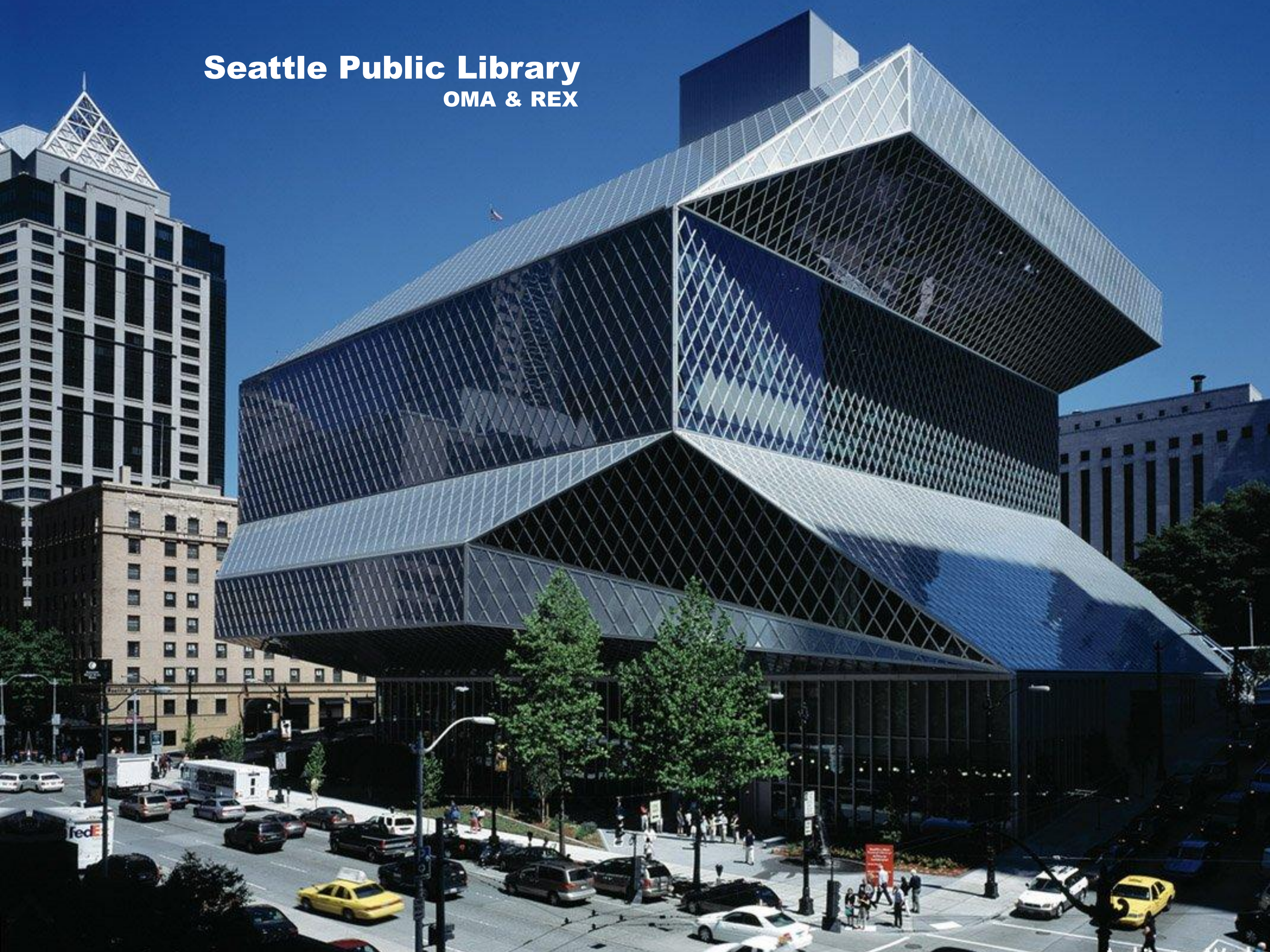
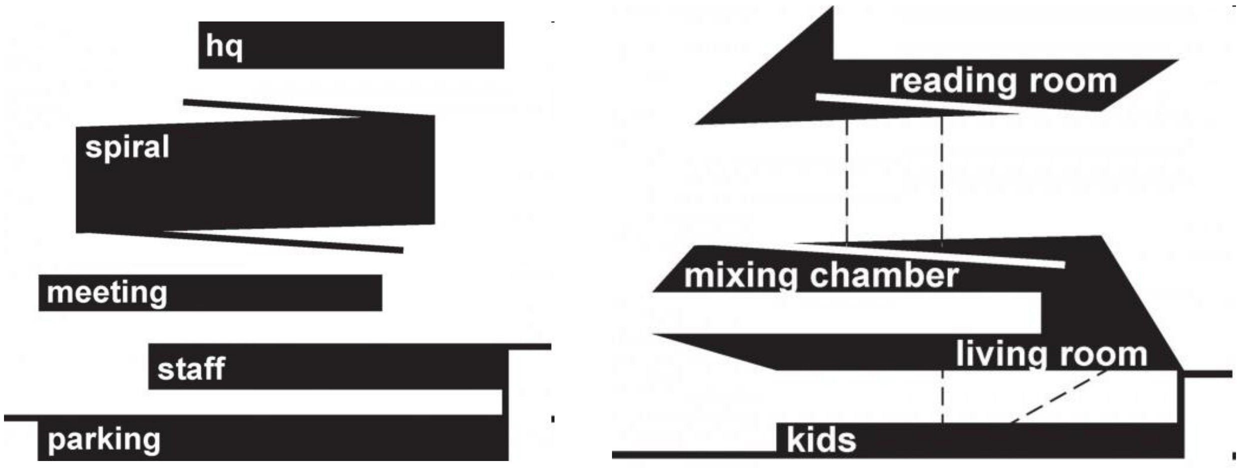

Seattle Public Library
OMA & REX

Seattle Public Library / General Information

Location:	**Seattle, Washington**
Architects:	**OMA & REX**
Structural Engineer:	**Arup & Magnusson Klemencic Associates**
Square Footage:	**362,987-square-foot**



