LDA-1505

Worcester Polytechnic Institute
Department of Civil and Environmental Engineering

Feasibility & Validation Study of Foundation Design Alternatives

Stantec Project Center
Boston, MA

A Major Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute
Worcester, MA

In partial fulfillment of the requirements for
the Degree of Bachelor of Science

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Abstract

Using software analysis for structural design is becoming more prevalent across the industry due to increasing technological resources. This project served as an investigation of foundation design alternatives and the feasibility of STAAD.foundation as a design aid for engineers at Stantec Consulting Ltd. Both design optimization and accuracy were tested against hand calculations in accordance with ACI 318-05 and ASCE 7-05 in order to identify the proficiencies and shortcomings of the software which were documented in a user tips manual.

Acknowledgements

Our team would like to thank Professor Albano and Professor Hart for all their guidance and assistance over the course of this project. We would also like to thank the employees of Stantec Consulting Service Inc. in the Boston office for being so helpful and welcoming to our team. The project would not be complete without the help and support of several specific Stantec employees; Greg Cuetara, Dennis Keough, and Ryan Hill.

Authorship

This project was a collaborative effort between all four team members. Our team collectively determined how to approach and effectively complete all aspects of the project. In order to be most efficient, sections of the report were written separately. However, the sections were reviewed and edited by each team member. A general delineation of team responsibilities is listed below.

Dominick Bossalini: Created Excel Spreadsheets that could be used for multiple design calculations and designed foundations. This team member was responsible for the analysis, results and conclusions sections concerning the evaluation and comparison of STAAD.*foundation*.

Paul Buchanan: Developed the Stantec User Tips Manual and focused on compiling the MQP report and Stantec Deliverable. This team member was responsible for the development of the Stantec Deliverable and the writing of associated report sections.

Margaret Freed: Created Excel Spreadsheet that could be used for multiple design calculations and focused on compiling the MQP report and Stantec Deliverable. This team member was responsible for the analysis, results and conclusions sections concerning the evaluation of design alternatives.

Dylan Heinricher: Verified Excel Spreadsheets through hand calculations and became proficient in STAAD.*foundation* program functions and limitations. This team member was responsible for the analysis, results and conclusions sections concerning the evaluation and comparison of STAAD.*foundation*.

Capstone Design Statement

According to the principles developed by the Accreditation Board for Engineering and Technology (ABET), students must demonstrate knowledge and skills acquired in earlier coursework through a capstone design experience. A capstone design experience must incorporate engineering principles and realistic design constraints. This Major Qualifying Project (MQP) incorporated the following six design constraints:

Economic

One of the six design constraints of the project is economics. Designing a structure for economic efficiency necessitates a greater amount of detail than would be required when designing for structural integrity alone. The amounts and types of material, as well as the ease of construction must all be considered, while still providing enough structural support strength. For this project, economic efficiency was designed by completing multiple foundation designs and providing a ranking based on design and construction costs. These designs were then evaluated by completing a cost estimate for the amount of steel rebar and concrete included in the design, as well as determining if the shape or size of the foundation will require a greater amount of site work and construction man-hours. The cost estimates for reinforcement and concrete were quoted from the *2013 National Construction Estimator*.

Ethical

The designs for this project were consistent with the code of ethics set forth by the American Society of Civil Engineers (ASCE). The designs meet the requirements of the ASCE's fundamental principles and fundamental canons. The ASCE's fundamental cannons are as follows:[1]

1. Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession and shall act with zero-tolerance for bribery, fraud, and corruption.
7. Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.

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[1] American Society of Civil Engineers. *Guidance on Licensing and Ethical Responsibilities for Civil Engineers*. Web. <http://www.asce.org/uploadedFiles/Education_and_Careers/Licensure/Content_Pieces/licensing-ethics-brochure.pdf>.

Health and Safety

Foundation designs were conscientiously designed keeping the well-being of those constructing the design and the future users of the facility in mind. The designs comply with the requirements of the governing regulatory codes and with pertinent industry standards. All the foundation designs were created considering the code standards laid out in ACI 318-05, the 14^{th} edition of AISC, and ASCE Standards: 9-1, 9-2, 9-3.

Constructability

The project created the foundation designs with the feasibility of construction in mind. This included considering the effective use of resources, labor, construction duration, and structure maintenance. It is important to consider the constructability of designs in the field. Producing designs that are too complicated or that expect unreasonable precision can lead to costly delays in the field and wasted resources.

Social

Since the project team worked in a professional environment during the length of the project, the social design constraint was addressed during our time at Stantec. A major aspect of completing the project was learning how to adapt to and be productive in a professional environment. Completing this constraint included meeting the expectations of a professional workplace. These requirements included adopting acceptable work attire and manners, adhering to Stantec's established schedule and hours, and integrating with fellow coworkers and managers.

Professional Licensure Statement

Obtaining a professional license as a civil engineer means that the applicant has accepted and understands the technical and ethical obligations of the profession.[2] Reliance on engineers who have obtained a professional ensures that engineering projects protect the health, safety, and welfare of the public. Each state has specific requirements for an individual to become a licensed professional engineer (P.E.). The National Council of Examiners for Engineering and Surveying (NCEES) is one prominent organization that oversees the licensing requirements for each state.

Requirements to Obtain a License

Although licensing requirements may very slightly from state to state, the general process remains fairly consistent throughout the United States. Listed below are the requirements to obtain a professional license according to the American Society of Civil Engineers: [3]

1. Graduating from an ABET accredited engineering program or an ABET accredited engineering technology program in some states.
2. Passing the national Fundamentals of Engineering (F.E.) exam offered by the National Council of Examiners for Engineering and Surveying (NCEES).
3. Obtaining four year (or three years past a masters degree in some states) of acceptable engineering experience with increasing levels of responsibility under the guidance of one or more licensed engineers.
4. Submitting a detailed application documenting among other things, a progressing increase in responsible professional experience and including both professional and character references.
5. Passing the Principles of Engineering (P.E.) exam offered by NCEES. Some states have an additional exam offered by the state board that convers its principles of conduct and ethics.

Importance of licensure to the profession, to the individual, and to the public

There are many reasons that civil engineering students and graduates should aspire to become licensed engineers. Having a professional license expands the knowledge of the profession, fulfills an ethical responsibility to the engineer's community and enhances the engineer's career. Since the majority of civil engineering work is done in close proximity to the public it is an engineer's responsibility to ensure the safety of the community. Professional licensure means that the engineer has a thorough understanding of fundamental engineering principles and has acquired engineering experience and judgment under the guidance of a professional engineer. A license legally enables an engineer to take personal responsibility for any technical work they complete.

According to the seventh fundamental ethical cannon laid out by the American Society of Civil Engineers (ASCE), "Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers

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[2] American Society of Civil Engineers. *Guidance on Licensing and Ethical Responsibilities for Civil Engineers*. Web. <http://www.asce.org/uploadedFiles/Education_and_Careers/Licensure/Content_Pieces/licensing-ethics-brochure.pdf>.

[3] Ibid.

under their supervision". Becoming a professional engineer satisfies this requirement in several ways. A young engineer aspiring to be licensed needs to complete several years under the guidance of a professional engineer. This increases the professional development of the younger engineer and allows the professional engineer in charge to pass along their knowledge. Passing down engineering knowledge is not only crucial to expanding the development of a younger engineers but it is also vial to the progress of the profession as a whole.

Relationship between this MQP and professional practice

The MQP is directly integrated with professional practice; both in its execution and end goal. This project was completed in Stantec Consulting Ltd.'s Boston office with direct supervision from several professional engineers. It required team members to consistently work in a professional environment under the guidance of experienced engineers. Spending time in the Stantec office helped each member of the team develop professionally and technically. Our project also helped develop a sense of professionalism. The team needed to consider how our project could be incorporated in the office workflow and the best method to present our findings to Stantec engineers.

Executive Summary

Purpose and Scope of Document

The Power Group at Stantec has previously worked with several different foundation software programs. The company was interested in the investigation of STAAD.*foundation* in order to determine range of applicability and reliability within the software package. By engaging in a parametric study of STAAD.*foundation*, it was possible to determine the reliability of the software and identify any potential limitations. In order to quantify the effectiveness and reliability of STAAD.*foundation*, foundation types were designed through hand calculations and then verified through the STAAD.*foundation* program. These foundation designs were then analyzed considering engineering principles and realistic design constraints. Specifically, the team considered direct cost of materials, labor, and equipment, design code compliance, health and safety regulations and aspects of constructability.

Three documents were created in order to complete the project. A deliverable to the company was created with the use of Microsoft Word and PowerPoint. To create the deliverable for Stantec, a standard operations was provided by them and followed until completion. The team met and worked with Ryan Hill (EIT) to ensure that the deliverable was up to standard with the company. The deliverable contains a table of contents, a purpose, an applicable codes and standards section, definitions, design criteria, and an appendix. The purpose defines the needs and specifics of the project. The deliverable will be printed and then compiled into a binder so that Stantec has a hard copy of it. In the appendix of the deliverable, the user can see the User Tip Manual, all of the hand calculations, and spread sheets of each specific foundation design used to verify the validity of STAAD.*foundation*. The deliverable can be used by any employee in the office that will be new to or using STAAD.*foundation.*

Tutorial videos and examples provided by the software were explored to best develop a user manual that can show a designer how to create and analyze specific foundations depending on the project's need. Essentially, should Stantec hire a new employee, this user manual would provide them with enough information to learn the fundamentals of the program. The user tips manual outlines proper methodology to use and setup various foundations and is in the form of a Microsoft PowerPoint. The PowerPoint has a table of contents which acts as chapters for each foundation design, limits and optimizations within the program section, importing and exporting within the program, and a tips and tricks section.

Methods

The objectives of this project are as follows:

1. Evaluate the reliability of STAAD.*foundation* and identify any software limitations
2. Consider design alternatives for various foundation types using a predefined rubric
3. Develop a user tips manual for use by Stantec Consulting Ltd. Engineers

To accomplish the project objectives, the team created design alternatives through hand calculations and by utilizing STAAD.*foundation*. The foundation types that were designed included isolated spread footings, combined footings, strap footings and mat foundations. For each foundation type, three models were created that could then be used for STAAD.*foundation* evaluation and consideration of design alternatives.

Results and Conclusions

Objective 1

A comparison of the hand-calculated designs with those produced by STAAD.*foundation* reveals that while STAAD offers the potential for a streamlined foundation design process, it does have several important flaws. The hand calculated designs in almost every instance produced a similar set of dimensions as those of the foundations STAAD designed. The most noticeable error within the dimensioning of the STAAD produced designs occurred within the combined footing, where STAAD suggested dimensions that would have been quite difficult to construct. Other errors seen within the results occur with regard to the reinforcement design and the analysis of shear forces. In several cases, STAAD was found to have produced a design in which the reinforcement would be spaced greater than the maximum 7.5 inches, or would require too large a number of bars with too wide a spacing, effectively moving reinforcement outside of the boundaries of the foundation. The analysis of shear within the program proved inaccurate as well. STAAD.*foundation* completed its analysis of the foundation not from the largest possible load case, but rather from the largest positive value computed. In the event that the design produced a significantly larger negative shear force than the selected positive shear force, the foundation would fail.

While STAAD.*foundation* is certainly a useful tool, designs which are produced exclusively within the software should be compared to a design which has been manually calculated. In addition to this, design constraints should be determined ahead of time based upon the users engineering judgment. While the program will design to the minimum constraints, a proper foundation design will come not from using exclusively the minimums, but rather from careful consideration of all of the variables within the structure and the site. Tools such as this act as design aids and supplements to the process, but should not be considered replacements to the traditional methods of structural design.

Objective 2

To determine the most appropriate design, there must be consideration of ethical standards, health and safety, cost, and constructability. In order to evaluate the three design alternatives a grading rubric was created. While the rubric does not determine the best design, it does offer the engineer an evaluation of the twelve foundation designs. All of the foundations were designed in accordance with the ASCE code of Ethics and Ethical Cannons as well as being designed in accordance with the various governing codes. In terms of cost estimation, the pricing of materials was considered for each design and is represented in the spreadsheets as either green (cheapest), yellow (middle) or red (most expensive). The overall cheapest design is that of the second combined footing design, whereas the most expensive is the third mat design. For constructability, all of the designs once again offer varying degrees of difficulty. While the mat foundation requires the smallest amount of formwork setups, it also does cover the largest amount of area.

The results obtained from the rubric offer a number of positive and negative factors for each of the designs as well as confirming that the design has met the required standards. These serve as a tool for analyzing each foundation design individually, as well as in comparison to the other designs within the type of foundation and the project as a whole. As the rubric does not propose any one design in particular, the engineers must decide for themselves what the overall best design would be, based upon the known constraints within the site, budget, and timeline.

Objective 3

The creation of a user tips manual serves as a guide for future users of STAAD.*foundation*. It offers insight into the import and export of STAAD files, as well as detailing the steps required to begin a design within the program. The user tips manual also covers the various areas of the program that we found lacking, such as the analysis of shear, the use of minimum design constraints, and reinforcement. While not all of these errors were solved, they are potential problems that can appear within the design and should be considered when using STAAD.*foundation.*

Contents

1.0 Introduction

By verifying the applicability and reliability of software used within a company, it is possible to gain financial benefits, facilitate communication across different departments, and ensure the effective use of company resources. It is important to determine whether software applications utilized by company employees are encouraging streamlined workflow by functioning to their intended standard. Letting discontinuities or inaccuracies creep into the intricate framework of structural design and construction projects can lead to wasted resources and delayed schedules. Having unreliable software applications can increase the frequency of reworks, the possibility of safety hazards, and the amount of wasted materials.

1.1 Project Need

The Power Group at Stantec has previously worked with several different foundation software programs. The company was interested in the investigation of STAAD.*foundation* in order to determine range of applicability and reliability within the software package. By engaging in a parametric study of STAAD.*foundation*, it was possible to determine the reliability of the software and identify any potential limitations. This involved the use of STAAD.*pro* in order to construct a structural steel model and perform the necessary structural analysis. Once the reaction forces from STAAD.*pro* were computed, they were applied to design various foundation types. In order to quantify the effectiveness and reliability of STAAD.*foundation*, foundation types were designed through hand calculations and then verified through the STAAD.*foundation* program.

1.2 Design Approach

To verify the applicability and reliability of STAAD.*foundation*, reaction forces from a STAAD.*pro* structural frame model was obtained. Reaction forces and loadings obtained from the structural analysis in STAAD.*pro* were then input into STAAD.*foundation*. The team inputted the design criteria for each type of foundation into STAAD.*foundation*. These selected foundation types were also designed through hand calculations to verify the results from the program. This comparison allowed for the analysis of software and design limitations inherent in STAAD.*foundation*. This project focused on the design of isolated spread footings, combined footings, strap footings and mat foundations. Once the verifications were documented, a User Tips Manual was created for use by Stantec Consulting Ltd.. The foundation designs were then analyzed considering several design criteria, specifically: direct labor, material and equipment costs, compliance with health and safety regulations, adherence to design codes and constructability.

2.0 Background

2.1 Stantec Consulting Ltd.

Stantec Consulting was founded in 1954 in Edmonton, Canada by Dr. Don Stanley as a civil and environmental engineering firm working primarily on water and sewage projects in rural Canadian towns. Within the first decade, the company grew to a size of thirty employees and was awarded its first major structural project: the redesign of the Peace River Bridge on the Alaska Highway. Today Stantec is one of the largest design firms in the world, with over 14,000 employees in over 230 different offices specializing in architecture, landscape architecture, and engineering

2.1.1 Company Structure

Stantec is divided into several project areas within the fields of architecture, civil engineering and landscape architecture, mechanical engineering, and chemical engineering. Within the framework of Stantec's corporate Structure, these sub areas are known as *Business Centers*, or "BC's." These BC's often have sub groups within them, which collaborate on projects related to their fields, allowing Stantec to better allocate resources, and better manage the flow of money from clients to sub-contractors.

2.1.2 Power Engineering Group at Stantec

The power group at Stantec in Boston, Massachusetts was added to their firm in early 2014[4]. The group came to Stantec after many years with Shaw Power and Stone & Webster. The power group designs and engineers projects involving heat, power, turbines, and air quality control. The group looks at traditional resources such as gas and coal, as well as renewable energy resources including wind and solar power. The power projects include the repurposing of old power plants to be more economically efficient. The power group is growing on both the East and West Coast of the United States, allowing Stantec to access a broader clientele.

2.2 Foundation Design

Foundations are the base and support in the structural system that transmit the superstructure's loads directly to the earth. All civil engineering structures require foundations to keep the structure from leaning or buckling. Buildings bestow their weight and loadings onto their foundations; therefore, the footing needs to be designed to withstand the weight of the building. The foundation design process cannot begin until the loads have been calculated. There are several different types of design loads including: normal loads, shear loads, moment loads, and torsion loads. Where weather is applicable, the bottom of the foundation must be constructed below the frost line to prevent cracking from freeze-thaw cycles.

[4] Smith, Allson. "Stantec Adds Power Engineering Team in Boston, Massachusetts." *Stantec Media Relations*. n. page. Web. 6 Mar. 2015. <http://www.stantec.com/about-us/news/2014/stanatec-adds-power-engineering-team-in-boston-massachusetts.html

2.2.1 Spread Footings

Spread footings are normally used to support the structural system of small to medium structures with moderate to good soil conditions. They can be used in high-rise buildings where the soil conditions are exceptional and can bear the load. Individual columns of the building are constructed on top of the spread footing because of its ability to bear extremely heavy loading. Many low-rise residential buildings consist of spread footings that distribute the load over a larger area. Spread footings are the most common type of foundation due to its low cost and quick construction. They are built in different shapes and sizes to accommodate each project's scenario. The shape of the footing is generally a rectangular.

Determination of soil pressures, shear forces, and bending moments then need to be established to determine design capability[5]. The design and layout of the footing is controlled by several factors: the load of the structure, penetration of soft layers near the surface, and penetration of layers near the surface due to the effects freezing and thawing. These foundations are more commonly found in residential construction buildings that have a basement. These footings are not sufficient for high-rise buildings. Three types of spread footings, isolated, combined and strap, are discussed below and can be seen in Figure 1.

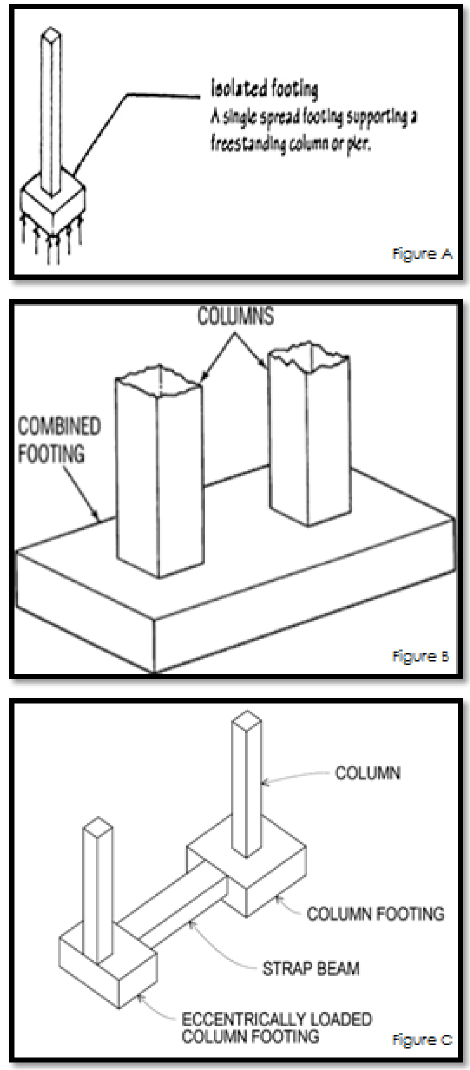

Figure 1: [A] Isolated Spread Footing, [B] Combined Footing, [C] Strap Footing
Taken from: http://eu.lib.kmutt.ac.th

Isolated Spread Footings

Isolated Spread support the structural system of small to medium structures. These footings are used to transmit a load from columns to the soil beneath it. If the soil supporting the column is weak or the column loading is too heavy, the isolated spread footing needs to be designed a lot larger. Isolated spread footings are more economical because less material is needed to create the footing than a normal spread footing.

Determination of soil bearing pressure and bearing capacity must be established to determine the design capability. If the soil has a higher bearing capacity, then the isolated spread footing is sufficient for the design.

Combined Footings

Combined Footings receive loading from more than one

[5] Tabsh, Sami W and Abdul Raouf AJ-Shawa. "Effect of Spread Footing Flexibility on Structural Response." *Structural Design and Construction* 2005, 10 ed.: 109-114. Web.

column or load-supporting element. Each column applies their own individual loading to the footing. The columns can be located at any distance from the footing ends, however, they must lie on the centerline along the longer axis of the footing. Determination of shear, service loading, soil bearing pressure, bending moments, and reinforcement need to be established to determine design capability. Combined footings are most commonly designed with a rectangular or trapezoidal geometry.

Strap Footings

Strap footings are generally used when one of the columns the footing is supporting undergoes extreme loading. When two columns are far apart, the strap is designed to transfer the large moment between the two columns. The strap does not provide any weight bearing; it is simply there to transfer the moment of one footing to the other. Strap footings are more economic than combined footings because it uses less material to construct the footing. Determination of loading, soil bearing capacity, and characteristic of the footing needs to be established to determine design capability.

2.2.2 Mat Foundations

Mat foundations, also known as raft foundations, are a type of foundation that is considered when using a spread foundation would not be economical or reasonable. Mats are considerably larger than spread footings and generally encompass the entire footprint of a building. This type of foundation can be considered economical for a variety of reasons, mostly depending on size and soil condition. If a spread footing is being considered and covers more than a third of the footprint, a mat may be considered as a more appropriate alternative. Additionally, a mat can be used when dealing with erratic soil conditions because the mechanics of the foundation will successfully bridge irregularities and differential settlements throughout a site. Location of the water table is another consideration for using a mat foundation. If the foundation is located below the depth of the water table, mat foundations are beneficial due to monolithic properties and ease of waterproofing. Depending on design, differential structural loads can cause irregular loading on the footing, in which case, a mat foundation would be beneficial because it is able to compensate for irregular loading. Although mats are able to withstand irregular loads

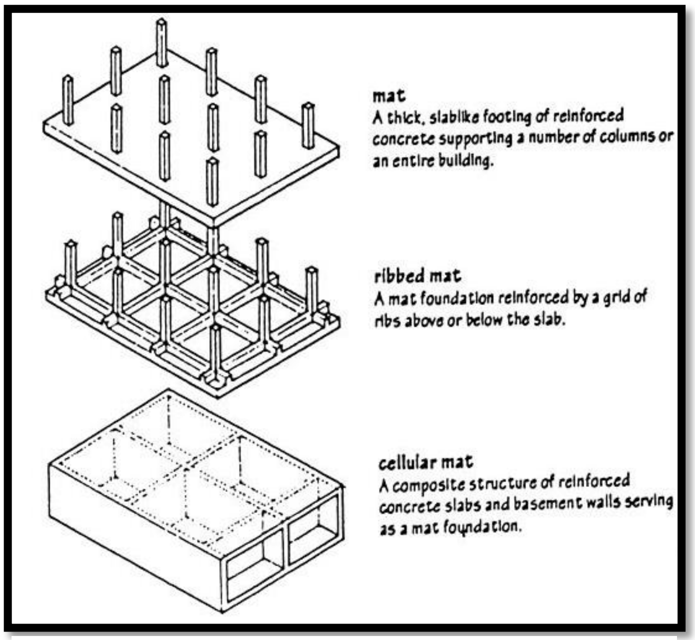

FIGURE 2: VARIOUS MAT FOUNDATION DESIGNS
Taken from: http://eu.lib.kmutt.ac.th

due to both superstructure bearing and soil conditions, piles or shafts may be necessary in order to fully support the mat foundation.[6]

When considering the design analysis of a mat foundation, it can be considered as rigid or non-rigid. The traditional method to evaluate the design of this type of foundation was to consider it a rigid structure. Using this approach, a high width-to-thickness ratio is generally observed. Furthermore, using this type of analysis yields less reliable estimates of shear, deformations and moments because there is no consideration to redistribution of the bearing pressure throughout the mat. [7]

The more developed and accurate way to analyze the design of a mat is using the non-rigid method. Using this analysis, the interaction between the mat and the underlying soil is assumed to be a "bed of springs." With this assumption, deformations can be calculated locally throughout the mat, rather than calculating one deformation for the entire foundation, which is unreasonable under the conditions that a mat foundation is selected. By considering both flexural deflections and corresponding soil bearing pressure redistribution, non-rigid analysis yields results that are more appropriate.[8]

2.3 STAAD.*pro*

STAAD.*pro* is a software application that assists professional engineers in the design of steel, concrete, timber, aluminum, and cold form steel structures with a user-friendly interface, optimized design and analysis capabilities. It is a product of Bentley Systems, a software company that specializes in, "comprehensive software solutions for the infrastructure lifecycle".[9] The software allows the user to create three-dimensional models of nearly any type of structure, featuring flexible modeling supporting over 70 international codes and over 20 U.S. codes. Three-dimensional model, as opposed to two-dimensional drawings, allow for heightened awareness of interferences within the design. By combining mechanical, electrical, and plumbing systems within a single model, the software allows for integration of structural elements. Additionally, analysis and design features, such as nuclear certification, are included within the software package. The interoperability of the software package allows for data exchange across several different programs. A notable component of STAAD software packages is the ability to link models to external project databases. Several different aspects of the model, such as mechanical and plumbing components, can be imported from third party resources such as AutoCAD. Along with structural analysis and interference reports, STAAD is able to produce virtual walkthroughs of the models.[10]

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[6] Coduto, D.P. *Foundation Design: Principles and Pracitices*. Upper Saddle River, New Jersey: Prentice-Hall, 2001. Print.
[7] Ibid.
[8] Ibid.
[9] *Bentley: Sustaining Infrastructure*. 2014. Web. <http://www.bentley.com/en-US/>.
[10] Bentley. STAAD.*pro*. n.d. Web. 10 December 2014. <http://www.bentley.com/en-US/Products/STAAD.*pro*/>.

Case Study in STAAD.pro

An example of a project that benefitted from the use of STAAD.*pro* was the design and construction of the Evergreen Community Power Plant in Reading, Pennsylvania. The project was contracted by ESI Inc. of Tennessee, and the engineers on the project had no previous experience using STAAD or Bentley software products. The difficulties associated with this project were attributed to size constraints and complexity of the project. Additionally, the customer was adamant on the use of three-dimensional modeling to ensure that proper operation and size could be achieved within the provided space.

The project team for the power plant consisted of 19 engineers, including structural, mechanical, electrical, and instrumentation engineers who were able to input their components of the design into the model. The engineers were able to review the model while 3D specialists simultaneously performed detailed modeling for the plant. The project was streamlined by utilizing STAAD's integration tools. Two and three-dimensional models from the vendors, which were created in third party applications, could be imported into the STAAD model. Interference reports were also generated using this model, opposed to two-dimensional interpretation. These reports identified major cost saving interferences between different engineering components before construction. Overall, the implementation and use of STAAD saved ESI Inc. about two months on the design schedule.[11]

2.4 STAAD.*foundation*

STAAD.*foundation* is used to design and model various types of complex and simple foundation systems. It is also a product of Bentley Systems. STAAD.*foundation* is designed to handle common foundations, such as isolated spread footings and pile caps. It can also tackle foundation designs for larger and more complex projects. According to Bentley Systems, "efficient design and documentation is realized through its plant specific design tools, multiple design codes with U.S. and metric bar sizes, design optimization and automatic drawing generation".[12] Application of STAAD.*foundation* can potentially benefit users of STAAD.*pro* due to the streamlined workflow between the two programs. STAAD.*foundation* can efficiently input geometry, loads and reactions from STAAD.*pro* and then effectively produce a foundation design.[13] While STAAD.*foundation* can be used cohesively with STAAD.*pro* and other building information modeling software, it can also be utilized as a standalone program.

2.4.1 STAAD.*foundation* Program Theory

STAAD.*foundation* allows the user the ability to model complex or simple footings, and these include: isolated spread footings, pile caps, strip footings, mat foundations, and octagonal

[11] Bentley.Company. *Bentley Helps Jump-Start 3K Design Services for Green Power Plant*. June 2009. <http://ftp2.bentley.com/dist/collateral/docs/case_studies/CS_ESI_Green-Power-Plant.pdf>.

[12] Ibid.

[13] Bentley Systems. STAAD.*foundation* - *User Manual*. Research Engineers International, 2009. 1-2

footings.[14] The program designs these various foundation types in accordance with ACI 318-05 code. [15]

2.4.2 Foundation Design in STAAD.*foundation*

Isolated Spread Footings and Strip Footings

In the design of isolated spread footings and strip footings, STAAD.*foundation* uses parameters concerning soil bearing capacity, shear and flexural strength of footing, and compressive and flexural strength of pedestal.[16] Depending on the bearing resistance of the soil and structure, the loading on a footing plan is determined. The footing thickness is determined by considering shear and bending capacity. The shear consideration includes punching shear and one-way shear. [17]

Mat Foundation

STAAD.*foundation* relies on finite element method (FEM) and slab-on-elastic-subgrade principles to analyze and design mat foundations.[18] When applying a load to a plate or mat foundation, there is more than one direction for the load to traverse the plate. Using the finite element method, a plate can be subdivided into smaller sections in order to obtain deflection information.[19]

2.4.3 Case Study in STAAD.*foundation*

Apollo Tyres Limited is India's largest automotive tire manufacturer, and is currently in the process of building a new plant on a 126-acre plot.[20] The project will include 30 buildings and a build area of approximately 167,226 square meters. The project included some difficult challenges, specifically the large size of the entire structure and the need to accommodate heavy loads. The consulting and engineering firm of Aswathanarayana and Eswara was awarded the contract for the project and utilized STAAD.*pro* and STAAD.*foundation* in the design.[21] The foundation design included 120 support positions and over 50 load combinations. Due to the complexity of the project, STAAD.*foundation* was able to streamline the design and analysis process. It allowed engineers to sort through massive amounts of data very effectively. By using STAAD.*foundation* software, the firm was able to save 50% to 60% in design time and saved 12 to 15% in materials.[22] The firm also saved approximately 80 hours of work per month over the course of a six-month project period.[23]

[14] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 2-19
[15] Ibid.
[16] Ibid.
[17] Ibid., 23.
[18] Ibid.
[19] Ibid.
[20]*Apollo Tyres Limited*. 2010. <http://ftp2.bentley.com/dist/collateral/docs/case_studies/CS_Apollo-Tyres.pdf>.
[21] Ibid..
[22] Ibid.
[23] Ibid..

3.0 Methodology

The objectives of this project are as follows:

1. Evaluate the reliability of STAAD.*foundation* and identify any software limitations
2. Consider design alternatives for various foundation types using a predefined rubric
3. Develop a user tips manual for use by Stantec Consulting Ltd. Engineers

3.1 Investigation of Foundation Designs

During the first week at Stantec Consulting Ltd.'s Boston office, the team met with our project supervisors. The team had separate meetings with our main supervisor, Greg Cuetara, from the Scarborough, Maine office, and with Dennis Keough, and Ryan Hill, from the Boston, Massachusetts office. During these meetings the project scope and project proposal were further defined. A copy of the proposal developed by Stantec Consulting Ltd. can be found in Appendix B.

During the initial meeting, Greg Cuetara also provided the team with a STAAD.*pro* structural steel frame model to be used for the foundation designs. The reference structure was originally designed as a portion of a Providence Landfill Gas to Energy Project completed by Stantec Consulting Ltd. in Johnston, Rhode Island. The reference structure can be seen in Figure 3. Having the reference structure allowed the team to plan which types of foundation were to be designed. It was also possible to define necessary parameters to aid in the design of the foundations. These parameters included: location of the structure, foundation geometry, the structure's purpose, etc. Defining the reference structure and these parameters was the initial step in determining the loading and forces present in the foundation system. After using the analysis feature in STAAD.*pro*, the team had definitive design loadings and reaction forces for each of the connection points.

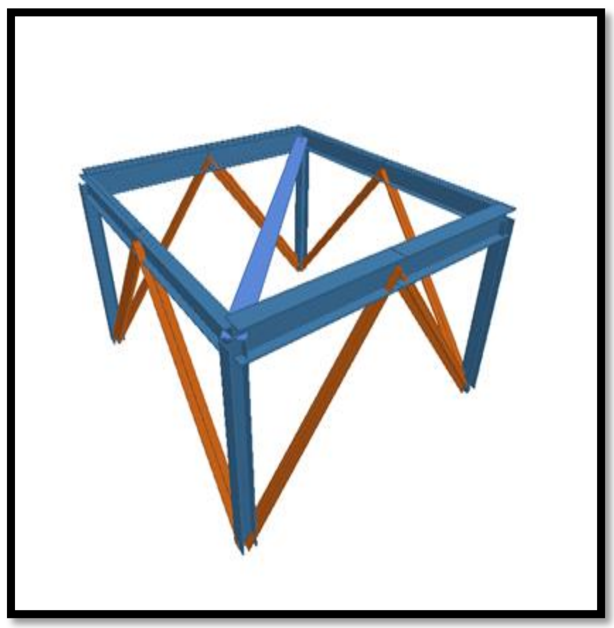


FIGURE 3: RENDERED DRAWING OF STAAD.*PRO* REFERENCE

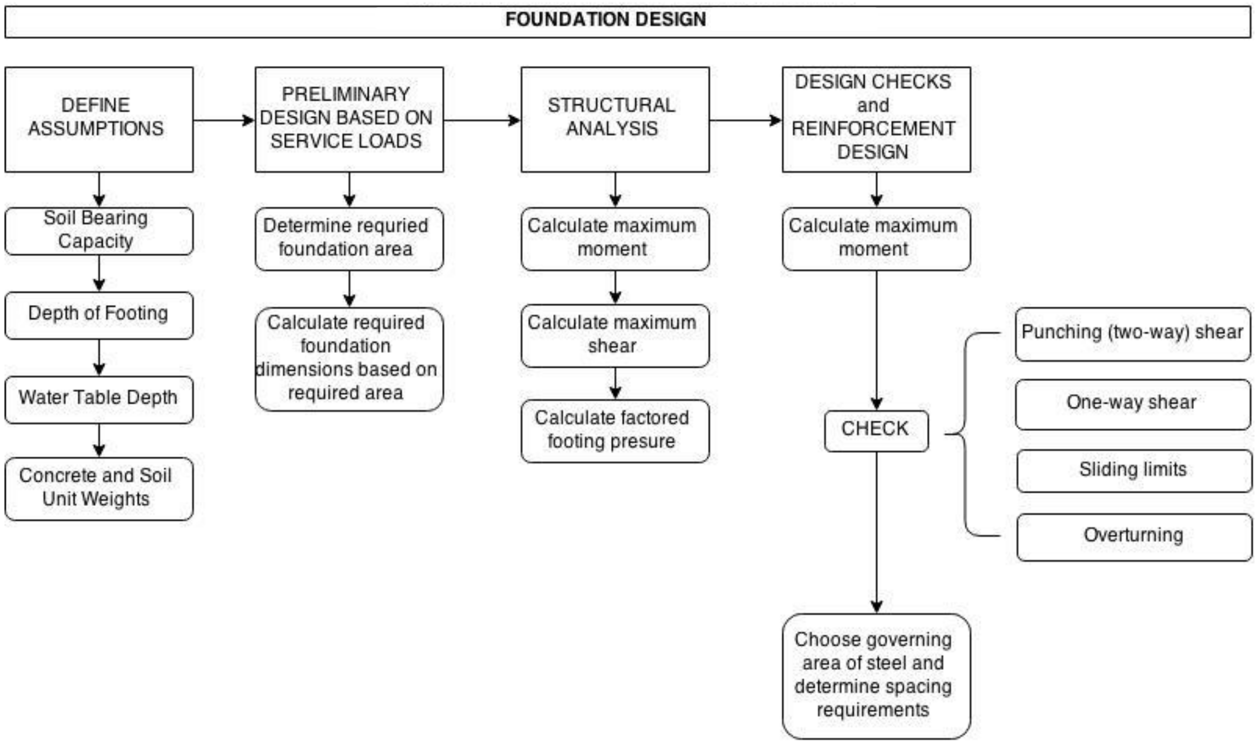
Having defined the type and function of the reference structure, the team made general assumptions for a range of other necessary parameters. These assumptions included information about the geotechnical condition in the area and various soil parameters. These can be seen in Table 1. For the design calculations the material properties to be determined included: strength of concrete, yield strength of steel, maximum and minimum bar size, clear cover values, and initial thickness. Soil parameters that were considered include soil types, unit weight of soil, and soil bearing capacity.

TABLE 1: DESIGN PARAMETERS

Design Parameters							
Concrete and Reinforcement				**Cover and Soil**			
Unit weight of concrete	γ_c	150	pcf	Clear cover values	C	3	in
Strength of concrete	f'_c	4	ksi	Unit weight of soil	γ_s	120	pcf
Yield strength of steel	f_y	60	ksi	Soil bearing capacity	q_a	3000	psf
Minimum bar spacing		-	in	Depth of soil above footing		12	in
Maximum bar spacing		-	in				
Minimum bar size	#	-					
Maximum bar Size	#	-					
Geometry				**Design Parameters**			
Minimum length	L_{max}	-	ft	Coefficient of friction	μ	0.5	
Maximum length	L_{min}	-	ft	Factor of safety against sliding	FS	1.5	
Minimum width	b_{max}	-	ft	Factor of safety against overturning	FS	1.5	
Maximum width	b_{min}	-	ft				
Minimum thickness	t_{max}	-	ft				
Maximum thickness	t_{min}	-	ft				
**Blank parameters indicate variable assumptions*							

Designing Foundations through Hand Calculations

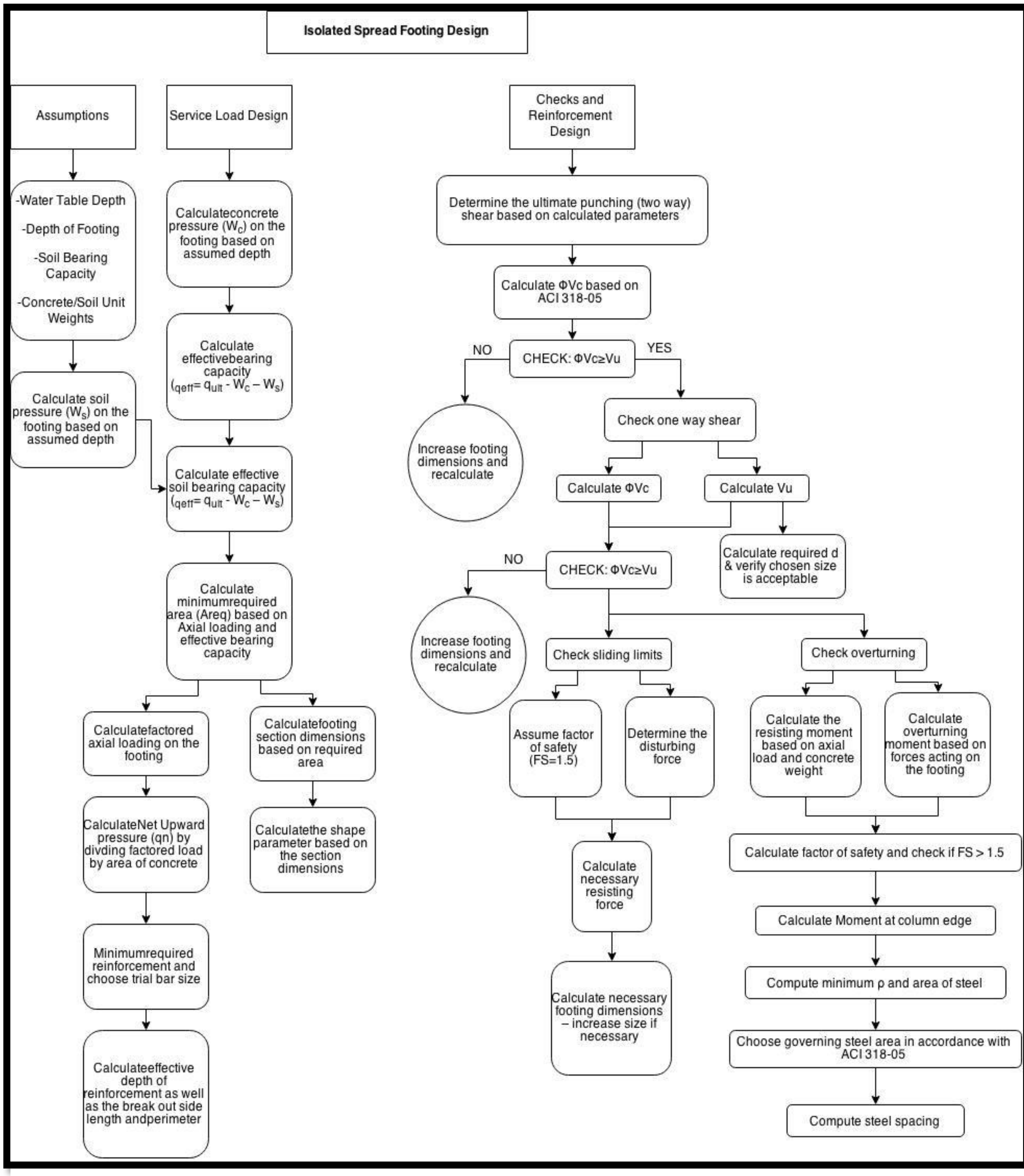
In order to create an efficient system for running multiple hand calculations, Excel Spreadsheets were developed for isolated footings, combined footings, strap footings and mat foundations. The design process used for the foundation designs can be seen in Flowchart 1. Excel Spreadsheets allows the user to change the design parameters and produce an accurate foundation design. Each of the Excel Spreadsheets were set up following the foundation design procedure shown in Flowchart 1. The different sheet within the Excel Spreadsheet follow the headings of defining assumptions, preliminary design based on service load, structural analysis and design checks and reinforcement design. In order to verify the accuracy of the Excel Spreadsheets, manual calculations were also computed for a trial design and then compared to the spreadsheet output. Any variations between the two design methods was then compared and corrected. The team implemented a specific methodology for producing these hand calculations. One team member would create an Excel Spreadsheet for a specific foundation design, and once complete another team member would work through a hand calculated example while verifying the spreadsheet outputs. These calculations were then reviewed and approved by the other members of the team.



FLOWCHART 1: FOUNDATION DESIGN

Isolated Spread Footing Design

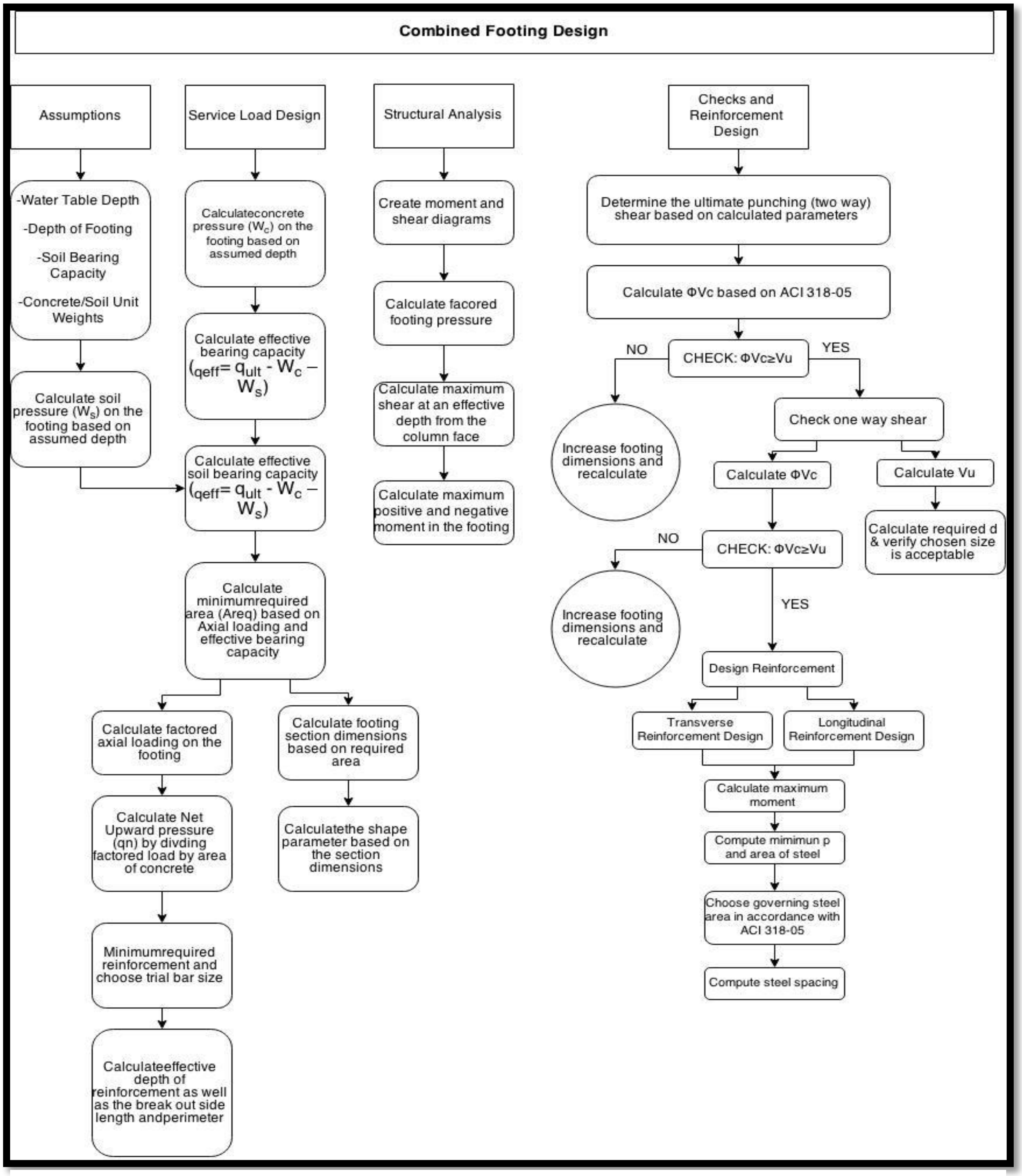
Isolated footings were designed in accordance ASCE 7-05 code and ACI 318-05. The design procedure to develop the isolated spread footing designs can be seen in Flowchart 2. For more information on isolated spread footing design calculations, a sample of the Excel Spreadsheet can be seen in Appendix D and the hand verifications can be reviewed in Appendix F.



FLOWCHART 2: DESIGN OF ISOLATED SPREAD FOOTINGS

Combined Footing Design

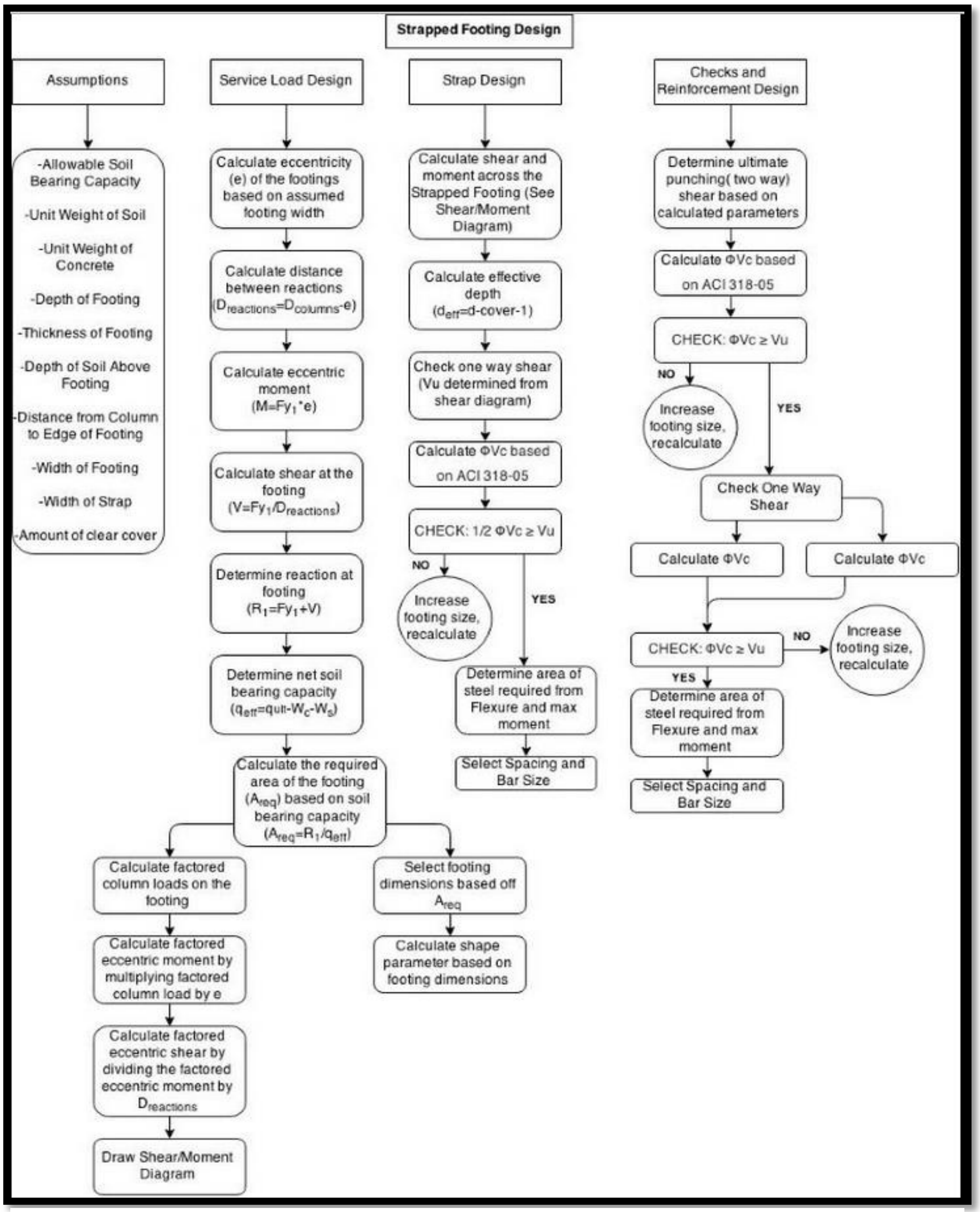
Combined footings were designed in accordance ASCE 7-05 code and ACI 318-05. The design procedure to develop the combined footing designs can be seen in Flowchart 3. For more information on combined footing design calculations, a sample of the Excel Spreadsheet can be seen in Appendix G and the hand verifications can be reviewed in Appendix I.



FLOWCHART 3: DESIGN OF COMBINED FOOTINGS

Strap Footing Design

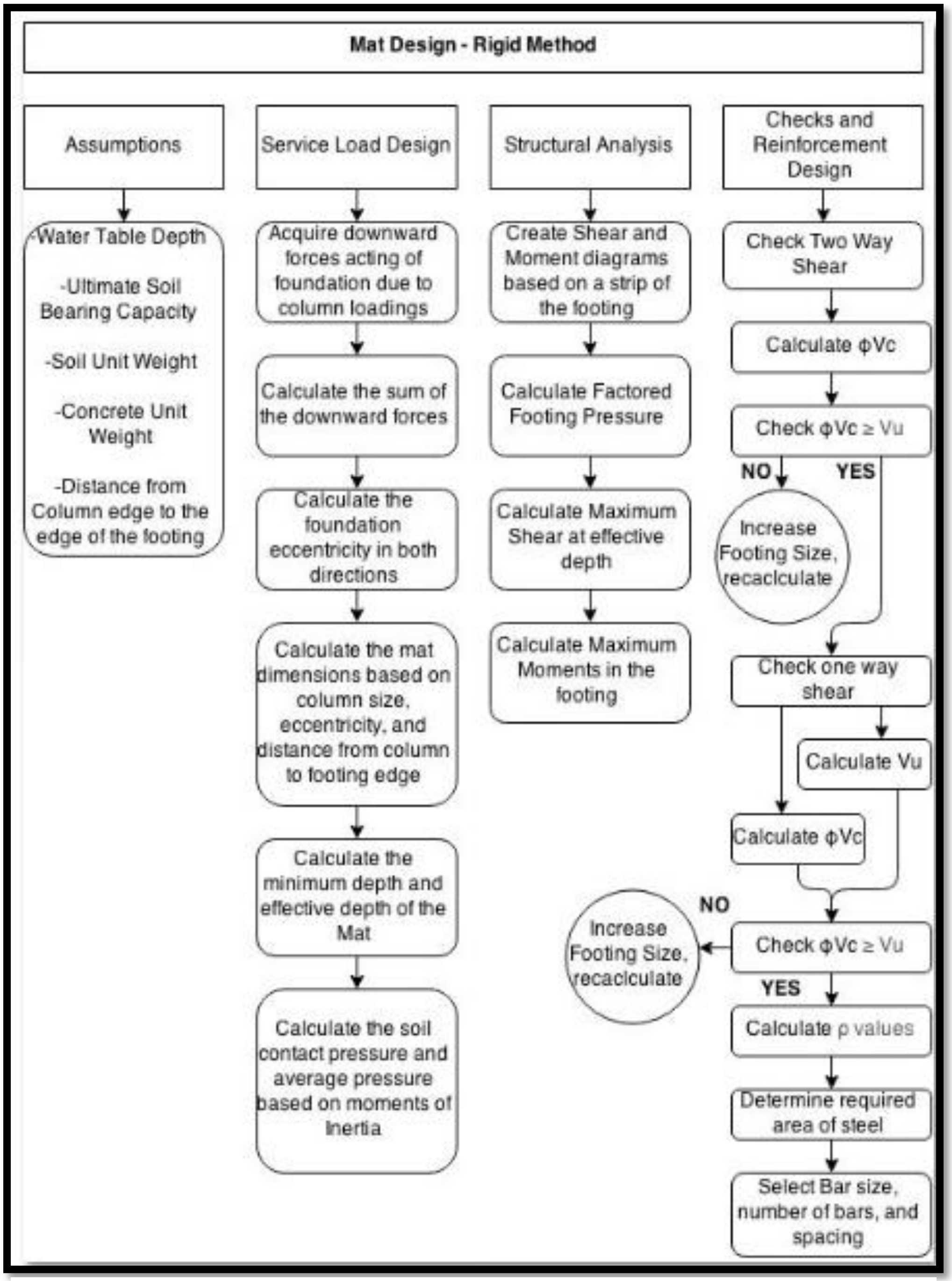
Strap footings were designed in accordance ASCE 7-05 code and ACI 318-05. The design procedure to develop the strap footing designs can be seen in Flowchart 4. For more information on strap footing design calculations, a sample of the Excel Spreadsheet can be seem in Appendix J and the hand verifications can be reviewed in Appendix L.



FLOWCHART 4: STRAPPED FOOTING DESIGN

Mat Foundation Design

Mat foundations were designed in accordance ASCE 7-05 code and ACI 318-05. The design procedure to develop the mat foundation designs can be seen in Flowchart 5. For more information on mat foundation design calculations, a sample of the Excel Spreadsheet can be seem in Appendix M and the hand verifications can be reviewed in Appendix O.



FLOWCHART 5: MAT FOUNDATION DESIGN

Designing Foundations using STAAD.*foundation*

To begin a design in STAAD.*foundation*, the team created a *Project* to hold all the pertinent information about the foundation design. This information included the physical aspects of the foundation and data about the reference structure.[24] Setting up the general parameters, structural geometry, and structural analysis of a project in STAAD.*foundation* can be either done through the input of data manually or imported from STAAD.*pro*. Manually inputting the project information involved entering support coordinates, defining structural loads, specifying design constraints, and entering design parameters.[25] Importing structural geometry and analysis results from STAAD.*pro* into STAAD.*foundation* created a streamlined design process. Integrating the two programs allowed the foundation design to be seamlessly combined with analysis of forces and moments in the superstructure. To take advantage of this streamlined process, the team imported the structural analysis of the reference structure from STAAD.*pro* into STAAD.*foundation*.

The design and analysis of a project in STAAD.*foundation* varies depending on the intended type of foundation project. The specifics of this project's structural geometry, foundation type, and support reactions were based off the reference structure provided by Stantec Infrastructure Ltd. The team's efforts were focused on designing and analyzing STAAD.*foundation* for isolated spread footings, combined footings, strap footings and mat foundations.

Creating Foundation Models

In order to address the project's first two objectives, several different models for foundation type were created. Each of these models was designed to satisfy the structural and loading requirements of the reference structure. For the various models, individual parameters were changed to develop final designs. The team created three models for each foundation type: isolated footings, combined footings, strap footings and mat foundations.

3.2 Completion of Project Objectives

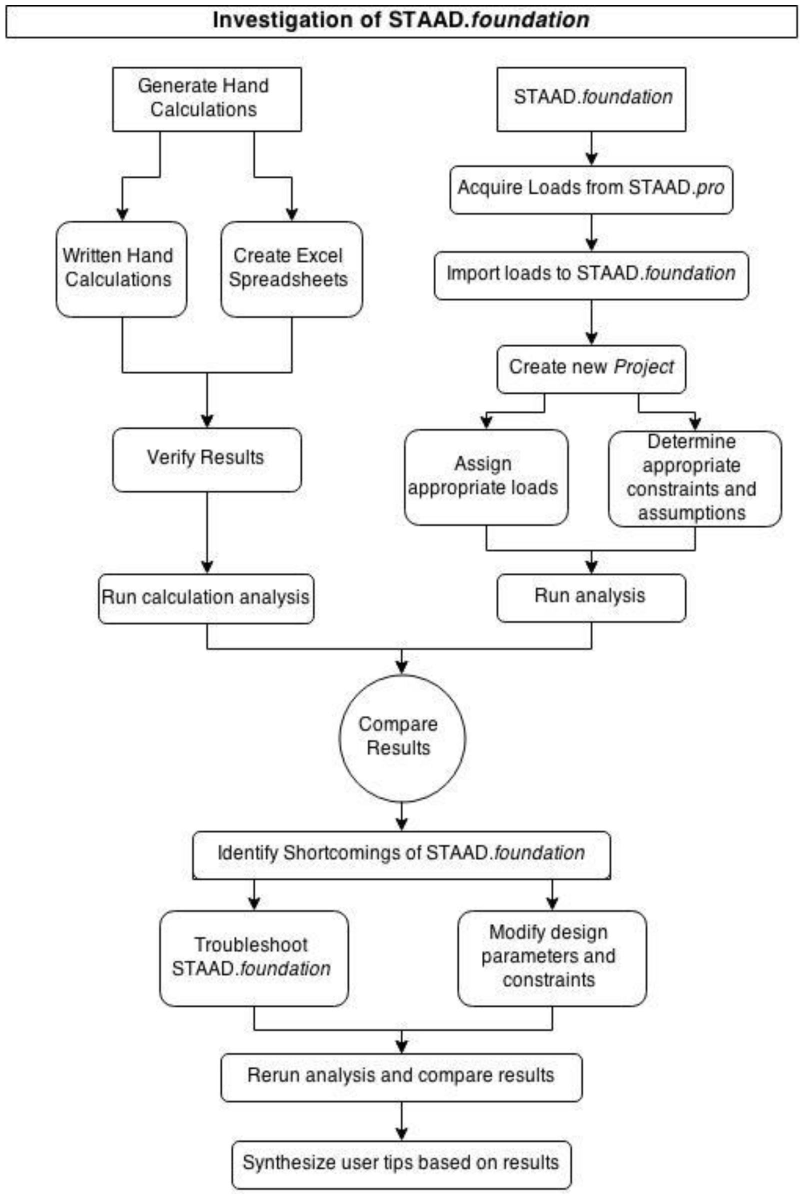
3.2.1 Evaluate the reliability of STAAD.*foundation* and identify any software limitations

The investigation into foundation designs was used to evaluate the reliability of STAAD.*foundation's* outputs and identify any potential software design limitations. The STAAD.*foundation* design outputs for isolated spread footings can be seen in Appendix E, combined footings in Appendix H, strap footings in Appendix K and mat foundations in Appendix N. After establishing the design parameters for three separate models of each foundation type, this criterion was imputed into STAAD.*foundation* and into the team's verified Excel Spreadsheets. Having the design specifications for each foundation type calculated by both sources allowed the team to compare differences in the outputs. The final design specifications

[24] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 2-20.

[25] Ibid.

calculated from these sources was then recorded and compiled. When comparing the STAAD.*foundation* and hand calculated results, the team specifically focused on the overall dimensions of the foundation and the spacing and design of the reinforcement. The methodology used to create foundation designs and then compare STAAD.*foundation* outputs with hand calculations can be seen in Flowchart 6.



FLOWCHART 6: INVESTIGATION OF STAAD.*FOUNDATION*

Testing Optimization in STAAD.*foundation*

In order to validate or discredit the design optimization of STAAD.foundation, several design alternatives were tested against the program's automated design results. Design parameters, such as footing geometry, rebar spacing and sizing, and soil conditions, for each foundation were modified and constricted within the program in order to record the effect on the evaluation process. The outputs were then analyzed to check for proficiency and feasibility against several failure modes including punching and direct shear, sliding, overturning, and flexure. Additionally, spacing of the rebar was further investigated to ensure the validity of the program output.

3.2.2 Consider alternatives for various foundation types using a design rubric

Using the foundation investigation and the designs created in STAAD.*foundation* the individual models were then compared. The team considered several different design constraints when comparing the models, including: direct cost of materials, equipment and labor, ethical standards, health and safety requirements, and constructability. Every design constraint was then given a rank based on how well a design met the design criteria. The team then conducted a side-by-side evaluation of the designs based on these criteria. The criteria considered in the design rubric can be seen in **Error! Reference source not found.**. Ethical, and health and safety consraints were considered a obligatory requirement for any of the foundation models. If the model did not meet ASCE Code of Ethics and Ethical Cannons, then the design was considered invalid. Likewise, if the design did not comply with code standards and could not sustain the loading requirements of the reference structure, the design was considered invalid. Economic constraints were considered based on the construction, equipment, and material costs for reinforcment and concrete footings. These costs were quoted from the *2013 National Construction Estimator*. The values used include the unit material cost and labor cost per linear foot of reinforcement. The concrete reinforcing bars considered were ASTM A615 Grade 60 and the cost data included tie wire and tying costs. The estimates for concrete foundation costs include material, labor and equipment costs per cubric foot. The *2013 National Construction Estimator* established these values based on normal weight structural concrete. The assumed construction costs were based on 4,000 PSI concrete with 3% waste, using a portable 55 KW 120/240 volt generator, two 25" diameter concrete vibrators, a truck-mounted hydraulic crane with 115' boom and small

TABLE 2: DESIGN COMPARISON RUBRIC

Design Rubric
Area of reference structure: 201 ft^2
Final Design Outputs
Thickness [ft]
Total Area [ft^2]
Volume Concrete [ft^3]
Ethical
Designed according to ASCE Code of Ethics and Ethical Cannons
Health and Safety
Designed according to Code Standards
Meets loading requirements of reference structure
Economic
Cost of Reinforcement
Cost of Concrete
Total Cost per Footing
Total Cost of Reference Structure Foundation
Constructability
Percentage of structure area
Number of Formwork Setups
Is this foundation typically used in this situation?

