thinness and thickness

building structure: spring 2017
MIT

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Design Concept

Our concept is to create a roof structure that both visually and structurally contrasts thinness and thickness. The roof, a simple frame structure, is supported by four folded columns that can be read as an almost triangle from its four facades. The precedents we took on are Ludwig Mies van der Rohe’s Crown Hall and Anton Garcia Abril’s Cervantes Theater.

Design Load

We assume that all forces are applied to the eight highlighted beams, and therefore we would be able to calculate the maximum dimension of the main structure.

Dead Load: 55 lbs/ft² → \( \omega_1 \)

Live Load: 30 lbs/ft² → \( \omega_2 \)

\[ \omega_1 = 55 \text{ lbs/ft}^2 \times \frac{170 \text{ ft}}{2} \times \frac{1}{2} \times \frac{1}{2} = 1.17 \text{ kips/ft} \]

\[ \omega_2 = 30 \text{ lbs/ft}^2 \times \frac{170 \text{ ft}}{2} \times \frac{1}{2} \times \frac{1}{2} = 0.638 \text{ kips/ft} \]

We assume that all forces are applied to the eight highlighted beams, and therefore we would be able to calculate the maximum dimension of the main structure.

\[ V = 2 \times (4.37 + 3.58) \text{ in} \times 2 \times (170 \text{ ft} \times 12) = 3190 \text{ ft}^3 \]

\[ W = \sqrt{\rho} = 3190 \text{ ft}^3 \times 490 \text{ pcf} = 1560000 \text{ lbs} \]

Dead Load: \[ W = \frac{1560000 \text{ lbs}}{\rho} = \frac{54 \text{ lbs/ft}^2}{55 \text{ lbs/ft}^2} \]

\[ V(\text{column}) = 1 \text{ in} \times \{[(60 \text{ in} + 10 \text{ in}) \times 240 \text{ in}]/2\} = 8400 \text{ in}^2 \]

\[ 8400 \text{ in}^2 \times 2 \times 4 = 134400 \text{ in}^3 = 78 \text{ ft}^3 \]

\[ W(\text{column}) = 78 \text{ ft}^3 \times 490 \text{ pcf} = 38220 \text{ lbs} \]

Carbon Dioxide Emission of Steel:

\[ (1560000 + 38220) \text{ lbs} \times 1.5 = 2397330 \text{ lbs} \]

\[ V(\text{concrete infill in column}) = 242112 \text{ in}^3 = 140 \text{ ft}^3 \]

\[ W(\text{concrete infill in column}) = 140 \text{ ft}^3 \times 150 \text{ pcf} = 21000 \text{ lbs} \]

Carbon Dioxide Emission of Concrete:

\[ 21000 \text{ lbs} \times 0.2 = 4200 \text{ lbs} \]

\[ (2397330 + 4200) \text{ lbs} / (170 \times 170) \text{ ft} = 83 \text{ lbs/ft}^2 \]
Global Equilibrium

The span of the cantilever is 1/5 of the entire span.

We aim to figure out the worst loading scenario, and therefore we want to look at both the symmetrical and asymmetrical loading conditions. The diagram to the left is the symmetrical loading graph.

\[ \omega_1 + \omega_2 = 1.81 \text{ kips/ft} \]

\[ M_1 = \frac{1}{2} \times (\omega_1 + \omega_2) \times L_1^2 \]

\[ M_2 = \frac{1}{8} \times (\omega_1 + \omega_2) \times L_1^2 - M_1 \]

The diagram to the left is the asymmetrical loading graph.

\[ M_1' = \frac{1}{2} \omega_1 L_1^2 \]

\[ M_2' = \frac{1}{8} \times (\omega_1 + \omega_2) \times L_1^2 - M_1' \]

Bending

\[ \omega_1 = 1.17 \text{ kips/ft}, \omega_2 = 0.638 \text{ kips/ft}, \]

\[ L_1 = 35 \text{ ft}, L_2 = 100 \text{ ft} \]

\[ M_1 = \frac{1}{2} \times (\omega_1 + \omega_2) \times L_1^2 = 1110 \text{ kips/ft} \]

\[ M_2 = \frac{1}{8} \times (\omega_1 + \omega_2) \times L_1^2 - \frac{1}{2} \omega_1 L_1^2 = 1540 \text{ kips/ft} \]

\[ M_2 > M_1 \]

\[ S = \frac{M_2}{\sigma} = \frac{1540}{15 \text{ ksi}} = 1230 \text{ in}^3 \]

\[ S = \frac{h^2 b}{6} \rightarrow h = \sqrt{\frac{6S}{b}} \]

