Piles Redesigned: A Comparison of Concrete and Timber

ARCE 453 Senior Project

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12/7/2021
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Part I: Timber Pile Design

Abstract

The idea for this project arose during my internship this past summer with IMEG Corp. I had the opportunity to learn about life cycle analyses which are used as a tool to assess the sustainability of buildings and construction. I gained experience using Life Cycle Analysis (LCA) software and explored the environmental impacts of various past projects with other interns and the guidance of IMEG’s Sustainability Task Force. The major finding from this research was that concrete was the most detrimental material and the foundation system frequently had the largest contribution of harmful environmental impacts. This is because concrete is the most common material used for foundation systems, although it is not the only option. An executive structural engineer at the San Francisco office, where I was interning, mentioned his previous experience using timber pile systems in the Bay Area. This led to the idea to investigate timber piles as possibly a more sustainable alternative foundation system for my senior project. IMEG kindly allowed me to use one of their completed buildings and assisted me throughout my project. Various engineers from IMEG’s San Francisco office and the Geotechnical Engineer that worked on the project helped me establish a starting point for my senior project by providing all necessary documents and drawings, as well as answering my questions throughout the project.

This report explores a comparison of a timber pile system and the actual cast-in-place auger pile system of IMEG’s past project, Building 1 on the Coleman Highline site in San Jose, California. After reading through the Geotechnical Report completed prior to construction in 2016 and other necessary documents, I reached out to a Senior Consultant at Langan. He was the principal engineer who provided the original geotechnical report and helped me better understand the report. From the test results of timber piles provided by the Geotechnical Engineer and with his help, I estimated capacities for various sizes of timber piles to use in the redesign. Then, the piles and pile caps were redesigned for the Building 1 foundation system. A new foundation plan and pile cap details were made to help visualize this new system and help with the design process. Next, two LCA’s were completed using the online OneClick LCA Software. Each LCA looked at the entire structural system of the building with the only difference being in the foundation systems. These two LCA’s are analyzed and compared in this report. The report assesses each foundation system and their effect on the buildings total environmental impacts. The construction process and cost of each system is also considered in an overall comparison of timber and concrete pile systems.

Background Information

Piles are a type of deep foundation system, which is used when a site has poor soil quality and shallow foundations are prone to failure. A pile is essentially a long, slender member that can be installed into the soil in various ways including driving and pouring. Piles are often categorized by material and can be made from concrete, steel, timber, or a combination of those materials.
Concrete piles are a very common deep foundation system. They can be precast, meaning they are manufactured before construction and driven into the ground. Concrete piles can also be cast-in-place, meaning they are poured into place rather than driven. This eliminates the potential for damage during the driving process. A cast-in-place concrete pile can require a shell, which can be permanent or temporary. If the pile is poured into the shell, the shell stays in the ground and it is a cased pile. The shell can also be removed while the concrete is being poured which makes it an uncased pile. Coleman Highline Building 1 is supported by an auger cast pile system. An auger pile is installed by drilling the auger into the ground and injecting the concrete as the auger is removed. Auger cast piles can be installed quickly and are relatively inexpensive. Concrete auger cast piles have a high capacity, which in addition to the other advantages, makes them a popular choice (Gallagher and Fritzges, 2015).

Timber piles have been historically used but are no longer as popular because new materials, such as concrete, have been introduced. Timber is an economical and sustainable material which makes it a responsible material to use. But timber is not always an appropriate choice. Timber piles have a lower capacity than concrete piles. This means when the loading is very high, they are not an efficient choice and more timber piles will be required than concrete piles under the same load. This can potentially increase cost due to the additional material. Each pile is also limited in length by the height of the tree it comes from, which has the potential to be a problem. In addition, they have the potential to rot or decay if untreated (Evett and Liu, 2014). This can reduce their life span, especially when they are not installed below the water table. When permanently encapsulated by water the timber is protected from harmful insects and slows the decaying process due less exposure to oxygen. Various treatments can be used to minimize this damage.

This site was specifically chosen because of the geotechnical conditions. IMEG helped decide on this site and the assumption was made that timber piles could be used for design assuming they had proper treatment where above the water table. The geotechnical report states that the groundwater table is approximately 6-8 feet below the ground surface (Walker and Rogers, 2014). Although the timber piles will not be completely submerged it water, the conditions were assumed to be suitable for the design if treated. Further testing would likely be required if the timber pile design was going to be used.

**Procedure**

Pile capacity is formed from end-bearing, skin friction or a combination of both. An end-bearing pile must be long enough to reach hard soil or rock that can support the pile load. This is not possible or reasonable to do when this layer is extremely far below the ground surface, and this is when friction piles are a better choice. A friction pile supports the pile load through adhesion between the pile surface and surrounding soil (Evett and Liu, 2014). This forms the pile capacity equation:

\[
Q_{\text{ultimate}} = Q_{\text{friction}} + Q_{\text{bearing}} = f \cdot A_{\text{surface}} + q \cdot A_{\text{tip}} \quad \text{(Eq. 1)}
\]
Here the term \((f)\) refers to the unit skin friction or adhesion between the pile and surrounding soil. The term \((A_{\text{surface}})\) refers to the surfaced area of one pile and \((A_{\text{tip}})\) refers to the cross-sectional area of the pile at the tip of the pile. The term \((q)\) refers to the ultimate bearing capacity of the soil under the tip of the pile. Since these terms are not only dependent on the pile but also the soil surrounding it, different methods are used for different soil types.

Piles capacity can also be found or verified on-site through testing. Test are done by driving test piles and adding load with dead weight or hydraulic jacking. From the loading a load versus settlement graph which is used to analyze the piles behavior. The settlements found are then verified with the allowable settlements given in applicable building codes (Evett and Liu, 2014). Figure 1 below is an example of a load versus settlement graph found in *Soils and Foundations 8th Edition*:

![Figure 1](image)

The Davisson’s (1973) Method was used to determine pile capacity from given load versus settlement graphs. This method calculates the deflection at failure through the formula (McCarthy, 2008):

\[
\delta_{\text{failure}} = \delta_E + \left(0.15 + \frac{D}{120}\right) \quad \text{(Eq. 2)}
\]

The term \((\delta_E)\) is a pile’s elastic deflection and \((D)\) is the pile diameter. This deflection can be found using the test load \((P)\), length of pile \((L)\), cross sectional area of the pile \((A)\), and Young’s Modulus of the pile material, \((E)\). The elastic deflection can be calculated with Eq. 3:

\[
\delta_E = \frac{PL}{AE} \quad \text{(Eq. 3)}
\]

The elastic deflection curve is then plotted onto the corresponding load versus settlement graph. The Davisson Curve from Eq. 2 is also plotted on the load versus settlement graph. The Davisson curve and elastic deflection line should be parallel and a value of \((0.15 + \frac{D}{120})\) apart. This will look like Figure 2 with the intersection of the Davisson Curve and the load versus settlement graph being the ultimate load (Infratech Energy, 2003):
The load to use as the pile design capacity is the ultimate load with a factor of safety of 2.0 applied to it. This means you take one half of the ultimate load \((Q_{\text{ultimate}})\) to be equal to the design capacity of a single pile \((Q_{\text{design}})\).

\[
Q_{\text{design}} = \frac{Q_{\text{ultimate}}}{2} \quad \text{(Eq. 4)}
\]

The Geotechnical Engineer provided 3 test result plots for 3 different pile diameters and lengths. The Davisson Method was used to get an approximate capacity for each pile type. These results can be found in *Appendix 1*. For the 14” pile, the Davisson Offset curve does not intersect the load versus settlement plot at any point. When this happens, the maximum test load can be taken as the failure load (McCarthy, 2008).

For this project, the loads were given in the provided construction documents as dead, live, and lateral for each pile group. These loads were then factored using ASD load combinations that can be found in *ASCE 7-16*. Of the ten load combinations, the governing combinations were checked to find the maximum load on each pile group. The governing combinations are as follows:

8. \(D + 0.7E_v + 0.7E_h\)

9. \(D + 0.525E_v + 0.525E_h + 0.75L\)

10. \(0.6D - 0.7E_v + 0.7E_h\)

The term \((D)\) refers to dead load and \((L)\) refers to live load. The terms \((E_v)\) and \((E_h)\) are the vertical and horizontal seismic load effects. \(E_v\) can be combined with the dead load using the relation in ASCE 7-16 of \(E_v = 0.2S_{DS}D\), with \((S_{DS})\) being the design spectral response parameter at short periods. \((E_h)\) is also defined in ASCE 7-16 as \(E_h = \rho Q_E\), with \((\rho)\) being the redundancy factor and \((Q_E)\) being the horizontal seismic forces. For Building 1, \(S_{DS} = 1.0g\) and \(\rho = 1.3\). Although \(\rho = 1.3\), it was assumed that this was already factored into the lateral loads, \((E)\), as...
given on the plan. This simplifies the load combinations above to the combinations used in excel:

8. \(1.14D + 0.7E\)

9. \(1.105D + 0.525E + 0.75L\)

10. \(0.46D + 0.7E\)

From these combinations, the maximum tension on compression loads were calculated for each pile group individually. The groups were checking individually because there were load variations from group to group. The max compression load was used to find the number of required piled with Eq. 5 for each size pile.

\[
N_{req} = \frac{c_{max}}{q_{design}} \quad (\text{Eq. 5})
\]

Once the number of required timber piles was found for each size, the piles were regrouped to minimize the required designs. The 16” pile was not used because the length from the test of the 16” pile was significantly longer at 80’. By using the 12” and 14” piles, the length of the piles was like that of the original auger cast pile design. The maximum forces from each new pile group were then used to design the pile caps.

From the maximum loads, the cap was sized based on the *ACI 318-19*. The dimensions were designed to be proportional to that of the auger cast pile caps used in the original design. The minimum center to center spacing of the piles was taken as:

\[
s = 3D \quad (\text{Eq. 6})
\]

With \(s\) being the center-to-center spacing and \(d\) referring to the pile diameter in inches. The edge center-to-edge of the pile cap distance used was the pile spacing with an additional 3 inches. This is the distance between the center of the pile and the edge of rebar and is equal to the center-to-center spacing of the piles. Further information on calculating pile spacing can be found in *ACI-18-19 13.4.1.1*, but the reason for using Eq. 6 is to size the pile caps proportional to the auger cast design. The minimum thickness of each pile cap in feet was calculated as:

\[
h = \frac{D}{12} + 2 \quad (\text{Eq. 7})
\]

This was used in the initial calculation of the pile size. The pile cap was then checked for one-way and two-way shear. Both shear checks are to satisfy Eq. 8 and both use \(\varphi = 0.75\):

\[
V_u \leq \varphi V_c \quad (\text{Eq. 8})
\]

The one-way shear check calculates \(V_c\) according to the *ACI 318-19 Table 22.5.5.1* The axial load is assumed to be negligible and Option (a) from the table is simplified to:

\[
V_c = [2\lambda \sqrt{f_{c}^*} + 0]b\omega d \quad (\text{Eq. 9})
\]
The modification factor ($\lambda$) is assumed to be 1.0. ($f'_{c}$) is the concrete compressive strength (psi). The term ($b_w$) refers to the width of the pile cap and the last term ($d$) refers to the pile cap thickness minus the concrete cover which is 3”.