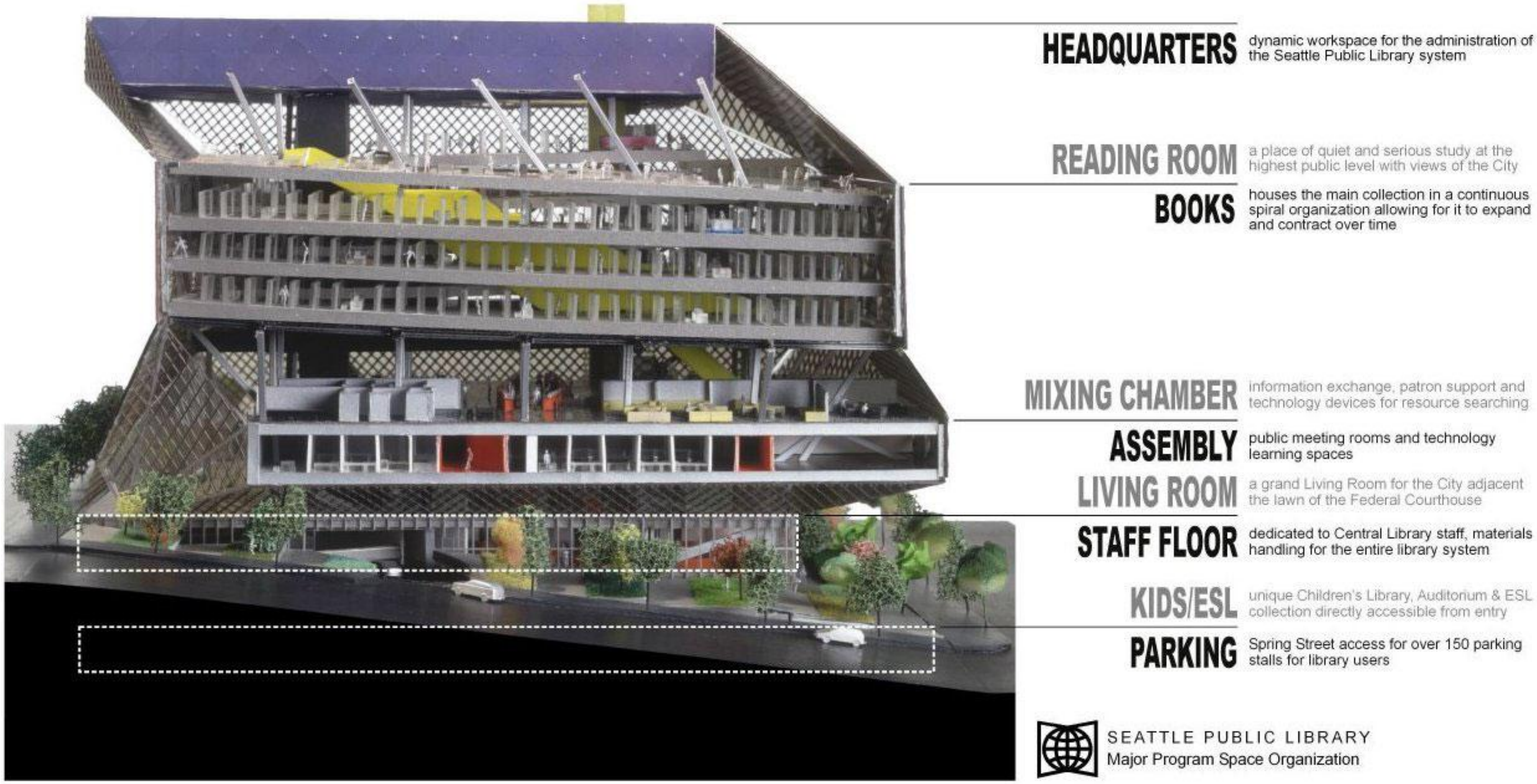
Ideas included books vs media, flexibility, and public vs private domain.

"Instead of this ambiguous flexibility, the library could…[organize] itself Into spatial compartments, each dedicated to…specific duties."

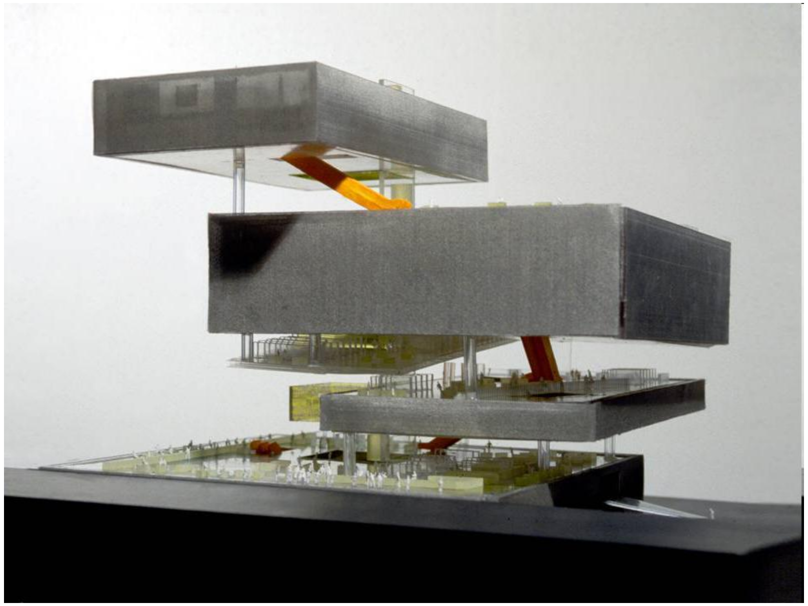
Similar programs were consolidated together, forming five "stable" and four "unstable" programmatic platforms.

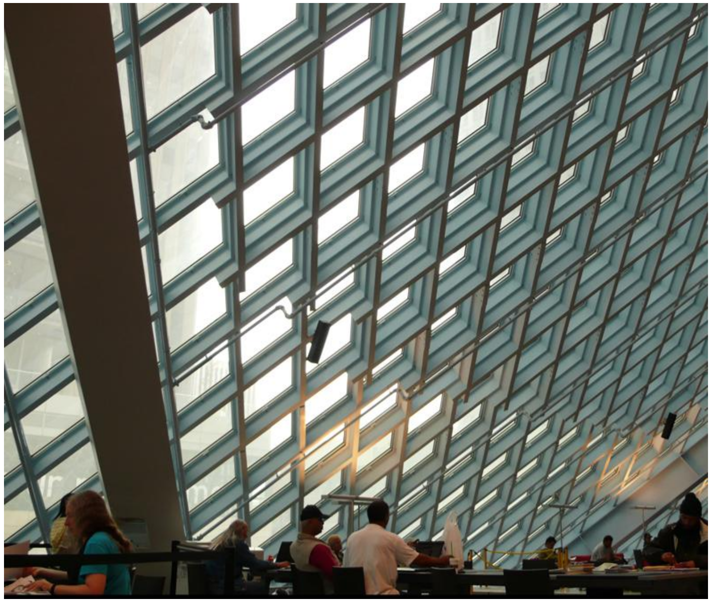
Stable platforms are dedicated for specific purposes such as books, meeting rooms, and parking. Unstable platforms exist in between stable platforms and shelther spaces for activities such as work, interaction, and play.

