

Arch 631: Structure System

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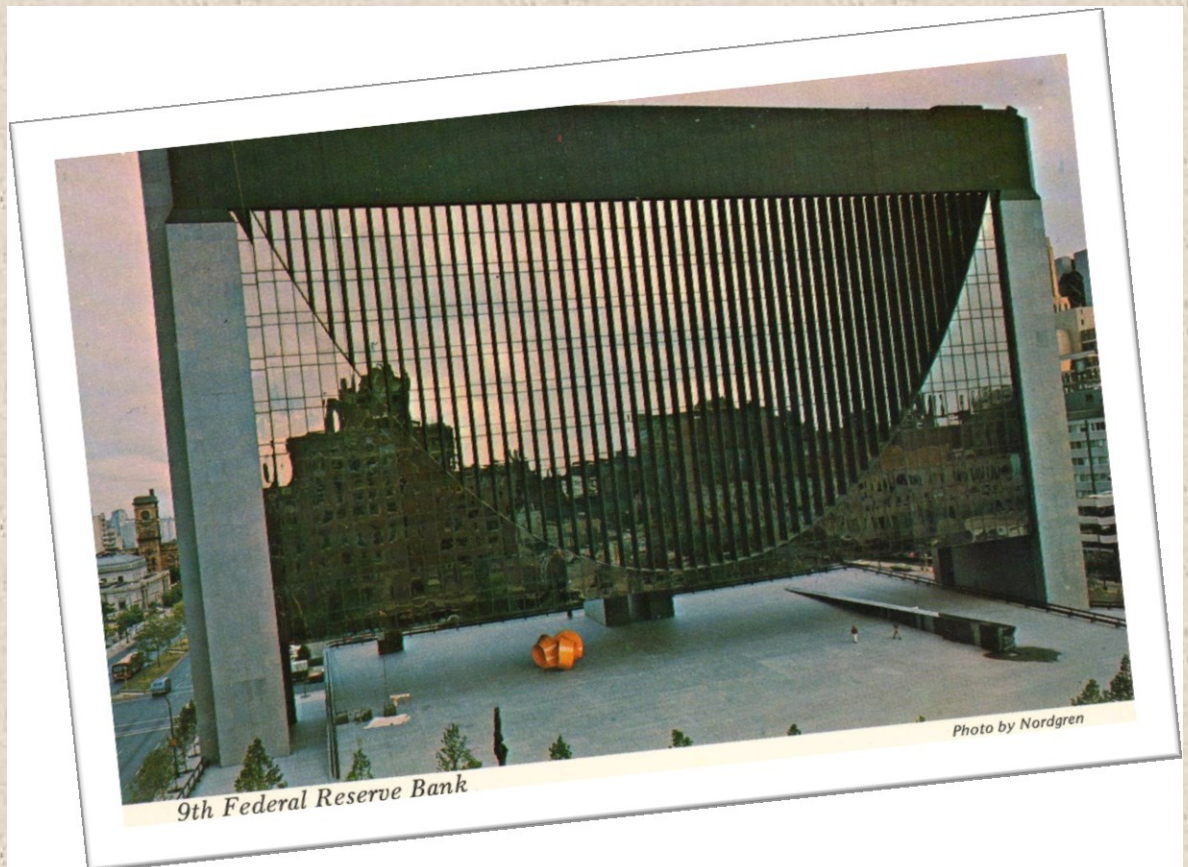
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11/22/14

Case Study

The Federal Reserve Bank of Minneapolis



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Structural Analysis

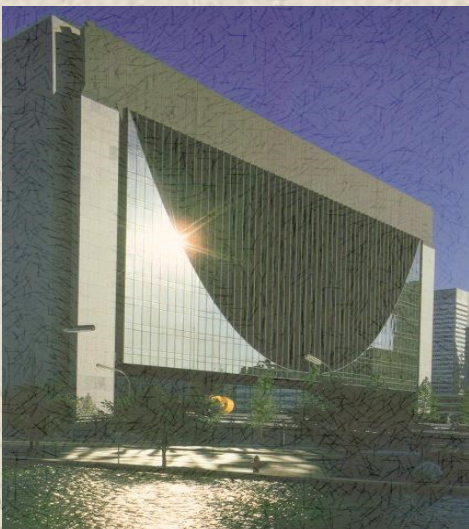
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Summary

introduction

The Federal Reserve Bank of Minneapolis is a famous suspended building. The structural form of the building was built referring to the suspension bridges. The two tall towers on the sides are of the same function of the bridge piers. Between the two towers, steel trusses were set at the top; and vertical steel columns were hanging on the trusses to hold the building.

The vault and safe of the bank were built under ground. Above the ground, there are 16 stories of offices. The covered area of the building only comes from the two tall towers, which are 100 meters apart from each other. Between these two towers, the 16-story-office space is built on stilts, so that the space underneath is connected to the square in front of the building. This design works not only on the function but also on the façade. This building represents the unique structural form from using different types of windows to distinguish the inside and outside of the hanging cable.



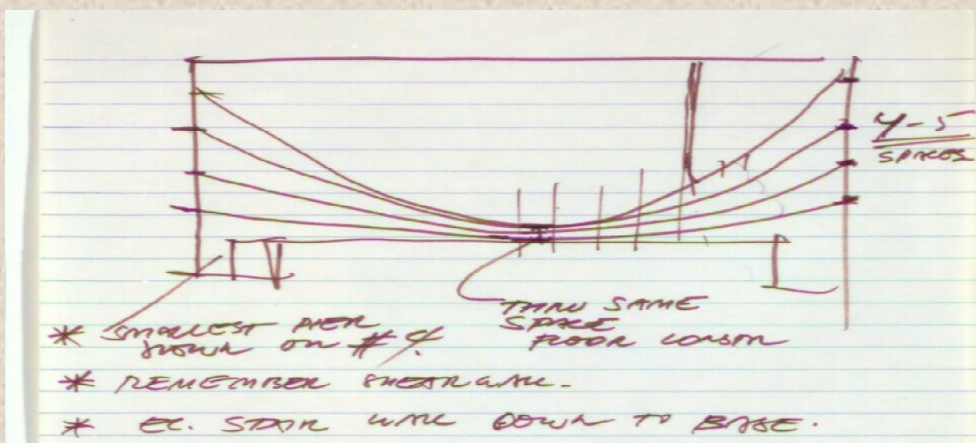
- Location: Minneapolis
- Building Size: 522,656 square feet total
- Loading: Six(6) internal loading docks
- Year Built: 1970
- Architect: Gunnar Birkets
- Area: Up to 37,000 square foot data center space available

Generally speaking, there are several structural systems that can be applied to a 16-story high-rise building with efficiency and capability of supporting the loads. To be distinct, the designer of the Federal



Reserve Bank of Minneapolis did not choose any of the traditional structural systems; instead, he made it the first suspended building. It is universally acknowledged that a suspension system is usually applied to bridges, which do not need to hold massive loads, for its long-span capability and ability to withstand lateral movement. When putting a suspension system into a building, however, difficulties may arise because buildings have larger loads than bridges, and it is tolerable for bridges to sway— not buildings. How these difficulties are solved is what brought about our interest in the structure.

In this study, we analyze the concept of the design, functions, and circulation to figure out why the suspension structure was chosen. Then we discover how this structural system works on the building by analyzing the construction and the reaction of loading through *Multiframe*.



background

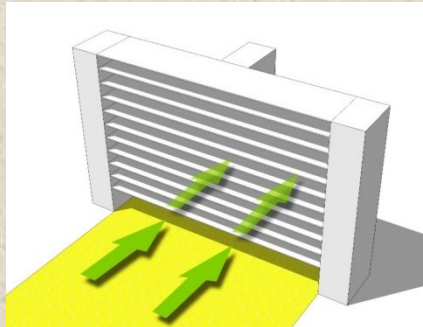
ARCHITECT

Gunnar Birkerts was born in Riga, Latvia, in 1925. The son of scholars and folklorists, **Birkerts** was surrounded by the history of his country from an early age. The stories his parents shared with him became a source of creative inspiration that influenced **Birkerts'** work throughout his career as both an architect and an educator. He graduated from the technical university **Stuttgart** in 1949, with the degree of **diplom-Ingenieur** architect. He is the professor of architecture at university Michigan in 1959–1990. He is one of America's greatest post-war architects, transformed modernism with metaphor and materiality.

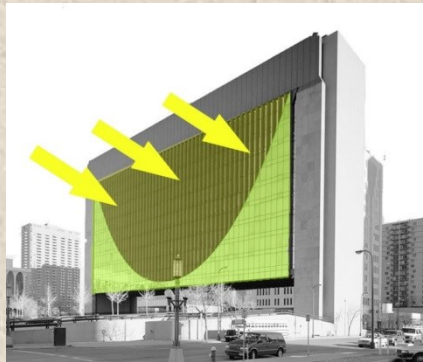


DESIGN CONCEPT

This building is required to span over the public square underneath so that the landscape would not be cut off by the building. This concept created an **open space** which can offer **broad views** of the city and a place people can stay.



Another important purpose is to bring in as much **sunlight** as possible. To give the people working inside great views of the city, a **glass curtain wall** was put on the whole front facade. To achieve this, the engineers Skilling Helle Christiansen and Robertson chose the **suspension system**.

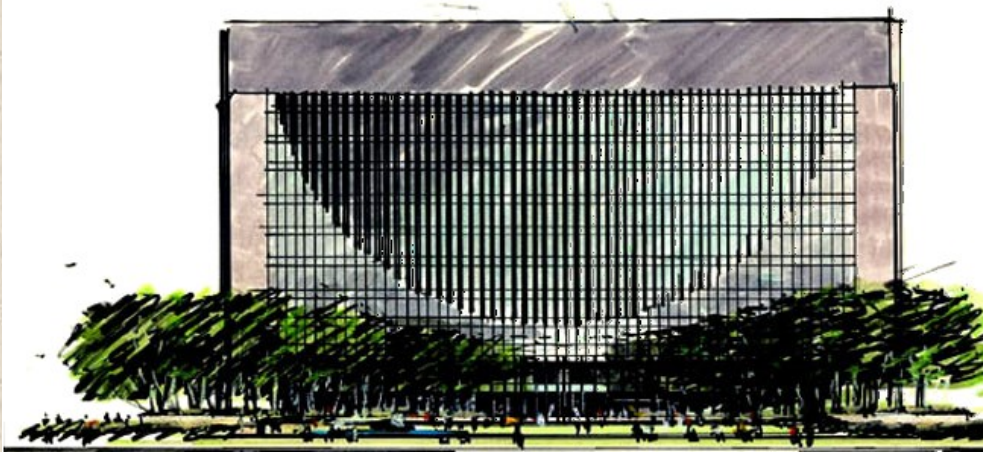


This remarkable building consists of an office tower that bridges 330ft (100 m) across the top of the plaza and a high-security facility below the plaza. The building epitomizes the effective use of tension in its application to high-rise buildings.

STRUCTURAL SYSTEM

Suspended buildings, which have roofs or floors hanging from the towers, uses scattered steel cables to hold the loads. It gives full play to the mechanical properties of steel, which can increase the span of the structure and reduce the material consumption. It also makes the building form more flexible. With the development of the theory of structural mechanism and steel strength increasing, suspension systems are gradually applied into buildings widely since the 1950s. The suspension systems can be applied in both single-story buildings and high-rise buildings.

High-rise suspended buildings are mainly consist of towers, hangers, steel cables and floor slabs. The towers are usually constructed in reinforced concrete structural systems and steel structural systems. The inner sides of the floors are supported by the wellbores, when the outside hang by steel cables. All of the loads are transferred to the center or at the ends of the towers, and then to the foundations. Referring to the levels, planes and the three-dimensional shape of the buildings, it can be top suspension or grouping suspension, and the ways of suspension can be separated into truss suspension and inclined-tensioned-rod suspension.



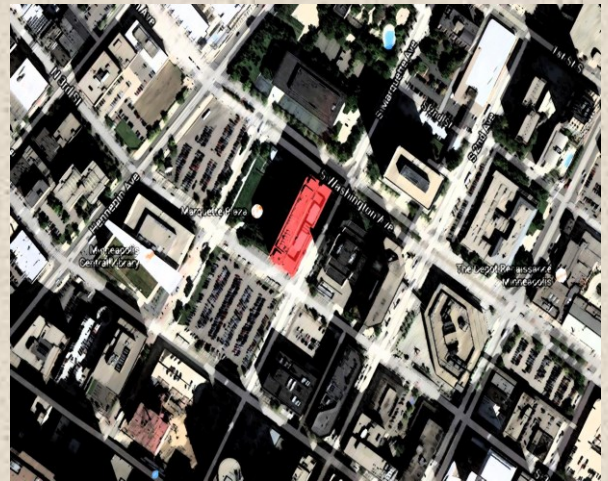
Edward R. Roybal Building
9 Sept 97

Architectural analysis

LOCATION

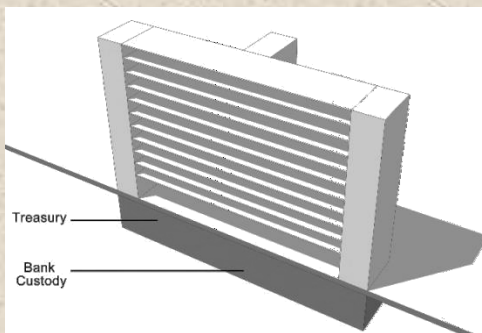
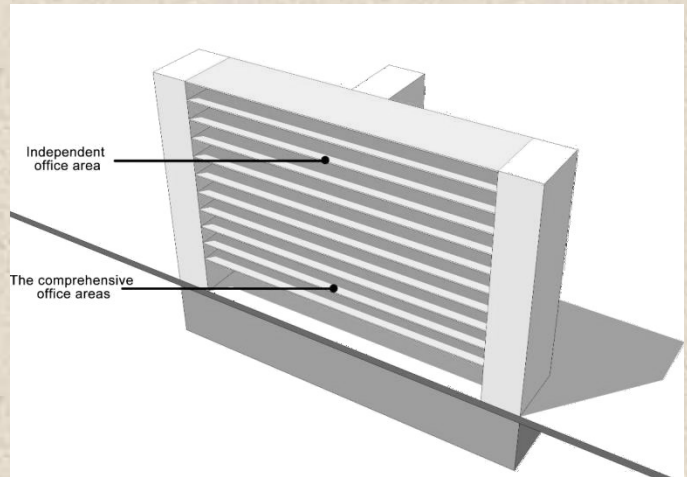
Marquette Plaza is a high-rise building in downtown Minneapolis, Minnesota located at 250 Marquette Avenue.

