CASE STUDY: CHALLENGES OF A SINGLE-LAYER RETICULATED DOME

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A New Temple
A Buddhist Monks
The dome is used to cover a tall Buddha statue located in Saraburi, Thailand.
The Challenges

• The form is pre-decided and is not the most efficient
  – Not spherical, not parabolic, but a combination
• The sub structure was already constructed by the time we were engaged
  – The foundations
  – The ring columns
• The height is governed by the height of the statue, already under construction
• Client had already purchased tones steel pipes of 260 dia mm of 4.5 mm thickness
Structural System

Single layer, reticulated shell, made from steel pipes
FINITE ELEMENT MODELING

- The steel circular pipes were modelled by using frame elements.
- The cladding areas were modelled by using shell elements with modification of stiffness in order to transfer only loads without contributing any stiffness.

- The structure was already completed up to columns.
- The RC columns and beams were modelled as linearly elastic members using frame element.
- The RC slabs were modelled as linearly elastic shell elements.

Steel dome structure

RC base structure
MODAL ANALYSIS

• The first two modes are pure translation in horizontal direction, respectively due to symmetrical configuration of the structure as expected.

• The third mode is vertical vibration, while the fourth mode performs in twisting.
• After the fifth mode, it is found that the steel dome structure starts to vibrate with the local vibration in various patterns.
The structural performances of the dome were firstly checked against the wind loads obtained from design guidelines before obtaining the wind pressure from the wind tunnel test.

The coefficients of external wind pressure for the top part of the steel dome were calculated based on ASCE 7–10, while those for the bottom part of the dome were obtained from a research on wind pressure and buckling of cylindrical steel tank.
To obtain more accurate wind pressure acting on the dome structure, wind study of the dome structure was performed by TU-AIT wind tunnel test.
The scaled model exposed to approaching wind was rotated by direction basis for 36 directions at 10 degree intervals.

Due to symmetry of the dome geometry, the structural analysis was performed under one direction of wind.

The time-history pressure at 79 locations were scaled up and assigned to the finite element model in SAP2000 for evaluation of the dynamic responses.

The sample time-history pressures at the different locations on the dome surface are illustrated in the figure.
Wind Pressure Simulation
DEFORMATIONS AND DIAPLACEMENTS

Deformation of the structure under wind obtained from the wind tunnel test

- The deformation shapes under wind pressure obtained from wind tunnel test at a time step are illustrated in the figure.
- As expected, the results show that the upward deformation are observed at the top of the dome due to the suction pressure at this region, while pushing pressure can be observed at the surface that directly resist wind load.
Earthquake load was obtained from the Thai seismic calculation guideline DPT 1302–52.

The response spectra at the design basis earthquake level (DBE) for 475 year return period (10% of probability of exceedance in 50 years) was used in this evaluation with the importance factor (I=1.25) and the response modification factor (R=1).
(Equivalent) Base Shear

<table>
<thead>
<tr>
<th>Base Shear (kN)</th>
<th>X</th>
<th>Y</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wind (Design Codes)</td>
<td>1,600</td>
<td>1,500</td>
</tr>
<tr>
<td>Wind (Wind Tunnel)</td>
<td>1,400</td>
<td>1,300</td>
</tr>
<tr>
<td>RS-DBE</td>
<td>1,450</td>
<td>1,350</td>
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</tbody>
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Along Direction

- X: (5.7%)
- Y: (6.4%)
- (6.7%)
DEFORMATIONS AND DIAPLACEMENTS

Maximum displacements under lateral and vertical loads

- It is found that the maximum lateral displacements is approximate 3.6 cm which is less than the limit 20 cm ($H/200 = 40 \times 100/200$).

- The maximum vertical displacements at the top of the dome is about 6.1 cm which is within the limit 17.9 cm ($L/480 = 86 \times 100/480$).
## Staged Construction Analysis

<table>
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<tr>
<th>Stages</th>
<th>Construction Activities</th>
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<tbody>
<tr>
<td>1</td>
<td>Build RC circular base structure including piles, foundations, columns, beams, and slabs</td>
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<tr>
<td>2</td>
<td>Construct the bottom part of the super steel dome supported by using steel frame shoring</td>
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<tr>
<td>3</td>
<td>Install a set of steel cells until completing the first ring of the top part of the super steel dome</td>
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<tr>
<td>4</td>
<td>Repeat the stage 3 until fishing the top part of the super steel dome</td>
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<tr>
<td>5</td>
<td>Remove the steel frame shoring from the bottom part of the super steel dome</td>
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<tr>
<td>6</td>
<td>Install cladding throughout the super steel dome</td>
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The 267.4 mm (10 inch) steel circular pipes with thickness 4.5 and 6.0 mm were used to be the primary components of the single-layer steel dome structure. The performances of these steel members, such as PMM interaction, axial tension, axial compression, moment and shear were evaluated against demand forces. The member PMM demand over capacity D/C ratio provided the highest value of 0.61 among the other D/C ratios. Thus, the steel circular pipes with these sections have sufficient capacities to resist the demand forces.
STEEL DOME SUPPORTS

To avoid the stress concentration and excessive moment at the supports between the steel dome structure and the ring beam under gravity and lateral loads, the pin-connected support was presented to release the excessive demand forces.
• At the intersection of the pipes, steel circular joint was proposed in order to make construction easy and convenient.
• The steel circular joint consists of steel ring plate, inner diaphragm and cover plate. For building this joint, the first part using three steel pipes are connected with the circular steel ring and inner diaphragms by welding, while the second part is combined by welding the other three steel pipes with steel cover plate.
• Finally, both parts are assembled by using bolts.
STEEL DOME CONNECTIONS
CONCLUSIONS

• A structural system was developed and optimized to fit the tight constraints of form and existing sub-structure and available materials

• Wind pressure time histories from wind tunnel test were applied to determine local wind induced response

• Constructing sequence carried out to reduce the need for falsework

• Minor retrofitting of columns was needed to accommodate the lateral loads