Seattle Public Library / General Information



Seattle Public Library / Structural System & Elements

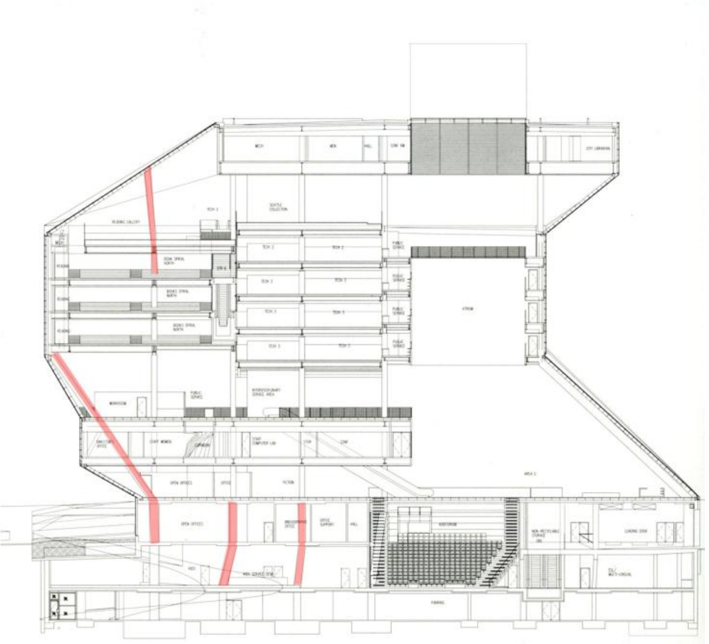


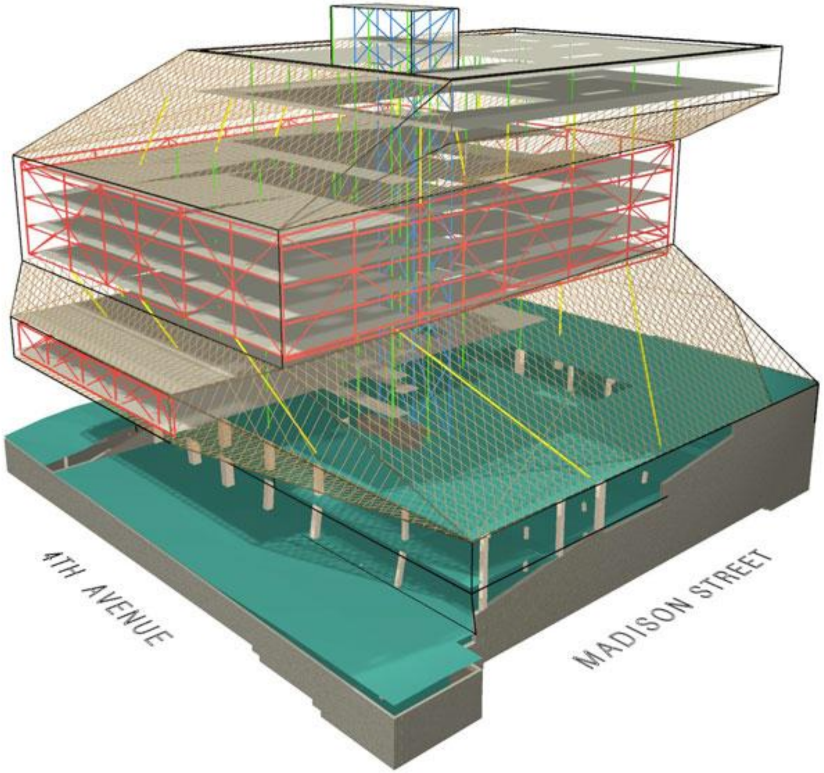


Goal: **Give the illusion of floating, offset boxes , while minimizing columns and transfer girders.**

Solution: **Columns carry gravity loads, while diamond grid and steel perimeter trusses oppose wind load and earthquake loads.**

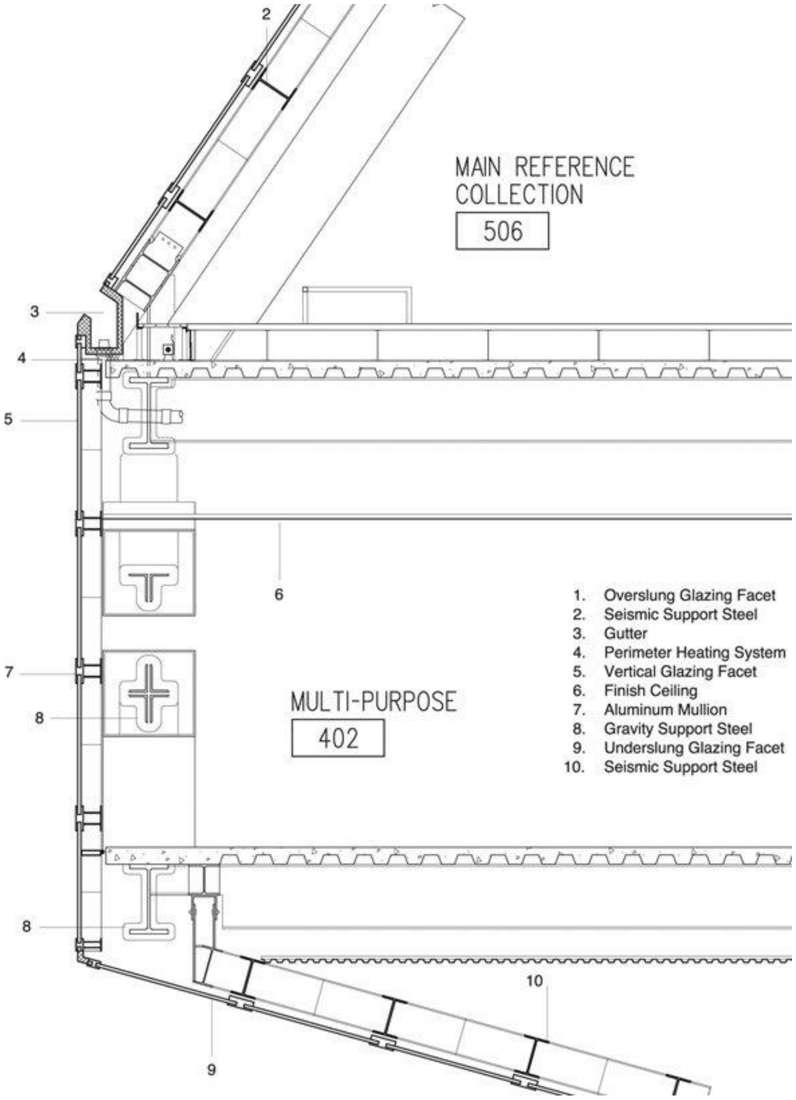
Seattle Public Library / Structural System





Each platform has different structural system.
To minimize column and girders, many columns are skewed to connect to each other in plan.
Columns at corners were pushed back to give the floating effect.
Cantilevers extend up to 52 ft, so skewed yellow columns support the loads.
Skewed yellow columns transfer gravity loads and maximize counterbalancing opportunities.
Skewed columns create thrust, which are then transferred to the floor diaphragm that then connect to the central core or other columns.
In substructure slabs, thrust is taken by extra reinforcing steel.
Perimeter trusses resist lateral loads and transfer gravity loads to ground.

Seattle Public Library / Skin



2nd floor Exterior south wall section

Distinctive exterior skin

10,000 glass diamond panels,
4,644 tons of steel,
165,000 feet of aluminum mullion.

Lateral and gravity loads: Split the structure in half

In general the structure is composed of both load-bearing and seismic systems. The loadbearing system, in the form of columns and beams, supports the elevated platforms containing program spaces.

Under the Seattle code, steel does not have to be fireproofed if it does not take gravity loads. Designers had to keep seismic grid from accepting gravity loads.

The primary frame to stand on its own, without benefit from the seismic grid.

Core columnar members carry the gravity load, while a structural skin and trusses oppose lateral forces.

Seattle Public Library / Skin

The seismic grid

Knits the platforms together, preventing them from tipping over.

Made from 12 in. deep wide-flange members.

The grid works like a giant braced frame, collecting seismic forces from each platform, the grid to the next platform and ultimately to the concrete base.

Designed based on an earthquake with a 500-year return period.

Custom curtain wall system

Why it has to be Diamond-shaped windows?
Actually, it is a second structure, providing additional bracing against earthquakes and wind.

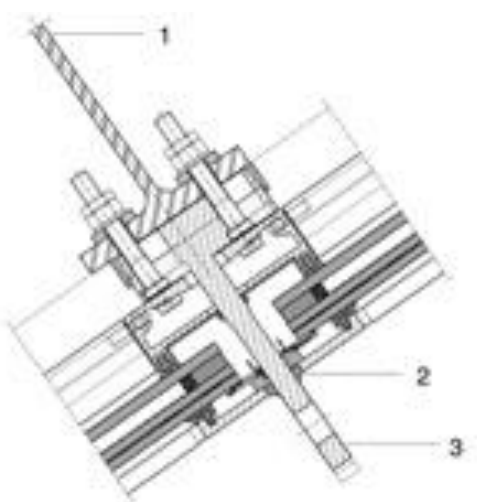
Diamonds are four by seven foot
Oriented from 21° to 45° from horizontal and up to 84 ft in length.

The grid size was determined by considering the optimum size for fabrication, construction and aesthetic.

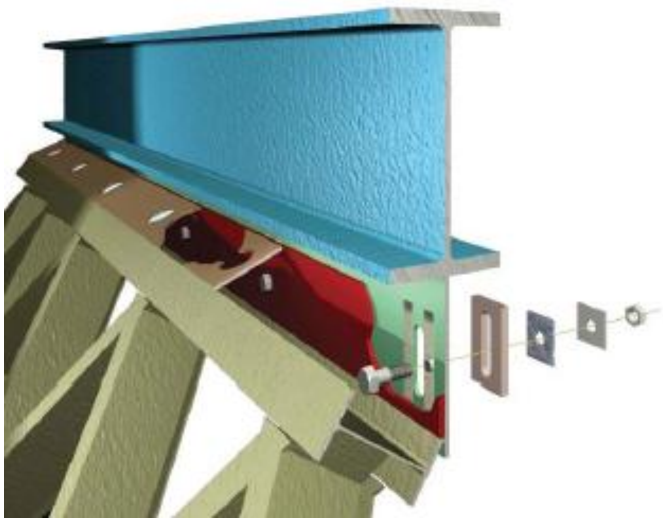
Seattle Public Library / Skin

- **Eyebolts**: Protrude through the mullion body and top and spaced at close intervals.
  Attached back to seismic steel grid members, providing loadcarrying capacity.