The two-way shear check calculated ($V_c$) according to the ACI 318-19 Table 22.6.5.2. Each the smallest resulting value is used.

\[
\begin{align*}
a) & \quad V_c = 4\lambda \lambda \sqrt{f'_{c}} \quad \text{(Eq. 10a)} \\
b) & \quad V_c = (2 + \frac{4}{\beta'}) \lambda \lambda \sqrt{f'_{c}} \quad \text{(Eq. 10b)} \\
c) & \quad V_c = (2 + \frac{\alpha_s d}{b_o}) \lambda \lambda \sqrt{f'_{c}} \quad \text{(Eq. 10c)}
\end{align*}
\]

In Eq.’s 10a-c the size modification factor is $\lambda_s = \sqrt{\frac{2}{1 + \frac{\beta'}{10}}}$ ≤ 1 (ACI 318-19 22.5.5.1.3). The term ($\beta'$) is the ratio of long to short sides of the reaction area. Eq. 10b will not govern so it is omitted from the design calculations. The term ($\alpha_s$) as defined in ACI 18 22.6.5.3 is 40 is for interior columns, 30 for edge columns and 20 for corner columns. Lastly, ($b_o$) is the perimeter of the critical section. For two-way shear, the critical section is $D/2$ from the center of the column. Therefore, the perimeter can be found with $b_o = (b_{col} + d)4$.

The shear occurring in the pile cap is calculated by finding the axial force in a single pile and multiplying it by the piles in the effective area. For one way-shear the effective area is located a distance ($D$) from the column and only looks at one side of the pile cap centerline. For two-way shear the effective area is located outside of the critical section, or $D/2$ from the column on all sides. The pile axial force is taken as the total load divided by the number of piles.

Next, the pile cap bottom or tension reinforcement is calculated according to the maximum moment, ($M_u$), about each axis. This is found by taking the sum of each pile moment on one side of the centerline of the pile cap, which is found by multiplying the single pile axial load by the distance for the column. The calculation of the required rebar in each direction is calculated according to ACI 318-19 22.2. The required steel area is calculated with:

\[
A_{s,reqd} = \frac{M_u}{\varphi(0.95f_{y}d)} \quad \text{(Eq. 11)}
\]

In Eq. 11, $\varphi = 0.9$ for bending and ($f_{y}$) refers the yield strength of the rebar (psi). This is then checked with the minimum required steel area, ($A_{s,min}$) by the larger of:

\[
\begin{align*}
a) & \quad A_{s,min} = \frac{3f'_{c}}{f_{y}} (b_w d) \quad \text{(Eq. 12a)} \\
b) & \quad A_{s,min} = 0.0018A_g \quad \text{(Eq. 12b)}
\end{align*}
\]

In Eq. 12b ($A_g$) refers to the cross cross-sectional area of the pile cap which can be found by $b_w h$. All the other variables as previously defined. The largest steel area found in Eq. 11 and Eq.’s 12a-b is then used to choose an appropriate size and number of bars for each pile cap.
There are a few pile groups that require rebar on the top or compression face of the pile cap along with the bottom layer. This calculation is to ensure the section of the pile cap is in equilibrium to maintain the required strain $\varepsilon = 0.003$, as stated in *ACI 318-19 22.2.21*. This steel area, $(A'_{s})$, is calculated to satisfy the following equation:

$$ C_s = C_c + T_s \quad \text{(Eq. 18)} $$

In Eq. 18, $C_s = A'_{s}f_y$, and is the steel component of the compression force in the section. The concrete component of this compression force is $C_c = 0.85f'c a_b w$. The term in this equation $a_b = \beta_1 (h - (c + 3))$, with $\beta_1 = 0.8$ and $c$ referring to the distance from the neutral axis to the center of the bottom rebar. The force resulting from the tension steel is $T_s = A_s f_y$.

**Results**

The pile caps were designed using Excel and can be referenced in *Appendix 2*. The related drawings can be found at the end of the report in Appendix 7. The new foundation plan and details are updated and are S2.03 and S2.04. This new layout can be compared to the original layout on 1S2.01 and 1S4.01 which were provided by IMEG.
Part II: Life Cycle Assessments and Comparison

Abstract

This portion of the project entails a life cycle analysis with OneClick LCA Software on the original Coleman Highline Building 1 and the redesigned Building 1. The results will be analyzed and compared to see if the timber piles had an impact of the environmental effect of the building.

Background Information

A life cycle analysis or assessment is a method of evaluating the environmental impact of a product over the course of its life (Nemerow et al., 2005). What this means is assessing the environmental impact from when it is created until it is disposed of. This takes into consideration the transportation and operational environmental impacts as well. A life cycle assessment can be done during a product’s life, but it can also be completed during design.

In this report, the life cycle analysis is going to be evaluating all the structural components in each design of Building 1. The operational component of the analysis is minimally included, and the analysis is focused on the structural components only. This means that the architectural components have also been excluded. A life cycle analysis is an excellent tool for the construction industry because it provides a better understanding of what is harmful so the negative impact of a product or project can be mitigated. This is not only beneficial to the environment, but also to many businesses, especially in the construction industry. Using a life cycle analysis has the potential to help businesses manage cost as well as environmental impact (About One Click LCA, 2021). This enables more people and businesses to design and build responsibly.

A life cycle analysis categorizes periods of a product or project’s life into various stages. They are the Product Stage, The Construction Process Stage, the Use Stage, the End-of-Life Stage and Benefits and Loads Outside the Systems Boundary. Each stage is broken down further and can be summarized in the figure below from OneClick’s Life Cycle Assessment Software FAQ page:
These categories are used to organize the life cycle assessment’s results. The results also can be organized by material or assembly. This way the most detrimental items can be identified and replaced with other choices if possible.

Procedure

The goal of these life cycle assessments is to quantify the impact each design has over the building’s life and see if the new foundation system is successful in reducing the global warming potential. To begin, a take-off of the entire structural system of Building 1 first with concrete piles and then with timber piles must be completed. This is then input into the LCA software. For this project, the only difference between the two take-offs are the foundation systems. The values in the take-offs were calculated with the original Revit model provided by IMEG. Refer to Appendix 3 for concrete pile takeoff and Appendix 4 for the timber pile take off.

These takeoff values are used as inputs for the LCA and OneClick is then able to return the results. The results of each life cycle assessment tell us the amount of embodied carbon in each building and where it is coming from. Embodied carbon is the total amount of greenhouse gas emissions released over the building’s life in terms of a carbon dioxide molecule. It is given in GWP, or global warming potential, and is a measurement relative to the impact a single carbon molecule has over a time frame, often 100 years (SE2050). The unit used is t CO₂, or tons of carbon dioxide. Carbon dioxide is often released by burning fossil fuels, a common form of energy, and other waste.

Other results from the life cycle analysis are given in t CO₂e, or tons of carbon dioxide equivalent. This means other greenhouse gases besides carbon dioxide are also included in the tons of emissions. Other common greenhouse gases as defined by the EPA include methane, nitrous oxide, and fluorinated gases. Methane is emitted during the production or extraction of fossil fuels such as oil, coal, and natural gas. It can also come from various agricultural practices. Nitrous oxide is typically the result of soil management practices, such as the use of fertilizers. A
much smaller portion of nitrous oxide emissions is also due to the use of fossil fuels and waste management. Fluorinated gases include hydrofluorocarbons and other synthetic greenhouse gases. They are emitted in smaller quantities than the other common greenhouse gases but are very detrimental the Earth’s ozone layer, which protects the planet from ultraviolet radiation.

Results

The results of each life cycle assessment can be found in Appendix 5 for the concrete foundation and in Appendix 6 for the timber foundation. The total embodied carbon of Building 1 with a concrete pile system is 3038.06 t CO₂ and the total for Building 1 with a timber pile system is 2913.38 CO₂. As shown in Table 1A and 1B, the timber pile system reduces the contribution of embodied carbon from the concrete by 13%. As shown in Figure 8A and 8B the timber pile design reduced the contribution of the foundation system to total embodied carbon by 4%.

Tables 3A and 3B break down the contribution of the foundation system by stage and material. The first two columns are categorized by stage. The Transportation Stage embodied carbon dropped by 12.9 t CO₂, from 12.9 t CO₂ in the original design to 73.3 t CO₂ in the timber pile design. But the Construction Stage increased by 4.1 t CO₂, with only 33.3 t CO₂ in the original design and 37.4 t CO₂ in the timber pile design. The third through fifth columns are categorized by material. The concrete in the foundation system is reduced by 115.0 t CO₂, from 572.0 t CO₂ to 457.0 t CO₂, with the use of timber piles. The steel contribution in the foundation system is reduced by 65.7 t CO₂, from 143.2 t CO₂ to 77.5 t CO₂. This is because the timber piles eliminate the need for rebar used to reinforce the concrete piles. Although the use of timber added 66.2 t CO₂ to the foundation system, the net reduction of embodied carbon or global warming potential is 123.3 t CO₂.

Tables 2A and 2B show results in terms of kg CO₂e, or overall greenhouse gas emissions, by material type and their cradle-to-gate percent contribution to the total. Cradle-to-gate refers to the early stages in the life cycle of a product with “cradle” meaning the source and extraction of raw materials and “gate” meaning factory doors prior to transportation to the consumer (Castro-Molinare et al., 2014). It lists the largest contributors in descending order.

Figures 4A and 4B break down the embodied carbon of the entire building by life-cycle stages as percentages. Figures 5A and 5B divide the embodied carbon of the entire building by material type.

