COURSE DESCRIPTION

This course will offer students a foundation and familiarity with the use of structural systems through various case studies and examples. Each case study will be presented holistically and then deconstructed and analyzed to determine structural systems used and the reasoning behind the selection. Through structural investigation, students will peel away the design and actively calculate loads and forces while discussing the possibility of modifying existing structures.

The course allows the student to immerse in a built example and imagine the evolution of the design and consider the effectiveness of the system as it pertains to the architectural design constraints and other building systems.

Students (teams) will be exposed to a lecture and seminar/analysis period to deconstruct their chosen building based on the lecture’s focus. The intent is to have the student dissect/deconstruct the building to understand the design constraints and forces, which influence the structural design to give the student a holistic understanding of structural systems at work.

SPRING 2015 STUDENTS

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Precedent assignment: Students, in groups of two, are assigned a building as the subject of their project. The students are required to investigate and research the structural system of the building. Their investigation should discuss the influence of the location, use/function and aesthetic design of the building under study when determining the structural design system selected. That is, buildings in a high wind or high seismic region will be subject to higher lateral loadings and certain systems function better than others. Also the use and function of the building, such as a school, hospital or library, often require column free areas, which will influence the structural system selected — this should be discussed. In addition, the structural system will often determine the materials of the building such as a concrete, steel, masonry or combination thereof.
**CASE STUDY**  
**INGALLS RINK**

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<th>ARCHITECT</th>
<th>Eero Saarinen</th>
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<tr>
<td>STRUCTURAL ENGINEER</td>
<td>Fred N. Severud</td>
</tr>
<tr>
<td>LOCATION</td>
<td>73 Sachem Street, New Haven, CT</td>
</tr>
<tr>
<td>YEAR</td>
<td>1953-1958</td>
</tr>
<tr>
<td>BUDGET</td>
<td>$750,000.00</td>
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Eero Saarinen  

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### Case Study: CCTV Headquarters

**Architects:** OMA  
**Engineers:** ARUP  
**Space:** 51 Million SF  
**Maximum Height:** 768 FT  
**Total Levels:** 31 Stories  
**Year Completed:** 2012

<table>
<thead>
<tr>
<th>Seismic Fortification Level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
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</thead>
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<tr>
<td>Description</td>
<td>Minor</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>Peak ground acceleration</td>
<td>0.07g</td>
<td>0.20g</td>
<td>0.40g</td>
</tr>
<tr>
<td>Average Return Period</td>
<td>1 in 50 years</td>
<td>1 in 475 years</td>
<td>1 in 2475 years</td>
</tr>
<tr>
<td>Probability of exceedance</td>
<td>63% in 50 years</td>
<td>10% in 50 years</td>
<td>2% in 50 years</td>
</tr>
<tr>
<td>Fortification Criteria</td>
<td>No damage (remain elastic)</td>
<td>Repeatable damage</td>
<td>No collapse</td>
</tr>
</tbody>
</table>

![CCTV Headquarters Image](image_url)
Figure 1: Preliminary analysis.

Figure 2: Structural diagram.

Figure 3: Eccentric analysis.

Figure 4:biekng jia

Figure 5: Final construction setup.

Figure 6: Final construction setup.
Students, in groups of two, create building forms (models) to study and examine the principles of repetitive structural forms such as Hyperbolic Paraboloids (HyPar), domes, vaults, shells, torus etc. By experimenting with these forms, the student better grasps the load paths and can explore form finding of structural shapes and development of structural modules.
STRUCTURAL ANATOMY OF BUILDINGS

PROFESSOR DOMINIC BILIA

24
Students returning back to their precedent building studies or an acceptable alternate are to dissect the building system and discuss key structural components by creating diagram studies of the assemblies illustrating the structural composition and load path of the system.
**SPITZER SCHOOL OF ARCHITECTURE**

**SYMMETRICALLY PLACED SHEAR WALLS**

Rigid floor and roof diaphragms also help in resisting lateral forces.