- **Slip connection**: where the dynamic grid is posed of the cantilevered boxes.
  Deflection is most likely to occur, the mullions are doubled up to increase the moment of inertia.
  The skin has excellent in shear strength, which is perfect for resisting lateral loads, but poor axial gravity strength.

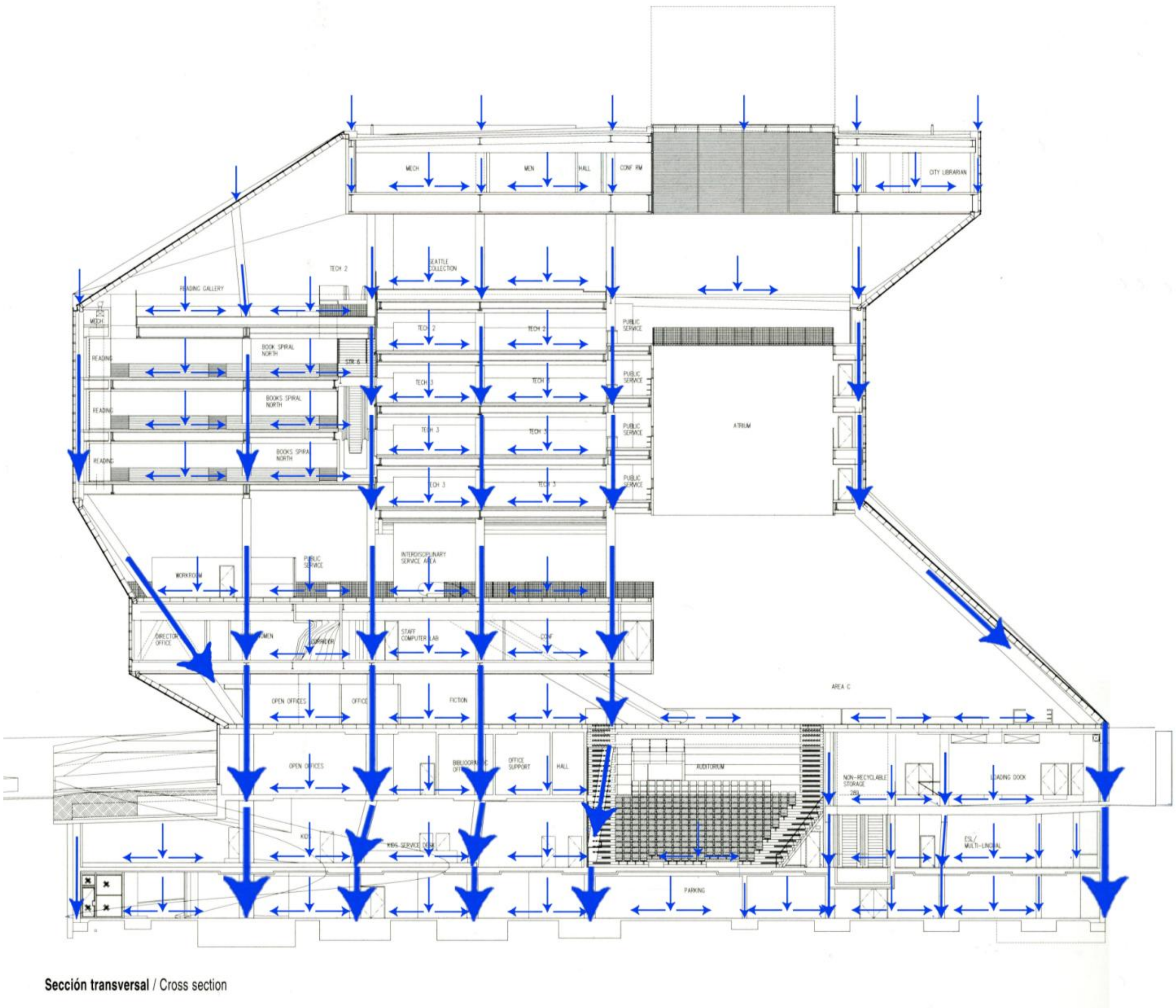


Eyebolts



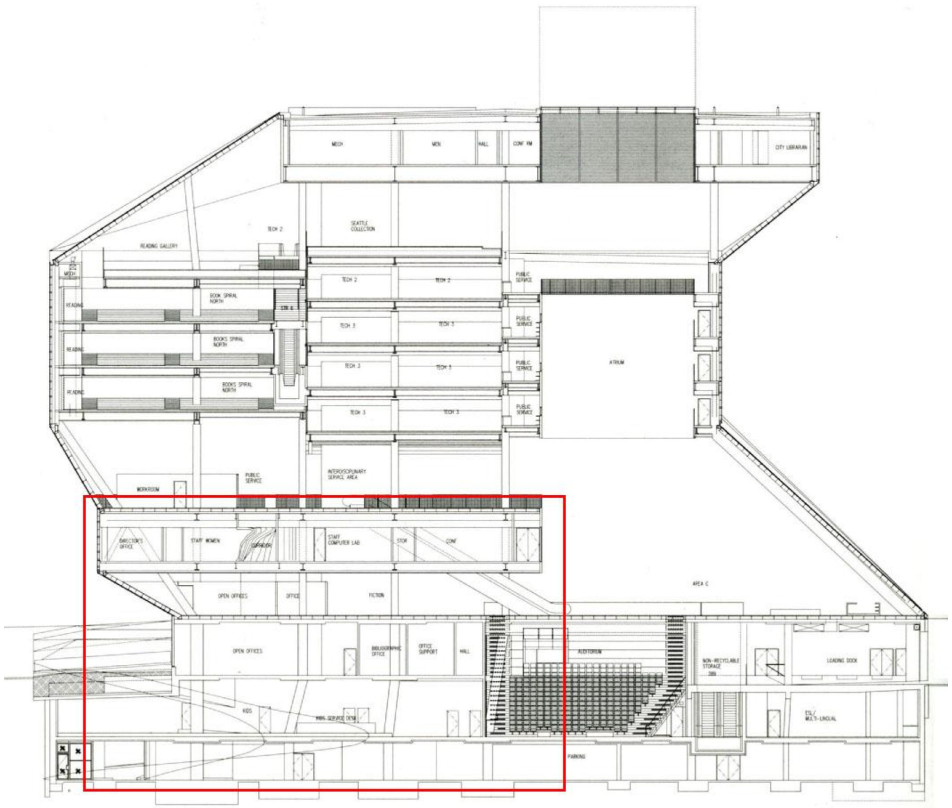
Perimeter truss to steel grid slip connection

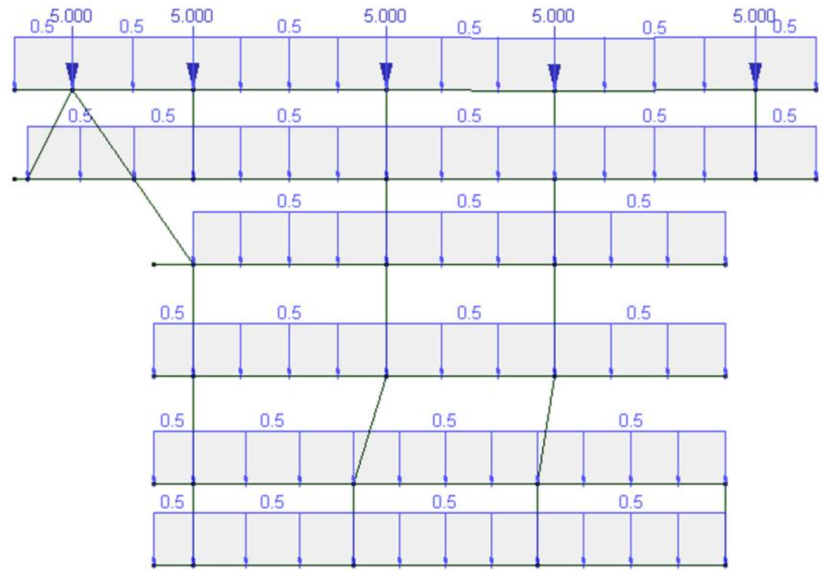
Seattle Public Library / Gravity Load Tracing