Figure 6A and 6B take a closer look at embodied carbon by displaying each assembly in the structure as a bar which is divided again by color to show the percent contribution by stage. This reduction of concrete in the foundation system is also shown numerically in Tables 3A and 3B.
Combined Analysis of Parts I and II

As shown in the Part II results in Appendix 4 and 5, the timber pile design reduces the total embodied carbon. This is because concrete as a material is known to reduce large amounts of carbon dioxide due to the production and use of cement (Ramsden, 2020). This can clearly be seen in below in Figure 9:

These results prove that the use of timber piles has the potential to mitigate embodied carbon in buildings such as Coleman Highline Building 1. Although more of the embodied carbon comes from the building’s horizontal superstructure, the foundation system has a large contribution and should not be disregarded. The use of timber piles can not only reduce the emissions due to concrete, but also eliminates the rebar contribution from the piles.

During the design process, the number of piles per group was greatly increased. This caused an increase in pile cap dimensions as well. For extremely large loads it would not be reasonable to use timber piles because it would require many more piles. In those situations, choices such as auger cast piles used in the original design are more practical to use. Timber piles can efficiently manage relatively small loads, making them a sustainable option to consider for designs of a smaller scale.
Conclusion

Timber piles have specific site requirements to be efficient and long-lasting. This includes being submerged to prevent damage or treated for protection. In this project the timber is assumed to be treated to prevent damage. The alternative would be to use a different material, such as reinforced concrete, for the unsubmerged portion of the pile or move the pile cap lower and extend the column below ground surface. The results proved treated timber piles to be a more sustainable choice than auger cast piles for Coleman Highline Building 1. If one of the alternatives mentioned previously is used, there is potential for the amount of concrete necessary to increase. This would make the use of timber piles less sensible.

It is also important to consider the availability of timber piles depending on the desired length. The 12” diameter pile was 50 ft. in length and the 14” diameter pile was 60 ft. in length. This is approximately the length of the auger cast pile originally used, of 55 ft. minimum. The 16” diameter pile test results were for a pile 80 ft in length. This would be an unreasonable length to source due to high limitations discussed earlier. Long length requirements make timber piles a poor choice. Additionally, more pile testing would likely be required to confirm capacities of each timber piles.

Life cycle assessments are growing in popularity in the construction industry. They are an excellent tool to monitor embodied carbon in buildings and minimize negative environmental impacts. Sustainable construction is the responsibility of structural engineers, geotechnical engineers, architects, general contractors, and building owners. To improve the global warming situation of today, everyone must make an effort to be environmentally conscientious regarding their role in the construction process. Minimizing embodied carbon in buildings is vital to reducing total greenhouse gas emissions. The construction industry has the ability to help mitigate this problem, the responsibility to do so should not be ignored.

This report shows that timber piles reduce the total embodied carbon in Coleman Highline Building 1. The change in building design for this report was purely in the foundation system. The superstructure has a far greater contribution to the embodied carbon total, which explains why that is often the first choice when altering design to be more sustainable. However, the foundation system should not be ignored and excluded from sustainable building design. When the foundation system is designed sustainably along with the building superstructure, there is an excellent opportunity to greatly reduce the embodied carbon total.
Sources:


Appendix 1

Notes: 1. Load test performed on a 12-inch-diameter timber pile located in test pit TP-2.
2. Pile loaded using the ASTM test method D1143 "Quick Load Test" procedure.
3. Length of pile is assumed to be 50 feet.
4. Modulus of elasticity is assumed to be 1,500 kips per square inch.
Notes: 1. Load test performed on a 14-inch diameter timber pile at column line E-7.5.
2. Pile loaded using the ASTM test method D1143 "Quick Load Test" procedure.
3. Length of pile assumed to be 60 feet.
4. Modulus of Elasticity is assumed to be 1,500 kips per square inch.

Load held at 141.5 kips for 5 minutes without significant settlement.

Load capacity, $Q_{ultimate} = 142/2 = 71$ kips
Notes: 1. Load test performed on a 16-inch diameter timber pile at column line A-7.5.
2. Pile loaded using the ASTM test method D1143 "Quick Load Test" procedure.
3. Length of pile assumed to be 80 feet.
4. Modulus of Elasticity is assumed to be 1,500 kips per square inch.

Load held at 158 kips for 5 minutes without significant settlement.

\[ Q_{\text{ultimate}} = \frac{158}{2} = 79 \text{ kips} \]
# of Piles: 1

size = 12 inches
length = 50 ft

$f'_c$ = 3000 psi
$sqrt(f'_c) = 0.054772256$ KSI
$f_y = 60$ ksi

$\gamma = 1$

DIMENSIONS:

3 x 3 ft thick
MIN use:
3 ft thick

SIZE: 3'-0" x 3'-0" x 3'-0"

d = 33 inches

LOADING:

SELF WEIGHT = 4.05 kips

factored load:
P_u = 43.05 kips
P_u/ pile = 43.05 kips

CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)

$\phi = 0.75$

$b_w*d = 1188.0000$ in$^2$

$\phi V_c = 97.60$ kips

# eff.cols = 0

$V_u = 0$ kips

$V_u < V_c$ OK

2- WAY SHEAR (punching shear) (d/2 from col)

$d/2 = 16.5$ in

$b_o = 12$ in

$\lambda_s = 0.6820 < 1$

check: OK

$v = a) 0.1494$ ksi

$c) 4.1837$ ksi

MIN = 0.1494 ksi

shear area = 396.0000 in$^2$

$\phi V_c = 44.38$ kips

# eff.cols = 0
\[ V_u = 0 \text{ kips} \]
\[ V_u < V_c \quad \text{OK} \]

**BENDING**

**X DIRECTION:***
- # piles = 0
- \( y = 0 \text{ ft} \)
- \( M_u = 0 \text{ kip-ft} \)

**Y DIRECTION:***
- # piles = 0
- \( x = 0 \text{ ft} \)
- \( M_u = 0 \text{ kip-ft} \)

**REINF:**

**X DIRECTION:**
- \( \phi = 0.9 \)
- \( \beta = 0.85 \)
- \( A_{\text{REQ}} = 0 \text{ in}^2 \)
- find \( A_{\text{min}} \) max of:
  - \( 3.2535 \text{ in}^2 \)
  - \( 2.3328 \text{ in}^2 \)

\( A_{\text{min}} = 3.253471992 \text{ in}^2 \)

Check \( A_s > A_{\text{min}} \) use \( A_{\text{min}} \)
- \( a = 0.0021 \text{ in} < d? \quad \text{OK} \)
- \( c = 0.0025 \text{ in} \)
- \( \varepsilon_t = 39.5700 > 0.005 \quad \text{OK} \)

**SPACING:**
- \( s_{\text{max}} = \text{lesser of:} \)
  - 108 in
  - 18 in

\( A_{\text{REQ}} = 3.253471992 \text{ in}^2 \)

bars used: **5 #8 bars**
- \( A_s = 3.95 \text{ in}^2 \quad \text{OK} \)
- spacing = 7.2000 in

**Y DIRECTION:**
- \( \phi = 0.9 \)
- \( \beta = 0.85 \)
As = 0 in²
find Asmin max of: 3.2535 in²
2.3328 in²
A_{smin} = 3.2535 in²
Check A_s > A_{smin} use Asmin

a = 2.1265 in < d? OK

c = 2.5017 in

e_t = 0.0366 > 0.005 OK

SPACING: s_{max} = lesser of: 108 in
18 in

As = 3.253471992 in²

bars used: 5 #8 bars

A_s = 3.9500 in² OK

spacing = 7.2000 in
PC2 DESIGN

# of Piles: 2

size = 12 inches
length = 50 ft
\( f'_c = 3000 \text{ psi} \quad \text{sqrt}(f'_c) = 0.054772256 \)
\( f_y = 60 \text{ ksi} \)
\( \lambda = 1 \)

DIMENSIONS:

7.5 x 3 min = 3
3 ft thick MIN
3 ft thick use:

SIZE: 7'-6" x 3'-0" x 3'-0"

d = 33 inches

LOADING:

SELF WEIGHT = 10.125 kips

factored load:
\( P_u = 100.125 \text{ kips} \)
\( P_u / \text{pile} = 50.0625 \text{ kips} \)

CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)

\( \phi = 0.75 \)
\( b_w \times d = 1188 \text{ in}^2 \)
\( \phi V_c = 97.60 \text{ kips} \)

# eff.cols = 2
\( V_u = 100.13 \text{ kips} \)
\( V_u < V_c \text{ NG} \)

2- WAY SHEAR (punching shear) (d/2 from col)

\( d/2 = 16.5 \text{ in} \)
\( b_o = 120 \text{ in} \)
\( \lambda_s = 0.6820 < 1 \)

check: OK

\( v_c = \)
\( a) 0.1494 \text{ ksi} \)
\( c) 0.4856 \text{ ksi} \)

MIN = 0.1494 ksi
shear area = 3960 \text{ in}^2
\( \phi V_c = 443.77 \text{ kips} \)

# eff.cols = 2
\( V_u = 100.125 \text{ kips} \)
\( V_u < V_c \quad \text{OK} \)

**BENDING**

**X DIRECTION:**
- \# piles = 0
- \( y = 0 \text{ ft} \)
- \( M_u = 0 \text{ kip-ft} \)

**Y DIRECTION:**
- \# piles = 1
- \( x = 1 \text{ ft} \)
- \( M_u = 50.06 \text{ kip-ft} \)

**REINF:**

**X DIRECTION:**
- \( \phi = 0.9 \)
- \( \beta = 0.85 \)
- \( A_s = 0 \text{ in}^2 \)

\[ \begin{align*}
\text{find } A_{s_{\text{min}}} & \quad \text{max of: } 3.5492 \text{ in}^2 \\
& \quad 2.3328 \text{ in}^2 \\
A_{s_{\text{min}}} & = 3.549242173 \text{ in}^2 \\
\text{Check } A_s & > A_{s_{\text{min}}} \quad \text{use } A_{s_{\text{min}}} \\
\end{align*} \]

- \( a = 0.9279 \text{ in} \quad < d? \quad \text{OK} \)
- \( c = 1.0917 \text{ in} \)
- \( \varepsilon_t = 0.0877 > 0.005 \quad \text{OK} \)

**SPACING:**
- \( s_{\text{max}} = \) lesser of: 108 in
  18 in

\[ \text{As} = 3.5492 \text{ in}^2 \]

bars used:
- \( A_s = 3.9500 \text{ in}^2 \quad \text{OK} \)
- \( \text{spacing} = 7.2000 \text{ in} \quad < s_{\text{max}} \quad \text{OK} \)