The Federal Reserve Bank of Minneapolis overlooks the Mississippi River from the historic Bridgehead Site. The 8-acre site is at the junction of the City's two major streets: Nicollet Mall and Hennepin Avenue. North of the site is a Riverfront park and the West River Parkway. To the south and west is the Historic Warehouse District, dating back to the late 19th century. Now the Federal Reserve Bank of Minneapolis becomes the Marquette Plaza which boasts wide-open floor plates of approximately 37,000 square feet – perfectly suited to contemporary, open-office designs.



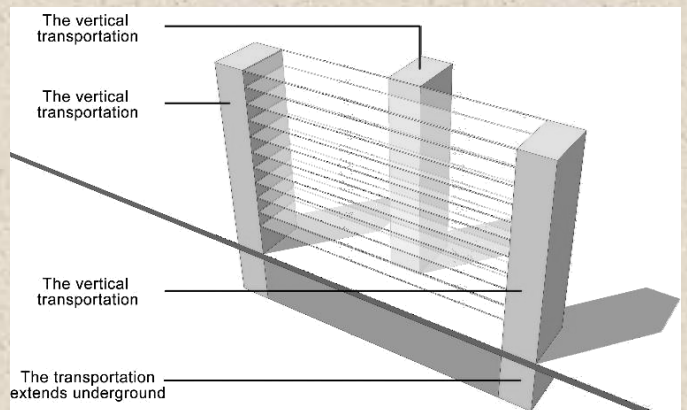
FUNCTIONS

The functions of the 16-story main building are basically for offices and management. Independent office areas are on the top floor, comprehensive office areas are at the bottom floors.



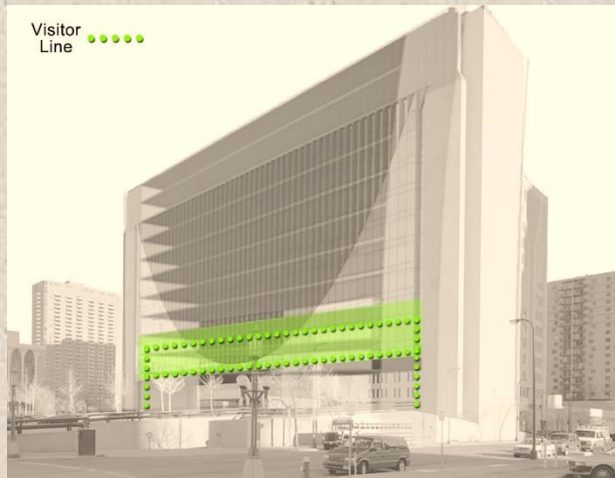
Bank vaults and parking garage are built in underground. It gives space to the continuous square and reduces the building-covered area.

The three towers of the building are of the vertical circulation space. The two on both sides also carry the vertical loads of the building. The one in the middle keeps the building away from swaying.

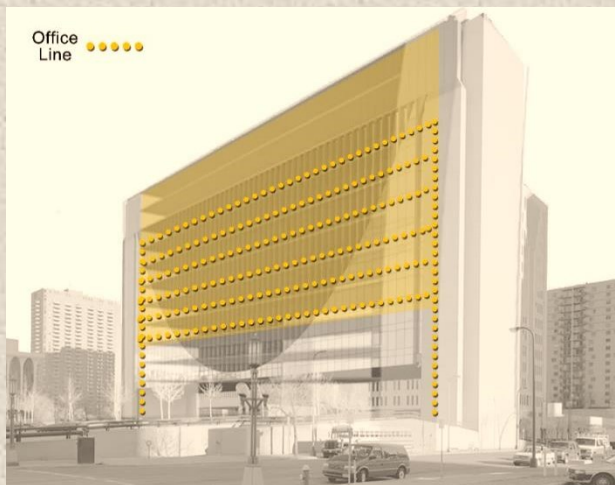


CIRCULATION

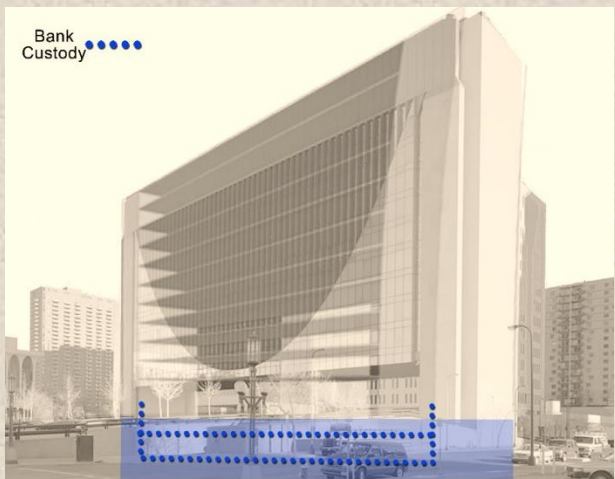
The visiting route are mainly at the bottom floors, and connect to the outside through the two towers.



Employees of the bank go to their working places through three towers.



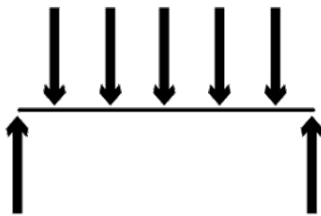
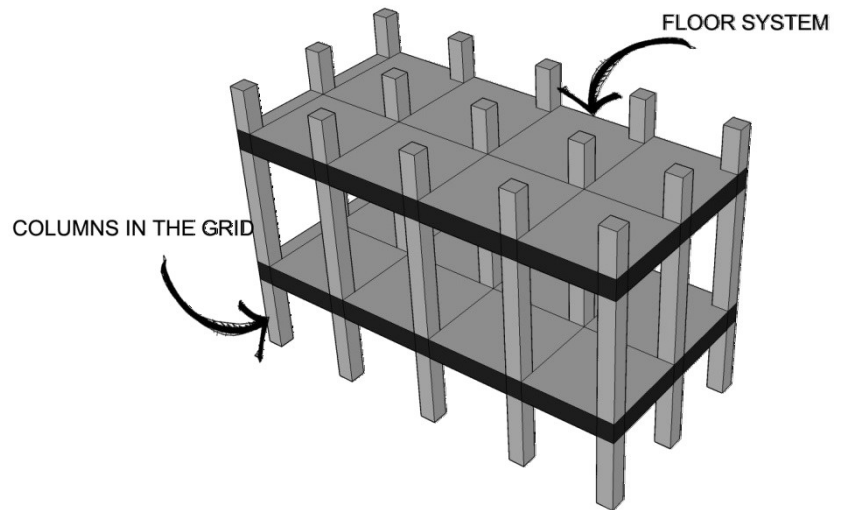
The vaults of the bank has a private circulation .



structural analysis

CHARACTERISTICS

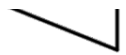
Buildings are usually designed with rectangular grid and columns are usually designed at the intersection of the grid lines.



LOAD

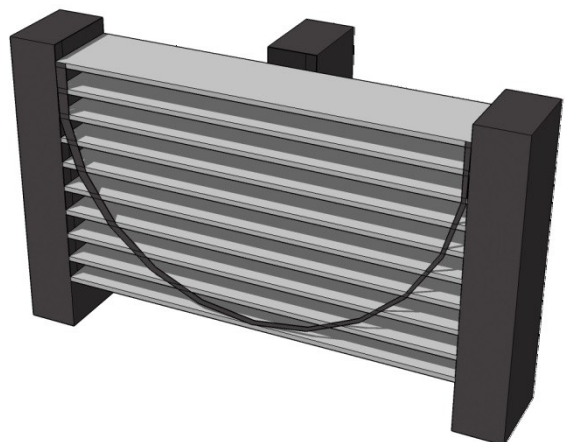


MOMENT

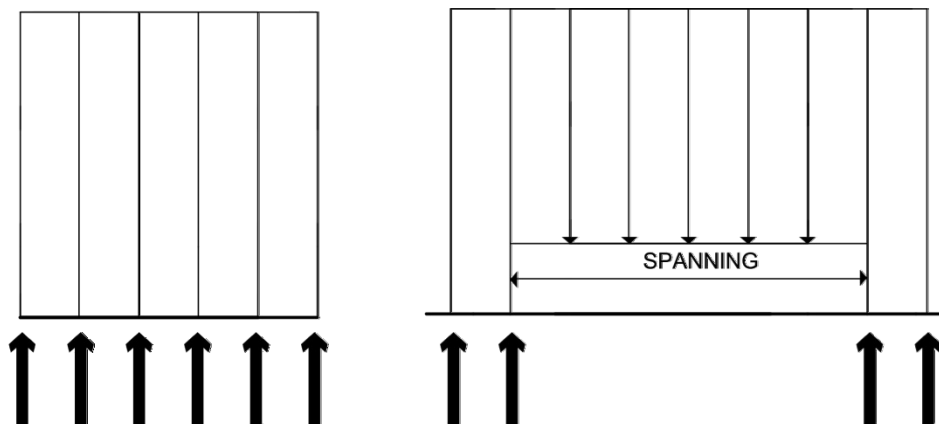
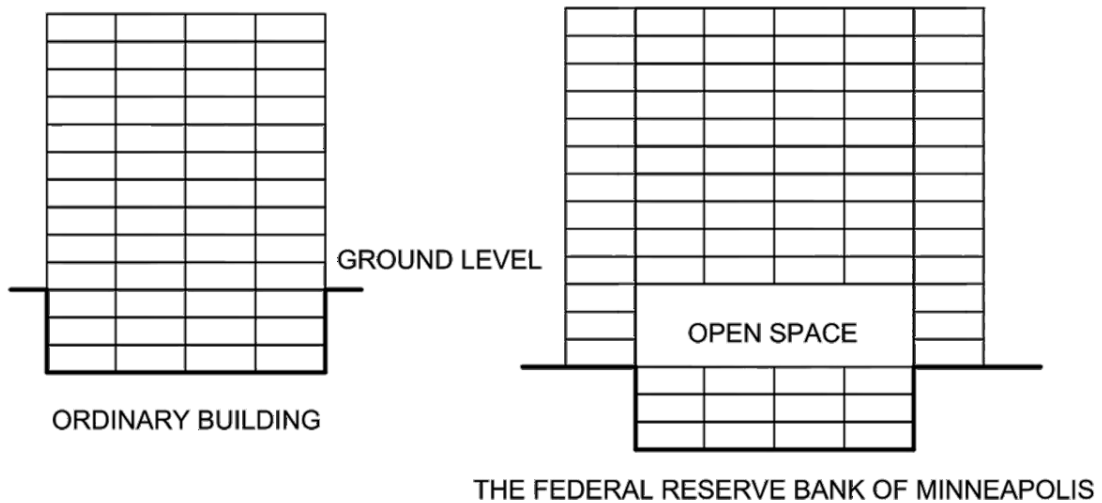


SHEAR

The suspension system gives large space to the building by taking away all the columns inside.

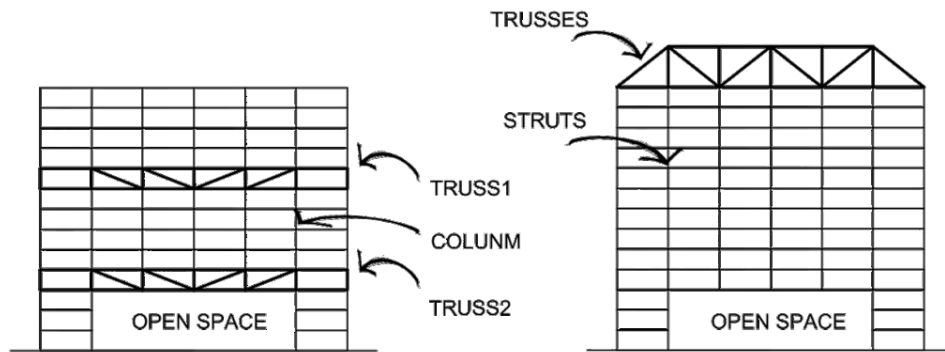


Most of the high-rise office buildings would set basements. Normally, the occupancy load would be transferred from beams to columns, and then to ground. The Federal Reserve Bank of Minneapolis takes away 3 floors above the basement, to make the main building hanging in the air. The load would be transferred horizontally to the towers.

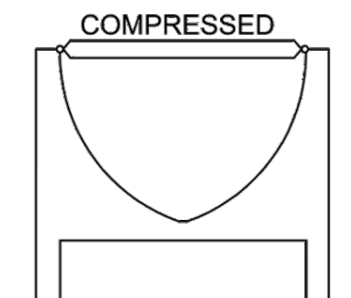
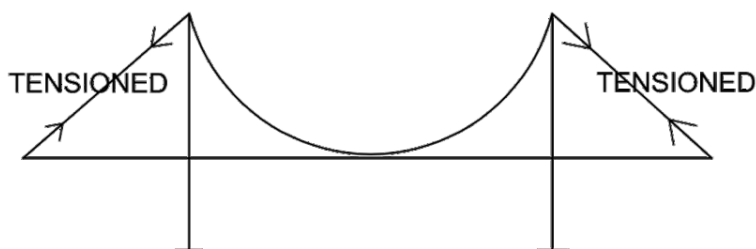


Trusses usually would be set under the floors and connected to the columns at the end to hold the occupancy load of long-span buildings.