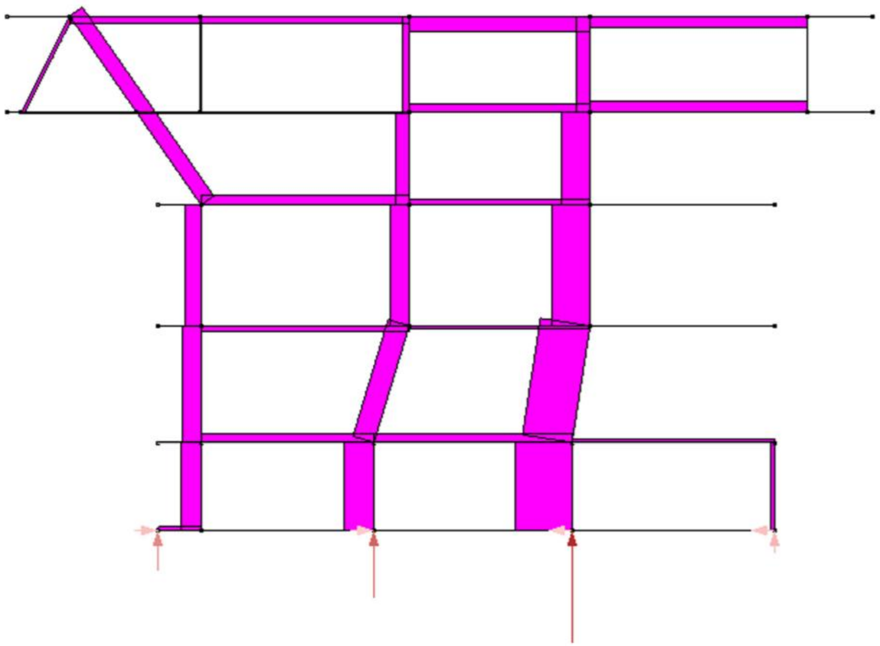
Sección transversal / Cross section

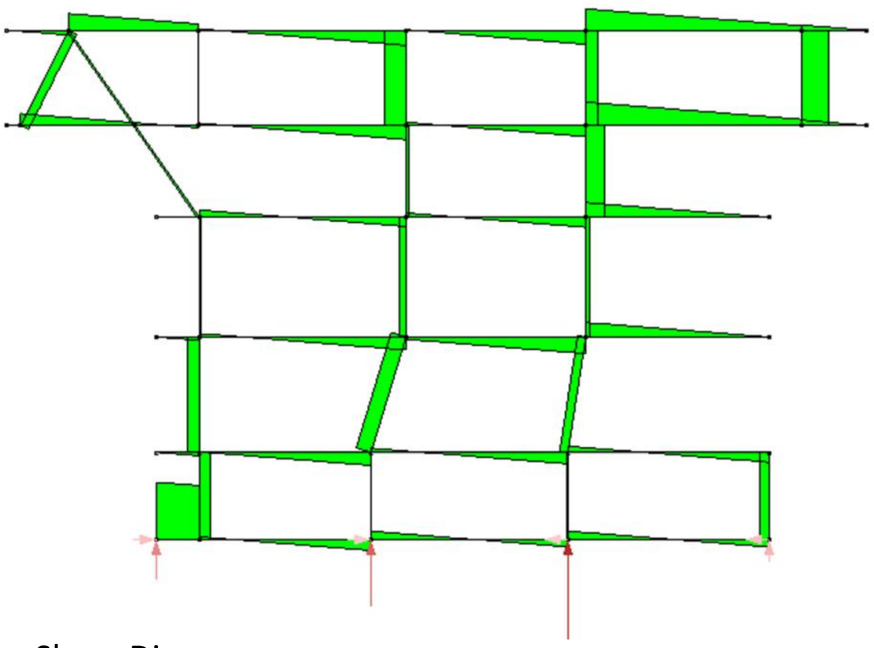
Seattle Public Library / Gravity Loads Multiframe Analysis





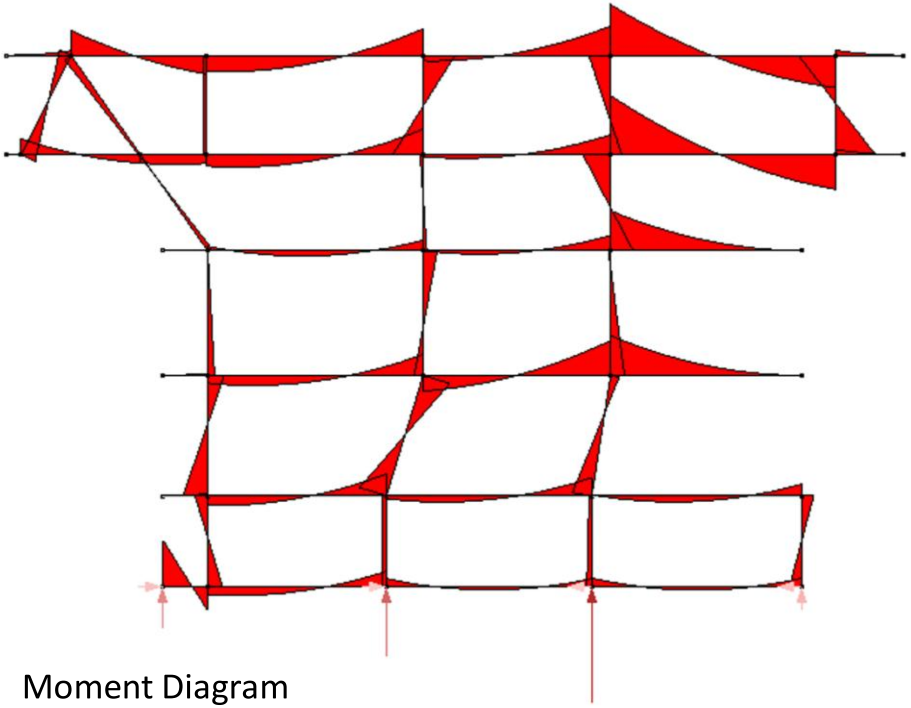
Seattle Public Library / **Gravity Loads Multiframe Analysis**



