Seismic Design Of Data Centers for Tier III and Tier IV Resilience: Project Examples

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Example:

**Tier I – Basic:** 99.671% Availability
- Susceptible to disruptions from both planned and unplanned activity
- Single path for power and cooling distribution, no redundant components (N)
- May or may not have a raised floor, UPS, or generator
- Takes 3 months to implement
- Annual downtime of 28.8 hours
- Must be shut down completely for perform preventive maintenance
Structural Requirements of ANSI/TIA-942

General Requirements:

Eg: “Tier III should have protection against most physical events, intentional or accidental, natural or manmade, which could cause data center to fail.”

For all Tiers: “The building structural system should be either steel or concrete. At a minimum, the building frame should be designed to withstand wind loads in accordance with the applicable building codes for the location under consideration and in accordance with provisions for structures designated as essential facilities (for example, Building Classification III from the International Building Code).”

Arch. Guide, Table 11:

Eg: For Tier IV, the following are stated:

- Site Spec. Response Spectra with Operational Status after 5% in 100 year event.
- Importance Factor, I = 1.5
- Floor loading capacity superimposed live load 12 kPa (250 lb/ft²)
- Building LFRS, Concrete Shearwall/Steel BF.
- Dampers/base isolation for SDC D.

➔ Structural design requirements are not clear & have inconsistencies
A detailed seismic design basis is proposed for Tier III and Tier IV D. C.

Three Main Components:
1. Building Structure
2. Sensitive Computer Equipment
3. Nonstructural Components

Two levels of Seismicity (X, Y and Z):
1. DBE: 10% Exceedance in 50 years
2. MCE: 2% Exceedance in 50 years

For highly seismic regions
→ Seismic Base Isolation

### Building Structure

<table>
<thead>
<tr>
<th>Performance</th>
<th>Operational Level for DBE and MCE events.</th>
</tr>
</thead>
</table>
| Structural Members | - Structure behaves elastic  
- Design for $R = 1$  
- Consider vertical ground acceleration |
| Connections, Anchorages, Collectors, Drag-strut Elements | - A minimum ordinary ductility detailing  
- Use overstrength factors  
- Capacity design where applicable |

### Nonstructural Components

<table>
<thead>
<tr>
<th>Performance</th>
<th>Operational Level for DBE and MCE events.</th>
</tr>
</thead>
</table>
| Displacement Sensitive | - Satisfy $1.25 \left(D_p \right)$ ($D_p$: relative displacement)  
- Design for $R = 1$ |
| Acceleration Sensitive | - Designed for the forces estimated  
- Design for $R = 1$ |
| Anchorages and Critical Connections | - Use overstrength factors  
- Capacity design where applicable  
- No yielding allowed |

### Sensitive Computer Equipment

<table>
<thead>
<tr>
<th>Performance</th>
<th>Operational Level for DBE and MCE events.</th>
</tr>
</thead>
</table>
| Enclosure, Cabinets and Raised Floor | - Use requirements of Nonstructural Components  
- Max. Accel. < 0.20g (X, Y Directions) |
| Computer Equipment | - Max. Accel. < 0.30g Resulant |
Project Examples

Star of Bosphorus, Istanbul
• Tier III Certified
• One of the largest Data Centers in Turkey
• In active seismic zone
• Private organization
• Completed

Is Bank, Istanbul
• Tier IV Certified
• One of the largest Data Centers in Turkey
• In active seismic zone
• Belongs to one of the biggest bank of Turkey
• Completed
Star of Bosphorus: Structural System

- Cantilever Columns
- First Floor
- Gravity Columns
- Collectors
- Braced Frames
- Roof Truss
- Isolation Slab
- Isolator Column
- Mat Foundation
- Hangers
- Servers
- Raised Floor
- Mechanical Equip.
**Star of Bosphorus: Structural System**

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**Isolation Layer**

**Superstructure**

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**Property** | **Value**
--- | ---
Seismic Weight | 300 000 kN
1. Mode (fixed-base): | T = 0.719 sec, X-Dir., MPR: 58.4%
2. Mode (fixed-base): | T = 0.569 sec, Y-Dir., MPR: 70.7%
3. Mode (fixed-base): | T = 0.503 sec, Torsion, MPR: 50.1%

**Direct.** | **Elevation** | **LFRS** | **Ductility**
--- | --- | --- | ---
X-Dir | 0.00m to 5.25m | CBF | Ordinary
| 5.25m to 11.70m | Cantilever Col. | N/A
Y-Dir | 0.00m to 5.25m | CBF | Ordinary
| 5.25m to 11.70m | CBF | Ordinary

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**Note:** Isolation slab weight is approximately %75 of the whole superstructure weight.
Star of Bosphorus: Isolation System