TABLE 3: CONCRETE PRICING

NORMAL WEIGHT STRUCTURAL CONCRETE		
	Spread Footings per ft^3	Mat Foundations per ft^3
Material	$ 3.89	$ 3.89
Labor	$ 1.11	$ 0.37
Equipment	$ 0.30	$ 0.10
REINFORCING BAR PRICING		
SIZE #	Unit Cost $/linear ft	Labor Cost $/linear ft
3	$ 0.26	$ 0.14
4	$ 0.44	$ 0.21
5	$ 0.60	$ 0.28
6	$ 0.84	$ 0.38
7	$ 1.37	$ 0.49
8	$ 1.56	$ 0.66
9	$ 2.72	$ 1.76
10	$ 3.45	$ 1.94
11	$ 4.26	$ 2.11
14	$ 5.74	$ 3.81

tools. The specific values can be seen in Table 3. In order to evaluate constructability of the foundation models, the team considered if the foundation size was resonable in comparision to the area of the reference structure. This was done by comparing the total area of the foundation designs to the total area of the reference structure. Each foundation type was given a percentage of the reference structure that was considered reasonable. The percentage limit for isolated footings was 20%, combined and strapped footings was 40% and mat foundations was between 100% and 125%. The area of was reference structural equals 201 ft^2. The comparison rubric also notes the number of formwork setups required to complete the construction of the foundations. Having multiple formwork setups requires extra labor and cost to complete the project. The team also considered if the type of foundation was typically used in similar situations. If the type of foundation was not considered a viable option for similar design situtions then it was not considered functional for this reference structure.

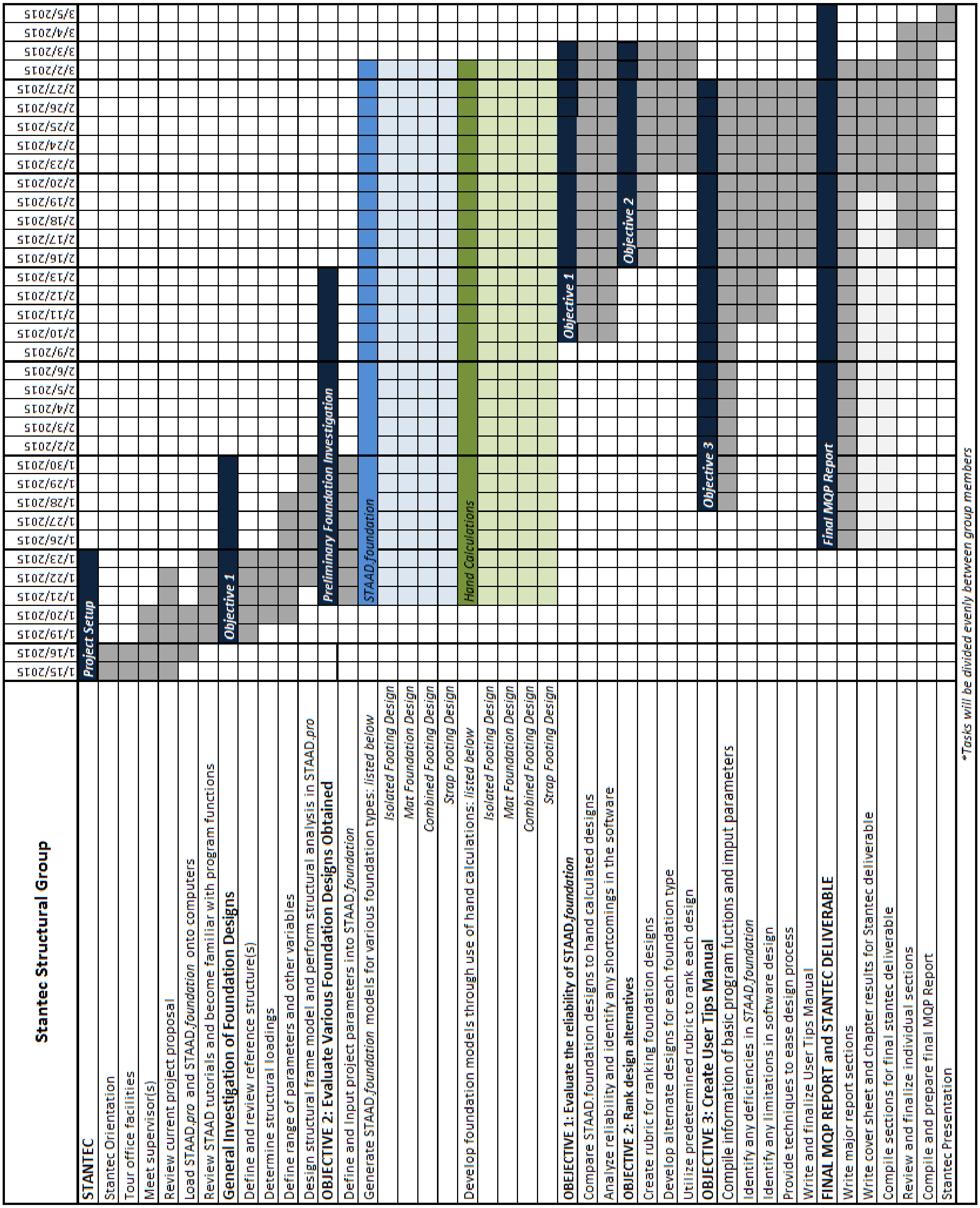
3.2.3 Develop a User Tips Manual for Stantec Consulting Ltd. Engineers.

In creating the User Tip Manual, the program STAAD.*foundation* was thoroughly investigated through examples and tutorial videos. The program allows the user to design or import a structure into the software and output a full analysis from the foundation up into the structure if the program deems it structurally sound. The designer needs to specify which job they are creating; whether it is a mat, pile, isolated, strap, or combined foundation. Once the job is created and specified, design parameters for each specific job open up in the main navigator pane on the left side of STAAD.*foundation*'s main window. The designer then needs to input all of the design variables for analysis. If the program finds that the inputted variables are not valid, the software will not output a detailed analysis of the infrastructure's calculations.

Due to the specificity of the program functions, the goal of the User Tips Manual was to provide Stantec Consulting Ltd. with a resource for the company's engineers. The User Tips Manual is designed to be used as a guide for all levels of STAAD.*foundation* users. It was design to include information on basic user functions within the program and steps on how to design various foundation types with in the program. For more advanced STAAD.*foundation* users the Tips Manual also was developed with information about program limitations and optimization techniques. To create the User Tips Manual, Microsoft PowerPoint was used. Through studying the tutorial videos provided by Bentley, the company who developed STAAD.*foundation*, an analysis of all types of foundations, limitations and optimizations, importing and exporting, and helpful user tricks were compiled to create the PowerPoint. Within the PowerPoint, one can find an interactive table of contents containing the aforementioned content divided up into individual chapters. By clicking on the chapter one needs to look at, the PowerPoint will open to the slide containing the desired chapter. At the end of the chapter a tutorial video is provided that one can watch if more assistance is needed; there is also a *Back to Table of Contents* button. Within each chapter is screenshots from STAAD.*foundation* and a detailed description of how to create each foundation job.

3.3 Project Schedule

The Gantt chart on below shows how the team divided and accomplished the project work over the course of a seven week period.



4.0 Results

4.1 Objective 1 Results [Investigation of STAAD.foundation]

A comparison of the designs produced by STAAD.*foundation* to that of our hand calculated foundations was completed for each of the four types of foundations examined. The purpose of this process was the examination of the reliability of the foundation designs produced by STAAD.*foundation* and determine in what areas the program was lacking. The designs that were hand calculated generally matched the dimensions of the STAAD produced designs, but due to certain limiting factors within STAAD, sometimes produced oddly shaped designs. In addition to this, a major error exposed by the results is that of STAAD suggesting reinforcement that would not fit within the designed footing. Examples of these errors can be seen within the following table, which details the comparison of the hand calculated designs to that of STAAD.

TABLE 4: RESULTS FROM PROGRAM DESIGNS AND HAND CALCULATED DESIGNS

Isolated Footing			Foundation Dimensions				Reinforcement Design						
							Location	Longtitudinal			Transverse		
Model	Variable Parameter		Thickness	Width	Length	Area			Size	Spacing		Size	Spacing
			ft	ft	ft	ft^2			#	in		#	in
C1	Footing Thickness	Hand Calc	3	7	7	49	Bottom	16	#7	5			
		STAAD	2	8.5	8.5	72.25	Top	11	#6	12	10	#6	10
							Bottom	11	#6	12	10	#6	10

Combined Footing			Foundation Dimensions				Reinforcement Design						
							Location	Longtitudinal			Transverse		
Model	Variable Parameter		Thickness	Width	Length	Area			Size	Spacing		Size	Spacing
			ft	ft	ft	ft^2			#	in		#	in
C1	Footing Thickness	Hand Calc	2	2	15	30	Bottom	16	#3	12	5	#5	5
		STAAD	2	2.33	16.208	37.76	Top	22	#6	11	4	#6	9
							Bottom	16	#7	13	4	#7	11

Strap Footing Design Alternatives

Design	Footing 1 Dimension	Footing 1 Reinforcement	Footing 2 Dimension	Footing 2 Reinforcement	Strap Dimensions	Strap Reinforcement
Hand Calc	4'x4'x2'	4#7 @12" O.C. (both directions)	4'x4'x2'	4#7 @8" O.C. (both directions)	8.875'x3'x2'	3#9 @12" O.C. (flexure)
STAAD	4'x4'x2'	5#6 @7" O.C. (both directions)	2.75'x2.75'x3'	3#8 @12" O.C. (both directions)	8.875'x3'x3'	4#9 @9" O.C. (flexure)

Mat Footing			Foundation Dimensions				Reinforcement Design						
							Location	Longtitudinal			Transverse		
Model	Variable Parameter		Thickness	Width	Length	Area			Size	Spacing		Size	Spacing
			ft	ft	ft	ft^2			#	in		#	in
M1	Footing Thickness	Hand Calc	1	15	16	240	Bottom	20	#14	7	24	#14	7
		STAAD	1	16	16	256							

4.2 Objective 2 Results [Evaluation of Design Alternatives]

The comparison of design alternatives involved the consideration of the three design alternatives for each foundation type. The goal of this design rubric is to highlight several realistic design constraints and compare how each alternative affects the design feasibility. The design rubric does not necessarily determine the best design alternative, but instead helps the designer evaluate the advantages and disadvantages of each design model.

Isolated Spread Footing

When designing the three isolated spread footing models the thickness of the footing and the overall area of the footing was varied. The final designs for the three isolated spread footing models can be seen below in Table 5.

TABLE 5: ISOLATED SPREAD FOOTING DESIGNS

Model	Variable Parameter	Foundation Dimensions				Reinforcement Design		
		Depth	Width	Length	Area	Number	Size	Spacing
		ft	ft	ft	ft^2		#	in
I1	Footing Thickness	3	7	7	49	16	#7	5.00
I2	Footing Thickness	2	7	7	49	16	#7	5.00
I3	Footing Area	4	9	9	81	27	#7	3.00

These models were then evaluated according to the design criteria rubric. This included consideration of ethical standards, health and safety, cost estimates and constructability. The rubric with the isolated spread footing models can be seen below in Table 6.

TABLE 6: DESIGN RUBRIC - ISOLATED SPREAD FOOTINGS

Design Rubric	Isolated Spread Footing		
	I1	I2	I3
Final Design Outputs			
Thickness [ft]	3	2	4
Total Area [ft^2]	49	49	81
Volume concrete [ft^3]	147	98	324
Ethical			
Designed according to ASCE Code of Ethics and Ethical Cannons	Yes	Yes	Yes
Health and Safety			
Designed according to Code Standards	Yes	Yes	Yes
Meets loading requirements of reference structure	Yes	Yes	Yes
Economic			
Cost of Reinforcement	$416.64	$416.64	$903.96
Cost of Concrete	$779.81	$519.87	$1,718.76
Total Cost per Footing	$1,196.45	$936.51	$2,622.72
Total Cost of Reference Structure Foundation	$4,785.79	$3,746.05	$10,490.88
Constructability			
Percentage of structure area	24.38%	24.38%	40.31%
Number of Formwork Setups	4	4	4
Is this foundation typically used in this situation?	Yes	Yes	Yes

Combined Footing

When designing the three combined footing models the thickness of the footing was varied between one and two feet. The final designs for the three combined footing models can be seen below in Table 7.

TABLE 7: COMBINED FOOTING DESIGNS

Model	Variable Parameter	Foundation Dimensions				Reinforcement Design					
						Longitudinal direction			Transverse Direction		
		Thickness	Width	Length	Area		Size	Spacing		Size	Spacing
		ft	ft	ft	ft^2		#	in		#	in
C1	Footing Thickness	2	2	15	30	16	#3	12	5	#5	5.00
C2	Footing Thickness	1	2	15	30	15	#5	12	6	#7	4.00
C3	Footing Thickness	1.5	2	15	30	16	#3	12	6	#5	4.00

These models were then evaluated according to the design criteria rubric. This included consideration of ethical standards, health and safety, cost estimates and constructability. The rubric with the combined footing models can be seen below in Table 8.

TABLE 8: DESIGN RUBRIC - COMBINED FOOTING

Design Rubric	Combined Footing		
	C1	C2	C3
Final Design Outputs			
Thickness [ft]	2	1	1.5
Total Area [ft^{2}]	30	30	30
Volume concrete [ft^{3}]	60	30	45
Ethical			
Designed according to ASCE Code of Ethics and Ethical Cannons	Yes	Yes	Yes
Health and Safety			
Designed according to Code Standards	Yes	Yes	Yes
Meets loading requirements of reference structure	Yes	Yes	Yes
Economic			
Cost of Reinforcement	$901.60	$418.32	$441.18
Cost of Concrete	$318.29	$159.14	$238.72
Total Cost per Footing	$1,219.89	$577.46	$679.90
Total Cost of Reference Structure Foundation	$2,439.78	$1,154.93	$1,359.79
Constructability			
Percentage of structure area	14.93%	14.93%	14.93%
Number of Formwork Setups	2	2	2
Is this foundation typically used in this situation?	Yes	Yes	Yes

Strap Footing

When designing the three strapped footing models the reinforcement design, foundation depth and foundation dimensions were varied. The final designs for the three strapped footing models can be seen below in Table 9.

TABLE 9: STRAPPED FOOTING DESIGNS

Model	Footing 1 Dimension	Footing 1 Reinforcement	Footing 2 Dimension	Footing 2 Reinforcement	Strap Dimensions	Strap Reinforcement
S1	4'x4'x2'	4#7 @12" O.C. (both directions)	4'x4'x2'	4#7 @8" O.C. (both directions)	8.875'x3'x2'	3#9 @12" O.C. (flexure)
S2	3'x3'x3'	5#6 @7" O.C. (both directions)	2.75'x2.75'x3'	3#8 @12" O.C. (both directions)	8.875'x3'x3'	4#9 @9" O.C. (flexure)
S3	3'x3'x3'	3#7 @12" O.C. (both directions)	3'x3'x3'	3#6 @12" O.C. (both directions)	8.875'x3'x2'	5#7 @7" O.C. (flexure)

These models were then evaluated according to the design criteria rubric. This included consideration of ethical standards, health and safety, cost estimates and constructability. The rubric with the strap footing models can be seen below in Table 10

TABLE 10: DESIGN RUBRIC - STRAP FOOTING

Design Rubric	Strap Footing		
	S1	S2	S3
Final Design Outputs			
Thickness [ft]	2	3	3
Total Area [ft^2]	59	43	45
Volume concrete [ft^3]	117	130	107
Ethical			
Designed according to ASCE Code of Ethics and Ethical Cannons	Yes	Yes	Yes
Health and Safety			
Designed according to Code Standards	Yes	Yes	Yes
Meets loading requirements of reference structure	Yes	Yes	Yes
Economic			
Cost of Reinforcement	$238.32	$231.72	$137.98
Cost of Concrete	$621.99	$687.31	$568.94
Total Cost per Footing	$860.31	$919.02	$706.92
Total Cost of Reference Structure Foundation	$1,720.62	$1,838.04	$1,413.84
Constructability			
Percentage of structure area	29.17%	21.49%	22.21%
Number of Formwork Setups	2	2	2
Is this foundation typically used in this situation?	Yes	Yes	Yes

Mat Foundation

When designing the three mat foundation models the reinforcement design, foundation depth and foundation dimensions were varied. The final designs for the three mat foundation models can be seen below in Table 11.

TABLE 11: MAT FOUNDATION DESIGNS

Model	Variable Parameter	Foundation Dimensions				Reinforcement Design					
						Longitudinal direction			Transverse Direction		
		Thickness	Width	Length	Area		Size	Spacing		Size	Spacing
		ft	ft	ft	ft^2		#	in		#	in
M1	Reinforcement	1	16	15	240	20	#14	7	24	#14	7
M2	Footing Thickness	1.5	16	15	240	24	#8	7	25	#8	7
M3	Dimensions	1	15.5	15.5	240	19	#14	7	21	#14	7

These models were then evaluated according to the design criteria rubric. This included consideration of ethical standards, health and safety, cost estimates and constructability. The rubric with the mat foundation models can be seen below in Table 12.

TABLE 12: DESIGN RUBRIC - MAT FOUNDATION

Design Rubric	Mat Foundations		
	M1	M2	M3
Final Design Outputs	TEST	TEST	TEST
Thickness [ft]	1	1.5	1
Total Area [ft^2]	240	240	240.25
Volume concrete [ft^3]	240	360	240.25
Ethical			
Designed according to ASCE Code of Ethics and Ethical Cannons	Yes	Yes	Yes
Health and Safety			
Designed according to Code Standards	Yes	Yes	Yes
Meets loading requirements of reference structure	Yes	Yes	Yes
Economic			
Cost of Reinforcement	$834.48	$1,687.20	$1,153.20
Cost of Concrete	$1,046.49	$1,569.73	$1,047.58
Total Cost per Footing	$1,880.97	$3,256.93	$2,200.78
Total Cost of Reference Structure Foundation	$1,880.97	$3,256.93	$2,200.78
Constructability			
Percentage of structure area	119.42%	119.42%	119.55%
Number of Formwork Setups	1	1	1
Is this foundation typically used in this situation?	Yes	Yes	Yes

4.3 Objective 3 Results [Creation of User Tips Manual]

To create the user tip manual, STAAD.*foundation* was looked at in great detail. Tutorial videos and examples provided by the software were explored to best develop a user manual that can show a designer how to create and analyze specific foundations depending on the project's need. Essentially, should Stantec hire a new employee, this user manual would provide them with enough information to learn the fundamentals of the program. The user tips manual outlines proper methodology to use and setup various foundations and is in the form of a Microsoft PowerPoint. The PowerPoint has a table of contents which acts as chapters for each foundation design, limits and optimizations within the program section, importing and exporting within the program, and a tips and tricks section.

Within the program, it was found that the output solves for the minimum constraints inputted by the designer. Although this is more cost effective, the designer needs to make sure the appropriate checks are made before the final design is completed. STAAD.*foundation* software does not use the absolute value of forces. It does not pick the largest shear force and does not consider negative answers. It was found that when importing from STAAD.*pro* into STAAD.*foundation* that the designer will be asked to rename all jobs in order to assign loading to the job. When exporting STAAD.*foundation* output into Microsoft Excel, the export is exact other than having to widen the columns to view the equations and output in the spreadsheet.

There were also errors discovered in the sizing and spacing of reinforcement. While the program tended to offer a reasonable amount of reinforcement, there were several designs of reinforcement that would lead to cracking of the foundation, or to reinforcement that would not fit within the dimensions of the foundation.

5.0 Deliverable

To create the deliverable for Stantec, a standard operations was provided by them and followed until completion. The team met and worked with Ryan Hill (EIT) to ensure that the deliverable was up to standard with the company. The deliverable contains a table of contents, a purpose, applicable codes and standards section, definitions, design criteria, and an appendix. The purpose defines the needs and specifics of the project. The deliverable will be printed and then compiled into a binder so that Stantec has a hard copy of it. In the appendix of the deliverable, the user can see the User Tip Manual, all of the hand calculations, and spread sheets of each specific foundation design used to verify the validity of STAAD.*foundation*, and examples of automated design outputs generated by the software. These outputs were used for comparison checks to hand calculations and helped provide a basis for analysis of feasibility and accuracy of the software as a design aid. Furthermore, the deliverable will include tips for optimization of the designs through parameter manipulation within the software. The deliverable can be used by any employee in the office that will be new to or using STAAD.*foundation*. The deliverable is included as a supporting document to this MQP project.

6.0 Conclusions

6.1 Objective 1 Conclusions [Investigation of STAAD.foundation]

Several steps were taken in order to verify the automated calculations run within STAAD.foundation. This process was aided by the use of an excel spreadsheet in order to iterate several designs quickly. The functionality and accuracy of the spreadsheet was verified against hand calculations. When designing these footings, checks against sliding, overturning, and direct and punching shear were considered. For each type of foundation a comparison of the outputs from the Excel spreadsheets and STAAD.*foundation* was conducted. The limitation found for each foundation type are discussed below.

Isolated Footing Design Optimization

Through hand calculations, the design process and accuracy has been verified for the design of an isolated footing in STAAD.foundation. However, through testing the program, it has been found that the most effective design alternative is not automatically designed through the software analysis unless the design parameters are sufficiently constrained. For example, the program seems to almost always design to match the minimum selected thickness as highlighted to the right in Figure 4. Also noted in the figure are the length with ratio and the set as default option. The length with ratio was kept at 1 throughout our testing in order to assure the design of square footing. Additionally, when "No" is chosen for set to default, the program is supposed to optimize the design. Although this option helped in making the design more feasible, constraining other variables such as the reinforcement sizing and spacing was necessary in order to produce the most effective design.

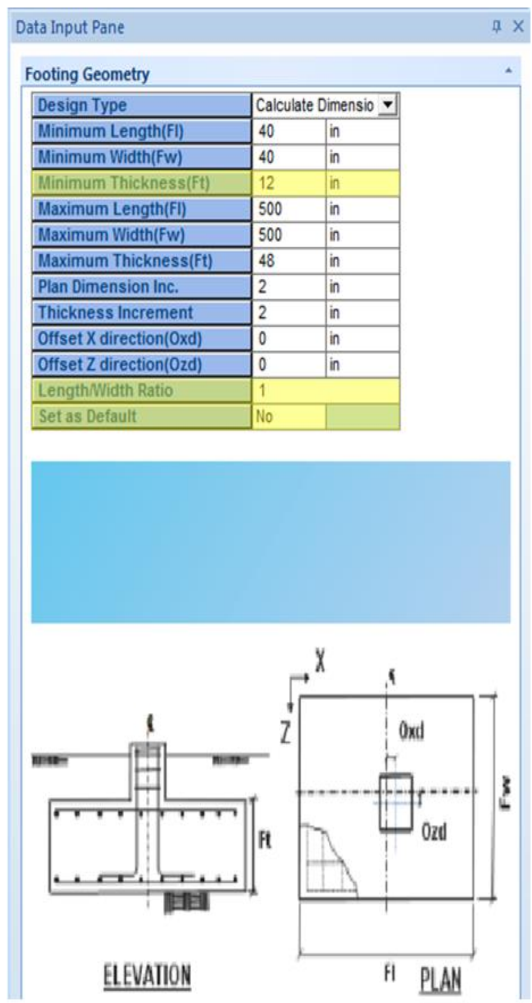


FIGURE 4: FOOTING GEOMETRY INPUT PANE IN STAAD.*FOUNDATION*

Another major issue within the automated analysis is the lack of consideration to negative forces when the governing loading is chosen. For example, when the design is analyzed, a 3.059 kip force will govern over a -3.134 kip force. Although this may be a negligible difference for this case, it may become an issue in which there is a more severe difference in the forces.

Overall, when using the design analysis for an isolated footing, it is up to the engineer to constrain the ranges to what he/she finds appropriate. For example, upon completion of an analysis, the designer may notice a large number of a small sized rebar is used, which may pose feasibility and constructability issues. For this reason, the designer may have to further constrain the design parameters in order to achieve a more economical result.

Combined Footing Design Optimization

When considering the optimization of a combined footing through design analysis in STAAD.foundation, several similarities in feasibility and reliability that were observed for and isolated footing are also noted for the isolated design. These parameters that generally need constraining include footing thickness, rebar spacing and sizing, and the width of the footing. More specific to a combined footing would be consideration to the minimum overhang, which is highlighted to the right in Figure 5. The default for this was five feet, which was far too larger for the testing case. In order to obtain a more reasonable result, the minimum was lowered to one foot and an over more feasible footing size was generated by the design analysis.

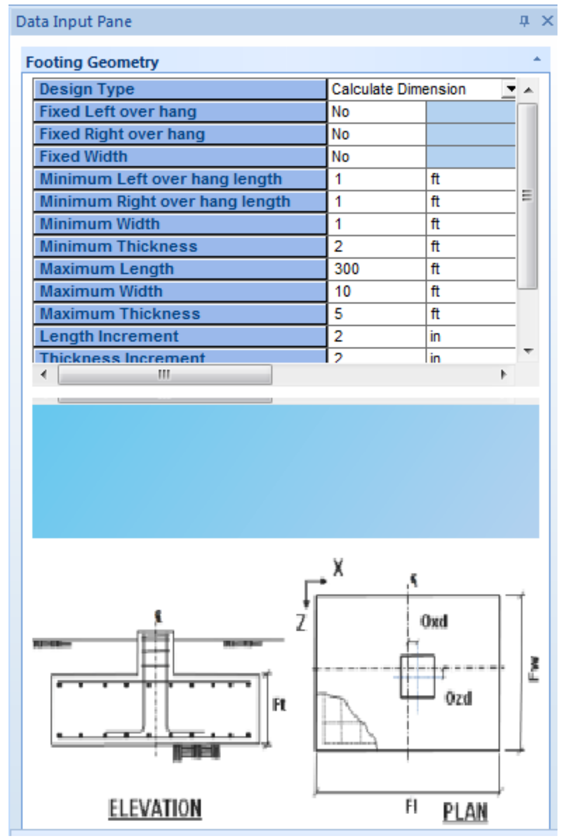
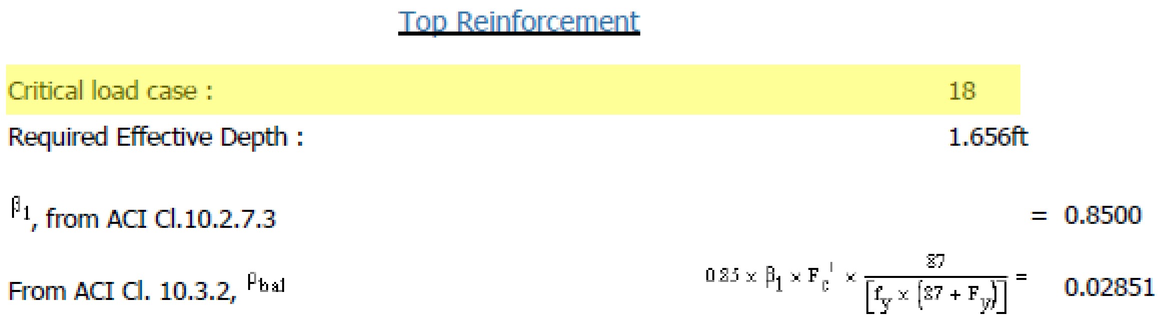


FIGURE 5: FOOTING GEOMETRY INPUT PANE

Another notable issue when reviewing the design sheet was the designation of an alpha value when calculating the factored allowable shear. The designated footing was designed for an exterior column and the designated value was chosen for an interior column. Although this was a negligible factor in this case, for more extreme shears in place, using a factor of 40 instead of 20 (in this case) could provide an adequate design where in reality the footing may fail.

Additionally, when verifying the designated governing loading cases for analysis there are some discrepancies between the hand calculations and STAAD.*foundation* output. Although the calculated shears are similar to the program output, the calculation sheet references a critical load case that is not defined within the project. This is shown below in Figure 6 which in this case was load case 18. Although this is a technical issue opposed to a design concern, it complicates the designer's ability to address and pinpoint flaws within the program.



Top Reinforcement

Critical load case :	18
Required Effective Depth :	1.656ft

β_1, from ACI Cl.10.2.7.3 $= 0.8500$

From ACI Cl. 10.3.2, ρ_{bal} $\quad 0.85 \times \beta_1 \times F_c' \times \frac{87}{\left[f_y \times \left(87 + F_y\right)\right]} = 0.02851$

FIGURE 6: COMBINED FOOTING CALCULATION SHEET

Strap Footing Design Optimization

Unlike previous foundation models, the design analysis for strap footing does not seem to design in accordance with the minimum defined design constraints. Although some dimensions of the design seem reasonable, the width of the footings within the design was too large, regardless of constraining the parameters. After analyzing and the calculation sheet produced within STAAD.foundation, there has been no conclusion as to why the designated width is far larger than necessary. For this reason, it is inadvisable to rely heavily on this design analysis for a strap design.

Mat Foundation

Validation of mat foundation designs proved to be more complicated than previous models due to the complexity of loads applied to the concrete and analysis process. In the hand calculation, the rigid method was used to create design alternatives, whereas computer analysis uses the finite method in order to create a more accurate, in depth representation of the forces across the mat. However, by comparing our results with the STAAD.foundation calculation sheet, it appears that the program is using reasonable dimensions and reinforcement when producing a design. A notable issue that may occur is spacing of reinforcement, which has been noted in other designs produced by the program. There is a tendency for the program’s automated analysis to provide spacing beyond the maximum bound, providing a design alternative with reinforcement which exceeds the length of the foundation.

6.2 Objective 2 Conclusions [Evaluation of Design Alternatives]

Each foundation model designed by the team was rated according to the design criteria rubric. Since the majority of the foundation models were feasible designs, and each foundation type has its advantages and disadvantages, the design comparison was not intended to establish the top ranking design. Instead, this rubric was intended to establish a side by side comparison for realistic design constraints that might be considered by a professional engineer.

The design rubric included ranking the designs based on ethical standards, health and safety, cost estimates and constructability. Each of the models designed is capable of sustaining the loads from the reference structure. Therefore, each isolated footing, combined footing, strap footing and mat foundation models meets the requirements for health and safety and also complies with relevant building codes. The team compared the material, labor and equipment cost to find the design with the optimal economic price. This comparison was done to find the most cost effective design for each type of foundation. The most economic designs from each foundation were then compared to determine the lowest cost design from all the design models. The most economic design for isolated footings was model I2, costing $3746.05. The most economic design for combined footings was model C2, costing $1154.93. The most economic design for strap footings was S3, costing $1413.84 and the most economic design for mat foundations was model M1, costing $1880.97. Out of these designs, model C2 for combined footing was the most cost effective design. For constructability criteria, the team considered the total area of the foundation in comparison to the reference structure, the number of formwork required to construct the foundation, and if the foundation type is suitable for project situation. All of the isolated footing models were above the limit of 20%. This means that these isolated foundation design take up a large percentage of the total reference structure, making them an unrealistic design. Each of the combined footings and strapped footings have an area of less than the limit of 50% the reference structure area. The models for the mat foundation each have an area between the required limits of 100% to 120% of the reference structure. This makes combined footings, strap footings and mat foundations variable options for the foundation design.

6.3 Objective 3 Conclusions [Creation of User Tips Manual]

The User Tips Manual and Stantec Deliverable provides the firm with viable information on STAAD.*foundation.* In the User Tips Manual, a table of contents is provided. Here, the designer can find tips on how to design specific foundations such as mat, spread, and isolated footings. The user can click the chapter needed to design the foundation and follow the detailed steps specified in the manual. By comparing hand calculations to the software's output, limits and optimizations that were found in the program are also specified in the deliverable. Stantec employees will be able to use this manual as a guide when first learning how to use STAAD.*foundation.* This guide will be most beneficial to Structural Engineers who will most likely be using this software for structural analysis.

It was found that STAAD.*foundation*'s output designs for the minimum structure required. Although this is more cost effective, it is not necessarily the best design choice as different loadings and more logical design alternatives can be used. Therefore, always follow up with calculations alongside the program's output. The program also limits reinforcement bar spacing between six and twelve inches. Therefore, STAAD.*foundation* needs to implement more realistic constraints. The program also limits itself by not using absolute values of shear stress; meaning the program does not choose the largest shear, whether negative or not, when analyzing the design. Reinforcement of the foundations poses an additional problem by designing in such a way that the steel bars are spaced far enough apart so they either will not satisfy cracking requirements, or will actually be located outside of the boundaries of the structure.

The User Tips Manual provides useful information about importing and exporting other Building Information Modeling and Microsoft Excel to and from STAAD.*foundation*. It was found that when importing into STAAD.*foundation*, the designer will need to rename the description of every load brought into the program. If the analysis is not completed, STAAD.*foundation*'s output will automatically fail. To export STAAD.*foundation*'s output successfully into Excel, the designer will need to choose the "Detail Output" option to get a better formatted shear, punching, sliding, and overturning spreadsheet. Copying and pasting the output into Excel will also work, however, the width of the columns in Excel will need to be adjusted.

The User Tips Manual and Deliverable also include helpful tips and tricks within STAAD.*foundation*. This includes creating line, quadrilateral, point, and circular pressure loading to different points on a mat foundation. Also, how to remove certain shapes from the mat foundation, should you need to, is specified within this chapter.

6.4 Project Limitations

There were several limitations encountered by the team throughout the course of this project. The most restricting being the limited time to complete the project. Since the team had just a few weeks to complete the project, it was necessary to focus the team's efforts on a few specific foundations types. STAAD.*foundation* has the capability to design more foundation designs than what could be included in the project scope. This investigation focused on isolated footings, combined footings, strap footings and mat foundations. Any future inquiries into STAAD.*foundation* should further analyze piles and pile caps, octagonal footings, and rotating/reciprocating machine foundations.

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8.0 Appendices

Appendix A: Team Information Sheet

Location: Stantec office, located in Boston, MA

WPI Students: Dominick Bossalini (CE '15), Paul Buchanan (CE '15), Margaret Freed (CE '15), Dylan Heinricher (CE '15)

Stantec Project Advisors: Greg Cuetara (Senior Structural Engineer), Dennis Keough (Senior Engineering Consultant – Power Team), Ryan Hill (Structural EIT – Power Team)

WPI Advisors and Co-Directors: Leonard Albano (CE Professor), Frederick Hart (CEE Professor)

Sponsor: Stantec

Optimization of Foundation Design Using STAAD.*foundation* Software

The Power Group at Stantec has previously worked with several different foundation software programs. The company is interested in the investigation of STAAD.*foundation* in order to determine range of applicability and reliability within the software package. By engaging in a parametric study of STAAD.*foundation*, it will be possible to determine the reliability of the software and identify any potential limitations. This involves the use of STAAD.*pro* in order to construct a structural steel model and perform the necessary structural analysis. Once the reaction forces from STAAD.*pro* are computed, they will be applied to design various foundation types. In order to quantify the effectiveness and reliability of STAAD.*foundation*, foundation types are designed through hand calculations and then verified through the STAAD.*foundation* program.

Appendix B: Stantec Consulting Ltd. Project Overview

Stantec

WPI Capstone Project
Spring 2015

Stantec is an engineering and architectural firm mainly located in the United States and Canada. There are currently over 14,000 employees broken down into many sectors such as transportation, environmental services, industrial and power, and building services.

Stantec's industrial and power sector is looking for a way to streamline the way they design their foundations. Currently Stantec structural engineers in the power and industrial sector use software called Staad.pro to design and code check a variety of different structures ranging from a simple pipe support to structures containing hundreds of tons of steel. Typically after a structural model has been completed, Stantec engineers review their results from the Staad.pro analysis and take its reactions to design foundations, footings, or pile caps either by hand or using some other piece software depending on the size of the structure being analysed. This approach has been proven to be not very efficient and Stantec is looking to simplify this process and hopes utilizing Staad Foundation for their projects will help achieve this.

Many of Stantec's engineers have yet to learn how to use Staad Foundation since its analysis and results have not been verified by Stantec personnel nor does a step-by-step instruction manual exist for staff training.

Objective: Verify Staad Foundation analysis and develop step-by-step instructions for exporting a Staad.pro model into Staad Foundation and designing the foundation. This step-by-step instruction manual will be used to train Stantec engineers on how to use and trust Staad Foundation for their own designs.

Tasks to be completed:

1.) Learn basic Staad.pro skills to develop several small structural models to be used to verify Staad Foundation analysis. Each structure created will be founded on different styles of foundations including a concrete slab or mat foundation, combined or spread footings, and pile caps. Use load combinations from ASCE7-10 or IBC 2012 and include both vertical and horizontal loads in your analysis.

2.) Export reactions from the Staad.pro models created, import them into Staad Foundation and develop preliminary foundation sizes for each structure.

3.) Use Staad foundation to check and resize foundations as necessary for stability including bearing, overturning, and sliding. Use 5 ksf as an allowable bearing pressure capacity and proper factors of safety.

4.) Develop stability calculations using MathCAD to show that foundations checks in Staad Foundation are being executed properly. Make sure to be detailed and use plenty sketches in your analysis.

5.) Use Staad Foundation to check and size foundation reinforcing. Check foundation for bending, one-way and two-way shear.

Stantec

6.) Develop concrete strength calculations using MathCAD to show that reinforcing in Staad Foundation is being completed correctly.

7.) Once Staad Foundation results have been verified, use a Staad.pro model provided by Stantec to design a slab or mat foundation using Staad Foundation. Your design will be compared to the actual designed foundation. Stantec will provide further details design criteria when this step is reached.

8.) Provide detailed step-by-step instructions for exporting a Staad.pro model into Staad Foundation and show how to set up parameters in Staad Foundation so it will analyse the foundation for both stability and strength. These step-by-step instructions will be used by Stantec engineers to design their foundations in the future. Make sure to use plenty of screenshots as part of this instruction package.

For questions regarding any of the tasks to be completed, please contact any of the Stantec staff listed below.

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Appendix C: Load Cases from STAAD.*pro* Reference Structure

Spread Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Data Input

1.0 Load Combinations

Node			Combination	F_x	F_y	F_z
642						
			1 DEAD LOAD	0.101	8.631	0.036
			20 WIND N-S	0.038	5.069	1.932
			21 WIND S-N	0.038	5.069	1.932
			22 WIND E-W	3.312	8.456	0.021
			23 WIND W-E	3.312	8.456	0.021
			100 DL	0.101	8.631	0.036
			110 D + W N-S	0.063	3.562	1.896
			111 D + W S-N	0.138	13.701	1.968
			112 D + W E-W	3.413	17.087	0.057
			113 D + W W-E	3.212	0.176	0.014
			120 0.6 DL + W N-S	0.023	0.109	1.911
			121 0.6 DL + W S-N	0.098	10.248	1.953
			122 0.6 DL + W E-W	3.373	13.635	0.043
			123 0.6 DL + W W-E	3.252	3.277	0
			200 1.4 DL	0.141	12.084	0.05
			210 1.2 DL + 1.6 W N-S	0.06	2.247	3.049
		CONTROLS Z	211 1.2 DL + 1.6 W S-N	0.181	18.469	3.134
CONTROLS X	CONTROLS Y		212 1.2 DL + 1.6 W E-W	5.42	23.887	0.077
			213 1.2 DL + 1.6 W W-E	5.179	3.171	0.009
			220 0.9 DL + 1.6 W N-S	0.03	0.343	3.059
			221 0.9 DL + 1.6 W S-N	0.151	15.879	3.123
			222 0.9 DL + 1.6 W E-W	5.39	21.298	0.066
			223 0.9 DL + 1.6 W W-E	5.209	5.761	0.002

643						
			1 DEAD LOAD	0.1	8.631	0.036
			20 WIND N-S	0.038	5.069	1.932
			21 WIND S-N	0.038	5.069	1.932
			22 WIND E-W	3.312	8.456	0.021
			23 WIND W-E	3.312	8.456	0.021
			100 DL	0.1	8.631	0.036
			110 D + W N-S	0.138	13.701	1.968
			111 D + W S-N	0.063	3.562	1.897
			112 D + W E-W	3.413	17.087	0.057
			113 D + W W-E	3.212	0.176	0.014
			120 0.6 DL + W N-S	0.098	10.248	1.953
			121 0.6 DL + W S-N	0.023	0.109	1.911
			122 0.6 DL + W E-W	3.373	13.635	0.043
			123 0.6 DL + W W-E	3.252	3.277	0
			200 1.4 DL	0.141	12.084	0.05
		CONTROLS Z	210 1.2 DL + 1.6 W N-S	0.181	18.469	3.134
			211 1.2 DL + 1.6 W S-N	0.06	2.247	3.049
CONTROLS X	CONTROLS Y		212 1.2 DL + 1.6 W E-W	5.42	23.887	0.077
			213 1.2 DL + 1.6 W W-E	5.179	3.172	0.009
			220 0.9 DL + 1.6 W N-S	0.151	15.879	3.123
			221 0.9 DL + 1.6 W S-N	0.03	0.343	3.059
			222 0.9 DL + 1.6 W E-W	5.39	21.298	0.066
			223 0.9 DL + 1.6 W W-E	5.209	5.761	0.002

671						
			1 DEAD LOAD	0.1	8.633	0.036
			20 WIND N-S	0.037	5.07	1.932
			21 WIND S-N	0.037	5.07	1.932
			22 WIND E-W	3.312	8.456	0.021
			23 WIND W-E	3.312	8.456	0.021
			100 DL	0.1	8.633	0.036
			110 D + W N-S	0.063	3.563	1.896
			111 D + W S-N	0.138	13.702	1.967
			112 D + W E-W	3.211	0.177	0.014
			113 D + W W-E	3.412	17.088	0.057
			120 0.6 DL + W N-S	0.023	0.11	1.911
			121 0.6 DL + W S-N	0.098	10.249	1.953
			122 0.6 DL + W E-W	3.251	3.276	0
			123 0.6 DL + W W-E	3.372	13.635	0.043
			200 1.4 DL	0.141	12.086	0.05
			210 1.2 DL + 1.6 W N-S	0.061	2.248	3.048
		CONTROLS Z	211 1.2 DL + 1.6 W S-N	0.18	18.471	3.134
			212 1.2 DL + 1.6 W E-W	5.178	3.17	0.009
CONTROLS X	CONTROLS Y		213 1.2 DL + 1.6 W W-E	5.419	23.888	0.077
			220 0.9 DL + 1.6 W N-S	0.031	0.342	3.059
			221 0.9 DL + 1.6 W S-N	0.15	15.881	3.123
			222 0.9 DL + 1.6 W E-W	5.208	5.76	0.002
			223 0.9 DL + 1.6 W W-E	5.389	21.298	0.066

672						
			1 DEAD LOAD	0.101	8.633	0.036
			20 WIND N-S	0.037	5.07	1.932
			21 WIND S-N	0.037	5.07	1.932
			22 WIND E-W	3.312	8.456	0.021
			23 WIND W-E	3.312	8.456	0.021
			100 DL	0.101	8.633	0.036
			110 D + W N-S	0.138	13.702	1.968
			111 D + W S-N	0.063	3.563	1.896
			112 D + W E-W	3.211	0.177	0.014
			113 D + W W-E	3.412	17.088	0.057
			120 0.6 DL + W N-S	0.098	10.249	1.953
			121 0.6 DL + W S-N	0.023	0.11	1.911
			122 0.6 DL + W E-W	3.251	3.276	0
			123 0.6 DL + W W-E	3.372	13.635	0.043
			200 1.4 DL	0.141	12.086	0.05
		CONTROLS Z	210 1.2 DL + 1.6 W N-S	0.18	18.471	3.134
			211 1.2 DL + 1.6 W S-N	0.061	2.248	3.048
			212 1.2 DL + 1.6 W E-W	5.178	3.17	0.009
CONTROLS X	CONTROLS Y		213 1.2 DL + 1.6 W W-E	5.419	23.888	0.077
			220 0.9 DL + 1.6 W N-S	0.15	15.881	3.123
			221 0.9 DL + 1.6 W S-N	0.031	0.342	3.059
			222 0.9 DL + 1.6 W E-W	5.208	5.76	0.002
			223 0.9 DL + 1.6 W W-E	5.389	21.299	0.066

1.1 Summary - Controlling Forces

Node	fx	fy	fz
642	5.42	23.887	3.134
643	5.42	23.887	3.134
671	5.419	23.888	3.134
672	5.419	23.888	3.134

Appendix D: Excel Spreadsheet – Isolated Spread Footing Models

Model: I1

		Spread Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

Footing

Length	7 ft
Width	7 ft
Thickness	3 ft
Depth to base	3 ft
Column Spacing	0 ft

Pedestal *PEDESTAL NOT USED*

Height	0 ft
Length	0 ft
Width	0 ft

Reinforcement

Size	# 7
Number	16
Spacing	5 in
Reinforcement	Bottom Reinforcement Only

		Spread Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

CHECKS:

1.0 Load & Sizing

NODE: 642

Check 1: OKAY!

Check 2: OKAY!

Check 3: OKAY!

1.1 Shear

Check 1: OKAY!

Check 2: OKAY!

1.2 Overturning

Check 1: OKAY!

1.3 Sliding

Check 1: OKAY!

Spread Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Data

1.0 Loads

Axial Load	23.887	kip	Downward Loading
Factored	28.6644		Downward Loading LRFD

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
λ	1		Normal Weight Concrete
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction

1.2 Allowable Soil-Bearing Pressure

q_{a}	4000	psf	Allowable Soil Pressure
q_{eff}	3550		Effective Soil Pressure

1.3 Type of Footing

h	3	ft	Depth to base of Footing
Type	Shallow		Shallow or Deep Footing

Footing Dimensions

2.0 Determine Control Footing Area*

Area 1	7	ft^2	
$Length_{Area1}$	2.6	ft	Minimum length of side Req'd from Area1
Length Reqd	6.813		Largest Req'd Length from Checks
Length Side 1	7	ft	
Length Side 2	7	ft^2	
Area Used	49	ft^2	

Thickness of Footing & Pedestal - Uplift Check

3.0 Initial Data

t_{min}		ft	Minimum thickness Hand Calced
t	3	ft	Selected thickness
D_{bew}	0	ft	Depth below water to top footing

γ_w	62.4	pcf	Unit weight of Water
FS_{up}	1.1		Factor of Safety for Uplift
u	187.2	lbs	Uplift Pressure
P_{up}	9.17	ksf	Uplift force
FP_{up}	11.01		Factored Uplift Force (1.2DL) LRFD
h_{soil}	0	ft	

3.1 Pedestal Size (Assumed-Can equal zero unless underground)

B_{tp}		ft	Transverse Width of Pedestal
B_{lp}		ft	Longitudinal Width of Pedestal
h_{ped}		ft	Height of Pedestal
W_{soil}	0	kips	Weight of soil above footing

Rebar

4.0 Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

4.1 Loads

qn	0.5850		
M_u =	19.47	ft - kips / b_w	Applied Moment

4.2 Reinforcing

	Layers	Bottom Reinforcement Only		
	Cover	3	in	Clear Cover - All Sides
	Width	12	in	
	As_1	8.650	in^2	Area of Steel 1
	As_2	9.1175	in^2	Area of Steel 2
	Ru	0.003	ksi	
	w	5.14E-05		
	ρ	0.000003		
	As_3	0.010	in^2	Area of Steel 3
	As_{min}	9.1175	in^2	Minimum Area of Steel
	Size	# 7		Size of Steel Reinforcing
	n	15.196		Number of Bars used to achieve Asmin
	n_{used}	16		Number of Bars used
	S_{max}	5.2	in	Maximum Allowable Spacing
Check	Spacing	5	in	
	Check:	**OKAY!**		Spacing<Smax

4.3 Rebar Provided

d =	32.56 in
As / b_w =	1.44 in^2

4.4 Moment Design

a =	2.12 in
ΦMn =	204.14 ft - kips / b_w
	CHECK: Moment Design Acceptable

4.5 Minimum Reinforcement Requirements

Reinf **Yes** — Reinf. Prov'd 1/3 Greater than Req'd

$A_{s\ t\&s}$	0.78 in^2	Temp. & Shrinkage Steel
$A_{s\ flex}$	in^2	Flexural
$As / b_{w\ prov'd}$	1.44 in^2	
$As / b_{w\ req'd}$	0.78 in^2	

Spread Footing Shear Check

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Data Input

1.0 Loading

Col_{wt}	0.15	kips	Column Weight
P_{uShear}	28.8444	kips	Factored Loads (LRFD)
Net_{Up}	0.589	ksf	Net Upward Pressure

1.1 Reinforcement

Size	0.875	in	Bar Size
Cover	3.00	in	Cover Depth
d	32.56	in	Reinforcement Depth

1.2 Critical Section

Cs	10	in	Column Side
c_1+d	42.5625	in	Critical Section
c_2+d	3.547	ft	Critical Section
b_0	170.25	in	

Shear

2.0 Shear & Footing Thickness

β	1		Shape Parameter
Vu	21.44	kips	
ϕ	0.85		
αs	40		Select Column Location
d_1	0.390	inch	Acceptable depth from 2 Way Shear
d_2	0.306	inch	Acceptable depth from 2 Way Shear
d_3	0.586	inch	Acceptable depth from 2 Way Shear

CHECK — CHECK: **OKAY!**

2.1 One Way Shear

	d_4	0.370	ft	Acceptable Depth from 1 Way Shear
	V_{u1}	1.5	kips	
CHECK	d_{OneWay}	0.169	inch	

CHECK: **OKAY!**

2.2 Bending Moment

B_{MEdge}	3.083	ft
M_{uBend}	19.6	k-ft

		Spread Footing Overturning Check		
DATE:	2/6/2015		**DESIGN #:**	**1**
PASS:	**YES**		**CHECK:**	DH

Overturning

1.0 Initial Conditions

V_t	3.134	kip	Governing Load Case
μ	0.5		
$Load_{Total}$	45.937	kip	
$FS_{Overturning}$	1.5		

1.1 Overturning Calculations

M_x	9.402	k-ft	Governing Moment
M_r	160.780	k-ft	Resisting Moment
Mr/Mx	17.101		
Check:	**OKAY!**		

		Spread Footing Sliding Check		
DATE:	2/6/2015		**DESIGN #:**	1
PASS:	**YES**		**CHECK:**	DH

DATA INPUT

1.0 Forces

DF_{shear}	5.42	kips	Disturbing Force (x-shear)
$FS_{sliding}$	1.5		Factor of Safety - Sliding
$Axial_{sliding}$	23.887	kips	Axial Downward Force
μ	0.5		Coefficient of Friction
Wc	0.15	kips	Self Weight

1.1 Sliding Calculations

	Fs_{force}	8.13	kips	
	$b^2_{sliding}$	46.416		Area of footing - Minimum
	$bmin_{sliding}$	6.813		
CHECK	$b_{sliding}$	7		Selected length of footing

CHECK: **OKAY!**

Reinforcement Reference

ASTM STANDARD REINFORCING BARS			
SIZE #	Nominal Dia. (in)	Nominal Area (in^2)	Nominal Weight (lb/ft)
# 3	0.375	0.11	0.376
# 4	0.5	0.2	0.668
# 5	0.625	0.31	1.043
# 6	0.75	0.44	1.502
# 7	0.875	0.6	2.044
# 8	1	0.79	2.67
# 9	1.278	1	3.4
# 10	1.27	1.27	4.303
# 11	1.41	1.56	5.313
# 14	1.693	2.25	7.65
# 18	2.257	4	13.6
N/A			

Top & Bottom Reinforcement	T & B	2
Bottom Reinforcement Only	Bott.	1

Model: I2

		Isolated Footing		
DATE:	2/28/2015		DESIGN #:	2
PASS:	YES		CHECK:	DCB

Footing

Length	7 ft
Width	7 ft
Thickness	2 ft
Depth to base	2 ft
Column Spacing	0 ft

Pedestal *PEDESTAL NOT USED*

Height	0 ft
Length	0 ft
Width	0 ft

Reinforcement

Size	# 7
Number	16
Spacing	5 in
Reinforcement	Bottom Reinforcement Only

		Isolated Footing		
DATE:	2/28/2015		DESIGN #:	2
PASS:	YES		CHECK:	DCB

CHECKS:

1.0 Load & Sizing

NODE: 642

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

1.1 Shear

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.2 Overturning

Check 1:	**OKAY!**

1.3 Sliding

Check 1:	**OKAY!**

Isolated Footing			
DATE:	2/28/2015	DESIGN #:	2
PASS:	YES	CHECK:	DCB

Data

1.0 Loads

Axial Load	23.887	kip	Downward Loading
Factored	28.6644		Downward Loading LRFD

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
λ	1		Normal Weight Concrete
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction

1.2 Allowable Soil-Bearing Pressure

q_{allo}	4000	psf	Allowable Soil Pressure
q_{eff}	3700		Effective Soil Pressure

1.3 Type of Footing

h	2	ft	Depth to base of Footing
Type	Shallow		Shallow or Deep Footing

Footing Dimensions

2.0 Determine Control Footing Area*

Area 1	6	ft^2	
$Length_{Area1}$	2.5	ft	Minimum length of side Req'd from Area1
Length Reqd	6.813		Largest Req'd Length from Checks
Length Side 1	7	ft	
Length Side 2	7	ft^2	
Area Used	49	ft^2	

Thickness of Footing & Pedestal - Uplift Check

3.0 Initial Data

t_{min}		ft	Minimum thickness Hand Calced
t	2	ft	Selected thickness
D_{bgw}	0	ft	Depth below water to top footing
γ_w	62.4	pcf	Unit weight of Water

FS_{up}	1.1		Factor of Safety for Uplift
u	124.8	lbs	Uplift Pressure
P_{up}	6.12	ksf	Uplift force
FP_{up}	7.34		Factored Uplift Force (1.2DL) LRFD
h_{soil}	0	ft	

3.1 Pedestal Size (Assumed-Can equal zero unless underground)

B_{tp}		ft	Transverse Width of Pedestal
B_{lp}		ft	Longtitudinal Width of Pedestal
h_{ped}	0	ft	Height of Pedestal
W_{soil}	0	kips	Weight of soil above footing

Rebar

4.0 Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

4.1 Loads

qn	0.5850		
M_u =	19.47	ft - kips / b_w	Applied Moment

4.2 Reinforcing

	Layers	Bottom Reinforcement Only		
	Cover	3	in	Clear Cover - All Sides
	Width	12	in	
	As_1	5.462	in^2	Area of Steel 1
	As_2	5.7575	in^2	Area of Steel 2
	Ru	0.007	ksi	
	w	1.29E-04		
	ρ	0.000009		
	As_3	0.017	in^2	Area of Steel 3
	As_{min}	5.7575	in^2	Minimum Area of Steel
	Size	# 7		Size of Steel Reinforcing
	n	9.596		Number of Bars used to achieve Asmin
	n_{used}	16		Number of Bars used
	S_{max}	5.2	in	Maximum Allowable Spacing
Check	Spacing	5	in	
	Check:	OKAY!		Spacing<Smax

4.3 Rebar Provided

d =	20.56 in
As / b_w =	1.44 in^2

4.4 Moment Design

a =	2.12 in
ΦMn =	126.38 ft - kips / b_w
	CHECK: **Moment Design Acceptable**

4.5 Minimum Reinforcement Requirements

Reinf **Yes** Reinf. Prov'd 1/3 Greater than Req'd

$A_{s\,t\&s}$	0.52 in^2	Temp. & Shrinkage Steel
$A_{s\,flex}$	in^2	Flexural
$As / b_{w\,prov'd}$	1.44 in^2	
$As / b_{w\,req'd}$	0.52 in^2	

	Isolated Footing		
DATE:	2/28/2015	**DESIGN#:**	2
PASS:	**YES**	**CHECK:**	DCB

Data Input

1.0 Loading

Col_{wt}	0.15	kips	Column Weight
P_{uShear}	28.8444	kips	Factored Loads (LRFD)
Net_{up}	0.589	ksf	Net Upward Pressure

1.1 Reinforcement

Size	0.875	in	Bar Size
Cover	3.00	in	Cover Depth
d	20.56	in	Reinforcement Depth

1.2 Critical Section

Cs	10	in	Column Side
c_1+d	30.5625	in	Critical Section
c_1+d	2.547	ft	Critical Section
b_o	122.25	in	

Shear

2.0 Shear & Footing Thickness

β	1		Shape Parameter
Vu	25.03	kips	
ϕ	0.85		
αs	40		Select Column Location
d_1	0.635	inch	Acceptable depth from 2 Way Shear
d_2	0.566	inch	Acceptable depth from 2 Way Shear
d_3	0.952	inch	Acceptable depth from 2 Way Shear

CHECK — **CHECK:** **OKAY!**

2.1 One Way Shear

d_4	1.370	ft	Acceptable Depth from 1 Way Shear
V_{u1}	5.6	kips	
d_{OneWay}	0.625	inch	

CHECK

CHECK: **OKAY!**

2.2 Bending Moment

B_{Wedge}	3.083	ft
M_{uBend}	19.6	k-ft

	Isolated Footing		
DATE:	2/28/2015	DESIGN #:	2
PASS:	YES	CHECK:	DCB

Overturning

1.0 Initial Conditions

V_z	3.134	kip	Governing Load Case
μ	0.5		
$Load_{Total}$	38.587	kip	
$FS_{Overturning}$	1.5		

1.1 Overturning Calculations

M_x	6.268	k-ft	Governing Moment
M_r	135.055	k-ft	Resisting Moment
Mr/Mx	21.547		
Check:	**OKAY!**		

	Isolated Footing		
DATE:	2/28/2015	DESIGN #:	2
PASS:	YES	CHECK:	DCB

DATA INPUT

1.0 Forces

DF_{shear}	5.42	kips	Disturbing Force (x-shear)
$FS_{sliding}$	1.5		Factor of Safety - Sliding
$Axial_{sliding}$	23.887	kips	Axial Downward Force
μ	0.5		Coefficient of Friction
Wc	0.15	kips	Self Weight

1.1 Sliding Calculations

	Fs_{force}	8.13	kips	
	$b^2_{sliding}$	46.416		Area of footing - Minimum
	$bmin_{sliding}$	6.813		
CHECK	$b_{sliding}$	7		Selected length of footing
	CHECK:	**OKAY!**		

Model: I3

	Isolated Footing		
DATE:	2/28/2015	DESIGN #:	2
PASS:	YES	CHECK:	DCB

Footing

Length	9 ft
Width	9 ft
Thickness	4 ft
Depth to base	1 ft
Column Spacing	0 ft

Pedestal *PEDESTAL NOT USED*

Height	0 ft
Length	0 ft
Width	0 ft

Reinforcement

Size	# 7
Number	27
Spacing	3 in
Reinforcement	Bottom Reinforcement Only

	Isolated Footing		
DATE:	2/28/2015	DESIGN #:	2
PASS:	YES	CHECK:	DCB

CHECKS:

1.0 Load & Sizing

NODE: 642

Check 1:	OKAY!
Check 2:	OKAY!
Check 3:	OKAY!

1.1 Shear

Check 1:	OKAY!
Check 2:	OKAY!

1.2 Overturning

Check 1:	OKAY!

1.3 Sliding

Check 1:	OKAY!

		Isolated Footing		
DATE:	2/28/2015		DESIGN #:	2
PASS:	YES		CHECK:	DCB

Data

1.0 Loads

Axial Load	23.887	kip	Downward Loading
Factored	28.6644		Downward Loading LRFD

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
λ	1		Normal Weight Concrete
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction

1.2 Allowable Soil-Bearing Pressure

q_{ult}	4000	psf	Allowable Soil Pressure
q_{eff}	3850		Effective Soil Pressure

1.3 Type of Footing

h	1	ft	Depth to base of Footing
Type	Shallow		Shallow or Deep Footing

Footing Dimensions

2.0 Determine Control Footing Area*

Area 1	6	ft^2	
$Length_{Area1}$	2.5	ft	Minimum length of side Req'd from Area1
Length Reqd	6.813		Largest Req'd Length from Checks
Length Side 1	9	ft	
Length Side 2	9	ft^2	
Area Used	81	ft^2	

Thickness of Footing & Pedestal - Uplift Check

3.0 Initial Data

t_{min}		ft	Minimum thickness Hand Calced
t	4	ft	Selected thickness
D_{bgw}	0	ft	Depth below water to top footing
γ_w	62.4	pcf	Unit weight of Water

FS_{up}	1.1		Factor of Safety for Uplift
u	249.6	lbs	Uplift Pressure
P_{up}	20.22	ksf	Uplift force
FP_{up}	24.26		Factored Uplift Force (1.2DL) LRFD
h_{soil}	3	ft	

3.1 Pedestal Size (Assumed-Can equal zero unless underground)

B_{tp}		ft	Transverse Width of Pedestal
B_{lp}		ft	Longtitudinal Width of Pedestal
h_{ped}		ft	Height of Pedestal
W_{soil}	29.16	kips	Weight of soil above footing

Rebar

4.0 Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

4.1 Loads

qn	0.3539		
M_u =	26.55	ft - kips / b_w	Applied Moment

4.2 Reinforcing

Layers	Bottom Reinforcement Only		
Cover	3	in	Clear Cover - All Sides
Width	12	in	
As_1	15.219	in^2	Area of Steel 1
As_2	16.0425	in^2	Area of Steel 2
Ru	0.001	ksi	
w	2.91E-05		
ρ	0.000002		
As_3	0.003	in^2	Area of Steel 3
As_{min}	16.0425	in^2	Minimum Area of Steel
Size	# 7		Size of Steel Reinforcing
n	26.738		Number of Bars used to achieve Asmin
n_{used}	27		Number of Bars used
S_{max}	3.923076923	in	Maximum Allowable Spacing
Spacing	3	in	
Check:	OKAY!		Spacing<Smax

Check

4.3 Rebar Provided

d =	44.56 in
As / b_w =	2.40 in^2

4.4 Moment Design

a =	3.53 in
ΦMn =	462.22 ft - kips / b_w
	CHECK: **Moment Design Acceptable**

4.5 Minimum Reinforcement Requirements

Reinf **Yes** — Reinf. Prov'd 1/3 Greater than Req'd

$A_{s\ t\&s}$	1.04 in^2	Temp. & Shrinkage Steel
$A_{s\ flex}$	in^2	Flexural
As / $b_{w\ prov'd}$	2.40 in^2	
As / $b_{w\ req'd}$	1.04 in^2	

		Isolated Footing			
DATE:	2/28/2015			DESIGN#:	2
PASS:	YES			CHECK:	DCB

Data Input

1.0 Loading

Col_{wt}	0.15	kips	Column Weight
P_{uShear}	28.8444	kips	Factored Loads (LRFD)
Net_{up}	0.356	ksf	Net Upward Pressure

1.1 Reinforcement

Size	0.875	in	Bar Size
Cover	3.00	in	Cover Depth
d	44.56	in	Reinforcement Depth

1.2 Critical Section

Cs	10	in	Column Side
c_1+d	54.5625	in	Critical Section
c_1+d	4.547	ft	Critical Section
b_0	218.25	in	

Shear

2.0 Shear & Footing Thickness

β	1		Shape Parameter
Vu	21.48	kips	
ϕ	0.85		
αs	40		Select Column Location
d_1	0.305	inch	Acceptable depth from 2 Way Shear
d_2	0.224	inch	Acceptable depth from 2 Way Shear
d_3	0.458	inch	Acceptable depth from 2 Way Shear

CHECK CHECK: **OKAY!**

2.1 One Way Shear

d_4	0.370	ft	Acceptable Depth from 1 Way Shear
V_{u1}	1.2	kips	
d_{OneWay}	0.102	inch	

CHECK CHECK: **OKAY!**

2.2 Bending Moment

B_{Wedge}	4.083	ft
M_{ubend}	26.7	k-ft

	Isolated Footing		
DATE: 2/28/2015		DESIGN #:	2
PASS: YES		CHECK:	DCB

Overturning

1.0 Initial Conditions

V_x	3.134	kip	Governing Load Case
μ	0.5		
$Load_{Total}$	72.487	kip	
$FS_{Overturning}$	1.5		

1.1 Overturning Calculations

M_x	12.536	k-ft	Governing Moment
M_r	326.192	k-ft	Resisting Moment
Mr/Mx	26.020		
Check:	OKAY!		