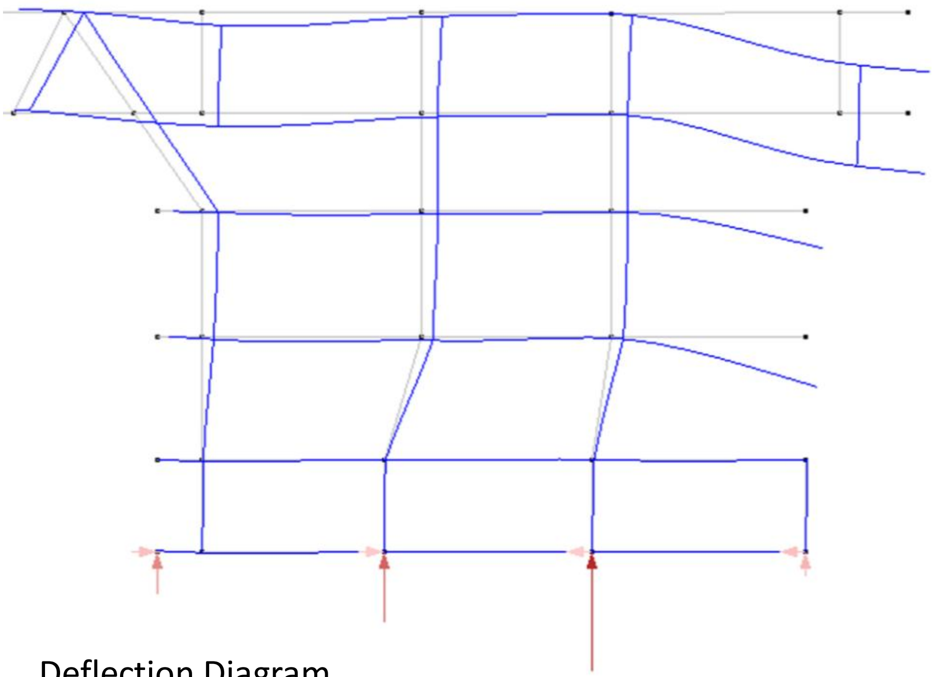


Shear Diagram

Seattle Public Library / Gravity Loads Multiframe Analysis

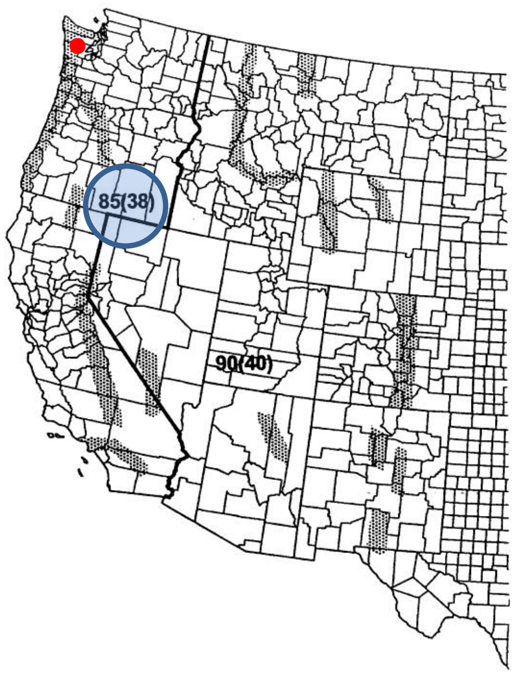


Moment Diagram



Deflection Diagram

Seattle Public Library / Wind Loads

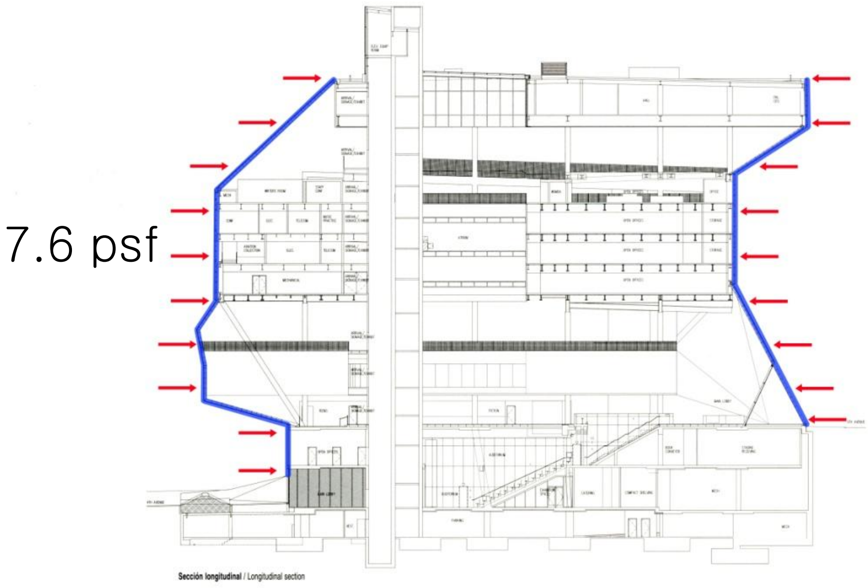


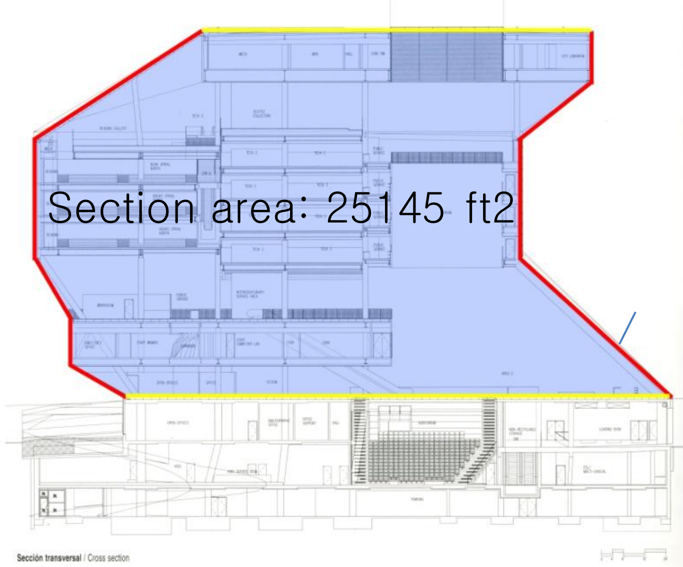
ASCE 7-05 FIGURE 6-1 BASIC WIND SPEED

Main Wind Force Resisting System – Method 1													h ≤ 60 ft.	
Figure 6-2 (cont'd)			Design Wind Pressures										Walls & Roofs	
Enclosed Buildings														
Simplified Design Wind Pressure, p_{s30} (psf) *(Exposure B at h = 30 ft., K_{zt} = 1.0, 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		
85	0 to 5°	1	11.5	-5.9	7.6	-3.5	-13.8	-7.8	-9.6	-6.1	-19.3	-15.1		
	10°	1	12.9	-5.4	8.6	-3.1	-13.8	-8.4	-9.6	-6.5	-19.3	-15.1		
	15°	1	14.4	-4.8	9.6	-2.7	-13.8	-9.0	-9.6	-6.9	-19.3	-15.1		
	20°	1	15.9	-4.2	10.6	-2.3	-13.8	-9.6	-9.6	-7.3	-19.3	-15.1		
	25°	1	14.4	2.3	10.4	2.4	-6.4	-8.7	-4.6	-7.0	-11.9	-10.1		
		2	-------	-------	-------	-------	-2.4	-4.7	-0.7	-3.0	-------	-------		
	30 to 45	1	12.9	8.8	10.2	7.0	1.0	-7.8	0.3	-6.7	-4.5	-5.2		
		2	12.9	8.8	10.2	7.0	5.0	-3.9	4.3	-2.8	-4.5	-5.2		
90	0 to 5°	1	12.8	-6.7	8.5	-4.0	-15.4	-8.8	-10.7	-6.8	-21.6	-16.9		
	10°	1	14.5	-6.0	9.6	-3.5	-15.4	-9.4	-10.7	-7.2	-21.6	-16.9		
	15°	1	16.1	-5.4	10.7	-3.0	-15.4	-10.1	-10.7	-7.7	-21.6	-16.9		
	20°	1	17.8	-4.7	11.9	-2.6	-15.4	-10.7	-10.7	-8.1	-21.6	-16.9		
	25°	1	16.1	2.6	11.7	2.7	-7.2	-9.8	-5.2	-7.8	-13.3	-11.4		
		2	-------	-------	-------	-------	-2.7	-5.3	-0.7	-3.4	-------	-------		
	30 to 45	1	14.4	9.9	11.5	7.9	1.1	-8.8	0.4	-7.5	-5.1	-5.8		
		2	14.4	9.9	11.5	7.9	5.6	-4.3	4.8	-3.1	-5.1	-5.8		

ASCE 7-05 Figure 6-2 (cont'd)