**PROSTHO MUSEUM BY KENGO KUMA**

**RIGID CONNECTION WOOD COLUMNS AND BEAMS**

The rigid connection of the wooden members are accompanied by shear walls to stabilize the lateral loads.
NEST WE GROW, BY KENGO KUMA

COMPOSITE CONSTRUCTION OF TIMBER COLUMNS, BEAMS, AND STEEL BRACING.

The composite system of columns, beams, and steel bracing along with moment connections stabilize the lateral forces.
CHAPTER 14: QUESTION 14.1

UNITED NATIONS SECRETARIATE BUILDING
LE CORBUSIER
505 FEET TALL

The shear walls are not enough to take care of all of the loads. They take gravity loads and wind loads coming from the sides but not the front or the back. The additional structure in the building, which consists of columns and internal core walls, are what makes up for the lack in the shear walls.

CHAPTER 14: QUESTION 14.3

NEW MUSEUM
SANAA
177 FEET TALL

Each box in the New Museum is its own diagonally framed structure which is then stacked on top of each other. They are connected by a concrete core in the back. We believe that the building would stand up without the concrete core as each box is, within itself, structurally sound.
The steel frame surrounds the entire building and is able to take the entire lateral load that would be applied on the structure. However, the floor plate is too large for the exterior frame to handle all of the gravity loads so the interior columns help distribute the gravity load throughout the building and into the ground.
The Bank of America Tower - Shear Walls

It appears that since the shear walls span in both directions, their pattern is capable of resisting loads in all directions.

3rd Floor Plan

11th Floor Plan

16th Floor Plan

46th Floor Plan

423 AVENUE
ARCHITECT: RAFAEL VINOLY
14.2 FRAMED BUILDING AND LATERAL STABILITY

Tube Structure

A
This building design uses a grid of exposed concrete that create a tube structure. I can suspect that the regularity of closely spaced columns are rigidly connected to spandrel beams which provided the lateral stability.

B
The size of the core is substantial compared to the floor plan in proportion. This suggests that the elevator and stair circulation core is playing a major role in the building's stiffness and gravity load carrying capacity.

(d) Tube Structure. Exterior columns are closely spaced and rigidly connected to spandrel beams.
The Hearst Tower - Diagonally Braced

The Hearst tower uses a diagrid as a facade, structural system that can carries both lateral and gravity loads due to its triangulation. The core, still back is the mega structure through beams running along the floor slabs to make up of a heavy steel portal and twin systems serving as a secondary lateral force resistance.

At the 40th floor, the diagrids are supported by a series of columns. Below the 40th floor, robust composite core shear wall comprised of steel braced frames ensnared in reinforced concrete walls. It also has gridded beams and columns that provided full vertical support for the facade system. Additional grid of vertical and horizontal framing was provided behind the existing facade. They are laterally supported by the new tower's third-floor framing system.
HL 23
ARCHITECT: NEIL M. DENAIR ARCHITECTS
14.1 SHEAR WALL AND LATERAL STABILITY

A steel plate shear wall system was used to create lateral stability located within the core. This system reduced the dimension of the structure itself by using 3/8" steel plates which provided more usable floor area.

B The second lateral-supporting system was a brace-frame system that wrapped around all four elevations of the building providing for both lateral structure support and a particular aesthetic look.

They do not form a pattern capable of resisting loads in all directions. Instead they use slanted columns, trusses to ensure complete stability.
Diagram A shows the building diagrid shell on the exterior and columns at the center or as core of the building. The building does not have a shear wall at the center for lateral stability because the diagrid shell takes both vertical loads and horizontal loads from all directions. Due to the shape of the building (no sharp edges) vortices produce less stress on the building cladding.

Diagram B shows the horizontal beam connecting the diagrid ring to core for stiffness. Notice the beams don’t connect directly to columns because the triangular cut (miters) shift 5 degrees on each floor creating a spiral of openings. Therefore the beams are also placed differently to ensure proper stability.
WOOLWORTH BUILDING
(New York, USA, 57 stories, 241 m)
Combination of rigid floor diaphragms, steel bracing, and shear walls around the fire stairs keep the lateral forces stabilized. The exterior is clad with stone.