	Isolated Footing		
DATE: 2/28/2015		DESIGN #:	2
PASS: YES		CHECK:	DCB

DATA INPUT

1.0 Forces

DF_{shear}	5.42	kips	Disturbing Force (x-shear)
$FS_{sliding}$	1.5		Factor of Safety - Sliding
$Axial_{sliding}$	23.887	kips	Axial Downward Force
μ	0.5		Coefficient of Friction
Wc	0.15	kips	Self Weight

1.1 Sliding Calculations

	FS_{force}	8.13	kips	
	$b^2_{sliding}$	46.416		Area of footing - Minimum
	$bmin_{sliding}$	6.813		
CHECK	$b_{sliding}$	9		Selected length of footing
	CHECK:	OKAY!		

Appendix E: STAAD.*foundation* –Isolated Spread Footing

Isolated Footing Design(ACI 318-05)

Design For Isolated Footing 642

Design For Isolated Footing 643

Design For Isolated Footing 671

Design For Isolated Footing 672

Footing No.	Group ID	Foundation Geometry		
-	-	Length	Width	Thickness
642	1	8.500ft	8.500ft	2.000ft

Footing No.	Footing Reinforcement				Pedestal Reinforcement	
-	Bottom Reinforcement(M_z)	Bottom Reinforcement(M_x)	Top Reinforcement(M_z)	Top Reinforcement(M_x)	Main Steel	Trans Steel
642	11 - #6	11 - #6	10 - #6	10 - #6	N/A	N/A

Footing No.	Group ID	Foundation Geometry		
-	-	Length	Width	Thickness
643	2	8.500ft	8.500ft	2.000ft

Footing No.	Footing Reinforcement				Pedestal Reinforcement	
-	Bottom Reinforcement(M_z)	Bottom Reinforcement(M_x)	Top Reinforcement(M_z)	Top Reinforcement(M_x)	Main Steel	Trans Steel
643	11 - #6	11 - #6	10 - #6	10 - #6	N/A	N/A

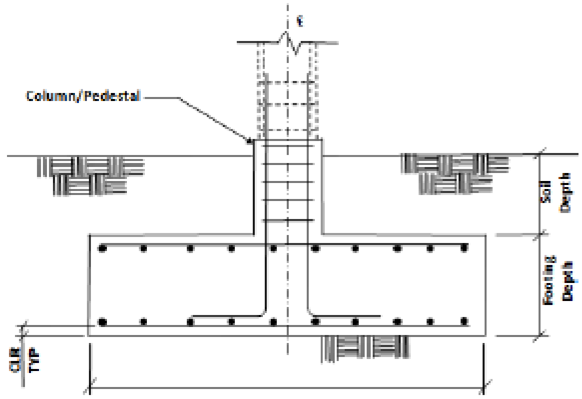
Footing No.	Group ID	Foundation Geometry		
-	-	Length	Width	Thickness
671	3	8.500ft	8.500ft	2.000ft

Footing No.	Footing Reinforcement				Pedestal Reinforcement	
-	Bottom Reinforcement(M_z)	Bottom Reinforcement(M_x)	Top Reinforcement(M_z)	Top Reinforcement(M_x)	Main Steel	Trans Steel
671	11 - #6	11 - #6	10 - #6	10 - #6	N/A	N/A

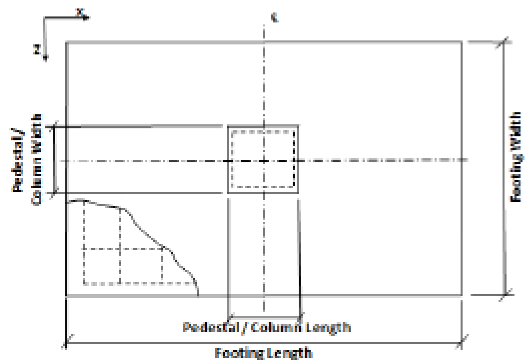
Footing No.	Group ID	Foundation Geometry		
-	-	Length	Width	Thickness
672	4	8.500ft	8.500ft	2.000ft

Footing No.	Footing Reinforcement				Pedestal Reinforcement	
-	Bottom Reinforcement(M_z)	Bottom Reinforcement(M_x)	Top Reinforcement(M_z)	Top Reinforcement(M_x)	Main Steel	Trans Steel
672	11 - #6	11 - #6	10 - #6	10 - #6	N/A	N/A

Isolated Footing 642



ELEVATION



PLAN

Input Values

Footing Geomtery

Design Type :	Calculate Dimension
Footing Thickness (Ft) :	24.000in
Footing Length - X (Fl) :	40.000in
Footing Width - Z (Fw) :	40.000in
Eccentricity along X (Oxd) :	0.000in
Eccentricity along Z (Ozd) :	0.000in

Column Dimensions

Column Shape :	Rectangular
Column Length - X (D_{col}) :	0.532ft
Column Width - Z (B_{col}) :	0.507ft

Pedestal

Include Pedestal?	No
Pedestal Shape :	N/A
Pedestal Height (Ph) :	N/A
Pedestal Length - X (Pl) :	N/A
Pedestal Width - Z (Pw) :	N/A

Design Parameters

Concrete and Rebar Properties

Unit Weight of Concrete :	150.000lb/ft3
Strength of Concrete :	4.000ksi
Yield Strength of Steel :	60.000ksi
Minimum Bar Size :	#6
Maximum Bar Size :	#10
Top Footing Minimum Bar Size :	#6
Top Footing Maximum Bar Size :	#10
Pedestal Minimum Bar Size :	#6
Pedestal Maximum Bar Size :	#10
Minimum Bar Spacing :	3.000in
Maximum Bar Spacing :	12.000in
Pedestal Clear Cover (P, CL) :	3.000in
Bottom Footing Clear Cover (F, CL) :	3.000in

Soil Properties

Soil Type :	Cohesionless Soil
Unit Weight :	120.000lb/ft3
Soil Bearing Capacity :	4.000kip/ft2
Soil Bearing Capacity Type:	Net Bearing Capacity
Soil Surcharge :	0.000kip/in2
Depth of Soil above Footing :	0.000in
Type of Depth :	Fixed Top
Undrained Shear Strength :	0.000kip/in2
Bearing Capacity Input Method:	Fixed Bearing Capacity

Sliding and Overturning

Coefficient of Friction :	0.500
Factor of Safety Against Sliding :	1.500
Factor of Safety Against Overturning :	1.500

Global Settings

Top Reinforcement Option :	Always calculate based on self weight
Concrete Design Option :	Gross Pressure
Top Reinforcement Factor :	1.000

Design Calculations

Footing Size

Initial Length (L_o) = 3.333ft

Initial Width (W_o) = 3.333ft

Load Combination/s- Service Stress Level				
Load Combination Number	Load Combination Title	Load Combination Factor	Soil Bearing Factor	Self Weight Factor
110	D + W N-S	1.00	1.00	1.00
111	D + W S-N	1.00	1.00	1.00
112	D + W E-W	1.00	1.00	1.00
113	D + W W-E	1.00	1.00	1.00
120	0.6 DL + W N-S	1.00	1.00	1.00
121	0.6 DL + W S-N	1.00	1.00	1.00
122	0.6 DL + W E-W	1.00	1.00	1.00
123	0.6 DL + W W-E	1.00	1.00	1.00
200	1.4 DL	1.00	1.00	1.00
210	1.2 DL + 1.6 W N-S	1.00	1.00	1.00
211	1.2 DL + 1.6 W S-N	1.00	1.00	1.00
212	1.2 DL + 1.6 W E-W	1.00	1.00	1.00
213	1.2 DL + 1.6 W W-E	1.00	1.00	1.00
220	0.9 DL + 1.6 W N-S	1.00	1.00	1.00
221	0.9 DL + 1.6 W S-N	1.00	1.00	1.00
222	0.9 DL + 1.6 W E-W	1.00	1.00	1.00
223	0.9 DL + 1.6 W W-E	1.00	1.00	1.00

Load Combination/s- Strength Level				
Load Combination Number	Load Combination Title	Load Combination Factor	Soil Bearing Factor	Self Weight Factor
110	D + W N-S	1.00	1.00	1.00
111	D + W S-N	1.00	1.00	1.00
112	D + W E-W	1.00	1.00	1.00
113	D + W W-E	1.00	1.00	1.00
120	0.6 DL + W N-S	1.00	1.00	1.00
121	0.6 DL + W S-N	1.00	1.00	1.00
122	0.6 DL + W E-W	1.00	1.00	1.00
123	0.6 DL + W W-E	1.00	1.00	1.00
200	1.4 DL	1.00	1.00	1.00
210	1.2 DL + 1.6 W N-S	1.00	1.00	1.00
211	1.2 DL + 1.6 W S-N	1.00	1.00	1.00
212	1.2 DL + 1.6 W E-W	1.00	1.00	1.00
213	1.2 DL + 1.6 W W-E	1.00	1.00	1.00
220	0.9 DL + 1.6 W N-S	1.00	1.00	1.00
221	0.9 DL + 1.6 W S-N	1.00	1.00	1.00
222	0.9 DL + 1.6 W E-W	1.00	1.00	1.00
223	0.9 DL + 1.6 W W-E	1.00	1.00	1.00

Applied Loads - Service Stress Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000
122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000

Applied Loads - Strength Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000
122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000

Reduction of force due to buoyancy = 0.000kip

Effect due to adhesion = 0.000kip

Area from initial length and width, $A_o = L_o \times W_o$ = 11.111ft^2

Min. area required from bearing pressure, $A_{min} = P / q_{max}$ = 6.420ft^2

Note: A_{min} is an initial estimation.
P = Critical Factored Axial Load(without self weight/buoyancy/soil).
q_{max} = Respective Factored Bearing Capacity.

Final Footing Size

Length (L_2) =	8.500 ft	Governing Load Case :	# 223
Width (W_2) =	8.500 ft	Governing Load Case :	# 223
Depth (D_2) =	2.000 ft	Governing Load Case :	# 212

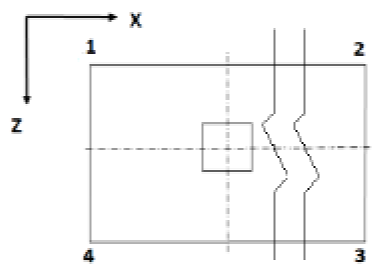
Depth is governed by Ultimate Load Case

(Service check is performed with footing thickness requirements from concrete check)

Area (A_2) =	72.250 ft^2
Final Soil Height =	0.000 ft
Footing Self Weight =	21.675 kip
Gross Soil Bearing Capacity =	4.24kip/ft2
Soil Weight On Top Of Footing =	0.000 kip

Pressures at Four Corners

Please note that pressures values displayed in tables below are calculated after dividing by soil bearing factor



Load Case	Pressure at corner 1 (q_1) (kip/ft2)	Pressure at corner 2 (q_2) (kip/ft2)	Pressure at corner 3 (q_3) (kip/ft2)	Pressure at corner 4 (q_4) (kip/ft2)	Area of footing in uplift (A_u) (ft^2)
212	**0.7380**	0.5262	0.5232	0.7350	0.000
211	0.6204	**0.6133**	0.4909	0.4979	0.000
212	0.7380	0.5262	**0.5232**	0.7350	0.000
212	0.7380	0.5262	0.5232	**0.7350**	0.000

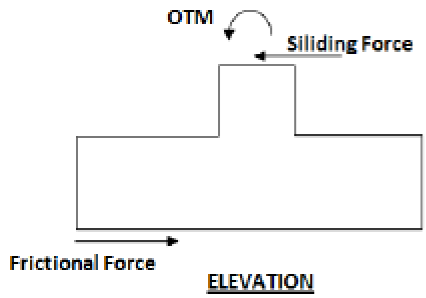
If A_u is zero, there is no uplift and no pressure adjustment is necessary. Otherwise, to account for uplift, areas of negative pressure will be set to zero and the pressure will be redistributed to remaining corners.

Summary of Adjusted Pressures at 4 corners Four Corners

Load Case	Pressure at corner 1 (q_1) (kip/ft2)	Pressure at corner 2 (q_2) (kip/ft2)	Pressure at corner 3 (q_3) (kip/ft2)	Pressure at corner 4 (q_4) (kip/ft2)
212	**0.7380**	0.5262	0.5232	0.7350
211	0.6204	**0.6133**	0.4909	0.4979

212	0.7380	0.5262	**0.5232**	0.7350
212	0.7380	0.5262	0.5232	**0.7350**

Check for stability against overturning and sliding



-	Factor of safety against sliding			Factor of safety against overturning	
Load Case No.	Along X-Direction	Along Z-Direction	Resultant	About X-Direction	About Z-Direction
110	200.897	6.654	6.650	28.278	853.812
111	127.962	8.990	8.968	38.206	543.837
112	5.679	341.470	5.678	1451.246	24.135
113	3.402	761.114	3.402	3234.734	14.457
120	481.893	5.701	5.700	24.228	2048.044
121	162.840	8.171	8.161	34.728	692.069
122	5.235	415.061	5.234	1764.010	22.248
123	2.829	69713.998	2.829	296284.492	12.022
200	119.945	339.092	113.079	1441.139	509.765
210	198.390	3.923	3.923	16.674	843.157
211	110.920	6.405	6.394	27.220	471.412
212	4.203	297.440	4.202	1264.119	17.862
213	1.786	1057.997	1.786	4496.486	7.592
220	353.961	3.486	3.486	14.818	1504.333
221	124.516	6.012	6.005	25.551	529.192
222	3.986	325.928	3.986	1385.194	16.941
223	1.527	4139.455	1.527	17592.683	6.492

Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - X Direction

Critical Load Case for Sliding along X-Direction : 223

Governing Disturbing Force : 5.209kip

Governing Restoring Force : 7.957kip

Minimum Sliding Ratio for the Critical Load Case : 1.527

Critical Load Case for Overturning about X-Direction : 220

Governing Overturning Moment : 6.119kip-ft

Governing Resisting Moment : 90.662kip-ft

Minimum Overturning Ratio for the Critical Load Case : 14.818

Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - Z Direction

Critical Load Case for Sliding along Z-Direction : 220

Governing Disturbing Force : 3.059kip

Governing Restoring Force : 10.666kip

Minimum Sliding Ratio for the Critical Load Case : 3.486

Critical Load Case for Overturning about Z-Direction : 223

Governing Overturning Moment : -10.418kip-ft

Governing Resisting Moment : 67.635kip-ft

Minimum Overturning Ratio for the Critical Load Case : 6.492

Critical Load Case And The Governing Factor Of Safety For Sliding Along Resultant Direction

Critical Load Case for Sliding along Resultant Direction : 223

Governing Disturbing Force : 5.209kip

Governing Restoring Force : 7.957kip

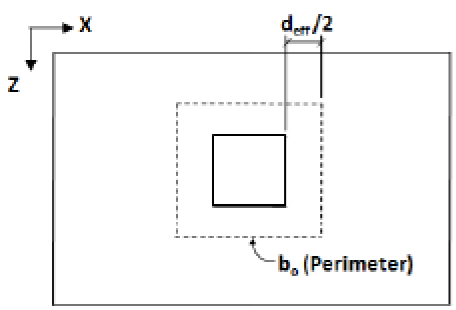
Minimum Sliding Ratio for the Critical Load Case : 1.527

Compression Development Length Check

Development length skipped as column reinforcement is not specified in input (Column Dimnesion Task Pane)

Shear Calculation

Punching Shear Check



PLAN

Total Footing Depth, D = 2.000ft

Calculated Effective Depth, d_{eff} = $D - C_{cover} - 0.5 * d_b$ = 1.714ft

For rectangular column, β_c = B_{col} / D_{col} = 1.049

Effective depth, d_{eff}, increased until $0.75XV_c \geq$ Punching Shear Force

Punching Shear Force, Vu = 42.418kip, Load Case # 212

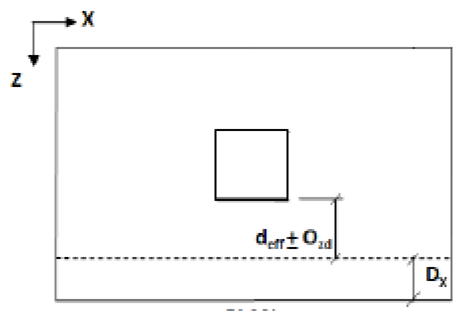
From ACI Cl.11.12.2.1, b_o for column=	$2 \times (B_{col} + D_{col} + 2 \times d_{eff}) =$	8.931ft
Equation 11-33, V_{c1} =	$\left(2 + \frac{4}{\beta_c}\right) \times b_o \times d_{eff} \times \sqrt{1000 \times F_c{}'} =$	810.025kip
Equation 11-34, V_{c2} =	$\left(\frac{\alpha_s \times d}{b_o} + 2\right) \times \lambda \times \sqrt{f_c} \times b_o \times d =$	1348.397kip
Equation 11-35, V_{c3} =	$4 \times b_o \times d_{eff} \times \sqrt{1000 \times F_c{}'} =$	557.493kip
Punching shear strength, V_c =	0.75 X minimum of (V_{c1}, V_{c2}, V_{c3}) =	418.119kip

0.75 X V_c > V_u hence, OK

One-Way Shear Check

Along X Direction

(Shear Plane Parallel to Global X Axis)



From ACI Cl.11.3.1.1, V_c =	$2 \times L \times d_{eff} \times \sqrt{1000 \times F_c{}'} =$	265.299kip
Distance along X to design for shear, D_x =	$0.5 \times (W \pm D_{col}) - d_{eff} + O_{zd} =$	2.283ft

Check that 0.75 X V_c > V_{ux} where V_{ux} is the shear force for the critical load cases at a distance d_{eff} from the face of the column caused by bending about the X axis.

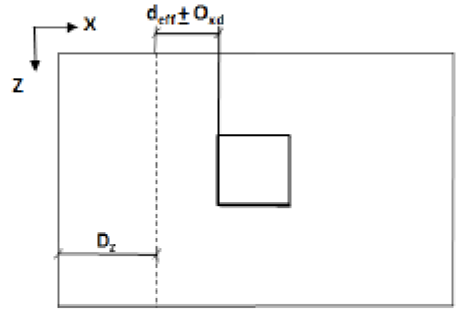
From above calculations,	0.75 X V_c =	198.974 kip
Critical load case for V_{ux} is # 212	$V_{ux} = V_{ux}\|_{x=D_X} =$	12.259 kip

0.75 X V_c > V_{ux} hence, OK

One-Way Shear Check

Along Z Direction

(Shear Plane Parallel to Global Z Axis)



PLAN

From ACI Cl.11.3.1.1, V_c =

$2 \times W \times d_{eff} \times \sqrt{1000 \times F_c'}$ = 265.299 kip

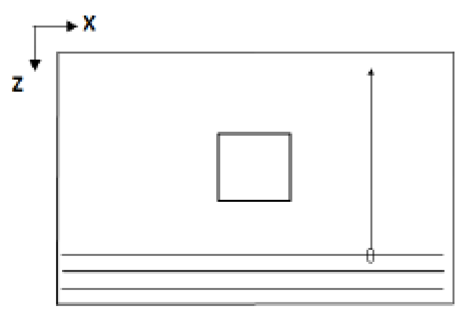
Distance along X to design for shear, D_z = $0.5 \times (L \pm B_{col}) - d_{eff} + O_{xd}$ = 2.271 ft

Check that **0.75 X V_c > V_{uz}** where V_{uz} is the shear force for the critical load cases at a distance d_{eff} from the face of the column caused by bending about the Z axis.

From above calculations,	0.75 X V_c =	198.974 kip
Critical load case for V_{uz} is # 212	$V_{uz} = V_{uz}\|_{x=D_z}$ =	13.669 kip
		0.75 X V_c > V_{uz} hence, OK

Design for Flexure about Z Axis

(For Reinforcement Parallel to X Axis)



PLAN

Calculate the flexural reinforcement along the X direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Bars parallel to X Direction are placed at bottom

Effective Depth d_{eff}= 1.719 ft

Factor β_1 from ACI Cl.10.2.7.3 = 0.850

From ACI Cl. 10.3.2, ρ_{bal} = $0.85 \times \beta_1 \times F_c' \times \frac{87}{\left[f_y \times (87 + F_y)\right]}$ = 0.02851

From ACI Cl. 10.3.3, ρ_{max} = $0.75 \times \rho_{bal}$ = 0.02138

From ACI Cl. 7.12.2, ρ_{min} = 0.00169

From Ref. 1, Eq. 3.8.4a, constant m = $\frac{F_y}{\left(0.85 \times F_c'\right)}$ = 17.647

Calculate reinforcement ratio ρ for critical load case

Design for flexure about Z axis is performed at the face of the column at a distance, D_x = $0.5 \times L \pm 0.5 \times D_{col} + O_{sd}$ = 3.984 ft

Ultimate moment, $M_u|_{x=D_x}$ = 47.454 kip-ft

Nominal moment capacity, M_n = $\frac{M_u}{\phi}$ = 52.726 kip-ft

(Based on effective depth) Required ρ = $\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{\left(F_y \times W \times d_{eff}^2\right)}}\right]$ = 0.00025

(Based on gross depth) ρ x d_{eff} / Depth = 0.00021

Since ρ≤ ρ_{min} ρ_{min} Governs

Area of Steel Required, A_s = $\rho \times W \times d_{eff}$ = 4.141 in2

Selected bar Size = #6

Minimum spacing allowed (S_{min}) = = 3.000in

Selected spacing (S) = 10.583in

S_{min}<= S <= S_{max} and selected bar size < selected maximum bar size...

The reinforcement is accepted.

According to ACI 318 Clause No- 10.6.4

Max spacing for Cracking Consideration = 7.500in

Warning:Calculated spacing is more than maximum spacing cosidering cracking condition. Modify spacing manually if cracking consideration is necessary.

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 10.000in o.c.

Required development length for bars = $\frac{3 \times d_b \times f_y}{40 \times \lambda \times \sqrt{f_c}}$ = =2.372 ft

Available development length for bars, D_L = $0.5 \times (L - D_{col}) - C_{cover}$ = 3.734 ft

Try bar size # 6 Area of one bar = 0.440 in2

Number of bars required, N_{bar} = $\frac{A_s}{A_{bar}}$ = 10

Because the number of bars is rounded up, make sure new reinforcement ratio < ρ_{max}

Total reinforcement area, A_{s_total} = N_{bar} X (Area of one bar) = 4.400 in2

d_{eff} = D - C_{cover} - 0.5 X (dia. of one bar) = 1.719 ft

Reinforcement ratio, ρ = $\frac{A_{s\_total}}{(d_{eff} \times W)}$ = 0.00209

From ACI Cl.7.6.1, minimum req'd clear distance between bars

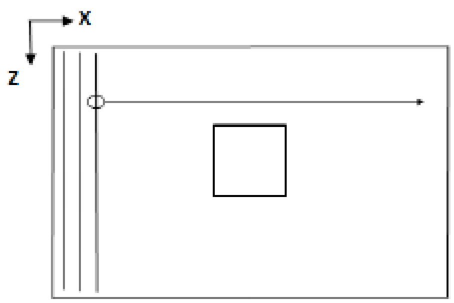
C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 3.000in

Provided Steel Area / Required Steel Area = 1.062

Check to see if width is sufficient to accomodate bars

Design for Flexure about X axis

(For Reinforcement Parallel to Z Axis)



PLAN

Calculate the flexural reinforcement along the Z direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Bars parallel to X Direction are placed at bottom

Effective Depth d_{eff}= 1.656 ft

Factor β_1 from ACI Cl.10.2.7.3 = 0.850

From ACI Cl. 10.3.2, ρ_{bal} = $0.85 \times \beta_1 \times F_c{}' \times \frac{87}{(F_y \times (87 + F_y))}$ = 0.02851

From ACI Cl. 10.3.3, ρ_{max} = $0.75 \times \rho_{bal}$ = 0.02138

From ACI Cl.7.12.2, ρ_{min} = 0.00170

From Ref. 1, Eq. 3.8.4a, constant m = $\frac{F_y}{(0.85 \times F_c{}')}$ = 17.647

Calculate reinforcement ratio ρ for critical load case

Design for flexure about X axis is performed at the face of the column at a distance, D_x = $0.5 \times L \pm 0.5 \times B_{col} + O_{zd}$ = 3.997 ft

Ultimate moment, $M_u|_{x=D_x}$ = 42.880 kip-ft

Nominal moment capacity, M_n = $\frac{M_u}{\phi}$ = 47.645 kip-ft

(Based on effective depth) Required ρ = $\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{\left(F_y \times W \times d_{eff}^2\right)}}\right]$ = 0.00024

(Based on gross depth) ρ x d_{eff} / Depth = 0.00020

Since $\rho \leq \rho_{min}$ ρ_{min} Governs

Area of Steel Required, A_s = $\rho \times W \times d_{eff}$ = 4.161 in2

Selected Bar Size = #6

Minimum spacing allowed (S_{min}) = 3.000in

Selected spacing (S) = 10.583in

S_{min}<= S <= S_{max} and selected bar size < selected maximum bar size...

The reinforcement is accepted.

According to ACI 318 Clause No- 10.6.4

Max spacing for Cracking Consideration = 7.500in

Warning:Calculated spacing is more than maximum spacing cosidering cracking condition. Modify spacing manually if cracking consideration is necessary.

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 10.000in o.c.

Required development length for bars = $\frac{d_b \times f_y}{25 \times \lambda \times \sqrt{f'_c}}$ = =2.372 ft

Available development length for bars, D_L = $0.5 \times (L - D_{col}) - C_{cover}$ = 3.747 ft

Try bar size # 6 Area of one bar = 0.440 in2

Number of bars required, N_{bar} = $\frac{A_s}{A_{bar}}$ = 10

Because the number of bars is rounded up, make sure new reinforcement ratio < ρ_{max}

Total reinforcement area, A_{s_total} = N_{bar} X (Area of one bar) = 4.400 in2

d_{eff} = D - C_{cover} - 1.5 X (dia. of one bar) = 1.656 ft

Reinforcement ratio, ρ = $\frac{A_{s\_total}}{(d_{eff} \times W)}$ = 0.00217

From ACI Cl.7.6.1, minimum req'd clear distance between bars

C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 3.000in

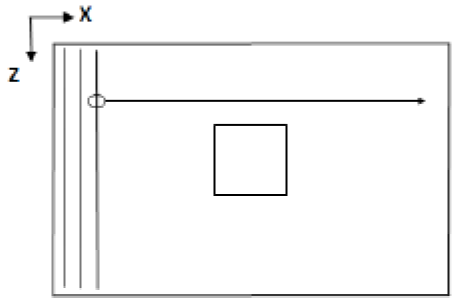
Provided Steel Area / Required Steel Area = 1.057

Check to see if width is sufficient to accomodate bars

Bending moment for uplift cases will be calculated based solely on selfweight, soil depth and surcharge loading.

As the footing size has already been determined based on all servicebility load cases, and design moment calculation is based on selfweight, soil depth and surcharge only, top reinforcement value for all pure uplift load cases will be the same.

Design For Top Reinforcement Parallel to Z Axis



PLAN

Top reinforcement is calculated based on self weight of footing and soil

Calculate the flexural reinforcement for M_x. Find the area of steel required

The strength values of steel and concrete used in the formulae are in ksi

Bars parallel to X Direction are placed at bottom

Effective Depth d_{eff} =		1.656	ft
Factor β_1 from ACI Cl.10.2.7.3 =		0.850	
From ACI Cl. 10.3.2, ρ_{bal} =	$0.85 \times \beta_1 \times F_c{}' \times \frac{87}{\left[f_y \times \left(87 + F_y\right)\right]} =$	0.02851	
From ACI Cl. 10.3.3, ρ_{max} =	$0.75 \times \rho_{bal} =$	0.02138	
From ACI Cl. 7.12.2, ρ_{min} =		0.00000	
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{F_y}{\left(0.85 \times F_c{}'\right)} =$	17.647	

Calculate reinforcement ratio ρ for critical load case

Design for flexure about X axis is performed at the face of the column at a distance, D_x =	$0.5 \times L \pm 0.5 \times D_{col} + O_{xd} =$	3.997	ft
Ultimate moment,	$M_u\big\|_{x = D_x} =$	20.366	kip-ft
Nominal moment capacity, M_n =	$\frac{M_u}{\phi} =$	22.629	kip-ft
(Based on effective depth) Required ρ =	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{\left(F_y \times W \times d_{eff}{}^2\right)}}\right] =$	0.00011	
	(Based on gross depth) ρ x d_{eff} / Depth =	0.00009	
Since	$\rho_{min} \leq \rho \leq \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff} =$	0.228	in2
Total reinforcement area, A_{s_total} =	N_{bar} X (Area of one bar) =	0.884	in2

Provided Steel Area / Required Steel Area = 3.876

Selected bar Size = #6

Minimum spacing allowed (S_{min}) = 3.000in

Selected spacing (S) = 12.000in

S_{min} <= S <= S_{max} and selected bar size < selected maximum bar size...

The reinforcement is accepted.

According to ACI 318 Clause No- 10.6.4

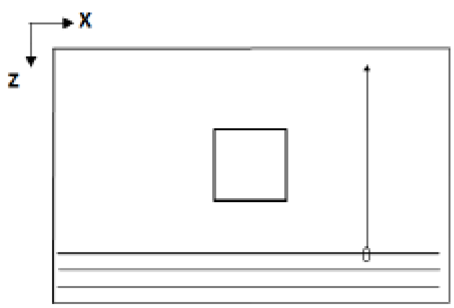
Max spacing for Cracking Consideration = 7.500in

Warning:Calculated spacing is more than maximum spacing cosidering cracking condition. Modify spacing manually if cracking consideration is necessary.

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 12.000in o.c.

Design For Top Reinforcement Parallel to X Axis



PLAN

Top reinforcement is calculated based on self weight of footing and soil

Calculate the flexural reinforcement for M_z. Find the area of steel required

The strength values of steel and concrete used in the formulae are in ksi

Bars parallel to X Direction are placed at bottom

Effective Depth d_{eff}=		1.719 ft
Factor β_1 from ACI Cl.10.2.7.3 =		0.850
From ACI Cl. 10.3.2, ρ_{bal} =	$0.85 \times \beta_1 \times F_c' \times \frac{87}{[f_y \times (87 + F_y)]}$ =	0.02851
From ACI Cl. 10.3.3, ρ_{max} =	$0.75 \times \rho_{bal}$ =	0.02138
From ACI Cl.7.12.2, ρ_{min} =		0.00000
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{F_y}{(0.85 \times F_c')}$ =	17.647

Calculate reinforcement ratio ρ for critical load case

Design for flexure about Z axis is performed at the face of the column at a distance, D_x =	$0.5 \times L \pm 0.5 \times D_{col} + O_{xd} =$	3.984	ft
Ultimate moment,	$M_u\big\|_{x=D_x} =$	20.239	kip-ft
Nominal moment capacity, M_n =	$\frac{M_u}{\phi} =$	22.488	kip-ft
(Based on effective depth) Required ρ =	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{\left(F_y \times W \times d_{eff}^2\right)}}\right] =$	0.000104	
	(Based on gross depth) $\rho \times d_{eff}$ / Depth =	0.000089	
Since	$\rho_{min} \leq \rho \leq \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff} =$	0.218	in2
Total reinforcement area, A_{s_total} =	N_{bar} X (Area of one bar) =	0.884	in2

Provided Steel Area / Required Steel Area = 4.048

Selected bar Size = #6

Minimum spacing allowed (S_{min}) = 3.000in

Selected spacing (S) = 12.000in

$S_{min} <= S <= S_{max}$ and selected bar size < selected maximum bar size...

The reinforcement is accepted.

According to ACI 318 Clause No- 10.6.4

Max spacing for Cracking Consideration = 7.500in

Warning:Calculated spacing is more than maximum spacing cosidering cracking condition. Modify spacing manually if cracking consideration is necessary.

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 12.000in o.c.

Appendix F: Hand Calculated - Isolated Spread Footing

Stantec

ISOLATED FOOTING DESIGN: #642

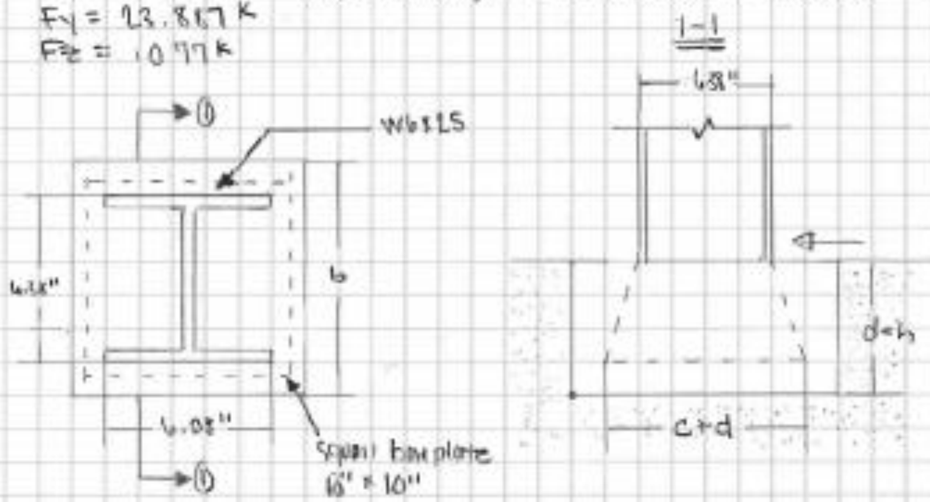
→ ASSUME SQUARE FOOTING

→ GOVERNING LOAD CASE 212: 1.2DL + 1.6W (E-W)

$F_x = 5.420$ k   Column weight = 25 lb/ft (6 ft) = 150 lb

$F_y = 23.867$ k

$F_z = 10.77$ k



ASSUME
- → FOOTING DEPTH = 3'
- → TOP OF FOOTING @ GROUND LEVEL
- → SOIL BEARING CAPACITY, q_{ult} = 4 KSF
- → 150 lb/ft³ concrete
- → 36" from steel column to edge of footing

$$W_c = 150 \frac{lb}{ft^3}(36 in)\left(\frac{1 ft}{12 in}\right)\left(\frac{1 k}{1000 lb}\right) = .45 k/ft^2$$

$$q_{eff} = q_{ult} - W_c = 4 - .45 = 3.55 k/ft^2$$

$$A_{min} = (10+6)(10+6) = 256 in^2 = 1.78 ft^2$$

MQP FOUNDATION DESIGN - ISOLATED FOOTING

STAAD.FDN REFERENCE: FOOTING #642

Designed by: DJH   Checked by:

Stantec

$A_{req} = \frac{P_{axial}}{q_{eff}} = \frac{23.887}{3.55} = 6.73\ ft^2 \rightarrow$ governs

$b = \sqrt{6.73} = 2.60$ ft → round up to 3', for breakout perimeter >4'

NET UPWARD PRESSURE: (b = 7' due to sliding)

FACTORED LOAD: $1.2DL = 1.2(23.887 + .150) = 28.84^k$

$q_n = \frac{DL}{A_f} = \frac{28.84^k}{(7^2)} = .589\ k/ft^2$

MINIMUM REINFORCEMENT

$A_g = (7 \times 7)(144) = 7056\ in^2$

$A_{se\,min} = .005A_g = 35.28\ in^2$
$A_{s\,min} = \rho bh = .0018\ bh = .0018(84)(36) = 5.4\ in^2$ (shrinkage)

∴ try 9#7, $d_b = .875"$ $a = .6\ in^2$

DEPTH OF REINFORCEMENT (

$d_{avg} = h - cover - .5d_b = 36 - 3 - .5(.875) = 32.56"$

breakout perimeter: $c + d = 32.56 + 10 = 41.56$
& side length $b_0 = 4(c+d) = 170.24"$

TWO WAY SHEAR

$V_u = P_u - q_n(c+d)^2$
$= 28.84 - .589(42.56/12)^2 = 21.41^k$

$\beta_c = 1$, square column

Designed by: Checked by:

Stantec

ACI 318-05 Ch. 10.5.1

$A_{s,min} = \frac{3\sqrt{f'c}\, b_w d}{f_y} = \frac{3\sqrt{4000}}{60000}(84)(32.56) = 8.65 \text{ in}^2$

$A_s = 5.4 \text{ in}^2$

$A_{s,min} = \frac{200 b_w d}{f_y} = \frac{200(84)(32.56)}{60{,}000} = 9.11 \text{ in}^2 \Rightarrow$ governs

$\therefore$ 5#10

$\rho_b = .85\left[\frac{87{,}000\,\beta_1 f'c}{f_y(87000 - f_y)}\right] = .85\left[\frac{87000(.85)(4000)}{60000(87000-60000)}\right] = .0285$

$\rho_{max} = .95\rho_b = .2138$

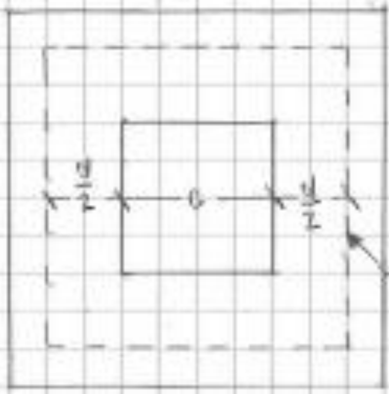
$\rho_{min} = .0018 > \rho_{calc} \Rightarrow$ governs

$S = \frac{L - 2(\text{cover})}{(n-1)} = \frac{84-6}{4} = 5.57 \Rightarrow 19''$ spacing

Designed by: Checked by:

Stantec

TWO WAY SHEAR:



* from previous pages:

$c = 10''$
$d = 32.56''$

$c+d = 42.56''$

$b_o = 4(c+d) = 170.24''$

breakout perimeter

$V_u = 21.41^k$

$\phi V_c = \left[2 + \frac{4}{1}\right]\sqrt{4000}\,(.85)(170.24)(32.56) = \qquad > V_u \checkmark$

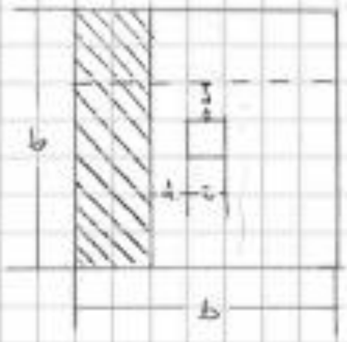
$\phi V_c = \left[\frac{(32.56)}{170.24} + 2\right]\sqrt{4000}\,(170.24)(32.56)(.85) = \qquad > V_u \checkmark$

$\phi V_c = 4\sqrt{4000}\,(170.24)(32.56)(.85) = \qquad > V_u \checkmark$

Designed by: Checked by:

Stantec

ONE WAY SHEAR:



$$\left[\frac{b}{2} - \frac{c}{2} - d\right] = \left[\frac{84}{2} - \frac{10}{2} - 32.56\right] = 4.44''$$

$$V_u = q_n(b)\left[\frac{b}{2} - \frac{c}{2} - d\right] = .589(7)(4.44) = 1.526^K$$

$$d = \frac{V_u}{\phi 2\sqrt{f'c}\, b} = \frac{1526.16}{.75(2)\sqrt{4000}(72)} = .15$$

Since square footing & square baseplate → Transverse = Longitudinal

$$\phi V_c = .75(2)\sqrt{f'c}\, b\, d$$
$$= .75(2)(4000)(84)(32.56) = 259.47^K > V_u \checkmark$$

Designed by: Checked by:

Stantec

overturning

governing moment: (220) $M_x = h_f(V_b) = 3(3.059) = 9.177$ k-ft

resisting moment: $M_r = (.\mu)(W_c)b$
$= .5[(.150(7^2)(3)) + 28.66](7)$
$=$ k-ft

$$\frac{M_r}{M_x} = \frac{75.9745}{9.177} = 8.28 > 1.5 ✓$$

Moment @ column edge

$$\left[\frac{L-c}{2}\right] = \frac{7-(10/12)}{2} = 3.083' \qquad q_n = .589$$

$$M_u = q_n(3.083)\left(\frac{3.083}{2}\right)b = .589(3.083)\left(\frac{3.083}{2}\right)7$$

$M_u = 19.59$ k-ft

$$R_u = \frac{M_u}{bd^2} = \frac{19.59(12)}{(84)(32.56)^2} = .0026 \text{ ksi}$$

$$\omega = \frac{1.7 - \sqrt{(1.7^2) - 4\left[1.7\left(\frac{R_u}{\phi f_y}\right)\right]}}{2} = \frac{1.7 - \sqrt{1.7^2 - 4\left(1.7\left(\frac{.0026}{.9(60)}\right)\right)}}{2}$$

$\omega = .000048 = \rho \frac{f_y}{f_c}$

$$\rho = \frac{.000048(4)}{60} = .000003$$

$A_s = .000003(36)(84) = .009707$

Flexure $A_s = (200/f_y)bd = (200/60000)84(32.56) = 9.11$

Designed by: Checked by:

Stantec

SLIDING

Disturbing force (x-shear): 5.209^k

Factor of safety = 1.5

Resisting force ≥ 1.5(5.209) = 7.8135^k

$$f = \left[.150 \frac{kip}{ft^3}\left(3b^2\right) + f_y\right]\mu \leftarrow \text{coefficient of friction}$$

↑ self weight; ↑ axial downward

$7.8135 = .5(.150)(3b^2) - .5(5.761)$

$\therefore b^2 = 47.5$

$b = 6.89 \rightarrow 7'$

Designed by: Checked by:

Appendix G: Excel Spreadsheet – Combined Footing Models

Design Procedure - Combined Footings

Service Load Design

1.0 Determine the size of combined footing

2.0 Calculated the required length of footing. The length of the footing is twice the distance from the edge footing of the exterier column to the resultant of column loads

3.0 Calculate the width of footing. The required area of footing is the total column load divided by allowable net soil bearing pressure. The width of footing is the required footing area divided my the

Structural Analysis

4.0 Perform structural analysis to determine moment and shear in various sections of the footing

5.0 Calculate factored footing pressure

6.0 Calculate maximum shear at an effective depth from the face of column

7.0 Calculate maximum positive and negative moment in the footing. Maximum positive moment occurs at face of column. Maximum Negative moment occurs between two columns at zero-shear

Reinforced Concrete Design

8.0 Check punching shear and direct shear

9.0 Design longitudinal reinforcements

10.0 Design transverse reinforcements

11.0 Design column dowels

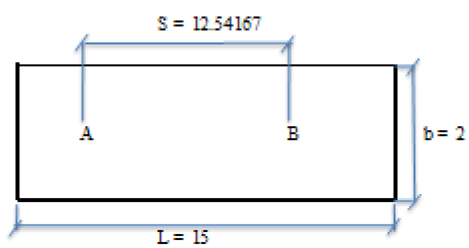
Model: C1

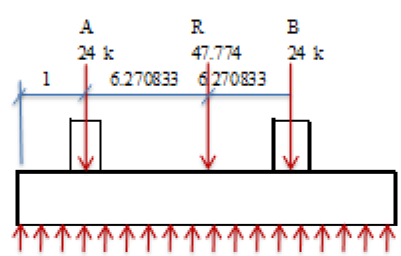
Design Checks			
Punching Shear Strength	ϕv_c	OK	
Punching Shear Strength	ϕv_c	OK	
Shear strength of concrete for footing section	ϕV_c	OK	
Bearing capacity of concrete at column base	P_c	Col A	OK
		Col B	OK

Combined Footings - Service Load Design

Column A: Node 642	Live Load	P_{1L}	0	Kips
	Dead Load	P_{1D}	23.887	Kips
	Total	P_{1T}	23.887	Kips
Column B: Node 643	Live Load	P_{2L}	0	Kips
	Dead Load	P_{2D}	23.887	Kips
	Total	P_{2T}	23.887	Kips
	Resultant	R	47.774	Kips
	Distance Between Columns	s	12.542	ft
	Allowable Soil Pressure	q_a	3000	psf
	Distance from column A to edge of footing	m	1	ft
	Depth of soil above footing		12	inches
	Unit weight of soil	γ_s	120	pcf
	Depth of footing		24	inches
	Unit weight of concrete	γ_c	150	pcf

Service Load Design			
Location of resultant from A	n	6	ft
Length of Footing	L	15	ft
Weight of Footing	q_f	300	psf
Weight of soil above footing	q_s	120	psf
Net soil bearing capacity	q_e	2580	psf
Required footing area	A_{req}	19	ft^2
Required width of footing	b_{req}	2	ft





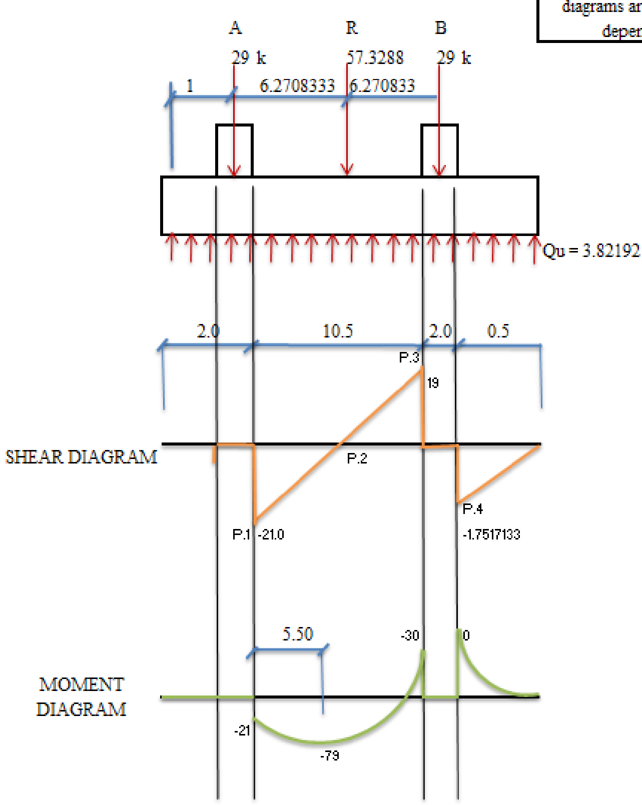
Combined Footings - Structural Analysis

Column Size	Depth	C_d	2	ft	Design Code
	Width	C_w	2	ft	ACI 318-05
	Area	A_c	4	ft^2	
Factored Column Loads	Column A	P_{ua}	28.66	kips	
	Column B	P_{ub}	28.66	kips	
Location of Resultant from column A		$R_{factored}$	7	ft	
Factored footing pressure per linear foot of footing		Q_u	3.8	k/ft	

Shear Diagram			
Point 1	V_{U1}	-21.0	kips
Point 3	V_{U3}	19.3	kips
Point 4	V_{U4}	-1.8	kips

Moment Diagram			
Distance from inside face of column A to peak moment	X	5.5	ft
Point 1	M_{U1}	-21	ft-kips
Point 2	M_{U2}	-78.8	ft-kips
Point 3	M_{U3}	-30.3	ft-kips
Point 4	M_{U4}	0.401	ft-kips

NOTE: Shear and moment diagrams are situation dependent



Combined Footings - Reinforcement Design

Compressive Strength of Concrete at 28 days	f'_c	4	ksi	
Yield Strength of rebar	f_y	60	ksi	
shear ratio	φ	0.75		

Check punching shear for column A				
Assume reinforcements are:	#	6	bars	
Bar Diameter	di	0.75	inches	
Cover	C	3	inches	
Effective depth	d	1.7	ft	
Factored footing pressure	$q_{f,u}$	1.91	kips/ft^2	
Perimeter of punching shear	b_{oA}	112.5	inches	
Punching shear stress	V_{uA}	3.8	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check punching shear for column B				
Perimeter of punching shear	b_{oB}	177	inches	
Punching shear stress	V_{uB}	0.7	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check Direct Shear				
Maximum Shear	V_{max}	19.3	kips	
Distance from zero shear to max shear	X	10.54167	ft	
Direct shear at the critical section	V_u	16.2	kips	
Shear strength of concrete for footing section	φV_c	115.265	kips	OK

Maximum Positive/Negative reinforcement in longitudinal direction				
Maximum Positive Moment	M_{max}	78.8	ft-kips	
Required width of footing	b_{req}	2	ft	
Moment ratio	φ_m	0.9		
Assume depth of Stress block	a	0.9	inches	
Iteration	T	53.1	kips	
	a	0.65	inches	
	T	52.7	kips	
	a	0.65	inches	
Converges	a	0.84	inches	
Area of steel	A_s	0.88	in^2	
Reinforcement ratio	ρ	0.00181		
Minimum Reinforcement Ratio	ρ_{min}	0.00241		
Adjusted Area of Steel	A_s	1.17	in^2	
Allowable Spacing	S	13.87	inches	
Choose Bar: Size	#	3		Manual
Number		16		Decision
Spacing		11.6	inches	OK

Determine reinforcement in transverse direction				
Distrance from face of column to footing edge	ℓ	0.5	ft	
For 1ft section		1	ft	
Factored moment at face of column	M_u	3.82	k-ft	
Assume "a"	a	0.1	inches	
Iteration	T	2.5	kips	
	a	0.06	inches	
	T	2.5	kips	
	a	0.06	inches	
Final "a"	a	0.06	inches	
Area steel for 1ft section	A_s	0.042006	in^2	
Reinforcement Ratio	ρ	0.00017		
Minimum Reinforcement Ratio	ρ_{min}	0.00023		
Adjusted Area of Steel	A_s	1.23		
Choose Bar: Size	#	5		Manual
Number		5		Decision
Spacing		4.50	inches	OK

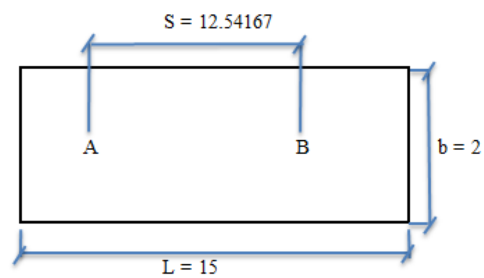
Model: C2

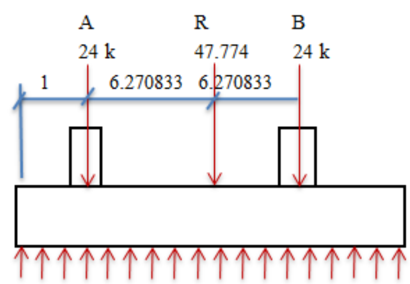
Design Checks		
Punching Shear Strength	φv_c	OK
Punching Shear Strength	φv_c	OK
Shear strength of concrete for footing section	φV_c	OK

Combined Footings - Service Load Design

Column A: Node 642	Live Load	P_{1L}	0	Kips
	Dead Load	P_{1D}	23.887	Kips
	Total	P_{1T}	23.887	Kips
Column B: Node 643	Live Load	P_{2L}	0	Kips
	Dead Load	P_{2D}	23.887	Kips
	Total	P_{2T}	23.887	Kips
	Resultant	R	47.774	Kips
	Distance Between Columns	s	12.542	ft
	Allowable Soil Pressure	q_a	3000	psf
	Distance from column A to edge of footing	m	1	ft
	Depth of soil above footing		12	inches
	Unit weight of soil	γ_s	120	pcf
	Depth of footing		12	inches
	Unit weight of concrete	γ_c	150	pcf

Service Load Design			
Location of resultant from A	n	6	ft
Length of Footing	L	15	ft
Weight of Footing	q_F	150	psf
Weight of soil above footing	q_s	120	psf
Net soil bearing capacity	q_e	2730	psf
Required footing area	A_{req}	18	ft^2
Required width of footing	b_{req}	2	ft



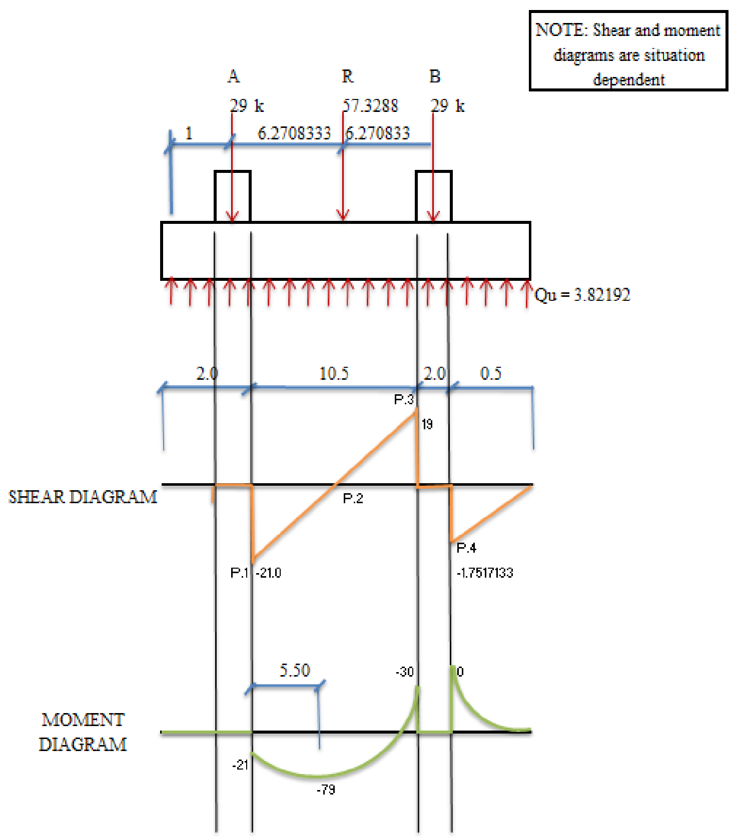


Combined Footings - Structural Analysis

Column Size	Depth	C_d	2	ft	Design Code
	Width	C_w	2	ft	ACI 318-05
	Area	A_c	4	ft^2	
Factored Column Loads	Column A	P_{ua}	28.66	kips	
	Column B	P_{ub}	28.66	kips	
Location of Resultant from column A		$R_{factored}$	7	ft	
Factored footing pressure per linear foot of footing		Q_u	3.8	k/ft	

Shear Diagram			
Point 1	V_{U1}	-21.0	kips
Point 3	V_{U3}	19.3	kips
Point 4	V_{U4}	-1.8	kips

Moment Diagram			
Distance from inside face of column A to peak moment	X	5.5	ft
Point 1	M_{U1}	-21	ft-kips
Point 2	M_{U2}	-78.8	ft-kips
Point 3	M_{U3}	-30.3	ft-kips
Point 4	M_{U4}	0.401	ft-kips



Combined Footings - Reinforcement Design

Compressive Strength of Concrete at 28 days	f'_c	4	ksi
Yield Strength of rebar	f_y	60	ksi
shear ratio	φ	0.75	

Check punching shear for column A				
Assume reinforcements are:	#	6	bars	
Bar Diameter	di	0.75	inches	
Cover	C	3	inches	
Effective depth	d	0.7	ft	
Factored footing pressure	q_{fact}	1.91	kips/ft^2	
Perimeter of punching shear	b_{oA}	88.5	inches	
Punching shear stress	V_{uA}	22.8	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check punching shear for column B				
Perimeter of punching shear	b_{oB}	129	inches	
Punching shear stress	V_{uB}	14.0	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check Direct Shear				
Maximum Shear	V_{max}	19.3	kips	
Distance from zero shear to max shear	X	10.54167	ft	
Direct shear at the critical section	V_u	18.0	kips	
Shear strength of concrete for footing section	φV_c	46.95982	kips	OK

Maximum Positive/Negative reinforcement in longitudinal direction				
Maximum Positive Moment	M_{max}	78.8	ft-kips	
Required width of footing	b_{req}	2	ft	
Moment ratio	φ_m	0.9		
Assume depth of Stress block	a	0.9	inches	
Iteration	T	134.7	kips	
	a	1.65	inches	
	T	141.5	kips	
	a	1.73	inches	
Converges	a	0.84	inches	
Area of steel	A_s	2.36	in^2	
Reinforcement ratio	ρ	0.01191		
Minimum Reinforcement Ratio	ρ_{min}	0.01588		
Adjusted Area of Steel	A_s	3.14	in^2	
Allowable Spacing	S	13.87	inches	
Choose Bar: Size	#	5		Manual Decision
Number		15		
Spacing		12.4	inches	OK

Determine reinforcement in transverse direction				
Distrance from face of column to footing edge	ℓ	0.5	ft	
For 1ft section		1	ft	
Factored moment at face of column	M_u	3.82	k-ft	
Assume "a"	a	0.1	inches	
Iteration	T	6.2	kips	
	a	0.15	inches	
	T	6.2	kips	
	a	0.15	inches	
Final "a"	a	0.15	inches	
Area steel for 1ft section	A_s	0.103907	in^2	
Reinforcement Ratio	ρ	0.00105		
Minimum Reinforcement Ratio	ρ_{min}	0.00140		
Adjusted Area of Steel	A_s	3.06		
Choose Bar: Size	#	7		Manual Decision
Number		6		
Spacing		3.60	inches	OK

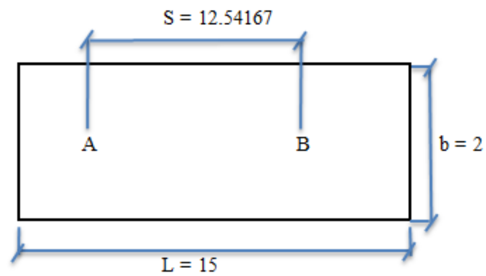
Model: C3

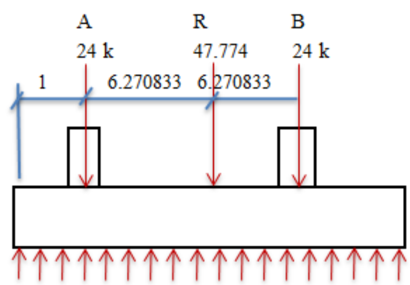
Design Checks		
Punching Shear Strength	φv_c	OK
Punching Shear Strength	φv_c	OK
Shear strength of concrete for footing section	φV_c	OK

Combined Footings - Service Load Design

Column A: Node 642	Live Load	P_{1L}	0	Kips
	Dead Load	P_{1D}	23.887	Kips
	Total	P_{1T}	23.887	Kips
Column B: Node 643	Live Load	P_{2L}	0	Kips
	Dead Load	P_{2D}	23.887	Kips
	Total	P_{2T}	23.887	Kips
	Resultant	R	47.774	Kips
	Distance Between Columns	s	12.542	ft
	Allowable Soil Pressure	q_a	3000	psf
	Distance from column A to edge of footing	m	1	ft
	Depth of soil above footing		12	inches
	Unit weight of soil	γ_s	120	pcf
	Depth of footing		18	inches
	Unit weight of concrete	γ_c	150	pcf

Service Load Design			
Location of resultant from A	n	6	ft
Length of Footing	L	15	ft
Weight of Footing	q_F	225	psf
Weight of soil above footing	q_s	120	psf
Net soil bearing capacity	q_e	2655	psf
Required footing area	A_{req}	18	ft^2
Required width of footing	b_{req}	2	ft





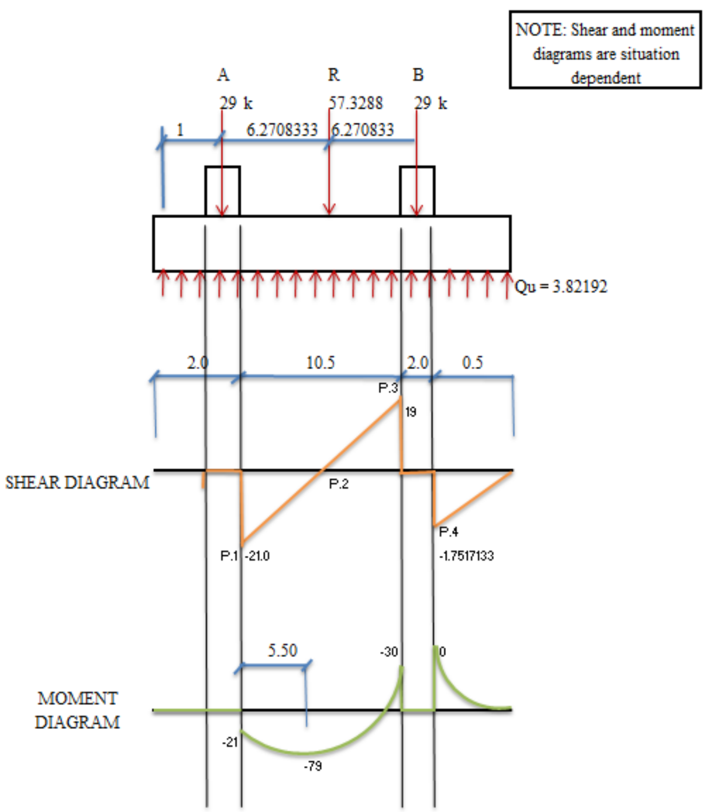
Combined Footings - Structural Analysis

Column Size	Depth	C_d	2	ft
	Width	C_w	2	ft
	Area	A_c	4	ft^2
Factored Column Loads	Column A	P_{ua}	28.66	kips
	Column B	P_{ub}	28.66	kips
Location of Resultant from column A		$R_{factored}$	7	ft
Factored footing pressure per linear foot of footing		Q_u	3.8	k/ft

Design Code
ACI 318-05

Shear Diagram				
	Point 1	V_{U1}	-21.0	kips
	Point 3	V_{U3}	19.3	kips
	Point 4	V_{U4}	-1.8	kips

Moment Diagram				
Distance from inside face of column A to peak moment		X	5.5	ft
	Point 1	M_{U1}	-21	ft-kips
	Point 2	M_{U2}	-78.8	ft-kips
	Point 3	M_{U3}	-30.3	ft-kips
	Point 4	M_{U4}	0.401	ft-kips



Combined Footings - Reinforcement Design

Compressive Strength of Concrete at 28 days	f'_c	4	ksi	
Yield Strength of rebar	f_y	60	ksi	
shear ratio	φ	0.75		

Check punching shear for column A				
Assume reinforcements are:	#	6	bars	
Bar Diameter	di	0.75	inches	
Cover	C	3	inches	
Effective depth	d	1.2	ft	
Factored footing pressure	$q_{u,net}$	1.91	kips/ft^2	
Perimeter of punching shear	$b_{o,A}$	100.5	inches	
Punching shear stress	V_{uA}	9.0	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check punching shear for column B				
Perimeter of punching shear	b_{oB}	153	inches	
Punching shear stress	V_{uB}	4.2	psi	
Punching Shear Strength	φv_c	189.7	psi	OK

Check Direct Shear				
Maximum Shear	V_{max}	19.3	kips	
Distance from zero shear to max shear	X	10.54167	ft	
Direct shear at the critical section	V_u	17.1	kips	
Shear strength of concrete for footing section	φV_c	81.11242	kips	OK