Seattle Public Library / Wind Loads

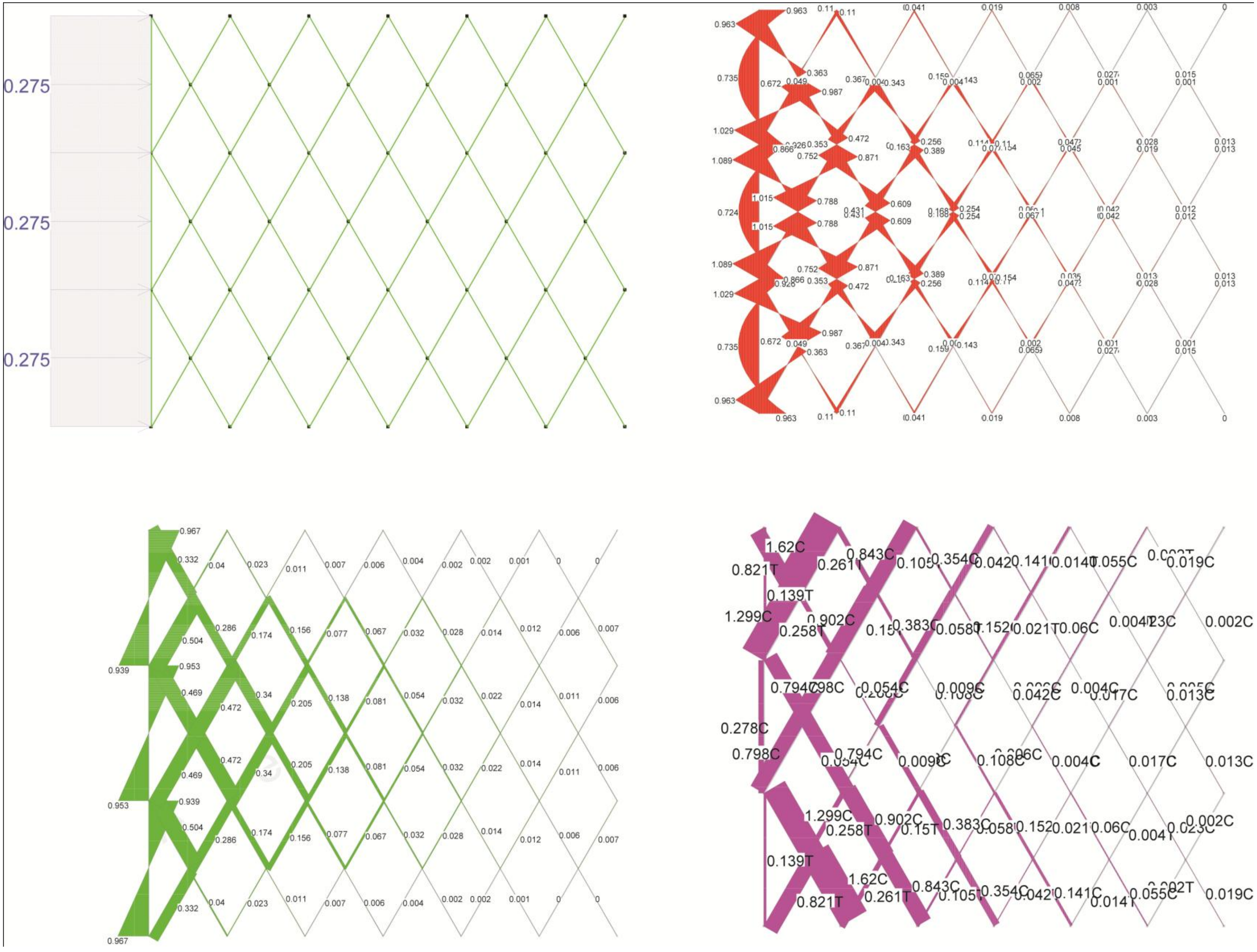




Total lateral load from one side
= 7.6 lb/ft^2 * 24145 ft^2 /4
= 47775.5 lb

Distributed load along the edge
= 47775.5 lb / 174 ft
= 275 lb/ft

Seattle Public Library / Wind Load Multiframe Analysis



Base Shear (V)

Uniform Building Code(1991)	
Goal	Life Safety
Seismic Load	Base Shear V (F=MA concept) V=ZICW/Rw (C=1.25S/T2/3)
Zone	Z 5 Zones 0.075, 0.15, 0.20, 0.30, 0.40
Importance	I Building Occupancy (1.0, 1.25)
Struct. Response	Rw Response Modifications based on 5 basic Structural types
Soil	S 4 Soil Profiles (1.0, 1.2, 1.5, 2.0)
Mass	W Building Weight
Period	T Building Period

Table 5.A, Chapter 5 : The basics Of Seismic Codes, Buildings at risk: seismic design basics for practicing architects, AIA, 1994

Zone (Z)

Zone 3 =0.3

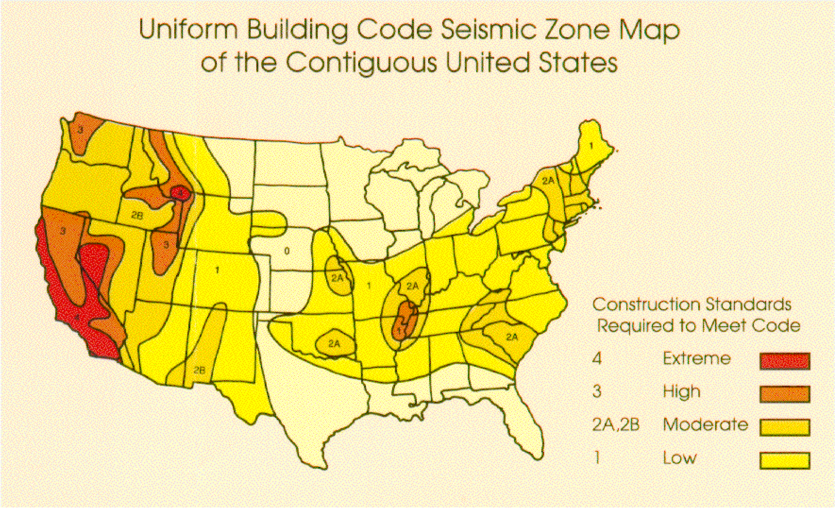


Figure 5.3 : Contour map for coefficient Aa for the continental United States, Chapter 5 : The basics Of Seismic Codes, Buildings at risk: seismic design basics for practicing architects, AIA, 1994

The following table (tab. 16-I) lists the five basic seismic zone categories and assigns a Z-factor to each. (UBC Apndx. Chap. 16):

NONE"Z"	1	2A	2B	3	4
factor	0.075	0.15	0.20	0.30	0.40

Building Occupancy (I_E)

$I_E = 1.25$

Occupancy Category	Nature of Occupancy* (for Buildings and Other Structures)
I	**LOW** hazard to human life in event of failure *Examples*: Agricultural, Temporary & Minor Storage Facilities
II	Those **NOT** listed in Occupancy Categories I, III or IV *Examples*: Office, Retail & Commercial Buildings
III	**SUBSTANTIAL** hazard to human life in event of failure *Examples*: Schools, Jails, Buildings with Public Assembly Areas containing greater than 300 occupants
IV	Designated as an **ESSENTIAL** facility *Examples*: Hospitals, Police, Fire & Rescue Stations, Designated Emergency Shelters, Critical National Defense Facilities

* Reference Table 1604.5 of *IBC 2006* for full description of each Category.