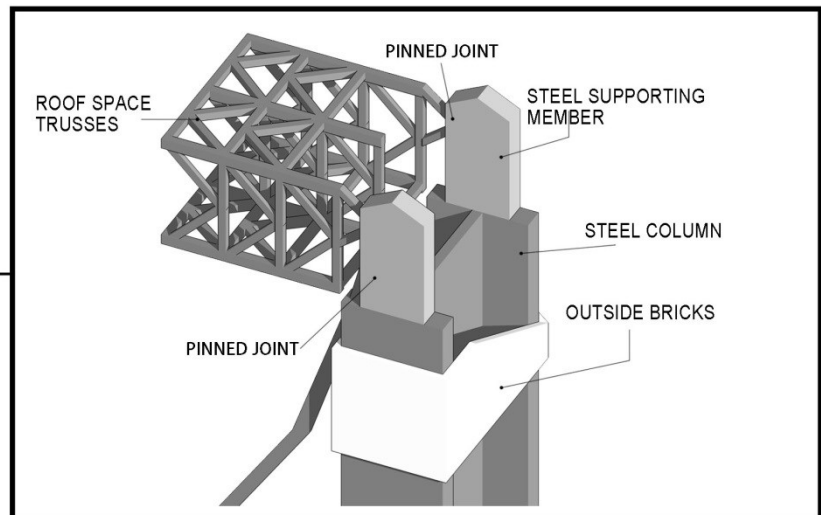
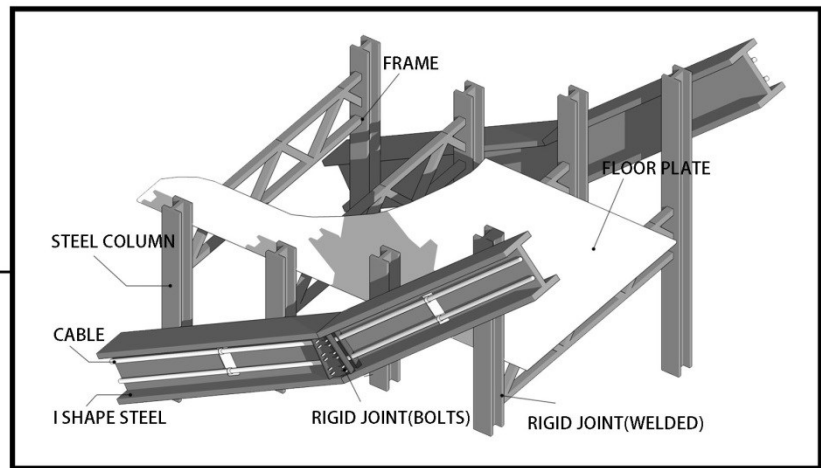
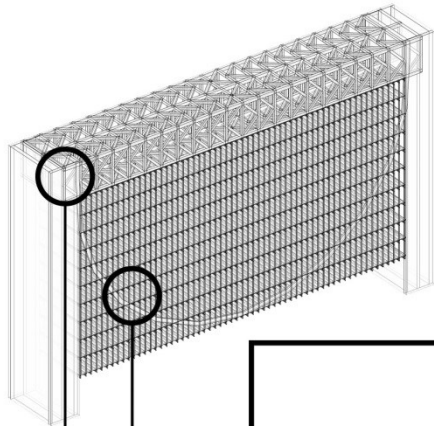
Designer of the Federal Reserve Bank of Minneapolis moved the trusses to the roof of the building to make the occupancy load hanging on it.



In the structural design of the Federal Reserve Bank of Minneapolis, towers on the two sides are of the same function as pier. Cables pull the towers to bend toward inside, and the trusses on the roof push them back.

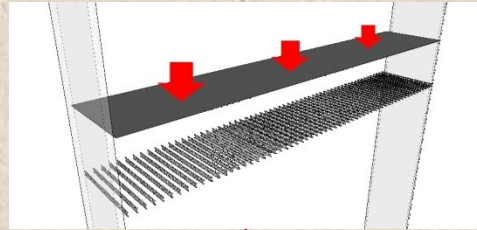


COMPONENTS

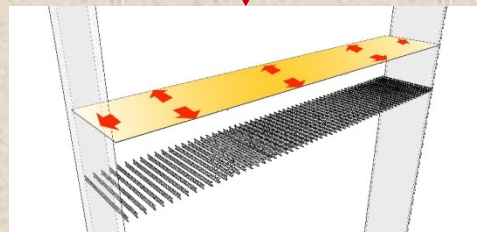


VERTICAL LOADING DESIGN

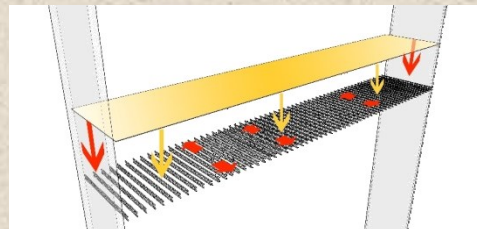
Occupancy loads are distributed on each floor.



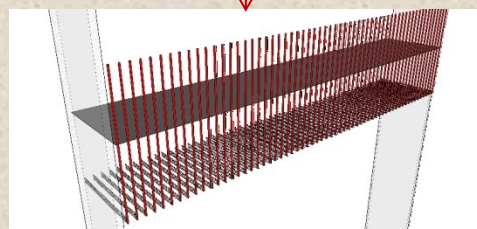
The floors are connected to the two towers on the sides and supported by the trusses underneath.



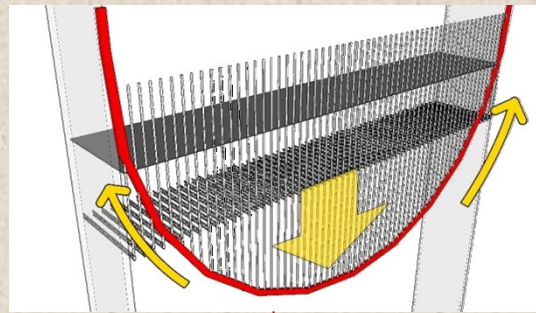
The loads are mainly transfer to the trusses..



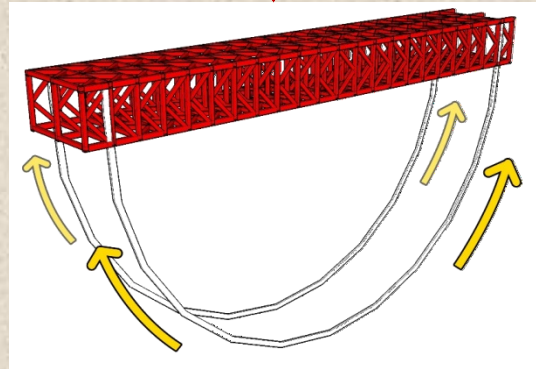
The trusses transfer the loads to the columns on the outside of the floors.



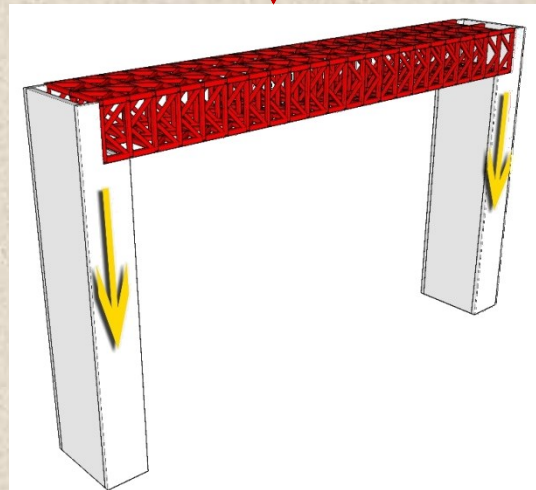
The columns are attach to the two cables, and transfer the loads to them.



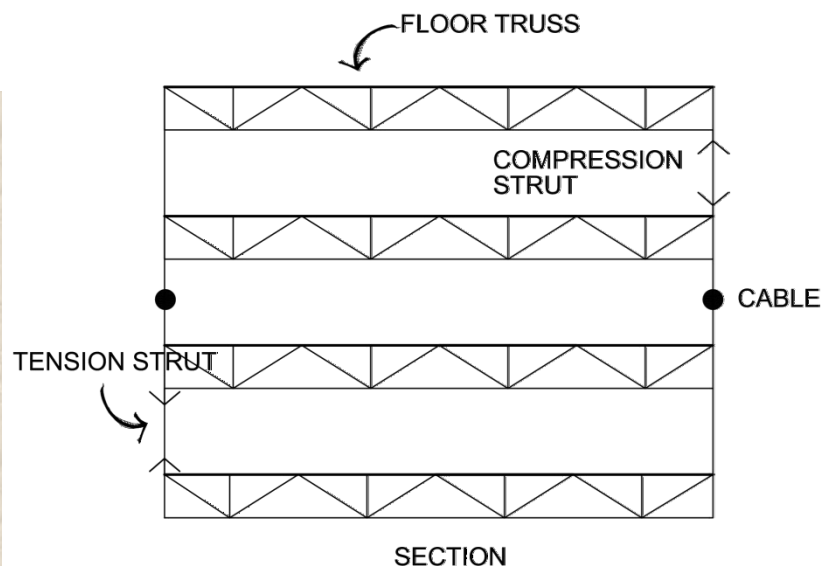
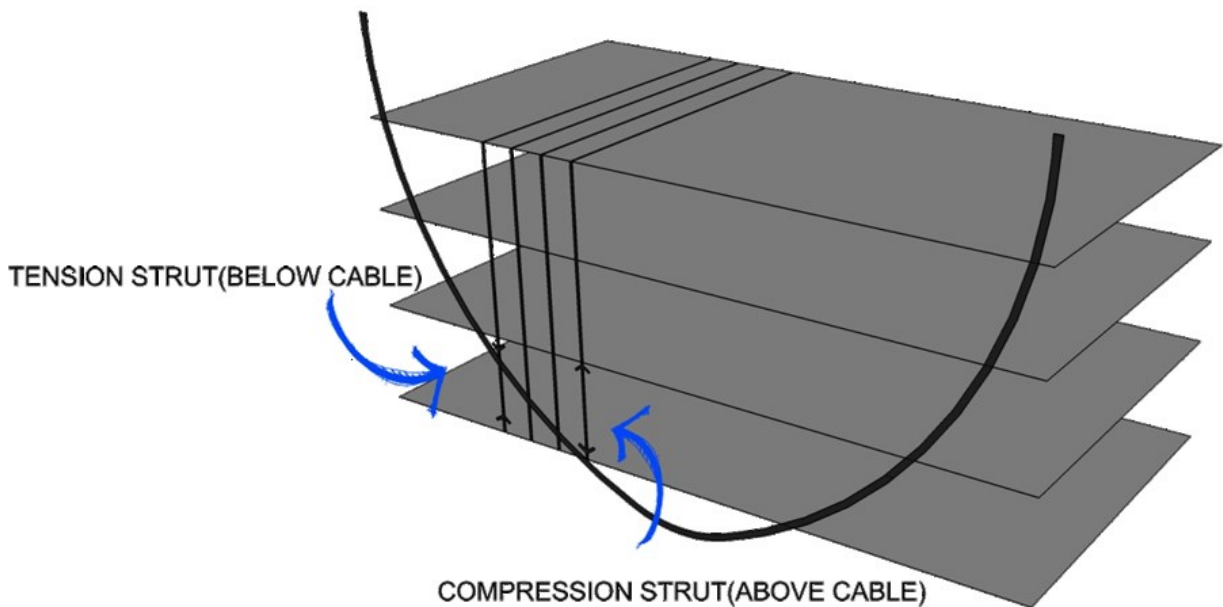
The two cables hanging on the roof trusses and transfer the loads to the trusses.



