- Materials Used for 2D Model:
  - Structural Steel – Given Material
  - Stainless Steel – Found in General Materials
  - Concrete – Found in General Materials
  - Resin Polyester – Composite Materials
  - Silicone Anisotropic – Found in General Material
- Materials Used for 3D Model:
  - Structural Steel – Given Material
  - Stainless Steel – Found in General Materials
  - Concrete – Found in General Materials
  - Glass – Found in Thermal Material
  - Rubber Hard – Found in Thermal Material
  - Resin Polyester – Found in Composite Materials
  - Silicone Anisotropic – Found in General Material
  - Aluminum Alloy – Found in

For manually defined material you have to define the properties, for Aluminum Alloy, Density, Isotropic Conductivity, and Specific Heat should be identified. To do so you first have name the material in the “Contents of Engineering” table. Once named the properties can be selected from the “Toolbox” tab on the left-hand side. Density can be found in “physical properties”, while isotropic thermal conductivity and enthalpy can be found in “thermal”.



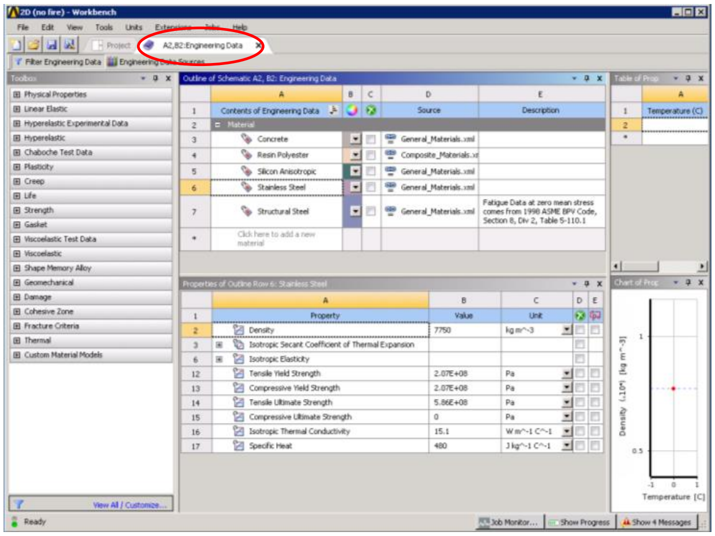
- Defining Materials:
  - Density – 2770 kgm^{-3}
  - Specific Heat – 875 $Jkg^{-1}K^{-1}$
  - Isotropic Thermal Conductivity – Tabular Data

Temperature (C)	**Thermal Conductivity ($W\ m^{-1}\ C^{-1}$)**
-100	114
0	144
100	165
200	175

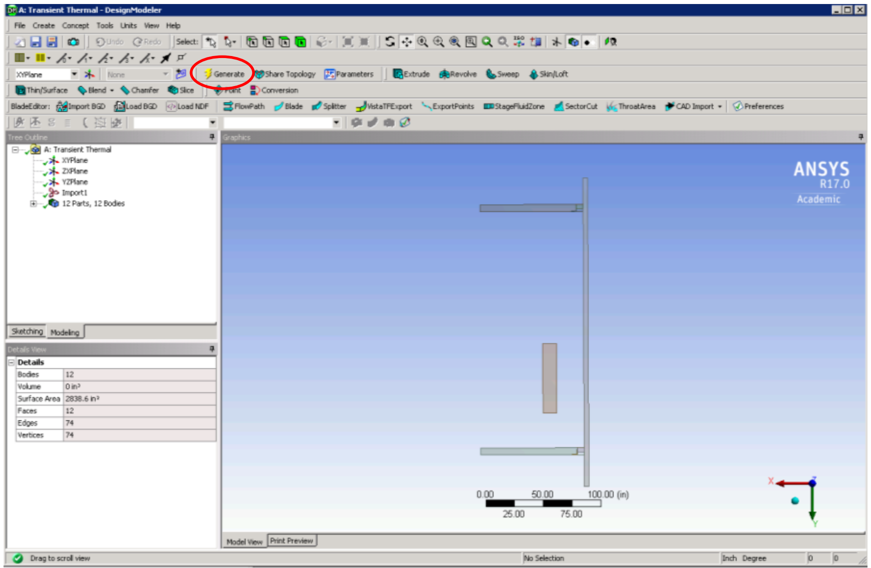
- Materials Used for 2D Model:

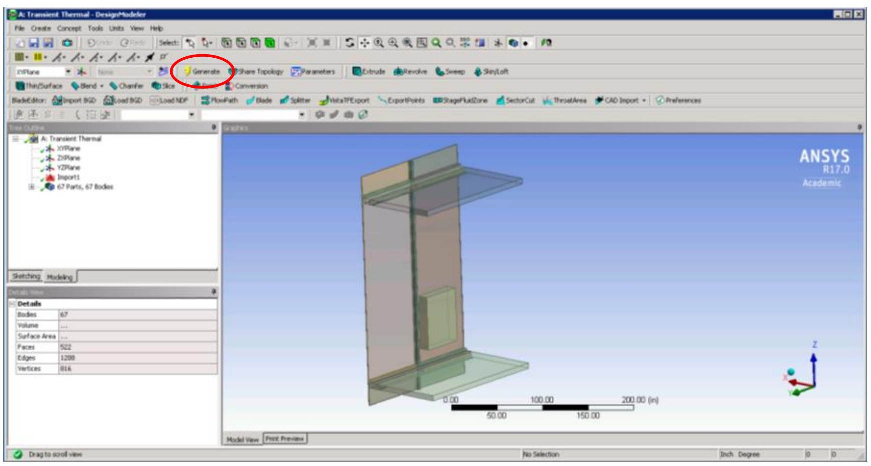
- Structural Steel – Given material
- Stainless Steel – Found in General Materials
- Concrete – Found in General Materials
- Resin Polyester – Composite Materials
- Silicone Anisotropic – Found in General Materials

When all the materials have been added click "A2:B2 Engineering Data" to check your completed list. You table should look like the image below.



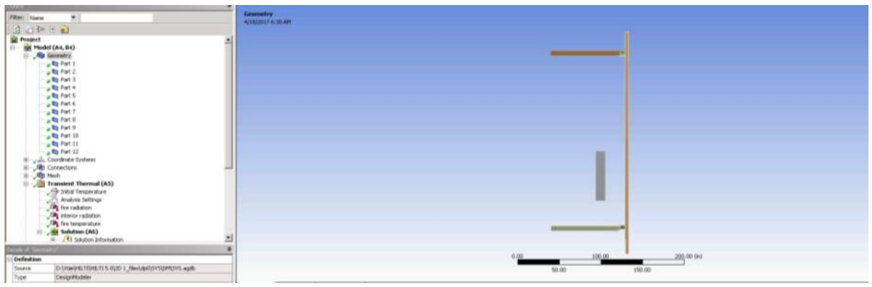
When you finish choosing the materials you can move to the next item on the list in the "Transient Thermal" table. To get back to the tables click on the "project" tab in the upper left hand corner. Next, on the list is "Geometry". For this section, you will be importing the model of the curtain wall from AutoCAD into ANSYS. Right click on "Geometry" and a list of options will appear, click on the "import" and browse your computer for your AutoCAD file. Note: When in AutoCAD make sure to save your file as an ".std" for easy import into ANSYS. After the file, has been imported double click "Geometry" and it will open a second ANSYS window labeled as "DM – Design Modeler". Once that window is up click the "generate" button to load in the model.





Subsequently, when the geometry is loaded the edits to the model can then be made. Double click “model” on the list under the transient thermal and it will load an additional window labeled “M: Multiple System – Mechanical”. In this section, you will define the materials of each element in the model, the connections between elements as well as, and meshing for better numeric results when analyzing.

For geometry, you will first rename bodies and assign materials to corresponding bodies. In the “outline” tab on the left-hand side you will click “Geometry” and it will open a list of parts in the model. Right click on the individual parts and then click on the “Rename” tab. Once clicked the individual parts will open a “Details” table in which you can then select the material you want to use. The materials will be shown in a drop-down list.