69 Triple Friction Pendulum Isolator

Prototype Test Results
Star of Bosphorus: Seismicity

**Record No** | **Earthquake Name** | **Mag.**
--- | --- | ---
RSN882 | Landers, U.S., 1992 | 7.28 M
RSN1110 | Kobe, Japan, 1995 | 6.90 M
RSN1166 | Kocaeli, Turkey, 1999 | 7.51 M
RSN1762 | Hector Mine, U.S., 1999 | 7.13 M
RSN3758 | Landers, U.S., 1992 | 7.28 M
RSN5836 | El Mayor, Mexico, 2010 | 7.20 M
RSN6953 | Darfield, N.Z., 2010 | 7.00 M
Star of Bosphorus: Computer Model (SAP2000)

Original Model

Modified Model
### Star of Bosphorus: Equivalent Linear Force Proc.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MCE-GM-LB</td>
<td>4.167 sec</td>
<td>27.8%</td>
<td>0.131</td>
<td>565 mm</td>
</tr>
<tr>
<td>MCE-MR-LB</td>
<td>4.477 sec</td>
<td>31.4%</td>
<td>0.164</td>
<td>815 mm</td>
</tr>
<tr>
<td>DBE-GM-UB</td>
<td>2.513 sec</td>
<td>50.0%</td>
<td>0.097</td>
<td>152 mm</td>
</tr>
<tr>
<td>DBE-MR-UB</td>
<td>3.082 sec</td>
<td>50.0%</td>
<td>0.112</td>
<td>263 mm</td>
</tr>
</tbody>
</table>

UB: Upper Bound  
LB: Lower Bound
Star of Bosphorus: Response Spectrum Analysis

### Composite Spectrum

MCE-GM-Lower Bound Composite Spectra for %5-%28 Damping

<table>
<thead>
<tr>
<th>Design Type</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELFP</td>
<td>RSA</td>
</tr>
<tr>
<td>MCE-LB-GM</td>
<td>565 mm</td>
</tr>
<tr>
<td>MCE-LB-MR</td>
<td>815 mm</td>
</tr>
<tr>
<td>DBE-UB-GM</td>
<td>152 mm</td>
</tr>
<tr>
<td>DBE-UB-MR</td>
<td>263 mm</td>
</tr>
</tbody>
</table>

UB: Upper Bound, LB: Lower Bound
Comprehensive Comparison of

- Effect of Precision
- Effect of Diaphragm
- Effect of Additional Mass
- Effect of Torsional Irregularity

Computer model is verified with comprehensive comparisons ✅
Star of Bosphorus: NLTHA Results for Darfield EQ
### Lower Bound Isolator Displacements

<table>
<thead>
<tr>
<th>Analysis</th>
<th>X-Dir (m)</th>
<th>Y-Dir (m)</th>
<th>Mag. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darfield-6953</td>
<td>0.707</td>
<td>0.586</td>
<td>0.880</td>
</tr>
<tr>
<td>Hector-1762</td>
<td>0.445</td>
<td>0.481</td>
<td>0.537</td>
</tr>
<tr>
<td>Kobe-1110</td>
<td>0.407</td>
<td>0.464</td>
<td>0.523</td>
</tr>
<tr>
<td>Kocaeli-1166</td>
<td>0.435</td>
<td>0.625</td>
<td>0.683</td>
</tr>
<tr>
<td>Landers-882</td>
<td>0.417</td>
<td>0.397</td>
<td>0.478</td>
</tr>
<tr>
<td>Landers-3758</td>
<td>0.629</td>
<td>0.492</td>
<td>0.679</td>
</tr>
<tr>
<td>Sierra-5836</td>
<td>0.448</td>
<td>0.455</td>
<td>0.495</td>
</tr>
<tr>
<td>Average</td>
<td>0.498</td>
<td>0.500</td>
<td>0.611</td>
</tr>
<tr>
<td>Average</td>
<td>GM: 0.510</td>
<td>MR: 0.611</td>
<td></td>
</tr>
<tr>
<td>Equiv. SDOF</td>
<td>GM: 0.587</td>
<td>MR: 0.822</td>
<td></td>
</tr>
<tr>
<td>RSA</td>
<td>GM: 0.585</td>
<td>MR: 0.820</td>
<td></td>
</tr>
</tbody>
</table>

