Structural Design of the New Airport Traffic Control Tower at the McCarran International Airport, Las Vegas, Nevada

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McCarran International Airport, Las Vegas

• Fifteenth Busiest Airport in the World, based on Passenger Traffic

• New Facilities Required to Accommodate Projected Increase in Air Travel

• New Airport Traffic Control Tower (ATCT), Terminal Radar Approach Control (TRACON) Building and Parking Facility

• Control Cab Level must be 335 Feet above Ground Level
Wind Design Criteria

- Serviceable Behavior During Frequent Winds (10-Year Wind)
  - Limit Acceleration at Cab Level to Acceptable Levels (25 milli-g’s)

- Linear Response During Extreme Winds (50-Year Wind)
  - Resist Wind Loads without Collapse
  - No Excessive Deflection of Structure
  - Undamaged Components and Cladding
## Wind Design Criteria

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure Category</td>
<td>C</td>
</tr>
<tr>
<td>Design Basic Wind Speed</td>
<td>90 mph</td>
</tr>
<tr>
<td>Occupancy Category</td>
<td>IV</td>
</tr>
<tr>
<td>Wind Importance Factor, I</td>
<td>1.15</td>
</tr>
<tr>
<td>Internal Pressure Coefficient, GC&lt;sub&gt;pi&lt;/sub&gt;</td>
<td>+.18, -.18</td>
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</table>
# Earthquake Design Criteria

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Acceleration at Short Period, $S_s$</td>
<td>0.56g</td>
</tr>
<tr>
<td>Spectral Acceleration at 1-sec Period, $S_1$</td>
<td>0.17g</td>
</tr>
<tr>
<td>Seismic Design Category</td>
<td>D</td>
</tr>
<tr>
<td>Site Class</td>
<td>C</td>
</tr>
<tr>
<td>Occupancy Category</td>
<td>IV</td>
</tr>
<tr>
<td>Importance Factor, $I$</td>
<td>1.5</td>
</tr>
<tr>
<td>Response Modification Factor, $R$</td>
<td>5</td>
</tr>
</tbody>
</table>

![Graph of spectral acceleration vs. period](graph.png)
Preliminary Tower Design

- Tower Footprint Determined by Site Constraints and Programming Requirements
- 22 Stories with a Building Aspect Ratio of 10:1
- Special Reinforced Concrete Walls for Levels 1-19
- Braced Frames for Levels 20-21
- Moment Frames at Cab Level
- Strength Requirements Determined by Wind Loads
Preliminary Tower Design

Concrete Walls
24 inches, Floor 1 - 6
18 inches, Floor 7 - 15,
12 inches, Floor 16 - 19
Computer Model
Alternative Seismic Design

- Prescriptive Code Provisions Require Dual System for Shear Walls in Buildings over 240 feet

- Performance Based Design Approach to Justify Elimination of Moment Frames
  - Serviceable Behavior During Frequent Earthquakes
  - Low Probability of Collapse During Extremely Rare Earthquakes
Tower Story Shears

- Wind Loads
- Earthquake Loads (Response Spectrum)

Elevation (ft)

East-West Direction

North-South Direction
Preliminary Wind Analysis

- Accelerations at Cab Level Calculated using ASCE 7-05 and Canadian Building Code

- Statistical Analysis was Performed Based on Recorded Wind Speeds of the Last 57 Years

- Strong Winds Usually Reach the Site from the Southwest or through the Pass from the Northwest.

- Inherent Damping of Tower is 1% of Critical

- Calculations to be Verified by Testing in a Wind Tunnel Laboratory
Wind Exposure in Various Directions
Wind Rose for 50 Year Winds
Wind Rose for 10 Year Winds
Maximum 10-Year Acceleration in NS Direction
National Building Code of Canada

![Graph showing maximum 10-Year Acceleration in the NS direction for different building weights and periods. The graph includes lines for T = 1.0 sec, T = 1.5 sec, T = 2.0 sec, T = 2.5 sec, and T = 3.0 sec, with each line representing a different period and corresponding to the acceleration in milli-g for a given building weight in kips.]
Maximum 10-Year Acceleration in EW Direction

National Building Code of Canada
Wind Tunnel Testing

• 1:300 Scale Model of Proposed Tower Mounted on High-Frequency Response Strain Gauge Force-Balance

• Tested in Boundary Layer Wind Tunnel for 36 Wind Directions at 10 Degree Intervals in a Fully Simulated Turbulent Wind

• Corrected for the Effects of Flexibility of the Nominally Rigid Model.
Wind Tunnel Testing
Wind Loads (50 Year Winds)

East-West Direction

![Graph showing comparison between Conventional Code Procedure and Wind Tunnel Testing for Story Shear (kips)]
Wind Loads (50 Year Winds)

North-South Direction
Cladding Design Pressures in psf

Note:
Cladding Pressures Using Conventional Code Procedures = 55 – 62 psf
Accelerations from Wind Tunnel
Causes of Unpredictable Response