Occupancy Category	Importance Factors*		
	Wind, I_W	Snow, I_S	Earthquake, I_E
I	0.87**	0.80	1.00
II	1.00	1.00	1.00
III	1.15	1.10	1.25
IV	1.15	1.20	1.50

* Reference *ASCE 7-05* for further information
** Wind Importance Factor is 0.77 when Wind Speed >100 mph

Response Modifications (Rw)

Builidng frame system : Braced Steel frame

Rw=5.6

Structural systems to resist lateral loads

BASIC STRUCTURAL SYSTEM[2]	LATERAL-FORCE-RESISTING SYSTEM DESCRIPTION	R	Ω_o	HEIGHT LIMIT FOR SEISMIC ZONES 3 AND 4 (ft) × 304.8 for mm
1. Bearing wall system	1. Light-framed walls with shear panels			
	a. Wood structural panel walls for structures three stories or less	5.5	2.8	65
	b. All other light-framed walls	4.5	2.8	65
	2. Shear walls			
	a. Concrete	4.5	2.8	160
	b. Masonry	4.5	2.8	160
	3. Light steel-framed bearing walls with tension-only bracing	2.8	2.2	65
	4. Braced frames where bracing carries gravity load			
	a. Steel	4.4	2.2	160
	b. Concrete[3]	2.8	2.2	–
	c. Heavy timber	2.8	2.2	65
2. Building frame system	1. Steel eccentrically braced frame (EBF)	7.0	2.8	240
	2. Light-framed walls with shear panels			
	a. Wood structural panel walls for structures three stories or less	6.5	2.8	65
	b. All other light-framed walls	5.0	2.8	65
	3. Shear walls			
	a. Concrete	5.5	2.8	240
	b. Masonry	5.5	2.8	160
	4. Ordinary braced frames			
	a. Steel	5.6	2.2	160
	b. Concrete[3]	5.6	2.2	–
	c. Heavy timber	5.6	2.2	65
	5. Special concentrically braced frames			
	a. Steel	6.4	2.2	240

Seattle Public Library / Seismic Loads

C = 1.25S/T2/3
= 1.25X1.5/(1.8)2/3
= 1.2 > 2.75(the maximum value specified by UBC Section 1628.2.1), <u>OK</u>

Soil (S)

$S_3 = 1.5$

Building Period (T)

Building Height : 196 ft
Material : Steel-MRF(Seismic)

T=1.8

Table 1. Site coefficients		
Type	**Description**	**S**
S_1	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 750 m/s, or (b) stiff or dense soil condition where the soil depth is less than 60 m of stable sands, gravel or hard clay characterized by a shear-wave velocity greater or equal to 400 m/s.	1.0
S_2	A soil profile with either: (a) stiff or dense soil conditions, where the soil depth exceeds 60 m or more, characterized by a shear-wave velocity greater or equal to 400 m/s, or (b) stiff, very stiff or medium dense soil conditions, where the soil depth is less than 60 m characterized by a shear-wave velocity greater or equal to 400 m/s.	1.2
S_3	A soil profile containing less than 12 m in thickness of soft clays imbedded in a deposit of soft to medium clay characterized by a shear-wave velocity between 150 and 270 m/s.	1.5
S_4	A soil profile, characterized by a shear wave velocity less than 150 m/s, containing more than 12 m of soft clay or cohesionless soil.	2.0

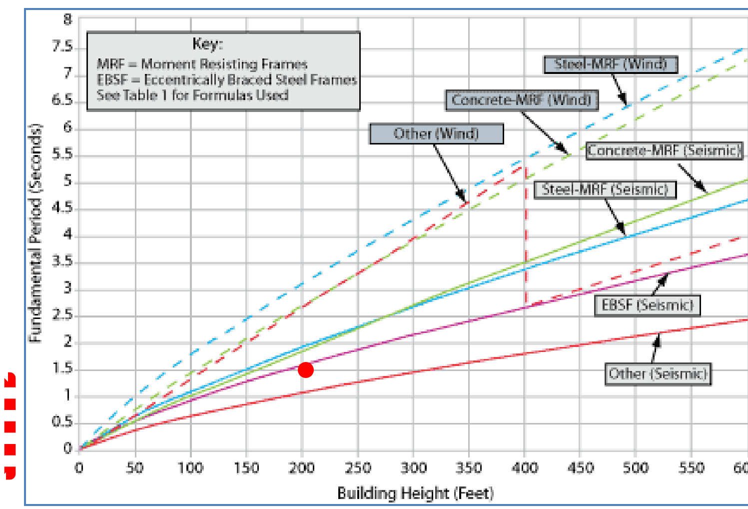


Figure 2: Approximate Fundamental Period vs. Building Height, Building Periods : Moving forward(and backward) *by William P. Jacobs, V. P.E.* ,Structure Magazine June, 2008

Building Weight (W=89280kips)

Steel = 4644ton X 2205lb/1ton = 10240020lb **= 10240kips**

Rebar = 2050ton X 2205lb/1ton = 4520250lb **= 4520kips**

Concrete = 18400yd3 X (3ft/1yd)3X150lb/ft3= 74520000 **= 74520kips**

Total = 10240kips + 4520kips+74520kips = <u>89280kips</u>

Base Shear V

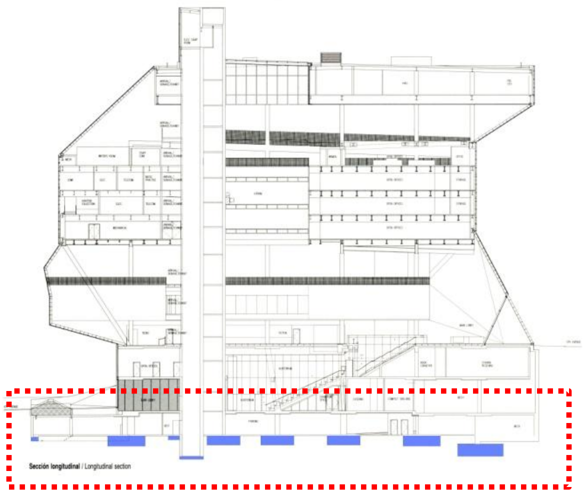
$$V = ZICW/R_w$$

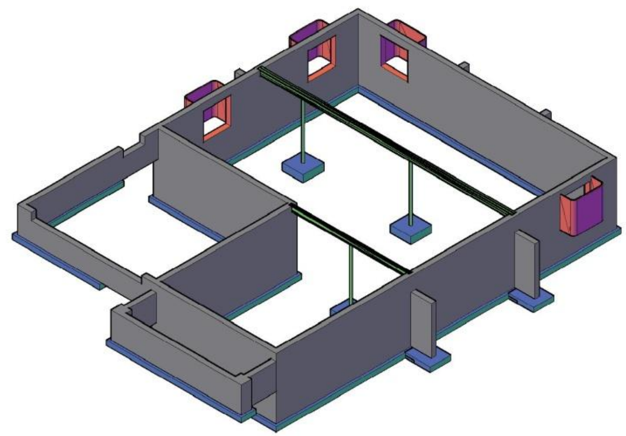
$$= 0.3 \times 1.25 \times 1.2 \times 89280\text{kips}/5.6$$

$$= \underline{7174.29\text{kips}}$$

Z=0.3, I=1.25, C= 1.2, W=89280 kips, R_w=5.6

Seattle Public Library / Soils and Foundation





Foundation: The spread footing foundations : **10ft below the west grade, to level three, which is at grade on the east.**

Soils: **A base of glacial till (an unconsolidated mixture of clay, sand, gravel, and boulders)**

- **Soft, organic and claylike soils that can easily cause landslides when disturbed.**
- **These soils retain water very well and sometimes need dewatering system to discharge excess water.**

Details:

- **The structure is concrete.**
- **A mat supports a 213-ft-tall, expressed concrete core, 65X44 ft in plan, in the southwest quadrant of the footprint.**
- **The core carries gravity loads but resists minimal lateral forces.**
- **A 28-ft-wide footing supports two concrete shear walls and a concrete column in the northwest corner of the concrete substructure.**

http://www.spl.org/lfa/central/structuralsteel/eseq_5thMad.gif

“Primary steel erected on 360 tons of falsework”

Six shore lines for books and assembly platforms.

Falsework required unloading from the middle towards the corners in order to “engage key gravity elements” and minimize twisting.

Grid to platform connection was made after platform deflected to to avoid transferring gravity loads to the grid.