Steel Towers: Lateral forces
arc422 Building Technology VI _ Structures III _ Spring 2010

This laboratory project challenges students to empirically investigate the means and methods of resisting lateral forces. Students iteratively design, fabricate and test these means and methods in the context of a structural tower. Towers were selected as the structures most vulnerable to lateral forces generated by seismic and wind conditions. The tower models are eight feet in height and are dimensionally constrained at the bottom and top. Materials are restricted to 1/8" diameter steel rod and 16 gauge sheet steel; the method of assembly is restricted to welding. Projects were categorized into four groups, each with a specific cross-sectional geometric basis [equilateral triangle, circle, square and rectangle]. The towers are evaluated on a floor mounted linear inertial shaker apparatus.

This project is executed by teams of four students and consists of two iterations. Each stage consists of a drawing component and a construction component for collective testing and analysis. This laboratory project is preceded by a precedent study through which students research and diagram three high-rise structures.

Objectives: following the completion of this project students should be able to:
- Understand lateral forces and employ strategies for rendering lateral stability
- Understand variations in the magnitudes of stress relative to the given conditions of base and apex
- Understand the inherent opportunities and challenges of the diverse geometric schemes
- Establish a design strategy that considers the variable conditions, locations and magnitudes of stress, inclusive of quantity and geometric distribution of material
- Develop diagramming methods effective in the conception, development and evaluation of your tower’s performance
- Address the challenges inherent to steel fabrication and the importance of jigging

Course Context:
The Steel Tower exercise is administered concurrently with lectures on lateral forces and with computational exercises related to the sizing of steel beams, columns and connections.
Equilateral Triangle Scheme - Example Project - Iteration 2

- Top Level Plan: Scale: 1-1/2"=1'-0"
- Level Seven Plan: Scale: 1-1/2"=1'-0"
- Level Nine Plan: Scale: 1-1/2"=1'-0"
- Top Level Plan: Scale: 1-1/2"=1'-0"

- Equilateral Triangle Diagram: Scale: 1-1/2"=1'-0"
- Equilateral Triangle Diagram: Scale: 2-1/2"=1'-0"

- Steel towers: 8" TYP.
- 0° to 90° face of triangle. Force one perpendicular to the primary vertical members.
- 0° to 90° face of triangle. Force two oblique forces acting on the triangle.
- 180° to 90° face of triangle. Force one perpendicular to the primary vertical members.
- 180° to 90° face of triangle. Force two oblique forces acting on the triangle.

- Force two oblique forces acting on the triangle.
- Force one perpendicular to the primary vertical members.
- Force two oblique forces acting on the triangle.
- Force one perpendicular to the primary vertical members.
- Adding torsion to introduce a bias to forces.
- Interconnected triangular members.
- Tapering form responds to forces.
- Each plate is rotated counter-clockwise from the bottom.
- The top is rotated 180º to forces.
- Moment from the bottom.

- Equilateral Triangle Scheme: 15º.
- Lateral Forces: [ARC 422: Building Technology VI]

- Decrease of lateral bracing.
- Corners rounded to allow the bottom three floors.
- 20 gauge steel shear planes.
- Cables from the bottom.
- Floorplate datum every 8 inches.
- Each plate is rotated counter-clockwise from the bottom.
- The top is rotated 180º to forces.
- Interconnected triangular members.
- Tapering form responds to forces.
- Each plate is rotated counter-clockwise from the bottom.
- The top is rotated 180º to forces.
- Moment from the bottom.
CONCEPT AND CONSTRUCTION:
Our original concept was based upon a strong core with a supporting outer frame that added lateral depth. For the second iteration we wanted to eliminate unnecessary weight while reinforcing critical sections within the tower. The core's hierarchy is now that a cluster of 3 vertical rods rise up and at the 5th plate a rod stops so that only 2 core rods rise up to the top of the tower. Lateral bracing is more concentrated at the base of the tower and at the critical area in the middle of the tower. Cross bracing is also more concentrated at the base of the tower and spans greater lengths in the upper portions of the tower where reinforcement is not as greatly needed. Unneeded material in the plates was eliminated and replaced with rod that distributes the loads from inner plate to outer plate.

Square Scheme - Example Project - Iteration 2
Rectangle Scheme - Example Project - Iteration 2

Design Development

- Rectangle extruded into an inverse of the base rectangle. Both the top and bottom measuring 1’ by 6”.
- The same concept of inversion was used but repeated into four modules.
- Modules spaced farther apart as the tower grows in height.
- Spacing between modules: (16”, 24”, 24”, 32”)
- A taper was introduced to reduce the dead load of the steel. The top plate measures 1/2 of the base.
- The floor plates were also introduced every 8”, also helping with overall stiffness.
- In order to respond to the bias given from the tapering modules; tension lines were added along the outside using triangular geometries to attach to. This aspect of the project has been developed further by extending them further laterally.

Bending moment weakness and response (tension lines)

- Moment Elev 1 (stage D)
- Moment Elev 1 (stage E)

Elevation Force Diagrams/Deformation

- Pretensioning
- Pretensioning

Plan sections at floor plates (@8”) 2-1/2” = 1’0”

- Rod spot welded as point of reference for placement of tension
- Tension rods welded in place for pre-tensioning
- Turnbuckle replaces original rod and as turnbuckle jack expands outward, it forces rods into tension
- Triangular compression pieces are added to hold tension rods in place and turnbuckle jack is removed

Pretensioning

- Leveled jigs and welded using them to maintain verticality
- Cardboard jigs placed on tube stock core
The overall strategy of the tower utilizes the diagrid structure due to the light weight and redundant functionality of the members.

The tower is built of 24 individual rods, 12 traveling in a clockwise rotation, 12 counterclockwise, each rod making one full revolution around the tower.

The 12 of each rotation direction are further paired into 6 groups of two each. Each of these two paired rods become closer together as the height also decreases in radius as it rises. These two strategies reflect the decreasing moment of the tower as it increases in height.

Rings encircling the tower help to resist outward forces, acting as tension rings to restrain the outward bulging of the tower when an axial load is imposed.
Concept Statement:
Our project is based on the idea of a torsion tower which uses a rotating triangular form. As thirteen levels of triangular plates are stacked on top of one another, each subsequent triangle is reduced by 3/16" and is rotated by 15°. This torsion throughout the structure implements a form-bias that helps to resolve lateral forces.

Another resolution to lateral forces comes from cross bracing, which continues from the bottom of the tower to the top. This is different from our previous iteration, in which cross bracing stopped in the center of the tower. Additionally, our triangular plates are now strengthened by rods along the bottom of their perimeter which act as tension rings.

Hierarchy is implemented by separate vertical members that move through the three points of the triangle and rotate with the tower. The rods are in bundles that reduce from three to two to one as they move upward. This is in observance of the idea that the bottom of the tower receives the most forces and thus needs the most material.

The other resolution to vertical hierarchy and lateral stability is the shear plates added to the edges of the first seven levels. In our last iteration, the tower failed in its seventh floor so we chose to strengthen this level and those below it. Our hope is that with a strong base, the tower can withstand the forces which would otherwise cause it to buckle.

There are two moves happening as the tower rises vertically: rotation and tapering. The following concept sketches depict those ideas separately and combined.

Concept A: Triangles are consistently the same size and are rotating

Concept B: Triangles are tapering in size and are oriented in the same direction

Combination: Triangles are both rotating and tapering