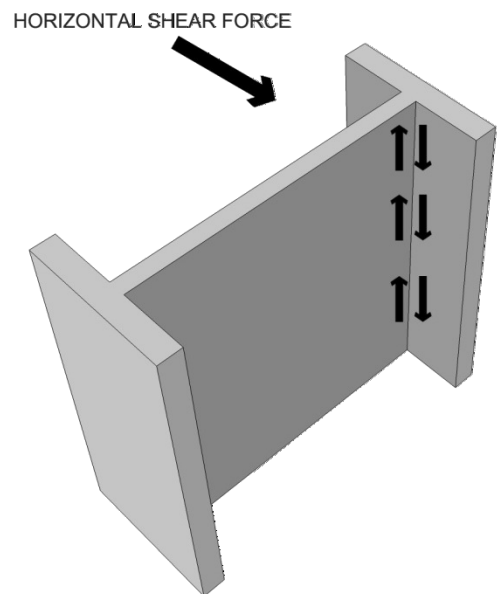
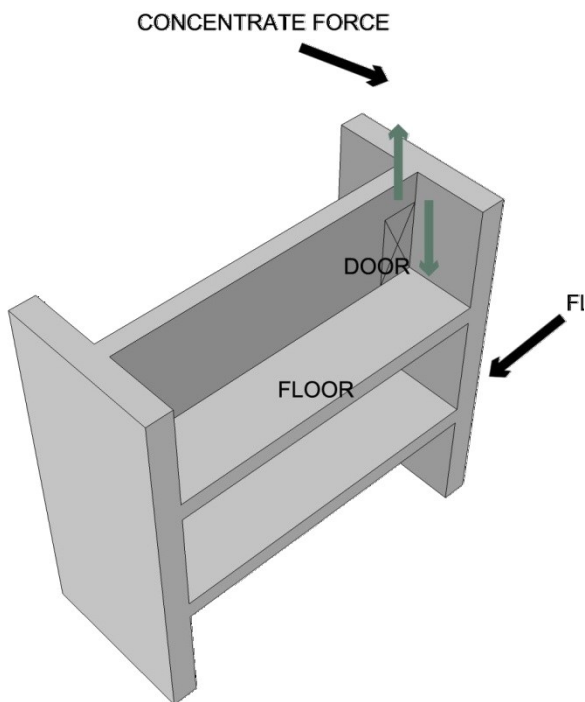
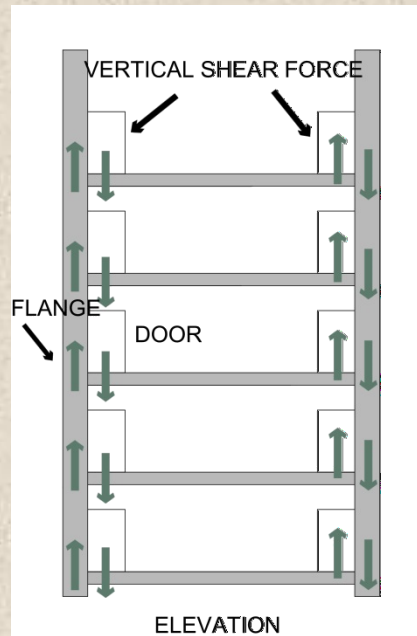
The roof trusses are pinned to the two towers and transfer the loads vertically to towers.



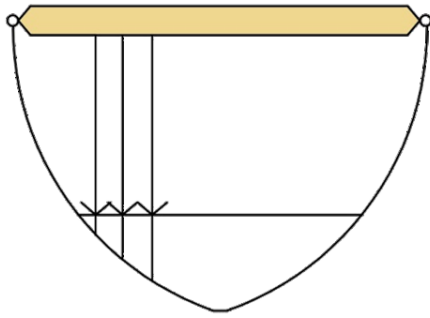
The Live load and the dead load on each floor are supported by the trusses under each floor. The struts transfer the reaction force of the trusses to the cables. Thus, struts above the cables are tensioned, and struts below the cable are compressed.



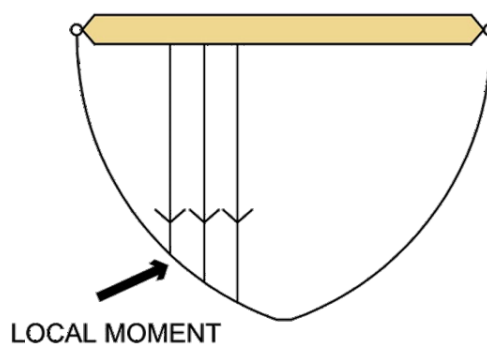
The floors are connected to the two towers, and part of the loads are transfer to the towers. Thus, there are reaction forces on the towers in order to hold the floors.



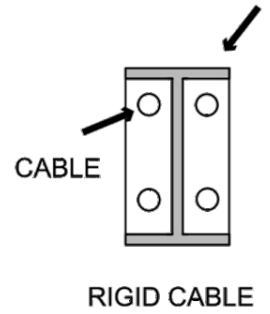
NONUNIFORMLY DISTRIBUTED LOAD



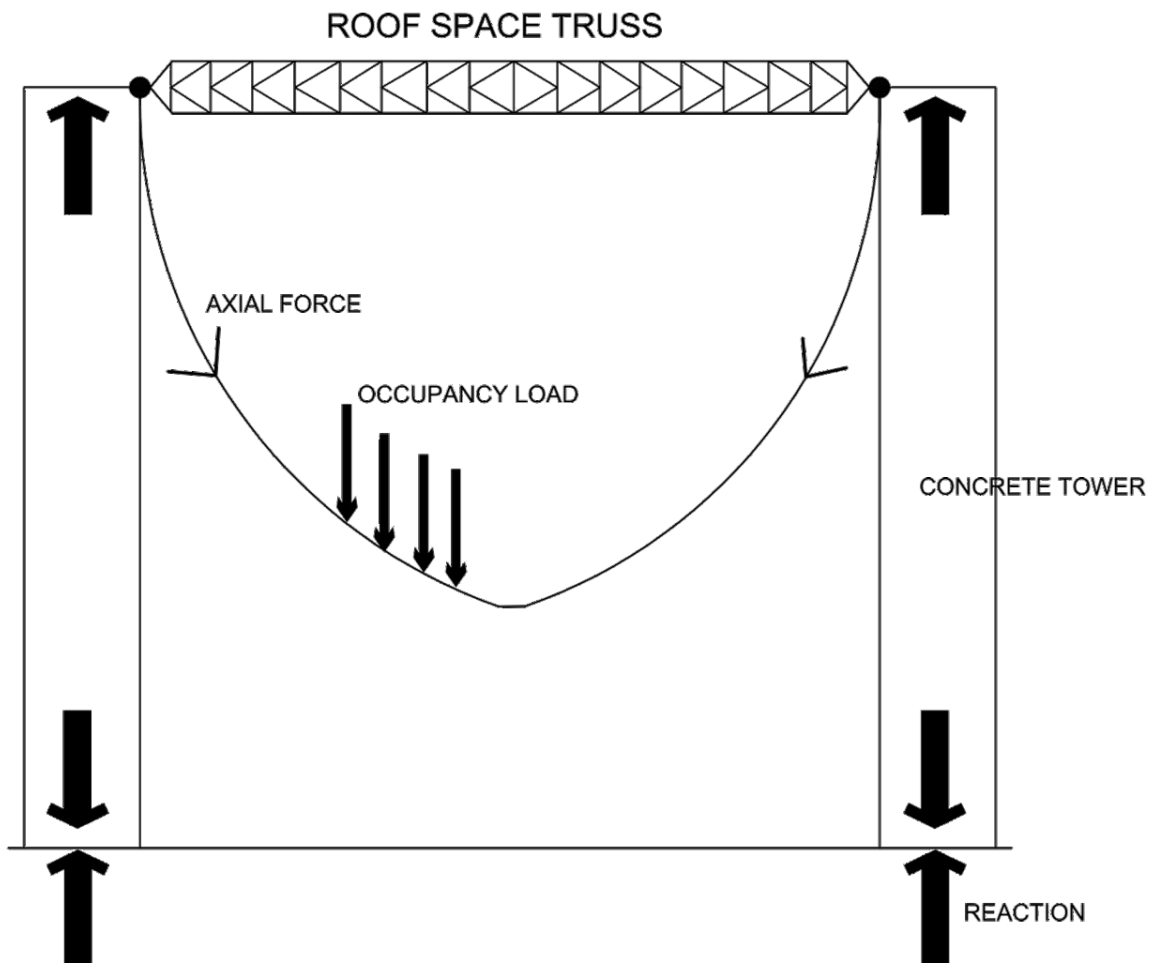
RESTRICTED VERTICAL MOVEMENT



I SHAPED STEEL

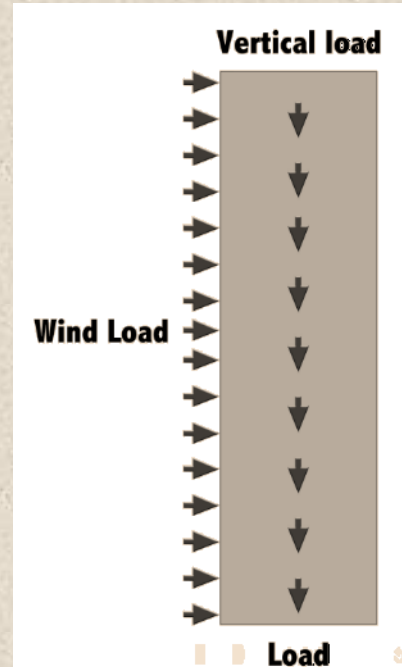


While the cable being pulled towards down, the roof space truss keep the towers from bending towards inside, so that the distance between the towers would not reduce, which restrict the movement of the cable. The loads are transferred vertically to the ground from roof space truss through the towers.

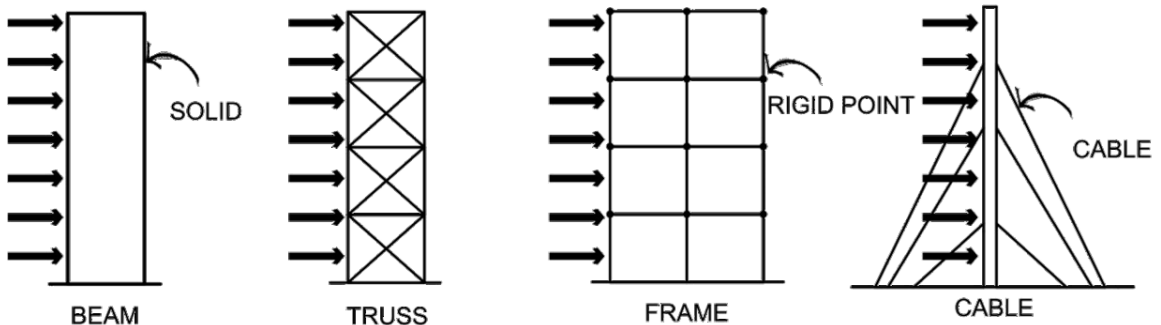


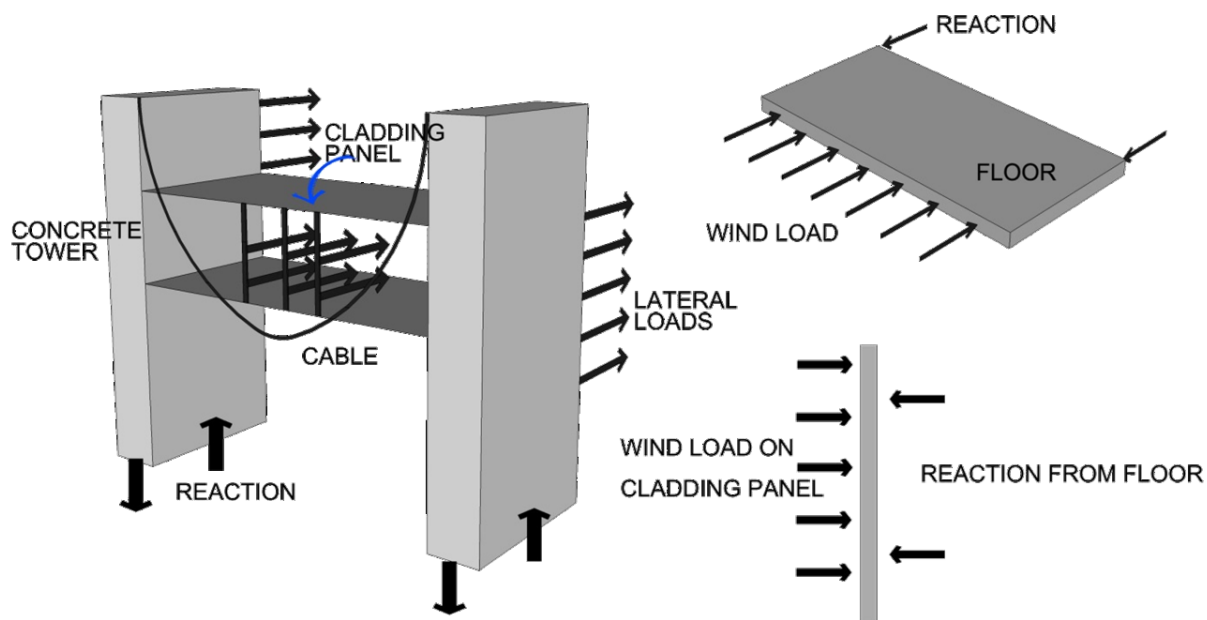
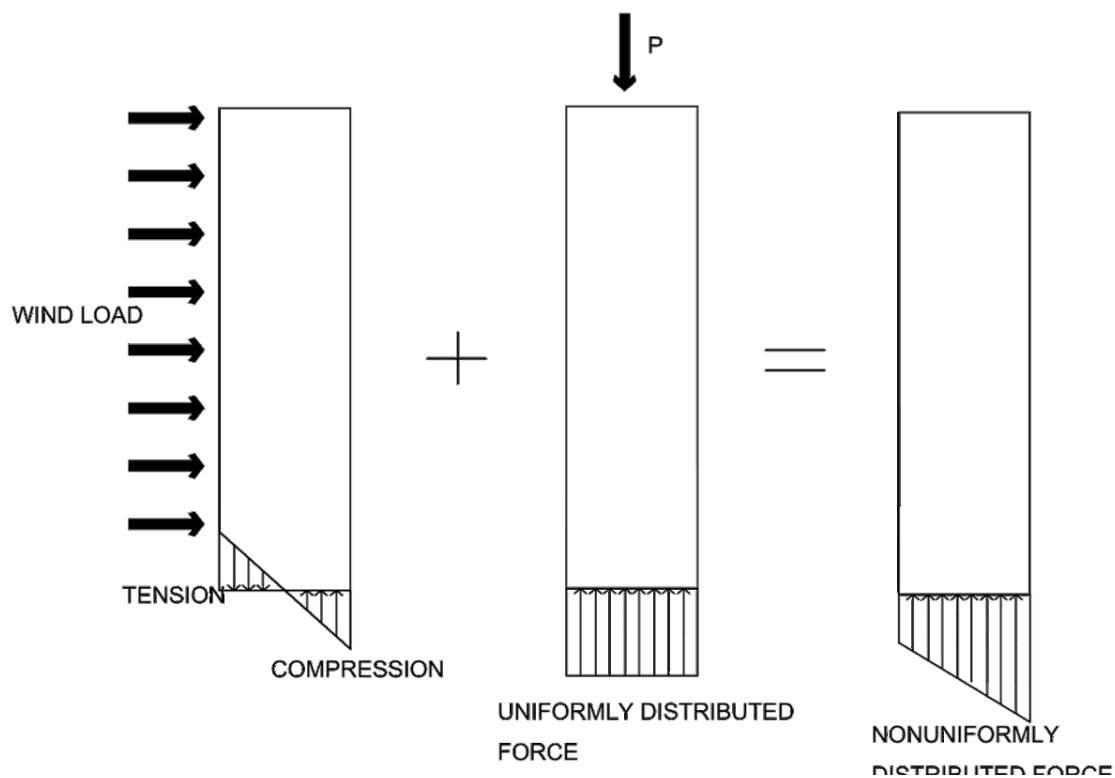
LATERAL LOADING DESIGN

Columns hold the vertical loads. Any type of building can be regarded as a cantilever beam fixed on the ground when facing wind load.