**Y DIRECTION:**
- \( \phi = 0.9 \)
- \( \beta = 0.85 \)
As = 3.9035 in$^2$
find $A_{\text{min}}$ max of: 
3.2535 in$^2$
5.8320 in$^2$

$A_{\text{min}} = 5.8320$ in$^2$
Check $A_s > A_{\text{min}}$ use $A_{\text{min}}$

$a = 3.8118$ in < $d$? OK
$c = 4.4844$ in

$\epsilon_t = 0.0191 > 0.005$ OK

SPACING: $s_{\text{max}} = \text{lesser of:} \ 108$ in
18 in

As = 5.8320 in$^2$

bars used: 8 #8 bars

$A_s = 6.3200$ in$^2$ OK
spacing = 4.5000 in < $s_{\text{max}}$ OK
PC3 DESIGN

# of Piles: 3

size = 12 inches
length = 50 ft
$f'_c =$ 3000 psi $\sqrt{f'_c} =$ 0.054772256
$f_y =$ 60 ksi
$\lambda =$ 1

DIMENSIONS: 6 x 6 min dimension: 6 ft
3 ft thick MIN

SIZE: SEE DETAIL

$d =$ 33 inches

LOADING:

SELF WEIGHT = 6.6375 kips

factored load:
$P_u =$ 159.6375 kips
$P_f/pile =$ 53.2125 kips

CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)

$\phi =$ 0.75
$b_w * d =$ 2376 in$^2$
$\phi V_c =$ 195.21 kips

# eff.cols = 3
$V_u =$ 159.64 kips
$V_u < V_c$ OK

2- WAY SHEAR (punching shear) (d/2 from col)

d/2 = 16.5 in
$b_o =$ 117 in
$\lambda_o =$ 0.6820 < 1
check: OK

$V_c =$ a) 0.1494 ksi
c) 0.4961 ksi
MIN = 0.1494 ksi

shear area = 3861 in$^2$
$\phi V_c =$ 432.68 kips

# eff.cols = 3
$V_u =$ 159.6375 kips
BENDING
X DIRECTION:
# piles = 2
y = 2 ft
\( M_u = 212.85 \text{ kip-ft} \)

Y DIRECTION:
# piles = 1
x = 2 ft
\( M_u = 106.43 \text{ kip-ft} \)

REINF:
X DIRECTION:
\( \phi = 0.9 \)
\( \beta = 0.85 \)
\( A_s = 1.5088 \text{ in}^2 \)

Find \( A_{\text{min}} \):
\[
\text{max of: } 6.5069 \text{ in}^2, 4.87296 \text{ in}^2
\]

\( A_{\text{min}} = 6.506943983 \text{ in}^2 \)
Check \( A_s > A_{\text{min}} \) use \( A_{\text{min}} \)

\( a = 2.1265 \text{ in} \) < d? \( \text{OK} \)
\( c = 2.5017 \text{ in} \)
\( \varepsilon_t = 0.0366 > 0.005 \) \( \text{OK} \)

SPACING:
\( s_{\text{max}} = \) lesser of: 108 in, 18 in

\( A_s = 6.5069 \text{ in}^2 \)

Bars used:
\( 9 \#8 \text{ bars} \)
\( A_s = 7.1100 \text{ in}^2 \) \( \text{OK} \)

Y DIRECTION:
\( \phi = 0.9 \)
\( \beta = 0.85 \)
\( A_s = 8.2982 \text{ in}^2 \)

Find \( A_{\text{min}} \):
\[
\text{max of: } 6.506943983 \text{ in}^2
\]
\[ A_{\text{min}} = 6.506943983 \text{ in}^2 \]

Check \( A_s > A_{\text{min}} \) use \( A_s \)

\[ a = 2.1265 \text{ in} < d? \quad \text{OK} \]
\[ c = 2.5017 \text{ in} \]
\[ \varepsilon_t = 0.0366 > 0.005 \quad \text{OK} \]

SPACING: \( s_{\text{max}} = \) lesser of: 108 in 18 in

\[ A_s = 6.506943983 \text{ in}^2 \]

bars used: 9 #8bars

\[ A_s = 7.11 \text{ in}^2 \quad \text{OK} \]

USE DIAGONAL BARS- 3 #8 EACH WAY
# of Piles: 5
size = 14 inches
length = 60 ft
f'_c = 3000 psi \quad \text{sqrt}(f'_c) = 0.054772256
f_y = 60 ksi
\lambda = 1

DIMENSIONS: 6.5 x 6.5 min = 6.5
use: 3.167 ft thick
SIZE: 6'-6" x 6'-6" x 3'-6"
d = 39 inches

LOADING:
SELF WEIGHT = 22.1813 kips

factored load:
P_u = 307.0813 kips
P_u/pile = 61.4163 kips
CHECK: OK

factored load:
T_u = 27.0813 kips
T_u/pile = 5.4163 kips
CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)
\phi = 0.75
b_w*d = 3042.00 in^2
\phi V_c = 249.93 kips

# eff.cols = 2
V_u = 122.83 kips
V_u < V_c OK

2- WAY SHEAR (punching shear) (d/2 from col)
d/2 = 19.5 in
b_o = 156.0000 in
\lambda_s = 0.6389 < 1
check: OK

\nu_c =
a) 0.1400 ksi
c) 0.4199 ksi
MIN = 0.1400 ksi

shear area = 6084.00 in²
φV_c = 638.69 kips

# eff.cols = 4
V_u = 245.67 kips
V_u < V_c OK

BENDING

X DIRECTION:
# piles = 2
y = 2.167 ft
M_u = 266.18 kip- ft

Y DIRECTION:
# piles = 2
x = 2.167 ft
M_u = 266.18 kip- ft

REINF:

X DIRECTION:
φ = 0.9
β = 0.85
A_s c. = 1.59651 in²
find A_{smin} max of: 8.3309 in² 5.8968 in²

A_{smin} = 8.3309 in²
Check A_s > A_{smin} use A_{smin}

a = 2.5131 in < d? OK

c = 2.9566 in

ε_t = 0.0366 > 0.005 OK

SPACING: s_{max} = lesser of: 126 in
18 in

As c. = 8.3309 in²
bars used: 7 #10 bars

8.8900 in² OK

spacing = 11.1429 in < s_max OK

Y DIRECTION:
ϕ = 0.9
β = 0.85
As = 1.5965 in²

find Asmin max of: 8.3309 in² 5.4756 in²

A_smin = 8.3309 in²

Check A_s > A_smin use A_smin

a = 2.5131 in < d? OK

c = 2.9566 in

ε_t = 0.0366 > 0.005 OK

SPACING: s_max = lesser of: 126 in 18 in

As = 8.3309 in²

bars used: 7 #10 bars

A_s = 8.8900 in² OK

spacing = 11.1429 in < s_max OK

NEGATIVE BENDING

X DIRECTION:
# piles = 2
y = 2.167 ft
M_u = 23.47 kip-ft

Y DIRECTION:
# piles = 2
x = 2.167 ft
M_u = 23.47 kip-ft

REINF:

X DIRECTION:
ϕ = 0.9
\( \beta = 0.8 \)
\( c = 18 \)
\( c' = 21.5000 \text{ in} \)
\( a' = 17.2000 \text{ in} \)
\( C_c = 2736.86 \text{ kips} \)
\( f's = 74.8605 \)
\( T_s = 665.51 \text{ kips} \)
\( A'_{s} = 8.09182581 \text{ in}^2 \)

bars used: 7 #10 bars

\( A_s = 8.8900 \text{ in}^2 \) \hspace{1cm} OK

spacing = 11.1429 in \hspace{1cm} < s_{max} \hspace{1cm} OK

REQ'D BARS = 4.33 BARS

bars used: 7 #10 bars

\( A_s = 8.8900 \text{ in}^2 \) \hspace{1cm} OK

Y DIRECTION: SAME IN BOTH
PC8 DESIGN

# of Piles: 8
size = 14 inches
length = 60 ft
$f'_c =$ 3000 psi $\sqrt{f'_c} = 0.054772256$
$f_y =$ 60 ksi
$\lambda =$ 1

DIMENSIONS: 9.5 x 9.5 min = 9.5
3.166666667 ft thick MIN
use: 3.5 ft thick

SIZE: 9'-6" x 9'-6" x 3'-6"
d = 35 inches

LOADING:
SELF WEIGHT = 47.38125 kips

factored load:
$P_u =$ 512.38125 kips
$P_u$/ pile = 64.04765625 kips
CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)
$\phi =$ 0.75
$b_w*d =$ 3990 in$^2$
$\phi V_c =$ 327.81 kips

# eff.cols = 3
$V_u =$ 192.14 kips
$V_u < V_c$ OK

2- WAY SHEAR (punching shear) (d/2 from col)
d/2 = 17.5 in
$b_o =$ 316 in
$\lambda_s =$ 0.6667 < 1
check: OK

$v_c =$ a) 0.1461 ksi
c) 0.2348 ksi
MIN = 0.1461 ksi

shear area = 11060 in$^2$
$\phi V_c =$ 1211.56 kips

# eff.cols = 6
V_u = 384.2859 kips
V_u < V_c  OK

BENDING
X DIRECTION:
# piles = 3
y = 4 ft
M_u = 768.57 kip-ft

Y DIRECTION:
# piles = 1
x = 2 ft
# piles = 2
x = 4
M_u = 640.48 kip-ft

REINF:
X DIRECTION:
ϕ = 0.9
β = 0.85
A_s = 5.1367 in²
find A_{smin} max of: 10.9271 in²
8.6184 in²

A_{smin} = 10.92706502 in²
Check A_s > A_{smin} use A_{smin}

a = 2.2553 in < d? OK
c = 2.6533 in

ε_t = 0.0366 > 0.005 OK

SPACING:
\( s_{\text{max}} = \) lesser of: 126 in
\( \) 18 in

As = 10.9271 in²

bars used: 9 #10 bars
A_s = 11.4300 in² OK
spacing = 12.6667 in < s_{\text{max}} OK

Y DIRECTION:
\( \phi = 0.9 \)
\( \beta = 0.85 \)
\( As = 4.2805 \text{ in}^2 \)

**find** \( As_{\text{min}} \)

\[ \text{max of: } 10.9271 \text{ in}^2 \]
\[ 8.6184 \text{ in}^2 \]

**As_{\text{min}} =** 10.9271 \text{ in}^2

**Check** \( A_s > A_{\text{min}} \)

**use** \( As_{\text{min}} \)

\( a = 0.8835 \text{ in} < d? \quad \text{OK} \)
\( c = 1.0394 \text{ in} \)