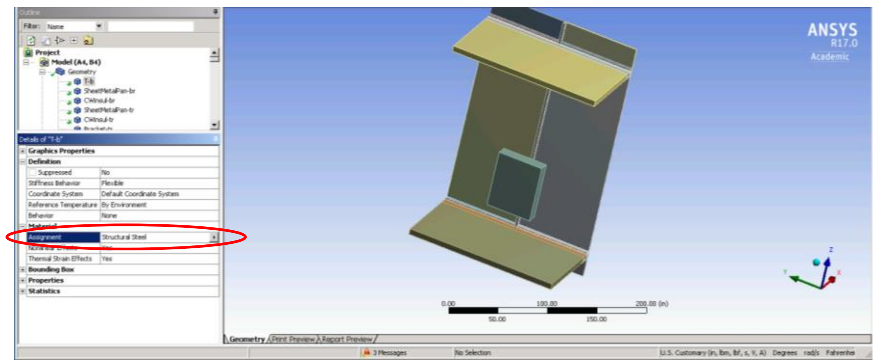


Table: 2D Model Materials of Elements

Elements of Curtain Wall	Material
Mullion	Stainless Steel
Floor Slab *Ceiling Slab*	Concrete
Brackets	Structural Steel
Wool Insulation *Air Space*	Silicon

Table: 3D Model Materials of Elements

Elements of Curtain Wall	Material
Mullion *Transoms* *Caps*	Stainless Steel

Floor Slab *Ceiling Slab*	Concrete
Vision Glass	Glass
Rubbers *Spacers*	Rubber Hard
Firestop Spray	Silicon
Sheet Metal Pans *T-Shape Steel Plates* *Brackets* *In-Concrete Steel Angles*	Structural Steel
Curtain Wall Insulation	Wool Insulation

Continuing in the modeling portion of ANSYS you will then start determining the connections between bodies. When you place the model into ANYS the software automatically defines connections that it sees between elements in the model, however, some of the connections defined are not necessary or need to be specified. For this curtain wall model the connections were defined as either bonded or no separate. The table below details the bodies that were connected and the type of connection the pair fell under. Defining the connections between the elements in the system will help with the meshing of the model.

Table: 2D Model Connection of Elements

Bonded	
Bracket	In-Concrete Steel Angle

	Mullion
In-Concrete Steel Angle	Wool Insulation
	Concrete Floor Slab
Wool Insulation	Silicone Firestop Spray
	Concrete Floor Slab
	Mullion
	Bracket
Silicone Firestop Spray	Mullion
	Concrete Floor Slab

Table: 3D Model Connection of Elements

Bonded		**No Separate**	
Rubber	Glass	**Curtain Wall**	Sheet Metal Pan
	Mullion		Brackets
	Transom		Transoms
	Caps		Mullions
T-Shape Steel Plate	In-concrete steel angle		Wool Insulation
	Mullion	**Wool Insulation**	Sheet Metal Pans
Sheet Metal Pans	In-Concrete Steel angle		Brackets
	Transoms		Concrete floor slab
Brackets	In-concrete steel angle		Silicone Firestop spray
	Mullion		Mullion
In-concrete Steel angle	Concrete Floor Slab	**Silicone Firestop Spray**	Sheet Metal Pan
	Wool Insulation		Concrete Floor Slab
Mullions	Transoms		Mullion
Vertical Caps	Horizontal Caps		
Glass	Spacers		

Keeping still in the Modeler window of ANYSY you will go down the list of commands in the Outline table and click on “Meshing”. You will individually mesh some smaller components defined in the 2D and 3D curtain wall.

The smaller elements that need to individually meshed for 2D are:

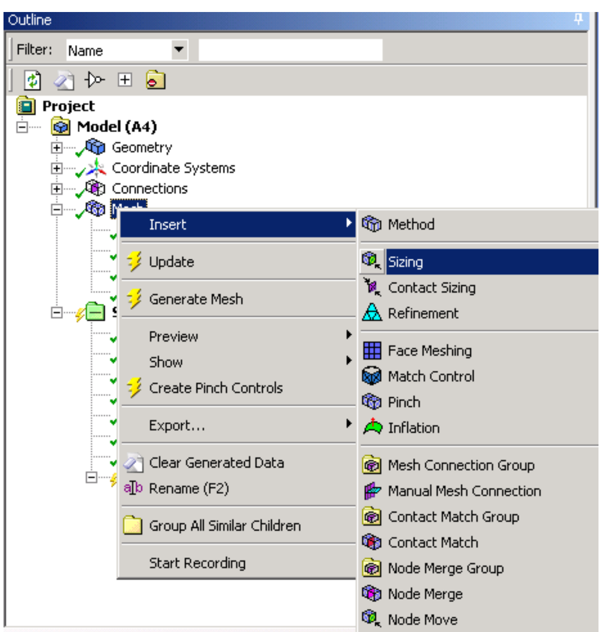
- In Concrete Steel Angle
- Bracket

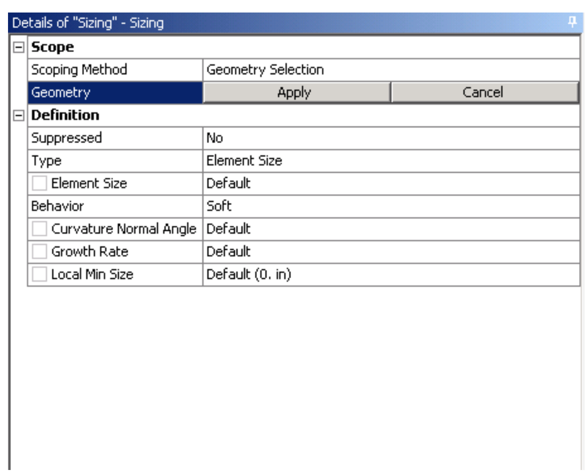
- Silicone

The smaller elements that need to individually meshed for 3D are:

- Rubber
- T-Shape
- Wool Insulation
- Cap

To do this right click meshing and in the table provided select insert sizing. Choosing this option will allow for ANSYS to create mesh that will fit the smaller elements. In indicating sizing in ANSYS there is the option of either face or body. For example, for the 3D model for Rubber and the T-shape select body, for wool insulation and cap select faces. In the body option ANSYS selects the whole object needing to be meshed. In the face option, you manually click each face of the object to receive proper meshing





For the 2D geometry select the option of face sizing for the meshing. In the table below are the the elements and its defined sizing for the definition of element sizing in the meshing table.

Table: 2D Mesh Type and Sizing

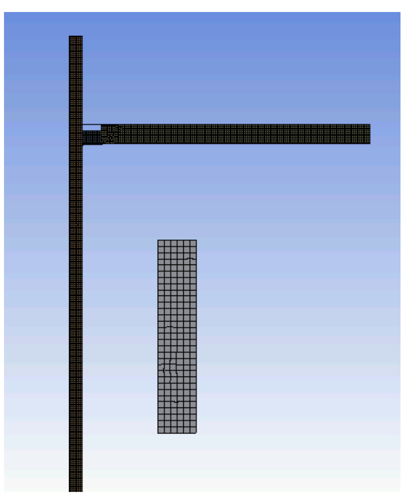
Elements	# of Faces	Size (in.)
In Concrete Steel Angel	6	0.0625
Bracket		
Silicone		
Mulion	5	0.5
Concrete slab		
Wool Insulation		

For the 3D geometery you will define elements as either being Face sizing or Body sizing. The table below is what should be defined in the property table thar pops up for each element of the curtain wall that is chosen to individually meshed.

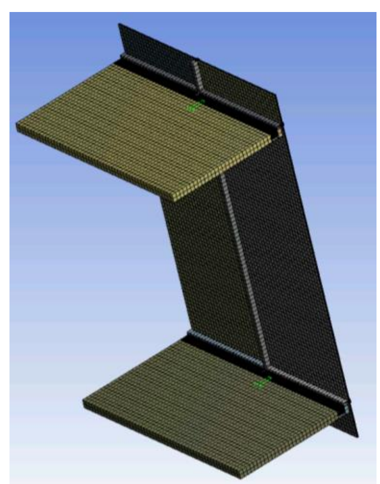
Table: 3D Mesh Type and Sizing

Faces			Bodies		
Elements	**# of Faces**	**Size (in.)**	**Elements**	**# of Bodies**	**Size (in.)**
Rubber	12	0.0625	Cap	6	0.0625
T-Shape	2	0.0625	Wool	4	0.5

Using the parameters listed above fill out the details table. Using the connections defined in the tables of connections for either the 2D or 3D model generate a meshing for the curtain wall by clicking “generate mesh” at the top of the page.



Zoomed in 2D meshing of geometry

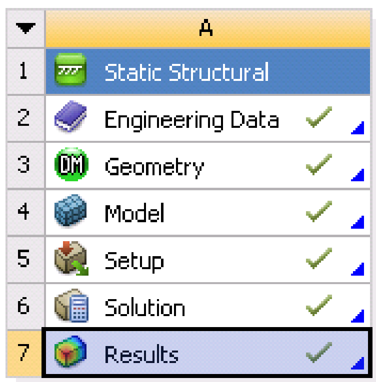


3D meshing of geometry

The set-up for the analysis of the curtain wall depend on the type of test you want to conduct. For the individual thermal and structural analysis use the 3D model. For the combination of thermal and structural, as well as parametric testing the 2D model is used.