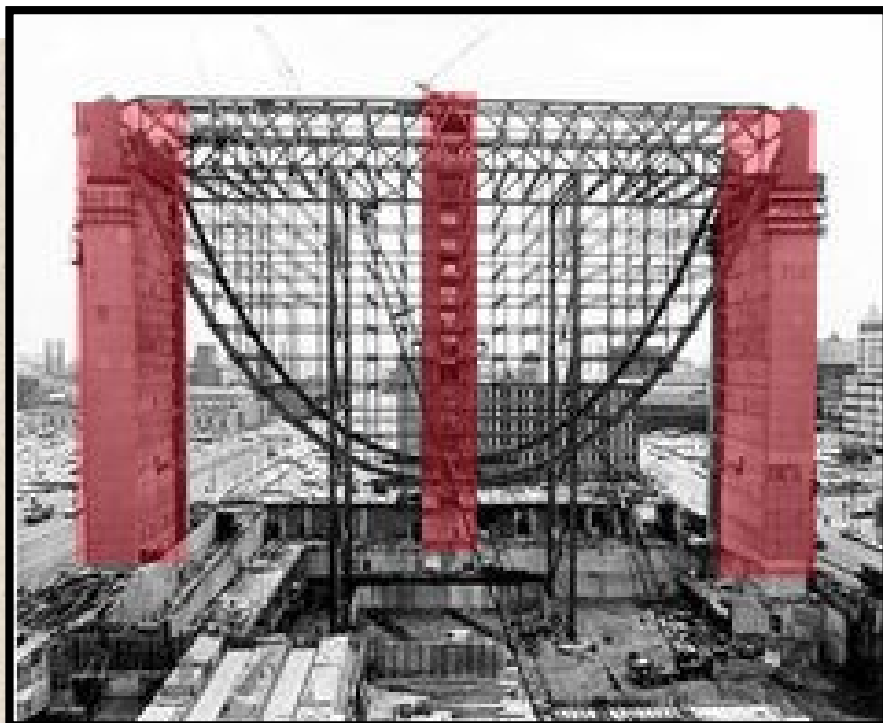
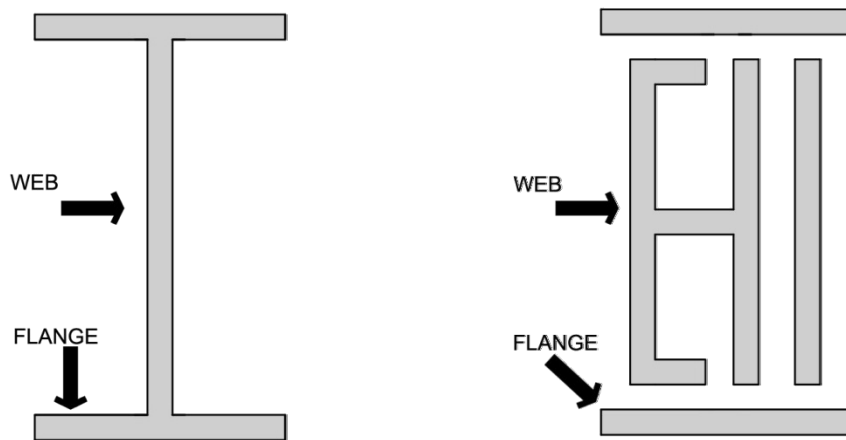


To resist the lateral wind load, structural systems like beam type, truss type and frame would usually be applied to the buildings. The Federal Reserve Bank of Minneapolis applies cable system, and uses horizontal steel trusses to sustain the loads.



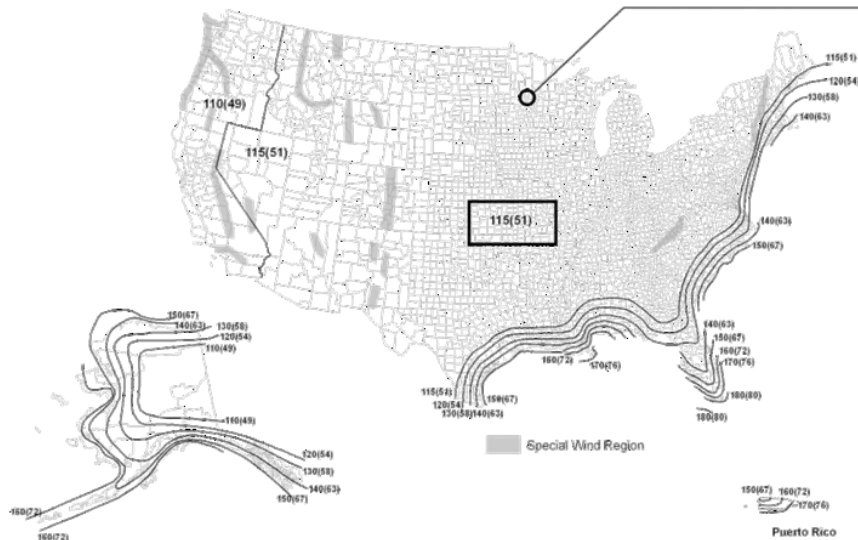


All the vertical loads and lateral loads are transferred to the two towers. In order to keep them stable, the towers are designed as two I-shaped beams, because it would help to enforce the resistance to lateral load.



WIND LOAD

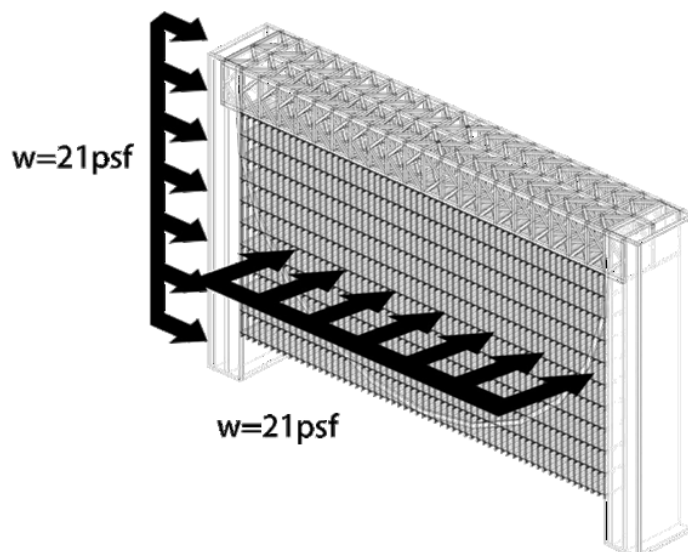
Minneapolis
The site position



Simplified Design Wind Pressure, p_{s30} (psf) (Exposure B at $h = 30$ ft. with $I = 1.0$)

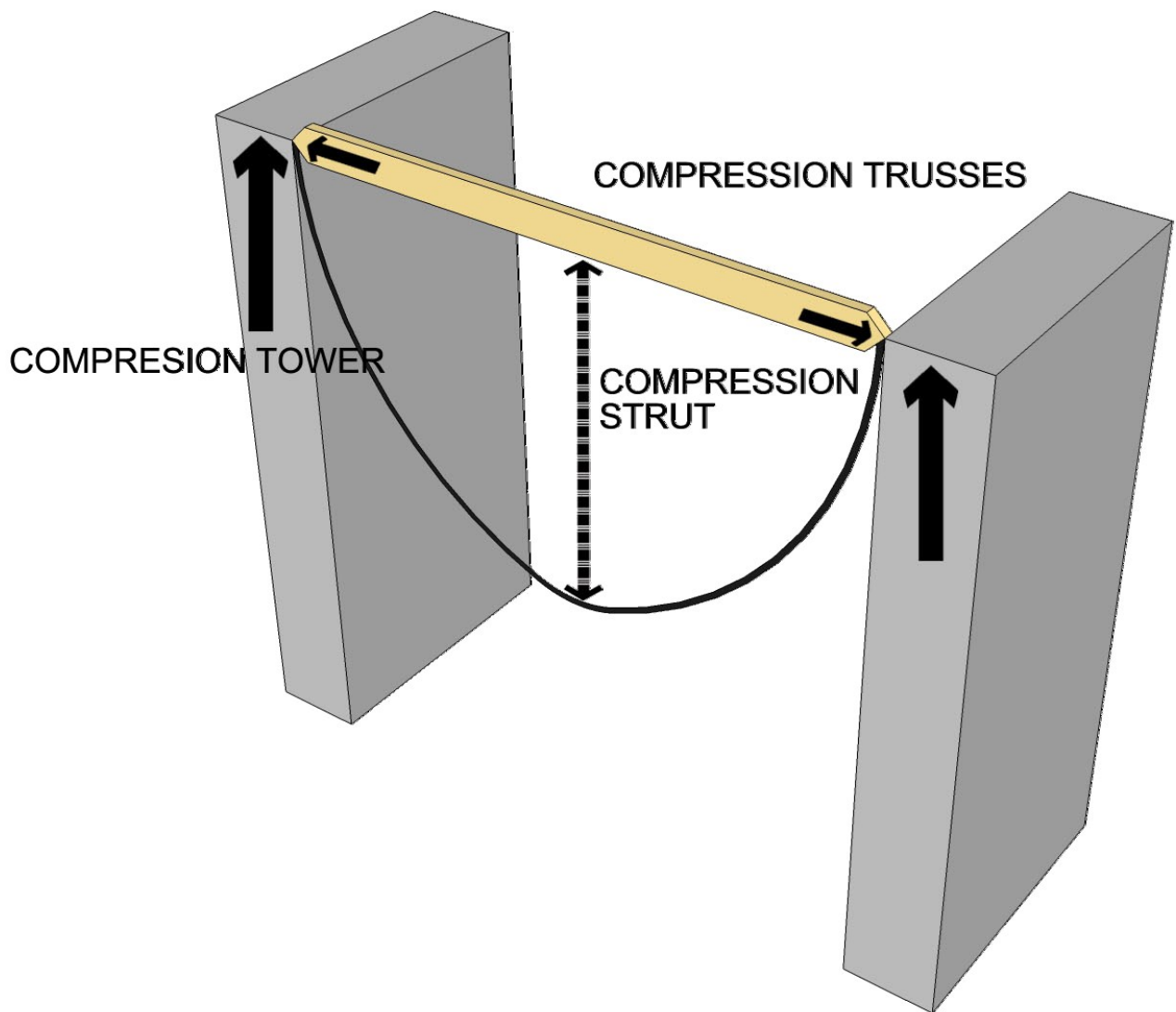
Basic Wind Speed (mph)	Roof Angle (degrees)	Load Case	Zones									
			Horizontal Pressures				Vertical Pressures				Overhangs	
			A	B	C	D	E	F	G	H	EOH	GOH
110	0 to 5°	1	19.2	-10.0	12.7	-5.9	-23.1	-13.1	-16.0	-10.1	-32.3	-25.3
	10°	1	21.6	-9.0	14.4	-8.2	-23.1	-14.1	-16.0	-10.8	-32.3	-25.3
	15°	1	24.1	-8.0	16.0	-4.6	-23.1	-15.1	-16.0	-11.5	-32.3	-25.3
	20°	1	26.6	-7.0	17.7	-3.9	-23.1	-16.0	-16.0	-12.2	-32.3	-25.3
	25°	1	24.1	3.9	17.4	4.0	-10.7	-14.6	-7.7	-11.7	-19.9	-17.0
		2	-----	-----	-----	-----	-4.1	-7.9	-1.1	-----	-----	-----
115	30 to 45	1	21.6	14.8	17.2	11.8	1.7	-13.1	0.6	-11.3	-7.6	-8.7
		2	21.6	14.8	17.2	11.8	8.3	-6.5	7.2	-4.6	-7.6	-8.7
	0 to 5°	1	21.0	-10.9	13.9	-6.5	-25.2	-14.3	-17.5	-11.1	-35.3	-27.6
	10°	1	23.7	-9.8	15.7	-5.7	-25.2	-15.4	-17.5	-11.8	-35.3	-27.6
	15°	1	26.3	-8.7	17.5	-5.0	-25.2	-16.5	-17.5	-12.6	-35.3	-27.6
	20°	1	29.0	-7.7	19.4	-4.2	-25.2	-17.5	-17.5	-13.3	-35.3	-27.6
120	25°	1	26.3	4.2	19.1	4.3	-11.7	-15.9	-8.5	-12.8	-21.8	-18.5
		2	-----	-----	-----	-----	-4.4	-8.7	-1.2	-5.5	-----	-----
	30 to 45	1	23.6	16.1	18.8	12.9	1.8	-14.3	0.6	-12.3	-8.3	-9.5
		2	23.6	16.1	18.8	12.9	9.1	-7.1	7.9	-5.0	-8.3	-9.5

21.0psf

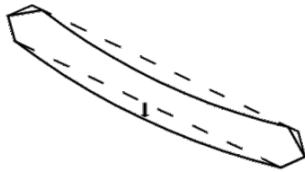


DEFLECTION

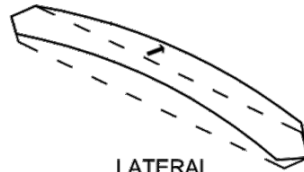
Most of the members in the building are compressed,
The main tensioned member is the steel cable.