\[ \omega_1' = 0.138 \text{ kips/ft}, \omega_2' = 0.075 \text{ kips/ft}, \]

\[ L_1 = 35 \text{ ft}, L_2 = 100 \text{ ft} \]

\[ M_1' = \frac{1}{2} \times (\omega_1' + \omega_2') \times L_1^2 = 130 \text{ kips/ft} \]

\[ M_2' = \frac{1}{8} \times (\omega_1' + \omega_2') \times L_1^2 - \frac{1}{2} \omega_1 L_1^2 \]

\[ = 182 \text{ kips/ft} \]

\[ S = \frac{M_2'}{\sigma} = \frac{182}{15 \text{ ksi}} = 146 \text{ in}^3 \]

\[ S = \frac{h'^2 b'}{6} \rightarrow b' = \frac{6S'}{h'^2} \]

When \( h = 84 \text{ in} \),

\[ b = \frac{6 \times 146 \text{ in}^3}{(84 \text{ in})^2} = 0.125 \text{ in} \]

\[ \frac{1}{8} \]
Beam Buckling Analysis (Main)

We consider the upper 1/3 of the beam to be subjected to load and we aim to figure out the buckling situation for the main beam in this case.

\[ T = C = \frac{M_2}{\frac{2h}{3}} = \frac{3M_2}{2h} = 326 \text{ kips} \]

\[ I_1 = 2 \left( A_1 \frac{d^2}{12} + \frac{h b^3}{12} \right) = 2 \left( \frac{b}{2} \times \frac{h}{3} \times \frac{h^2}{3} \times \frac{h^2}{3} \right) = 16.5 \text{ in}^4 \]

\[ P_{cr} = \frac{\pi^2EI}{(KL)^2} = \frac{3.14^2 \times 29000 \text{kpsi} \times 16.5 \text{ in}^4}{(0.5 \times 5 \text{ ft})^2} = 1670 \text{ kips} \]

\[ 3T = 3 \times 326 \text{ kips} = 978 \text{ kips} \]

1670 kips > 978 kips \(\rightarrow\) No local buckling

Beam Buckling Analysis (Secondary)

We consider the upper 1/3 of the beam to be subjected to load and we aim to figure out the buckling situation for the secondary beam in this case.

\[ T' = C = \frac{M_2'}{\frac{2h}{3}} = \frac{3M_2}{2h} = 38.5 \text{ kips} \]

\[ I_1 = 2 \left( A_2 \frac{d^2}{12} + \frac{h b^2}{12} \right) = 2 \left( \frac{b}{2} \times \frac{h}{3} \times \frac{h^2}{3} \times \frac{h^2}{3} \right) = 3.11 \text{ in}^4 \]

\[ P_{cr} = \frac{\pi^2EI}{(KL)^2} = \frac{3.14^2 \times 29000 \text{kpsi} \times 3.11 \text{ in}^4}{(0.5 \times 5 \text{ ft})^2} = 988 \text{ kips} \]

\[ 3T' = 3 \times 38.5 \text{ kips} = 115.5 \text{ kips} \]

\[ P_{cr} > 3T' \rightarrow \text{No local buckling} \]
Shear Analysis

The intersection of beams is only half of the original size of the beam, and therefore we need to check the shear.

\[
A_{\text{required}} = \frac{\text{shear}}{\sigma} = \frac{90 \text{ kips}}{15 \text{ ksi}} = 6 \text{ in}^2
\]

\[
A = \frac{1}{2} b \times \frac{1}{2} h \times 2 = \frac{1}{2} \times 1 \text{ in} \times \frac{1}{2} \times 84 \text{ in} \times 2 = 42 \text{ in}^2
\]

\[A_{\text{required}} < A\]

Column Crushing Analysis

Here we only calculate the crushing possibility of steel, and we find out that it is already safe enough. Hence, we do not need to check the concrete crushing situation.

\[A_1 = 60 \text{ in} \times 1 \text{ in} = 60 \text{ in}^2\]

\[A_2 = (36 \text{ in} + 36 \text{ in}) \times 1 \text{ in} = 72 \text{ in}^2\]

Column Support:

\[
\frac{(30+55) \text{ lbs/ft}^2 \times (170 \text{ ft})^2}{12} \times \frac{1}{2} = 614 \text{ kips}
\]

\[A_{\text{required}} = 614 \text{ kips} = 50 \text{ in}^2\]

\[A_2 > A_1 > A_{\text{required}} \Rightarrow \text{No Crushing}\]

Column Buckling Analysis

Here we calculate the buckling possibility of steel, and we find out that it is already safe enough. Hence, we do not need to check the concrete buckling situation.