\( \varepsilon_t = 0.0980 > 0.005 \quad \text{OK} \)

**SPACING:** \( s_{\text{max}} = \) lesser of:
\[ 126 \text{ in} \]
\[ 18 \text{ in} \]

\( As = 10.9271 \text{ in}^2 \)

**bars used:**

\textbf{9 #10 bars}

\( 11.4300 \text{ in}^2 \quad \text{OK} \)
\( \text{spacing} = 25.3333 \text{ in} < s_{\text{max}} \quad \text{NG} \)
# of Piles: 9
size = 14 inches
length = 60 ft
f'_c = 3000 psi  sqrt(f'_c) = 0.054772256
f_y = 60 ksi
λ = 1

DIMENSIONS: 9.5 x 9.5 min = 9.5

use: 3.166666667 ft thick MIN
use: 3.5 ft thick

SIZE: 9'-6" x 9'-6" x 3'-6"
d = 35 inches

LOADING:
SELF WEIGHT = 47.38125 kips

factored load:
Pu = 590.38125 kips
Pu/pile = 65.59791667 kips
CHECK: OK

1- WAY SHEAR (beam shear) (d from edge)
ϕ = 0.75
bw*d = 3990 in²
ϕV_c = 327.81 kips

# eff.cols = 3
Vu = 196.79 kips
Vu < V_c OK

2- WAY SHEAR (punching shear) (d/2 from col)
d/2 = 17.5 in
b_o = 316 in
λ_s = 0.6667 < 1
check: OK

vc = a) 0.1461 ksi
c) 0.2348 ksi
MIN = 0.1461 ksi

shear area = 11060 in²
ϕV_c = 1211.56 kips

# eff.cols = 8
\[ V_u = 524.7833 \text{ kips} \]

\[ V_u < V_c \quad \text{OK} \]

---

**BENDING**

**X DIRECTION:**

\# piles = 3

\[ y = 4 \text{ ft} \]

\[ M_u = 787.18 \text{ kip-ft} \]

**Y DIRECTION:**

\# piles = 3

\[ x = 4 \text{ ft} \]

\[ M_u = 787.18 \text{ kip-ft} \]

---

**REINF:**

**X DIRECTION:**

\[ \phi = 0.9 \]

\[ \beta = 0.85 \]

\[ A_s = 5.2610 \text{ in}^2 \]

find \( A_{smin} \) max of:

\[ 10.9271 \text{ in}^2 \]

\[ 8.6184 \text{ in}^2 \]

\[ A_{smin} = 10.92706502 \text{ in}^2 \]

Check \( A_s > A_{smin} \) use \( A_{smin} \)

\[ a = 2.2553 \text{ in} \quad \text{< d? OK} \]

\[ c = 2.6533 \text{ in} \]

\[ \varepsilon_t = 0.0366 > 0.005 \quad \text{OK} \]

**SPACING:**

\[ s_{max} = \text{lesser of:} \]

\[ 126 \text{ in} \]

\[ 18 \text{ in} \]

\[ A_s = 10.9271 \text{ in}^2 \]

bars used: 9 #10 bars

\[ A_s = 11.4300 \text{ in}^2 \quad \text{OK} \]

spACING = 12.6667 in \quad < s_{max} \quad \text{OK}

**Y DIRECTION:**

\[ \phi = 0.9 \]

\[ \beta = 0.85 \]

---

pg. 36
As = 5.2610 in²
find As min max of: 10.9271 in²
8.6184 in²

A_{smin} = 10.9271 in²
Check A_s > A_{smin} use As min

a = 1.0859 in < d? OK

c = 1.2775 in

e_{t} = 0.0792 > 0.005 OK

SPACING: s_{max} = lesser of: 126 in
18 in

As = 10.9271 in²

bars used: 9 #10 bars

A_s = 11.4300 in² OK

spacing = 12.6667 in < s_{max} OK
### PC12 DESIGN

<table>
<thead>
<tr>
<th># of Piles:</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>size =</td>
<td>14 inches</td>
</tr>
<tr>
<td>length =</td>
<td>60 ft</td>
</tr>
<tr>
<td>$f'_c$ =</td>
<td>3000 psi</td>
</tr>
<tr>
<td>$f_y =</td>
<td>60 ksi</td>
</tr>
<tr>
<td>$\lambda =</td>
<td>1</td>
</tr>
</tbody>
</table>

#### DIMENSIONS:

<table>
<thead>
<tr>
<th>12.5 x 9.5 min = 9.5 ft thick</th>
<th>3.166666667 ft thick</th>
</tr>
</thead>
<tbody>
<tr>
<td>use:</td>
<td>MIN</td>
</tr>
<tr>
<td>SIZE:</td>
<td>12'-6&quot; x 9'-6&quot; x 3'-6&quot;</td>
</tr>
<tr>
<td>d =</td>
<td>39 inches</td>
</tr>
</tbody>
</table>

#### LOADING:

**SELF WEIGHT =** 62.34375 kips

Factored load:

- $P_u = 784.34375$ kips
- $P_u/\text{pile} = 65.36197917$ kips

**CHECK:** OK

#### 1- WAY SHEAR (beam shear) (d from edge)

| $\phi = 0.75$ |
| $b_w*d = 4446 \text{ in}^2$ |
| $\phi V_c = 365.28$ kips |

- # eff.cols = 5.5
- $V_u = 359.49$ kips
- $V_u < V_c$ OK

#### 2- WAY SHEAR (punching shear) (d/2 from col)

| $d/2 = 19.5 \text{ in}$ |
| $b_o = 372 \text{ in}$ |
| $\lambda_s = 0.6389 < 1$ |

- check: OK
- $v_c = a) 0.1400 \text{ ksi}$
- $c) 0.2167 \text{ ksi}$
  - MIN = 0.1400 ksi

- shear area = 14508 in$^2$
- $\phi V_c = 1523.02$ kips

- # eff.cols = 10
\[ V_u = 653.6198 \text{ kips} \]
\[ V_u < V_c \quad \text{OK} \]

**BENDING**

**X DIRECTION:**
- \# piles = 4
- \( y = 4 \text{ ft} \)
- \( M_u = 1045.79 \text{ kip}-\text{ft} \)

**Y DIRECTION:**
- \# piles = 3
- \( x = 2 \text{ ft} \)
- \# piles = 3
- \( x = 6 \text{ ft} \)
- \( M_u = 1568.69 \text{ kip}-\text{ft} \)

**REINF:**

**X DIRECTION:**
- \( \phi = 0.9 \)
- \( \beta = 0.85 \)
- \( A_s = 6.2726 \text{ in}^2 \)

find \( A_{s_{\text{min}}} \): max of:
- 12.1759 \text{ in}^2
- 8.6184 \text{ in}^2

\( A_{s_{\text{min}}} = 12.1759 \text{ in}^2 \)

Check \( A_s > A_{s_{\text{min}}} \) use \( A_{s_{\text{min}}} \)

\( a = 1.9099 \text{ in} \quad \text{< d? \quad OK} \)
\( c = 2.2470 \text{ in} \)
\( \varepsilon_t = 0.0491 > 0.005 \quad \text{OK} \)

**SPACING:**
- \( s_{\text{max}} = \) lesser of:
  - 126 \text{ in}
  - 18 \text{ in}

\( A_s = 12.7000 \text{ in}^2 \quad \text{OK} \)

bars used: **10 #10 bars**

\( \text{spacing} = 11.4000 \text{ in} \quad \text{< } \text{s}_{\text{max}} \quad \text{OK} \)

**Y DIRECTION:**
\[ \phi = 0.9 \]
\[ \beta = 0.85 \]
\[ A_s = 9.4088 \text{ in}^2 \]

find \( A_{\text{min}} \) max of:

\[ 16.0209 \text{ in}^2 \]
\[ 11.3400 \text{ in}^2 \]

\[ A_{\text{min}} = 16.0209 \text{ in}^2 \]

Check \( A_s > A_{\text{min}} \) use \( A_{\text{min}} \)

\[ a = 1.9420 \text{ in} \quad < d? \quad \text{OK} \]
\[ c = 2.2847 \text{ in} \]

\[ \varepsilon_t = 0.0482 > 0.005 \quad \text{OK} \]

SPACING: \( s_{\text{max}} \) lesser of:

\[ 126 \text{ in} \]
\[ 18 \text{ in} \]

\[ A_s = 16.5100 \text{ in}^2 \quad \text{OK} \]

bars used: \[ 13 \#10 \text{ bars} \]

\[ \text{spacing} = 8.7692 \text{ in} \quad < s_{\text{max}} \quad \text{OK} \]
TPC17 DESIGN

# of Piles: 17

size = 14 inches
length = 60 ft
$f'_c = 3000$ psi  $\sqrt{f'_c} = 0.054772256$
$f_y = 60$ ksi
$\lambda = 1$

DIMENSIONS: 

\begin{tabular}{l c c}
6.5 x & 18.5 min = & 6.5 \\
3.167 ft thick & & \\
use: & 4.0 ft thick & \\
\end{tabular}

SIZE: \textbf{6'-6" x18'-6" x 4'-0"}

d = 45 inches

LOADING:

SELF WEIGHT = 72.1500 kips

factored load:

$P_u = 1154.3300$ kips
$P_u / pile = 67.9018$ kips
CHECK: \textbf{OK}

factored load:

$T_u = 667.7300$ kips
$T_u / pile = 39.2782$ kips
CHECK: \textbf{OK}

1- WAY SHEAR \textbf{(beam shear)} \hspace{1cm} (d from edge)

$\phi = 0.75$

$b_w * d = 3510.00$ in$^2$
$\phi V_c = 288.38$ kips

# eff.cols = 4

$V_u = 271.61$ kips
$V_u < V_c$ \hspace{1cm} \textbf{OK}

2- WAY SHEAR \textbf{(punching shear)} \hspace{1cm} (d/2 from col)

$d/2 = 22.5$ in

$b_o = 420.0000$ in

$\lambda_s = 0.6030 < 1$

check: \hspace{1cm} \textbf{OK}

$V_c =$

\begin{itemize}
  \item a) 0.1321 ksi
  \item c) 0.2076 ksi
\end{itemize}
shear area = 18900.00 in\(^2\)

\[ \phi V_c = 1872.74 \text{ kips} \]