Maximum Positive/Negative reinforcement in longitudinal direction				
Maximum Positive Moment	M_{max}	78.8	ft-kips	
Required width of footing	b_{req}	2	ft	
Moment ratio	φ_m	0.9		
Assume depth of Stress block	a	0.9	inches	
Iteration	T	76.1	kips	
	a	0.93	inches	
	T	76.2	kips	
	a	0.93	inches	
Converges	a	0.84	inches	
Area of steel	A_s	1.27	in^2	
Reinforcement ratio	ρ	0.00371		
Minimum Reinforcement Ratio	ρ_{min}	0.00495		
Adjusted Area of Steel	A_s	1.69	in^2	
Allowable Spacing	S	13.87	inches	
Choose Bar: Size	#	3		Manual Decision
Number		16		
Spacing		11.6	inches	OK

Determine reinforcement in transverse direction				
Distrance from face of column to footing edge	ℓ	0.5	ft	
For 1ft section		1	ft	
Factored moment at face of column	M_u	3.82	k-ft	
Assume "a"	a	0.1	inches	
Iteration	T	3.6	kips	
	a	0.09	inches	
	T	3.6	kips	
	a	0.09	inches	
Final "a"	a	0.09	inches	
Area steel for 1ft section	A_s	0.059786	in^2	
Reinforcement Ratio	ρ	0.00035		
Minimum Reinforcement Ratio	ρ_{min}	0.00047		
Adjusted Area of Steel	A_s	1.75		
Choose Bar: Size	#	5		Manual Decision
Number		6		
Spacing		3.60	inches	OK

Appendix H: STAAD.*foundation* – Combined Footing

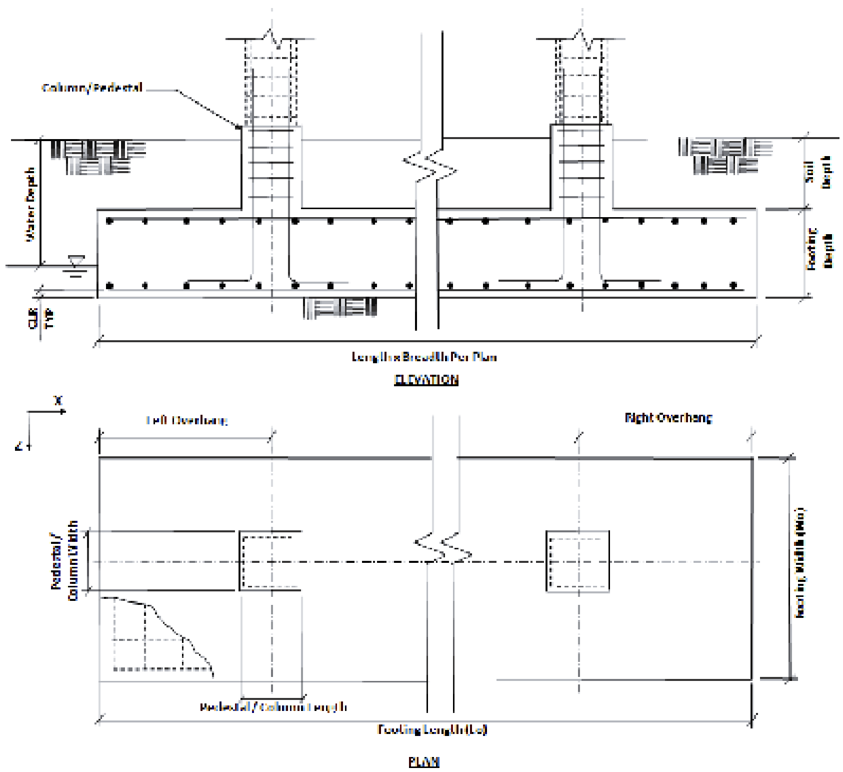
COMBINED FOUNDATION DESIGN (ACI 318-05)

Design For Combined Footing 1

Result Summary

Footing No.	Left Overhang (ft)	Right Overhang (ft)	Length (ft)	Width (ft)	Thickness (ft)
1	1.833	1.833	16.208	2.333	2.000

Footing No.	Footing Reinforcement			
-	Main Steel Top	Main Steel Bottom	Secondary Steel Top	Secondary Steel Bottom
1	4 - #6	4 - #7	22 - #6	16 - #7



Combined Footing 1

Input Data

COMBINED FOUNDATION DESIGN (ACI 318-05)

Design For Combined Footing 1

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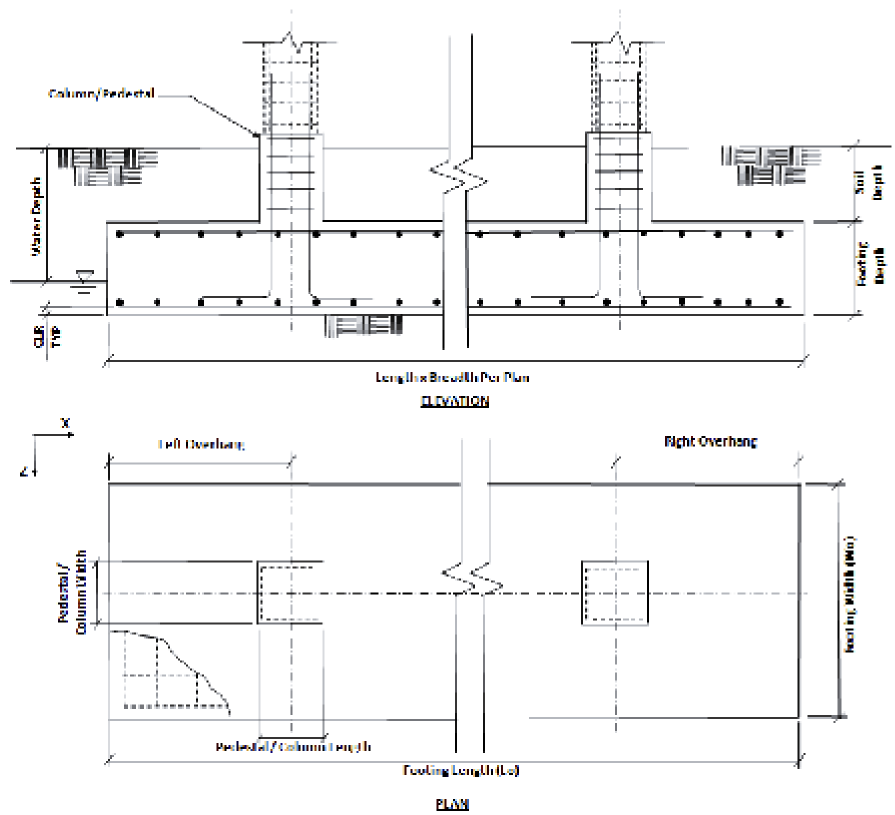

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Input Data

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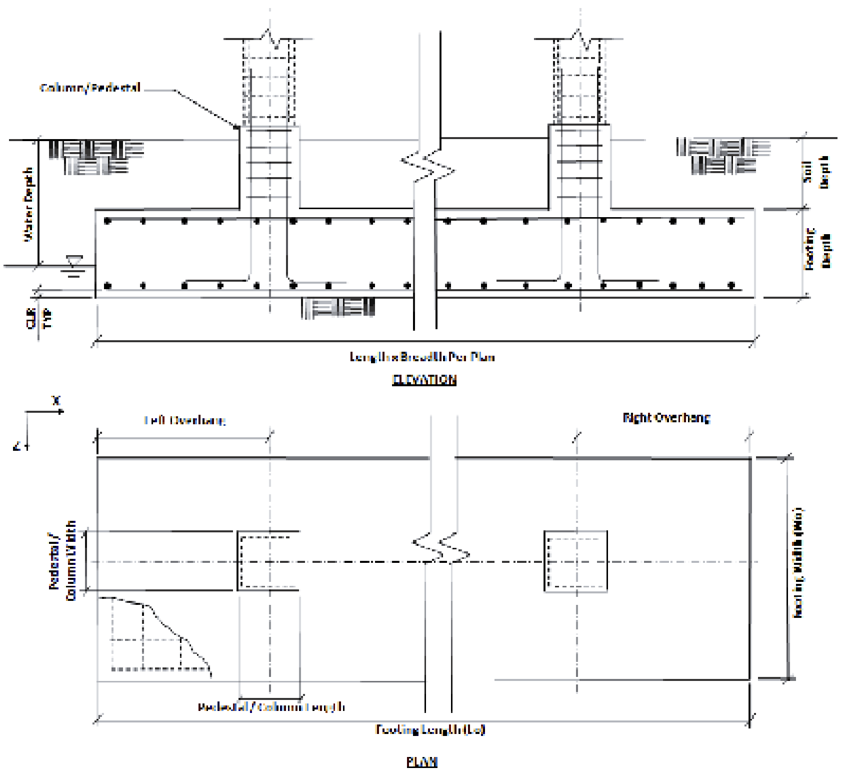

Combined Footing 1

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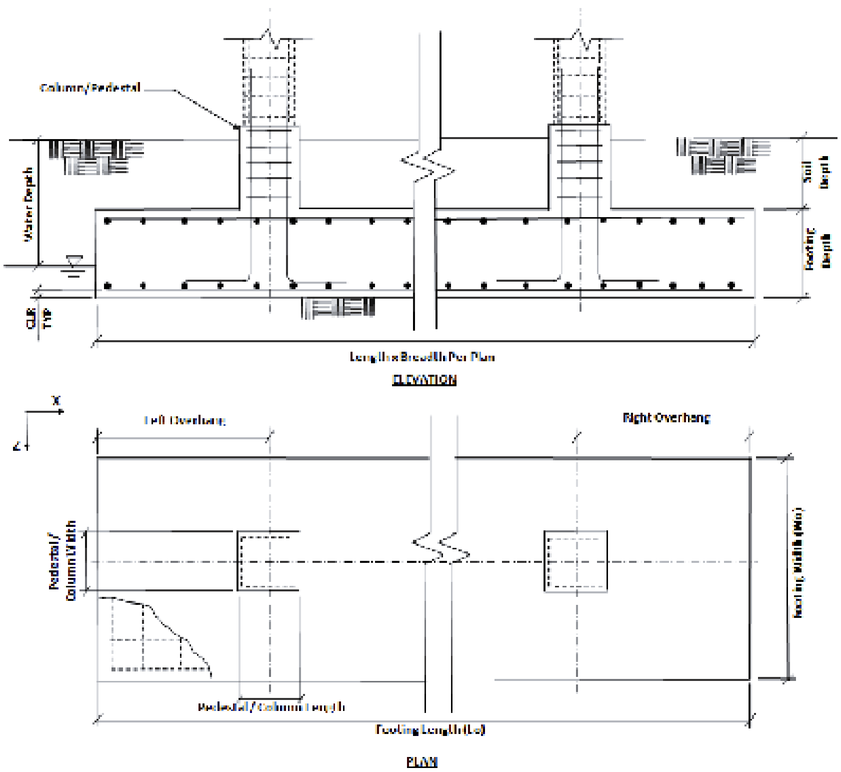

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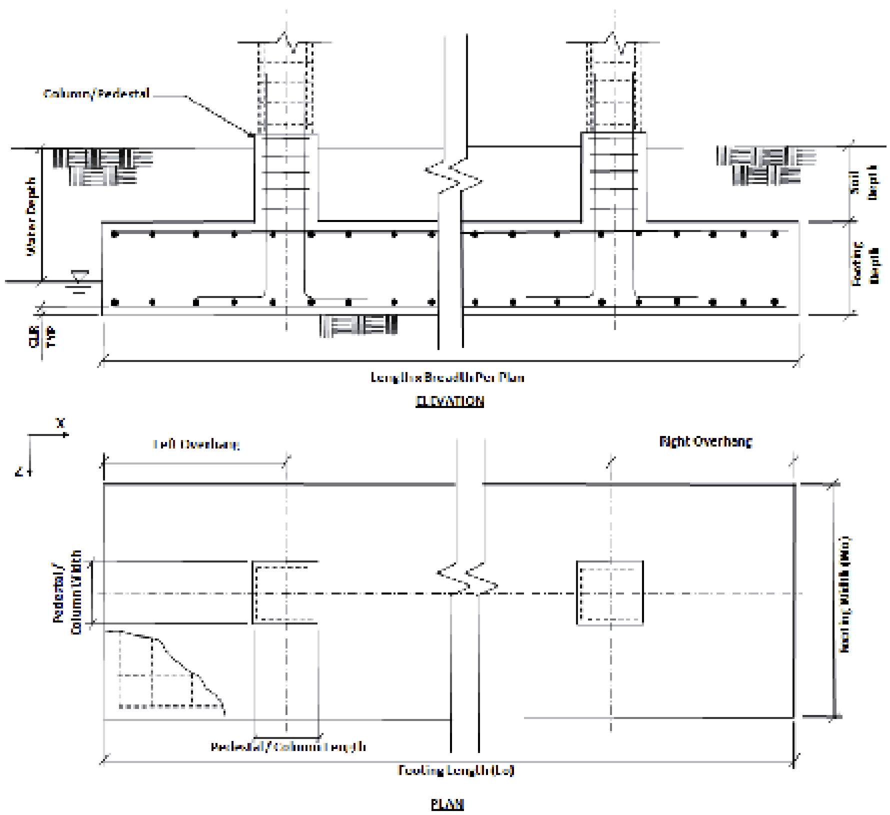

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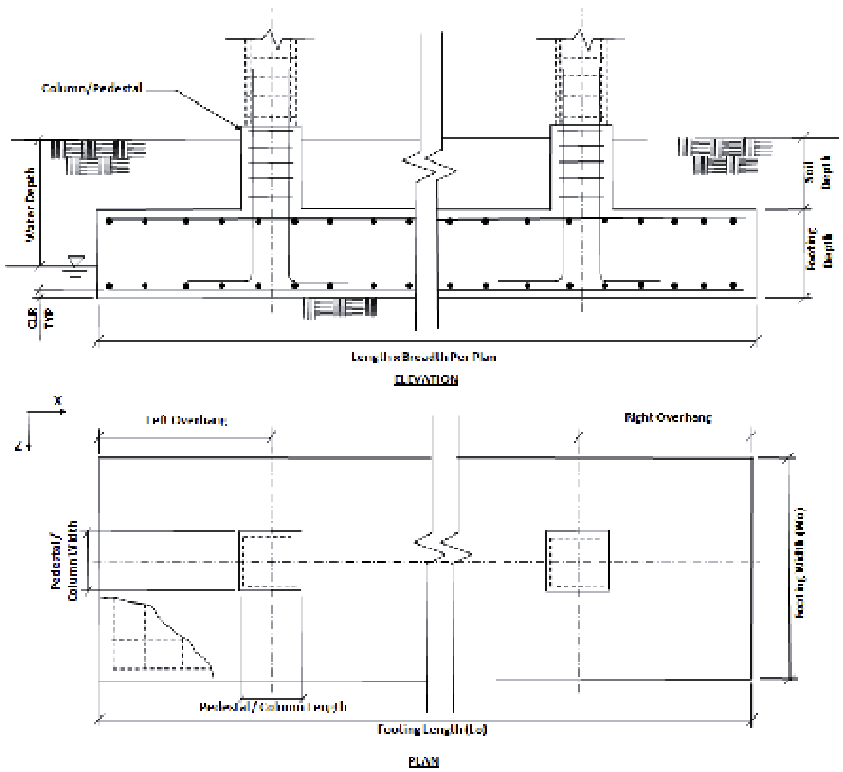

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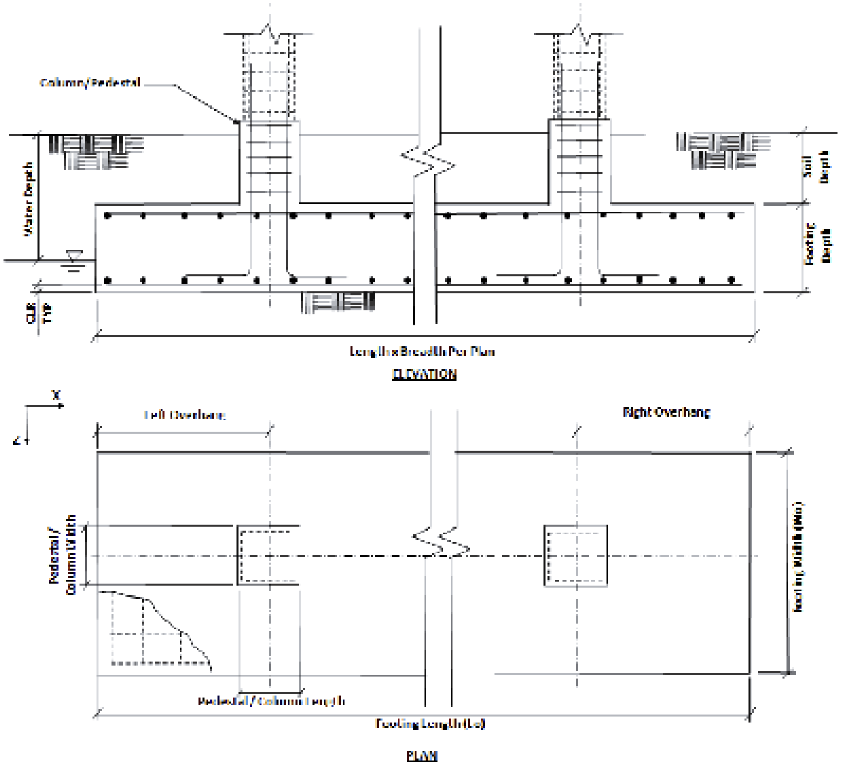

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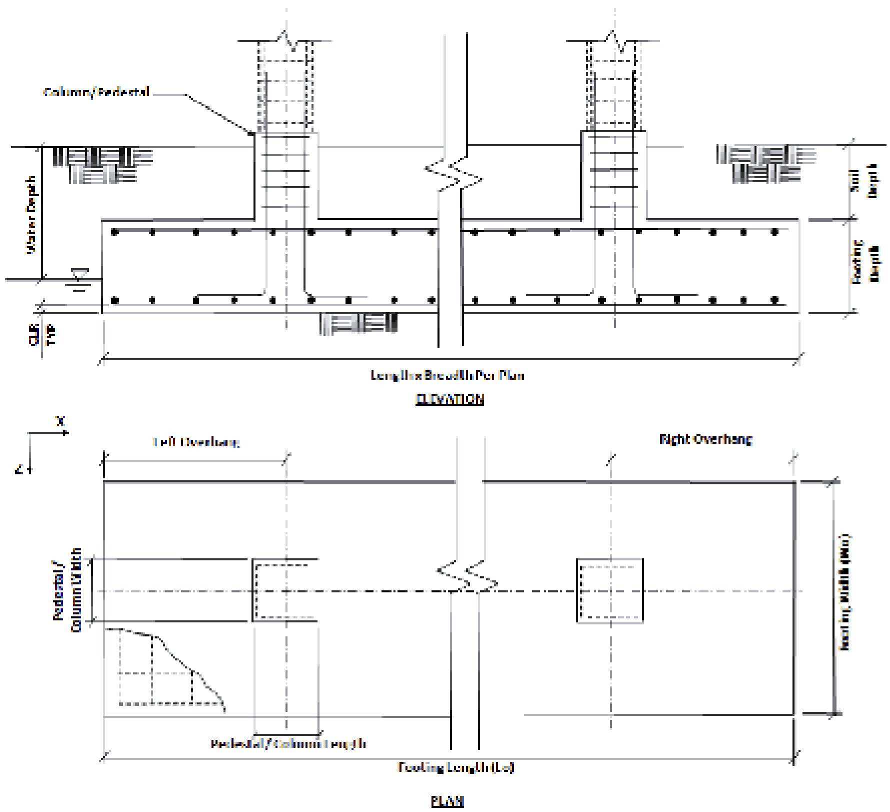

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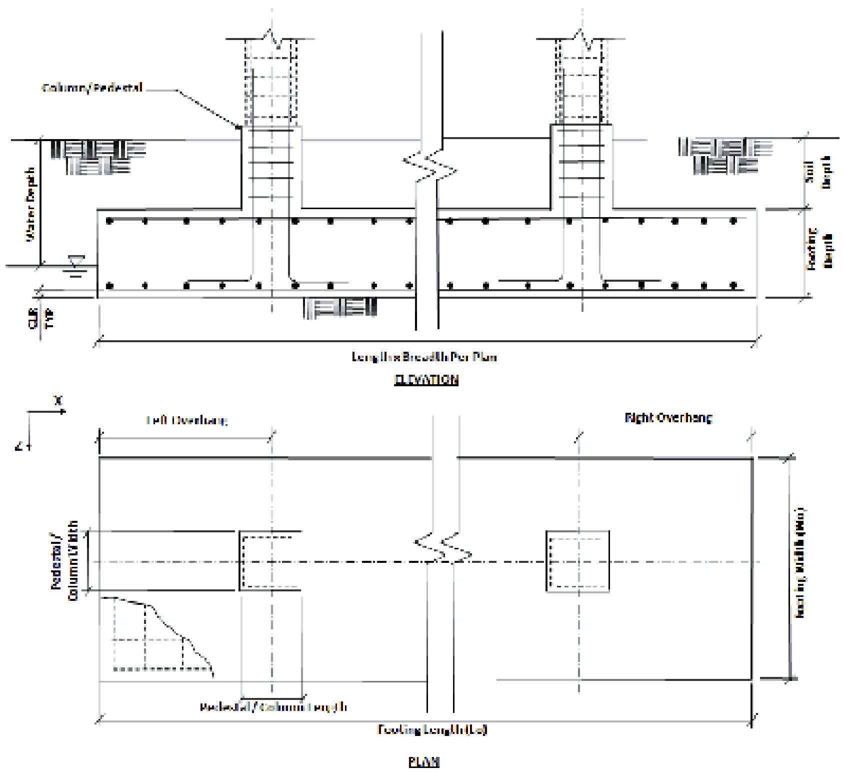

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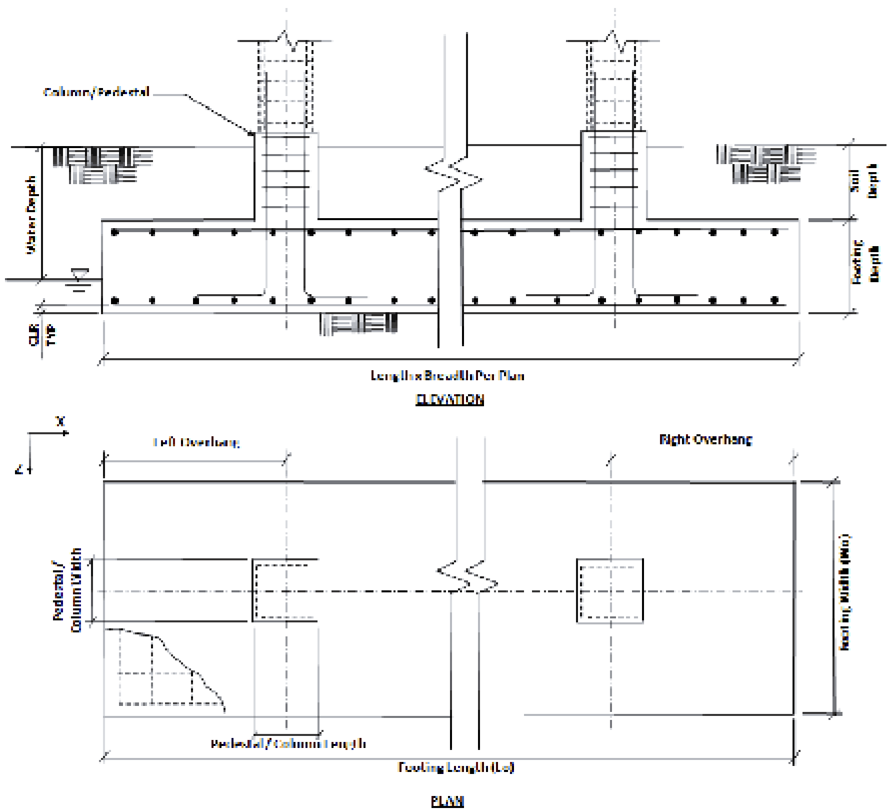

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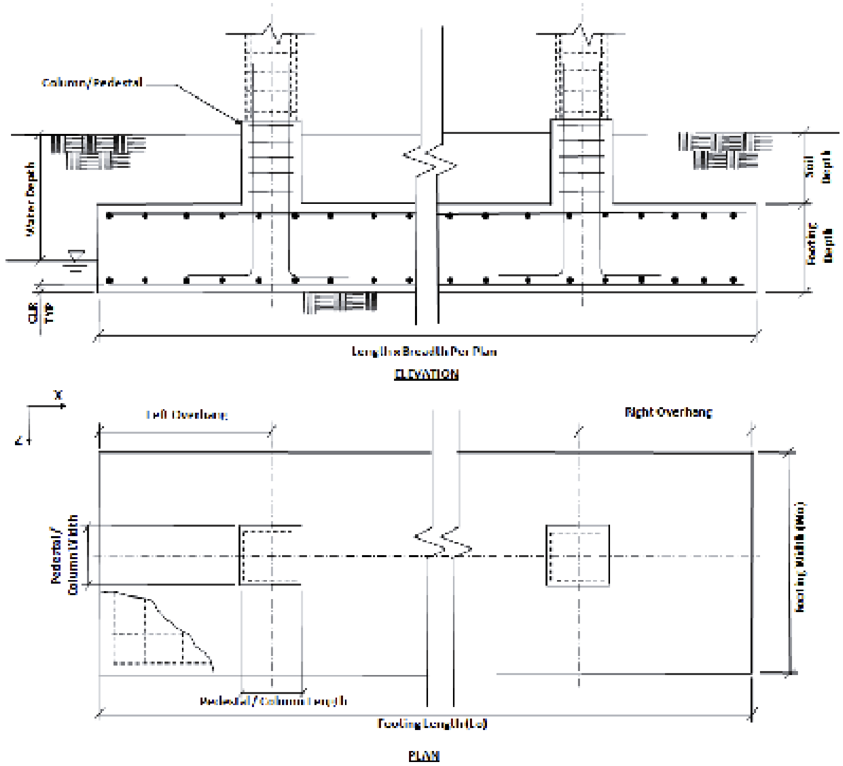

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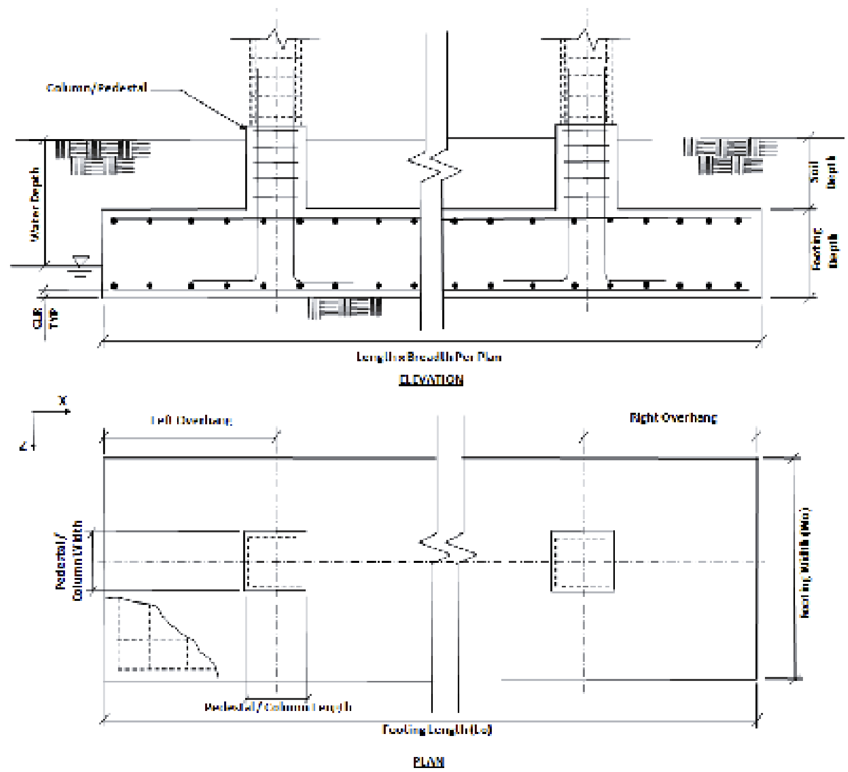

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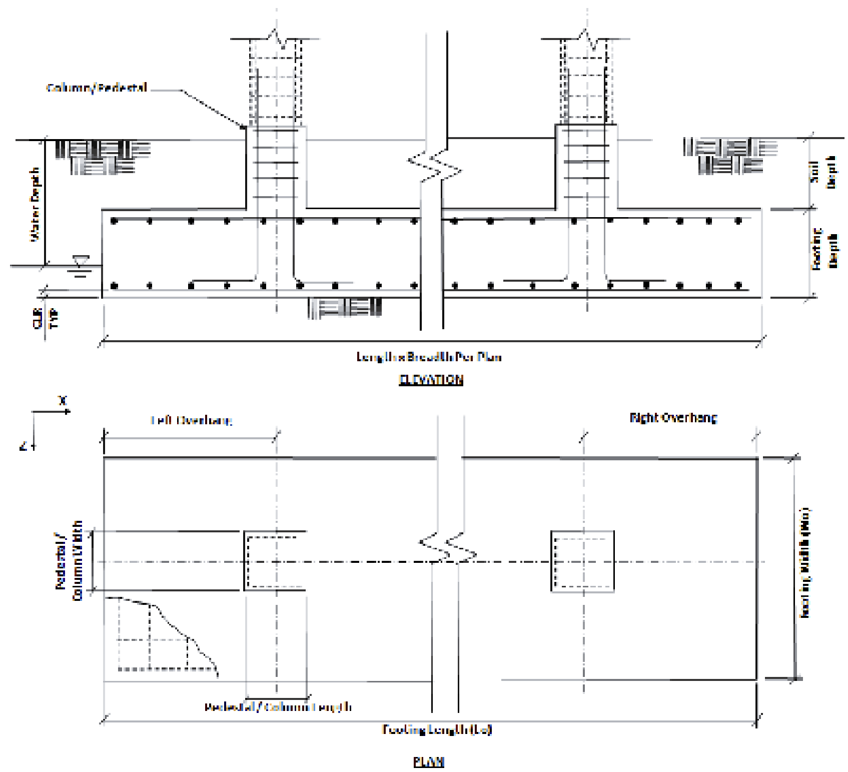

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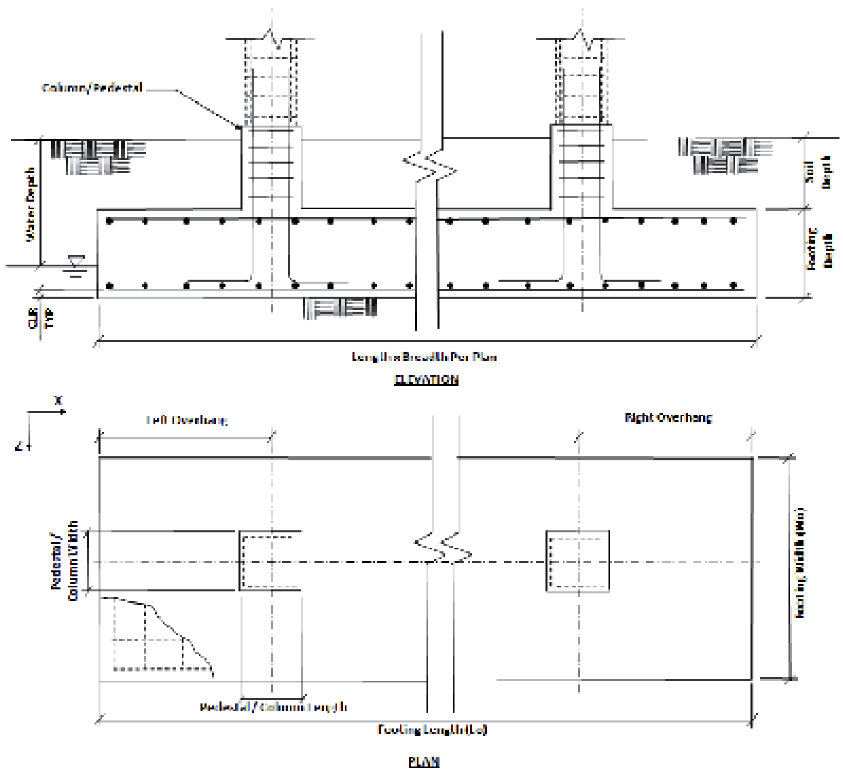

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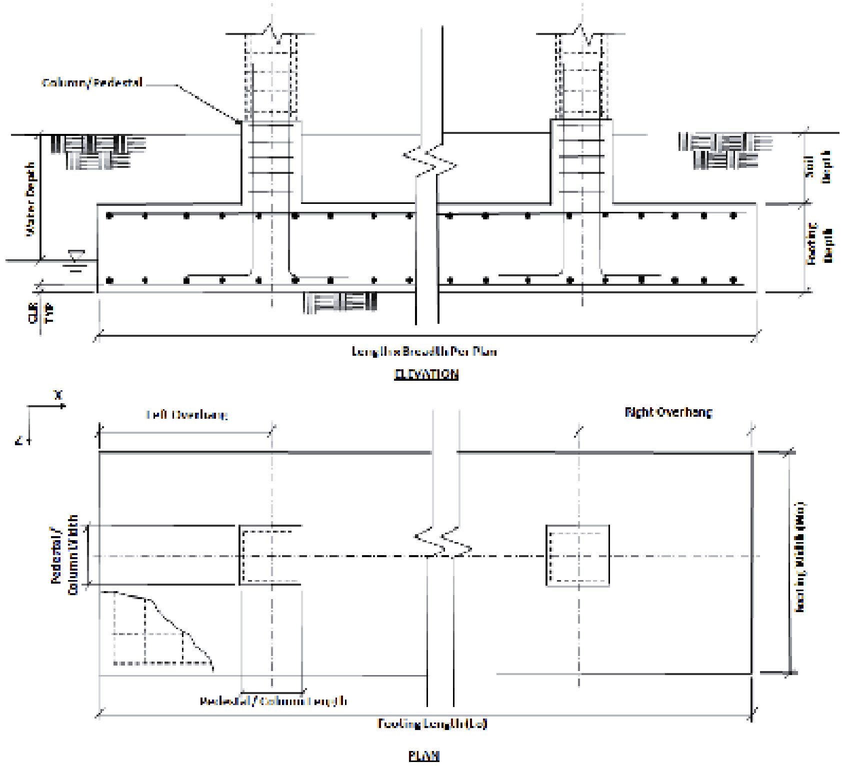

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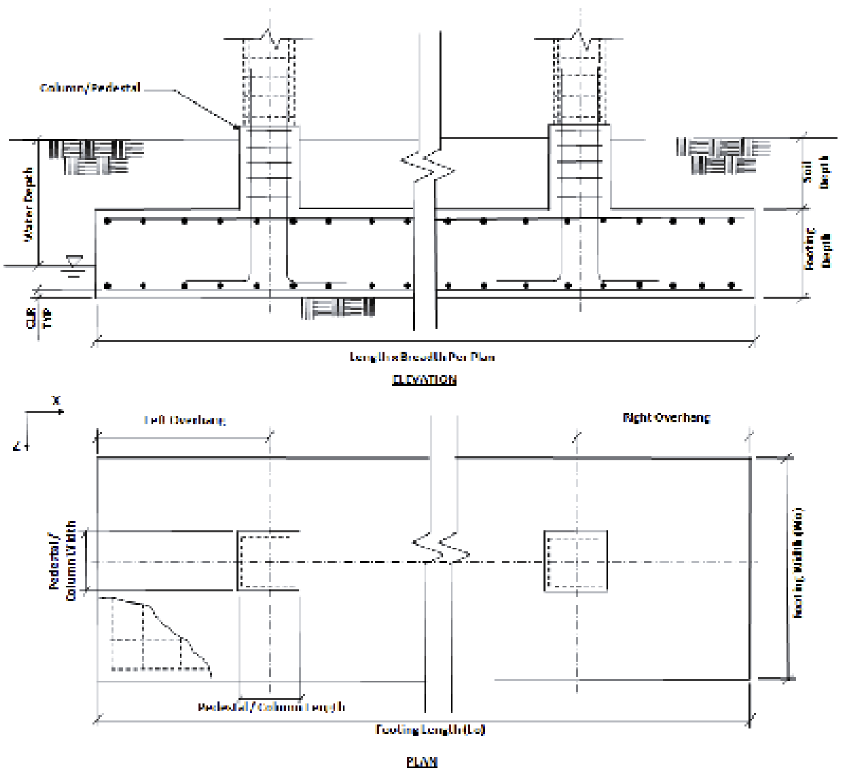

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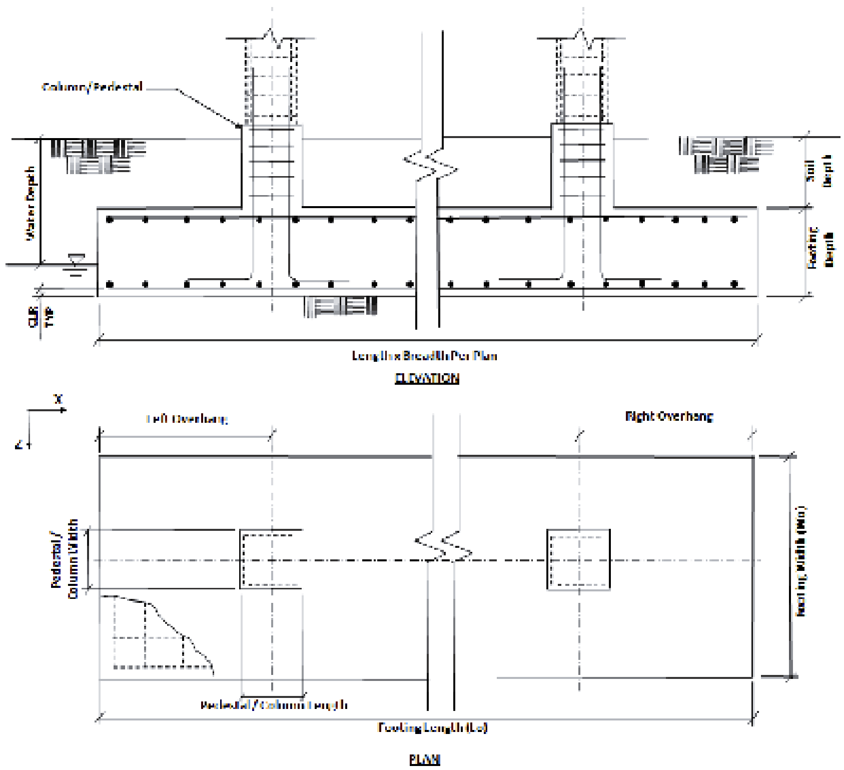


Combined Footing 1

Input Data

Geometry of Footing

For Column 642

Column Dimensions

Column Shape : Rectangular
Column Length - X (D_{col}) : 0.532ft
Column Width - Z (B_{col}) : 0.507ft

Pedestal

Include Pedestal? No
Pedestal Shape : N/A
Pedestal Height (Ph) : N/A
Pedestal Length - X (Pl) : N/A
Pedestal Width - Z (Pw) : N/A

Eccentricity

Column Offset in Transverse Direction : 0.000ft

For Column 643

Column Dimensions

Column Shape : Rectangular
Column Length - X (D_{col}) : 0.532ft
Column Width - Z (B_{col}) : 0.507ft

Pedestal

Include Pedestal? No
Pedestal Shape : N/A
Pedestal Height (Ph) : N/A
Pedestal Length - X (Pl) : N/A
Pedestal Width - Z (Pw) : N/A

Eccentricity

Column Offset in Transverse Direction : 0.000ft

Length of left overhang : 1.000ft
Length of right overhang : 1.000ft
Is the length of left overhang fixed? No
Is the length of right overhang fixed? No
Minimum width of footing (Wo) : 1.000ft
Minimum Thickness of footing (Do) : 2.000ft
Maximum Width of Footing (Wo) : 10.000ft
Maximum Thickness of Footing (Do) : 5.000ft

Maximum Length of Footing (Lo) : 300.000ft
Length Increment : 2.000in
Depth Increment : 2.000in

Cover and Soil Properties

Pedestal Clear Cover : 2.000in
Footing Clear Cover : 3.000in
Unit Weight of soil : 120.000lb/ft3
Soil Bearing Capacity : 4.000kip/ft2
Soil Bearing Capacity Type: Net Bearing Capacity
Soil Surcharge : 0.000kip/in2
Depth of Soil above Footing : 12.000in
Type of Depth : Fixed Top
Depth of Water Table : 120.000ft

Concrete and Rebar Properties

Unit Weight of Concrete : 0.610kip/ft3
Compressive Strength of Concrete : 4.000ksi
Yield Strength of Steel : 60.000ksi
Minimum Bar Size : #7
Maximum Bar Size : #14
Minimum Pedestal Bar Size : #3
Maximum Pedestal Bar Size : #10
Minimum Bar Spacing : 2.000in
Maximum Bar Spacing : 18.000in

Design Calculations

Footing Size Calculations

Gross Soil Bearing Capacity = 4.36kip/ft^2
Reduction of force due to buoyancy = 0.000kip

Area from initial length and width, $A_o = L_o \times W_o$ = 14.542ft^2
Min. area required from bearing pressure, $A_{min} = P / q_{max}$ = 15.413ft^2

Note: A_{min} is an initial estimation.
P = Critical Factored Axial Load(without self weight/buoyancy/
q_{max} = Respective Factored Bearing Capacity.

Final footing dimensions are:

Length of footing, L : 16.208ft
Width of footing, W : 2.333ft
Depth of footing, Do : 2.000ft
Area, A : 37.820ft^2
Length of left overhang, $L_{left\_overhang}$: 1.833ft
Length of right overhang, $L_{right\_overhang}$: 1.833ft
Footing self weight : 46.140kip
Soi weight on top of footing : 4.474kip

Load Combination Number	Load Combination Title	Load Combination Factor	Soil Bearing Factor	Self Weight Factor
110	D + W N-S	1.00	1.00	1.00
111	D + W S-N	1.00	1.00	1.00
112	D + W E-W	1.00	1.00	1.00
113	D + W W-E	1.00	1.00	1.00
120	0.6 DL + W N-S	1.00	1.00	1.00
121	0.6 DL + W S-N	1.00	1.00	1.00
122	0.6 DL + W E-W	1.00	1.00	1.00
123	0.6 DL + W W-E	1.00	1.00	1.00
200	1.4 DL	1.00	1.00	1.00
210	1.2 DL + 1.6 W N-S	1.00	1.00	1.00
211	1.2 DL + 1.6 W S-N	1.00	1.00	1.00
212	1.2 DL + 1.6 W E-W	1.00	1.00	1.00
213	1.2 DL + 1.6 W W-E	1.00	1.00	1.00
220	0.9 DL + 1.6 W N-S	1.00	1.00	1.00
221	0.9 DL + 1.6 W S-N	1.00	1.00	1.00
222	0.9 DL + 1.6 W E-W	1.00	1.00	1.00
223	0.9 DL + 1.6 W W-E	1.00	1.00	1.00

Load Combination Number	Load Combination Title	Load Combination Factor	Soil Bearing Factor	Self Weight Factor
110	D + W N-S	1.00	1.00	1.00
111	D + W S-N	1.00	1.00	1.00
112	D + W E-W	1.00	1.00	1.00
113	D + W W-E	1.00	1.00	1.00
120	0.6 DL + W N-S	1.00	1.00	1.00
121	0.6 DL + W S-N	1.00	1.00	1.00
122	0.6 DL + W E-W	1.00	1.00	1.00
123	0.6 DL + W W-E	1.00	1.00	1.00
200	1.4 DL	1.00	1.00	1.00
210	1.2 DL + 1.6 W N-S	1.00	1.00	1.00
211	1.2 DL + 1.6 W S-N	1.00	1.00	1.00
212	1.2 DL + 1.6 W E-W	1.00	1.00	1.00
213	1.2 DL + 1.6 W W-E	1.00	1.00	1.00
220	0.9 DL + 1.6 W N-S	1.00	1.00	1.00
221	0.9 DL + 1.6 W S-N	1.00	1.00	1.00
222	0.9 DL + 1.6 W E-W	1.00	1.00	1.00
223	0.9 DL + 1.6 W W-E	1.00	1.00	1.00

Applied Loads - Service Stress Level

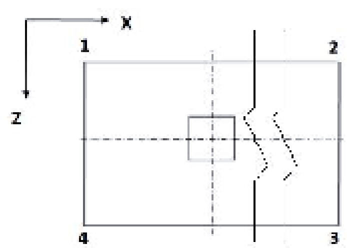
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
-					
Column Number : 642					
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000
122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000
-					
Column Number : 643					
110	13.701	-0.138	1.968	0.000	0.000
111	3.562	-0.063	-1.897	0.000	0.000
112	17.087	-3.413	0.057	0.000	0.000
113	0.176	3.212	0.014	0.000	0.000
120	10.248	-0.098	1.953	0.000	0.000
121	0.109	-0.023	-1.911	0.000	0.000
122	13.635	-3.373	0.043	0.000	0.000
123	-3.277	3.252	0.000	0.000	0.000
200	12.084	-0.141	0.050	0.000	0.000
210	18.469	-0.181	3.134	0.000	0.000
211	2.247	-0.060	-3.049	0.000	0.000
212	23.887	-5.420	0.077	0.000	0.000
213	-3.172	5.179	0.009	0.000	0.000
220	15.879	-0.151	3.123	0.000	0.000
221	-0.343	-0.030	-3.059	0.000	0.000
222	21.298	-5.390	0.066	0.000	0.000
223	-5.761	5.209	-0.002	0.000	0.000

Applied Loads - Strength Level

LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
-					
Column Number : 642					
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000

122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000
-					
Column Number : 643					
110	13.701	-0.138	1.968	0.000	0.000
111	3.562	-0.063	-1.897	0.000	0.000
112	17.087	-3.413	0.057	0.000	0.000
113	0.176	3.212	0.014	0.000	0.000
120	10.248	-0.098	1.953	0.000	0.000
121	0.109	-0.023	-1.911	0.000	0.000
122	13.635	-3.373	0.043	0.000	0.000
123	-3.277	3.252	0.000	0.000	0.000
200	12.084	-0.141	0.050	0.000	0.000
210	18.469	-0.181	3.134	0.000	0.000
211	2.247	-0.060	-3.049	0.000	0.000
212	23.887	-5.420	0.077	0.000	0.000
213	-3.172	5.179	0.009	0.000	0.000
220	15.879	-0.151	3.123	0.000	0.000
221	-0.343	-0.030	-3.059	0.000	0.000
222	21.298	-5.390	0.066	0.000	0.000
223	-5.761	5.209	-0.002	0.000	0.000

Calculated Pressures at Four Corners



Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)	Area of footing in uplift (A_u) (sq. ft)
211	**2.9700**	0.7365	0.8021	3.0356	0.000
210	0.7365	**2.9700**	3.0356	0.8021	0.000
212	1.1273	1.1273	**4.0757**	4.0757	0.000
212	1.1273	1.1273	4.0757	**4.0757**	0.000

If A_u is zero, there is no uplift and no pressure adjustment is necessary. Otherwise, to account for uplift, areas of negative pressure will be set to zero and the pressure will be redistributed to remaining corners.

Summary of Adjusted Pressures at Four Corners

Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)
211	**2.9700**	0.7365	0.8021	3.0356
210	0.7365	**2.9700**	3.0356	0.8021
212	1.1273	1.1273	**4.0757**	4.0757
212	1.1273	1.1273	4.0757	**4.0757**

Check for stability against sliding

Load Case	Shear X (kip)	Shear Z (kip)	Resultant Shear (kip)	Resisting Sliding Force (kip)	Ratio X	Ratio Z	Resultant Ratio
110	-0.201	3.864	3.869	28.688	142.726	7.424	7.414
111	-0.201	-3.864	3.869	28.688	142.726	7.424	7.414
112	-6.826	-0.000	6.826	35.453	5.194	N/A	5.194
113	6.424	-0.000	6.424	21.924	3.413	N/A	3.413
120	-0.121	3.864	3.866	25.926	214.974	6.710	6.706
121	-0.121	-3.864	3.866	25.926	214.974	6.710	6.706
122	-6.745	0.000	6.745	32.691	4.847	N/A	4.847
123	6.504	-0.000	6.504	19.162	2.946	N/A	2.946
200	-0.281	-0.000	0.281	31.451	111.762	N/A	111.762
210	-0.241	6.183	6.187	30.070	124.664	4.864	4.860
211	-0.241	-6.183	6.187	30.070	124.664	4.864	4.860
212	-10.841	0.000	10.841	40.893	3.772	N/A	3.772
213	10.358	-0.000	10.358	19.246	1.858	187028.728	1.858
220	-0.181	6.183	6.185	27.998	154.767	4.529	4.527
221	-0.181	-6.183	6.185	27.998	154.767	4.529	4.527
222	-10.780	0.000	10.780	38.821	3.601	N/A	3.601
223	10.419	-0.000	10.419	17.175	1.648	N/A	1.648

Check for stability against overturning (Moments printed against Local axis)

Load Case	Moment X (kip-ft)	Moment Z (kip-ft)	Resisting Moment X (kip-ft)	Resisting Moment Z (kip-ft)	Ratio X	Ratio Z
110	0.436	-71.951	83.675	581.242	192.131	8.078
111	0.436	71.952	83.675	581.242	192.131	8.078
112	14.789	0.000	103.405	718.296	6.992	N/A
113	-13.918	0.001	63.945	444.188	4.594	426232.000

120	0.261	-71.951	75.619	525.282	289.388	7.301
121	0.261	71.952	75.619	525.282	289.388	7.300
122	14.615	-0.000	95.349	662.336	6.524	3236169.967
123	-14.092	0.001	55.889	388.227	3.966	466048.754
200	0.610	0.001	91.731	637.202	150.449	875162.136
210	0.523	-115.122	87.703	609.222	167.816	5.292
211	0.523	115.123	87.703	609.222	167.816	5.292
212	23.488	-0.000	119.271	828.509	5.078	4180125.941
213	-22.443	0.001	56.135	389.935	2.501	267463.273
220	0.392	-115.122	81.661	567.252	208.340	4.927
221	0.392	115.123	81.661	567.252	208.340	4.927
222	23.357	-0.000	113.229	786.539	4.848	2150476.606
223	-22.574	0.001	50.093	347.965	2.219	267190.760

Calculations of Footing Thickness

Footing thickness is calculated based on the ultimate load cases

Check for Punching Shear

For Column 642

Critical Load case for Punching Shear Check : 18

Total Footing Depth, D_o = 2.000ft

Calculated Effective Depth, d_{eff} = 1.714ft

For rectangular column, β_c = B_{col} / D_{col} : 1.049

Considering the particular column as interior column, Slab Edge Factor α_s : 40.0

Effective depth, d_{eff}, increased until $0.75 * V_c \geq$ Punching Shear Force

Punchng Shear Force, Vu = 17.599kip

From ACI Cl.11.12.2.1, b_o for column 8.931ft

Equation 11-33, V_{c1} $\left(2 + \frac{4}{\beta_c}\right) \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'}$ = 810.025kip

Equation 11-34, V_{c2} = $\left(\frac{\alpha_s \times d}{b_o} + 2\right) \times \lambda \times \sqrt{F_c} \times b_o \times d$ = 1348.397kip

Equation 11-35, V_{c3} = $4 \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'}$ = 557.493kip

Punching shear strength, V_c= 0.75 x minimum of (V_{c1}, V_{c2}, V_{c3}) = 418.119kip

$0.75 * V_c > V_u$ hence, OK

For Column 643

Critical Load case for Punching Shear Check : 18

Total Footing Depth, D_o = 2.000ft

Calculated Effective Depth, d_{eff} = 1.714ft

For rectangular column, β_c = B_{col} / D_{col} : 1.049

Considering the particular column as interior column, Slab Edge Factor α_s : 40.0

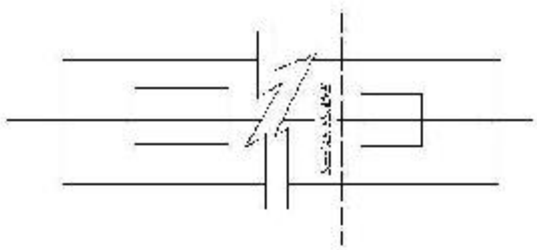
Effective depth, d_{eff}, increased until $0.75*V_c \geq$ Punching Shear Force

Punchng Shear Force, Vu = 17.599kip

From ACI Cl.11.12.2.1, b_o for column		8.931ft
Equation 11-33, V_{c1}	$\left(2+\frac{4}{\beta_c}\right) \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'}$ =	810.025kip
Equation 11-34, V_{c2} =	$\left(\frac{\alpha_s \times d}{b_o}+2\right) \times \lambda \times \sqrt{f_c'} \times b_o \times d$ =	1348.397kip
Equation 11-35, V_{c3} =	$4 \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'}$ =	557.493kip
Punching shear strength, V_c=	0.75 x minimum of (V_{c1},V_{c2},V_{c3}) =	418.119kip

$0.75 * V_c > V_u$ hence, OK

Check for One-Way Shear



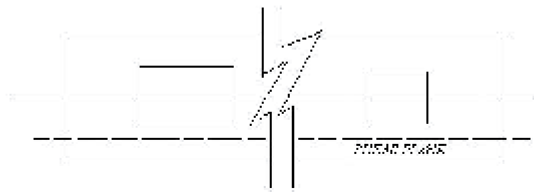
Shear Plane Parallel to Foundation Width

Critical load case for maximum shear force along the length of footing : 18

Critical Shear force, V_u	For the critical load case:	12.632kip
Point of occurance of V_u	Critical one-way shear position:	12.396ft
From ACI Cl.11.3.1.1, V_c =	$2 \times W \times d_{eff} \times \sqrt{1000 \times F_c'}$ =	72.827kip

0.75 x V_c = 54.620kip

Since $0.75 * V_c > V_u$ hence, OK



Shear Plane Parallel to Foundation Length

Critical load case for maximum shear force along the width of footing :

Critical Shear force, V_u	For the critical load case:	0.000kip
Point of occurance of V_u	Critical one-way shear position:	3.134ft
From ACI Cl.11.3.1.1, V_c =	$2 \times W \times d_{eff} \times \sqrt{1000 \times F_c'}$ =	0.000kip

$0.75 \times V_c =$ 0.000kip

Since $0.75 * V_c > V_u$ hence, OK

Design of flexure

Bottom Reinforcement

Critical load case :		23
Required Effective Depth :		1.641ft
β_1, from ACI Cl.10.2.7.3	=	0.8500
From ACI Cl. 10.3.2, ρ_{bal}	$0.85 \times \beta_1 \times \frac{F_c'}{F_y} \times \frac{87}{(87 + F_y)}$	0.02851
From ACI Cl. 10.3.3, ρ_{max}	$0.75 \times \rho_{bal}$ =	0.02138
From ACI Cl. 7.12.2, ρ_{min}	$\max\left(0.0018 \frac{60ksi}{F_y}, 0.0014\right)$ =	0.00180
Modular Ratio,m	$\frac{F_y}{(0.85 \times F_c')}$ =	17.6471
Ultimate Moment :		12.785kip-ft
Point of occurrence of the ultimate moment along the length of footing :		8.019ft
Nominal Moment Capacity :		14.205kip-ft
Required ρ (based on effective depth) :		0.0022
$\rho \times d_{eff}$ / Depth (based on gross depth) :		0.0018

Area of main steel required, A_s = ρ * W * deff :	1.210in2

Top Reinforcement

Critical load case :		18
Required Effective Depth :		1.656ft
β_1, from ACI Cl.10.2.7.3	=	0.8500
From ACI Cl. 10.3.2, ρ_{bal}	$0.85 \times \beta_1 \times f'_c \times \frac{87}{f_y \times (87 + f_y)}$ =	0.02851
From ACI Cl. 10.3.3, ρ_{max}	$0.75 \times \rho_{bal}$ =	0.02138
From ACI Cl. 7.12.2, ρ_{min}	$\max\left(0.0018 \cdot \frac{60ksi}{f_y}, 0.0014\right)$	0.00180
Modular Ratio,m	$\frac{f_y}{(0.85 \times f'_c)}$ =	17.6471
Ultimate Moment :		53.143kip-ft
Point of occurrence of the ultimate moment along the length of footing :		8.189ft
Nominal Moment Capacity :		59.048kip-ft
Required ρ (based on effective depth):		0.0022
ρ x d_{eff} / Depth (based on gross depth) :		0.0018
Area of main steel required, A_s = ρ * W * deff :		1.210in2

Distribution Reinforcement

Critical load case :	212	
Critical Moment for distribution steel :	15.9307	kip-l
Nominal moment Capacity :	17.7008	kip-l
Point of occurance of the critical moment along length:	1.4200	ft
Required ρ (based on effective depth):	0.0022	
ρ x d_{eff} / Depth (based on gross depth) :	0.0018	
Area of distribution steel required, A_s = ρ * L * deff :	8.402	in2

Top surface disribution reinforcement

Moment at column face :	9.0473	kip-l
Provided Area for distribution steel along Z(Top reinforcement):	8.402	in2

Provided Reinforcement

Main bar no. for top Reinforcement:	#6

Spacing of top reinforcement bar :	11.000	in

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 11in o.c.

Main bar no. for bottom Reinforcement:	#7	
Spacing of bottom reinforcement bar :	11.000	in

Based on spacing reinforcement increment; provided reinforcement is

#7 @ 11in o.c.

Distribution bar no. (Bottom):	#7	
Spacing of distribution bars (Bottom):	13.464	in

Based on spacing reinforcement increment; provided reinforcement is

#7 @ 13in o.c.

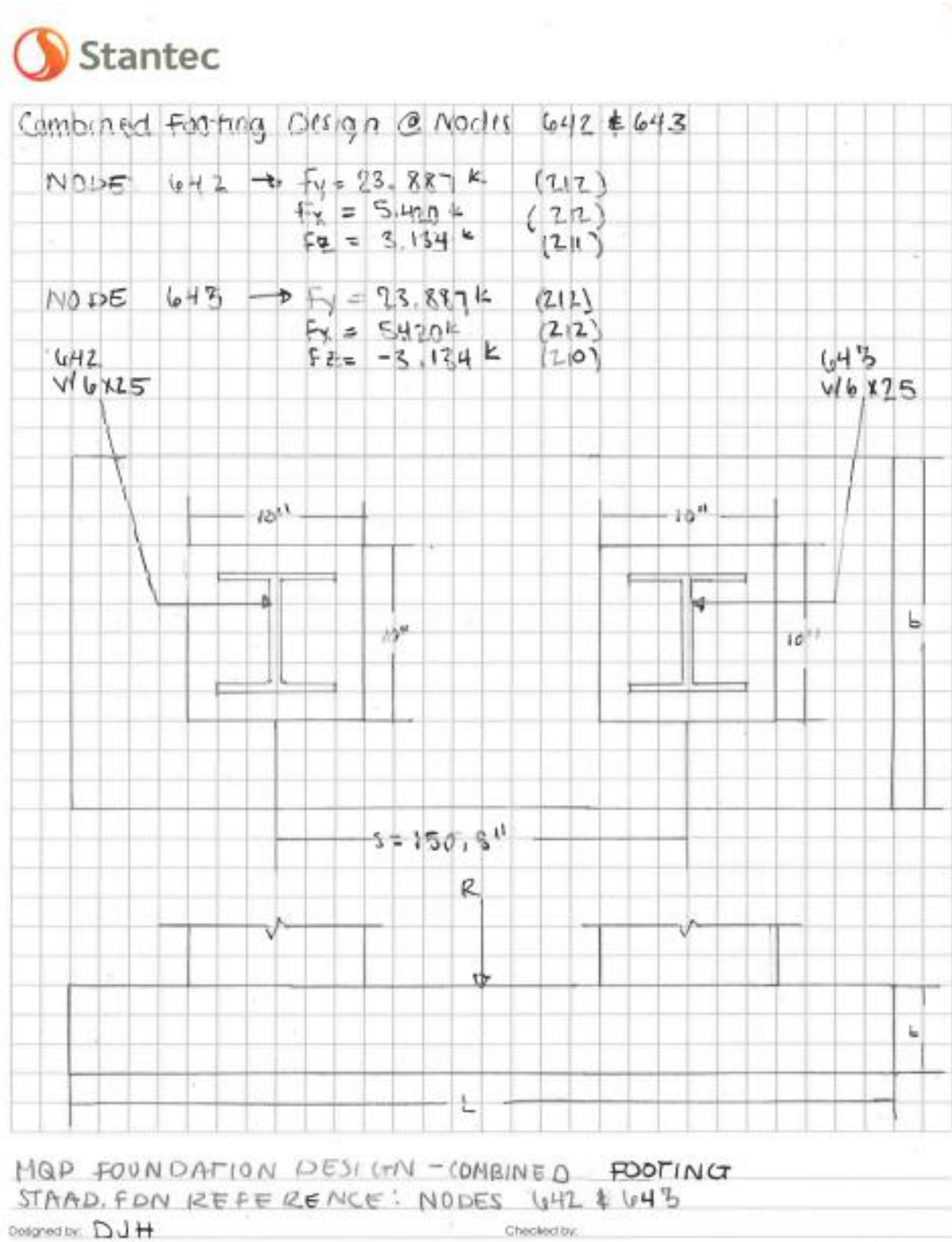
Distribution bar no.(Top):	#6	
Spacing of distribution bars(Top) :	9.921	in

Based on spacing reinforcement increment; provided reinforcement is

#6 @ 9in o.c.