Structural Analysis:

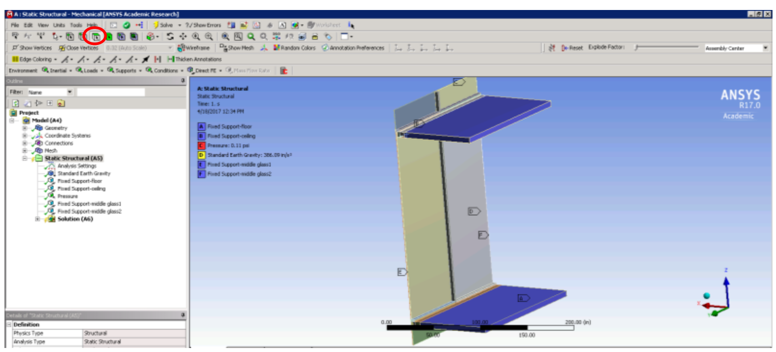
For structural analysis assure that you use static structural when defining the project type in ANSYS. Follow what is stated at the beginning of the user's guide to assure that you select the proper   The Geometry and Model steps should follow those that are mentioned in the above steps for the 3D model.



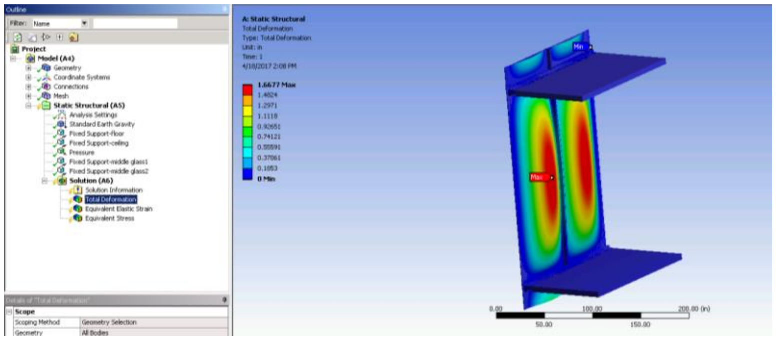
The set-up for structural analysis there are conditions that need to be defined in the model. You want to take into consideration the boundary conditions for instance, the loading being applied to the system both laterally and longitudinally, as well as fixed supports.

Geometry	Boundary	Value	Applied by
11 faces	Pressure	0.11 psi	Surface Effect
All Bodies	Gravity	-386.09 in/s^2 (z-direction)	

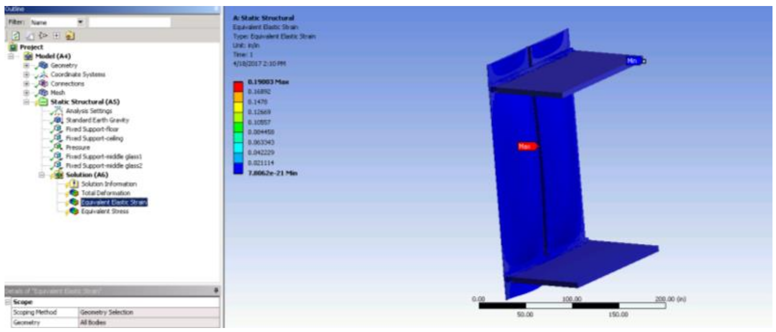
`To apply these specific boundary conditions right click "Static Structural" in the outline table. A drop-down list will appear and you will click "insert" and select the conditions you want to add under the static structural umbrella. You will again be selecting gravity, pressure, and fixed support. For the fixed support, you want to be sure to select what elements of the curtain wall will be treated as such. In this simulation, the floor and ceiling, as well as the glasses are fixed. Make sure that when you are selecting the geometry that you click on “faces”, circled in red in the image below, on the top tool bar so that you are not selecting the whole system or the wrong element. The umbrella under static structural should look like the one in the image below. The elements that are either colored blue, yellow, or red and have a tag with a letter have structural boundaries applied to them.