\[y = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2} \]

\[y_1 = 0.5 \text{ in}, y_2 = 18.5 \text{ in}\]

\[A_1 = 36 \text{ in} \times 1 \text{ in} = 36 \text{ in}^2, A_2 = 35 \text{ in} \times 1 \text{ in} = 35 \text{ in}^2\]

\[y = 9.37 \text{ in}\]

\[d_1 = y - y_1 = 9.37 \text{ in} - 0.5 \text{ in} = 8.87 \text{ in}\]

\[d_2 = y_2 - y = 18.5 \text{ in} - 9.37 \text{ in} = 9.13 \text{ in}\]

\[I = I_1 + A_1 d_1^2 + I_2 + A_2 d_2^2\]

\[= \frac{b h^3}{12} + A_1 d_1^2 + \frac{b h^3}{12} + A_2 d_2^2 = 9330 \text{ in}^4\]

\[P_u = \frac{\pi^2 E I}{(KL)^2} = 3.14^2 \times 129000 \text{ ksf} \times 9330 \text{ in}^4 = 94500 \text{ kips}\]

\[P_u = \frac{\pi^2 E I}{(KL)^2} = 3.14^2 \times 29000 \text{ ksf} \times 9330 \text{ in}^4 = 94500 \text{ kips}\]

\[614 \text{ kips} \times 3 = 1842 \text{ kips} < 94500 \text{ kips} \Rightarrow \text{No global buckling}\]
time machine tower

building structure
spring 2017
MIT

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Geometry

The overall geometry of the truss is like a time-machine that has wider top and bottom surfaces. The truss is constituted by four identical individual parts. The individual piece is illustrated in the diagram below. Two parts are attached at the edge, forming a group to cross attach with another group of two.
two-point perspective
green timber tower

independent studies: green architecture
spring 2015
brandeis university
prof. talinn grigor
Copenhagen, the city of towers, is full of spires and towers built nearly three centuries ago. The Green Timber Tower, located in Ekipagemastervej, however, is built with a contemporary frame, contrasting to the old towers around it. It is a modular design that works closely with nature and context.
modular design

design the core

- a box?

duplicate

each turns 90°
height: 2' | floor dimension: 1' x 1' 2" | scale: 1" = 8' 0"

main materials: timber, fishing line, foam board
portable housing project

independent studies: small architecture
fall 2015
brandeis university
prof. christopher abrams
The portable housing project is located near the Haymarket Square Farmer’s Market and the well-known Rose Fitzgerald Kennedy Greenway Conservancy, a linear urban park located in the midst of several downtown neighborhoods of Boston.

There is often a traffic congestion on Blackstone Street, which is next to the site, because of the unlimited commercial activities. In addition to promoting a new living style, the portable housing project also aims to solve the disorder in this forgotten area.

The removal of the current market and gathering merchants to a new market site clears Blackstone Street, alleviating the traffic and increasing the accessibility to the portable housing project. The circulation for the larger context is also benefited.
16 different forms have been studied. Each form is composed by two identical cuboids. The dimension of each cuboid is 6.6' (width) x 9.8' (length) x 6.6' (height). These cuboids can be transported by container trucks. Owners can easily bring their entire homes to another city.

The one with blue circle background has been chosen because it, although seemingly simple, is easy to assemble and disassemble. This characteristic is the essence of being portable. This simple form also optimizes effective use of space and admission of sunlight.
height: 1' | floor dimension: 1' 3" x 8" | scale: 1" = 8' 0"

main materials: timber, illustration board
Crane is an important part of the portable housing project. Unlike other projects in which cranes only exist and function in their construction, portable housing project permanently keeps its crane on site to move components.
charles river cabin

modern architecture
fall 2014
brandes university
prof. talinn grigor
Charles River Cabin is located in Waltham, MA. It sits on the north bank of Charles River, and is close to the Brandeis campus. It is a single family house with a living room, three bedrooms, and a small cantilevered sun room.
fine arts quad cabin

independent studies: small architecture fall 2015 brandeis university

prof. christopher abrams
Designed to support the studio art program at Brandeis University, this visionary cabin locates on a hill between a forested lowland and the fine arts quad. The first floor of this cabin is facing the woods, giving inhabitants a great view to boost artistic creation. The second floor is facing Goldman-Schwartz studio to stress its relation with the Fine Arts Department.
height: 0.9' | floor dimension: 0.78' x 1.18' | scale: 3/8" = 1' 0"

main materials: bass wood, foam board, acetate board, aluminum, cardboard, chalk