Print Calculation Sheet

Appendix I: Hand Calculation - Combined Footing Design



Stantec

Combined Footing Design @ Nodes 642 & 643

NODE 642 → $F_y = 23.887^k$ (212)
$F_x = 5.420^k$ (212)
$F_z = 3.134^k$ (211)

NODE 643 → $F_y = 23.887^k$ (212)
$F_x = 5420^k$ (212)
$F_z = -3.134^k$ (210)

MQP FOUNDATION DESIGN - COMBINED FOOTING
STAAD. FDN REFERENCE: NODES 642 & 643
Designed by: DJH
Checked by:

Stantec

TOTAL AXIAL LOAD:

$P_{ax} = P_{642} + P_{643} = 2(23.887) = 47.774^k$
$S = 150.5"$

→ assume allowable soil pressure: $4000 \text{ lb/ft}^2 = q_a$
→ assume soil unit weight: $120 \text{ lb/ft}^3 = \gamma_s$
→ assume unit weight of concrete: $150 \text{ lb/ft}^3 = \gamma_c$
→ assume distance from 642 to edge of ftng: 1 ft

→ Try: column thickness = 24"
depth of soil above footing = 12"

→ Length of footing: L = 184.5"

NET SOIL BEARING CAPACITY

$$W_c = 150 \frac{lb}{ft^3}(24 in)\left(\frac{1 ft}{12 in}\right)\left(\frac{1^k}{1000}\right) = .3 \text{ k/ft}^2$$

$$W_s = 120 \frac{lb}{ft^3}(12 in)\left(\frac{1 ft}{12 in}\right)\left(\frac{1^k}{1000}\right) = .12 \text{ k/ft}^2$$

$$q_{eff} = q_a - W_c - W_s = 4 - .3 - .12 = 3.58 \text{ k/ft}^2$$

REQUIRED FOOTING AREA

$$A_{req} = \frac{P_{ax}}{q_{eff}} = \frac{47.774}{3.58} = 13.34 \text{ ft}^2$$

$$b = \frac{A_{req}}{L} = \frac{13.34}{(14.54)} = .92 \text{ ft} \quad \therefore \text{use } 1 \text{ ft} = b$$

Designed by: Checked by:

SHEAR & MOMENT CALCULATIONS

footing pressure:

$$q_n = \frac{2(23.887)}{184.5} = .26 \text{ k/in}$$

Shear:

$$+V_{P_1} = .26(17'') - 23.887$$
$$= -19.467^k$$

$$+V_{P_3} = .26(17 + 150.5) - 23.887$$
$$= 19.663^k$$

$$-V_{P_1} = 17(.26) = 4.42$$

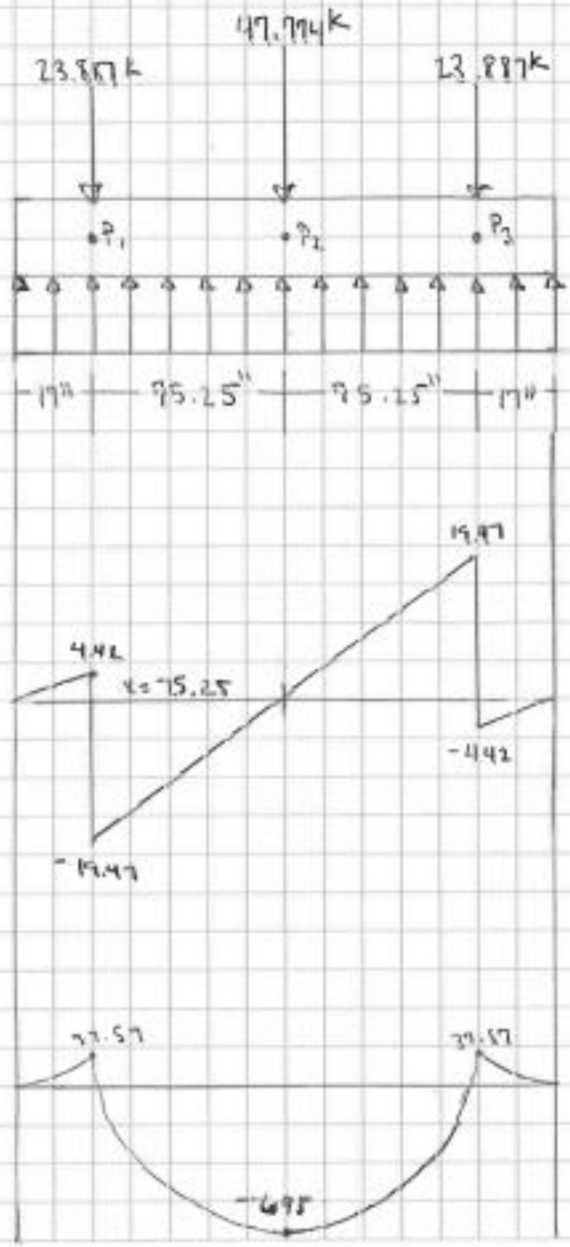
$$-V_{P_3} = -17(.26) = -4.42$$

moment:

$$M_{P_1} = \frac{4.42(17)}{2} = 37.57 \text{ k-in}$$

$$M_{P_2} = \frac{(-19.47)(75.25)}{2} = -732.56 \text{ k-in}$$
$$+37.57 = -695$$

$$M_{P_3} = \frac{(-4.42)(-17)}{2} = 37.57 \text{ k-in}$$



Designed by:

Checked by:

Stantec

CHECK FOR FLEXURE:

$M_u = 645$ k-in, $b = L = 184.5''$, $d = 24''$

$R_n = \frac{M_u}{\phi b d^2} = \frac{645}{.9(184.5)(24^2)} = .0073$ k/in² $(1000) = 7.3$ lb/in²

$\rho = \frac{.85 f'c}{f_y}\left[1 - \sqrt{1 - \frac{2R_n}{.85 f'c}}\right] = \frac{.85(4000)}{60000}\left[1 - \sqrt{1 - \frac{2(7.3)}{.85(4000)}}\right] = .00013$

$\rho_b = .85\left[\frac{87000 B_1 f'c}{f_y(87000 + f_y)}\right] = .85\left[\frac{87000(.85)(4000)}{60000(87000 + 60000)}\right] = .0335$

$\rho_{max} = .75\rho_b = .0251 > \rho$, $\rho_{min} = .0018 \rightarrow$ use

$A_s = \rho b d = .0018(184.5)(24) = 7.79$ in², use 7 #10, $A_s = 8.89$ in²

CHECK FOR PUNCHING SHEAR: $\Rightarrow$ column 642 = column 643

$\rightarrow$ assume 3'' cover

$d_{avg} = 24 - 3 - .5(1.278) = 20.361''$, $c = 10''$

punchout perimeter: $b_o = 4(20.36 + 10) = 121.44''$

$V_u = P_c - q_n(c + d)^2 = 23.887 - .022(30.36)^2 = 3.61^k$

$\phi V_c = \left[\frac{\alpha d}{b_o} + 2\right]\sqrt{f'c}\, b_o d = .75\left(\frac{20(20.36)}{121.44} + 2\right)\sqrt{4000}\,(121.44)(20.36)$

$\phi V_c = 627.82 > V_u$ ✓

Designed by: Checked by:

Stantec

CHECK FOR 1 WAY SHEAR:

$V_u = 19.47^k$

$\phi V_c = \phi 2.75\sqrt{f'c}\, bd = .75(2)\sqrt{4000}\,(184.5)(12) = 210.04^k > V_u$ ✓

CHECK FOR SLIDING:

Disturbing force: 3.134^k (from STAAD.pro Analysis)

Resisting force: μ [Self weight + Axial force)

$.5[.150(2)(1)(14.54) + 23.887] = 14.125$

CHECK FACTOR OF SAFETY: $fs = \frac{14.125}{3.134} = 4.5 > 1.5$ ✓

REINFORCEMENT SPACING

$S = \frac{L - 2(\text{cover})}{n-1} = \frac{184.5 - 2(3)}{6} = 30''$ → max

Designed by: Checked by:

Appendix J: Excel Spreadsheet – Strapped Footing Models

Model: S1

Strap Footing Design			
DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Footing	Node 642	
Length	4	ft
Width	4	ft
Thickness	2	ft
Depth to base	3	ft
Size	# 7	
Number	4	
Spacing	12	in

Footing	Node 643	
Length	3	ft
Width	3	ft
Thickness	2	ft
Depth to base	3	ft
Size	# 7	
Number	4	
Spacing	8	in

Strap Design		
Width	3	ft
Thickness	2	ft
Size	# 9	
Number	3	
Spacing	12	in

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Node 1

Check 1:	**OKAY!**

1.1 Node 2

Check 1:	**OKAY!**

1.2 Strap

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.3 Node 1 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

1.4 Node 2 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Data

1.0 Loads

Nodes: 642 & 643

Load 1	23.887
Load 2	23.887

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction
q_{ult}	4000	psf	

1.2 Initial Assumptions & Structure Information

b	4	ft	Assumed Width of Footing
d	3	ft	Depth to Base of Footing
t	2	ft	Thickness of Footing
$D_{EdgeFooting}$	1	ft	Distance from Column to Footing Edge
D_{nodes}	150.5	in	Distance Between Nodes
$D_{Reactions}$	138.5	in	Distance Between Reactions
ColWidth	10	in	Width of Column
e	1	ft	Eccentricity

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

1.0 Node 1

M	23.887	ft-kip	Moment
V	2.07	kip	Shear
R_1	25.96	kip	Reaction at Node 1
q_{eff}	3580	lb	Net Soil Bearing Capacity
q_{eff}	3.58	kip	Net Soil Bearing Capacity
A_{Reqd}	7.25	ft^2	Required Area of Footing
Side 1	4	ft	Length of Side 1
Side 2	4	ft	Length of Side 2
A_{Ftng}	16	ft^2	Area of Footing
CHECK:	**OKAY!**		

2.0 Factored Node 1

Fy_1	28.66	kip
M	28.66	
V	2.48	

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

1.0 Node 2

M	23.887	ft-kip	Moment
V	2.07	kip	Shear
R_2	25.96	kip	Reaction at Node 1
q_{eff}	3580	lb	Net Soil Bearing Capacity
q_{eff}	3.58	kip	Net Soil Bearing Capacity
A_{Reqd}	7.25	ft^2	Required Area of Footing
Side 1	3	ft	Length of Side 1
Side 2	3	ft	Length of Side 2
A_{Ftng}	9	ft^2	Area of Footing
CHECK:	**OKAY!**		

2.0 Factored Node 2

Fy_2	28.66	kip
M	28.66	
V	2.48	

Strap Footing Design

DATE:	2/6/2015		**DESIGN #:**	1
PASS:	**YES**		**CHECK:**	DH

1.0 Factored Upward Pressures

qn1	7.79
qn2	8.73

1.2 Diagram & Shear Forces

+P1	14.28
-P1	-14.39
P2	2.48
P3	2.48
+P4	15.57
-P4	-13.09

1.3 X-Distances

X1	1.83	ft
X2	1.84	ft
X3	0.33	ft
X4	8.875	ft
X5	1.5	ft
X6	1.5	ft

1.4 Moments

Mu	13.062675
Mu	-26.176703
Mu	-25.766916
Mu	-3.7253372
Mu	9.8178157

Strap Footing Design

DATE:	2/6/2015	**DESIGN #**	1
PASS:	**YES**	**CHECK:**	DH

1.0 Initial Data

$Strap_{Width}$	3	ft	
$Strap_{Depth}$	2	ft	
$Strap_{Cover}$	3	in	Clear Cover
$D_{EffStrap}$	20.361	in	Effective Depth

1.1 One Way Shear

Vu	15.57		
ϕ	0.75		
ϕVc	34769.05	lb	
ϕVc	34.77	kip	
1/2 ϕVc	17.38	kip	
CHECK:	**OKAY!**		What is the check here?

1.2 Flexure

ϕ	0.9		
Mu	26.18		
a	2	in	Assumed
T	18.03	kip	
a	0.15	in	
a_{Used}	1	in	
T	17.57	kip	
As	0.29	in^2	
ρ	0.0004		
ρ_{min}	0.003333		
As_{min}	2.44332	in^2	
As	2.44332	in^2	
Size	# 9		Size of Steel Reinforcing
n	2.44		Number of Bars used to achieve Asmin
n_{used}	3		Number of Bars used
S_{max}	15	in	Maximum Allowable Spacing
Spacing	12	in	
Check:	**OKAY!**		Spacing<Smax

Strap Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Node 642

Cover	3	in
d_{eff}	20	in
c+d	30	in
b_o	120	in
q_n	1.95	k/ft^2
F_y	28.66	kip

1.1 Two Way Shear

α	20		Select Column Location
Vu	16.50	kip	
ϕVc	809543.08	lb	
ϕVc	809.54308	kip	
	CHECK:	OKAY!	

1.2 One Way Shear

Vu	14.39	kip
ϕ	0.75	
ϕVc	227683.99	lb
ϕVc	227.68	kip
	CHECK:	OKAY!

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	26.18	kip-ft
Rn	0.018	k/in^2
Rn	18.18	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0003		
ρ_b	0.0335		
ρ_{max}	0.0251531		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	1.728		
Size	#7		Size of Steel Reinforcing
n	2.88		Number of Bars used to achieve Asmin
n_{used}	4		Number of Bars used
A_{steel}	2.4	in^2	Area of Steel
S_{max}	14.0	in	
Spacing	12	in	
	Check:	OKAY!	

		Strap Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Node 643

Cover	3	in	
d_{eff}	20	in	
c+d	30	in	
b_o	120	in	
q_n	2.91	k/ft^2	
F_y	28.66	kip	

1.1 Two Way Shear

α	20		Select Column Location
Vu	10.48	kip	
ϕVc	809543.08	kip	
ϕVc	809.54308	ln	
	CHECK:	OKAY!	

1.2 One Way Shear

Vu	15.57	kip
ϕ	0.75	
ϕVc	227683.99	lb
ϕVc	227.68	kip
	CHECK:	OKAY!

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	26.18	kip-ft
Rn	0.018	k/in^2
Rn	18.18	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0003		
ρ_b	0.03		
ρ_{max}	0.0251531		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	1.296		
Size	# 7		Size of Steel Reinforcing
n	2.16		Number of Bars used to achieve Asmin
n_{used}	4		Number of Bars used
A_{steel}	2.4	in^2	Area of Steel
S_{max}	10	in	
Spacing	8	in	
	Check:	OKAY!	

Model: S2

Strap Footing Design			
DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Footing	Node	642
Length		3 ft
Width		3 ft
Thickness		3 ft
Depth to base		3 ft
Size		# 6
Number		5
Spacing		7 in

Footing	Node	643
Length		2.75 ft
Width		2.75 ft
Thickness		3 ft
Depth to base		3 ft
Size		# 8
Number		3
Spacing		12 in

Strap Design	
Width	3 ft
Thickness	3 ft
Size	# 9
Number	4
Spacing	9 in

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Node 1

Check 1:	**OKAY!**

1.1 Node 2

Check 1:	**OKAY!**

1.2 Strap

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.3 Node 1 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

1.4 Node 2 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Data

1.0 Loads

Nodes: 642 **&** 643

Load 1	23.887
Load 2	23.887

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction
q_{ult}	4000	psf	

1.2 Initial Assumptions & Structure Information

b	4	ft	Assumed Width of Footing
d	3	ft	Depth to Base of Footing
t	3	ft	Thickness of Footing
$D_{EdgeFooting}$	1	ft	Distance from Column to Footing Edge
D_{nodes}	150.5	in	Distance Between Nodes
$D_{Reactions}$	138.5	in	Distance Between Reactions
ColWidth	10	in	Width of Column
e	1	ft	Eccentricity

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

1.0 Node 1

M	23.887	ft-kip	Moment
V	2.07	kip	Shear
R_1	25.96	kip	Reaction at Node 1
q_{eff}	3550	lb	Net Soil Bearing Capacity
q_{eff}	3.55	kip	Net Soil Bearing Capacity
A_{Reqd}	7.31	ft^2	Required Area of Footing
Side 1	3	ft	Length of Side 1
Side 2	3	ft	Length of Side 2
A_{Ftng}	9	ft^2	Area of Footing
CHECK:	**OKAY!**		

2.0 Factored Node 1

Fy_1	28.66	kip
M	28.66	
V	2.48	

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

1.0 Node 2

M	23.887	ft-kip	Moment
V	2.07	kip	Shear
R_2	25.96	kip	Reaction at Node 1
q_{eff}	3550	lb	Net Soil Bearing Capacity
q_{eff}	3.55	kip	Net Soil Bearing Capacity
A_{Reqd}	7.31	ft^2	Required Area of Footing
Side 1	2.75	ft	Length of Side 1
Side 2	2.75	ft	Length of Side 2
A_{Ftng}	7.5625	ft^2	Area of Footing
CHECK:	**OKAY!**		

2.0 Factored Node 2

Fy_2	28.66	kip
M	28.66	
V	2.48	

Strap Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Factored Upward Pressures

qn1	10.38
qn2	9.52

1.2 Diagram & Shear Forces

+P1	19.03
-P1	-9.63
P2	2.48
P3	2.48
+P4	15.57
-P4	-13.09

1.3 X-Distances

X1	1.83	ft
X2	1.84	ft
X3	0.33	ft
X4	8.875	ft
X5	1.5	ft
X6	1.5	ft

1.4 Moments

Mu	17.4169
Mu	-26.176703
Mu	-25.766916
Mu	-3.7253372
Mu	9.8178157

		Strap Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Initial Data

$Strap_{Width}$	3	ft	
$Strap_{Depth}$	3	ft	
$Strap_{Cover}$	3	in	Clear Cover
$D_{effstrap}$	32.361	in	Effective Depth

1.1 One Way Shear

3

Vu	19.03		
ϕ	0.75		
ϕVc	55260.61	lb	
ϕVc	55.26	kip	
1/2 ϕVc	27.63	kip	
	CHECK:	OKAY!	What is the check here?

1.2 Flexure

ϕ	0.9		
Mu	26.18		
a	2	in	Assumed
T	11.13	kip	
a	0.09	in	
a_{Used}	1	in	
T	10.95	kip	
As	0.18	in^2	
ρ	0.000157		
ρ_{min}	0.003333		
As_{min}	3.88332	in^2	
As	3.88332	in^2	
Size	#9		Size of Steel Reinforcing
n	3.88		Number of Bars used to achieve Asmin
n_{used}	4		Number of Bars used
S_{max}	10	in	Maximum Allowable Spacing
Spacing	9	in	
	Check:	OKAY!	Spacing<Smax

Strap Footing Design			
DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Node 642

Cover	3	in
d_{eff}	32	in
c+d	42	in
b_o	168	in
q_n	3.46	k/ft^2
F_y	28.66	kip

1.1 Two Way Shear

α	20		Select Column Location
Vu	-13.73	kip	
ϕVc	1975285	lb	
ϕVc	1975.285	kip	
	CHECK:	OKAY!	

1.2 One Way Shear

Vu	9.63	kip
ϕ	0.75	
ϕVc	510012.14	lb
ϕVc	510.01	kip
	CHECK:	OKAY!

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	26.18	kip-ft
Rn	0.009	k/in^2
Rn	9.47	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0002		
ρ_b	0.0335		
ρ_{max}	0.025153		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	2.0736		
Size	# 6		Size of Steel Reinforcing
n	4.71		Number of Bars used to achieve Asmin
n_{used}	5		Number of Bars used
A_{steel}	2.2	in^2	Area of Steel
S_{max}	7.5	in	
Spacing	7	in	
	Check:	OKAY!	

Strap Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Node 643

Cover	3	in
d_{eff}	32	in
c+d	42	in
b_o	168	in
q_n	3.46	k/ft^2
F_y	28.66	kip

1.1 Two Way Shear

α	20		Select Column Location
Vu	-13.74	kip	
ϕVc	1975285.1	kip	
ϕVc	1975.2851	In	
	CHECK:	OKAY!	

1.2 One Way Shear

Vu	15.57	kip
ϕ	0.75	
ϕVc	510012.14	lb
ϕVc	510.01	kip
	CHECK:	OKAY!

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	26.18	kip-ft
Rn	0.009	k/in^2
Rn	9.47	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0002		
ρ_b	0.03		
ρ_{max}	0.0251531		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	1.9008		
Size	#8		Size of Steel Reinforcing
n	2.41		Number of Bars used to achieve Asmin
n_{used}	3		Number of Bars used
A_{steel}	2.37	in^2	Area of Steel
S_{max}	13.5	in	
Spacing	12	in	
	Check:	OKAY!	

Model: S3

Strap Footing Design			
DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Footing	Node	642
Length		3 ft
Width		3 ft
Thickness		2 ft
Depth to base		3 ft
Size		# 7
Number		3
Spacing		12 in

Footing	Node	643
Length		3 ft
Width		3 ft
Thickness		2 ft
Depth to base		3 ft
Size		# 6
Number		3
Spacing		12 in

Strap Design	
Width	3 ft
Thickness	2 ft
Size	# 7
Number	5
Spacing	7 in

Strap Footing Design

DATE:	2/6/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Node 1

Check 1:	**OKAY!**

1.1 Node 2

Check 1:	**OKAY!**

1.2 Strap

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.3 Node 1 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

1.4 Node 2 Reinforcement

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**

Strap Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

Data

1.0 Loads

Nodes: 642 & 643

Load 1	23.887
Load 2	23.887

1.1 Material Properties

f'c	4000	psi	Concrete Compressive Strength
f_y	60	ksi	Steel Yield Strength
Wc	150	pcf	Density of Concrete
γ	120	pcf	Unit Weight of Soil
μ	0.5		Coefficient of Friction
q_{ult}	4000	psf	

1.2 Initial Assumptions & Structure Information

b	4	ft	Assumed Width of Footing
d	3	ft	Depth to Base of Footing
t	2	ft	Thickness of Footing
$D_{EdgeFooting}$	0.5	ft	Distance from Column to Footing Edge
D_{nodes}	150.5	in	Distance Between Nodes
$D_{Reactions}$	144.5	in	Distance Between Reactions
ColWidth	10	in	Width of Column
e	1.5	ft	Eccentricity

Strap Footing Design

DATE:	2/6/2015			**DESIGN #:**	1
PASS:	**YES**			**CHECK:**	DH

1.0 Node 1

M	11.9435	ft-kip	Moment
V	0.99	kip	Shear
R_1	24.88	kip	Reaction at Node 1
q_{eff}	3580	lb	Net Soil Bearing Capacity
q_{eff}	3.58	kip	Net Soil Bearing Capacity
A_{Reqd}	6.95	ft^2	Required Area of Footing
Side 1	3	ft	Length of Side 1
Side 2	3	ft	Length of Side 2
A_{Ftng}	9	ft^2	Area of Footing
	CHECK:	**OKAY!**	

2.0 Factored Node 1

Fy_1	28.66	kip
M	14.33	
V	1.19	

Strap Footing Design

DATE:	2/6/2015			**DESIGN #:**	1
PASS:	**YES**			**CHECK:**	DH

1.0 Node 2

M	11.9435	ft-kip	Moment
V	0.99	kip	Shear
R_2	24.88	kip	Reaction at Node 1
q_{eff}	3580	lb	Net Soil Bearing Capacity
q_{eff}	3.58	kip	Net Soil Bearing Capacity
A_{Reqd}	6.95	ft^2	Required Area of Footing
Side 1	3	ft	Length of Side 1
Side 2	3	ft	Length of Side 2
A_{Ftng}	9	ft^2	Area of Footing
	CHECK:	**OKAY!**	

2.0 Factored Node 2

Fy_2	28.66	kip
M	14.33	
V	1.19	

Strap Footing Design

DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Factored Upward Pressures

qn1	9.95
qn2	9.16

1.2 Diagram & Shear Forces

+P1	13.27
-P1	-15.40
P2	1.19
P3	1.19
+P4	14.93
-P4	-13.74

1.3 X-Distances

X1	1.83	ft
X2	1.84	ft
X3	0.33	ft
X4	8.875	ft
X5	1.5	ft
X6	1.5	ft

1.4 Moments

Mu	12.140878
Mu	-12.54489
Mu	-12.348504
Mu	-1.785326
Mu	10.302819

Strap Footing Design			
DATE:	2/6/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Initial Data

$Strap_{Width}$	3	ft	
$Strap_{Depth}$	2	ft	
$Strap_{Cover}$	3	in	Clear Cover
$D_{Effstrap}$	20.5625	in	Effective Depth

1.1 One Way Shear

2

Vu	14.93		
ϕ	0.75		
ϕVc	35113.14	lb	
ϕVc	35.11	kip	
1/2 ϕVc	17.56	kip	
CHECK:	OKAY!		What is the check here?

1.2 Flexure

ϕ	0.9		
Mu	12.54		
a	2	in	Assumed
T	8.55	kip	
a	0.07	in	
a_{Used}	1	in	
T	8.34	kip	
As	0.14	in^2	
ρ	0.00018771		
ρ_{min}	0.00333333		
As_{min}	2.4675	in^2	
As	2.4675	in^2	
Size	# 7		Size of Steel Reinforcing
n	4.11		Number of Bars used to achieve Asmin
n_{used}	5		Number of Bars used
S_{max}	7.5	in	Maximum Allowable Spacing
Spacing	7	in	
Check:	OKAY!		Spacing<Smax

		Strap Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Node 642

Cover	3	in	
d_{eff}	20	in	
c+d	30	in	
b_o	120	in	
q_n	3.32	k/ft^2	
F_y	28.66	kip	

1.1 Two Way Shear

α	20		Select Column Location
Vu	7.93	kip	
ϕVc	809543.08	lb	
ϕVc	809.54308	kip	
	CHECK:	OKAY!	

1.2 One Way Shear

Vu	15.40	kip
ϕ	0.75	
ϕVc	227683.99	lb
ϕVc	227.68	kip
	CHECK:	OKAY!

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	12.54	kip-ft
Rn	0.012	k/in^2
Rn	11.62	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0002		
ρ_b	0.0335		
ρ_{max}	0.0251531		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	1.296		
Size	# 7		Size of Steel Reinforcing
n	2.16		Number of Bars used to achieve Asmin
n_{used}	3		Number of Bars used
A_{steel}	1.8	in^2	Area of Steel
S_{max}	15.0	in	
Spacing	12	in	
	Check	OKAY!	

		Strap Footing Design		
DATE:	2/6/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Node 643

Cover	3	in	
d_{eff}	20	in	
c+d	30	in	
b_o	120	in	
q_n	3.05	k/ft^2	
F_y	28.66	kip	

1.1 Two Way Shear

α	20		Select Column Location
Vu	9.59	kip	
ϕVc	809543.08	kip	
ϕVc	809.54308	In	
CHECK:	OKAY!		

1.2 One Way Shear

Vu	14.93	kip
ϕ	0.75	
ϕVc	227683.99	lb
ϕVc	227.68	kip
CHECK:	OKAY!	

1.3 Flexure - Longtitudinal

ϕ	0.9	
Mu	12.54	kip-ft
Rn	0.012	k/in^2
Rn	11.62	lb/in^2

1.4 Reinforcement

β	1		Shape Paremeter
ρ	0.0002		
ρ_b	0.03		
ρ_{max}	0.0251531		
ρ_{min}	0.0018		
ρ_{used}	0.0018		
As_{min}	1.296		
Size	#6		Size of Steel Reinforcing
n	2.95		Number of Bars used to achieve Asmin
n_{used}	3		Number of Bars used
A_{steel}	1.32	in^2	Area of Steel
S_{max}	15	in	
Spacing	12	in	
Check:	OKAY!		

Appendix K: STAAD.foundation – Strapped Footing

Strap Footing Design

Strap Footing Design(ACI 318-05)

Design For Strap Footing 1

Strap Footing 1

Input Parameters

Footing Geometry

Left Footing Geometry

Footing Thickness : 2.000ft
Footing Length : 4.000ft
Footing Width : 4.000ft
Max Footing Thickness : 120.000in
Max Footing Length : 240.000in
Max Footing Width : 240.000in
Eccentricity along X (Oxd) : 0.000in
Eccentricity along Z (Ozd) : 0.000in

Right Footing Geometry

Footing Thickness : 2.000ft
Footing Length : 3.000ft
Footing Width : 3.000ft
Max Footing Thickness : 120.000in
Max Footing Length : 240.000in
Max Footing Width : 240.000in
Eccentricity along X (Oxd) : 0.000in
Eccentricity along Z (Ozd) : 0.000in

Concrete and Rebar Properties

Unit Weight of Concrete : 0.150kip/ft3
Strength of Concrete : 4.000ksi
Yield Strength of Steel : 60.000ksi
Minimum Bar Size : #7
Maximum Bar Size : #14
Minimum Bar Spacing : 2.000in
Maximum Bar Spacing : 18.000in
Pedestal Clear Cover (P, CL) : 2.000in
Footing Clear Cover (F, CL) : 2.000in

Soil Properties

Unit Weight : 120.000lb/ft3
Soil Bearing Capacity : 4.000kip/ft2
Soil Bearing Capacity Type: Net Bearing Capacity
Soil Surcharge : 0.000kip/in2
Depth of Soil above Footing : 12.000in
Depth of Water Table : 120.000ft

Other Parameters

Footing Plan Increment : 1.000in
Footing Thickness Increment : 1.000in
Beam Depth : 24.000in
Beam Width : 36.000in
Coefficient of Friction : 0.500
Factor of Safety Against Sliding : 1.500
Factor of Safety Against Overturning : 1.500

Load Combination/s- Service Stress Level	
Load Combination Number	Load Combination Title
110	D + W N-S
111	D + W S-N
112	D + W E-W
113	D + W W-E
120	0.6 DL + W N-S
121	0.6 DL + W S-N
122	0.6 DL + W E-W
123	0.6 DL + W W-E
200	1.4 DL
210	1.2 DL + 1.6 W N-S
211	1.2 DL + 1.6 W S-N
212	1.2 DL + 1.6 W E-W
213	1.2 DL + 1.6 W W-E
220	0.9 DL + 1.6 W N-S
221	0.9 DL + 1.6 W S-N
222	0.9 DL + 1.6 W E-W
223	0.9 DL + 1.6 W W-E
Load Combination/s- Strength Level	
Load Combination Number	Load Combination Title
110	D + W N-S
111	D + W S-N
112	D + W E-W

113	D + W W-E
120	0.6 DL + W N-S
121	0.6 DL + W S-N
122	0.6 DL + W E-W
123	0.6 DL + W W-E
200	1.4 DL
210	1.2 DL + 1.6 W N-S
211	1.2 DL + 1.6 W S-N
212	1.2 DL + 1.6 W E-W
213	1.2 DL + 1.6 W W-E
220	0.9 DL + 1.6 W N-S
221	0.9 DL + 1.6 W S-N
222	0.9 DL + 1.6 W E-W
223	0.9 DL + 1.6 W W-E

Footing 642

Applied Loads - Service Stress Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000
122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000

Applied Loads - Strength Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	3.562	-0.063	1.896	0.000	0.000
111	13.701	-0.138	-1.968	0.000	0.000
112	17.087	-3.413	-0.057	0.000	0.000
113	0.176	3.212	-0.014	0.000	0.000
120	0.109	-0.023	1.911	0.000	0.000
121	10.248	-0.098	-1.953	0.000	0.000

122	13.635	-3.373	-0.043	0.000	0.000
123	-3.277	3.252	-0.000	0.000	0.000
200	12.084	-0.141	-0.050	0.000	0.000
210	2.247	-0.060	3.049	0.000	0.000
211	18.469	-0.181	-3.134	0.000	0.000
212	23.887	-5.420	-0.077	0.000	0.000
213	-3.171	5.179	-0.009	0.000	0.000
220	-0.343	-0.030	3.059	0.000	0.000
221	15.879	-0.151	-3.123	0.000	0.000
222	21.298	-5.390	-0.066	0.000	0.000
223	-5.761	5.209	0.002	0.000	0.000

Footing 643

Applied Loads - Service Stress Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	13.701	-0.138	1.968	0.000	0.000
111	3.562	-0.063	-1.897	0.000	0.000
112	17.087	-3.413	0.057	0.000	0.000
113	0.176	3.212	0.014	0.000	0.000
120	10.248	-0.098	1.953	0.000	0.000
121	0.109	-0.023	-1.911	0.000	0.000
122	13.635	-3.373	0.043	0.000	0.000
123	-3.277	3.252	0.000	0.000	0.000
200	12.084	-0.141	0.050	0.000	0.000
210	18.469	-0.181	3.134	0.000	0.000
211	2.247	-0.060	-3.049	0.000	0.000
212	23.887	-5.420	0.077	0.000	0.000
213	-3.172	5.179	0.009	0.000	0.000
220	15.879	-0.151	3.123	0.000	0.000
221	-0.343	-0.030	-3.059	0.000	0.000
222	21.298	-5.390	0.066	0.000	0.000
223	-5.761	5.209	-0.002	0.000	0.000

Applied Loads - Strength Level					
LC	Axial (kip)	Shear X (kip)	Shear Z (kip)	Moment X (kip-ft)	Moment Z (kip-ft)
110	13.701	-0.138	1.968	0.000	0.000
111	3.562	-0.063	-1.897	0.000	0.000
112	17.087	-3.413	0.057	0.000	0.000
113	0.176	3.212	0.014	0.000	0.000
120	10.248	-0.098	1.953	0.000	0.000
121	0.109	-0.023	-1.911	0.000	0.000
122	13.635	-3.373	0.043	0.000	0.000
123	-3.277	3.252	0.000	0.000	0.000
200	12.084	-0.141	0.050	0.000	0.000

210	18.469	-0.181	3.134	0.000	0.000
211	2.247	-0.060	-3.049	0.000	0.000
212	23.887	-5.420	0.077	0.000	0.000
213	-3.172	5.179	0.009	0.000	0.000
220	15.879	-0.151	3.123	0.000	0.000
221	-0.343	-0.030	-3.059	0.000	0.000
222	21.298	-5.390	0.066	0.000	0.000
223	-5.761	5.209	-0.002	0.000	0.000

Footing 642

Design Calculations

Footing Size

Initial Length (L_o) = 4.00ft

Initial Width (W_o) = 4.00ft

Gross Soil Bearing Capacity = 4.24kip/ft^2

Reduction of force due to buoyancy = -0.00kip

Effect due to adhesion = 0.00kip

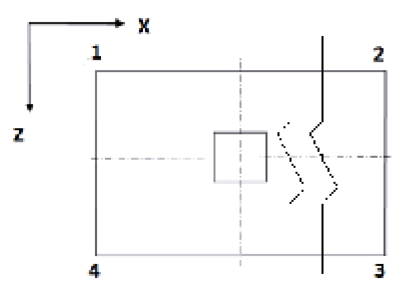
Min. area required from bearing pressure, A_{min} = P / q_{max} = 6.766ft^2

Area from initial length and width, A_o = $L_o * W_o$ = 16.00ft^2

Final Footing Size

Length (L_2) =	8.67	ft	Governing Load Case :	# 223
Width (W_2) =	8.33	ft	Governing Load Case :	# 223
Depth (D_2) =	2.00	ft	Governing Load Case :	# 223
Area (A_2) =	72.22	ft^2		

Pressures at Four Corners



Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)	Area of footing in uplift (A_u) (ft^2)

212	**0.7309**	0.5270	0.5239	0.7278	0.0000
211	0.6184	**0.6116**	0.4878	0.4946	0.0000
212	0.7309	0.5270	**0.5239**	0.7278	0.0000
212	0.7309	0.5270	0.5239	**0.7278**	0.0000

If A_u is zero, there is no uplift and no pressure adjustment is necessary.

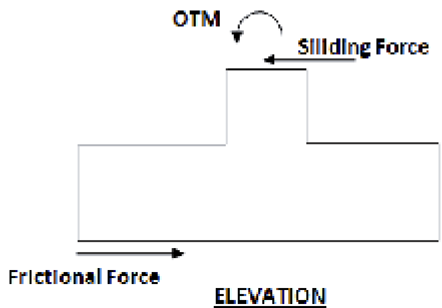
Otherwise, to account for uplift, areas of negative pressure will be set to zero and the pressure will be redistributed to remaining corners.

Summary of Adjusted Pressures at Four Corners

Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)
212	**0.7309**	0.5270	0.5239	0.7278
211	0.6184	**0.6116**	0.4878	0.4946
212	0.7309	0.5270	**0.5239**	0.7278
212	0.7309	0.5270	0.5239	**0.7278**

Adjust footing size if necessary.

Check for stability against overturning and sliding



-	Factor of safety against sliding			Factor of safety against overturning	
Load Case No.	Along X-Direction	Along Z-Direction	Resultant	About X-Direction	About Z-Direction
110	200.831	6.651	6.648	27.714	870.266
111	127.931	8.988	8.965	37.448	554.370
112	5.678	341.396	5.677	1422.484	24.603

113	3.400	760.824	3.400	3170.098	14.735
120	481.708	5.698	5.698	23.744	2087.403
121	162.797	8.169	8.159	34.038	705.455
122	5.233	414.963	5.233	1729.013	22.678
123	2.827	69682.422	2.827	290343.423	12.252
200	119.915	339.008	113.051	1412.533	519.632
210	198.321	3.922	3.921	16.342	859.390
211	110.897	6.403	6.393	26.681	480.556
212	4.202	297.385	4.202	1239.106	18.209
213	1.786	1057.520	1.786	4406.335	7.737
220	353.822	3.485	3.485	14.521	1533.230
221	124.488	6.011	6.004	25.045	539.448
222	3.985	325.865	3.985	1357.770	17.270
223	1.527	4137.287	1.527	17238.697	6.616

Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - X Direction

Critical Load Case for Sliding along X-Direction : 223
Governing Disturbing Force : 5.209kip
Governing Restoring Force : 7.953kip
Minimum Sliding Ratio for the Critical Load Case : 1.527
Critical Load Case for Overturning about X-Direction : 220
Governing Overturning Moment : 6.119kip-ft
Governing Resisting Moment : 88.849kip-ft
Minimum Overturning Ratio for the Critical Load Case : 14.521

Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - Z Direction

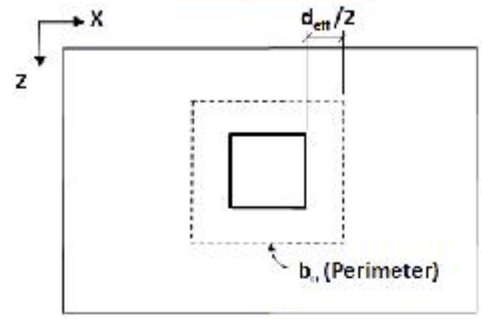
Critical Load Case for Sliding along Z-Direction : 220
Governing Disturbing Force : 3.059kip
Governing Restoring Force : 10.662kip
Minimum Sliding Ratio for the Critical Load Case : 3.485
Critical Load Case for Overturning about Z-Direction : 223
Governing Overturning Moment : -10.418kip-ft
Governing Resisting Moment : 68.925kip-ft
Minimum Overturning Ratio for the Critical Load Case : 6.616

Critical Load Case And The Governing Factor Of Safety For Sliding Along Resultant Direction

Critical Load Case for Sliding along Resultant Direction : 223
Governing Disturbing Force : 5.209kip
Governing Restoring Force : 7.953kip
Minimum Sliding Ratio for the Critical Load Case : 1.527

Shear Calculation

Punching Shear Check



PLAN

Total Footing Depth, D = 2.00ft

Calculated Effective Depth, d_{eff} = $D - C_{cover} - 1.0 =$ 1.79ft

For rectangular pier, β_c = $B_{col} / D_{col} =$ 1.00

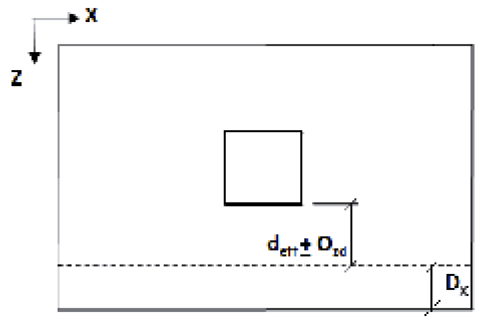
Effective depth, d_{eff} increased until $0.75 * V_c \geq$ Punching Shear Force

Punching Shear Force, Vu = 19.18kip, Load Case # 212

From ACI Cl.11.12.2.1, b_o for pier=	$2 \times (B_{col} + D_{col} + 2 \times d_{eff}) =$	15.17ft
Equation 11-33, V_{c1} =	$\left(2 + \frac{4}{\beta_c}\right) \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'} =$	1484.88kip
Equation 11-34, V_{c2} =	$\left(\frac{\alpha_s \times d}{b_o} + 2\right) \times \lambda \times \sqrt{f_c'} \times b_o \times d =$	1664.37kip
Equation 11-35, V_{c3} =	$4 \times b_o \times d_{eff} \times \sqrt{1000 \times F_c'} =$	989.92kip
Punching shear strength, V_c =	0.75 * minimum of (V_{c1}, V_{c2}, V_{c3}) =	742.44kip

$0.75 * V_c > V_u$ hence, OK

One-Way Shear Check
Along X Direction



PLAN

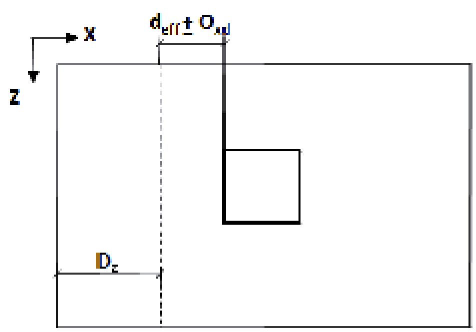
From ACI Cl.11.3.1.1, V_c = $2 \times W \times d_{eff} \times \sqrt{1000 \times f_c'} =$ 285.55kip

Distance along Z to design for shear, D_z = $0.5 \times (L - B_{col}) + d_{eff} + O_{zd} =$ 1.58ft

Check that 0.75 * $V_c > V_{ux}$ where V_{ux} is the shear force for the critical load cases at a distance d_{eff} from the face of the pier caused by bending about the X axis.

From above calculations,	0.75 * V_c =	214.17	kip
Critical load case for V_{ux} is # 212		$V_{ux} = V_{ux}\|_{x=D_z} =$	3.96 kip
			0.75 * $V_c > V_{ux}$ hence, OK

Along Z Direction



PLAN

From ACI Cl.11.3.1.1, V_c = $2 \times W \times d_{eff} \times \sqrt{1000 \times f_c'} =$ 285.55 kip

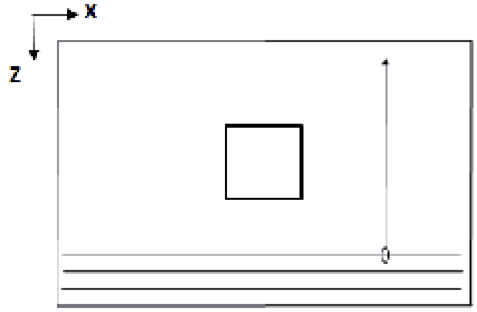
Distance along X to design for shear, D_x = [illegible] 1.38 ft

Check that **0.75 * $V_c > V_{uz}$** where V_{uz} is the shear force for the critical load cases at a distance d_{eff} from the face of the pier caused by bending about the Z axis.

From above calculations,	$0.75 * V_c =$	203.97	kip
Critical load case for V_{uz} is # 212	$V_{uz} = V_{uz}\|_{x=D_z} =$	5.42	kip

$0.75 * V_c > V_{uz}$ hence, OK

Design for Flexure about Z axis



PLAN

Calculate the flexural reinforcement along the X direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Factor β_1 from ACI Cl.10.2.7.3	for $F_c' \leq 4$ ksi,	0.85
From ACI Cl. 10.3.2, $\rho_{bal} =$	$0.85 \times \beta_1 \times F_c' \times \frac{87}{[F_y \times (87 - F_y)]} =$	0.02851
From ACI Cl. 10.3.3, $\rho_{max} =$	$0.75 \times \rho_{bal} =$	0.02138
From ACI Cl. 7.12.2, $\rho_{min} =$		0.00174
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{F_y}{(0.85 \times F_c')} =$	17.65

Calculate reinforcement ratio ρ for critical load case

Design for flexure about Z axis is performed at the face of the pier at a distance, $D_x =$	$0.5 \times L - 0.5 \times D_{col} - C_{x1} =$	3.38	ft
Ultimate moment,	$M_{u\,x=D_x} =$	19.14	kip-ft
Nominal moment capacity, $M_n =$	$\frac{M_u}{\phi} =$	21.27	kip-ft
Required $\rho =$	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{(F_y \times W \times d_{eff}^2)}}\right] =$	0.00009	

Since	$\rho_{min} \le \rho \le \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff}$	4.18	in2

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, D_L =	$0.5 \times (L - D_{col}) - C_{cover}$ =	38.50	in
Try bar size	Area of one bar =	0.60	in2
Number of bars required, N_{bar} =	$\frac{A_s}{A_{bar}}$ =	7	

Because the number of bars is rounded up, make sure new reinforcement ratio < ρ_{max}

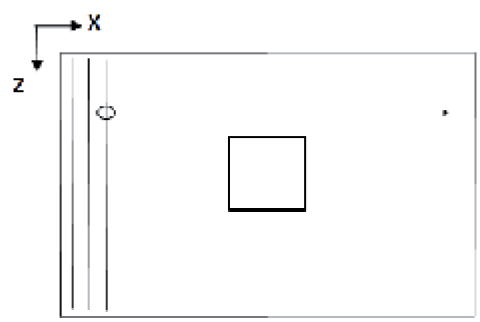
Total reinforcement area, A_{s_total} =	N_{bar} * (Area of one bar) =	4.20	in2
d_{eff} =	D - C_{cover} - 0.5 * (dia. of one bar) =	1.80	ft
Reinforcement ratio, ρ =	$\frac{A_{s\_total}}{(B_{col} \times d_{eff})}$ =	0.00195	

From ACI Cl.7.6.1, minimum req'd clear distance between bars

C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 2.000in

Check to see if width is sufficient to accomodate bars

Design for Flexure about X axis



PLAN

Calculate the flexural reinforcement along the Z direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Factor β_1 from ACI Cl.10.2.7.3	for $F_c' \le$ 4 ksi,	0.85	

From ACI Cl. 10.3.2, ρ_{bal} =	$0.85 \times \beta_1 \times f_c' \times \frac{87}{[f_y \times (87 - f_y)]}$ =	0.02851	
From ACI Cl. 10.3.3, ρ_{max} =	$0.75 \times \rho_{bal}$ =	0.02138	
From ACI Cl.7.12.2, ρ_{min} =		0.00173	
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{f_y}{(0.85 \times f_c')}$	17.65	

Calculate reinforcement ratio ρ for critical load case

Design for flexure about X axis is performed at the face of the pier at a distance, D_z =	$0.5 \times L \pm 0.5 \times B_{col} - C_{col}$ =	3.17	ft
Ultimate moment,	$M_u(D_z)$ =	14.42	kip-ft
Nominal moment capacity, M_n =	$\frac{M_u}{\phi}$ =	16.02	kip-ft
Required ρ =	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{(f_y \times W \times d_{eff}^2)}}\right]$ =	0.00007	
Since	$\rho_{min} \leq \rho \leq \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff}$ =	4.37	in2

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, D_L =	$0.5 \times (L - B_{col}) - C_{cover}$ =	36.00	in
Try bar size	Area of one bar =	0.79	in2
Number of bars required, N_{bar} =	$\frac{A_s}{A_{bar}}$ =	6	

Because the number of bars is rounded up, make sure new reinforcement ratio < $_{max}$

Total reinforcement area, A_{s_total} =	N_{bar} * (Area of one bar) =	4.74	in2
d_{eff} =	D - C_{cover} - 0.5 * (dia. of one bar) =	1.72	ft
Reinforcement ratio, ρ =	$\frac{A_{s\_total}}{(d_{eff} \times W)}$	0.00219	

From ACI Cl.7.6.1, minimum req'd clear distance between bars

C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 2.000in

Check to see if width is sufficient to accomodate bars

Footing 643

Design Calculations

Footing Size

Initial Length (L_o) = 3.00ft

Initial Width (W_o) = 3.00ft

Gross Soil Bearing Capacity = 4.24kip/ft^2

Reduction of force due to buoyancy = -0.00kip

Effect due to adhesion = 0.00kip

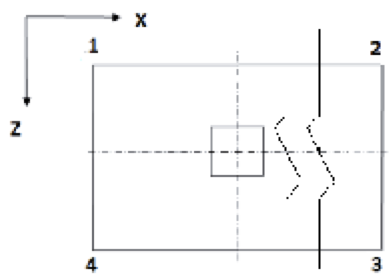
Min. area required from bearing pressure, A_{min} = P / q_{max} = 6.271ft^2

Area from initial length and width, A_o = $L_o * W_o$ = 9.00ft^2

Final Footing Size

Length (L_2) =	8.58	ft	Governing Load Case :	# 223
Width (W_2) =	8.33	ft	Governing Load Case :	# 223
Depth (D_2) =	2.00	ft	Governing Load Case :	# 223
Area (A_2) =	71.53	ft^2		

Pressures at Four Corners



Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)	Area of footing in uplift (A_u) (ft^2)
212	**0.7278**	0.5239	0.5270	0.7309	0.0000
212	0.7278	**0.5239**	0.5270	0.7309	0.0000
210	0.4946	0.4878	**0.6116**	0.6184	0.0000
212	0.7278	0.5239	0.5270	**0.7309**	0.0000

If A_u is zero, there is no uplift and no pressure adjustment is necessary.

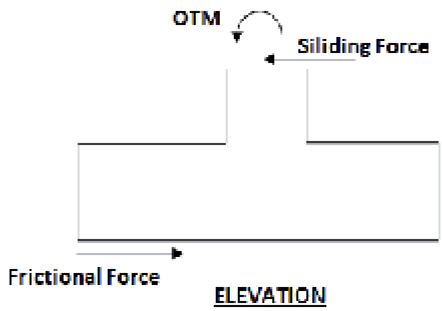
Otherwise, to account for uplift, areas of negative pressure will be set to zero and the pressure will be redistributed to remaining corners.

Summary of Adjusted Pressures at Four Corners

Load Case	Pressure at corner 1 (q_1) (kip/ft^2)	Pressure at corner 2 (q_2) (kip/ft^2)	Pressure at corner 3 (q_3) (kip/ft^2)	Pressure at corner 4 (q_4) (kip/ft^2)
212	**0.7278**	0.5239	0.5270	0.7309
212	0.7278	**0.5239**	0.5270	0.7309
210	0.4946	0.4878	**0.6116**	0.6184
212	0.7278	0.5239	0.5270	**0.7309**

Adjust footing size if necessary.

Check for stability against overturning and sliding



-	Factor of safety against sliding			Factor of safety against overturning	
Load Case No.	Along X-Direction	Along Z-Direction	Resultant	About X-Direction	About Z-Direction
110	127.210	8.935	8.913	37.227	545.942
111	199.282	6.596	6.593	27.484	855.252
112	5.647	339.563	5.646	1414.847	24.236
113	3.368	757.443	3.368	3156.013	14.454
120	161.769	8.116	8.106	33.816	694.258
121	477.541	5.644	5.643	23.516	2049.445
122	5.203	412.375	5.202	1718.229	22.328
123	2.795	N/A	2.795	517575.720	11.997
200	119.216	337.265	112.400	1405.271	511.634
210	110.347	6.370	6.360	26.542	473.573
211	196.729	3.888	3.887	16.199	844.294
212	4.183	295.971	4.182	1233.211	17.952

213	1.765	1058.048	1.765	4408.533	7.577
220	123.823	5.977	5.970	24.905	531.406
221	350.729	3.451	3.451	14.379	1505.214
222	3.966	324.161	3.966	1350.669	17.021
223	1.507	3896.915	1.507	16237.147	6.466

Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - X Direction

Critical Load Case for Sliding along X-Direction : 223
Governing Disturbing Force : 5.209kip
Governing Restoring Force : 7.849kip
Minimum Sliding Ratio for the Critical Load Case : 1.507
Critical Load Case for Overturning about X-Direction : 221
Governing Overturning Moment : -6.119kip-ft
Governing Resisting Moment : 87.981kip-ft
Minimum Overturning Ratio for the Critical Load Case : 14.379

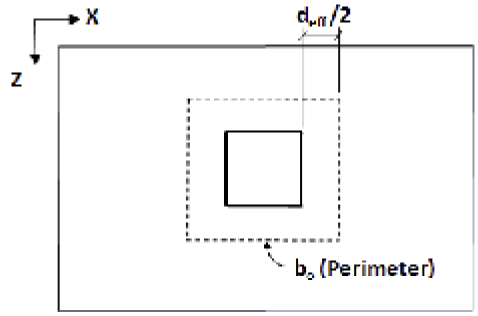
Critical Load Case And The Governing Factor Of Safety For Overturning And Sliding - Z Direction

Critical Load Case for Sliding along Z-Direction : 221
Governing Disturbing Force : -3.059kip
Governing Restoring Force : 10.558kip
Minimum Sliding Ratio for the Critical Load Case : 3.451
Critical Load Case for Overturning about Z-Direction : 223
Governing Overturning Moment : -10.419kip-ft
Governing Resisting Moment : 67.367kip-ft
Minimum Overturning Ratio for the Critical Load Case : 6.466

Critical Load Case And The Governing Factor Of Safety For Sliding Along Resultant Direction

Critical Load Case for Sliding along Resultant Direction : 223
Governing Disturbing Force : 5.209kip
Governing Restoring Force : 7.849kip
Minimum Sliding Ratio for the Critical Load Case : 1.507

Shear Calculation
Punching Shear Check



PLAN

Total Footing Depth, D = 2.00ft

Calculated Effective Depth, d_{eff} = $D - C_{cover} - 1.0 =$ 1.79ft

For rectangular pier, β_c = $B_{col} / D_{col} =$ 1.00

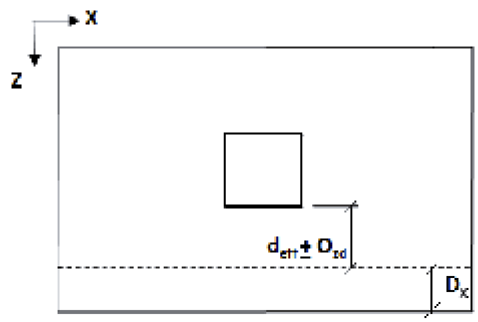
Effective depth, d_{eff} increased until $0.75 * V_c \geq$ Punching Shear Force

Punching Shear Force, Vu = 19.18kip, Load Case # 212

From ACI Cl.11.12.2.1, b_o for pier=	$2 \times (B_{col} + D_{col} + 2 \times d_{eff}) =$	15.17ft
Equation 11-33, V_{c1} =	$\left(2 - \frac{4}{\beta_c}\right) \times b_o \times d_{eff} \times \sqrt{1000 \times f_c'} =$	1484.88kip
Equation 11-34, V_{c2} =	$\left(\frac{\alpha_s \times d}{b_o} + 2\right) \times \lambda \times \sqrt{f_c} \times b_o \times d =$	1664.37kip
Equation 11-35, V_{c3} =	$4 \times b_o \times d_{eff} \times \sqrt{1000 \times f_c'} =$	989.92kip
Punching shear strength, V_c =	$0.75 *$ minimum of $(V_{c1}, V_{c2}, V_{c3}) =$	742.44kip

$0.75 * V_c > V_u$ hence, OK

One-Way Shear Check
Along X Direction



PLAN

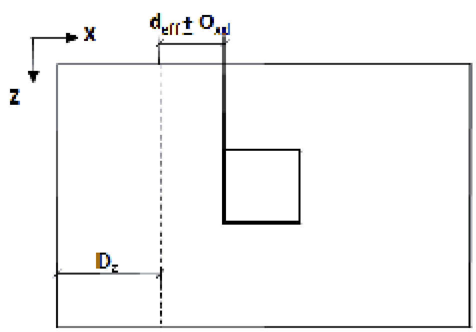
From ACI Cl.11.3.1.1, V_c = [illegible] 285.55kip

Distance along Z to design for shear, D_z = [illegible] 1.58ft

Check that 0.75 * V_c > V_{ux} where V_{ux} is the shear force for the critical load cases at a distance d_{eff} from the face of the pier caused by bending about the X axis.

From above calculations,	0.75 * V_c =	214.17	kip
Critical load case for V_{ux} is # 212		[illegible]	3.96 kip
			0.75 * V_c > V_{ux} hence, OK

Along Z Direction



PLAN

From ACI Cl.11.3.1.1, V_c = [illegible] 285.55 kip

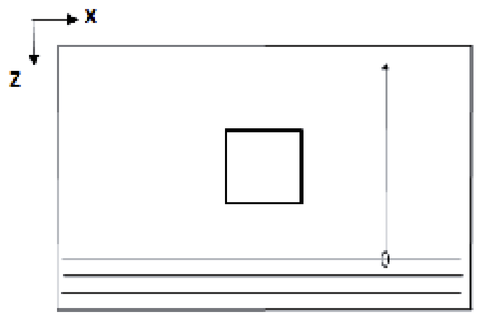
Distance along X to design for shear, D_x = [illegible] 6.96 ft

Check that **0.75 * V_c > V_{uz}** where V_{uz} is the shear force for the critical load cases at a distance d_{eff} from the face of the pier caused by bending about the Z axis.

From above calculations,	$0.75 * V_c =$	203.97	kip
Critical load case for V_{uz} is # 212	$V_{uz} = V_{uz}\|_{x=D_z} =$	5.42	kip

$0.75 * V_c > V_{uz}$ hence, OK

Design for Flexure about Z axis



PLAN

Calculate the flexural reinforcement along the X direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Factor β_1 from ACI Cl.10.2.7.3	for $F_c' \le$ 4 ksi,	0.85
From ACI Cl. 10.3.2, $\rho_{bal} =$	$0.85 \times \beta_1 \times F_c' \times \frac{87}{\left[F_y \times (87 + F_y)\right]} =$	0.02851
From ACI Cl. 10.3.3, $\rho_{max} =$	$0.75 \times \rho_{bal} =$	0.02138
From ACI Cl. 7.12.2, $\rho_{min} =$		0.00174
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{F_y}{(0.85 \times F_c')} =$	17.65

Calculate reinforcement ratio ρ for critical load case

Design for flexure about Z axis is performed at the face of the pier at a distance, $D_x =$	$0.5 \times L - 0.5 \times D_{col} - C_{col} =$	3.38	ft
Ultimate moment,	$M_{u\,x=D_x} =$	19.14	kip-ft
Nominal moment capacity, $M_n =$	$\frac{M_u}{\phi} =$	21.27	kip-ft
Required $\rho =$	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{(F_y \times W \times d_{eff}^2)}}\right] =$	0.00009	

Since	$\rho_{min} \leq \rho \leq \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff}$	4.18	in2

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, D_L =	$0.5 \times (L - D_{col}) - C_{cover}$ =	38.50	in
Try bar size	Area of one bar =	0.60	in2
Number of bars required, N_{bar} =	$\frac{A_s}{A_{bar}}$ =	7	

Because the number of bars is rounded up, make sure new reinforcement ratio < ρ_{max}

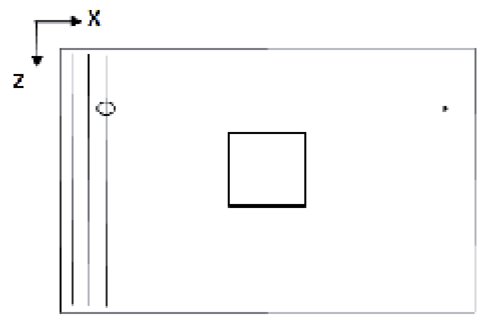
Total reinforcement area, A_{s_total} =	N_{bar} * (Area of one bar) =	4.20	in2
d_{eff} =	D - C_{cover} - 0.5 * (dia. of one bar) =	1.80	ft
Reinforcement ratio, ρ =	$\frac{A_{s\_total}}{(d_{eff} \times W)}$ =	0.00195	

From ACI Cl.7.6.1, minimum req'd clear distance between bars

C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 2.000in

Check to see if width is sufficient to accomodate bars

Design for Flexure about X axis



PLAN

Calculate the flexural reinforcement along the Z direction of the footing. Find the area of steel required, A, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 212

The strength values of steel and concrete used in the formulae are in ksi

Factor β_1 from ACI Cl.10.2.7.3	for $F_c' \leq$ 4 ksi,	0.85

From ACI Cl. 10.3.2, ρ_{bal} =	$0.85 \times \beta_1 \times f_c' \times \frac{87}{[f_y \times (87 + f_y)]}$ =	0.02851	
From ACI Cl. 10.3.3, ρ_{max} =	$0.75 \times \rho_{bal}$ =	0.02138	
From ACI Cl.7.12.2, ρ_{min} =		0.00173	
From Ref. 1, Eq. 3.8.4a, constant m =	$\frac{f_y}{(0.85 \times f_c')}$	17.65	

Calculate reinforcement ratio ρ for critical load case

Design for flexure about X axis is performed at the face of the pier at a distance, D_z =	$0.5 \times L \pm 0.5 \times B_{col} + C_{col}$ =	3.17	ft
Ultimate moment,	$M_{u(-D_z)}$ =	14.42	kip-ft
Nominal moment capacity, M_n =	$\frac{M_u}{\phi}$ =	16.02	kip-ft
Required ρ =	$\frac{1}{m} \times \left[1 - \sqrt{1 - 2 \times m \times \frac{M_n}{(f_y \times W \times d_{eff}^2)}}\right]$ =	0.00007	
Since	$\rho_{min} \le \rho \le \rho_{max}$	OK	
Area of Steel Required, A_s =	$\rho \times W \times d_{eff}$ =	4.37	in2

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, D_L =	$0.5 \times (L - B_{col}) - C_{cover}$ =	36.00	in
Try bar size	Area of one bar =	0.79	in2
Number of bars required, N_{bar} =	$\frac{A_s}{A_{bar}}$ =	6	

Because the number of bars is rounded up, make sure new reinforcement ratio < ρ_{max}

Total reinforcement area, A_{s_total} =	N_{bar} * (Area of one bar) =	4.74	in2
d_{eff} =	D - C_{cover} - 0.5 * (dia. of one bar) =	1.72	ft
Reinforcement ratio, ρ =	$\frac{A_{s\_total}}{(d_{eff} \times W)}$	0.00219	

From ACI Cl.7.6.1, minimum req'd clear distance between bars

C_d = max (Diameter of one bar, 1.0" (25.4mm), Min. User Spacing) = 2.000in

Check to see if width is sufficient to accomodate bars

Concrete Beam Design

CODE ACI 318-05

Analysis Results

Bending Moment Results

Load Case	Maximum Sagging Moment	Maximum Hogging Moment
211	0.00kip-ft	6.27kip-ft

Design Calculations

Optimization of Beam Size

Basic Design Data

β_1 (ACI 10.2.7.3)	$0.85, \max\left[0.85 - 0.05\cdot(f_c - 4), 0.65\right]$	= 0.85
ρ_{min} (ACI 10.5.1)	$\max\left(\frac{0.2}{f_y}, 3\cdot\frac{\sqrt{f_c}}{f_y}\right)$	= 0.0033
ρ_{bal} (ACI B8.4.3)	$0.85\cdot\beta_1\cdot f_c\cdot\frac{87}{\left[f_y\,(87 + f_y)\right]}$	= 0.0285
ρ_{max} (ACI B10.3.3)	$0.75\,\rho_{bal}$	= 0.0214
Modular ratio, m	$\frac{f_y}{0.85\cdot f_c}$	= 17.6471

Moment Strength Calculation

Moment reduction factor, ϕ = 0.9

Modulas of elasticity, E_s = 29000 ksi

Strain in concrete at extreme compression fiber, ε_c = 0.003

Yield strain of main reinforcement, ε_s	$\frac{F_{y\ main}}{E_s}$	= 0.0021
Effective depth, D_{eff}	$D - Cover_{bot} - 0.5\,Dia_{main} - Dia_{secon}$	= 1.7179ft
Distance from extreme compression fiber to neutral axis at balanced condition, C_b	$D_{eff}\cdot\frac{\varepsilon_c}{\varepsilon_c + \varepsilon_s}$	= 1.0167ft
Depth of equivalent rectangular stress block at balanced condition, A_b	$\beta_1 C_b$	= 0.8642ft
Depth of equivalent rectangular stress block at maximum ratio of tension reinforcement, A_{max}	$0.75\,A_b$	= 0.6482ft
Moment strength at balanced		=

condition, M_n	$\phi\left[0.85 \cdot f'_c \cdot W \cdot A_{max} \cdot \left(D_{eff} - 0.5 \cdot A_{max}\right)\right]$	1194.27kip-ft

Checking of Beam Size

Beam size is optimized to withstand the maximum moment and shear.

Check For Sagging Moment

Maximum sagging moment, M_{max_sag}	Obtained from analysis	= 0.00kip-ft
Ultimate sagging moment, M_{u_sag} =	$\frac{M_{max\_sag}}{0.9}$	= 0.00kip-ft
Coefficient of resistance, R_u =	$\frac{M_u}{W \cdot D_{eff}^2}$	= 0.0000kip/ft^2
$1 - 2 \cdot m \cdot \frac{R_u}{f_y}$	= 1.0000	is greater than zero, it is o.k.