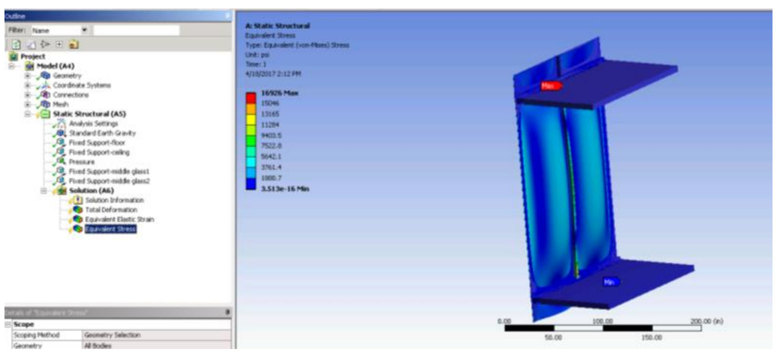
Once the setup is complete you can move on to the solution portion in the outline table. To perform the necessary analysis right click the “solution” tab and insert solutions for Total Deformation, Equivalent Elastic Strain, and Equivalent Stress. When those are placed under the solution umbrella click “generate” at the top tool bar, to run the simulation. Note that it might take a while for ANSYS to run the simulation. When the simulation is complete you should be able to click each solution type defined to view the results.



Result for Total Deformation in Static Structural



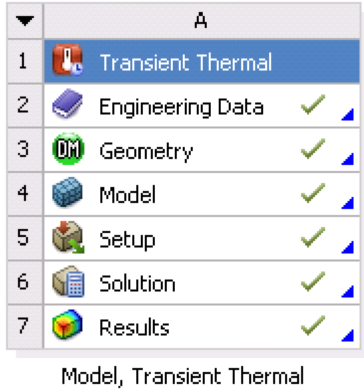
Results for Equivalent Elastic Strain



Results for Equivalent Stress

Thermal Analysis:

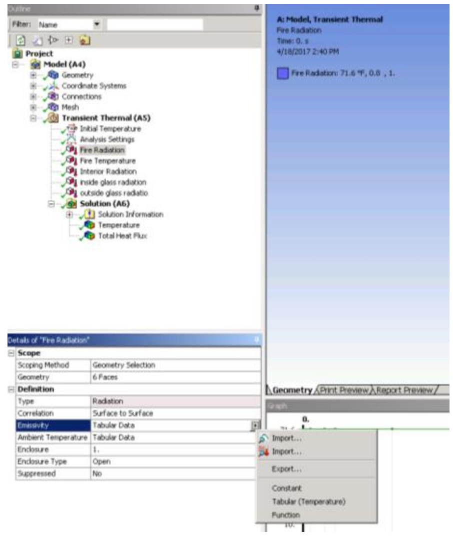
For Thermal Analysis assure that you choose "Transient Thermal" in your initial set of ANSYS and you insert your 3D Auto CAD drawing for your geometry. Similar to structural analysis the steps you will take for geometry and model will be the same and are mentioned in the initial portion of the user's guide.



The setup for Thermal Analysis there are conditions that need to be defined. The boundary conditions for thermal analysis include: radiation of the fire, interior, outside and inside glass. You also want to apply temperature to the fire. To insert these conditions you right click on "Transient Thermal" and insert the four radiations and the temperature, renaming the conditions to make it easier to distinguish. You will select each component of the curtain wall that you want to apply the condition of radiation to separately make sure that the number of faces selected for each component meets that of the table below.

Radiation	**# of Faces**
Fire	6
Interior Glass	6
Exterior Glass	6
Interior	36

For radiation you want to manually define properties like ambient temperature and emissivity once the geometry for fire, inside glass, outside glass, and interior are distinguished. For ambient temperature and emissivity for inside glass, outside glass, and fire will be tabular data. To select that option in ANSYS you will go to the details table of the chosen element and click on emissivity an arrow will appear, click the arrow, and a drop down table will appear and select "tabular data". You will do the same for ambient temperature.



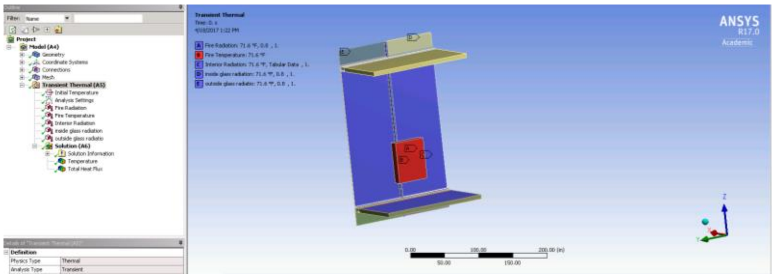
Once tabular data is click a table will appear and you will manual input the values. For inside glass, outside glass, interior and fire the data below is what should be used.