• Vortex Shedding has a Dominant Influence on Across-Wind Response

• Galloping Instability

• Dynamic Properties of Tower (Mass & Stiffness Distribution)

• Aerodynamic Properties of Tower (Geometric Characteristics)
Normalized Wind Speeds for Miami and Las Vegas
Reduction of Building Accelerations

• Modification of Aerodynamic Properties by Changing Geometry

• Modification of Dynamic properties by Changing Mass and Stiffness

• Increase in Building Damping by Using Supplemental Damping Devices
Aerodynamic Modifications

- Fins
- Chamfers

Typical Floor Plan

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CONSULTING ENGINEERS
Wind Tunnel Model with Geometric Modifications
Computer Model
Other Modifications

• Increase Wall Thickness
  ▪ Levels 1-6, 30 inches
  ▪ Level 7-18, 24 inches
  ▪ Level 19, 18 inches

• Additional Mass at Upper Floors

• Fins Provide Additional Stiffness
Maximum Accelerations

![Graph showing maximum accelerations vs return period in years]

- **Original Design**: Blue line
- **Modified Design**: Red line
Tuned Mass Damper

• Pendulum-Supported Mass Placed at Level 15

• Frequency of Pendulum Support Tuned to Counteract Tower Motion

• Viscous Dampers used to Supplement Inherent Damping

• Results in Reduced Building Accelerations and Increased Occupant Comfort
Conceptual Representation of Effect of Tuned Mass Damper

Without TMD

With TMD
Tuned Mass Damper

- **Upper Support Assembly:** The TMD will hang from this assembly. It will also transfer the forces imparted by the viscous damping devices.

- **Support Columns (or similar) Required**

- **Viscous Damping Devices Required**

- **TMD Pendulum Cables:** Alternatively may be a mechanical linkage, but a single linkage to match the different N-S and E-W sway frequencies not shown.

- **Tuning Blocks:** Elevation of block position used to adjust TMD frequency to match the tower's as-built frequency. Tuning block incorporated is ±15-25% of the as-designed frequency.

- **Snubber Assembly:** The TMD will be designed to travel freely to the 500 year design wind event. Beyond that level, the TMD amplitude will be restrained by the snubber system. This will also contain the TMD amplitudes during a seismic event.

- **Mass Box:** 60 tons with lead ballast

- **Level 15 with Comm Chase Cutout**

- **Level 16**
# Summary of Wind Response

<table>
<thead>
<tr>
<th></th>
<th>Preliminary Model</th>
<th>Final Model</th>
<th>Wind Tunnel Test</th>
<th>Wind Tunnel Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10-Year Acceleration</strong></td>
<td>10 milli-g</td>
<td>22 milli-g</td>
<td>48 milli-g</td>
<td>16 milli-g</td>
</tr>
<tr>
<td><strong>Total Damping</strong></td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Period, (NS, EW)</strong></td>
<td>1.66 s, 1.37 s</td>
<td>1.66 s, 1.37 s</td>
<td>1.66 s, 1.37 s</td>
<td>1.80 s, 1.53 s</td>
</tr>
<tr>
<td><strong>Building Weight</strong></td>
<td>12500 kips</td>
<td>12500 kips</td>
<td>12500 kips</td>
<td>19200 kips</td>
</tr>
</tbody>
</table>
One Year Accelerations

Architectural Institute of Japan (AIJ) Guidelines

Graph showing acceleration vs. frequency for different design configurations:
- Original Design
- Modified Design
- Modified Design + TMD

Lines for Office and Residential categories.
Performance-Based Earthquake Design

• Based on LATBSDC Criteria

• Serviceable Behavior During Frequent Earthquakes – 72 Year Earthquake (50% Probability of being Exceeded in 50 Years)

• Low Probability of Collapse During Extremely Rare Earthquakes (Life Safety During MCE)
Site Specific Response Spectra

![Graph showing site specific response spectra with spectral acceleration on the y-axis and period on the x-axis. The graph includes a line for MCE Design Spectrum and a line for Typical Time History.]
Peak Story Drift Ratio in EW Direction

Nonlinear Analyses for MCE

- Typical Time History
- Average

Drift Limit
Maximum Shear in EW Direction
Nonlinear Analyses for MCE
Maximum Overturning Moment in NS Direction

Nonlinear Analyses for MCE

- Typical Time History
- Average

Wall Moment Capacity

Elevation (ft)

Moment (k-ft)
Conclusions

• Need for Dual Systems in Sites with Relatively Low Spectral Accelerations may be Easily Eliminated by use of Performance-Based Design Procedures

• Aerodynamic and Stiffness Modifications Result in Cab Level Accelerations in the Upper Range of Acceptable Response

• Aerodynamic Modifications + Tuned Mass Damper Result in Cab Level Accelerations Well within Range of Acceptable Response

• Criteria Based on 1-Year Wind may be more Acceptable for Las Vegas Wind Environment
Lateral Loads in East West Direction
Lateral Loads in East West Direction