# eff.cols = 16

\[ V_u = 1086.43 \text{ kips} \]

\[ V_u < V_c \quad \text{OK} \]

**POSITIVE BENDING**

**X DIRECTION:**

\[ \# \text{ piles } = \begin{cases} 2 \\ y = 2 \text{ ft} \\ \# \text{ piles } = 1 \\ y = 4 \text{ ft} \\ \# \text{ piles } = 2 \\ y = 6 \text{ ft} \\ \# \text{ piles } = 1 \\ y = 8 \text{ ft} \\ \# \text{ piles } = 2 \\ y = 10 \text{ ft} \end{cases} \]

\[ M_u = 3259.28 \text{ kip-ft} \]

**Y DIRECTION:**

\[ \# \text{ piles } = \begin{cases} 6 \\ x = 2 \text{ ft} \\ \# \text{ piles } = 0 \\ x = 0 \text{ ft} \end{cases} \]

\[ M_u = 814.82 \text{ kip-ft} \]

**REINF:**

**X DIRECTION:**

\[ \phi = 0.9 \]

\[ \beta = 0.85 \]

\[ A_{s,c} = 16.94235 \text{ in}^2 \]

\[ \text{find } A_{s,min} \quad \text{max of:} \quad \begin{cases} 27.3587 \text{ in}^2 \\ 19.1808 \text{ in}^2 \end{cases} \]

\[ A_{s,min} = 27.3587 \text{ in}^2 \]

Check \[ A_o > A_{s,min} \] use \( A_{s,min} \)

\[ a = 8.2530 \text{ in} \quad < d? \quad \text{OK} \]

\[ c = 9.7094 \text{ in} \]
\[ \varepsilon_t = 0.0109 > 0.005 \quad \text{OK} \]

SPACING: \[ s_{\text{max}} = \text{lesser of:} \]
\[ 144 \text{ in} \]
\[ 18 \text{ in} \]

As c. = \[ 27.3587 \text{ in}^2 \]

bars used:

<table>
<thead>
<tr>
<th>#10 bars</th>
</tr>
</thead>
</table>

\[ A_s = 27.9400 \text{ in}^2 \quad \text{OK} \]

spacing = \[ 10.0909 \text{ in} < s_{\text{max}} \quad \text{OK} \]

Y DIRECTION:

\[ \phi = 0.9 \]
\[ \beta = 0.85 \]
\[ A_s = 4.2356 \text{ in}^2 \]

find \( A_{s_{\text{min}}} \) max of:
\[ 9.6125 \text{ in}^2 \]
\[ 6.3180 \text{ in}^2 \]

\[ A_{s_{\text{min}}} = 9.6125 \text{ in}^2 \]

Check \( A_s > A_{s_{\text{min}}} \) use \( A_{s_{\text{min}}} \)

a = \[ 1.0188 \text{ in} < d? \quad \text{OK} \]

b = \[ 1.1986 \text{ in} \]

\[ \varepsilon_t = 0.1096 > 0.005 \quad \text{OK} \]

SPACING: \[ s_{\text{max}} = \text{lesser of:} \]
\[ 144 \text{ in} \]
\[ 18 \text{ in} \]

As = \[ 9.6125 \text{ in}^2 \]

bars used:

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<thead>
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<th>#10 bars</th>
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</thead>
</table>

\[ A_s = 10.1600 \text{ in}^2 \quad \text{OK} \]

spacing = \[ 9.7500 \text{ in} < s_{\text{max}} \quad \text{OK} \]

NEGATIVE BENDING

X DIRECTION:

<table>
<thead>
<tr>
<th># piles = 2</th>
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</thead>
</table>

y = \[ 2 \text{ ft} \]

<table>
<thead>
<tr>
<th># piles = 1</th>
</tr>
</thead>
</table>

y = \[ 4 \text{ ft} \]

| # piles = 2 |
y = 6 ft
# piles = 1
y = 8 ft
# piles = 2
y = 10 ft
M_u = 1885.36 kip-ft

Y DIRECTION:
# piles = 6
x = 2 ft
# piles = 0
x = 4 ft
M_u = 471.34 kip-ft

REINF:

X DIRECTION:
\( \phi = 0.9 \)
\( \beta = 0.8 \)
c = 20.76923077
\( c' = 24.7308 \) in
\( a' = 19.7846 \) in
\( C_c = 8960.06 \) kips
\( f's = 76.4463 \)
\( T_s = 2135.91 \) kips
\( A'_{s} = 32.59851477 \) in^2

bars used: 21 #11 bars
\( A_s = 32.7600 \) in^2  
OK
spacing = 10.5714 in  
\(< s_{\text{max}} \)  
OK
REQ'D BARS = 4.33 BARS

bars used: 21 #11 bars
\( A_s = 32.7600 \) in^2  
OK

REINF:

Y DIRECTION:
\( \phi = 0.9 \)
\( \beta = 0.8 \)
c = 20.76923077
\( c' = 24.7308 \) in
\( a' = 19.7846 \) in
\( C_c = 3148.13 \) kips
\( f's = 76.4463 \)
\( T_s = 776.69 \) kips
\( A'_{s} = 9.944914463 \) in^2
bars used: 8 #10 bars

\[ A_s = 10.1600 \text{ in}^2 \quad \text{OK} \]
 spacing = 27.7500 in  \text{NG}  
REQ'D BARS= 4.33 BARS

bars used: 8 #10 bars

10.1600 \text{ in}^2 \quad \text{OK}
<table>
<thead>
<tr>
<th>Grade Beam Total Concrete:</th>
<th>5090 lb concrete</th>
<th>60 ksi steel</th>
<th>400 psi</th>
<th>300 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Stories:</td>
<td>5</td>
<td>20546 5 ft</td>
<td>1912.38285 m$^3$</td>
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</tr>
<tr>
<td>Height (Roof):</td>
<td>$67$ m$^2$</td>
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<tr>
<td>Height (Max H):</td>
<td>$74$ m$^2$</td>
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</tr>
<tr>
<td>Type</td>
<td>Count</td>
<td>Area (m$^2$)</td>
<td>Volume (m$^3$)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>GB1</td>
<td>1</td>
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<td>0.00465044</td>
<td></td>
</tr>
<tr>
<td>GB2</td>
<td>1</td>
<td>0.506594644</td>
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### Slab

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<tr>
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<th>Count</th>
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<th>Volume (m$^3$)</th>
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### Ties Longitudinal

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</thead>
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<tr>
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<td>0.00005645</td>
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<tr>
<td>PC2</td>
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<td>0.00005645</td>
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<tr>
<td>PC3</td>
<td>1</td>
<td>0.00059464</td>
<td>0.00005645</td>
</tr>
<tr>
<td>PC4</td>
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### Ties Transversal

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<tbody>
<tr>
<td>GB1</td>
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### Piles Reinforcement

<table>
<thead>
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<th>Count</th>
<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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</thead>
<tbody>
<tr>
<td>PC1</td>
<td>1</td>
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<td>0.00005645</td>
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<tr>
<td>PC2</td>
<td>1</td>
<td>0.00059464</td>
<td>0.00005645</td>
</tr>
<tr>
<td>PC3</td>
<td>1</td>
<td>0.00059464</td>
<td>0.00005645</td>
</tr>
<tr>
<td>PC4</td>
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### Pile Total Concrete

<table>
<thead>
<tr>
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<th>Count</th>
<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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</thead>
<tbody>
<tr>
<td>GB1</td>
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<td>0.00059464</td>
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</table>

### Pile Cap Reinforcement

<table>
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<th>Count</th>
<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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<tbody>
<tr>
<td>PC1</td>
<td>1</td>
<td>0.00059464</td>
<td>0.00005645</td>
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<tr>
<td>PC2</td>
<td>1</td>
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<td>0.00005645</td>
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<td>PC3</td>
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<td>PC4</td>
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### Pile Cap Total Volume

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<th>Count</th>
<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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</thead>
<tbody>
<tr>
<td>GB1</td>
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<td>0.00005645</td>
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</table>

### Slab Reinforcement

<table>
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<tr>
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<th>Count</th>
<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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<tbody>
<tr>
<td>GB1</td>
<td>1</td>
<td>0.00059464</td>
<td>0.00005645</td>
</tr>
<tr>
<td>GB2</td>
<td>1</td>
<td>0.00059464</td>
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### Slab Total Area:

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<tr>
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<th>Area (m$^2$)</th>
<th>Volume (m$^3$)</th>
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<tbody>
<tr>
<td>GB1</td>
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### Slab Total Volume:

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<th>Area (m$^2$)</th>
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<tbody>
<tr>
<td>GB1</td>
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<td>0.00005645</td>
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### Slab Reinforcement

#### Depressed Slab

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<tr>
<th>Type</th>
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<th>Size (in²)</th>
<th>Bar Count</th>
<th>total</th>
<th>Size (in²)</th>
<th>Bar Count</th>
<th>total</th>
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</thead>
<tbody>
<tr>
<td>Slab</td>
<td>1</td>
<td>0.00188889</td>
<td>7</td>
<td>0.00188889</td>
<td>30</td>
<td>0.01750</td>
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### Slab Total

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Slab</td>
<td></td>
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</table>

### Slab Total Steel

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<tbody>
<tr>
<td>Slab</td>
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### Slab Total Concrete

<p>| | | | | |</p>
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<tbody>
<tr>
<td>Slab</td>
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### Slab Reinforcement

#### 2-1/2" Metal Deck

<table>
<thead>
<tr>
<th>Decking</th>
<th>2nd Floor</th>
<th>3rd Floor</th>
<th>4th Floor</th>
<th>5th Floor</th>
<th>Roof Total</th>
<th>Rooftop Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ft²)</td>
<td>Volume (ft³)</td>
<td>Area (ft²)</td>
<td>Volume (ft³)</td>
<td>Area (ft²)</td>
<td>Volume (ft³)</td>
</tr>
<tr>
<td>2-1/2&quot; Metal Deck</td>
<td>1338.5</td>
<td>3651.2</td>
<td>1338.5</td>
<td>3651.2</td>
<td>1338.5</td>
<td>3651.2</td>
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### Slab Total

<p>| | | | | |</p>
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<tbody>
<tr>
<td>Slab</td>
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</table>

### Slab Total Steel

<p>| | | | | |</p>
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<tbody>
<tr>
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### Slab Total Concrete

