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 shelter spaces for activities such as work, interaction, and play.
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.
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

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.

2nd floor Exterior south wall section
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.
- **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.
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
### ASCE 7-05 Figure 6-1: Basic Wind Speed

![Map of Basic Wind Speeds](image)

### ASCE 7-05 Figure 6-2 (cont’d): Simplified Design Wind Pressure, $p_{w30}$ (psf)

<table>
<thead>
<tr>
<th>Zones</th>
<th>Horizontal Pressures</th>
<th>Vertical Pressures</th>
<th>Overhangs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>0 to 5'</td>
<td>11.5</td>
<td>-5.9</td>
<td>7.6</td>
</tr>
<tr>
<td>10'</td>
<td>12.9</td>
<td>-5.4</td>
<td>7.3</td>
</tr>
<tr>
<td>15'</td>
<td>14.4</td>
<td>-4.8</td>
<td>9.6</td>
</tr>
<tr>
<td>20'</td>
<td>15.9</td>
<td>-4.2</td>
<td>10.6</td>
</tr>
<tr>
<td>25'</td>
<td>14.4</td>
<td>2.3</td>
<td>10.4</td>
</tr>
<tr>
<td>30 to 45</td>
<td>12.9</td>
<td>8.8</td>
<td>10.2</td>
</tr>
<tr>
<td>2</td>
<td>12.9</td>
<td>8.8</td>
<td>10.2</td>
</tr>
<tr>
<td>0 to 5'</td>
<td>12.8</td>
<td>-6.7</td>
<td>8.5</td>
</tr>
<tr>
<td>10'</td>
<td>14.5</td>
<td>-6.0</td>
<td>9.6</td>
</tr>
<tr>
<td>15'</td>
<td>16.1</td>
<td>-5.4</td>
<td>10.7</td>
</tr>
<tr>
<td>20'</td>
<td>17.8</td>
<td>-4.7</td>
<td>11.9</td>
</tr>
<tr>
<td>25'</td>
<td>16.1</td>
<td>2.6</td>
<td>11.7</td>
</tr>
<tr>
<td>2</td>
<td>14.4</td>
<td>9.9</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Exposure B at $h = 30$ ft, $K_v = 1.0$, with $I = 1.0$.
7.6 psf

Section area: 25145 ft²

Total lateral load from one side
= $7.6 \text{ lb/ft}^2 \times 24145 \text{ ft}^2 / 4$
= 47775.5 lb

Distributed load along the edge
= $47775.5 \text{ lb} / 174 \text{ ft}$
= 275 lb/ft
The following table (tab. 16-I) lists the five basic seismic zone categories and assigns a Z-factor to each. (UBC Apndx. Chap. 16):

<table>
<thead>
<tr>
<th>Zone (Z)</th>
<th>1</th>
<th>2A</th>
<th>2B</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>factor</td>
<td>0.075</td>
<td>0.15</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
</tr>
</tbody>
</table>
# Building Occupancy ($I_E$)

$I_E = 1.25$

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>Nature of Occupancy* (for Buildings and Other Structures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>LOW hazard to human life in event of failure. <em>Examples: Agricultural, Temporary &amp; Minor Storage Facilities</em></td>
</tr>
<tr>
<td>II</td>
<td>Those NOT listed in Occupancy Categories I, III or IV. <em>Examples: Office, Retail &amp; Commercial Buildings</em></td>
</tr>
<tr>
<td>III</td>
<td>SUBSTANTIAL hazard to human life in event of failure. <em>Examples: Schools, Jails, Buildings with Public Assembly Areas containing greater than 300 occupants</em></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>Wind, $iw$</th>
<th>Snow, $is$</th>
<th>Earthquake, $if$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.87**</td>
<td>0.80</td>
<td>1.00</td>
</tr>
<tr>
<td>II</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>III</td>
<td>1.15</td>
<td>1.10</td>
<td>1.25</td>
</tr>
<tr>
<td>IV</td>
<td>1.15</td>
<td>1.20</td>
<td>1.50</td>
</tr>
</tbody>
</table>

* Reference ASCE 7-05 for further information.

** Wind Importance Factor is 0.77 when Wind Speed > 100 mph
Response Modifications (Rw)

Building frame system: Braced Steel frame

Rw=5.6

Structural systems to resist lateral loads

Reproduced from the 1997 edition of the Uniform Building Code, copyright © 1997, with permission of the publisher, the International Conference of Building Officials.
C = 1.25S/T^{2/3} \\
= 1.25 \times 1.5 / (1.8)^{2/3} \\
= 1.2 > 2.75 \text{(the maximum value specified by UBC Section 1628.2.1), OK}

**Soil (S)**

\( S_3 = 1.5 \)

**Building Period (T)**

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

\( T = 1.8 \)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>( S )</th>
</tr>
</thead>
</table>
| \( S_1 \) | 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 200 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 160 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 = 89280kips

Base Shear V

\[ V = \frac{ZICW}{Rw} \]

= 0.3X1.25X1.2X89280kips/5.6

= 7174.29kips

Z=0.3, I=1.25, C=1.2, W=89280 kips, Rw=5.6
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.
Seattle Public Library / Construction

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 avoid transferring gravity loads to the grid.