Steps	Time (s)	Emissivity	Ambient Temp (F)
1	1	0.8	71.6
2	120	0.8	71.6
3	360	0.8	71.6
4	540	0.8	71.6
5	1500	0.8	71.6
6	7200	0.8	71.6

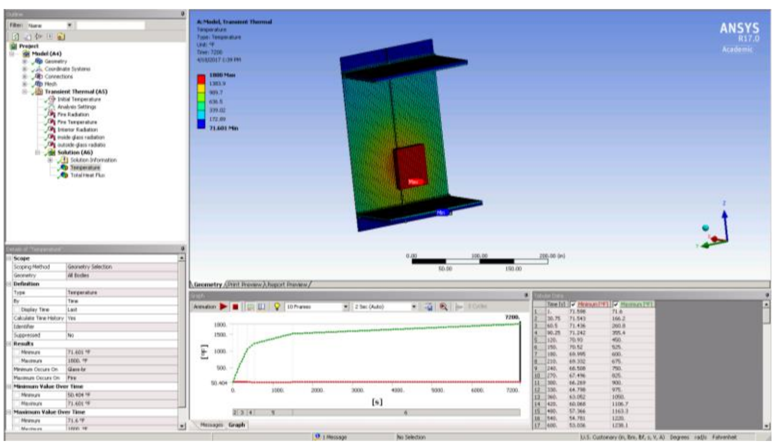
For the temperature of fire you will select the “body” and not the faces of the rectangular prism. Then you will define the details for temperature which again, will be tabular data increasing in steps over a period of time.

Steps	Time (s)	Temperature (F)
1	1	71.6
2	120	450
3	360	1050
4	540	1220
5	1500	1510
6	7200	1800

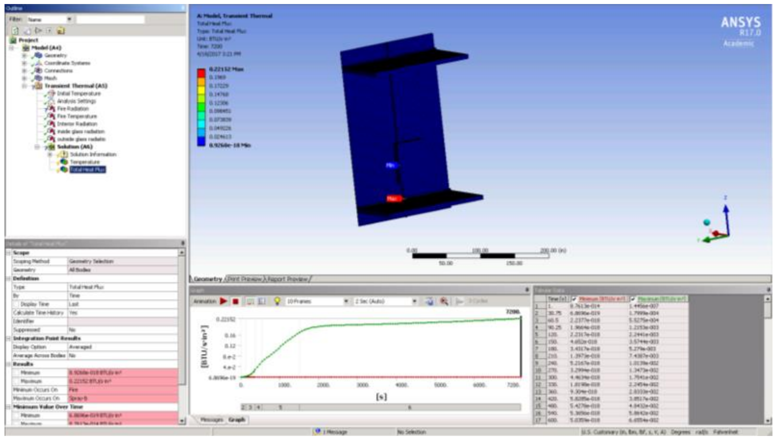
When the boundary conditions are defined you can move on to the solution portion of ANSYS. For the Thermal you want to analyze temperature and total heat flux.



Similar to the solutions in structural analysis, you will right click on "Transient Thermal" and in the drop down table you will select temperature and total heat flux. You will then click "generate" to run the simulation and the results for each temperature and total heat flux will be computed.