Check For Hogging Moment

Maximum hogging moment, M_{max_hog}	Obtained from analysis	= 6.27kip-ft
Ultimate hogging moment, M_{u_hog} =	$\frac{M_{max\_hog}}{0.9}$	= 6.96kip-ft
Coefficient of resistance, R_u =	$\frac{M_u}{W \cdot D_{eff}^2}$	= 0.7866kip/ft^2
$1 - 2 \cdot m \cdot \frac{R_u}{f_y}$	= 0.9968	is greater than zero, it is o.k.

Check For Shear

Maximum shear force, V_{max}	Obtained from analysis	= 0.00kip
Shear reduction factor	ϕ	= 0.75
Ultimate shear force, V_u	V_{max} / ϕ	= 0.00kip
Nominal shear strength of concrete, V_c	$2 \cdot \sqrt{f'_c} \cdot W \cdot D_{eff}$	97.33kip
Shear force to be resisted by stirrups, V_s	$\frac{V_u - \phi \cdot V_c}{\phi}$	0.00kip

Maximum shear force that can be resisted by stirrups, V_{s_max}	$8 \cdot \sqrt{f_c} \cdot W \cdot D_{eff}$	389.3396kip

Since V_s is less than V_{s_max}, it is o.k.

Since nominal shear strength of concrete is greater than maximum shear force, shear reinforcement is not required.

Final depth of beam, D	= 2.00ft
Final width of beam, W	= 3.00ft
Final moment capacity of the section, M_n	= 1194.27kip-ft

If M_n is less than M_{max}, the beam is to be designed as a doubly reinforced beam.

It is a singly reinforced beam.

Reinforcement Design

This is the primary design of reinforcements and it is performed considering the maximum values of hogging and sagging moments and the maximum shear force.

Design For Bottom Reinforcement

% of steel required, ρ_{req}	$\max\left[\rho_{min}, \frac{1}{m} \cdot \left(1 - \sqrt{1 - 2 \cdot m \cdot \frac{R_n}{f_y}}\right)\right]$	0.0033
Area of steel required, A_{st_bot}	$\rho_{req} \cdot W \cdot D_{eff}$	2.47in2
Area of steel used, A_{st_b}	no. of bars used x area of 1 bar	2.60in2
Moment capacity	$\phi\left[0.85 \cdot f_c \cdot A_{st\_bot} \cdot m \cdot \left(D_{eff} - 0.5 \cdot A_{st\_bot} \cdot \frac{m}{W}\right)\right]$	242.63kip-ft

Bar no. used = 4

Number of bars required = 13

Number of reinforcement layers = 1

Design For Top Reinforcement

% of steel required, ρ_{req}	$\max\left[\rho_{min}, \frac{1}{m} \cdot \left(1 - \sqrt{1 - 2 \cdot m \cdot \frac{R_n}{f_y}}\right)\right]$	0.0033
Area of steel required, A_{st_top}	$\rho_{req} \cdot W \cdot D_{eff}$	2.47in2
Area of steel used, A_{st_t}	no. of bars used x area of 1 bar	2.40in2
Moment capacity	$\phi\left[0.85 \cdot f_c \cdot A_{st\_top} \cdot m \cdot \left(D_{eff} - 0.5 \cdot A_{st\_top} \cdot \frac{m}{W}\right)\right]$	247.83kip-ft

Bar no. used = 4

Number of bars required = 12

Number of reinforcement layers = 1

Beam depth is less than 36 inches. Hence side reinforcement is not necessary.

Design For Shear Reinforcement

If design shear force > 2 V_c, spacing calculated from boundary condition is reduced by 50%.

Spacing calculated from boundary condition, Sp	$(0.5 \cdot D_{eff}, 24)$	10.69in
Minimum stirrup spacing, Sp_{min}	$0.75 \cdot \frac{\sqrt{f_c} \cdot W}{f_y}$	7.73in
Required stirrup spacing (cannot be zero)	$\min\left(Sp_{min}, \frac{V_s}{f_y \cdot D_{eff}}\right)$	7.73in

Bar no. used = 3

Print Calculation Sheet

Appendix L: Hand Calculations – Strapped Footing

Stantec

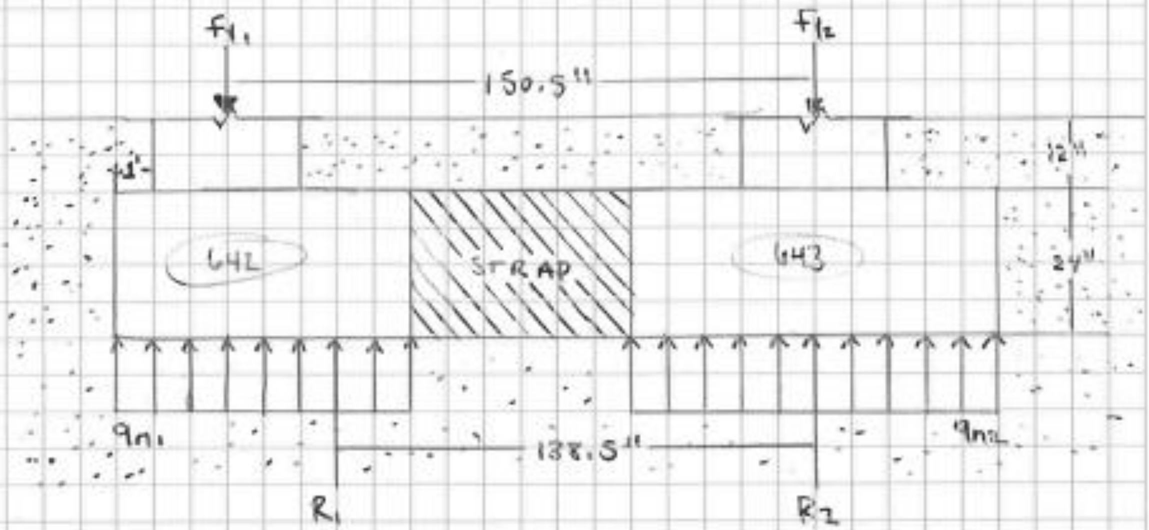
- STRAPPED FOOTING DESIGN FOR NODES 642 & 643

LOADING @ 642:

F_{Y_1} = 23.887 k (case 212)
F_{X_1} = 5.42 k (case 212)
F_{Z_1} = 3.134 k (case 211)

LOADING @ 643:

F_{Y_2} = 23.887 k (case 212)
F_{X_2} = 5.41 k (case 212)
F_{Z_2} = -3.134 k (case 210)



- ASSUME → Allowable soil bearing capacity q_a = 4000 lb/ft²
→ soil unit weight w_s = 120 lb/ft³
→ concrete unit weight w_c = 150 lb/ft³
→ depth of footing t = 24" = 2'
→ depth of soil above footing h_s = 12" = 1'
→ distance from column 642 edge to footing 1'

MQP FOUNDATION DESIGN - STRAPPED FOOTING
STAAD fdn REFERENCE NODES
Designed by: DJH
Checked by:

Stantec

- ASSUME FOOTING WIDTH, b = 4' (642)

$c = 4/2 - 1 = 1' = 12"$

distance between R_1 & R_2 = 150.5" - 12" = 138.5"

- CALCULATE ECCENTRIC MOMENT:

$M = (23.887k)(1') = 23.887$ ft-kip

&

$V = \frac{23.887}{(138.5/12)} = 2.07^k$

- REACTION AT FOOTING 642:

$R_1 = 23.887 + 2.07 = 25.96$ K

- NET SOIL BEARING CAPACITY

$q_{eff} = q_a - w_c - w_s$

$= 4000 - 150 \frac{lb}{ft^3}(2 ft) - 120 \frac{lb}{ft^3}(1 ft) = 3580$ lb $= 3.58^k$

- REQUIRED FOOTING AREA:

$A_{req} = \frac{R_1}{q_{eff}} = \frac{25.96}{3.58} = 7.25$ ft²

use 4'x 2' dimensions, A = 8 ft² > A req

- REACTION AT FOOTING 643:

$R_2 = 23.887 - 2.07 = 21.817$ K

Designed by: Checked by:

Stantec

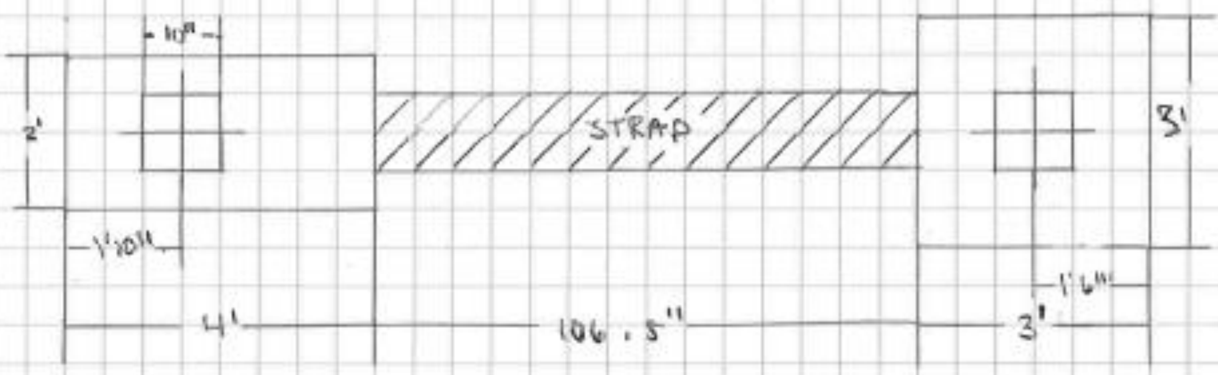
- REQUIRED FOOTING AREA

$$A_{req} = \frac{21.817}{3.58} = 6.09\ ft^2$$

(assume square footing) $bh = b^2$

* use $3' \times 3'$ → $A = 9\ ft^2 > A_{req}$

- MOMENT & SHEAR DIAGRAMS



- FACTORED COLUMN LOADS

$F_{y1} = 1.2(23.887) = 28.66^K$
$F_{y2} = 1.2(23.887) = 28.66^K$

- FACTORED ECCENTRIC MOMENT:

$M = 28.66\ k\ (1\ ft) = 28.66\ ft-k$

$V = 28.66/(138.5/12) = 2.5\ K$

Designed by: Checked by:

Stantec

- FACTORED UPWARD FOOTING PRESSURES

$$q_{n1} = \frac{(28.66 + 2.5)}{4} = 7.79 \text{ k/ft}$$

$$q_{n2} = \frac{(28.66 - 2.5)}{3} = 8.72 \text{ k/ft}$$

Shear:

$+P_1 = 7.79(1.83') = 14.26^{k}$

$-P_1 = 7.79(1.83) - 28.66 = -14.40$

$P_2 = 7.79(4') - 28.66 = 2.5$

$P_3 = 28.66 - 3(8.72) = 2.5$

$+P_4 = 7.79(1.83+2.17) - 28.66 + 8.72(1.5) = 15.58$

$-P_4 = 7.79(4) + 1.5(8.72) - 2(28.66) = -13.08$

Moment:

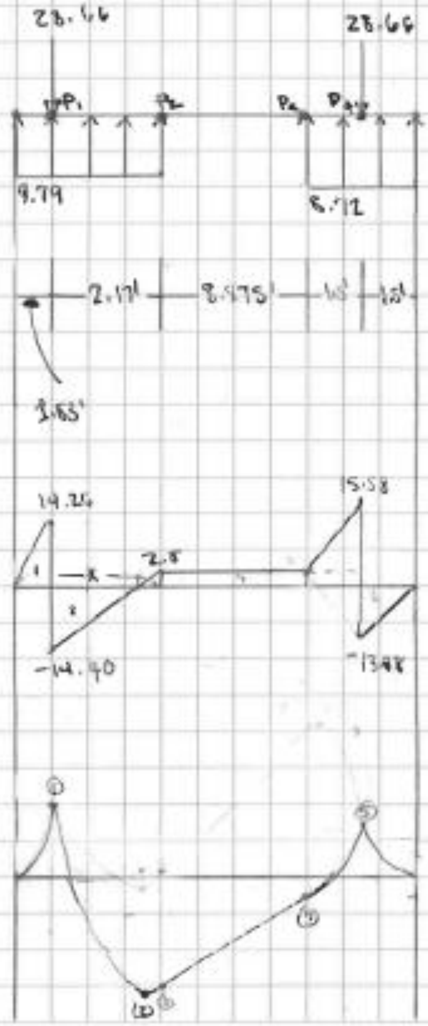
Moment 1 : 13.10

2 : -26.35 (MAX MOMENT)

3 : -25.9375

4 : -3.75

5 : 4.81



Designed by:

Checked by:

Stantec

DESIGN STRAP:

b = 3'

d = 2' , use 3" clear cover

$d_{eff} = 24 - 3 - 1 = 20"$

CHECK ONE WAY SHEAR

$V_u = 15.58$ (from shear diagram)

$\phi V_c = \phi \sqrt{f'_c}\, bd = .75 \sqrt{4000}\,(20)(36) = 34.15^k$

$\frac{1}{2}\phi V_c = 17.07$ → no shear reinforcement needed in strap

CHECK FOR FLEXURE:

$M_u = 26.35$ k-ft , assume a = 2

$T = \frac{M_u}{\phi(d - a/2)} = \frac{26.35(12)}{.9(20 - 2/2)} = 18.49^k$

$a = \frac{T}{.85 f'_c b} = \frac{18.49}{.5(4)(36)} = .257" \rightarrow$ use 1"

$T = \frac{26.35(12)}{.9(20 - 1/2)} = 18^k$

$A_s = \frac{T}{f_y} = \frac{18}{60} = .30$

$\rho = \frac{A_s}{bd} = \frac{.30}{20(36)} = .000417$

Designed by: Checked by:

Stantec

$\rho_{min} = \frac{200}{F_y} = .0033 \rightarrow$ governs $\left[A_{s\,min} = \frac{200\, b_w d}{f_y},\ A_s = \rho b_w d \right]$

$A_s = \rho b d = .0033(20)(36) = 2.4\ in^2$, use 3#9, $A_s = 3.0\ in^2$

DESIGN FOOTING 642 REINFORCEMENT: (4 x 4)

- 2' depth, $d_{eff} = 24 - 3 - 1 = 20''$

$b_o = 4(20 + 10) = 120''$, $c + d = 10 + 20 = 30''$

$q_n = \frac{7.79}{4} = 1.95\ k/ft^2$, $F_y = 28.66\ k$

TWO WAY SHEAR (PUNCHING)

$V_u = 28.66 - 1.95\left[(30/12)^2\right] = 16.47^k$

$\phi v_c = \left[\frac{\alpha d}{b_o} + 2\right]\sqrt{f'c}\ b_o d =$

ϕv_c

ONE WAY SHEAR (DIRECT)

$V_u = 14.40^k$

$\phi v_c = 2\phi\sqrt{f'c}\ b_o d = 2(.75)\sqrt{4000}\,(120)(20) = 228^k$ ✓

FLEXURE - longitudinal

$M_u = 26.35\ k\text{-}ft$

$R_n = \frac{M_u}{\phi b d^2} = \frac{26.35(12)}{.9(48)(20^2)} = .018\ k/in^2 = 18\ lb/in^2$

Designed by: Checked by:

Stantec

$$\rho = \frac{.85 f'c}{fy}\left[1 - \sqrt{1 - \frac{2Rn}{.85 f'c}}\right] = \frac{.85\ 4000}{60000}\left[1 - \sqrt{1 - \frac{2(18)}{.85(4000)}}\right] = .0003$$

$$\rho_b = .85\left[\frac{87000 \beta_1 f'c}{fy(87000 + fy)}\right] = .033$$

$\rho_{max} = .2138$

$\rho_{min} = .0018$ ← use

$As = \rho bd = .0018(20)(48) = 1.728\ in^2 \Rightarrow$ use 4#7

$$s = \frac{L - 2(cover)}{n - 1} = \frac{48 - 6}{4 - 1} = 14'' \Rightarrow MAX$$

Designed by: Checked by:

Appendix M: Excel Spreadsheet – Mat Foundation Models

Model: M1

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Footing

Length	15	ft
Width	16	ft
Thickness	1	ft

Reinforcement (X-Direction)

Size	# 14	
Number	20	
Spacing	7	in
Cover	3	in

Reinforcement (Y-Direction)

Size	# 14	
Number	24	
Spacing	7	in
Cover	3	in

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Foundation Dimensions

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.1 Shear & Foundation Thickness

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**
Check 4:	**OKAY!**
Check 5:	**OKAY!**

1.2 Reinforcement Design

Check 1:	**OKAY!**
Check 2:	**OKAY!**

		Mat Design		
DATE:	2/24/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Loads

Q1	23.887	kip	
Q2	23.887	kip	
Q3	23.888	kip	
Q4	23.888	kip	
Q	95.55	kip	

1.1 Structure Dimensions

Dmpointx	141.84	in	X Distance between midpoint of columns
Dmpointy	150.50	in	Y Distance between midpoint of columns
Dmpointx	11.82	ft	X Distance between midpoint of columns
Dmpointy	12.54	ft	Y Distance between midpoint of columns
Col B	0.83	ft	Length of Column base
Col L	0.83	ft	Length of Column base
Col Area	0.69	ft^2	Area of Column base
Col cov	1	ft	Min Distance from column to footing edge

1.2 Material Properties

qult	4000	lb/ft^2	
Ws	120	lb/ft^3	Weight of Soil
Wc	150	lb/ft^3	Weight of Concrete
f'c	4000	psi	
fy	60,000	psi	

2.0 Size Calculations X Direction

$\bar{x}$	5.91	ft	
e_x	0.00	ft	
x'	5.91	ft	
bmin	14.65	ft	Minimum length of side of mat
bused	15	ft	Length of side of Mat selected
	CHECK:	OKAY!	

2.1 Size Calculations Y Direction

$\bar{y}$	6.27	ft	
ey	0.00	ft	
y'	6.27	ft	
hmin	15.37	ft	Minimum length of side of mat
hused	16	ft	Length of side of Mat selected
	CHECK:	OKAY!	
$Area_{Mat}$	240	ft^2	Total Area of the Mat

Mat Design

DATE:	2/24/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Mat Thickness

qc	0.398	k/ft_2	
CHECK:	OKAY!		
Ix	5120	ft^4	
Iy	4500	ft^4	
ϕ	0.85		
β	1		Shape Parameter
d	1	ft	Assumed initial thickness. 1 ft min for reinforced
b0	7.33	ft	Breakout Perimeter
b0	88	in	Breakout Perimeter
ϕVc	1578.922		
dmin	4.635501	in	Minimum Calculated depth of concrete
dused	1	ft	Selected depth of concrete
deff	7.307	in	
CHECK:	OKAY!		dused > dmin
Vu_0	28.66	kip	Factored Shear Force

1.1 Pressure on Footing

qn	3.58	kip/ft
qult	1.27	ft^2
Wsoil	3.58	k/ft
Vu1	22.97	k/ft
Vu_2	26.48	k
b_{odeff}	69.228	

1.2 ϕVc > Vu Check (Two Way)

ϕVc_1	163.2	kip
ϕVc_2	111.8	kip
ϕVc_3	108.8	kip
CHECK:	OKAY!	

1.3 Two Way Shear

Vu	21.21135	kip
CHECK:	OKAY!	

1.4 One Way Shear

Vu	20.29	kip
ϕVc_1	133.1	kip
CHECK:	OKAY!	

Mat Design

DATE:	2/24/2015	DESIGN #:	1
PASS:	YES	CHECK:	DH

1.0 Data Input

b_{strip}	12	in	One foot wide strip analyzed
ϕ_{Reinf}	0.9		

1.1 Calculations - X Direction

$Dist_{px}$	1.590	ft	Distance column mid-pt. to footing edge (x)
$Vucol_x$	5.70	kip	
Max Vu_X	22.97	kip-ft	
Mu_x	67.87	kip-ft	
Mu_xin	814.42	kip-in	
Rn_x	1.41	kip/in^2	
Rn_xlb	1412.37	lb/in^2	
ρ_x	0.0334		
preqdx	0.033358		

Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	45.87409783	in^2	
	Cover	3	in	Clear Cover - All Sides
	Size	# 14		Size of Steel Reinforcing (Selectable)
	n	19.500		Number of Bars used to achieve Asmin
	n_{used}	20		Number of Bars used
	S_{max}	9.157894737	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
		Check:	OKAY!	Spacing<Smax

1.2 Calculations Y Direction

$Dist_{py}$	1.729	ft	Distance column mid-pt. to footing edge (y)
$Vucol_y$	6.20	kip	
Max Vu_Y	22.47	kip-ft	
Mu_y	70.45	kip-ft	
Mu_yin	845.39	kip-in	
Rn_y	1.47	kip/in^2	
Rn_ylb	1466.06	lb/in^2	
ρ_y	0.036		
preqdy	0.035646		

Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	50.00892906	in^2	Area of Steel Req'd per total length
	Cover	3	in	Clear Cover - All Sides
	Size	# 14		Size of Steel Reinforcing (Selectable)
	n	22.226		Number of Bars used to achieve Asmin
	n_{used}	24		Number of Bars used
	S_{max}	8.098958322	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
		Check:	OKAY!	Spacing<Smax

Model: M2

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Footing

Length	15.5	ft
Width	15.5	ft
Thickness	1	ft

Reinforcement (X-Direction)

Size	# 14	
Number	19	
Spacing	7	in
Cover	3	in

Reinforcement (Y-Direction)

Size	# 14	
Number	23	
Spacing	7	in
Cover	3	in

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Foundation Dimensions

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.1 Shear & Foundation Thickness

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**
Check 4:	**OKAY!**
Check 5:	**OKAY!**

1.2 Reinforcement Design

Check 1:	**OKAY!**
Check 2:	**OKAY!**

Mat Design				
DATE:	2/24/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Loads

Q1	23.887	kip	
Q2	23.887	kip	
Q3	23.888	kip	
Q4	23.888	kip	
Q	95.55	kip	

1.1 Structure Dimensions

Dmpointx	141.84	in	X Distance between midpoint of columns
Dmpointy	150.50	in	Y Distance between midpoint of columns
Dmpointx	11.82	ft	X Distance between midpoint of columns
Dmpointy	12.54	ft	Y Distance between midpoint of columns
Col B	0.83	ft	Length of Column base
Col L	0.83	ft	Length of Column base
Col Area	0.69	ft^2	Area of Column base
Col cov	1	ft	Min Distance from column to footing edge

1.2 Material Properties

qult	4000	lb/ft^2	
Ws	120	lb/ft^2	Weight of Soil
Wc	150	lb/ft^2	Weight of Concrete
f'c	4000	psi	
fy	60,000	psi	

2.0 Size Calculations X Direction

$\bar{x}$	5.91	ft	
e_x	0.00	ft	
x'	5.91	ft	
bmin	14.65	ft	Minimum length of side of mat
bused	15.5	ft	Length of side of Mat selected
	CHECK:	OKAY!	

2.1 Size Calculations Y Direction

$\bar{y}$	6.27	ft	
ey	0.00	ft	
y'	6.27	ft	
hmin	15.37	ft	Minimum length of side of mat
hused	15.5	ft	Length of side of Mat selected
	CHECK:	OKAY!	
$Area_{Mat}$	240.25	ft^2	Total Area of the Mat

	Mat Design		
DATE: 2/24/2015		**DESIGN #:**	1
PASS: YES		**CHECK:**	DH

1.0 Mat Thickness

qc	0.398	k/ft_2	
	CHECK:	OKAY!	
Ix	4810.005	ft^4	
Iy	4810.005	ft^4	
φ	0.85		
β	1		Shape Parameter
d	1	ft	Assumed initial thickness. 1 ft min for reinforced
b0	7.33	ft	Breakout Perimeter
b0	88	in	Breakout Perimeter
φVc	1578.922		
dmin	4.635501	in	Minimum Calculated depth of concrete
dused	1	ft	Selected depth of concrete
deff	7.307	in	
	CHECK:	OKAY!	dused > dmin
Vu_0	28.66	kip	Factored Shear Force

1.1 Pressure on Footing

qn	3.70	kip/ft
qult	1.31	ft^2
Wsoil	3.70	k/ft
Vu1	21.86	k/ft
Vu_2	26.41	k
$b_{o,eff}$	69.228	

1.2 φVc > Vu Check (Two Way)

ϕVc_1	163.2	kip
ϕVc_2	111.8	kip
ϕVc_3	108.8	kip
	CHECK:	OKAY!

1.3 Two Way Shear

Vu	20.97093	kip
	CHECK:	OKAY!

1.4 One Way Shear

Vu	20.94	kip
ϕVc_1	128.9	kip
	CHECK:	OKAY!

		Mat Design		
DATE:	2/24/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Data Input

b_{strip}	12	in	One foot wide strip analyzed
ϕ_{flexur}	0.9		

1.1 Calculations - X Direction

$Dist_{1fx}$	1.840	ft	Distance column mid-pt. to footing edge (x)
$Vucol_x$	6.81	kip	
$MaxVu_x$	21.86	kip-ft	
Mu_x	64.59	kip-ft	
Mu_x in	775.12	kip-in	
Rn_x	1.34	kip/in^2	
Rn_x lb	1344.20	lb/in^2	
ρ_x	0.0307		
preqdx	0.0307426		

Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	41.78251254	in^2	
	Cover	3	in	Clear Cover - All Sides
	Size	#14		Size of Steel Reinforcing (Selectable)
	n	18.570		Number of Bars used to achieve Asmin
	n_{used}	19		Number of Bars used
	S_{max}	10	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
	Check:	OKAY!		Spacing<Smax

1.2 Calculations Y Direction

$Dist_{1fy}$	1.479	ft	Distance column mid-pt. to footing edge (y)
$Vucol_y$	5.47	kip	
$MaxVu_y$	23.19	kip-ft	
Mu_y	72.72	kip-ft	
Mu_y in	872.66	kip-in	
Rn_y	1.51	kip/in^2	
Rn_y lb	1513.36	lb/in^2	
ρ_y	0.038		
preqdy	0.0378903		

Material

ϕ_t =	0.9		Strength Reduction Factor in Tension
MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	51.49882448	in^2	Area of Steel Req'd per total length
	Cover	3	in	Clear Cover - All Sides
	Size	#14		Size of Steel Reinforcing (Selectable)
	n	22.887		Number of Bars used to achieve Asmin
	n_{used}	25		Number of Bars used
	S_{max}	8.181818182	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
	Check:	OKAY!		Spacing<Smax

Model: M3

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

Footing

Length	15	ft
Width	16	ft
Thickness	1.5	ft

Reinforcement (X-Direction)

Size	# 8	
Number	24	
Spacing	7	in
Cover	3	in

Reinforcement (Y-Direction)

Size	# 8	
Number	25	
Spacing	7	in
Cover	3	in

Mat Design

DATE:	2/24/2015	**DESIGN #:**	1
PASS:	**YES**	**CHECK:**	DH

CHECKS:

1.0 Foundation Dimensions

Check 1:	**OKAY!**
Check 2:	**OKAY!**

1.1 Shear & Foundation Thickness

Check 1:	**OKAY!**
Check 2:	**OKAY!**
Check 3:	**OKAY!**
Check 4:	**OKAY!**
Check 5:	**OKAY!**

1.2 Reinforcement Design

Check 1:	**OKAY!**
Check 2:	**OKAY!**

Mat Design				
DATE:	2/24/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Loads

Q1	23.887	kip	
Q2	23.887	kip	
Q3	23.888	kip	
Q4	23.888	kip	
Q	95.55	kip	

1.1 Structure Dimensions

Dmpointx	141.84	in	X Distance between midpoint of columns
Dmpointy	150.50	in	Y Distance between midpoint of columns
Dmpointx	11.82	ft	X Distance between midpoint of columns
Dmpointy	12.54	ft	Y Distance between midpoint of columns
Col B	0.83	ft	Length of Column base
Col L	0.83	ft	Length of Column base
Col Area	0.69	ft^2	Area of Column base
Col cov	1	ft	Min Distance from column to footing edge

1.2 Material Properties

qult	4000	lb/ft^2	
Ws	120	lb/ft^3	Weight of Soil
Wc	150	lb/ft^3	Weight of Concrete
f'c	4000	psi	
fy	60,000	psi	

2.0 Size Calculations X Direction

$\bar{x}$	5.91	ft	
e_x	0.00	ft	
x'	5.91	ft	
bmin	14.65	ft	Minimum length of side of mat
bused	15	ft	Length of side of Mat selected
CHECK:	OKAY!		

2.1 Size Calculations Y Direction

$\bar{y}$	6.27	ft	
ey	0.00	ft	
y'	6.27	ft	
hmin	15.37	ft	Minimum length of side of mat
hused	16	ft	Length of side of Mat selected
CHECK:	OKAY!		
$Area_{Mat}$	240	ft^2	Total Area of the Mat

		Mat Design		
DATE:	2/24/2015		**DESIGN #:**	1
PASS:	**YES**		**CHECK:**	DH

1.0 Mat Thickness

qc	0.398	k/ft_2	
CHECK:		**OKAY!**	
Ix	5120	ft^4	
Iy	4500	ft^4	
ϕ	0.85		
β	1		Shape Parameter
d	1	ft	Assumed initial thickness. 1 ft min for reinforced
b0	7.33	ft	Breakout Perimeter
b0	88	in	Breakout Perimeter
ϕVc	1578.922		
dmin	4.635501	in	Minimum Calculated depth of concrete
dused	1.5	ft	Selected depth of concrete
deff	14	in	
CHECK:		**OKAY!**	dused > dmin
Vu_o	28.66	kip	Factored Shear Force

1.1 Pressure on Footing

qn	3.58	kip/ft
qult	1.27	ft^2
Wsoil	3.58	k/ft
Vu1	22.97	k/ft
Vu_2	24.48	k
b_{odeff}	96	

1.2 ϕVc > Vu Check (Two Way)

ϕVc_1	433.5	kip
ϕVc_2	355.2	kip
ϕVc_3	289.0	kip
CHECK:		**OKAY!**

1.3 Two Way Shear

Vu	14.3322	kip
CHECK:		**OKAY!**

1.4 One Way Shear

Vu	18.29	kip
ϕVc_1	255.0	kip
CHECK:		**OKAY!**

		Mat Design		
DATE:	2/24/2015		DESIGN #:	1
PASS:	YES		CHECK:	DH

1.0 Data Input

b_{strip}	12	in	One foot wide strip analyzed
ϕ_{Reinf}	0.9		

1.1 Calculations - X Direction

$Dist_{ex}$	1.590	ft	Distance column mid-pt. to footing edge (x)
$Vucol_x$	5.70	kip	
Max Vu_x	22.97	kip-ft	
Mu_x	67.87	kip-ft	
Mu_xin	814.42	kip-in	
Rn_x	0.38	kip/in^2	
Rn_xlb	384.74	lb/in^2	
ρ_x	0.0068		
preqdx	0.006823		

Material

	ϕ_t =	0.9		Strength Reduction Factor in Tension
	MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	17.19434491	in^2	
	Cover	3	in	Clear Cover - All Sides
	Size	#8		Size of Steel Reinforcing (Selectable)
	n	21.765		Number of Bars used to achieve Asmin
	n_{used}	24		Number of Bars used
	S_{max}	7.565217391	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
	Check:	OKAY!		Spacing<Smax

1.2 Calculations Y Direction

$Dist_{ey}$	1.729	ft	Distance column mid-pt. to footing edge (y)
$Vucol_y$	6.20	kip	
Max Vu_Y	22.47	kip-ft	
Mu_y	70.45	kip-ft	
Mu_yin	845.39	kip-in	
Rn_y	0.40	kip/in^2	
Rn_ylb	399.37	lb/in^2	
ρ_y	0.007		
preqdy	0.007101		

Material

	ϕ_t =	0.9		Strength Reduction Factor in Tension
	MinShrink	0.0018	x b x h	Min. Shrinkage & Temp. Reinf.

Reinforcing

	Asreqd	19.0877229	in^2	Area of Steel Req'd per total length
	Cover	3	in	Clear Cover - All Sides
	Size	#8		Size of Steel Reinforcing (Selectable)
	n	24.162		Number of Bars used to achieve Asmin
	n_{used}	25		Number of Bars used
	S_{max}	7.75	in	Maximum Allowable Spacing
Check	Spacing	7	in	Selected Spacing
	Check:	OKAY!		Spacing<Smax

Appendix N: STAAD.*foundation* – Mat Foundation

DESIGN OF MAT FOUNDATION

Mat Foundation Design(ACI 318-05)

Job Details

Job Name : Mat Foundation Design

Included Support	X (ft)	Y (ft)	Z (ft)
1	66.917	0.000	50.000
2	66.917	0.000	62.542
3	78.737	0.000	50.000
4	78.737	0.000	62.542

Load Details

Included Loads

Load Case No 110: D + W N-S
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.063	-3.562	1.896	0.000	0.000	0.000
643	-0.138	-13.701	1.968	0.000	0.000	0.000
671	0.063	-3.563	1.896	0.000	0.000	0.000
672	0.138	-13.702	1.968	0.000	0.000	0.000

Load Case No 111: D + W S-N
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.138	-13.701	-1.968	0.000	0.000	0.000
643	-0.063	-3.562	-1.897	0.000	0.000	0.000
671	0.138	-13.702	-1.967	0.000	0.000	0.000
672	0.063	-3.563	-1.896	0.000	0.000	0.000

Load Case No 112: D + W E-W
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-3.413	-17.087	-0.057	0.000	0.000	0.000
643	-3.413	-17.087	0.057	0.000	0.000	0.000
671	-3.211	-0.177	-0.014	0.000	0.000	0.000
672	-3.211	-0.177	0.014	0.000	0.000	0.000

Load Case No 113: D + W W-E
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	3.212	-0.176	-0.014	0.000	0.000	0.000
643	3.212	-0.176	0.014	0.000	0.000	0.000
671	3.412	-17.088	-0.057	0.000	0.000	0.000
672	3.412	-17.088	0.057	0.000	0.000	0.000

Load Case No 120: 0.6 DL + W N-S
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.023	-0.109	1.911	0.000	0.000	0.000
643	-0.098	-10.248	1.953	0.000	0.000	0.000
671	0.023	-0.110	1.911	0.000	0.000	0.000
672	0.098	-10.249	1.953	0.000	0.000	0.000

Load Case No 121: 0.6 DL + W S-N
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.098	-10.248	-1.953	0.000	0.000	0.000
643	-0.023	-0.109	-1.911	0.000	0.000	0.000
671	0.098	-10.249	-1.953	0.000	0.000	0.000
672	0.023	-0.110	-1.911	0.000	0.000	0.000

Load Case No 122: 0.6 DL + W E-W
Primary Primary

Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-3.373	-13.635	-0.043	0.000	0.000	0.000
643	-3.373	-13.635	0.043	0.000	0.000	0.000
671	-3.251	3.276	-0.000	0.000	0.000	0.000
672	-3.251	3.276	0.000	0.000	0.000	0.000

Load Case No 123: 0.6 DL + W W-E
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	3.252	3.277	-0.000	0.000	0.000	0.000
643	3.252	3.277	0.000	0.000	0.000	0.000
671	3.372	-13.635	-0.043	0.000	0.000	0.000
672	3.372	-13.635	0.043	0.000	0.000	0.000

Load Case No 200: 1.4 DL
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.141	-12.084	-0.050	0.000	0.000	0.000
643	-0.141	-12.084	0.050	0.000	0.000	0.000
671	0.141	-12.086	-0.050	0.000	0.000	0.000
672	0.141	-12.086	0.050	0.000	0.000	0.000

Load Case No 210: 1.2 DL + 1.6 W N-S
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.060	-2.247	3.049	0.000	0.000	0.000
643	-0.181	-18.469	3.134	0.000	0.000	0.000
671	0.061	-2.248	3.048	0.000	0.000	0.000

672	0.180	-18.471	3.134	0.000	0.000	0.000

Load Case No 211: 1.2 DL + 1.6 W S-N
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.181	-18.469	-3.134	0.000	0.000	0.000
643	-0.060	-2.247	-3.049	0.000	0.000	0.000
671	0.180	-18.471	-3.134	0.000	0.000	0.000
672	0.061	-2.248	-3.048	0.000	0.000	0.000

Load Case No 212: 1.2 DL + 1.6 W E-W
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-5.420	-23.887	-0.077	0.000	0.000	0.000
643	-5.420	-23.887	0.077	0.000	0.000	0.000
671	-5.178	3.170	-0.009	0.000	0.000	0.000
672	-5.178	3.170	0.009	0.000	0.000	0.000

Load Case No 213: 1.2 DL + 1.6 W W-E
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	5.179	3.171	-0.009	0.000	0.000	0.000
643	5.179	3.172	0.009	0.000	0.000	0.000
671	5.419	-23.888	-0.077	0.000	0.000	0.000
672	5.419	-23.888	0.077	0.000	0.000	0.000

Load Case No 220: 0.9 DL + 1.6 W N-S
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)

642	-0.030	0.343	3.059	0.000	0.000	0.000
643	-0.151	-15.879	3.123	0.000	0.000	0.000
671	0.031	0.342	3.059	0.000	0.000	0.000
672	0.150	-15.881	3.123	0.000	0.000	0.000

Load Case No 221: 0.9 DL + 1.6 W S-N
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-0.151	-15.879	-3.123	0.000	0.000	0.000
643	-0.030	0.343	-3.059	0.000	0.000	0.000
671	0.150	-15.881	-3.123	0.000	0.000	0.000
672	0.031	0.342	-3.059	0.000	0.000	0.000

Load Case No 222: 0.9 DL + 1.6 W E-W
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	-5.390	-21.298	-0.066	0.000	0.000	0.000
643	-5.390	-21.298	0.066	0.000	0.000	0.000
671	-5.208	5.760	0.002	0.000	0.000	0.000
672	-5.208	5.760	-0.002	0.000	0.000	0.000

Load Case No 223: 0.9 DL + 1.6 W W-E
Primary Primary
Serviceability Factor 1.000
Design Factor 1.000
Self Weight Factor 1.000

Reactions

NODE NO.	Fx (kip)	Fy (kip)	Fz (kip)	Mx (kip-ft)	My (kip-ft)	Mz (kip-ft)
642	5.209	5.761	0.002	0.000	0.000	0.000
643	5.209	5.761	-0.002	0.000	0.000	0.000
671	5.389	-21.298	-0.066	0.000	0.000	0.000
672	5.389	-21.299	0.066	0.000	0.000	0.000

Properties Details

Region	Thickness(ft)	Material
Boundary	1.000	Concrete

Soil Details

Boundary	Subgrade Modulus	Soil Height Above Mat	Soil Density	Applied Load due to Soil
Boundary	0.083kip/in2/in	0.000ft	120.000lb/ft3	0.000kip/ft^2

Mat Dimension

Boundary Name : AutoGen672

Node No	X Coor(ft)	Y Coor(ft)	Z Coor(ft)
17	78.471	0.000	62.288
18	79.003	0.000	62.288
19	79.003	0.000	62.795
20	78.471	0.000	62.795

Boundary Name : AutoGen671

Node No	X Coor(ft)	Y Coor(ft)	Z Coor(ft)
13	78.471	0.000	49.747
14	79.003	0.000	49.747
15	79.003	0.000	50.253
16	78.471	0.000	50.253

Boundary Name : AutoGen643

Node No	X Coor(ft)	Y Coor(ft)	Z Coor(ft)
9	66.651	0.000	62.288
10	67.183	0.000	62.288
11	67.183	0.000	62.795
12	66.651	0.000	62.795

Boundary Name : AutoGen642

Node No	X Coor(ft)	Y Coor(ft)	Z Coor(ft)
5	66.651	0.000	49.747
6	67.183	0.000	49.747
7	67.183	0.000	50.253
8	66.651	0.000	50.253

Boundary Name : Boundary

Node No	X Coor(ft)	Y Coor(ft)	Z Coor(ft)
21	65.000	0.000	48.500
22	81.000	0.000	48.500
23	81.000	0.000	64.500
24	65.000	0.000	64.500

Analysis Results

Node Displacement Summary Table

-	Node Number	Load Case	Dx(ft)	Dy(ft)	Dz(ft)	Rx (Rad)	Ry (Rad)	Rz (Rad)
Max Dx	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Max Dy	2	222	0.00000	491223.33333	0.00000	0.00039	0.00000	30701.46094
Max Dz	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Max Rx	80	220	0.00000	0.02018	0.00000	0.00196	0.00000	0.00009

Max Ry	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Max Rz	1	222	0.00000	-0.03043	0.00000	-0.00055	0.00000	30701.46094
Min Dx	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Min Dy	2	213	0.00000	-0.04166	0.00000	-0.00111	0.00000	-758.62750
Min Dz	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Min Rx	93	221	0.00000	0.04246	0.00000	-0.00392	0.00000	0.00012
Min Ry	1	110	0.00000	-0.00048	0.00000	0.00002	0.00000	0.00008
Min Rz	1	223	0.00000	437388.33333	0.00000	0.00006	0.00000	-27336.77148

Plate Stress Summary Table

-	Plate	Load Case	SQx (kip/ft2)	SQy (kip/ft2)	Sx (kip/ft2)	Sy (kip/ft2)	Sxy (kip/ft2)	Mx (kip-ft/ft)	My (kip-ft/ft)	Mxy (kip-ft/ft)
Max SQX	16	223	30.46750	16.07704	0.00000	0.00000	0.00000	-79.24924	5.81375	34.77990
Max SQY	15	223	-20.05009	25.10551	0.00000	0.00000	0.00000	2.20863	1.87493	9.56435
Max SX	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Max SY	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Max SXY	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Max MX	16	222	-32.23732	-17.96679	0.00000	0.00000	0.00000	90.12712	-6.22540	-38.91974
Max MY	16	223	30.46750	16.07704	0.00000	0.00000	0.00000	-79.24924	5.81375	34.77990
Max MXY	16	223	30.46750	16.07704	0.00000	0.00000	0.00000	-79.24924	5.81375	34.77990
Min SQX	16	222	-32.23732	-17.96679	0.00000	0.00000	0.00000	90.12712	-6.22540	-38.91974
Min SQY	15	222	24.89568	-27.57301	0.00000	0.00000	0.00000	-1.38497	-1.53560	-10.38084
Min SX	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Min SY	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Min SXY	1	110	0.03393	0.04299	0.00000	0.00000	0.00000	0.04896	0.07778	-0.04659
Min MX	16	223	30.46750	16.07704	0.00000	0.00000	0.00000	-79.24924	5.81375	34.77990
Min MY	248	213	-2.02148	0.03779	0.00000	0.00000	0.00000	0.95577	-6.58576	-0.04113
Min MXY	16	222	-32.23732	-17.96679	0.00000	0.00000	0.00000	90.12712	-6.22540	-38.91974

Base Pressure Summary for Service Load conditions

-	Node	X-Coor(ft)	Y-Coor(ft)	Z-Coor(ft)	Load Case	Base Pressure (kip/ft2)
Maximum Base Pressure	2	81.000	0.000	48.500	213	5.99921
Minimum Base Pressure	11	72.000	0.000	48.500	110	0.00000

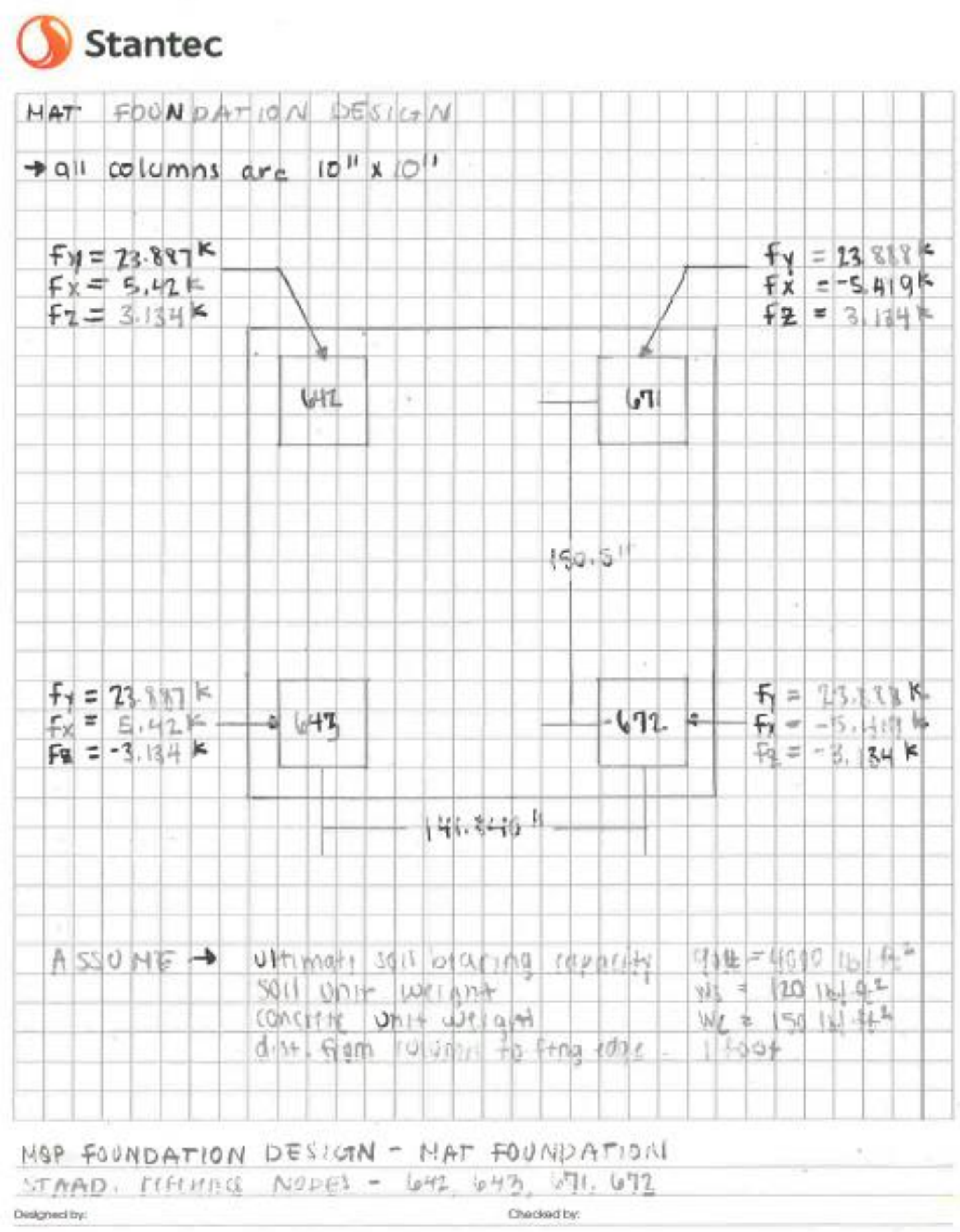
Contact Area

Load Case	Area in Contact(ft2)	% of Total Area	Area out of Contact(ft2)	% of Total Area
110	253.50000	99.02344	2.50000	0.97656
111	237.00000	92.57813	19.00000	7.42188

112	78.00000	30.46875	178.00000	69.53125
113	94.50000	36.91406	161.50000	63.08594
120	82.00000	32.03125	174.00000	67.96875
121	62.00000	24.21875	194.00000	75.78125
122	8.00000	3.12500	248.00000	96.87500
123	8.00000	3.12500	248.00000	96.87500
200	256.00000	100.00000	0.00000	0.00000
210	153.50000	59.96094	102.50000	40.03906
211	128.50000	50.19531	127.50000	49.80469
212	8.00000	3.12500	248.00000	96.87500
213	8.00000	3.12500	248.00000	96.87500
220	62.00000	24.21875	194.00000	75.78125
221	40.50000	15.82031	215.50000	84.17969
222	8.00000	3.12500	248.00000	96.87500
223	8.00000	3.12500	248.00000	96.87500

Print Calculation Sheet

Appendix O: Hand Calculation – Mat Foundation



Stantec

$\Sigma F_y = 2(23.887) + 2(23.888) = 95.55\,K$

$95.55\,\bar{X} = (23.888 - 23.888)\left(\frac{141.840''}{12}\right)$

$\bar{X} = 5.91'$

$e_x = \left(\frac{141.840}{12(2)}\right) - 5.91 = 0$

$X' = 5.91'$

$b_{min} = 2(5.91 + 1 + (5/12)) = 14.65' \Rightarrow$ use $15'$

$95.55\,\bar{Y} = (23.887 + 23.888)\left(\frac{150.5''}{12}\right)$

$\bar{Y} = 6.27'$

$e_y = \left(\frac{150.5}{12(2)}\right) - 6.27 = 0$

$Y' = 6.27'$

$h_{min} = 2(6.27 + 1 + (5/12)) = 15.373' \Rightarrow$ use $16'$

∴ USE MAT DIMENSIONS 15' x 16'

Contact Pressure: $q_c = \frac{95.55^K}{(15 \times 16)} = .398\,K/ft^2 < q_{allow}$ ✓

↓

$I_x = \frac{1}{12}(15)(16^3) = 5120\ ft^4$

since eccentricity = 0

$q_{avg} = q_c$

↓

Soil pressure check ✓

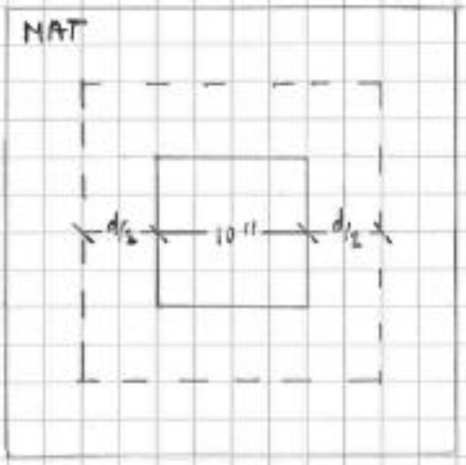
$I_y = \frac{1}{12}(16)(15^3) = 4500\ ft^4$

Designed by:

Checked by:

Stantec

MAT THICKNESS



breakout perimeter:

$b_o = 4(10 + 2(d/2))$
$= 40 + 4d$

$\phi V_c = \left(2 + \frac{4}{\beta}\right)\sqrt{f'c}\, b_o d\, \phi$

$\phi = .85$
$\beta = 1$
$V_u = 1.2(23.884) = 28.66$

$28.66 = (6)\sqrt{4000}(40 + 4d)\, d\, (.85)$
$0 = 1290d^2 + 12903d - 28.66$

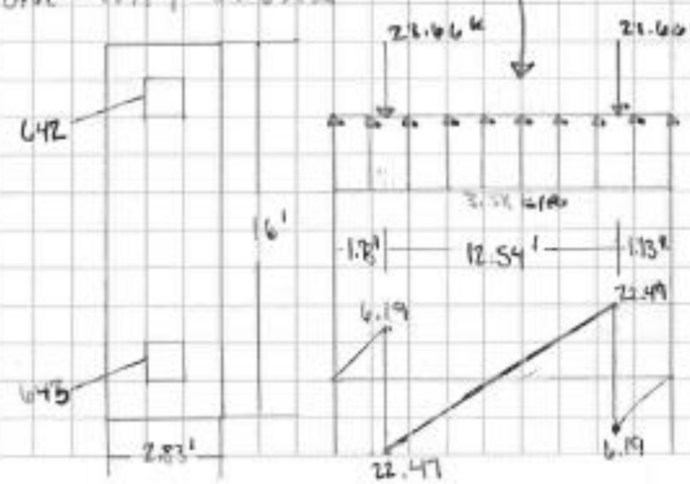
d = 5", need 1' → use 1' depth

diff = 12 - 3 - .75 = 8.25"

* footing pressure

$q_u = \frac{2(28.66)}{16} = 3.58\ \frac{k}{ft}$

ONE-WAY SHEAR



$q_{ult} = \frac{\Sigma F_y}{A_{strip}} = \frac{2(28.66)}{12.83(16)}$

$q_{ult} = 1.27\ k/ft^2$

$W_{soil} = q_{ult}(W_{strip}) = 1.27(2.83)$
$= 3.58\ k/ft$

$d_{eff} = 8.25"$

$V_u = 22.49 - (8.25/12)(3.58)$
$= 20.01k$

Designed by:
Checked by:

Stantec

- check $\phi V_c > V_u$

$$\phi V_c = \left[2 + \frac{4}{1}\right]\sqrt{4000}\,(8.25)[40 + 4(8.25)](.85) = 194.3^k > V_u \checkmark$$

$$\phi V_c = \left[\frac{20(8.25)}{73} + 2\right]\sqrt{4000}\,(73)(8.25)(.85) = 137.9^k > V_u \checkmark$$

$$\phi V_c = 4\sqrt{4000}\,(73)(8.25)(.85) = 129.5^k > V_u \checkmark$$

TWO WAY SHEAR:

$$V_u = F_y - \left(\frac{d+10}{12}\right)^2 (W_{soil})$$
$$= 28.66 - \left(\frac{8.25 + 10}{12}\right)^2 (1.27) = 25.67^k < \phi V_c \checkmark$$

ONE WAY SHEAR:

$V_u = 20.01k$

$$\phi V_c = .75(2)\sqrt{f'c}\,bd$$
$$= .75(2)\sqrt{4000}\,(16)(8.25)(12) = 150.3 > V_u \checkmark$$

Designed by: Checked by:

Stantec

REINFORCEMENT DESIGN

* design will be based on 1ft unit of the strip.

$b = 1' = 12''$

$d = 8.25''$

$M_u = \frac{21.79}{2}(6.58) - \frac{5.08}{2}(1.42) = 68.08\ k\text{-}ft = 816.99\ k\text{-}in$

(A_{r2}) (A_{r1})

$R_n = \frac{M_u}{\phi b d^2} = \frac{816.99}{.9(12)(8.25^2)} = 1.11\ k/in^2 = 1110\ lb/in^2$

$\rho = \frac{.85 f'c}{fy}\left[1 - \sqrt{1 - \frac{2R_n}{.85 f'c}}\right] = \frac{.85(4000)}{60000}\left[1 - \sqrt{1 - \frac{2(1110)}{.85(4000)}}\right] = .023$

$\rho max > \rho > \rho min$

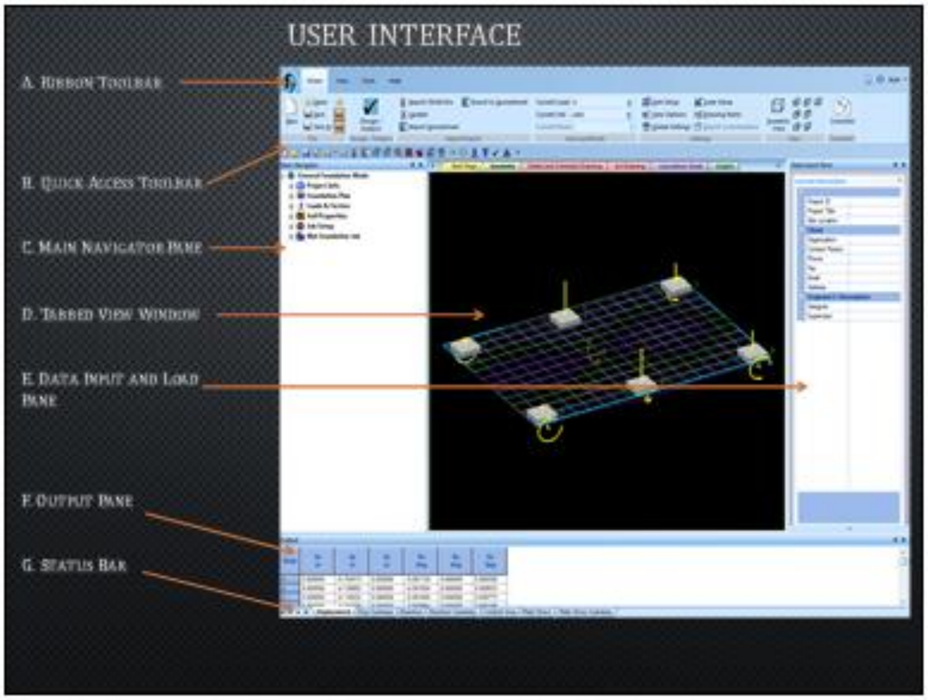
$A_s = \rho bd = .023(12)(8.25) = 2.28\ (16) = 36.48$

∴ use 20 #14, 7" spacing O.C.

$S = \frac{L - 2(c)}{n-1} = \frac{16(12) - 6}{19} = 9.78'' \to max$

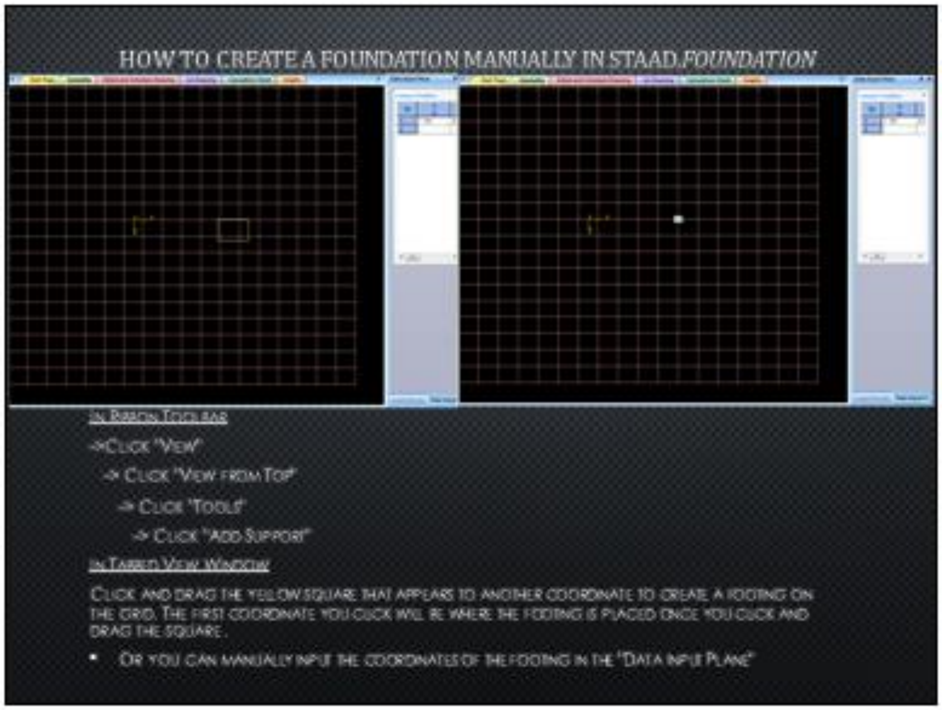
Designed by: Checked by:

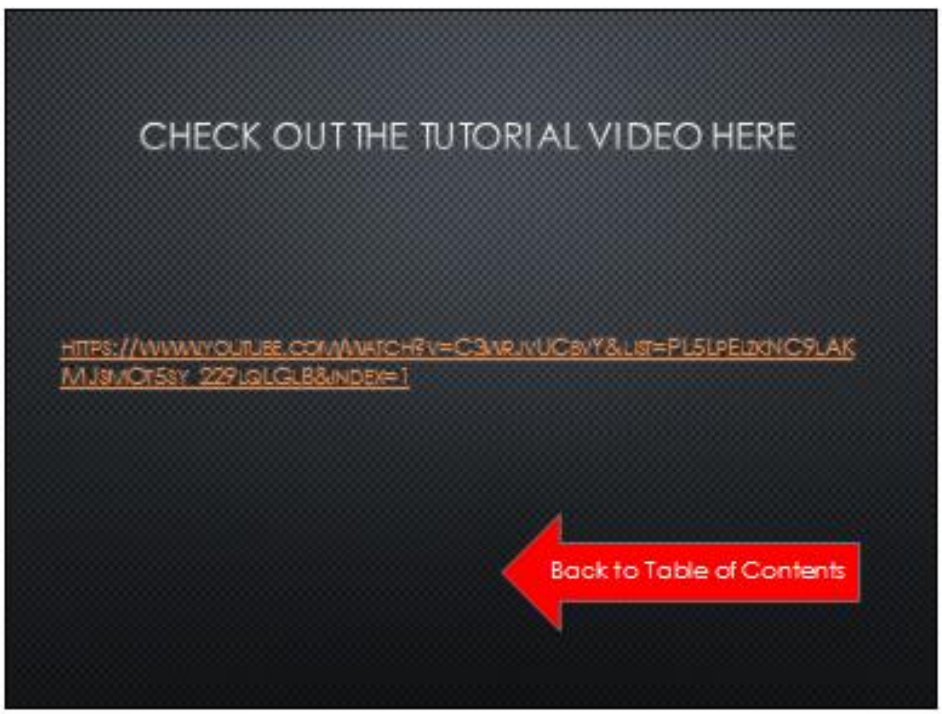
Appendix P: User Tips Manual - Stantec Consulting Ltd.



FOUNDATION LOADING IN STAAD.*FOUNDATION*

- Purpose: To increase efficiency in each support design.
- Service Loads are used to design footing dimensions.
- Ultimate Loads are used to design the concrete reinforcement and footing thickness.
- These Load Combinations (Service and Ultimate Loads) need to be combined with factors of safety within the program to create a realistic load case scenario. When toggling through each Load, it is shown that they are not added to the foundation in the geometric view at the same time. Load combinations are used for the foundation's actual design.
- Primary Loads allow loading to be used for both Primary and Service Loads. Primary load cases are treated as if they are acting on the foundation separately. They are they initial step towards the design of the foundation. Exclude Primary Loads when creating Load Cases because only Load Combinations should be used for design purposes. STAAD foundation individually applies each Load Combination to the foundation and designs each support according to its Limiting Load Combination.