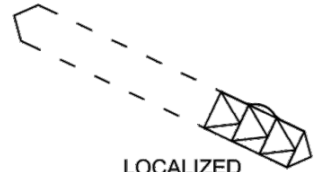
Different deflections in roof space trusses



VERTICAL

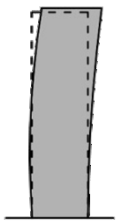


LATERAL

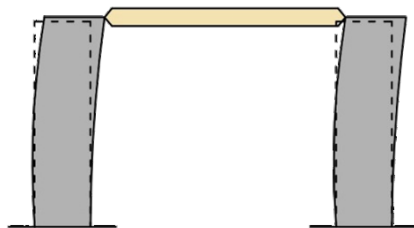


LOCALIZED

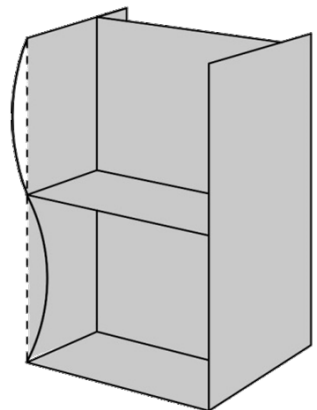
Different deflections in the towers



LATERAL



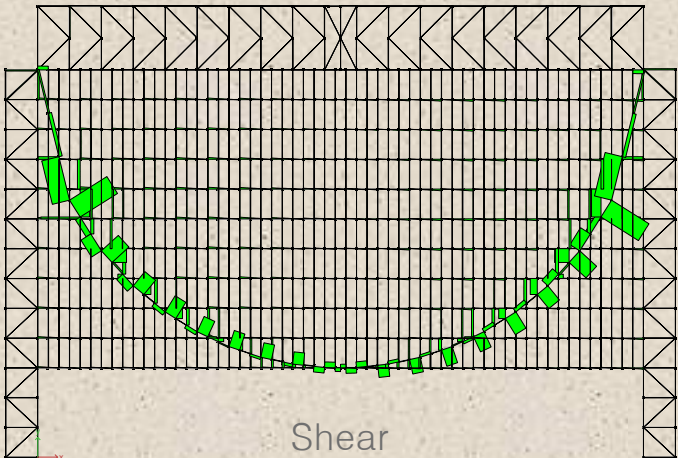
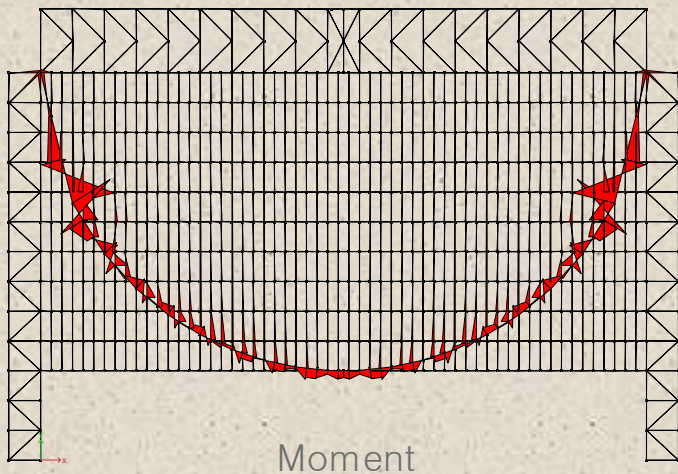
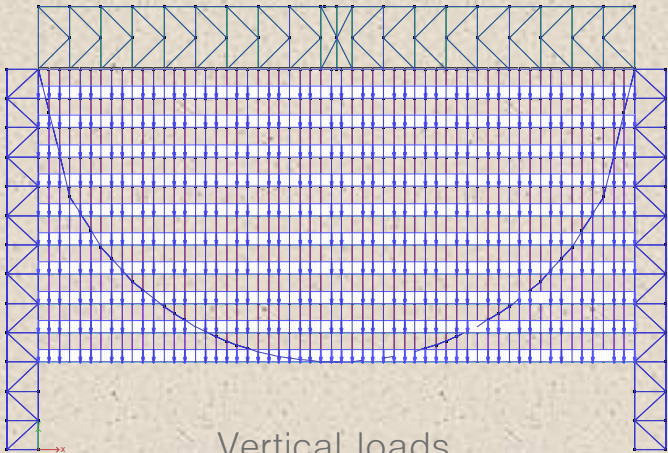
VERTICAL

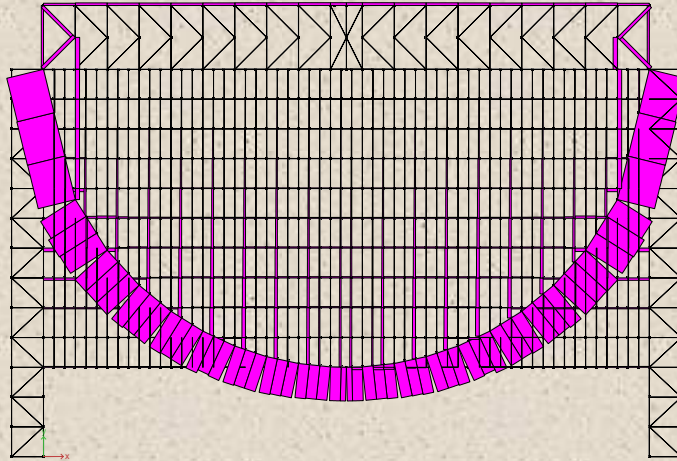


LOCALIZED

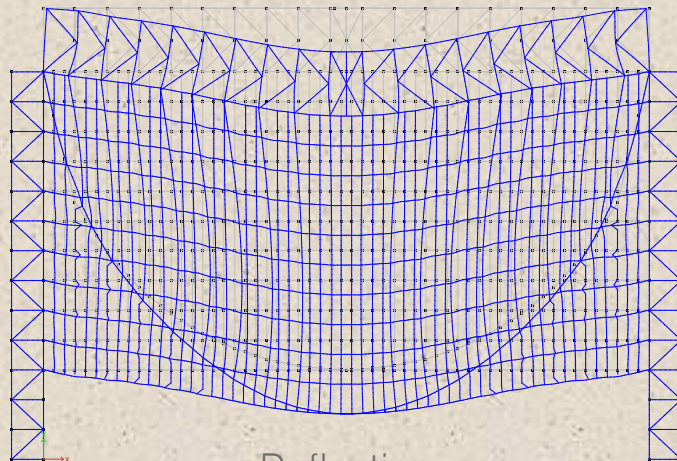
MULTIFRAME

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W14x342	
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All loads	

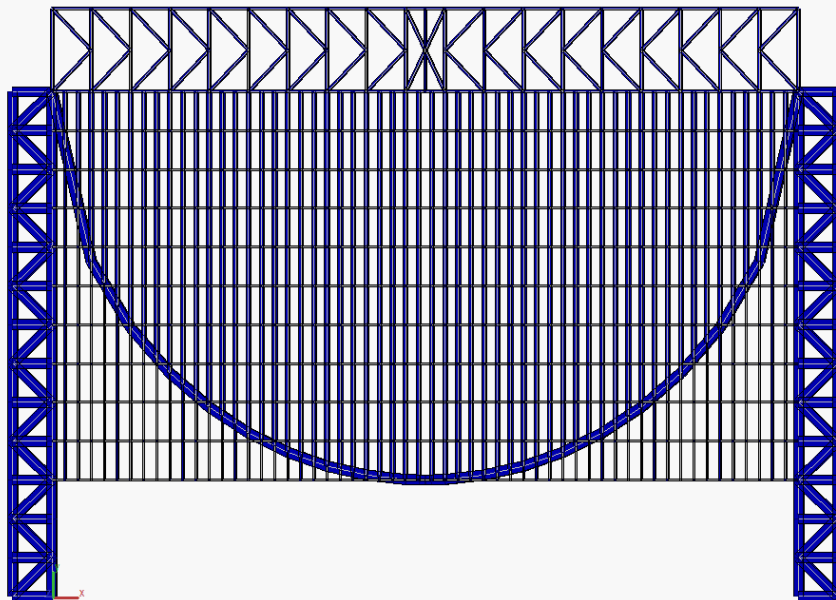


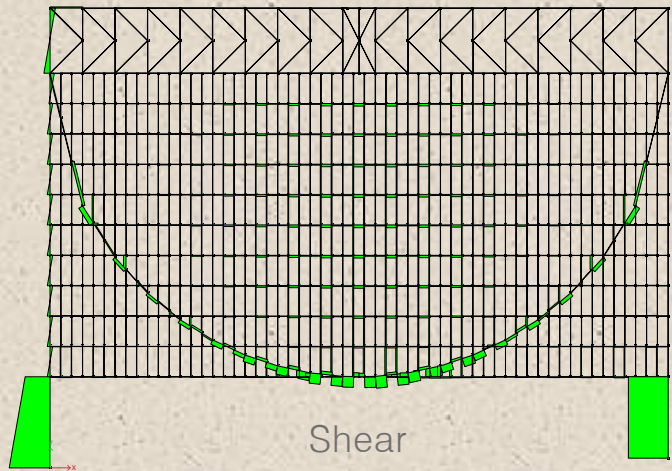
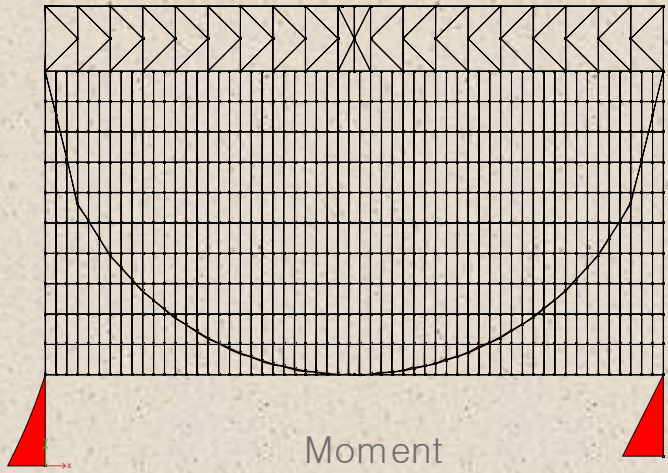
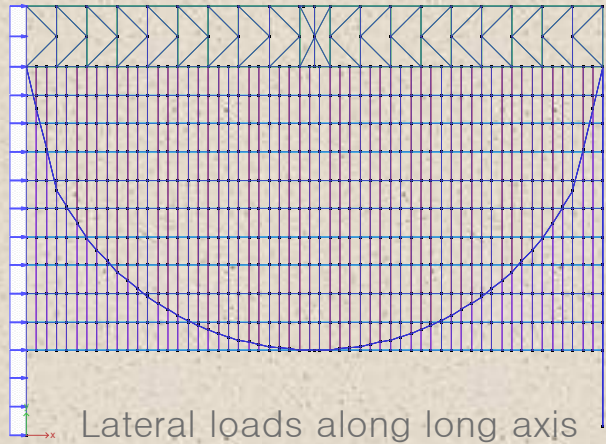