Results of Thermal Temperature

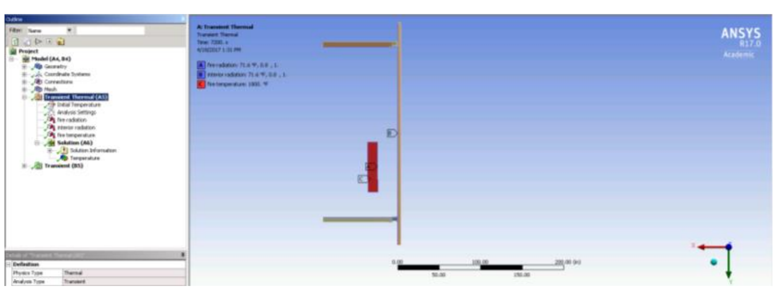


Results from Total Heat Flux

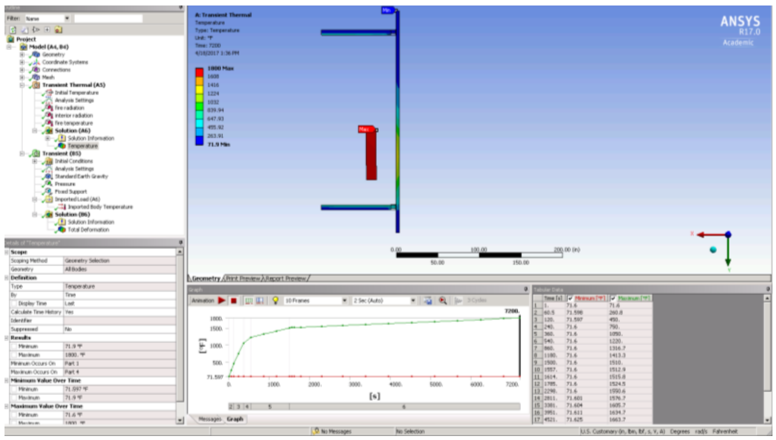
Thermal and Structural:

For the combined thermal and structural follow the set up for a custom system in ANSYS. The geometry you will use for this analysis is the 2D auto CAD. You will follow the steps provide for modeling the 2D geometry that is mention in the beginning of the users guide. For the set up of this analysis you will first start in Thermal and then go into the Structural set up.

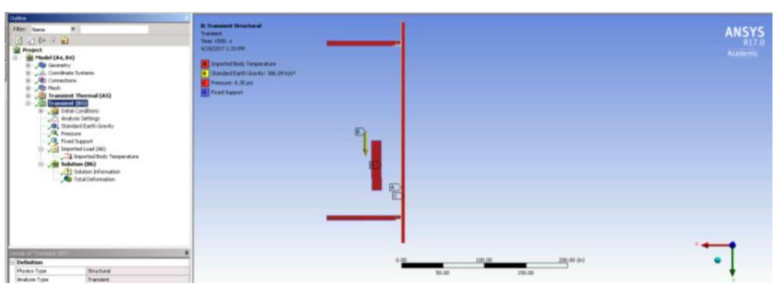
The setup for Thermal will be similar to that of the 3D model thermal analysis. However, glass will not be analyzed and the solution you are looking for is only temperature. You will still have boundary condition of radiation on the interior of the curtain wall and fire. The tablular data detailed in the thermal analysis for radiation will remain the same. The temperature data for fire will also remain the same.



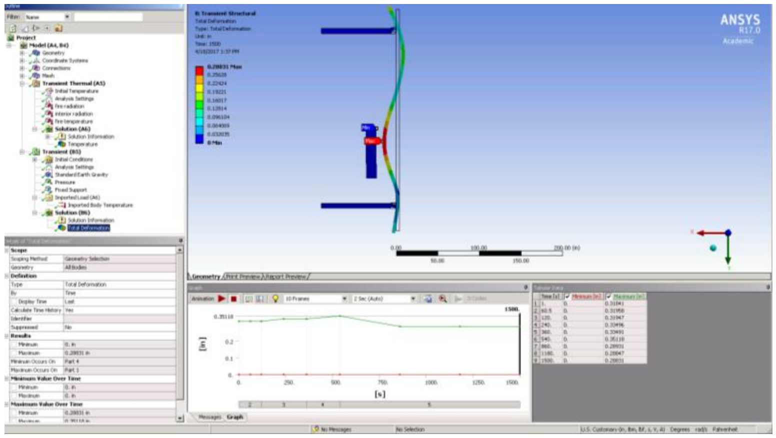
For the solution again, you will follow the same steps only selecting “temperature” as a solution. Click “generate” and run the simulation to get the results for thermal analysis.



For structural set up you will follow the same procedure defined in the 3D structural analysis. The boundary conditions will be pressure, gravity loads, and the curtain wall will all be defined as fixed support.



For the solution for structural analysis only total deformation will be taken into consideration. Also because the thermal and structural are a combined analysis the temperature defined in the thermal analysis will be automatically imported into the transient umbrella in the outline table. You will click “generate” and ANSYS should run the simulation for both thermal and structural giving you the deflection of the mullion as a result of the loading, wind pressure and the temperature of the fire.



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