HOW TO CREATE A FOUNDATION MANUALLY IN STAAD.FOUNDATION
IN RIBBON TOOLBAR
->CLICK "VIEW"
-> CLICK "VIEW FROM TOP"
-> CLICK "TOOLS"
-> CLICK "ADD SUPPORT"
IN TABBED VIEW WINDOW
CLICK AND DRAG THE YELLOW SQUARE THAT APPEARS TO ANOTHER COORDINATE TO CREATE A FOOTING ON THE GRID. THE FIRST COORDINATE YOU CLICK WILL BE WHERE THE FOOTING IS PLACED ONCE YOU CLICK AND DRAG THE SQUARE.
• OR YOU CAN MANUALLY INPUT THE COORDINATES OF THE FOOTING IN THE "DATA INPUT PLANE"


CHECK OUT THE TUTORIAL VIDEO HERE
HTTPS://WWW.YOUTUBE.COM/WATCH?V=C3WRJVUCBVY&LIST=PL5LPELZKNC9LAKMJSMOT5SY_229LQLGLB&INDEX=1
Back to Table of Contents

ISOLATED SPREAD FOOTING

DESIGN PARAMETERS
CONCRETE AND REINFORCEMENT

SPECIFIES:

-Unit Weight of Concrete

-Minimum and Maximum Bar Spacing

-Strength of Concrete

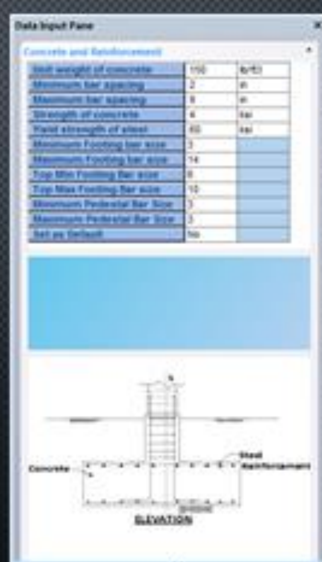
-Yield Strength of Steel

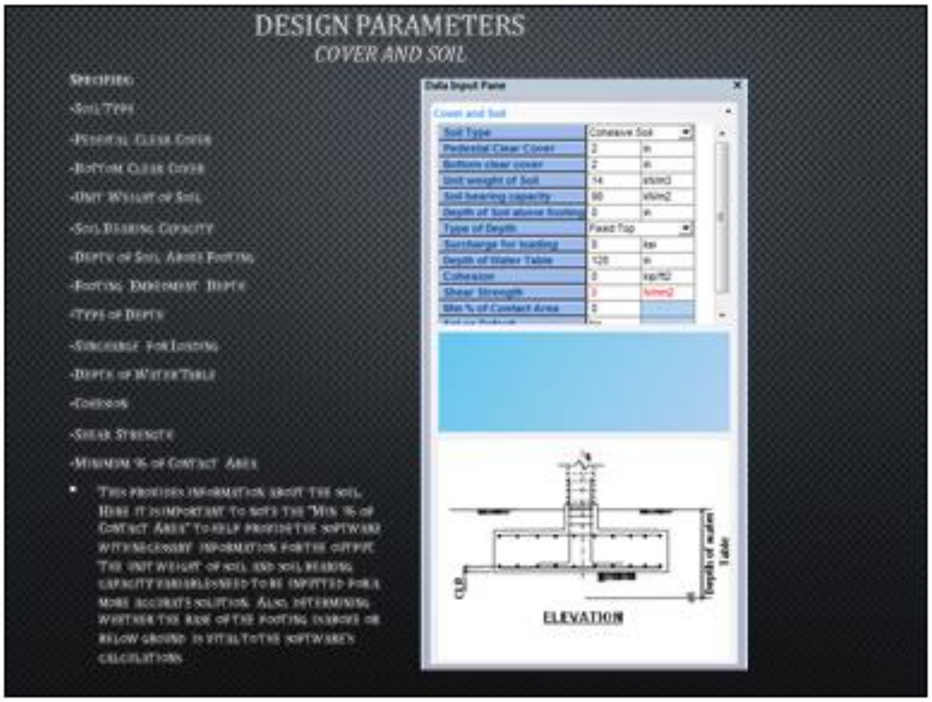
-Minimum and Maximum Bar Size

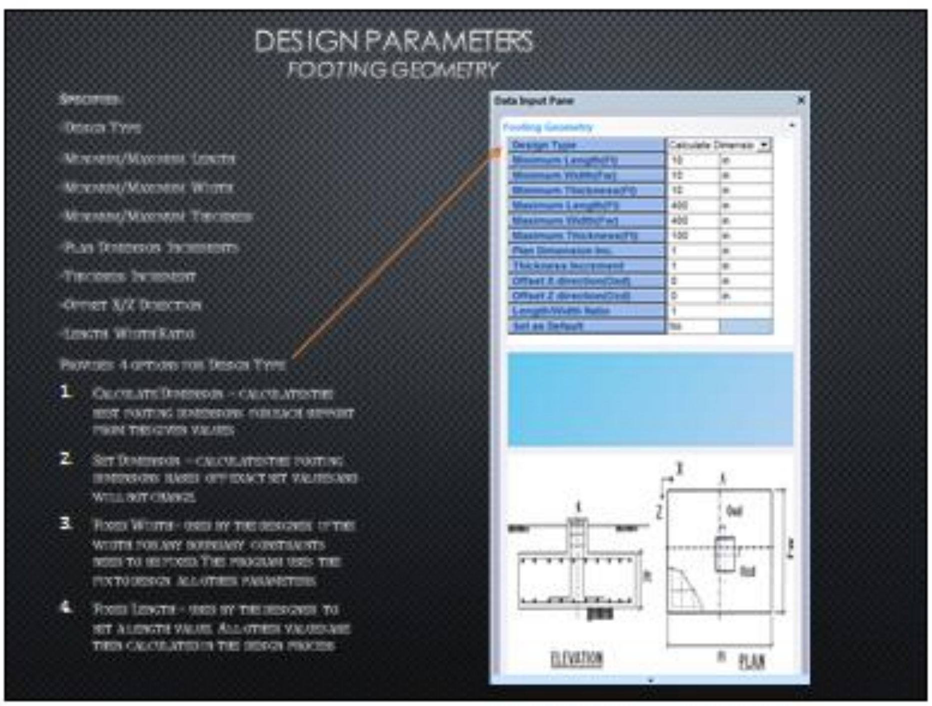
-Top Minimum and Maximum Bar Size

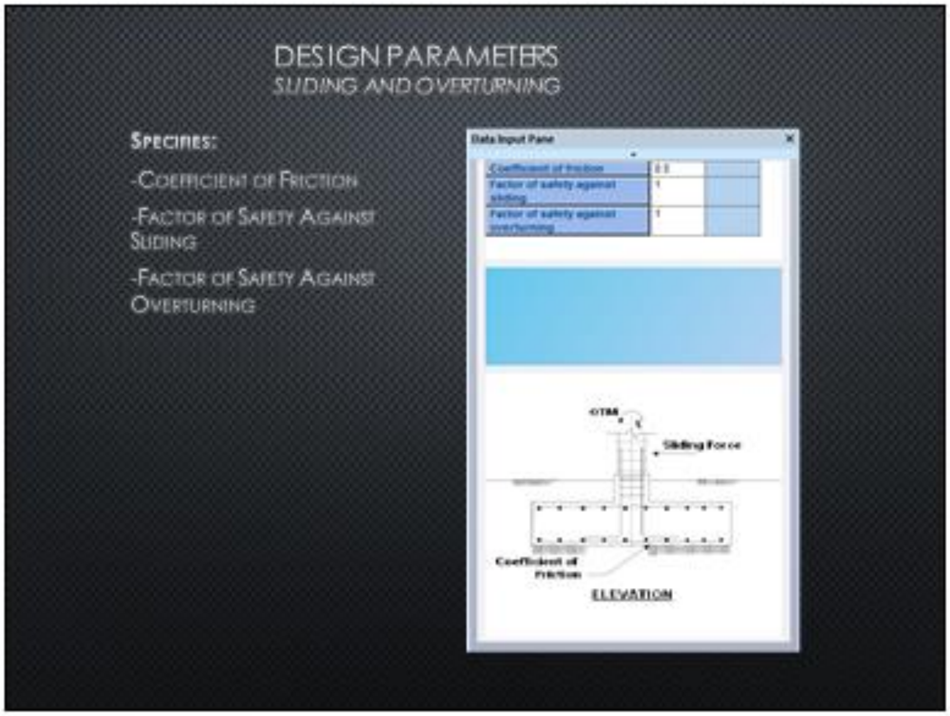
-Minimum and Maximum Pedestal Bar Size

- This provides concrete and reinforcement related information in a table under the "Data Input Plane" menu.
- Check the "Set as Default" box to "Yes" to designate all other footings that are created to the specific variables inputted above.

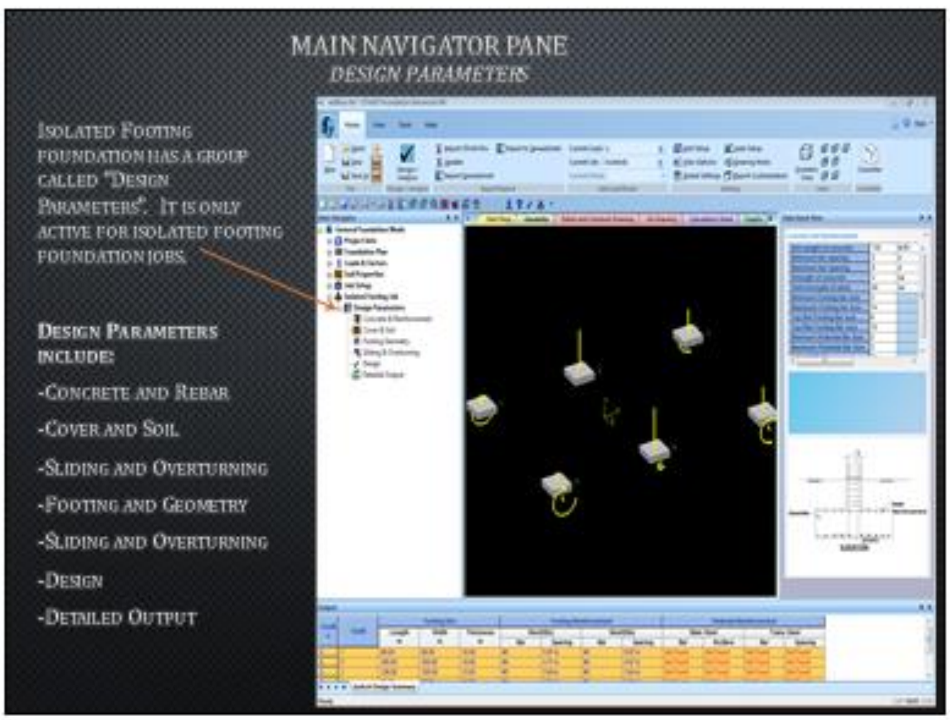



DESIGN PARAMETERS
COVER AND SOIL
Data Input Pane
Soil Type
Pedestal Clear Cover
Bottom clear cover
Unit weight of Soil
Soil bearing capacity
Type of Depth
Depth of Water Table
Cohesion
Shear Strength
ELEVATION

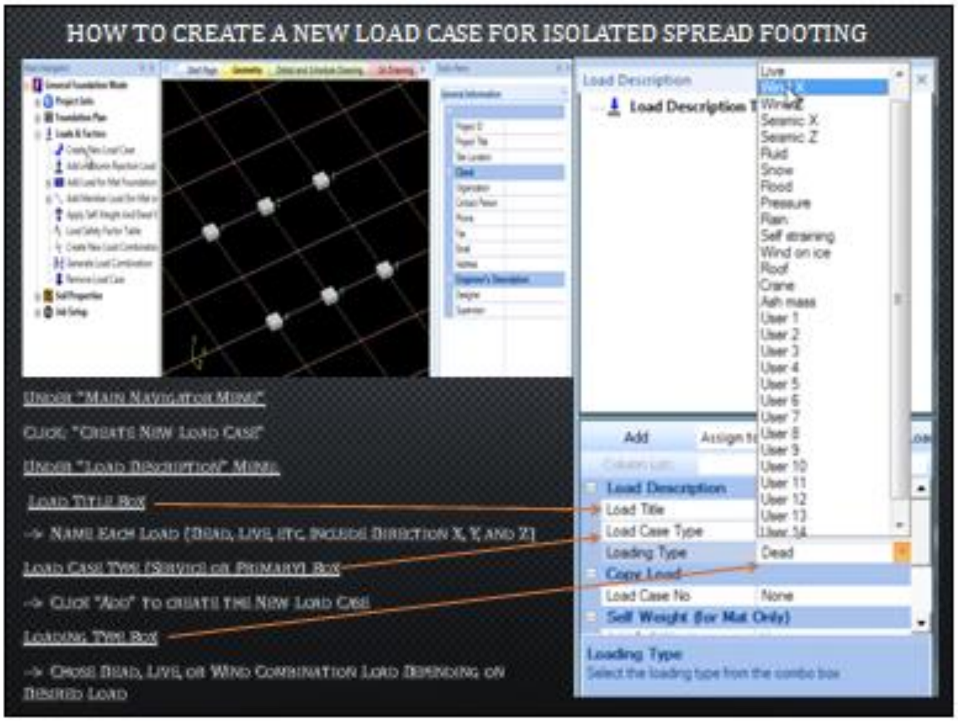

DESIGN PARAMETERS
FOOTING GEOMETRY
Data Input Pane
Footing Geometry
Design Type
ELEVATION
PLAN

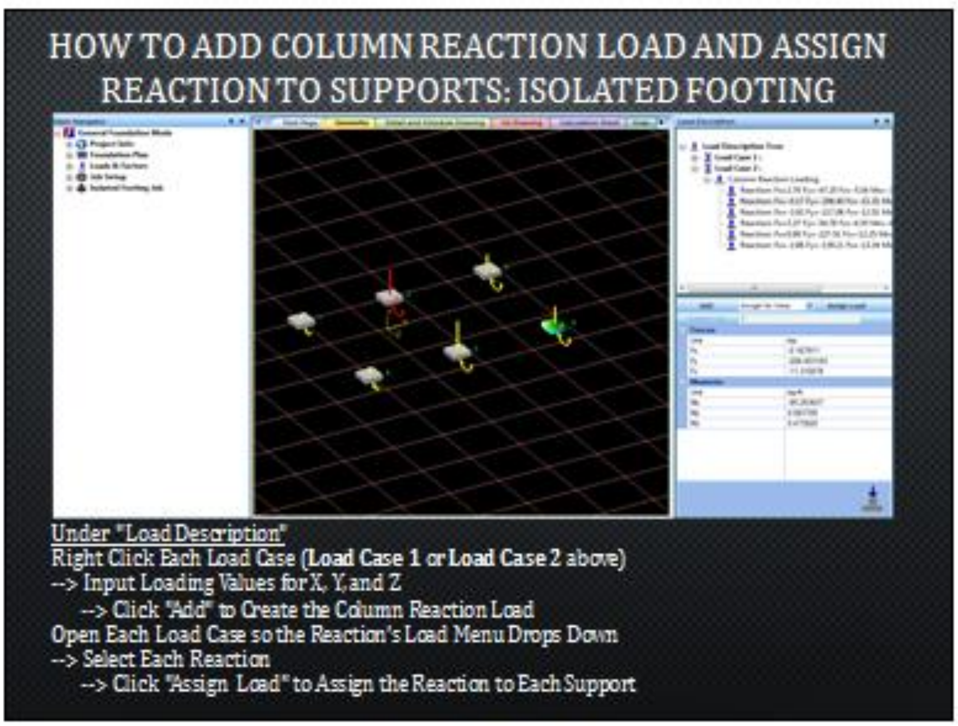


DESIGN PARAMETERS
SLIDING AND OVERTURNING
SPECIFIES:
-COEFFICIENT OF FRICTION
-FACTOR OF SAFETY AGAINST SLIDING
-FACTOR OF SAFETY AGAINST OVERTURNING
Data Input Pane
Coefficient of friction
Factor of safety against sliding
Factor of safety against overturning
OTM
Sliding Force
Coefficient of Friction
ELEVATION



MAIN NAVIGATOR PANE
DESIGN PARAMETERS
ISOLATED FOOTING FOUNDATION HAS A GROUP CALLED "DESIGN PARAMETERS". IT IS ONLY ACTIVE FOR ISOLATED FOOTING FOUNDATION JOBS.
DESIGN PARAMETERS INCLUDE:
-CONCRETE AND REBAR
-COVER AND SOIL
-SLIDING AND OVERTURNING
-FOOTING AND GEOMETRY
-SLIDING AND OVERTURNING
-DESIGN
-DETAILED OUTPUT


HOW TO CREATE A NEW LOAD CASE FOR ISOLATED SPREAD FOOTING
Under "Main Navigator Menu"
Click: "Create New Load Case"
Under "Load Description" Menu:
Load Title Box
-> Name Each Load (Dead, Live, etc. Include Direction X, Y, and Z)
Load Case Type (Service or Primary) Box
-> Click "Add" to create the New Load Case
Loading Type Box
-> Chose Dead, Live, or Wind Combination Load Depending on Desired Load
Load Description
Live
Seismic X
Seismic Z
Fluid
Snow
Flood
Pressure
Rain
Self straining
Wind on ice
Roof
Crane
Ash mass
Add
Load Description
Load Title
Load Case Type
Loading Type
Dead
Copy Load
Load Case No
None
Self Weight (for Mat Only)
Loading Type
Select the loading type from the combo box


HOW TO ADD COLUMN REACTION LOAD AND ASSIGN REACTION TO SUPPORTS: ISOLATED FOOTING
Under "Load Description"
Right Click Each Load Case (Load Case 1 or Load Case 2 above)
--> Input Loading Values for X, Y, and Z
--> Click "Add" to Create the Column Reaction Load
Open Each Load Case so the Reaction's Load Menu Drops Down
--> Select Each Reaction
--> Click "Assign Load" to Assign the Reaction to Each Support

GENERATING LOAD COMBINATIONS AND ASSIGNING THEM TO EACH FOUNDATION: ISOLATED FOOTING

Under "Main Navigator"

Click "Loads & Factors" to Open the Drop Menu.

--> Click "Generate Load Combination" to Open the Input Menu.

In the "Load Combination Input" Menu

Here, one is able to automatically generate all possible Service and Ultimate Load Combinations. These Load Combination values can be specified by choosing the correct building code in the Drop Menu "Load Combination Table".

--> Click "Generate Load Combination" under "Service and Ultimate Load Combinations" to create the Combination Loads.

--> The Load Combinations will then show up in the "Load Description" Menu.

ASSIGNING DESIGN LOAD COMBINATIONS TO EACH SUPPORT FOR STRUCTURAL ANALYSIS

UNDER "MAIN NAVIGATOR" MENU

CLICK ON JOB SETUP

--> CREATE NEW JOB

--> NAME THE JOB "ISOLATED FOOTING"

UNDER "DATA INPUT PLANE" MENU

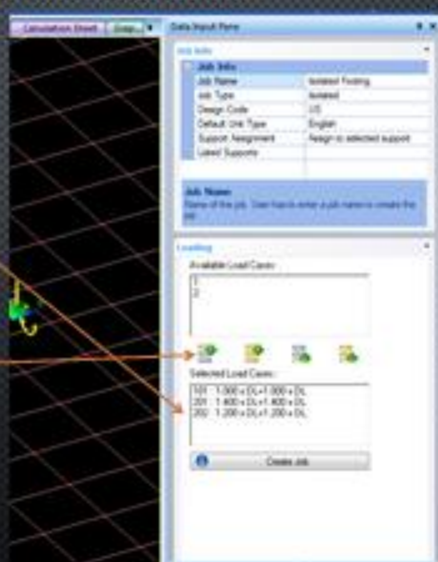
SELECT ALL OF THE NON PRIMARY LOADS, BECAUSE ONLY LOAD COMBINATIONS SHOULD BE USED FOR DESIGN PURPOSES

(1: AND 2: IN THIS CASE).

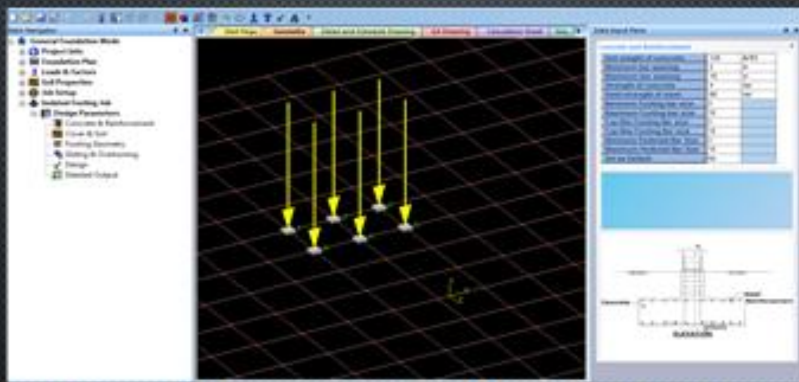
--> ONCE THE OTHER LOAD CASES ARE SELECTED FROM THE "AVAILABLE LOAD CASES" BOX, MOVE THEM DOWN INTO THE "SELECTED LOAD CASES" BOX.

--> CLICK "CREATE JOB" TO APPLY THE DESIGN LOADS TO EACH ISOLATED FOUNDATION.

STAAD.FOUNDATION WILL ASSIGN EACH LOAD COMBINATION TO THE FOUNDATION AND DESIGN EACH SUPPORT TO ITS LIMITING LOAD COMBINATION.

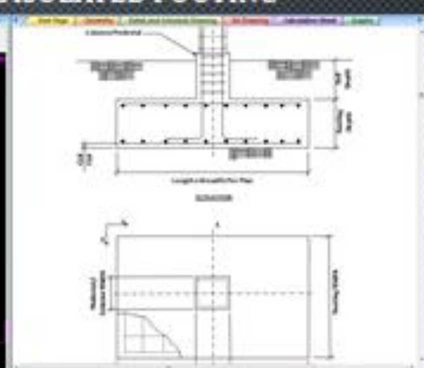


HOW TO CREATE ISOLATED FOOTINGS



Once the footings have been created and all load cases have been assigned, the job can then be created. A new tab under the "Main Navigator" will become available named "Isolated Footing Job".
See Slides 6-9 to view the "Design Parameters" of the Isolated Footing Job

HOW TO ANALYZE THE ISOLATED FOOTING



Under "Main Navigator"

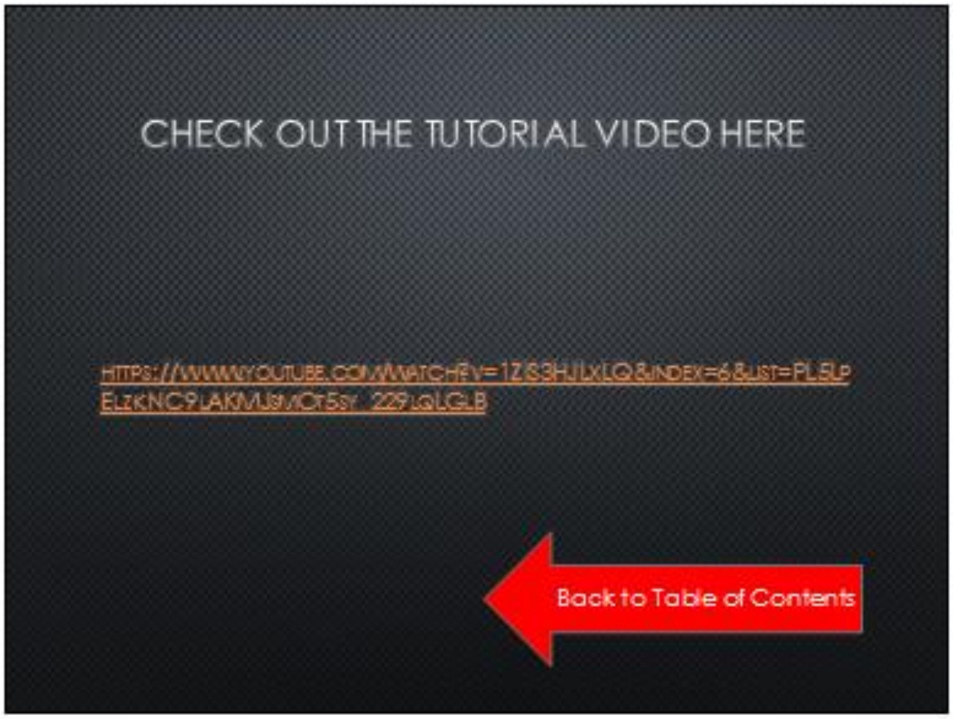
Click "Design"

> Click "Yes" to analyze the design

- The "Detail and Schedule Drawing", "Calculation Sheet", and "GA Drawing" will now be available in their respective tabs
- The Calculation Sheet shows how each footing will be designed

Under the "Detail and Schedule Drawing" Tab

- This tab shows support and footing design dimensions. If there are pedestals or anchor bolts, they are also shown in this view.
- The drawn plans shown in this view can be exported into AutoCAD by using the "Save Drawing As" button.



CHECK OUT THE TUTORIAL VIDEO HERE
HTTPS://WWW.YOUTUBE.COM/WATCH?V=1ZS3HJILXLQ&INDEX=6&LIST=PL5LPELZKNC9LAKMJSMCT5SY_229LQLGLB
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STRAP FOUNDATION

DESIGN PARAMETERS
CONCRETE & REINFORCEMENT

Specifies:

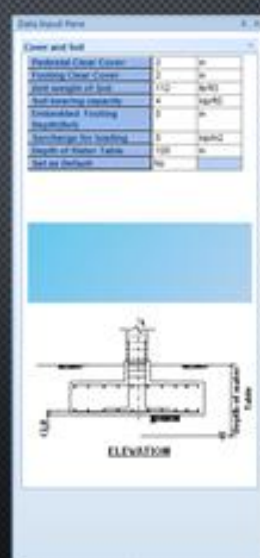
- Unit weight of concrete
- Minimum bar spacing
- Maximum bar spacing
- Strength of concrete
- Yield strength of steel
- Minimum Footing bar size
- Maximum Footing bar size
- Top Min Footing Bar size
- Top Max Footing Bar size
- Minimum Pedestal Bar Size
- Maximum Pedestal Bar Size

DESIGN PARAMETERS
COVER & SOIL

Specifies:

- Pedestal Clear Cover
- Footing Clear Cover
- Unit weight of Soil
- Soil Bearing capacity
- Embedded Footing Depth (Bottom)
- Surcharge for loading
- Depth of Water Table

Water Table depth is used to calculate uplift forces if some of the foundation is above the water table. The unit weight of water is used to calculate the uplift forxe for the volume of concrete above the water table.



DESIGN PARAMETERS
FOOTING GEOMETRY

SPECIFIES:

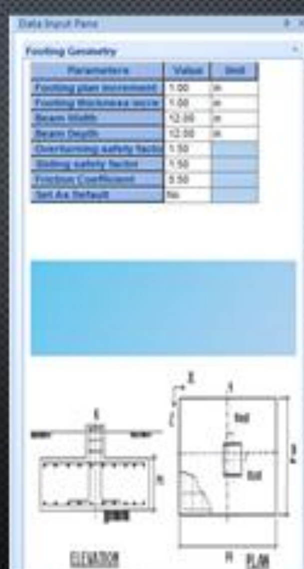
- LENGTH
- WIDTH
- HEIGHT
- MAXIMUM LENGTH
- MAXIMUM WIDTH
- MAXIMUM HEIGHT
- OFFSET X
- OFFSET Z

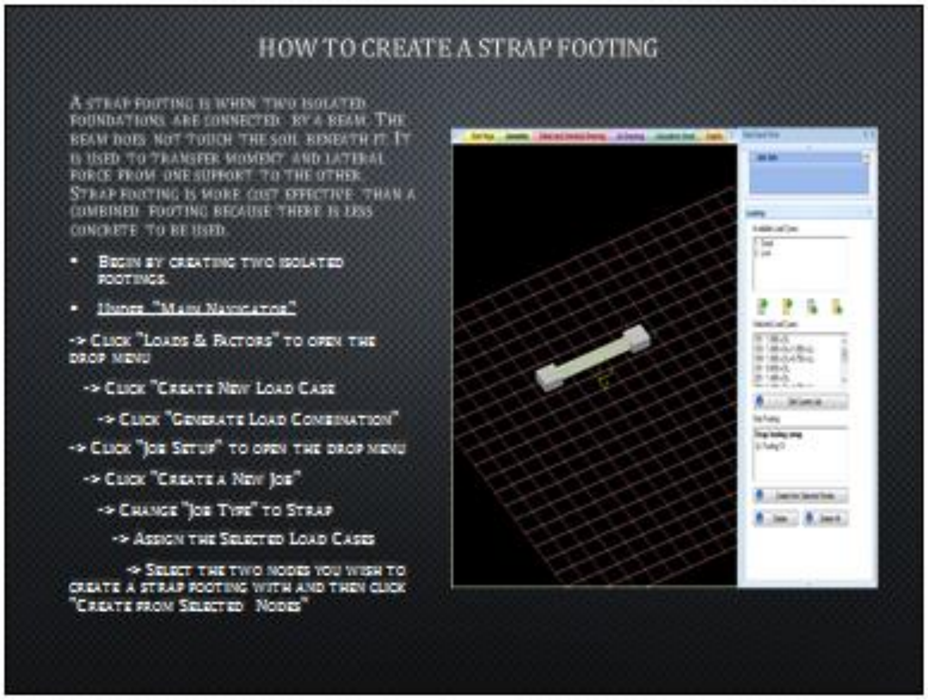
DUE TO THE FACT THAT THE STRAP FOOTING CONSISTS OF TWO ISOLATED FOOTINGS, THE PROGRAM NEEDS TO DIFFERENTIATE BETWEEN THE TWO. THEREFORE, THERE IS A LEFT FOOTING AND A RIGHT FOOTING. THE RIGHT FOOTING IS ALWAYS THE FOOTING THAT HAS THE HIGHER COORDINATES OF THE TWO.

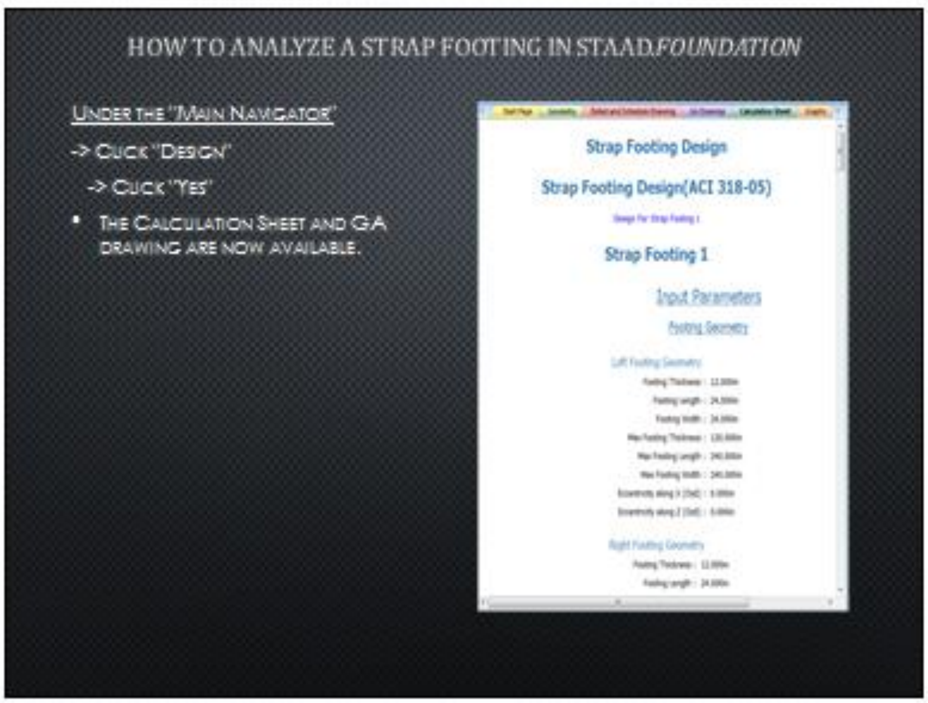
DESIGN PARAMETERS
OTHER PARAMETERS

SPECIFIES:

- FOOTING PLAN INCREMENT
- FOOTING THICKNESS INCREMENT
- BEAM WIDTH
- BEAM DEPTH
- OVERTURNING SAFETY FACTOR
- SLIDING SAFETY FACTOR
- FRICTION COEFFICIENT




HOW TO CREATE A STRAP FOOTING
A strap footing is when two isolated foundations are connected by a beam. The beam does not touch the soil beneath it. It is used to transfer moment and lateral force from one support to the other. Strap footing is more cost effective than a combined footing because there is less concrete to be used.
• Begin by creating two isolated footings.
• Under "Main Navigator"
-> Click "Loads & Factors" to open the drop menu
-> Click "Create New Load Case
-> Click "Generate Load Combination"
-> Click "Job Setup" to open the drop menu
-> Click "Create a New Job"
-> Change "Job Type" to Strap
-> Assign the Selected Load Cases
-> Select the two nodes you wish to create a strap footing with and then click "Create from Selected Nodes"


HOW TO ANALYZE A STRAP FOOTING IN STAAD.FOUNDATION
Under the "Main Navigator"
-> Click "Design"
-> Click "Yes"
• The Calculation Sheet and GA drawing are now available.
Strap Footing Design
Strap Footing Design(ACI 318-05)
Strap Footing 1
Input Parameters
Footing Geometry

CHECK OUT THE TUTORIAL VIDEO HERE

HTTPS://WWW.YOUTUBE.COM/WATCH?V=E2ASWWBK74D&LIST=PL5LPELZKNC9LAKMJBMOT5SY_229LQLGL6&INDEX=16

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COMBINED FOOTING

HOW TO CREATE COMBINED FOOTINGS

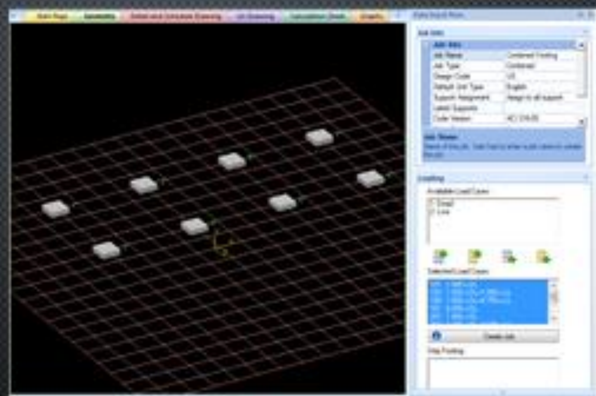
CREATE ALL OF THE ISOLATED FOOTINGS OR IMPORT THE FOUNDATION INTO STAAD.FOUNDATION. AFTER DOING THIS, CREATE AND GENERATE THE LOAD CASES AND ASSIGN THEM TO THE FOUNDATIONS.

UNDER "DATA INPUT PLANE"

-> CHANGE "JOB TYPE" TO COMBINED

-> CREATE "JOB NAME"

-> CLICK "CREATE JOB"

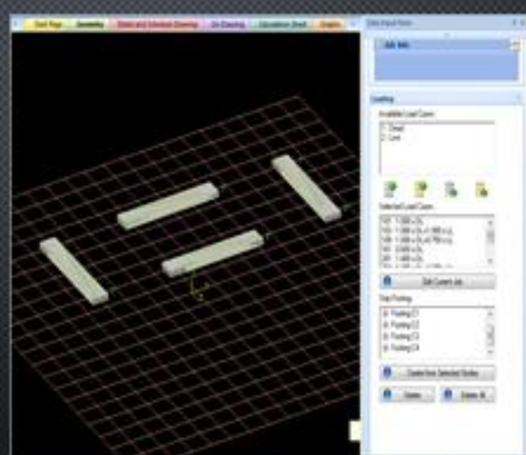


HOW TO CREATE A COMBINED FOOTING (CONT.)

UNDER "DATA INPUT PLANE"

THE TWO FOOTINGS YOU WANT TO CREATE A COMBINED FOOTING FOR NEED TO BE PARALLEL OR PERPENDICULAR TO EACH OTHER.

-> SELECT THE TWO YOU WANT AND THEN SELECT "CREATE FROM SELECTED NODES"



HOW TO ANALYZE A COMBINED FOOTING IN STAAD.*FOUNDATION*

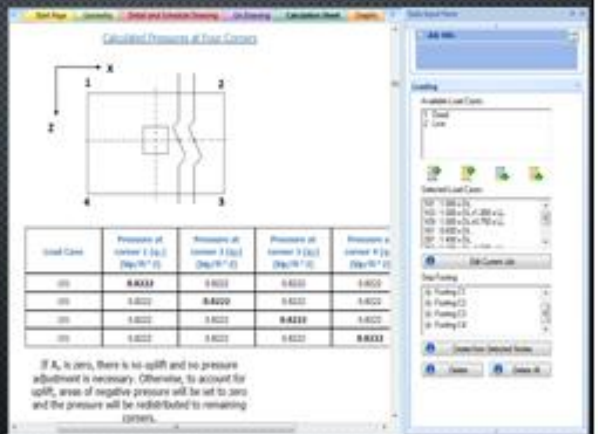
Under "Main Navigator"

-> Click "Combined Footing Job"

-> Click "Design Parameters"

-> Click "Design"

The calculations and GA drawing will then become available if all inputs were done correctly. The output is the design of each combined footing and the forces they withstand.



CHECK OUT THE TUTORIAL VIDEO HERE

HTTPS://WWW.YOUTUBE.COM/WATCH?V=DT71OAY9LTO&LIST=PLSLPBLKNC9LAKIVI8M OT5SY_229LQLG1B&INDEX=7

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PILE CAP FOUNDATION

PILE CAP JOB
DESIGN PARAMETERS

SPECIFIES:

-STRENGTH OF CONCRETE

-UNIT WEIGHT OF CONCRETE

-YIELD STRENGTH OF STEEL

-SIDE COVER

-BOTTOM COVER

-PEDESTAL CLEAR COVER

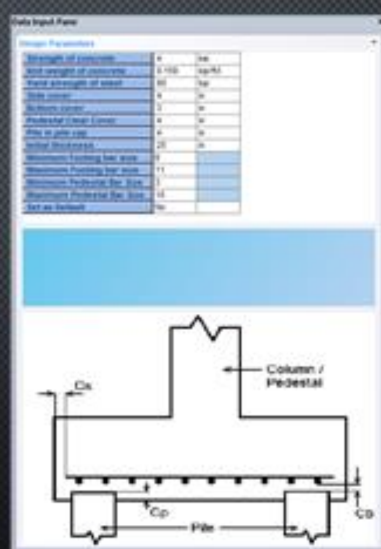
-PILE IN PILE CAP

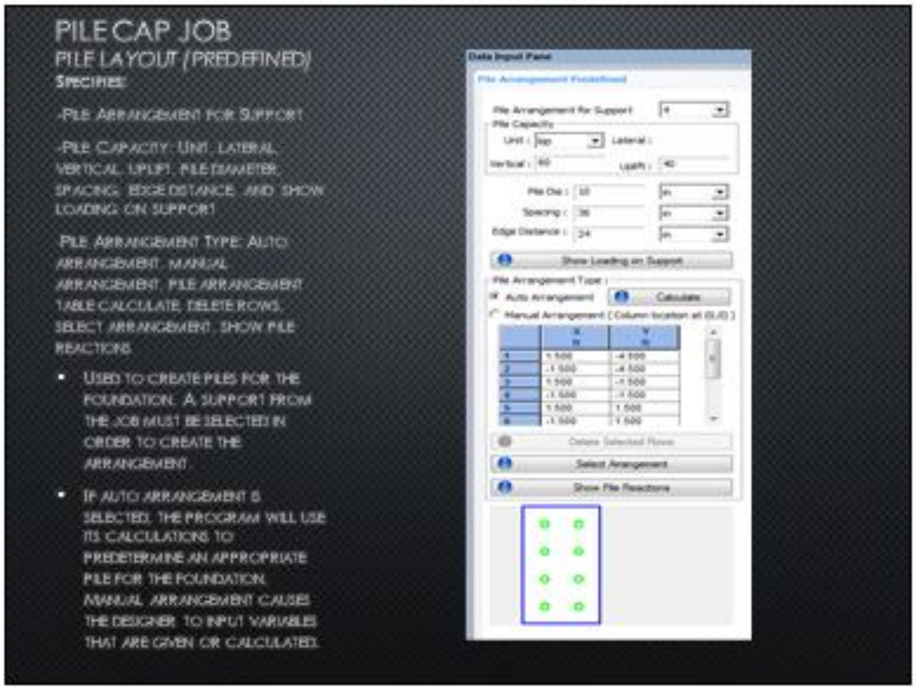
-INITIAL THICKNESS

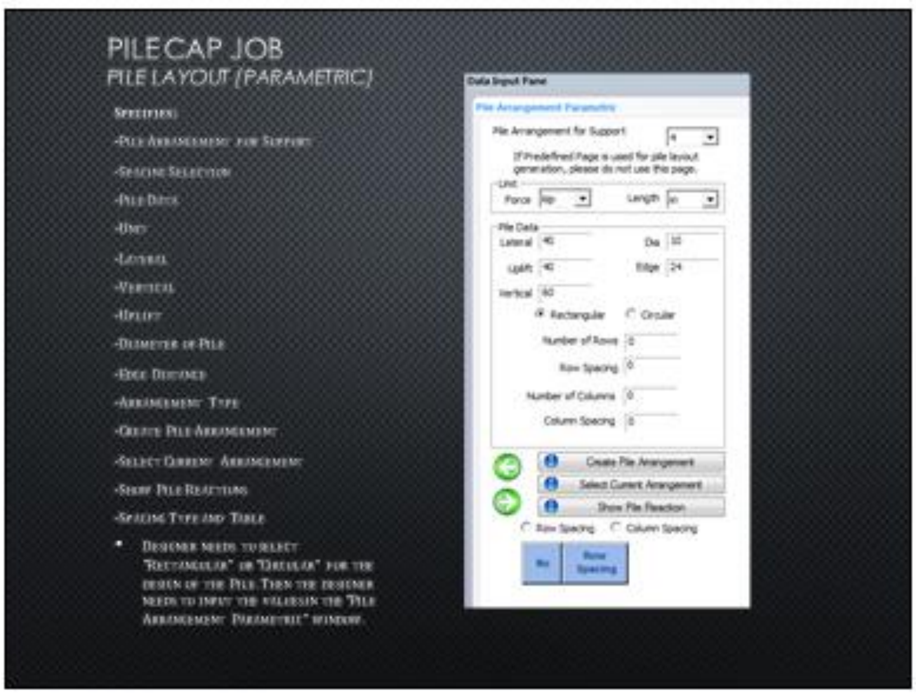
-MINIMUM/MAXIMUM BAR SIZE

-MINIMUM/MAXIMUM PEDESTAL BAR SIZE

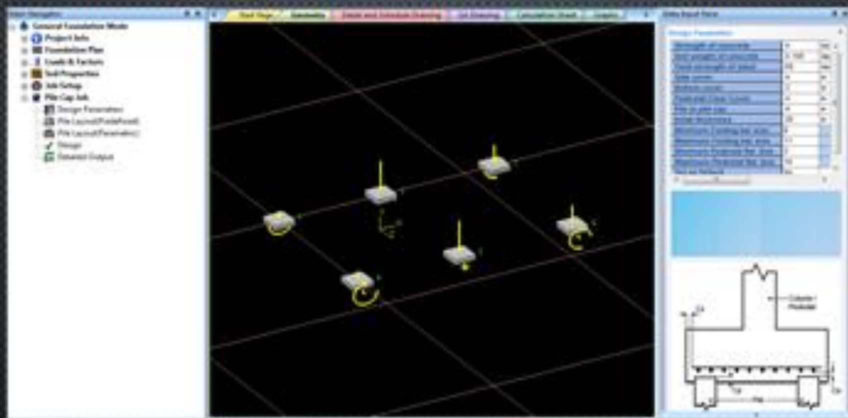
- ALLOWS FOR CONCRETE AND REINFORCEMENT PARAMETERS. THE DESIGNER NEEDS TO INPUT THE STRENGTH OF CONCRETE, YIELD STRENGTH OF THE STEEL, AND THE FOOTING BAR SIZE TO ACCURATELY CALCULATE THE PILE CAP.




PILE CAP JOB
PILE LAYOUT (PREDEFINED)
SPECIFIES:
-PILE ARRANGEMENT FOR SUPPORT
-PILE CAPACITY: UNIT, LATERAL, VERTICAL, UPLIFT, PILE DIAMETER, SPACING, EDGE DISTANCE, AND SHOW LOADING ON SUPPORT
-PILE ARRANGEMENT TYPE: AUTO ARRANGEMENT, MANUAL ARRANGEMENT, PILE ARRANGEMENT TABLE CALCULATE, DELETE ROWS, SELECT ARRANGEMENT, SHOW PILE REACTIONS
• USED TO CREATE PILES FOR THE FOUNDATION. A SUPPORT FROM THE JOB MUST BE SELECTED IN ORDER TO CREATE THE ARRANGEMENT.
• IF AUTO ARRANGEMENT IS SELECTED, THE PROGRAM WILL USE ITS CALCULATIONS TO PREDETERMINE AN APPROPRIATE PILE FOR THE FOUNDATION. MANUAL ARRANGEMENT CAUSES THE DESIGNER TO INPUT VARIABLES THAT ARE GIVEN OR CALCULATED.


PILE CAP JOB
PILE LAYOUT (PARAMETRIC)
SPECIFIES:
-PILE ARRANGEMENT FOR SUPPORT
-SPACING SELECTION
-PILE DATA
-UNIT
-LATERAL
-VERTICAL
-UPLIFT
-DIAMETER OF PILE
-EDGE DISTANCE
-ARRANGEMENT TYPE
-CREATE PILE ARRANGEMENT
-SELECT CURRENT ARRANGEMENT
-SHOW PILE REACTIONS
-SPACING TYPE AND TABLE
• DESIGNER NEEDS TO SELECT "RECTANGULAR" OR "CIRCULAR" FOR THE DESIGN OF THE PILE. THEN THE DESIGNER NEEDS TO INPUT THE VALUES IN THE "PILE ARRANGEMENT PARAMETRIC" WINDOW.

HOW TO DESIGN A PILE CAP FOUNDATION IN STAAD.*FOUNDATION*



- Once all isolated footing foundations have been created and all load cases are applied, the pile cap design can begin.
- See slides 19-21 to see the "Design Parameter" of the Pile Cap Job.

APPLYING THE PILE CAPS TO THE FOUNDATION

- After deciding whether to use the parametric or predefined pile layout, click 'Select Current Arrangement'. If the message popsup saying 'Pile Arrangement Successfully Assigned' this means that the program has checked pile capacity vs pile reaction.

-> Click 'OK'

<u>Under 'Main Navigator'</u>

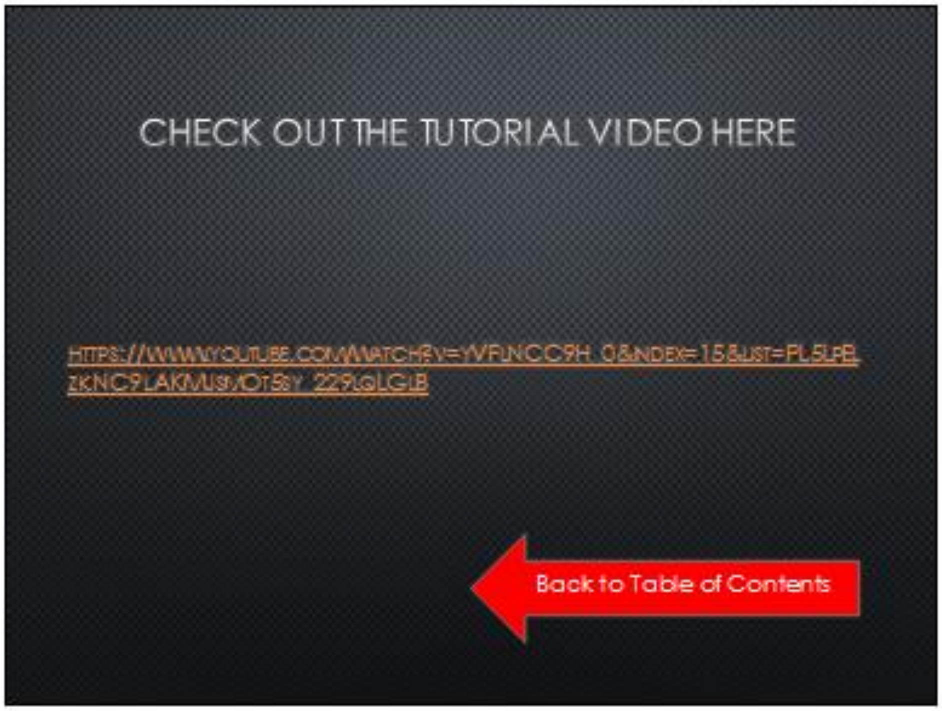
-> Click 'Design' to begin the analysis.

-> Click 'Yes'

- The calculation sheet provides the designer with steps for each pile cap that is being designed in the software's analysis.

<u>Under 'Detail and Schedule Drawing' Tab</u>

The analysis provides the designer with drawn plan and elevation views for the individual footings. It can also be exported to AutoCAD by using the 'Save Drawing As' feature.


CHECK OUT THE TUTORIAL VIDEO HERE
HTTPS://WWW.YOUTUBE.COM/WATCH?V=YVFLNCC9H_0&INDEX=15&LIST=PL5LPB-ZKNC9LAKMUSMOT5SY_229LQLGLB
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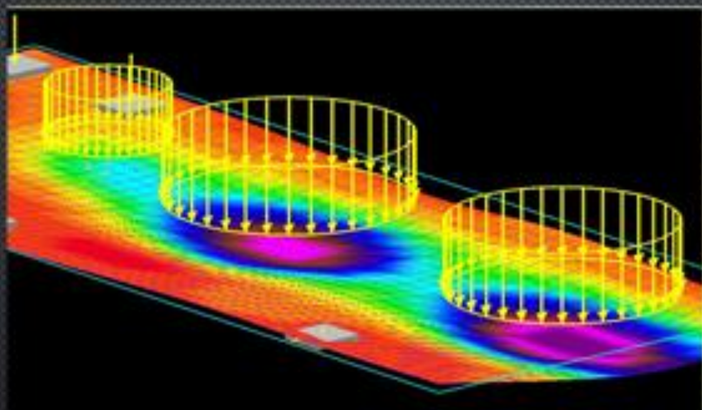
MAT FOUNDATION DESIGN

MAT FOUNDATION LOADS



- STAAD foundation will automatically distribute the load on the Mat foundation even though the loads are not associated with an object. Mat specific loads can be simulated as an external static load; heavy equipment like vehicles, water tanks, and storage units will all need a Mat Foundation underneath to prevent the ground deforming below its heavy load.
- Loads specific to Mat foundation are Point Load, Line Load, Quadrilateral Load and Circular Pressure Loads. These loads are independent of any object, whether a column position, beam, or mesh node. They are defined by their X, Y and Z coordinates. Below is a Mat Foundation that is undergoing Circular Pressure Loading. Here, one can see the deformity of the surface underneath each loading.
- Mat foundations are the most complicated foundation design. This is shown through the extensive menu under "Mat foundation Job" in the "Main Navigator".

MAT FOUNDATION JOB

DEFAULT PROPERTIES

Specifies:

-Slab Analysis Thickness

-Slab Design Thickness

-Subgrade Modulus

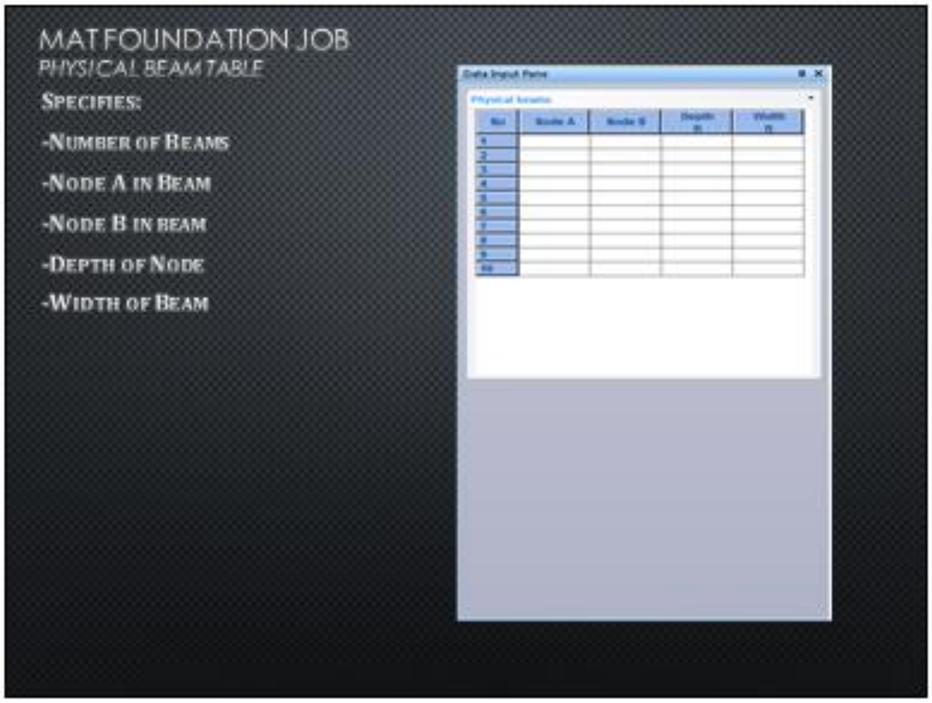
-Soil Property

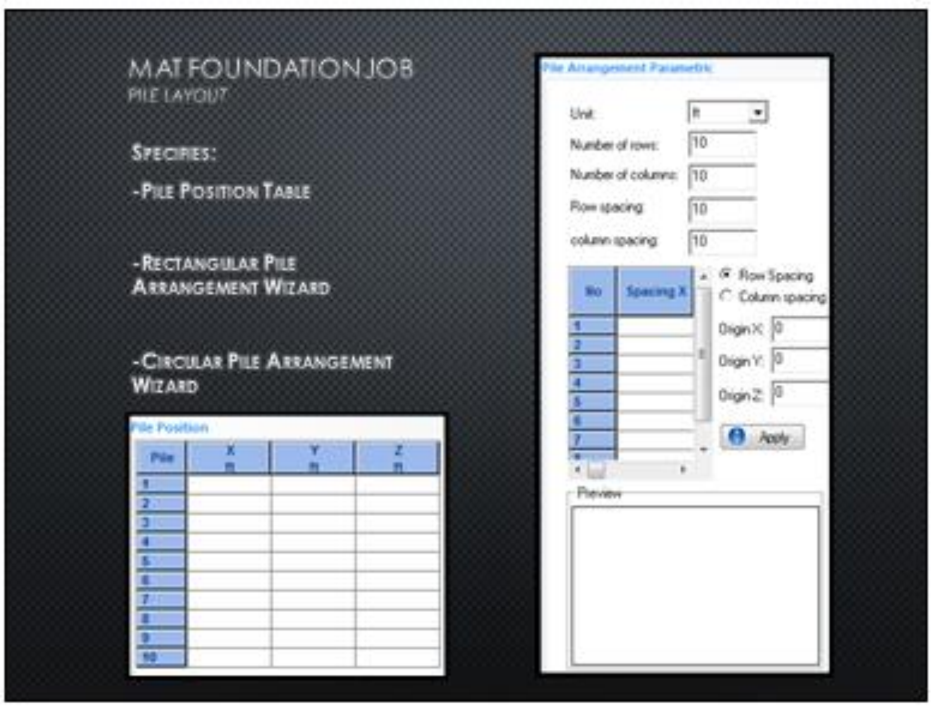
-Beam Sectional Property

-Pile Spring Values

Default properties

Slab analysis thickness	
Unit	in
Thickness	12.000000
Slab design thickness	
Unit	in
Thickness	12.000000
Subgrade modulus	
Unit	kip/in2/in
Subgrade modulus	0.040000
Soil Property	
Unit	lb/ft3
Soil Density	110.000000
Beam sectional property	
Unit	in
Depth	12.000000
Width	12.000000
Pile spring values	
Unit	kip/in
Spring along X (Kx)	30.000000
Spring along Y (Ky)	300.000000


MAT FOUNDATION JOB
PHYSICAL BEAM TABLE
SPECIFIES:
-NUMBER OF BEAMS
-NODE A IN BEAM
-NODE B IN BEAM
-DEPTH OF NODE
-WIDTH OF BEAM


MAT FOUNDATION JOB
PILE LAYOUT
SPECIFIES:
-PILE POSITION TABLE
-RECTANGULAR PILE ARRANGEMENT WIZARD
-CIRCULAR PILE ARRANGEMENT WIZARD
Pile Position
Pile
X ft
Y ft
Z ft
Pile Arrangement Parametric
Unit: ft
Number of rows: 10
Number of columns: 10
Row spacing 10
column spacing 10
No
Spacing X
Row Spacing
Column spacing
Origin X: 0
Origin Y: 0
Origin Z: 0
Apply
Preview

MAT FOUNDATION JOB
MESH GENERATION

Specifies:

- Add Meshing Regions

- Meshing Setup

MAT FOUNDATION JOB
ANALYSIS PROPERTIES

Specifies:

- Slab Thickness

- Soil Property

- Pile Spring

HOW TO CREATE A MAT FOUNDATION SLAB

Insert your Isolated Footings

Under "Main Navigator"

-> "Job Setup"

-> "Create a New Job"

Under "Data Input Pane"

Enter "Job Name" in the "Data Input Pane" Meant to differentiate between other footings and slabs.

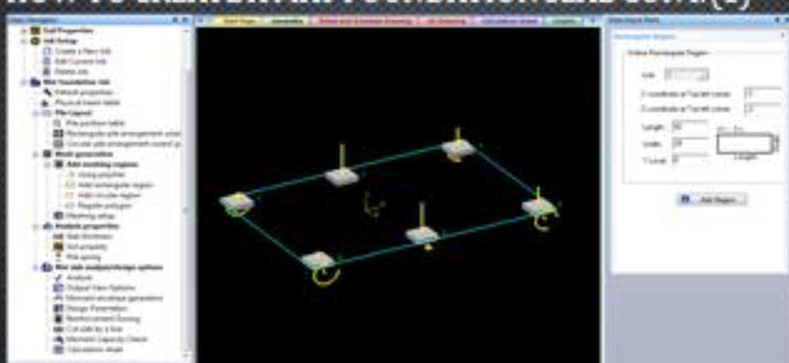
-> Change "Job Type" to "Mat" from the drop down menu.

-> Choose what supports you want to include in the Mat Foundation (Assign all in this case).

-> Select the Service and Ultimate Load Cases. These are typically just the Load Combinations for design purposes.

-> Click "Create Job" to begin the design of the mat foundation.

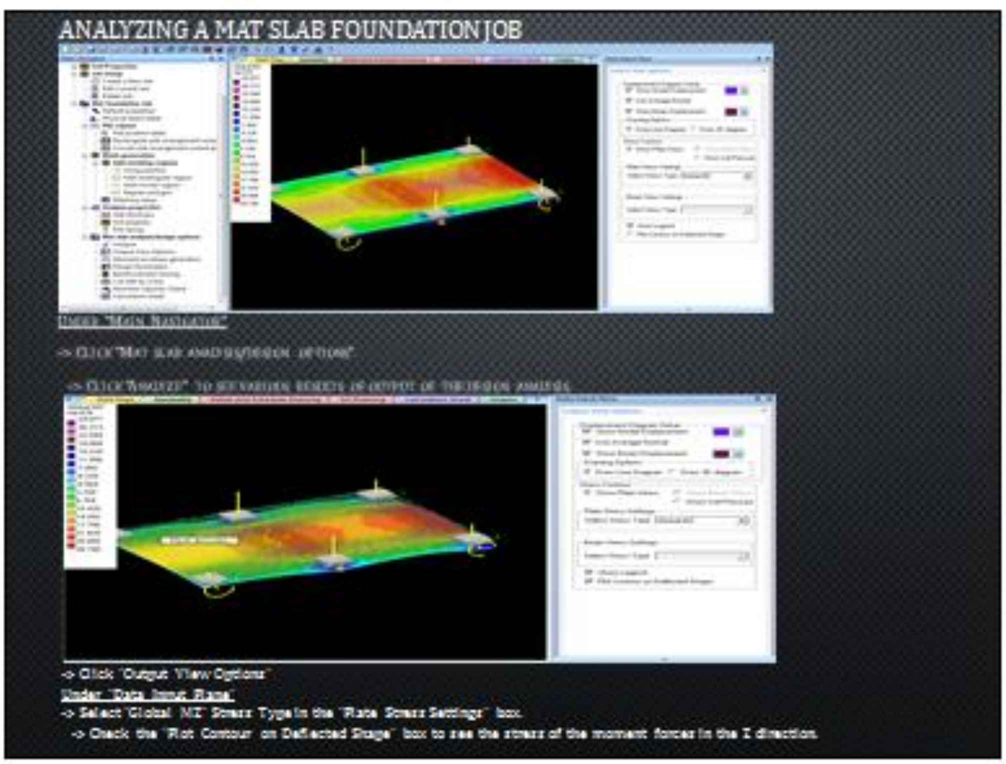
HOW TO CREATE A MAT FOUNDATION SLAB CONT. (1)

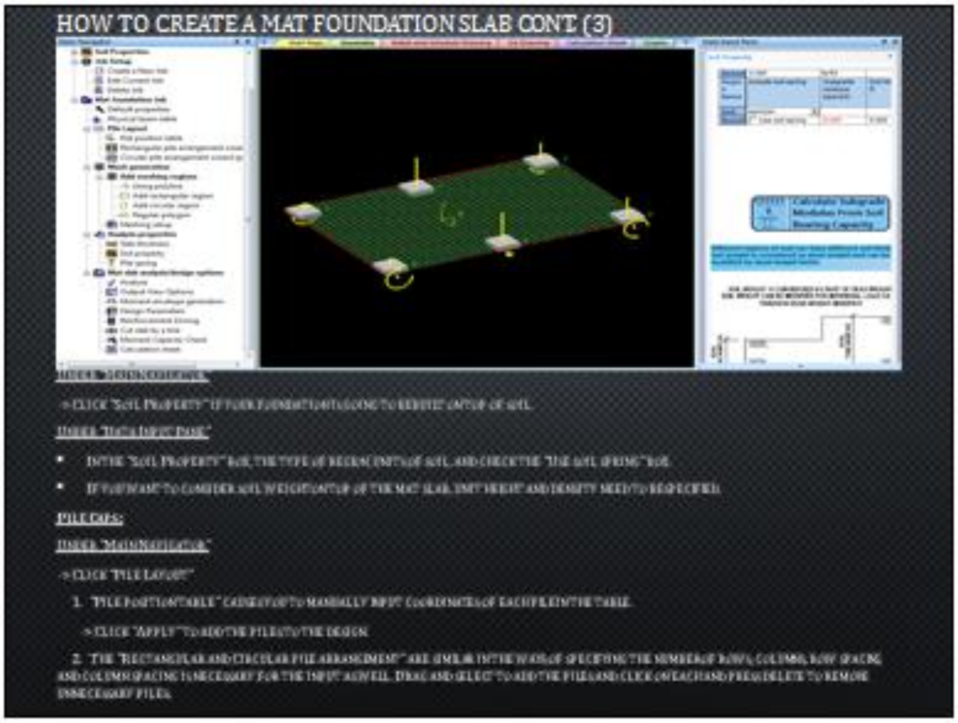


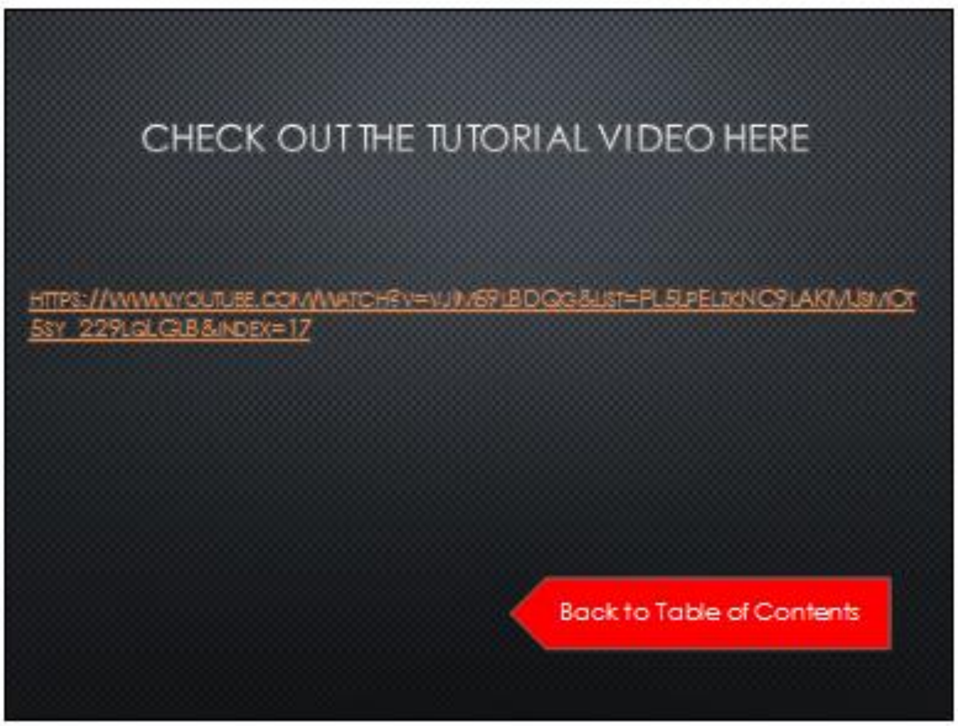
Under "Main Navigator"

Under "Data Input Pane"


HOW TO CREATE A MAT FOUNDATION SLAB CONT (2)


ANALYZING A MAT SLAB FOUNDATION JOB
-> Click "Output View Options"
Under "Data Input Plane"
-> Select "Global MZ" Stress Type in the "Plate Stress Settings" box.
-> Check the "Plot Contour on Deflected Shape" box to see the stress of the moment forces in the Z direction.