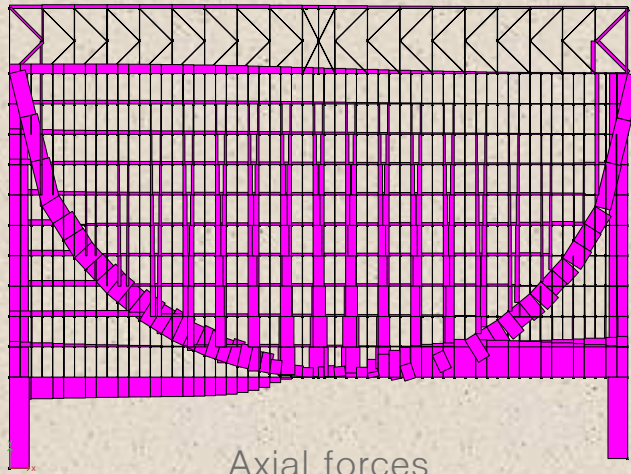
Axial forces



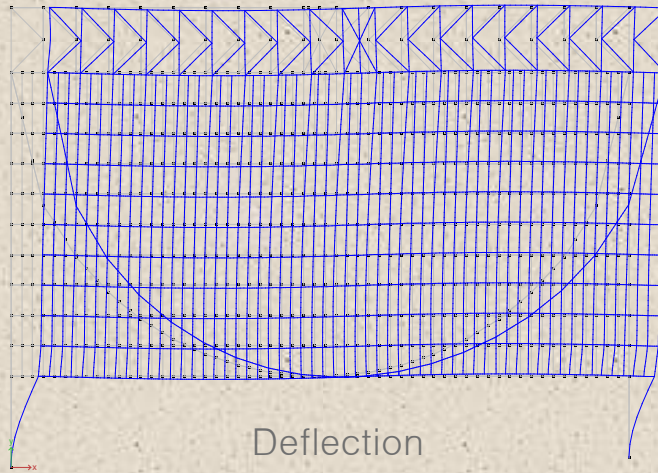
Deflection



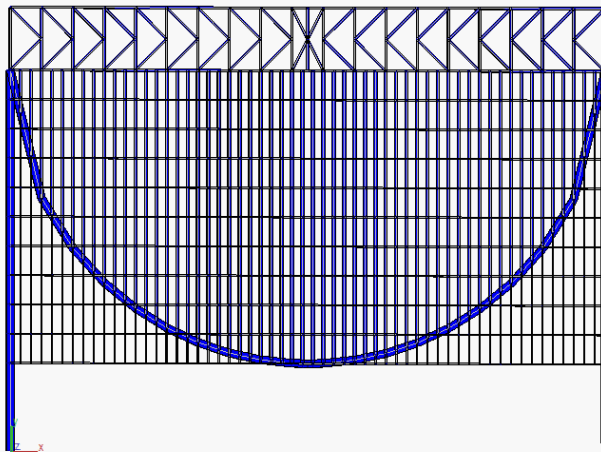




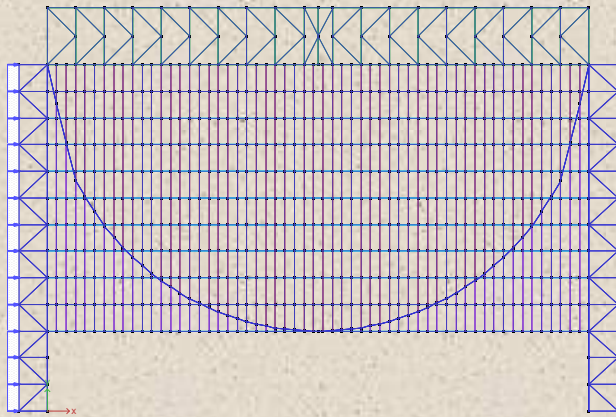
Axial forces



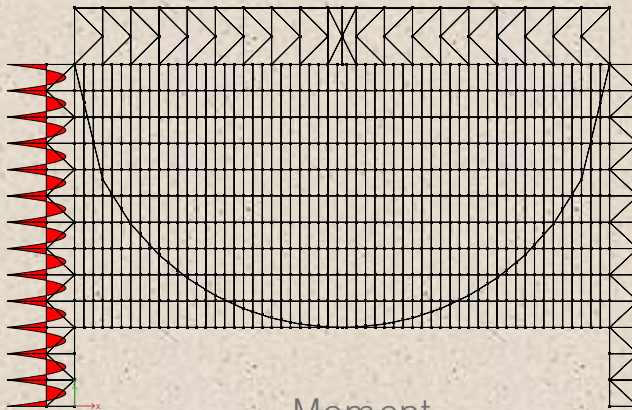
Deflection



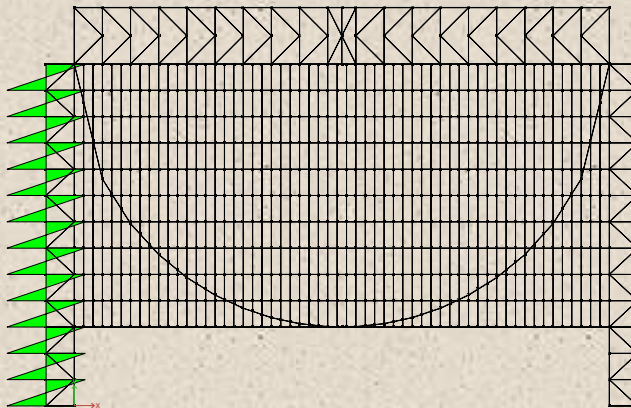
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All loads	



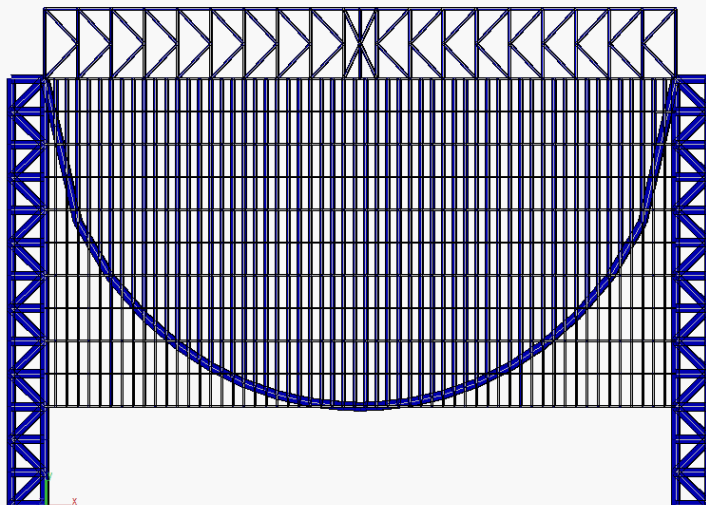
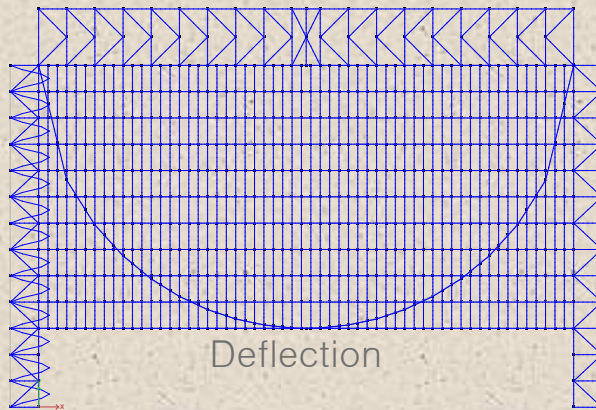
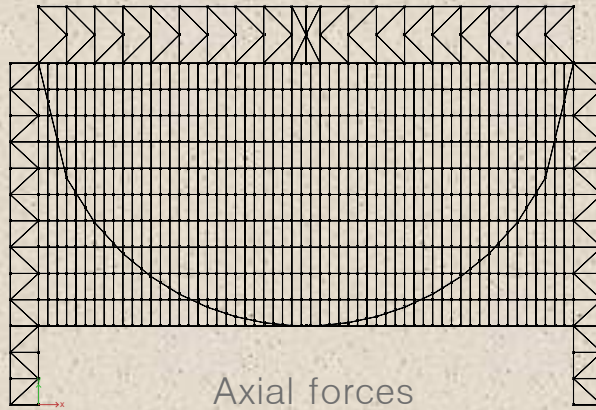
Lateral loads along long axis

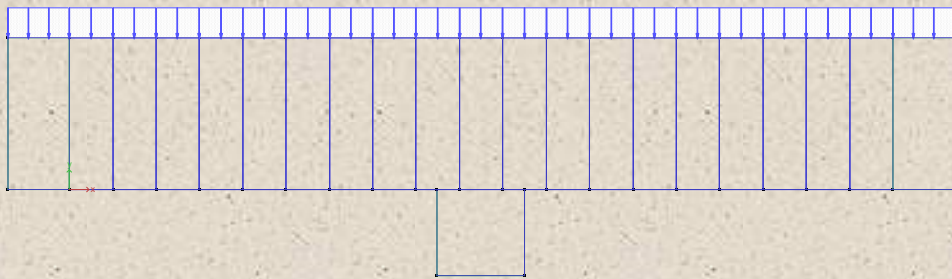


Moment

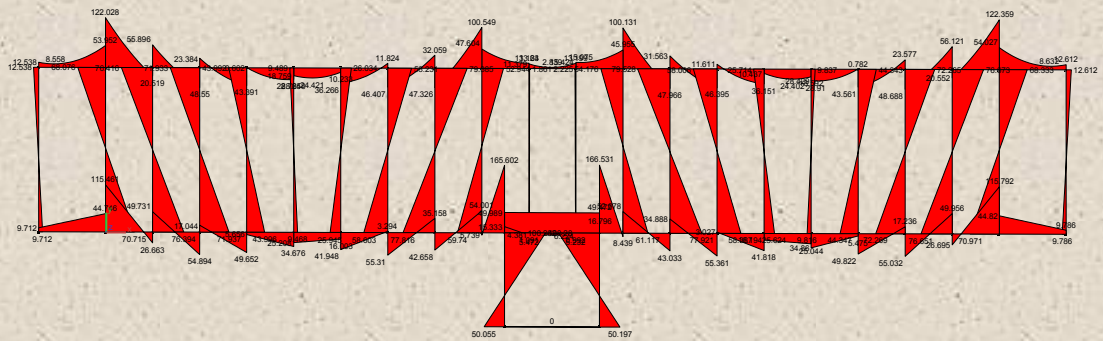


Shear



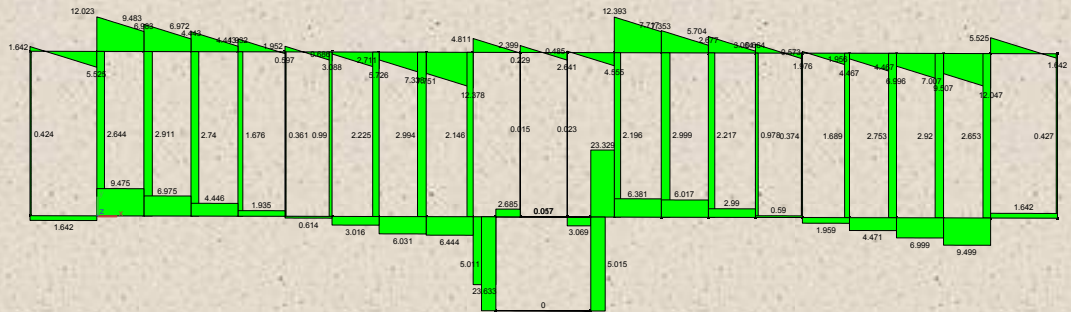


Axial forces



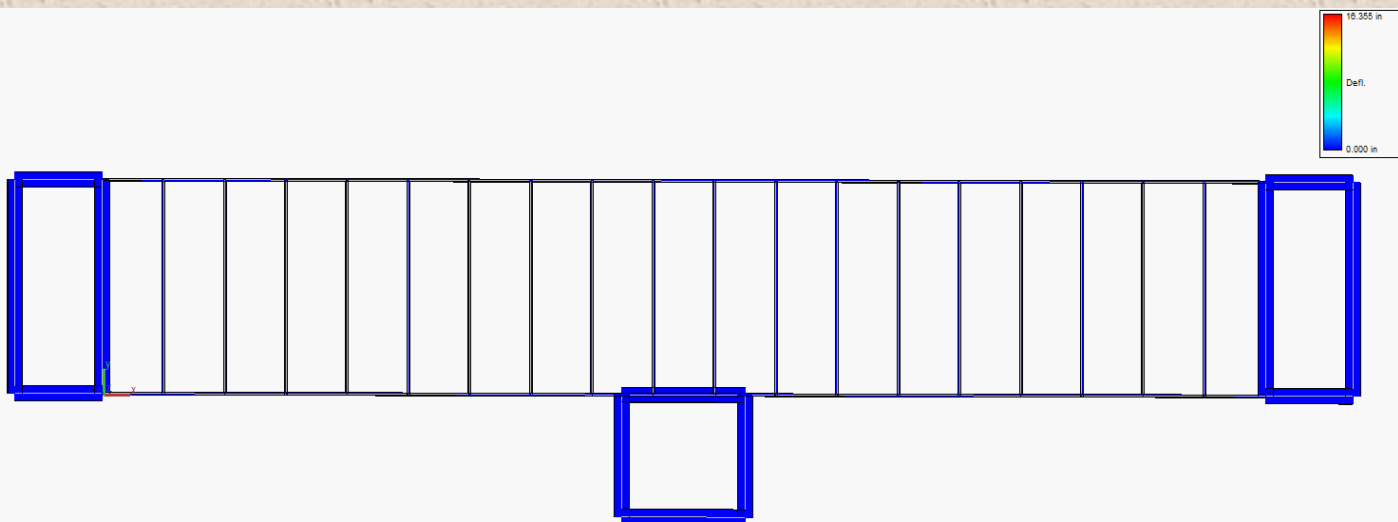
Moment

Static Case: Load Case 1 M_z^* (kip-ft)



Shear

Static Case: Load Case 1 V_y' (kip)

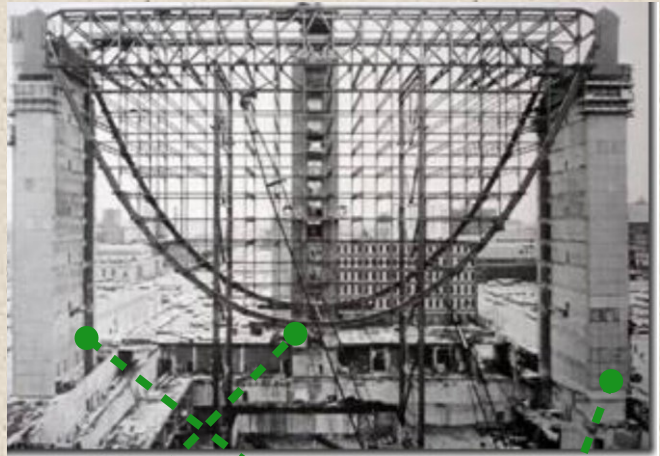


Static Case: Load Case 1 Defl. (in)

Material

Steel

Steel possess characteristics such as high strength, light weight, good integral rigidity and good flexibility. It is suitable to be used in building long-span, high-rise and high-density buildings. It has good plasticity and ductility, so that it can bear large deformation and dynamic loads.