### Upper Bound Isolator Shear Forces

<table>
<thead>
<tr>
<th>Analysis</th>
<th>X-Dir (m)</th>
<th>Y-Dir (m)</th>
<th>Mag. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darfield-6953</td>
<td>0.173</td>
<td>0.132</td>
<td>0.207</td>
</tr>
<tr>
<td>Hector-1762</td>
<td>0.119</td>
<td>0.135</td>
<td>0.145</td>
</tr>
<tr>
<td>Kobe-1110</td>
<td>0.128</td>
<td>0.140</td>
<td>0.155</td>
</tr>
<tr>
<td>Kocaeli-1166</td>
<td>0.131</td>
<td>0.150</td>
<td>0.156</td>
</tr>
<tr>
<td>Landers-882</td>
<td>0.133</td>
<td>0.127</td>
<td>0.133</td>
</tr>
<tr>
<td>Landers-3758</td>
<td>0.136</td>
<td>0.124</td>
<td>0.172</td>
</tr>
<tr>
<td>Sierra-5836</td>
<td>0.127</td>
<td>0.119</td>
<td>0.133</td>
</tr>
<tr>
<td>Average</td>
<td>0.135</td>
<td>0.132</td>
<td>0.157</td>
</tr>
<tr>
<td>Average</td>
<td>GM: 0.133 g</td>
<td>MR: 0.157</td>
<td></td>
</tr>
<tr>
<td>Equiv. SDOF</td>
<td>GM: 0.129 g</td>
<td>MR: 0.150</td>
<td></td>
</tr>
<tr>
<td>RSA</td>
<td>GM: 0.128 g</td>
<td>MR: 0.150</td>
<td></td>
</tr>
</tbody>
</table>
Star of Bosphorus: NLTHA Results

Average Absolute Accelerations

| H(m) | Location          | X (g) | Y (g) | |XY| (g) |
|------|------------------|-------|-------|------|------|
| 0.00 | Foundation       | 0.656 | 0.607 | 0.712 |
| 1.80 | Bot. of Iso.     | 0.657 | 0.607 | 0.712 |
| 2.20 | Top of Iso.      | 0.152 | 0.142 | 0.177 |
| 9.05 | 1.st Floor       | 0.159 | 0.142 | 0.178 |
| 14.30| Roof             | 0.201 | 0.17  | 0.218 |
All elements are shown to remain elastic under MCE event ✔
Star of Bosphrus: Design of Other Components

Design of other components are performed per proposed design basis:

• Nonstructural Components
  • Raised Floor
  • Mechanical Equipment
  • Cabling
  • Architectural Components
• Connections
• Anchorages
Star of Bosphorus
Star of Bosphorus
Star of Bosphorus
Star of Bosphorus
Is Bank Data Center: Structural System

- Concept is similar to Star of Bosphorus system.
- Superstructure LFRS is Moment Frames
- Triple Friction Pendulum
- Superstructure is more flexible, therefore ASCE 7-16 is used in ELFP
Is Bank Data Center
Conclusions & Future Work

• Projects that are designed using the proposed design basis are presented.

• Both project satisfy all the design and performance requirements of the proposed design basis.

• Collapse Probability Analysis of the first project will be conducted and the design will be submitted to US Resilience Council for seismic rating certification.
Thank You for Your Attention!
## Star of Bosphorus: NLTHA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric Nonlinearity</td>
<td>None</td>
</tr>
<tr>
<td>Number of Output Steps</td>
<td>Picked from data duration</td>
</tr>
<tr>
<td>Output Step Size</td>
<td>0.01 seconds</td>
</tr>
<tr>
<td>Damping</td>
<td>Proportional Damping</td>
</tr>
<tr>
<td>Damping Coefficients</td>
<td>Specify Damping by Period</td>
</tr>
<tr>
<td>First Period and Damping</td>
<td>4.5 Seconds and 2% Damping</td>
</tr>
<tr>
<td>Second Period and Damping</td>
<td>0.3 Seconds and 2% Damping</td>
</tr>
<tr>
<td>Time Integration</td>
<td>Hilber-Hughes-Taylor</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.8333</td>
</tr>
<tr>
<td>Beta</td>
<td>0.4444</td>
</tr>
<tr>
<td>Alpha</td>
<td>-0.3333</td>
</tr>
<tr>
<td>Maximum Substep Size</td>
<td>0.005</td>
</tr>
<tr>
<td>Minimum Substep Size</td>
<td>0</td>
</tr>
<tr>
<td>Use Event-to-event Stepping</td>
<td>Yes</td>
</tr>
<tr>
<td>Event Lumping Tolerance (Relative)</td>
<td>0.005</td>
</tr>
<tr>
<td>Maximum Events per Step</td>
<td>24</td>
</tr>
<tr>
<td>Use Iteration</td>
<td>Yes</td>
</tr>
<tr>
<td>Maximum Const-Stiff Iter. per Step</td>
<td>10</td>
</tr>
<tr>
<td>Max. New.-Raph. Iter. per Step</td>
<td>20</td>
</tr>
<tr>
<td>Iteration Convergence Tol. (Rel)</td>
<td>0.005</td>
</tr>
<tr>
<td>Use Line Search</td>
<td>No</td>
</tr>
</tbody>
</table>
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