HOW TO CREATE A MAT FOUNDATION SLAB CONT. (3)
PILE CAPS:
UNDER "MAIN NAVIGATOR"
-> CLICK "PILE LAYOUT"
-> CLICK "APPLY" TO ADD THE PILES TO THE DESIGN.


CHECK OUT THE TUTORIAL VIDEO HERE
HTTPS://WWW.YOUTUBE.COM/WATCH?V=VJIM69LBDQG&LIST=PL5LPELZKNC9LAKMUSMCT5SY_229LGLGLB&INDEX=17
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LIMITATIONS OF STAAD.*FOUNDATION* SOFTWARE

- Optimization
  - Choosing "set as default = no"
- Choosing minimum thickness
- Inputting realistic constraints
- Only apply factored load cases

Limitation and Optimization of the Footing Geometry

<u>Limitation</u>

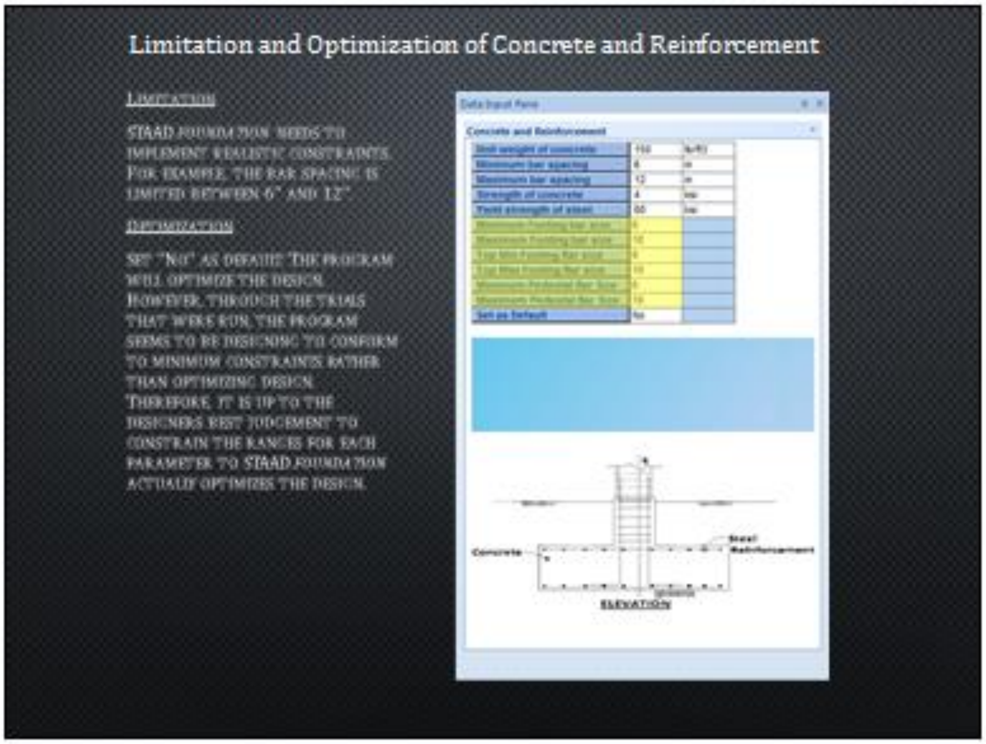
Minimum thickness seems to automatically set footing thickness to an equivalent of the minimum.

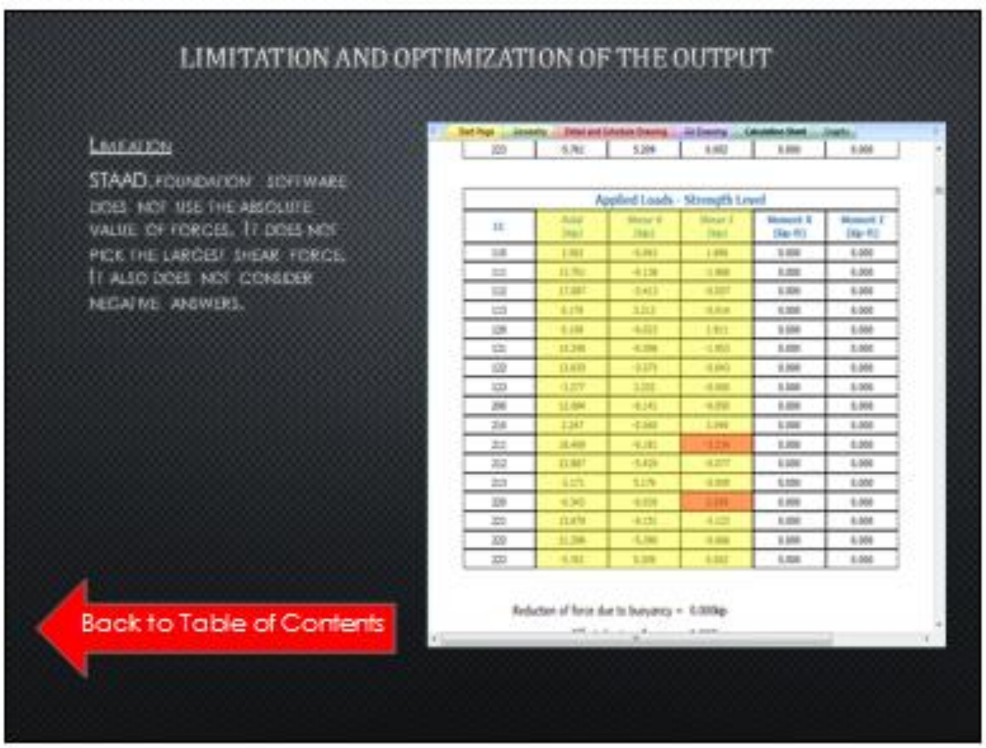
<u>Optimization</u>

There is no optimization as it seems to design to accommodate minimums.

<u>Set as Default</u>

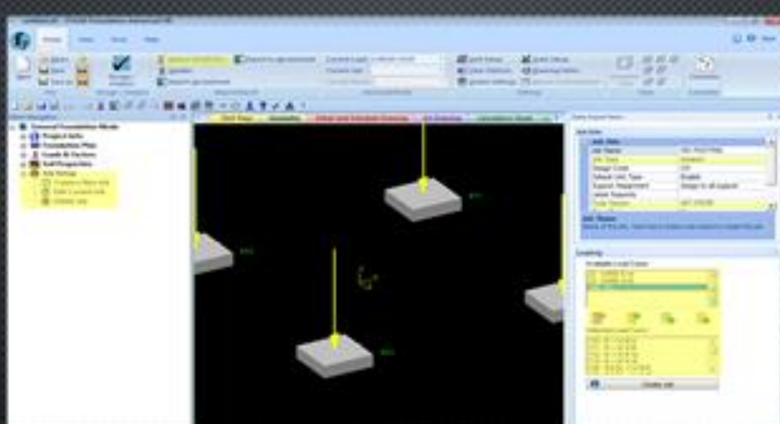
Set "No" as default. This allows for optimization of the footing. When yes is chosen, footing size will increase in direction where loads are applied. This is because STAAD.*foundation* is still choosing the min thickness value.


Limitation and Optimization of Concrete and Reinforcement
Limitation
STAAD.foundation needs to implement realistic constraints. For example, the bar spacing is limited between 6" and 12".
Optimization
Set "No" as default. The program will optimize the design. However, through the trials that were run, the program seems to be designing to confirm to minimum constraints rather than optimizing design. Therefore, it is up to the designers best judgement to constrain the ranges for each parameter to STAAD.foundation actually optimizes the design.
Concrete and Reinforcement
Concrete
Steel Reinforcement
ELEVATION


LIMITATION AND OPTIMIZATION OF THE OUTPUT
Limitation
STAAD.foundation software does not use the absolute value of forces. It does not pick the largest shear force. It also does not consider negative answers.
Applied Loads - Strength Level
Back to Table of Contents

Importing and Exporting with STAAD.*foundation*

STAAD.*PRO* -> STAAD.*FOUNDATION*



- When importing load cases from STAAD.*pro*, STAAD.*foundation* forces the designer to change the description of every load and load case one by one. If the design is imported and not factored, STAAD.*foundation* gives the designer the option to factor it.
- Before any structure from STAAD.*pro* can be imported into STAAD.*foundation*, the analysis needs to be completed. STAAD.*foundation* uses the data of the support reactions from the structural analysis in STAAD.*pro*. Therefore, if the reactions are not calculated, the import will fail.

STAAD.*FOUNDATION* -> MICROSOFT EXCEL

- When exporting the "Calculation Sheet" to Excel using "Detail Output", the full calculation sheet is not outputted into Excel. It is also formatted differently. Only sliding, overturning, shear, punching, etc. checks are shown as tables in Excel. However, you can copy the data and paste it into Excel and all of the data will be present. The column widths in Excel will need to be adjusted to see all calculations.
- Do not simply copy and paste the output into an Excel sheet and pass it on to a client. Do your calculations as well to check for any discrepancies!

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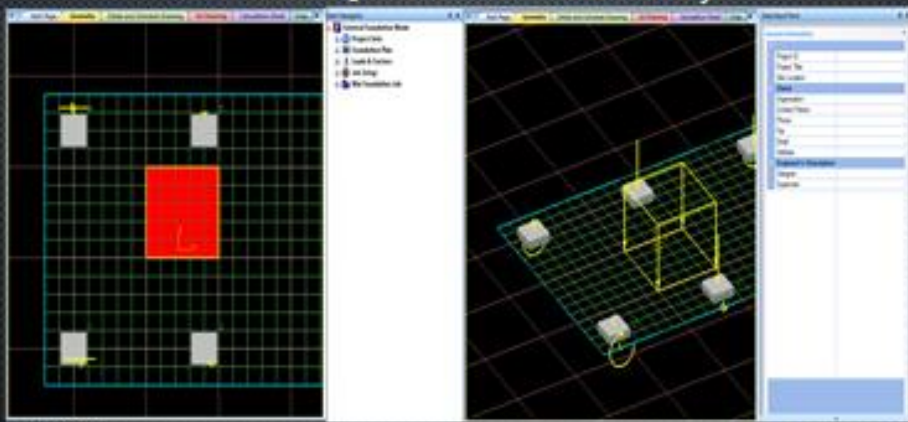
HOW TO STREAMLINE PROGRAM USE

Helpful tips and tricks

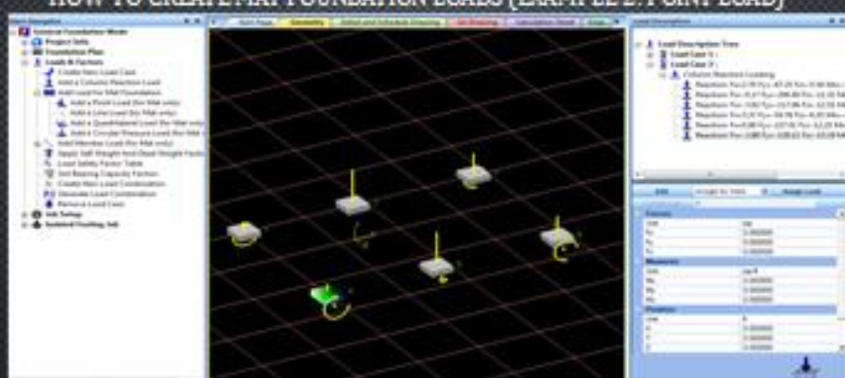
HOW TO CREATE MAT FOUNDATION LOADS (EXAMPLE 1: GENERATE QUAD OR CIRCULAR LOAD)



Click "Tools"
→ Menu
→ Select "Circular Pressure" or "Quad Pressure" Depending on desired loading.

- Loads need to be added on Grid Nodes (Defined by the red lines, X, Y, and Z). The coordinates of the loads are assigned according to the designated nodes.
- When creating these loads both points where you initially click and let go of the load you are creating needs to be on a grid node. You may then enter more detailed information in the wizard menu that pops up.
- Once you select "ok" in the wizard menu, you will be able to see the (in this case) Rectangular Loading in the Geometric View Window

HOW TO CREATE MAT FOUNDATION LOADS (EXAMPLE 2: POINT LOAD)



- In this example, load positions are given according to the specified coordinates. Here you can see the moments of the added loads at 4 & 6.

<u>Under 'Main Navigator'</u>

Open 'Loads & Factors' Drop Menu

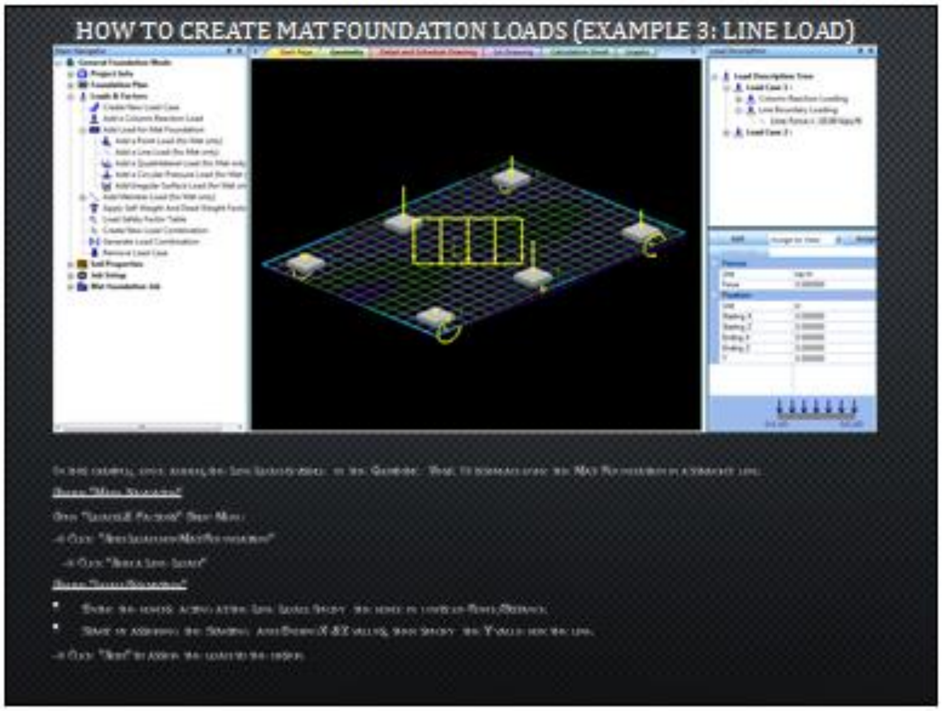
-> Click 'Add Load for Mat Foundation'

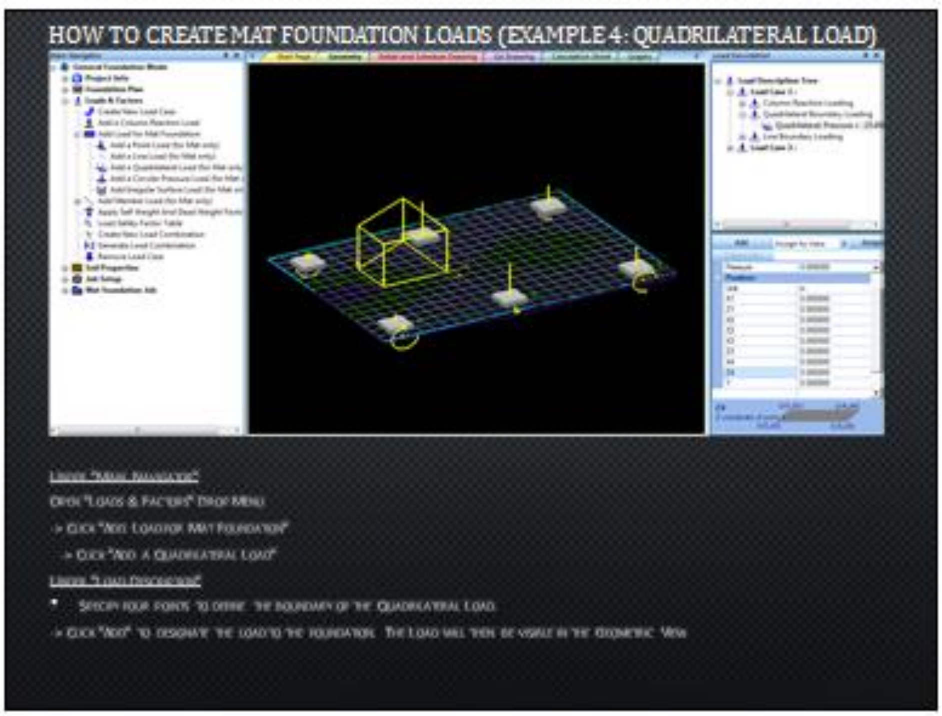
-> Click 'Add a Point Load'

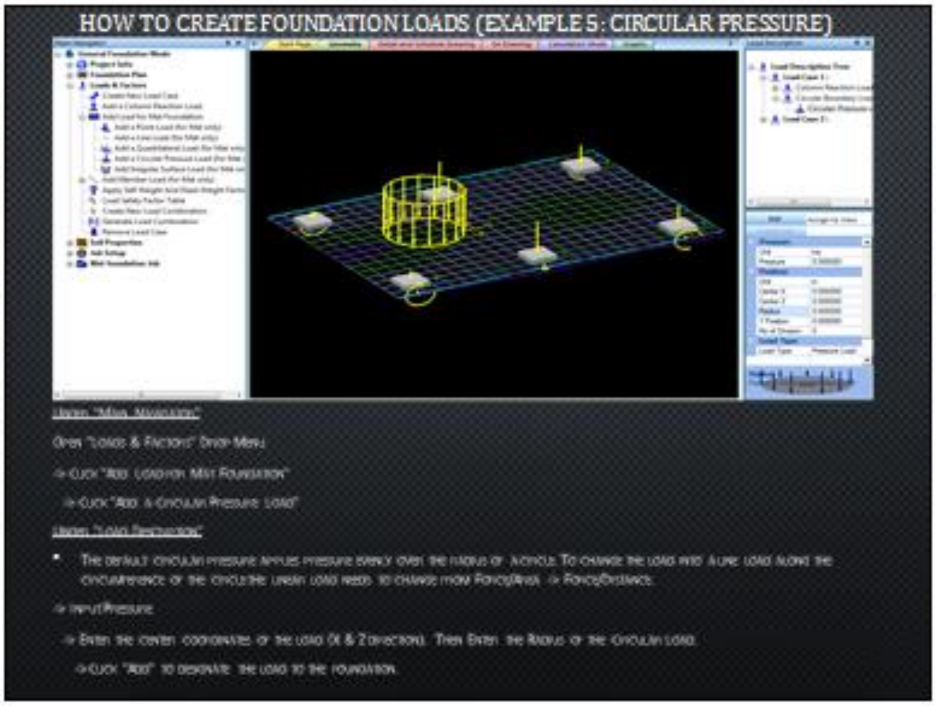
<u>Under 'Load Description'</u>

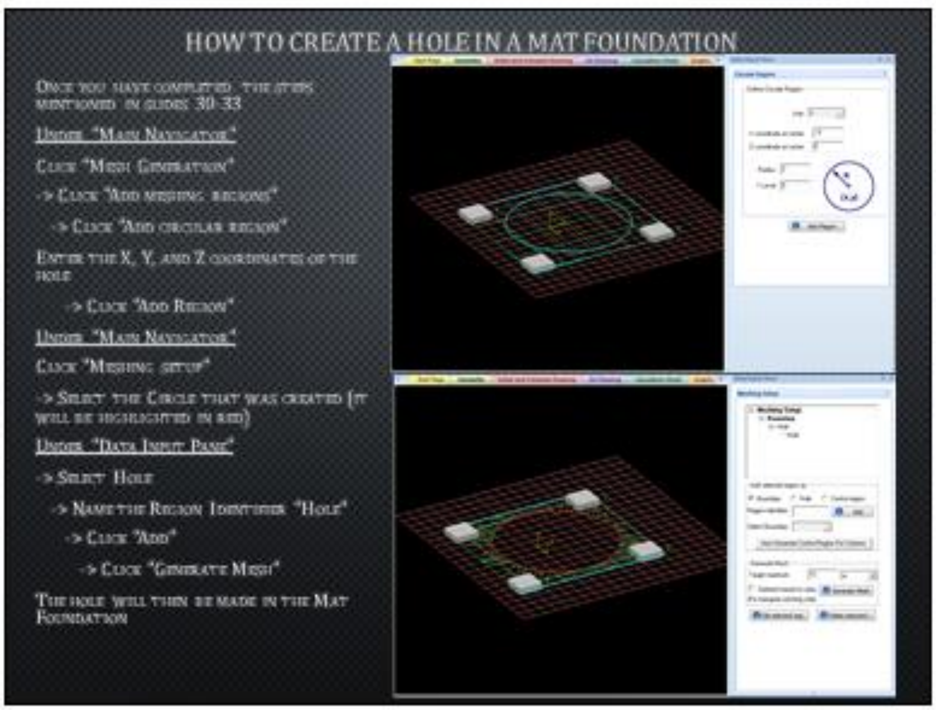
Enter the forces acting at the Point Load and any moments that are occurring. You can add the Point Load in relation to the supports in the 'Position' part of the 'Load Description' Menu.

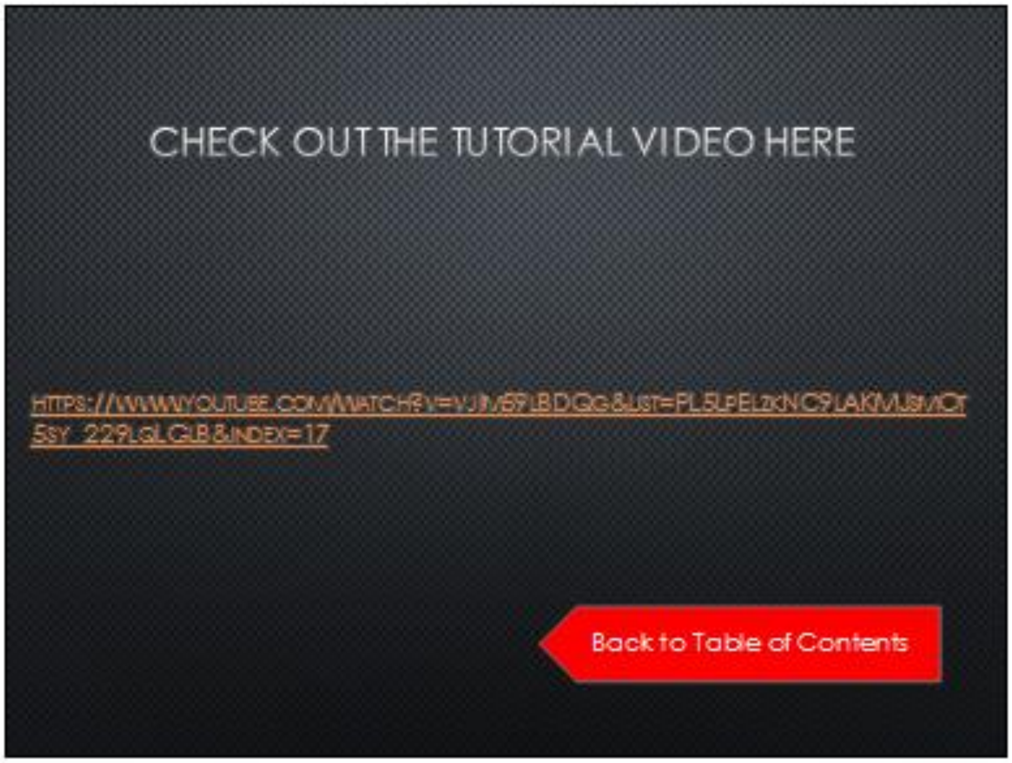
-> Click 'Add' to designate the Point Load into the design.


HOW TO CREATE MAT FOUNDATION LOADS (EXAMPLE 3: LINE LOAD)


HOW TO CREATE MAT FOUNDATION LOADS (EXAMPLE 4: QUADRILATERAL LOAD)
Under "Main Navigator"
Open "Loads & Factors" Drop Menu
-> Click "Add Load for Mat Foundation"
-> Click "Add a Quadrilateral Load"
Under "Load Description"
Specify four points to define the boundary of the Quadrilateral Load
-> Click "Add" to designate the load to the foundation. The Load will then be visible in the Geometric View


HOW TO CREATE FOUNDATION LOADS (EXAMPLE 5: CIRCULAR PRESSURE)
Under "Main Navigator"
Open "Loads & Factors" Drop Menu
-> Click "Add Load for Mat Foundation"
-> Click "Add a Circular Pressure Load"
Under "Load Description"
The default circular pressure applies pressure evenly over the radius of a circle. To change the load into a line load along the circumference of the circle the unit load needs to change from Force/Area -> Force/Distance.
-> Input Pressure
-> Enter the center coordinates of the load (X & Z directions). Then Enter the Radius of the circular load.
-> Click "Add" to designate the load to the foundation.


HOW TO CREATE A HOLE IN A MAT FOUNDATION
Once you have completed the steps mentioned in slides 30-33
Under "Main Navigator"
Click "Mesh Generation"
-> Click "Add meshing regions"
-> Click "Add circular region"
Enter the X, Y, and Z coordinates of the hole
-> Click "Add Region"
Under "Main Navigator"
Click "Meshing setup"
-> Select the Circle that was created (it will be highlighted in red)
Under "Data Input Pane"
-> Select Hole
-> Name the Region Identifier "Hole"
-> Click "Add"
-> Click "Generate Mesh"
The hole will then be made in the Mat Foundation


CHECK OUT THE TUTORIAL VIDEO HERE
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Appendix Q: Final Project Proposal

Worcester Polytechnic Institute
Department of Civil and Environmental Engineering

Stantec Structural MQP

Stantec Project Center
Boston, MA

Project Proposal
Date: January 20, 2015

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Contents

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Authorship

The entirety of the Stantec Structural MQP team contributed equally to the completion of this proposal. All material contained within this document is the original work of the Stantec Structural MQP team, unless otherwise stated.

Identify Project Need – Margaret
Stantec Consulting - Dominick
Foundation Designs:
- Introduction - Paul
- Isolated Spread Footings – Paul
- Piles and Pile Caps - Dominick
- Mat Foundations: Dylan

STAAD.*pro* – Dylan
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Capstone Design Statement – Margaret
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- Objective 2: Margaret, Dylan, Paul, Dominick
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- Gantt chart: Margaret, Dominick

Appendix:
- Appendix A: Dylan
- Appendix B
  - Isolated Spread Footings: Paul
  - Piles and Pile Cap: Dominick
  - Mat Foundation: Dylan

Introduction

By verifying the applicability and reliability of software used within a company, it is possible to gain financial benefits, facilitate communication across different departments, and ensure the effective use of company resources. It is important to determine whether software applications utilized by company employees are encouraging streamlined workflow by functioning to their intended standard. Letting discontinuities or inaccuracies creep into the intricate framework of structural design and construction projects can lead to wasted resources and delayed schedules. Having unreliable software applications can increase the frequency of reworks, the possibility of safety hazards, and the amount of wasted materials.

Project Need

The Power Group at Stantec has previously worked with several different foundation software programs. The company is interested in the investigation of STAAD.*foundation* in order to determine range of applicability and reliability within the software package. By engaging in a parametric study of STAAD.*foundation,* it will be possible to determine the reliability of the software and identify any potential limitations. This involves the use of STAAD.*pro* in order to construct a structural steel model and perform the necessary structural analysis. Once the reaction forces from STAAD.*pro* have been computed, they can be applied to design various foundation types. In order to quantify the effectiveness and reliability of STAAD.*foundation*, foundation types will be designed through hand calculations and then verified through the STAAD.*foundation* program.

Design Approach

To verify the applicability and reliability of STAAD.*foundation*, reaction forces from a STAAD.*pro* structural frame model will be obtained. A preliminary foundation type will then be constructed in STAAD.*foundation* to begin the design process. Reaction forces and loadings obtained from the structural analysis in STAAD.*pro* will then be input into STAAD.*foundation* and the program will design the foundation to meet the specifications of the situation. The team will also design the selected foundation types by hand to verify the results from STAAD.*foundation*. This comparison will allow for the analysis of software and design limitations inherent in STAAD.*foundation*. Once the verifications have been documented, a User Tips Manual will be created for use by Stantec.

Background

Stantec Consulting

History

Stantec Consulting was founded in 1954 in Edmonton, Canada by Dr. Don Stanley as a civil and environmental engineering firm working primarily on water and sewage projects in rural Canadian towns. Within the first decade, the company grew to a size of thirty employees and was awarded its first major structural project: the redesign of the Peace River Bridge on the Alaska Highway. Today Stantec is one of the largest design firms in the world, with over 14,000 employees in over 230 different offices specializing in architecture, landscape architecture, and engineering.

Company Structure

Stantec is divided into several project areas within the fields of architecture, civil engineering and landscape architecture, mechanical engineering, and chemical engineering. Within the framework of Stantec's corporate Structure, these sub areas are known as *Business Centers*, or "BC's." These BC's often have sub groups within them, which collaborate on projects related to their fields, allowing Stantec to better allocate resources, and better manage the flow of money from clients to sub-contractors.

Power Engineering Group at Stantec

The power group at Stantec in Boston, Massachusetts was added to their firm in early 2014[1]. The group came to Stantec after many years with Shaw Power and Stone & Webster. The power group designs and engineers projects involving heat, power, turbines, and air quality control. The group looks at traditional resources such as gas and coal, as well as renewable energy resources including wind and solar power. The power projects include the repurposing of old power plants to be more economically efficient. The power group is growing on both the East and West Coast of the United States, allowing Stantec to access a broader clientele.

Foundation Designs

Foundations are the base and support in the structural system that transmit the superstructure's loads directly to the earth. All civil engineering structures require foundations to keep the structure from leaning or buckling. Buildings bestow their weight and loadings onto their foundations; therefore, the footing needs to be designed to withstand the weight of the building. The foundation design process cannot begin until the loads have been calculated. There are several different types of design loads including: normal loads, shear loads, moment loads, and torsion loads. Where weather is applicable, the bottom of the foundation must be constructed below the frost line to prevent cracking from freeze-thaw cycles.

[1] http://www.stantec.com/about-us/news/2014/stanatec-adds-power-engineering-team-in-boston-massachusetts.html

Spread Footings

Spread footings are normally used to support the structural system of small to medium structures with moderate to good soil conditions. They can be used in high-rise buildings where the soil conditions are exceptional and can bear the load. Individual columns of the building are constructed on top of the spread footing because of its ability to bear extremely heavy loading. Many low-rise residential buildings consist of spread footings that support the load over a larger area. The foundation of residential homes, for example, is often used as a basement that supports the infrastructure of the house above it. Spread footings are the most common type of foundation due to its low cost and quick construction. They are built in different shapes and sized to accommodate each project's scenario. The shape of the footing is generally a rectangle and larger in lateral dimensions than the load it is supporting.

Determination of soil pressures, shear forces, and bending moments then need to be looked at to determine design capability[2]. The design and layout of the footing is controlled by several factors: the load of the structure, penetration of soft layers near the surface, and penetration of layers near the surface due to the effects freezing and thawing. These foundations are more commonly found in residential construction buildings that have a basement. These footings are not sufficient for high-rise buildings.

Piles and Pile Caps

Piles

The use of piles is one of the oldest forms of foundations, dating back at least as far the Roman Empire. Piles are designed to transfer applied loads of the structure above through the upper portion of the soil and deep into the soil below. Typically, piles are used where the soil has a low bearing capacity in the upper strata, but a significantly stronger bearing capacity at greater depths. Piles can provide an economically viable alternative to other types of foundations in soils with this type of geologic profile as excavation to the firm strata can prove to be both expensive and difficult.[3] A typical pile cap design can be seen in **Error! Reference source not found.**.

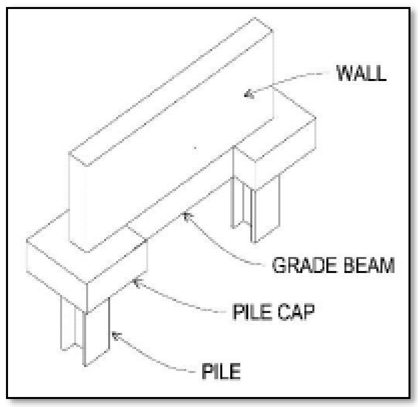

FIGURE 1: A TYPICAL PILE CAP DESIGN

There are two types of piles, end bearing piles and skin friction piles. An end bearing pile is driven through the weak upper strata of the soil down to bedrock, densely packed gravel, or another

[2] Tabsh, Sami W and Abdul Raouf AJ-Shawa. "Effect of Spread Footing Flexibility on Structural Response." *Structural Design and Construction* 2005, 10 ed.: 109-114. Web.
[3] Curtin, W. G., Shaw, Gerry, and Parkinson, Gary. Structural Foundation Designers' Manual. Chichester, GBR: John Wiley & Sons, 2008. ProQuest ebrary. Web. 15 December 2014.

suitably strong material, in order to achieve its load bearing capacity. A skin friction pile supports the load above by using the friction between the buried section of the pile and the surrounding soil to keep the foundation in place and provide an adequate factor of safety for the load of the structure. Often foundations will use both of these types of piles to ensure support for the structure above.

In many instances, it is impossible to sit a structure directly onto the piles, which support it. This can be for several reasons, but occurs most often because piles are rarely in the exact position defined on in the design drawings. During the process of driving the piles into the ground, they can wander from their intended position or angle; although this is acceptable, the piles must not be off their horizontal position by more than ±75 mm. When a pile is not placed accurately, the columns supported by the pile will not only apply direct stresses to the pile, but will also exert a bending forcing on the pile. Pile caps are also used when it is necessary to distribute the force from a heavily loaded column over an entire pile group.[4]

Pile Caps

A pile cap is the structural element of a foundation that connects the column with multiple deep foundations. When using pile foundations, the piles are almost always placed in groups so that multiple piles will support a single column. In order to distribute the load from the column to all of the piles, a pile cap is used. Normally these are constructed of reinforced concrete, but a pile cap can also be a large slab of rock or a treated timber mat.

To account for the potential wandering of the piles or other deep foundation below, the pile cap is designed to protrude between 100 and 150 millimeters away from the outer face of the piles, although the centroid of the pile cap should remain above the centroid of the pile. The design of a pile cap must satisfy punching shear near the individual piles and shafts[5] and therefore the depth of the pile cap must be adequate to account for this high shear force.[6] This effective depth must be at least 12 inches with a minimum thickness of 18 inches.[7]

Mat Foundations

Mat foundations, also known as raft foundations, are a type of foundation that are considered when using a spread foundation would not be economical or reasonable. Mats are considerably larger than spread footings and generally encompass the entire footprint of a building. This type of foundation can be considered economical for a variety of reasons, mostly depending on size and soil condition. If a spread footing is being considered and covers more than a third of the footprint, a mat may be considered as a more appropriate alternative. Additionally, a mat can be used when dealing with erratic soil conditions because the mechanics of the foundation will successfully

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[4] Curtin, W. G., Shaw, Gerry, and Parkinson, Gary. Structural Foundation Designers' Manual. Chichester, GBR: John Wiley & Sons, 2008. ProQuest ebrary. Web. 15 December 2014.
[5] *ACI 15.5*
[6] Curtin, W. G., Shaw, Gerry, and Parkinson, Gary. Structural Foundation Designers' Manual. Chichester, GBR: John Wiley & Sons, 2008. ProQuest ebrary. Web. 15 December 2014.
[7] *ACI 15.8.1*

bridge irregularities and differential settlements throughout a site. Location of the water table is another consideration for using a mat foundation. If the foundation is located below the depth of the water table, mat foundations are beneficial due to monolithic properties and ease of waterproofing. Depending on design, differential structural loads can cause irregular loading on the footing, in which case, a mat foundation would be beneficial because it is able to compensate for irregular loading. Although mats are able to withstand irregular loads due to both superstructure bearing and soil conditions, piles or shafts may be necessary in order to fully support the mat foundation.[8]

When considering the design analysis of a mat foundation, it can be considered as rigid or non-rigid. The traditional method to evaluate the design of this type of foundation was to consider it a rigid structure. Using this approach, a high width-to-thickness ratio is generally observed. Furthermore, using this type of analysis yields less reliable estimates of shear, deformations and moments because there is no consideration to redistribution of the bearing pressure throughout the mat. [9]

The more developed and accurate way to analyze the design of a mat is using the non-rigid method. Using this analysis, the interaction between the mat and the underlying soil is assumed to be a "bed of springs." With this assumption, deformations can be calculated locally throughout the mat, rather than calculating one deformation for the entire foundation, which is unreasonable under the conditions that a mat foundation is selected. By considering both flexural deflections and corresponding soil bearing pressure redistribution, non-rigid analysis yields results that are more appropriate.[10]

STAAD*.pro*

STAAD*.pro* is a software application that assists professional engineers in the design of steel, concrete, timber, aluminum, and cold form steel structures with a user-friendly interface, optimized design and analysis capabilities. It is a product of Bentley Systems, a software company that specializes in, "comprehensive software solutions for the infrastructure lifecycle".[11] The software allows the user to create three-dimensional models of nearly any type of structure, featuring flexible modeling supporting over 70 international codes and over 20 U.S. codes. Three-dimensional model, as opposed to two-dimensional drawings, allow for heightened awareness of interferences within the design. By combining mechanical, electrical, and plumbing systems within a single model, the software allows for integration of structural elements. Additionally, analysis and design features, such as nuclear certification, are included within the software package. The interoperability of the software package allows for data exchange across several different programs. A notable component of STAAD software packages is the ability to link

[8] Coduto, D.P. *Foundation Design: Principles and Pracitices*. Upper Saddle River, New Jersey: Prentice-Hall, 2001. Print.
[9] Ibid.
[10] Ibid.
[11] *Bentley: Sustaining Infrastructure*. 2014. Web. <http://www.bentley.com/en-US/>.

models to external project databases. Several different aspects of the model, such as mechanical and plumbing components, can be imported from third party resources such as AutoCAD. Along with structural analysis and interference reports, STAAD is able to produce virtual walkthroughs of the models.[12]

Case Study in STAAD.*pro*

An example of a project that benefitted from the use of STAAD.*pro* was the design and construction of the Evergreen Community Power Plant in Reading, Pennsylvania. The project was contracted by ESI Inc. of Tennessee, and the engineers on the project had no previous experience using STAAD or Bentley software products. The difficulties associated with this project were attributed to size constraints and complexity of the project. Additionally, the customer was adamant on the use of three-dimensional modeling to ensure that proper operation and size could be achieved within the provided space.

The project team for the power plant consisted of 19 engineers, including structural, mechanical, electrical, and instrumentation engineers who were able to input their components of the design into the model. The engineers were able to review the model while 3D specialists simultaneously performed detailed modeling for the plant. The project was streamlined by utilizing STAAD's integration tools. Two and three-dimensional models from the vendors, which were created in third party applications, could be imported into the STAAD model. Interference reports were also generated using this model, opposed to two-dimensional interpretation. These reports identified major cost saving interferences between different engineering components before construction. Overall, the implementation and use of STAAD saved ESI Inc. about two months on the design schedule.[13]

STAAD.*foundation*

STAAD.*foundation* is a used to design and model various types of complex and simple foundation systems. It is also a product of Bentley Systems. STAAD.*foundation* is designed to handle common foundations, such as isolated spread footings and pile caps. It can also tackle foundation designs for larger and more complex projects. According to Bentley Systems, "efficient design and documentation is realized through its plant specific design tools, multiple design codes with U.S. and metric bar sizes, design optimization and automatic drawing generation".[14] Using STAAD.*foundation* can potentially benefit users of STAAD.*pro* due to the streamlined workflow between the two programs. STAAD.*foundation* can efficiently input geometry, loads and reactions from STAAD.*pro* and then effectively produce a foundation design.[15] While STAAD.*foundation* can be used cohesively with STAAD.*pro*, it can also be utilized as a standalone program.

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[12] Bentley. STAAD.*pro*. n.d. Web. 10 December 2014. <http://www.bentley.com/en-US/Products/STAAD.pro/>.

[13] Bentley.Company. *Bentley Helps Jump-Start 3K Design Services for Green Power Plant*. June 2009. <http://ftp2.bentley.com/dist/collateral/docs/case_studies/CS_ESI_Green-Power-Plant.pdf>.

[14] Ibid.

[15] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 1-2

STAAD.*foundation* Program Theory

STAAD.*foundation* allows the user the ability to model complex or simple footings these include; isolated spread footings, pile caps, strip footings, mat foundations, and octagonal footings.[16] The program designs these various foundation types in accordance with ACI 318-05 code. [17]

Foundation Design in STAAD.*foundation*

Isolated Spread Footings and Strip Footings

In the design of isolated spread footings and strip footings, STAAD.*foundation* uses parameters concerning soil bearing capacity, shear and flexural strength of footing, compressive and flexural strength of pedestal.[18] Depending on the bearing resistance of the soil and structure, loading a footing plan is determined. The footing thickness is determined by considering shear and bending capacity. The shear consideration includes punching shear, and one-way shear. [19]

Piles and Pile Caps

According to the STAAD.*foundation* – *User's Manual* the program outputs for pile cap design include; required quantity, layout and geometry of the pile cap based on shear and bending strength requirements at critical sections of the footing.[20] In order to determine the proper pile arrangement and design the program user can input bearing, uplift and later capacity, and desired diameter, spacing and edge distance. In the design of pile caps, STAAD.*foundation* considers the required shear and bending components at applicable critical sections. [21]

Mat Foundation

STAAD.*foundation* relies on finite element method (FEM) and slab-on-elastic-subgrade principles to analyze and design mat foundations.[22] When applying a load to a plate or mat foundation, there is more than one direction for the load to transverse the plate. Using the finite element method, a plate can be subdivided into smaller sections in order to obtain deflection information.[23]

Case Study in STAAD.*foundation*

Apollo Tyres Limited: STAAD.*foundation* Provides Comprehensive Foundation Design

Apollo Tyres Limited in India's largest automotive tire manufacturer, and is currently in the process of building a new plant on a 126-acre plot.[24] The project will include 30 buildings and a build area of approximately 167,226 square meters. The project included some difficult

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[16] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 2-19
[17] Ibid.
[18] Ibid.
[19] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 2-4-2-23.
[20] Ibid.
[21] Ibid.
[22] Ibid.
[23] Ibid.
[24] *Apollo Tyres Limited*. 2010. <http://ftp2.bentley.com/dist/collateral/docs/case_studies/CS_Apollo-Tyres.pdf>.

challenges, specifically the large size of the entire structure and need to accommodate heavy loads. The consulting and engineering firm of Aswathanarayana and Eswara was awarded the contract for the project and utilized STAAD.*pro*, and STAAD.*foundation* in the design of the project.[25] The foundation design included 120 support positions and over 50 load combinations. Due to the complexity of the project, STAAD.*foundation* was able to streamline the design and analysis process. It allowed engineers to sort through massive amounts of data very effectively. By using STAAD.*foundation* software, the firm was able to save 50% to 60% in design time and saved 12 to 15% in materials.[26] The firm also saved approximately 80 hours of work per month over the course of a six-month project period.[27]

[25] Ibid.
[26] Ibid.
[27] Ibid.

Methodology

In order to evaluate the reliability and stability of STAAD.*pro* and STAAD.*foundation*, several design alternatives will be created. The foundation will compare the transparency of the Building Information Modeling software between STAAD.*pro* and design and analysis process within STAAD.*foundation*. Hand calculations will be performed in order to verify the accuracy of the software's analysis capabilities. The three main objectives for this project include:

Objective 1: Define scope of the project
Objective 2: Evaluate various foundation designs obtained from STAAD.*foundation*
Objective 3: Create user tips manual for engineers at Stantec Consulting Ltd.

Objective 1: Define Scope of the Project

Task 1: Define reference structures and loadings

In order to begin designing various foundation types, it will first be necessary to establish the main reference structure. Determining the reference structure narrows down the scope of the project by directing the focus onto a particular set of design structures. Optimally, this reference structure will be based off of recommendations by Stantec. Once the reference structure is determined, it will be possible to define necessary parameters to aid in the design of the foundations. These parameters include: location of the structure, foundation geometry, the structure's purpose, etc. Defining the reference structure and these parameters is the initial step in determining the loading and forces present in the foundation system.

Task 2: Define range of parameters and other variables

Having defined the type and function of the reference structure, a range of other parameters needs to be established. These parameters include information about the intended use of materials along with a range of soil parameters. For the design calculations, material properties to be determined include: strength of concrete, yield strength of steel, maximum and minimum bar size, clear cover values, and initial thickness. Soil parameters to consider include soil types, unit weight of soil, and soil bearing capacity.

Task 3: Design structural frame model and perform structural analysis in STAAD.*pro*

Once the reference structure and the range of parameters has been defined, the structural frame model can be designed and structural analysis completed in STAAD.*pro*. STAAD.*pro* provides design analysis for linear static, P-Delta, nonlinear, and several types of dynamic analyses. Further review of these various types of design analyses can be found in Appendix A. Corresponding data, such as load and statics check information can be included and printed within the report.

Objective 2: Evaluate various foundation designs obtained from STAAD.*foundation*

Task 4: Input project parameters and calculated reaction forces into STAAD.*foundation* and generate foundation model

When starting a design in STAAD.*foundation*, the user first creates a *Project* to hold all the pertinent information about the foundation design. This includes the physical information about the foundation and data about the structure that the foundation will support.[28] Setting up the general parameters, structural geometry, and structural analysis of a project in STAAD.*foundation* can be either done through the input of data manually or imported from STAAD.*pro*. Manually inputting the project information involves entering support coordinates, defining structural loads, specifying design constraints, and entering design parameters.[29] Importing structural geometry and analysis results from STAAD.*pro* into STAAD.*foundation* creates a streamlined design process. Integrating the two programs allows the foundation design to be seamlessly combined with analysis of forces and moments in the superstructure. To take advantage of this streamlined process, this project will import the structural analysis from STAAD.*pro* into STAAD.*foundation*.

The design and analysis of a project in STAAD.*foundation* varies depending on the intended type of foundation project. The specifics of this project's structural geometry, foundation type, and support reaction have not yet been determined. Therefore, a brief overview of the design and analysis process in STAAD.*foundation* for isolated footings, strip footings, mat foundations and pile caps will be discussed.

Isolated footing Design:[30]

-Define design parameters: concrete and rebar, cover and soil, footing geometry, sliding and overturning, and design

Mat Foundation Design:

-Create grid and define the mat boundary
-Create a mesh

In order to evaluate the reliability and continuity of STAAD.*pro* and STAAD.*foundation*, several design alternatives will be created. These alternatives will be designed and analyzed within STAAD.*foundation*, using loading results exported from STAAD.*pro*. Additionally, hand calculations will be performed in order to verify the accuracy of the softwares' analysis capabilities.

-Define soil properties
-Analyze the slab

[28] Bentley Systems. STAAD.*foundation* - *User Manual*. Research Engineers International, 2009. 2-20.
[29] Ibid.
[30] Ibid.

Slab design:[31]

-Generate moment envelope
-Design the slab
-Create reinforcement zone for reinforcement layout

Pile Cap Design:[32]

-Enter pile data: vertical, lateral and uplift pile capacities for each support, pile diameter, spacing, and distance of the edge from the corner piles
-Enter pile cap design parameters: strength of concrete, yield strength of steel, maximum and minimum bar size, clear cover values, and initial thickness
-Perform pile cap analysis and view results

Strip Footing Design:[33]

-Input strip footing design parameters: unit weight of concrete, minimum and maximum bar spacing and size, strength of concrete, yield strength of steel, clear cover values, unit weight of soil, and soil bearing capacity

Task 5: Develop foundation model through application of hand calculations

The design of foundations through hand calculations will be completed in accordance with the various design procedures, as described in Appendix B. These hand calculations will use the same input parameters as were used in the development of foundations in STAAD.*foundation* and will be generated within MathCAD. Additionally, loading and force specifications pertaining to calculations will be determined in accordance with specifications and standards defined by the client's needs.

Task 6: Analyze reliability of STAAD.*foundation* and identify any shortcomings in the software

In order to properly determine the reliability of STAAD.*foundation*, we plan to complete various structural designs with STAAD.*pro* and then import them into STAAD.*foundation* to initiate the analysis of the software. Within STAAD.*foundation*: isolated footings, mat foundations, slab design, pile caps, and strip footings will be analyzed. Once this has been completed, the results generated by the program will be compared to the calculations that the team has completed by hand to check for any potential errors or variations made by the program. The program will be examined by comparing the results and formulas on the STAAD.*foundation* Calculation Sheet to hand calculations and will be checked for output forces, moment resultants, shear stresses, and flexure.

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[31] Bentley Systems. STAAD.*foundation - User Manual*. Research Engineers International, 2009. 3-56.
[32] Ibid, 3-72
[33] Ibid, 3-85

Objective 3: Create user tips manual for engineers at Stantec Consulting Ltd.

Task 7: Summarize the overall efficiency of STAAD.*foundation*

We will be looking at different types of foundations within STAAD.*foundation* to determine the overall effectiveness and accuracy of the program's design. We will be able to determine the efficiency of the foundation through the design process. From the output of the program, we will be able to determine the foundations shear forces, bending moments, and rigidity of the foundation for the structure. Using the outputs from the program and comparing them to our hand calculations will allow us to see potential deficiencies in the program.

Task 8: Develop step-by-step user tips manual that can be utilized by Stantec engineers

Based upon trials that will be undergone in C-Term, a database for user tips will be developed. Through exploring the program and designing foundations based off of structures, we will be able to find techniques that are easier for users. This user tips manual will include information on how to export a STAAD.*pro* model into STAAD.*foundation* and step-by-step instructions on how to set up parameters in STAAD.*foundation*. In order to alert Stantec engineers of any issues in STAAD.*foundation*, the user tips manual will also highlight any limitations or inaccuracies. Creating a user tips manual will help Stantec employees understand and trust designs computed by STAAD.*foundation*.

Deliverables

This project will produce a report detailing our study on STAAD.*foundation*, which will act as both a summation of our time with Stantec Consulting and as a summation of all of the deliverables created. Additional deliverables will include multiple foundation designs and analyses that were calculated by hand, as well as the companion calculations and analyses that were produced by STAAD.*foundation*. These designs will be compiled to show the various design alternatives and will include information relating to the viability of the designs. An additional user tips manual and analysis of STAAD.*foundation* will be produced to provide Stantec with an overview of the capabilities of STAAD.*foundation*, as well as to provide future users with a synopsis of any potential errors or shortcuts.

Schedule

A proposed schedule for the project can be seen in Figure 2. The Gantt chart relates the project objectives and tasks to a timeframe spanning between January 15, 2015 and March 5, 2015.

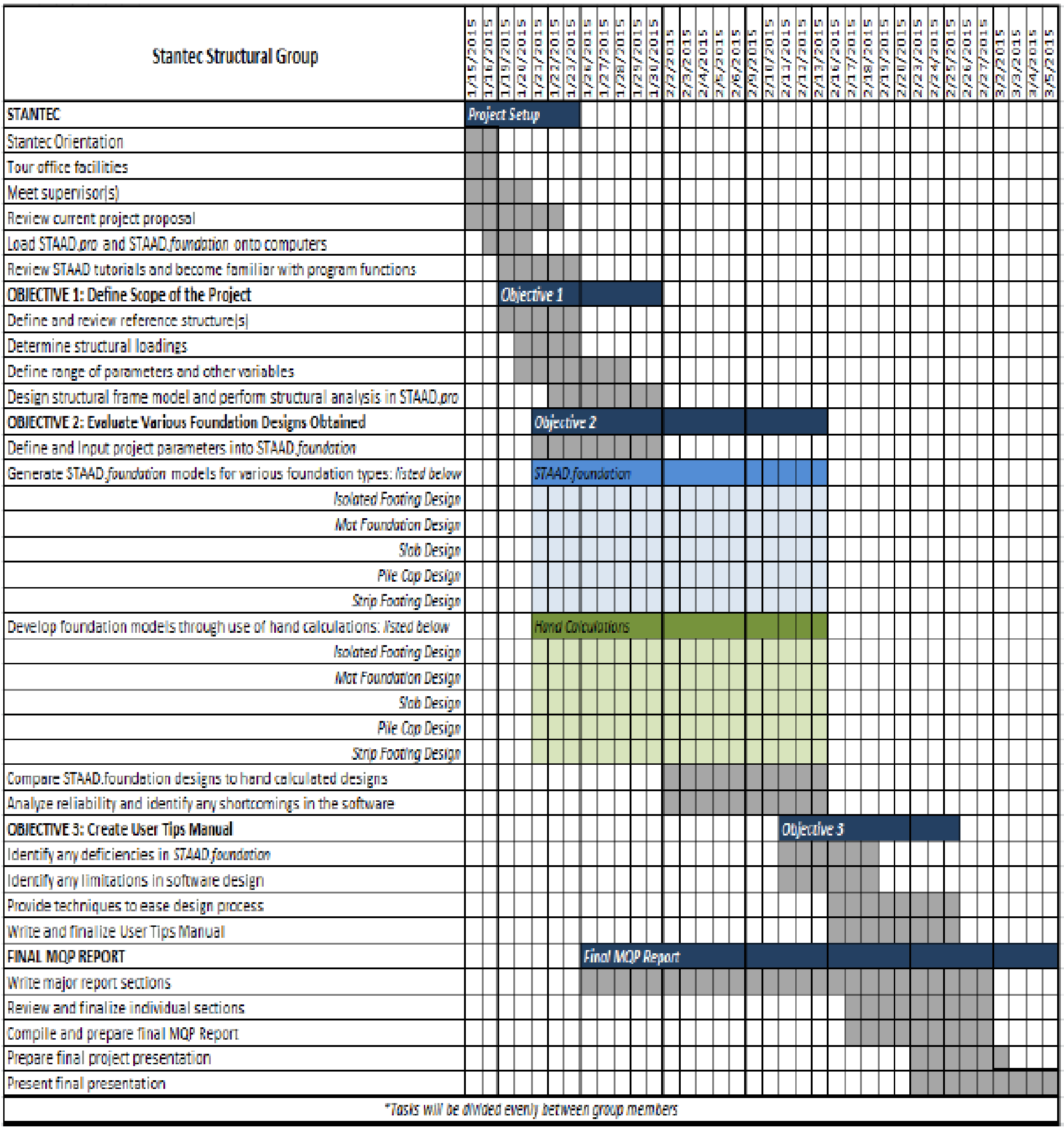

FIGURE 2: STANTEC STRUCTURAL GROUP GANTT CHART

Capstone Design Statement

Capstone Design

The Accreditation Board for Engineering and Technology (ABET) must demonstrate knowledge and skills acquired in earlier coursework through a capstone design experience. A capstone design experience must incorporate engineering principles and realistic design constraints. This Major Qualifying Project (MQP) will incorporate the following five design constraints:

Economic: When designing various foundation types, economic constraints will be considered in order to create designs that are cost effective and use economical materials.
Environmental: The designs for various foundations will consider environmental impact.
Constructability: The project will be designed with the feasibility of construction in mind. This includes considering effective use of resources, labor, construction time, and maintenance.
Ethical: The designs will be developed to comply with the principles set forth by ACI Standards and the American Society of Civil Engineers (ASCE).
Health and safety: Foundation designs will be conscientiously designed keeping the well-being of those constructing the design and the future users in mind. The designs will meet the requirements of the governing regulatory codes and comply with the pertinent industry standards.

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Appendices

Appendix A: STAAD.*pro* program overview

Linear Elastic Analysis

The command to run a linear analysis is shown in Figure 3. If any part of the analysis command shown is missing, it will not be performed. Furthermore, these additional reports can be generated if analyses are necessary for different phases of the design.

```
PERFORM ANALYSIS (PRINT { LOAD DATA | STATICS CHECK
| STATICS LOAD | BOTH | ALL } )
```

FIGURE 3: STATIC ANALYSIS COMMAND LINE

This command directs the program to check whether all necessary information is provided, form the joint stiffness matrix, check the stability of the structure, solve simultaneous equations, and compute the member forces and displacements. Additionally, STAAD allows multiple analyses to be run at once, which allows for optimized design and simultaneous attainment for load-dependent structures.

P-Delta Analysis

The software package allows for several options for the P-Delta analysis, differing based on the desired effects to the structure. Different effects include small and large delta, large delta only, or analysis including stress-stiffening effect on the KG matrix. In order to attain a proper analysis, three to thirty iterations should be specified in the command. Furthermore, global buckling can occur during this analysis, in which case the results should be neglected. An example of command base on small and large delta effects can be seen below in Figure 4.

```
PDELTA ANALYSIS
PDELTA 5 ANALYSIS
PDELTA ANALYSIS CONVERGE
PDELTA ANALYSIS CONVERGE 5
PDELTA 20 ANALYSIS SMALLDELTA PRINT STATICS CHECK
```

FIGURE 4: P-DELTA ANALYSIS COMMAND LINE

Buckling Analysis

This command directs the software package to perform analysis that includes solving for the static case, reforming global joint stiffness matrix to include the Kg matric terms, and solving simultaneous equations for displacements. If the loads must be in opposite directions, the program will automatically stop iteration after the one iteration. Additionally, convergence will occur if two successive iterations are within 0.1% of each other. An example of the buckling analysis command can be seen below in Figure 5.

```
PERFORM BUCKLING ANALYSIS MAXSTEPS 15 -
PRINT LOAD DATA
```

FIGURE 5: BUCKLING ANALYSIS COMMAND LINE

Direct Analysis

This type of analysis will reflect the secondary effects of a combination of load cases that are defined as repeat loads and reference loads. Furthermore, the analysis will solve simultaneous equations for displacements, reform the global joint stiffness matrix and repeat until the iterations converge. An example of a command for this analysis can be seen below in Figure 6.

PERFORM DIRECT ANALYSIS ({LRFD or ASD} TAUTOL f1 DISPtol f2 ITERDIRECT i3 (REDUCEDEI i4) (PDiter i5) PRINT *print-options*)

print-options **= { LOAD DATA | STATICS CHECK | STATICS LOAD | BOTH | ALL }**

FIGURE 6: DIRECT ANALYSIS COMMAND LINE

Appendix B: Foundation Hand Calculations

Isolated spread footings

Compute the footing-plan dimensions B x L.

For a square footing $B \times B = \sqrt{\frac{Q}{qall}}$

For a rectangular footing $B \times L = \frac{Q}{qall}$

Q is the critical load combination

Convert the allowable soil pressure to an ultimate value for use in USD.

Find the "ultimate" bearing $q_0 = \frac{Qu}{BL}$

Make sure $q_0 < q_u$

Calculate the allowable two-way action shear stress

For a square footing, check for diagonal tension:

$$Vall = 4\emptyset\sqrt{(f'c)}$$

For a rectangular footing, check for wide beam shear:

$$Vall \leq 2\emptyset\sqrt{(f'c)}$$

Find the effective footing depth

For the case of a square column

$$d^2\left(Vc + \frac{q_0}{4}\right) + d\left(Vc + \frac{q_0}{2}\right)w - (B^2 - w^2)\frac{q_0}{4} = 0$$

For the case of a round column (a = diameter)

$$d^2\left(Vc + \frac{q_0}{4}\right) + d\left(Vc + \frac{q_0}{2}\right)a - (BL - A_{col})\frac{q_0}{4} = 0$$

Compute the required steel for bending and use the same amount each way for square footings. Use the effective d to the intersection of the two bar layers for square footings if d > 12 in. For d < 12 in. and for rectangular footings use the actual d for the two directions. The bending moment is computed at the critical section (face). Check the steel ratio verses minimum and maximum steel ratios.

$$Mu = \frac{q\,L^2}{2} = \emptyset A_s f_y\left(d - \frac{a}{2}\right)$$

Compute the column bearing and use dowels for bearing if the allowable bearing stress is exceeded. Minimum dowels must always be provided. If dowels are required, the length must be adequate for compression bond.

$$A_s = 0.005(A_{col})$$

Draw a detailed design based off the information you found above.

Piles and Pile Caps

The size of a pile cap is dependent upon the spacing of the piles below and the soil type. The first step is to assume a pile type and material based on economic need and site conditions. Following this, the ultimate bearing capacity of a single pile should be calculated to determine the design pile capacity, obtained from the application of a factor of safety. Once the ultimate bearing pressure of a pile is found, the number of piles needed to support the load can be determined. To space the piles, the center-to-center distance between them is assumed to be between 2.5d to 3.0d. Spacing, however, should be kept as small as possible, unless the site has heavy obstruction, to keep from increasing the cost of the individual pile cap.[34]

Ultimate bearing Capacity is found using the equation:

$$Q_{ult} = Q_p + Q_f$$

Where:

Q_{ult} =Ultimate bearing capacity of pile
Q_p =Theoretical bearing capacity for tip of foundation
Q_f =Theoretical bearing capacity due to shaft friction

Mat foundations

Evaluating a design for a mat foundation is similar to the process of evaluating a shallow foundation, however, additional factors such as the coefficient of subgrade reaction, are accounted for. The equation for evaluating the coefficient of subgrade reaction is calculated as follows:

$$k_s = \frac{q}{\delta},$$

Where:

[34] Rajapakse, Ruwan. *Pile Design and Construction Rules of Thumb*. 2008. <http://app.knovel.com/hotlink/toc/id:kpPDCRT002/pile-design-construction/pile-design-construction>.

$$k_s = coefficient\ of\ subgrade\ reaction$$

$$q = bearing\ pressure$$

$$\delta = settlement$$

Settlement is calculated using the equations as discussed for shallow foundations. Additionally, the coefficient of subgrade reaction can be recalculated based on the defined zones of the mats.

Since the interaction between the mat and the underlying soil is treated as field of springs, the sum of the spring forces must equal the applied structural load plus the weight of the mat as shown below:

$$\sum P + W_f - u_D = \int q dA = \int \delta k_s dA,$$

Where:

$$u_d = pore\ water\ pressure\ along\ base\ of\ the\ mat$$

$$q = bearing\ pressure\ between\ the\ mat\ at\ soil$$

$$A = mat\ soil\ contact\ area$$

$$\delta = settlement\ at\ a\ point\ on\ the\ mat$$