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### Slab Reinforcement

#### 2-1/2" Metal Deck

<table>
<thead>
<tr>
<th>Decking</th>
<th>2nd Floor</th>
<th>3rd Floor</th>
<th>4th Floor</th>
<th>5th Floor</th>
<th>Roof Total</th>
<th>Rooftop Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ft²)</td>
<td>Volume (ft³)</td>
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<td>Volume (ft³)</td>
</tr>
<tr>
<td>2-1/2&quot; Metal Deck</td>
<td>1338.5</td>
<td>3651.2</td>
<td>1338.5</td>
<td>3651.2</td>
<td>1338.5</td>
<td>3651.2</td>
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### Slab Total

<p>| | | | | |</p>
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<tbody>
<tr>
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### Slab Total Steel

<p>| | | | | |</p>
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### Slab Total Concrete

<p>| | | | | |</p>
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<thead>
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<tbody>
<tr>
<td>Slab</td>
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### Slab Total

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Slab</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width (ft)</td>
<td>Thickness (ft)</td>
<td>Volume (ft^3)</td>
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<tr>
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**Bolts/Anchor Bolts:**

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<th>Width (ft)</th>
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<th>Conc (ft)</th>
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<tbody>
<tr>
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<td>4.275</td>
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<td>4.275</td>
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<td>4.275</td>
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<tr>
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**Vol (ft^3) total:**

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<td>125.7</td>
<td>2nd</td>
</tr>
<tr>
<td>122.5</td>
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<tr>
<td>82.7</td>
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**Mech. Stud Wall:**

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<th>Conc (ft)</th>
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**Vol (ft^3) total:**

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>47.7</td>
<td>Total</td>
</tr>
</tbody>
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**Bolts/Anchor Bolts:**

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<th>Conc (ft)</th>
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<tr>
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**Vol (ft^3) total:**

<table>
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<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.7</td>
<td>Total</td>
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### Project:
- **UPDATED Coleman Highlands Building 1**
- **Story Height:** 14.5 ft
- **Total Area:** 34316 ft²
- **Location:** San Jose, California
- **No. Stories:** 5
- **Height (Roof):** 74 ft
- **Height (Mech):** 87 ft

### Foundation Details:

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<th>No.</th>
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<th>Diameter(ft)</th>
<th>Area (ft^2)</th>
<th>Volume Per (ft^3)</th>
<th>Total Volume (ft^3)</th>
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</thead>
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<td>807.271201000</td>
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</table>

### Extras:
- pile caps, grade beams and pilasters (and all other) = 4000psi
- 5000 ksi grout slab/fill = 3000 psi
- 50 ksi steel A99S STEEL = 0.2836 #/in³
- 35 psi (DF-L)

### Type Piles per Count Length (ft) Diameter (ft) Area (ft^2) Volume Per (ft^3) Total (ft^3)

| PC1 | 50 | 1  | 0.785398163 | 39.26990817 | 117.807597521 |
| PC2 | 50 | 1  | 0.785398163 | 78.53981634 | 397.69908178  |
| PC3 | 50 | 1  | 0.785398163 | 117.80759752| 595.39908178  |
| PC9 | 50 | 1  | 0.785398163 | 388.4063901 | 1942.0319005  |
| TPC5| 60 | 1.166666667 | 1.069014167 | 320.7042501  | 962.1127502   |
| PC8 | 60 | 1.166666667 | 1.069014167 | 513.1246010  | 3078.753606   |
| PC9 | 60 | 1.166666667 | 1.069014167 | 760.0030001  | 4560.018606   |

### Pile Total TIMBER DF-L:
- Sum = 13023.21 ft³

### Grade Beam:
- **Type** | **Length(ft)** | **Count** | **Size** | **Area (ft²)** | **Volume (ft³)** | **Total (ft³)**
- GB1 | 20.5 | 2 | 2' x 2' | 8 | 2.0 | 160 |
- GB2 | 14.0 | 2 | 3' x 3' | 9 | 3.0 | 270 |

### Grade Beam Total Concrete:
- Sum = 13217.83 ft³

### Pile Cap:

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<th>Total (ft³)</th>
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<td>0.00548611</td>
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<td>0.135</td>
<td>0.00884996</td>
<td>0.135</td>
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</table>

### Pile Cap Reinforcement:

<table>
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<th>Type</th>
<th>Count</th>
<th>Area (ft²)</th>
<th>Bar Count</th>
<th>Total Area (ft²)</th>
<th>Bar Count</th>
<th>Total Area (in²)</th>
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<tr>
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<td>0.1095</td>
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<td>0.2767</td>
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</table>

### Foundation System:
- **Pile:**
- **Pile Cap:**
- **Pile Cap Reinforcement:**
- **Grade Beam:**
- **Grade Beam Reinforcement:**
- **Slab:**
- **Slab Reinforcement:**

### Slab:
- **Type** | **Count** | **Size** | **Area (ft²)** | **Volume (ft³)** | **Total (ft³)**

### Slab Total Concrete:
- Sum = 3973275.00 ft³

### pg. 49
### Decking:

<table>
<thead>
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<th>Floor</th>
<th>Volume (ft³)</th>
<th>Volume (ft³)</th>
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<tr>
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<td>3rd</td>
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<tr>
<td>4th</td>
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<tr>
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<tr>
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### Framing System:

- **2-1/2" NW Conc. Over 3" Comp. Metal Deck**
- **12" Concrete Slab**
- **3" Steel Deck**
- **3" Concrete Slab**

### Beams:

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<th>Beam</th>
<th>Count</th>
<th>Avg Length</th>
<th>Count</th>
<th>Avg Length</th>
<th>Count</th>
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<th>Count</th>
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<th>Count</th>
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</thead>
<tbody>
<tr>
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<td>6</td>
<td>16</td>
<td>5</td>
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<td>16</td>
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<td>16</td>
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<td>16</td>
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### Roof: Count Avg Length Count Avg Length Count Avg Length Count Avg Length Count Avg Length Count Avg Length

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<td>6390.625</td>
<td>6250.625</td>
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<td>46385.8</td>
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<tr>
<td>46491.625</td>
<td>46529.625</td>
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</table>

### Panels:

**W18-11** 36" strip

- **Area:** 61.5 inches
- **Volume:** 3.758L1033

### For 36" Strip:

- **Material:** 61.5 inches
- **Total Conc:** 2856.525 ft³
- **Total Sheet:** 27643.0079 ft³

### Beams:

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<th>Count</th>
<th>Avg Length</th>
<th>Count</th>
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### Roof: Count Avg Length Count Avg Length Count Avg Length Count Avg Length Count Avg Length Count Avg Length

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<td>46385.8</td>
</tr>
<tr>
<td>46491.625</td>
<td>46529.625</td>
</tr>
</tbody>
</table>

### Plates:

**W18-11** 36" strip

- **Area:** 61.5 inches
- **Volume:** 3.758L1033

### For 36" Strip:

- **Material:** 61.5 inches
- **Total Conc:** 2856.525 ft³
- **Total Sheet:** 27643.0079 ft³
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<th>Height (ft)</th>
<th>Thickness (ft)</th>
<th>Volume (ft³)</th>
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<th>Width ft</th>
<th>Steel Area ft²</th>
<th>Concrete ft³</th>
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</tr>
<tr>
<td></td>
<td>WB 12</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.205</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>WB 11</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.25</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>WB 10</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.205</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>WB 9.5</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.15643939</td>
<td>35.1781862</td>
</tr>
<tr>
<td>1BF-4</td>
<td>WB 14.5</td>
<td>2</td>
<td>25.5</td>
<td>2</td>
<td>0.31723879</td>
<td>59.6568893</td>
</tr>
<tr>
<td></td>
<td>WB 13</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.28875915</td>
<td>55.8679487</td>
</tr>
<tr>
<td></td>
<td>WB 12</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.27085999</td>
<td>49.7953786</td>
</tr>
<tr>
<td></td>
<td>WB 11</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.25969759</td>
<td>43.7213535</td>
</tr>
<tr>
<td></td>
<td>WB 10</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.205</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>WB 9.5</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.15643939</td>
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<td>WB 9</td>
<td>2</td>
<td>22.5</td>
<td>2</td>
<td>0.205</td>
<td>45</td>
</tr>
</tbody>
</table>

### General:

- Total: 975.105871 ft² 67.09722222 ft³ 97703.8784 lbs
- 477801.8768 10064.58333 lbs 77.3618938

### Connections:

- **1BF-1**:
  - Roof: 0.51664667
  - Bolts/Anchor Bolts:
    - 5th: 0.51664667 1BF-1 (20) - 2" DIA
    - 4th: 0.51664667 (20) 2.25" DIA
    - 3rd: 0.51664667 (22) 2" DIA
    - 2nd: 0.30333333 (22) 2" DIA
    - Base: 10.3070327 1BF-1 (36) 1.5" DIA

- **1BF-2**:
  - Roof: 0.51664667
  - 5th: 0.51664667 1BF-2 (20) 2.25" DIA
  - 4th: 0.33333333 1BF-2 (20) 2" DIA
  - 3rd: 0.33333333 1BF-2 (20) 2" DIA
  - 2nd: 0.25 (22) 2.25" DIA
  - Base: 10.3070327 1BF-2 (36) 1.5" DIA

- **1BF-3**:
  - Roof: 0.51664667
  - Note: 0.51664667
  - 5th: 0.51664667 1BF-3 (22) 2" DIA
  - 4th: 0.51664667 (22) 2" DIA
  - 3rd: 0.51664667 (22) 2" DIA
  - 2nd: 0.25 (22) 2" DIA
  - Base: 7.65391585 1BF-3 (36) 1.5" DIA

- **1BF-4**:
  - Roof: 0.51664667
  - 5th: 0.51664667 1BF-4 (20) 2.25" DIA
  - 4th: 0.51664667 1BF-4 (20) 2" DIA
  - 3rd: 0.51664667 1BF-4 (20) 2" DIA
  - 2nd: 0.25 (22) 2" DIA
  - Base: 7.65391585 1BF-4 (36) 1.5" DIA

- Total: 42.79398148 ft³ 49.2130787 10064.58333 lbs 77.3618938

### Materials:

- MF: 7.33333333 3593.33333 lbs 56.5461204
- Total: 96232.66578 lbs
Appendix 5

Concrete Pile Coleman Highline Building 1 Results:

Table 1A: Summary Report

<table>
<thead>
<tr>
<th>Section</th>
<th>Activity category</th>
<th>Global warming CO2e</th>
<th>Global warming kg CO2e/m²</th>
<th>Mass of raw materials</th>
<th>Mass of raw materials kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ready mix concrete (A1-A2)</td>
<td>0.02</td>
<td>0.04</td>
<td>1.341</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>Precast concrete (A1-A3)</td>
<td>1.350</td>
<td>9.24</td>
<td>1.24</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>Cables (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>Steel (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>Aluminium (A1-A3)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>Glass (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>Glass (A1-A3)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>Insulation (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>Wood (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>Other materials (A1-A2)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>Other materials (A1-A3)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A1-A3</td>
<td>Concrete site</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A2</td>
<td>Transportation site</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A3</td>
<td>Site operations &amp; site waste handling</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A3B</td>
<td>Site setup / construction</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A3C</td>
<td>Construction site - material storage - materials</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A3D</td>
<td>Construction site - material storage - transport</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 2A

<table>
<thead>
<tr>
<th>No.</th>
<th>Resource</th>
<th>Cradle to gate impacts (A1-A3)</th>
<th>Of cradle to gate (A1-A3)</th>
<th>Sustainable alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete, ready mix</td>
<td>71 kg CO2e</td>
<td>45.2 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>2</td>
<td>Concrete, ready mix</td>
<td>60 kg CO2e</td>
<td>38.2 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>3</td>
<td>Fabricated hot-rolled structural sections</td>
<td>13 kg CO2e</td>
<td>8.2 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>4</td>
<td>Primary structural steel frame components</td>
<td>4.5 kg CO2e</td>
<td>2.8 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>5</td>
<td>Steel sheet profiles, rolled-formed</td>
<td>2.5 kg CO2e</td>
<td>1.6 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>6</td>
<td>Rebar</td>
<td>2.3 kg CO2e</td>
<td>1.5 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>7</td>
<td>Steel plate</td>
<td>2.4 kg CO2e</td>
<td>1.5 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>8</td>
<td>Hotdip structural steel sections</td>
<td>1.1 kg CO2e</td>
<td>0.7 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>9</td>
<td>Thin facing bricks</td>
<td>0.39 kg CO2e</td>
<td>0.2 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>10</td>
<td>Concrete, ready mix</td>
<td>0.11 kg CO2e</td>
<td>0.1 %</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>11</td>
<td>Steel stud framing for drywall/gypsum plasterboard per sq. meter of wall area (incl. air gaps per m³)</td>
<td>0.05 kg CO2e</td>
<td>0.0 %</td>
<td>Show sustainable alternatives</td>
</tr>
</tbody>
</table>
Figure 4A
Global warming t CO2e - Life-cycle stages

- 1 Ready mix concrete (A1-A3) - 28.0%
- 6 Bricks (A1-A3) - 0.6%
- A5 Construction - 3.5%
- 4 Steel (A1-A3) - 62.6%
- A4 Transportation - 5.2%

Figure 5A
Global warming t CO2e - Resource types

- Metals - 65.7%
- Ready-mix - 33.7%
- Bricks and ceramics - 0.7%
Figure 6A

Global warming (GWP) grouped by classification breakdown

![Chart showing global warming (GWP) grouped by classification breakdown]

Table 3A

<table>
<thead>
<tr>
<th>Category</th>
<th>A4 Transportation</th>
<th>A5 Construction</th>
<th>1 Ready mix concrete (A1-A3)</th>
<th>4 Steel (A1-A3)</th>
<th>6 Bricks (A1-A3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation, sub-surface, basement and retaining walls</td>
<td>0.057E+08</td>
<td>0.033E+08</td>
<td>0.057E+08</td>
<td>0.057E+08</td>
<td>0.057E+08</td>
</tr>
<tr>
<td>External walls and facade</td>
<td>0.033E+08</td>
<td>0.033E+08</td>
<td>0.033E+08</td>
<td>0.033E+08</td>
<td>0.033E+08</td>
</tr>
<tr>
<td>Columns and load-bearing vertical structures</td>
<td>0.027E+08</td>
<td>0.027E+08</td>
<td>0.027E+08</td>
<td>0.027E+08</td>
<td>0.027E+08</td>
</tr>
<tr>
<td>Internal walls and non-bearing structures</td>
<td>0.017E+08</td>
<td>0.017E+08</td>
<td>0.017E+08</td>
<td>0.017E+08</td>
<td>0.017E+08</td>
</tr>
<tr>
<td>Floor slabs, ceilings, roofing decks, beams and roof</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
</tr>
<tr>
<td>Construction site scenarios</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
<td>0.019E+08</td>
</tr>
</tbody>
</table>

Figure 7A: Embodied Carbon by Structure

![Chart showing embodied carbon by structure]
Appendix 6

Timber Pile Coleman Highline Building 1 Results:

Table 1B: Summary Report

One Click LCA Planetary results - Download Results Summary

One Click LCA Planetary reports the product cradle to gate (A1-A3) carbon impacts as well as material efficiency for your project. Biogenic carbon is not deducted from totals. You can compare number of designs to identify the most environmentally sustainable design, material and/or supplier. Results are also displayed per m2 Gross Internal Floor Area, if you have inputted area.

<table>
<thead>
<tr>
<th>Result category</th>
<th>Global warming tCO2 T</th>
<th>Global warming kg CO2/m2</th>
<th>Mass of raw materials t</th>
<th>Mass of raw materials kg/m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ready mix concrete (A1-A3)</td>
<td>737.2</td>
<td>-12%</td>
<td>3.58</td>
<td>-12%</td>
</tr>
<tr>
<td>2 Precast concrete (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Cement (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Steel (A1-A3)</td>
<td>1,836.01</td>
<td>-35%</td>
<td>8.92</td>
<td>-35%</td>
</tr>
<tr>
<td>5 Aluminium (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Bricks (A1-A3)</td>
<td>18.89</td>
<td>-1%</td>
<td>0.09</td>
<td>-1%</td>
</tr>
<tr>
<td>7 Glass (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Insulation (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Wood (A1-A3)</td>
<td>66.16</td>
<td>+100%</td>
<td>0.32</td>
<td>+100%</td>
</tr>
<tr>
<td>10 Gypsum (A1-A3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Other materials (A1-A2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1-A3 Construction Materials</td>
<td>2,658.06</td>
<td>-42%</td>
<td>12.01</td>
<td>-42%</td>
</tr>
<tr>
<td>A4 Transportation to site</td>
<td>145.03</td>
<td>-42%</td>
<td>0.7</td>
<td>-42%</td>
</tr>
<tr>
<td>A5 Construction/installation process</td>
<td>110.29</td>
<td>+100%</td>
<td>0.54</td>
<td>+100%</td>
</tr>
</tbody>
</table>

The percentages given in red denote the percent change from the concrete foundation option.

Table 2B

<table>
<thead>
<tr>
<th>No.</th>
<th>Resource</th>
<th>Cradle to gate impacts (A1-A3)</th>
<th>Of cradle to gate (A1-A3)</th>
<th>Sustainable alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete, ready mix</td>
<td>71 kg CO2</td>
<td>49.2%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>2</td>
<td>Concrete, ready mix</td>
<td>44 kg CO2</td>
<td>30.6%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>3</td>
<td>Fabricated hot-rolled structural sections</td>
<td>13 kg CO2</td>
<td>8.9%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>4</td>
<td>Primary structural steel frame components</td>
<td>4.5 kg CO2</td>
<td>3.1%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>5</td>
<td>Softwood lumber</td>
<td>4.2 kg CO2</td>
<td>2.9%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>6</td>
<td>Steel sheet pannels, m sq formed</td>
<td>2.5 kg CO2</td>
<td>1.7%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>7</td>
<td>Steel plate</td>
<td>2.4 kg CO2</td>
<td>1.6%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>8</td>
<td>Retard</td>
<td>1.3 kg CO2</td>
<td>0.9%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>9</td>
<td>Hollow structural steel sections</td>
<td>1.1 kg CO2</td>
<td>0.8%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>10</td>
<td>Thin facing bricks</td>
<td>0.39 kg CO2</td>
<td>0.3%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>11</td>
<td>Concrete, ready mix</td>
<td>0.11 kg CO2</td>
<td>0.1%</td>
<td>Show sustainable alternatives</td>
</tr>
<tr>
<td>12</td>
<td>Steel stud framing for drywall/gypsum plasterboard per sq meter of wall area (incl. air gaps per m3)</td>
<td>0.03 kg CO2</td>
<td>0.0%</td>
<td>Show sustainable alternatives</td>
</tr>
</tbody>
</table>
Figure 4B

Global warming t CO2e - Life-cycle stages

- 1 Ready mix concrete (A1-A3) - 25.3%
- 6 Bricks (A1-A3) - 0.6%
- A4 Transportation - 5.0%
- 4 Steel (A1-A3) - 63.0%
- 9 Wood (A1-A3) - 2.3%
- A5 Construction - 3.8%

Figure 5B

Global warming t CO2e - Resource types

- Metals - 66.0%
- Wood - 2.8%
- Ready mix - 30.5%
- Bricks and ceramics - 0.7%
Figure 6B

Table 3B

<table>
<thead>
<tr>
<th>Category</th>
<th>A4 Transportation</th>
<th>A5 Construction</th>
<th>1 Ready mix concrete (A1-A3)</th>
<th>4 Steel (A1-A3)</th>
<th>6 Bricks (A1-A3)</th>
<th>9 Wood (A1-A3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation, sub-surface, basement and retaining</td>
<td>73.525000136151073</td>
<td>37.40712507275446</td>
<td>457.9713055890147</td>
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<td>0</td>
<td>66.1659157878473</td>
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<tr>
<td>walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>External walls and facade</td>
<td>0.39</td>
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<td>0</td>
<td>0</td>
<td>18.6027071437334</td>
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<tr>
<td>Columns and load-bearing vertical structures</td>
<td>7.95324331820301</td>
<td>18.941402974401</td>
<td>401.09624880957151</td>
<td>564.7737006331439</td>
<td>0</td>
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<tr>
<td>Internal walls and non-bearing structures</td>
<td>0.0279</td>
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<td>0</td>
<td>0</td>
<td>2.9165705147495</td>
<td>0</td>
</tr>
<tr>
<td>Floor slabs, ceilings, roofing decks, beams and</td>
<td>33.36572151502354</td>
<td>52.91053720701988</td>
<td>278.1333040467204</td>
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<td>0</td>
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<td>roof</td>
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<td>Construction site scenarios</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 7B: Embodied Carbon by Structure

- Foundations and substructure - 51%
- Vertical structures and facade - 6%
- Horizontal structures: beams, floors and roofs - 44%
Appendix 7: Drawings