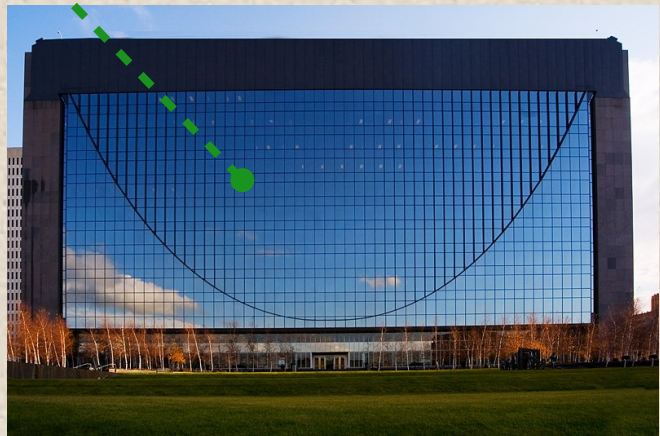
Steel

Reinforced concrete

Reinforced Concrete

The Federal Reserve Bank of Minneapolis needs a strong, durable and construction on the both side of the Building. The reinforced concrete have the following properties, it has high relative strength, and high toleration of tensile strain and thermal compatibility.

Glass



Soil Condition In Minnesota

Estimated area of each order and suborder of soil in Minnesota, and the percent of Minnesota it occupies.

Order	Suborder	Acres	Percent
Alfisols		16,069,000	27.4
	Aqualfs	2,943,000	5.1
	Udalfs	13,126,000	22.3
Inceptisols		5,512,000	9.4
	Aquepts	40,000	0.1
	Udepts	5,472,000	9.3
Entisols		10,729,000	18.4
	Aquents	1,465,000	2.4
	Orthents	5,470,000	9.4
	Psamments	3,794,000	6.6
Mollisols		18,880,000	32.1
	Aquolls	13,973,000	12.7
	Udolls	4,655,000	12.7
	Ustolls	252,000	.04
Hisosols		3,130,000	5.3
	Hemists	3,130,000	5.3
Vertisols	Aquerts	784,000	1.2
Spodosols	Orthods	122,000	.02
Lakes		2,836,000	4.9
	TOTAL	58,062,000	100.0

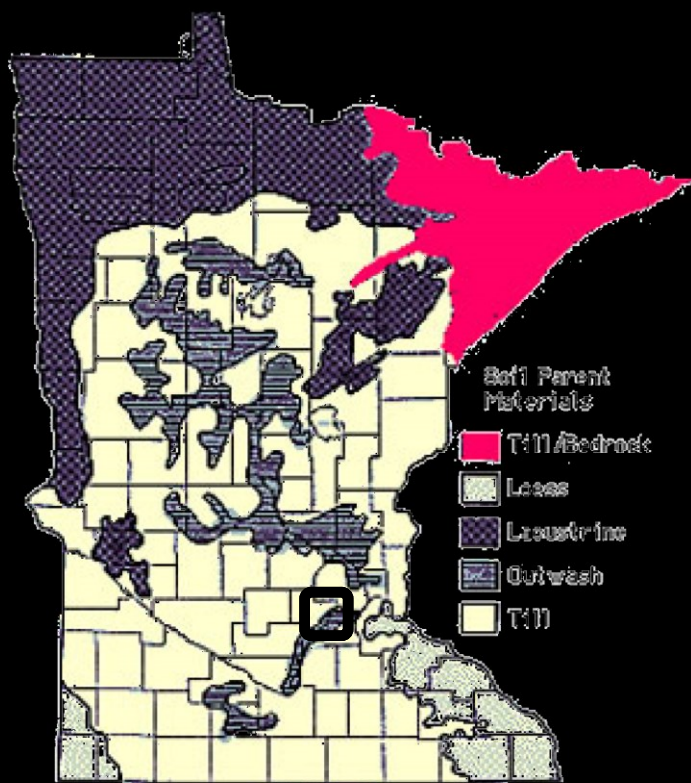


Figure 1. Soil parent materials in Minnesota.

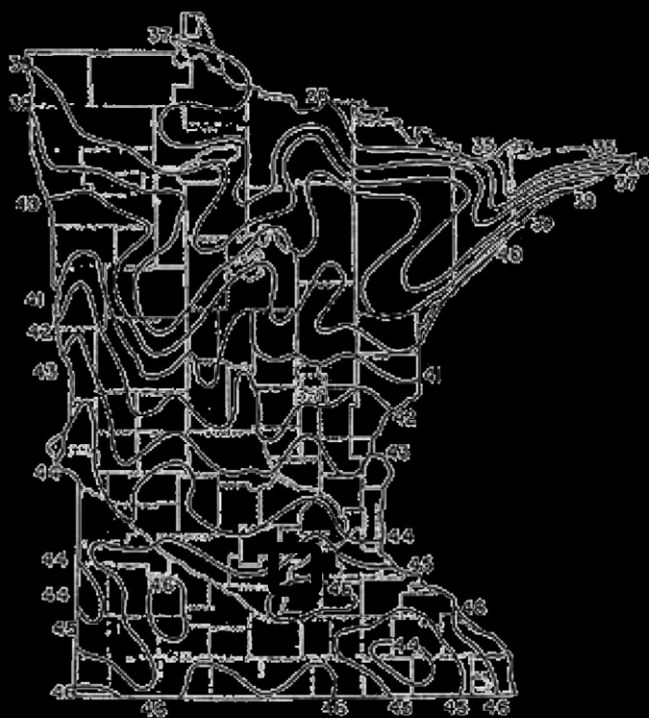
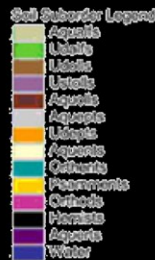


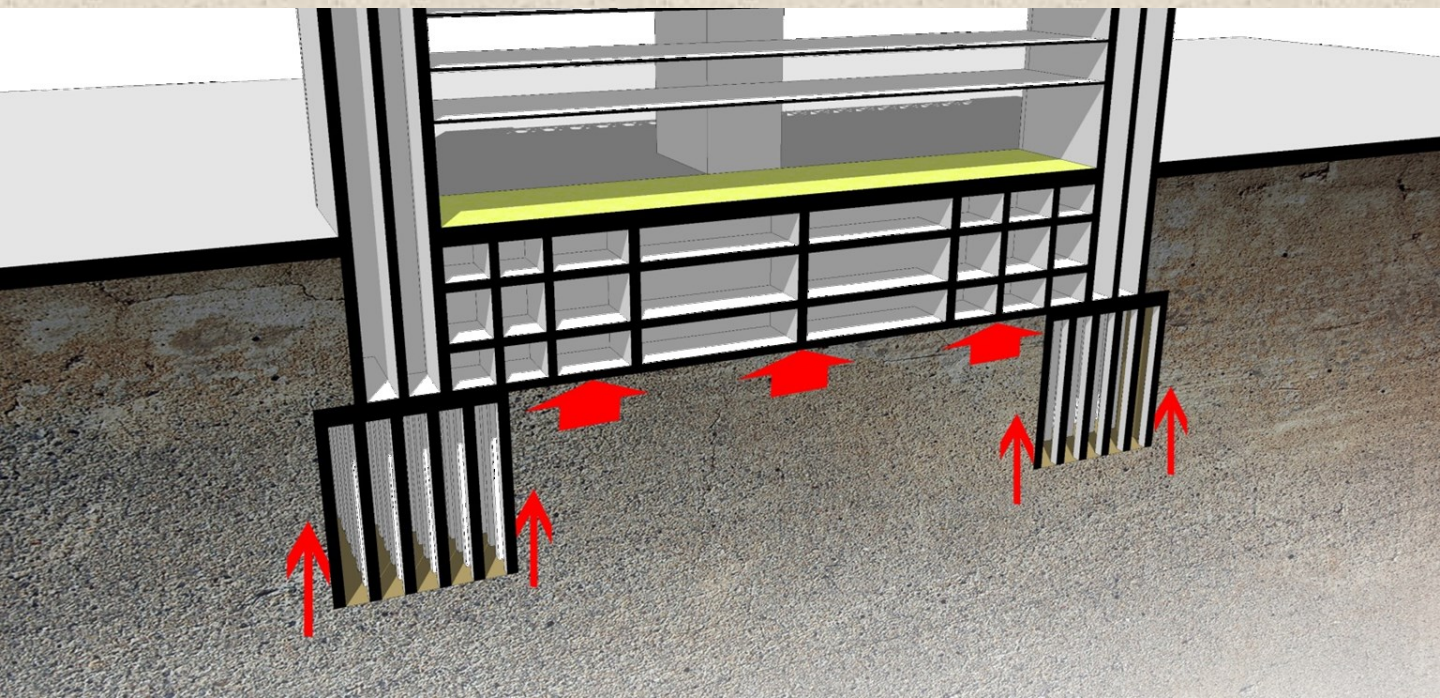
Figure 2. Mean annual temperatures (From Baker & Straub, 1965)

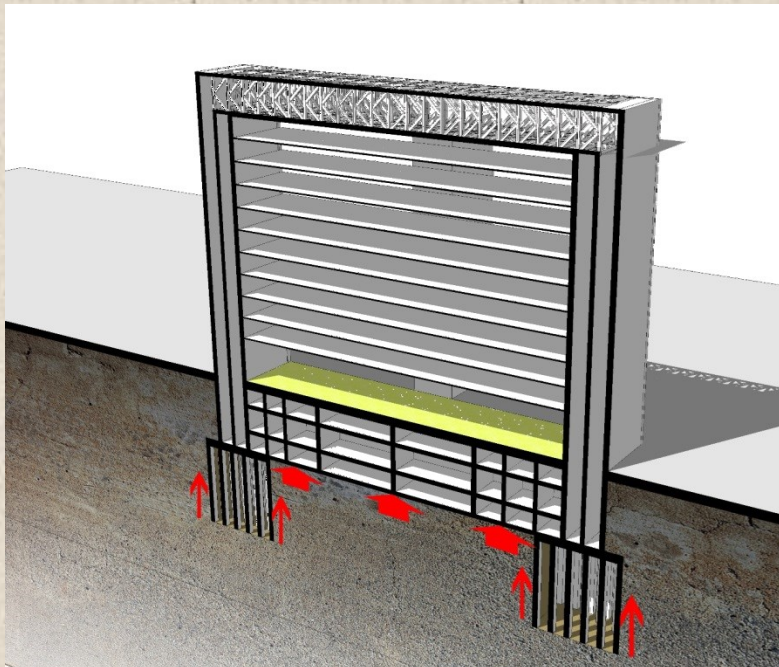
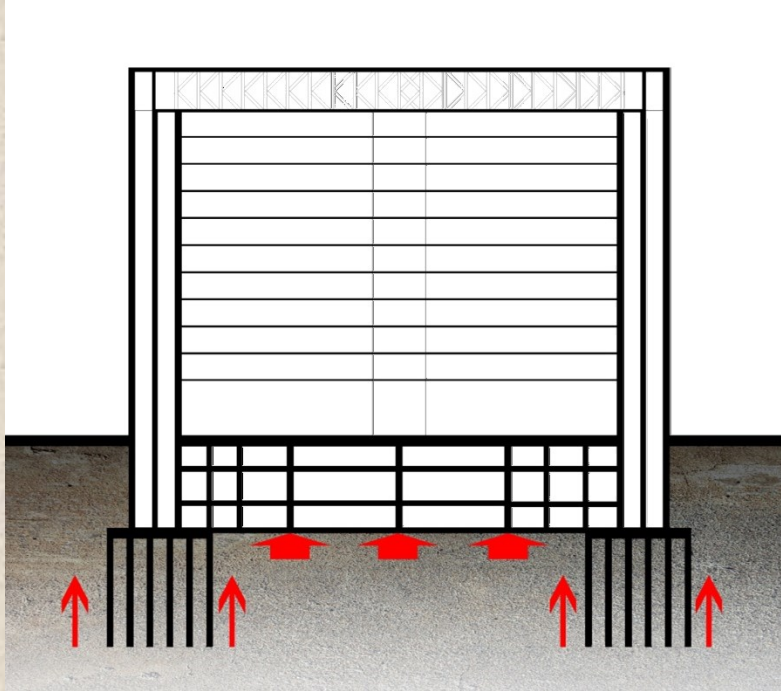
Soil Survey Staff, D. Gilpin, J. Anderson, T. Cooper
Minnesota Agricultural Experiment Station
In cooperation with the USDA Forest Service
and Soil Conservation Service
Digital Cartography by J. Hall, P. Chazama, and J. Nielsen
Soil and Landscape Analysis Laboratory



From the diagrams we can find that the soil in Minneapolis is primarily till. The characters of the till can be described as no hierarchy, no separation, but the stone, gravel, sand and cohesive soil mixed and disorderly accumulation, distribution is not uniform; On the moraine soil engineering construction, attention should be paid to non-uniformity of glacial deposits. Without water carrying, directly from the ice moraine soil shelved in the impervious material can be used as an earth dam, and chemical cementation moraine soil with high density, is often a good building foundation.

The building apply the friction pile system because the soil condition is good for building construction. Friction piles can carry loads by frictional forces developed during driving or by transferring the loads directly from the building structure to an underlying bearing stratum .





- Number Of Piles: 75
- Size of Piles: 24" x24"
- Deep of Piles: 40 ft
- Distance Of Piles: 72"

Summary

All in all, the advantage of suspension system is:

1. The function consumes less steel.
2. The function or rooms is much more effective, because it does not need the column or shear wall.
3. It is good at resistant the earthquake.
4. It can decrease the number of foundation and also can avoid the uneven settlement.

The disadvantage of suspension system is:

1. It is difficult to resist lateral force, especially for wind load.
2. It may have more vibration comparing with other buildings.
3. The shape is simple, normally symmetry.