EMPIRE STATE BUILDING
(New York, USA, 102 stories, 381 m)
A concrete foundation takes the load of the rigid braced steel framework which is anchored to shear walls around the core which assist in the lateral forces. Rivets and bolts hold the framework together. Effectively resists lateral loads by producing shear truss - frame interacting system.
TAIPEI 101
(Taipei, Taiwan, 101 stories, 509 m)

Shear Cores (Steel Trusses) + Outriggers
(Steel Trusses) + Belt Trusses + Concrete Composite Columns. Effectively resists bending by exterior columns connected to outriggers extended from the core. Outrigger structure does not add shear resistance. Spherical damper helps resist the seismic loads.

John Hancock Center
(Chicago, USA, 100 stories, 344 m)

Steel braced tube structural system. Efficiently resists lateral shear by axial forces in the diagonal members. Wider column spacing possible compared with framed tubes. Reduced shear lag. Bracings obstruct the view.
TUBULAR STRUCTURE AND FLOOR PLATES CREATE RIGID STRUCTURE, SEPARATE FOUNDATION STRUCTURE DISCONNECTED FROM THE MAIN TUBULAR STRUCTURE TO REDUCE SEISMIC IMPACT ON THE BUILDING.

A BASE ISOLATION DEVICE AT BASEMENT LEVEL AND MULTIPLE DAMPING SYSTEMS TO INCLUDE PERIMETER WALLS TO RESIST SEISMIC FORCES.
HSBC BANK

(Hong Kong, 44 stories, 178 m)

Steel suspension structure. Columns and tension members take gravity loads, floor diaphragms and bracing assist in the lateral loads.

**MARINA CITY TOWERS**

ARCHITECT: BERTRAND GOLDBERG

The circular residential towers consist of a 35-foot diameter, reinforced concrete central core wall. The core, and two sets of perimeter columns support the petal shaped concrete floor slabs which act as rigid diaphragms.
The Monadnock is a load bearing masonry structure, with brick walls 8’ at the base tapering to 2’ at the top. The internal skeletons of the northern portion of the building consist of a penta frame, providing increased rigidity against lateral forces.

These theater is held up on three sides by only 6 supercolumns, to maximize transparency on the ground level. On levels 4-7, columns also act as trusses, and the fourth side is a shear wall. A shear bell truss takes lateral and gravity loads, and is augmented by smaller interior trusses.
The GE Building is made up of a steel rigid frame system. Interior columns carry the gravity loads, while the exterior columns resist the lateral forces.
Hearst Tower is composed of a combination of a moment frame system overlayed with a diagrid system. The diagrid system is visible on the exterior and is used for aesthetic purposes also.

The CCTV Headquarters is constructed of a diagrid framing system, similar to the one shown above in Hearst Tower, but in this case it adjusts based on how much load is in each area. The more concentrated the diagrid the more load there is.
The Eiffel Tower is composed of multiple types of steel design ranging from arches, to beams, to trusses. When they all combine they create a structure that has lasted against the elements and the loads on it for a long time.

The Flatiron Building is constructed of a steel frame which is then clad in limestone at the bottom and terracotta at the top. The interior has a few steel columns to help with the gravity loads.
The CCTV Headquarters is constructed of a diagrid framing system, similar to the one shown above in Hearst Tower, but in this case it adjusts based on how much load is in each area. The more concentrated the diagrid the more load there is.

The new building for the Whitney Museum combines different types of framing to create an open space to house art. The building mixes standard framing with diagonal framing.
**Structural Anatomy of Buildings**

**Professor Dominick R. Pilla**

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**Municipal Services Building in Glendale**

1. Elevated Building Foundation (EBF) Seismic base isolation improves seismic performance by lowering seismic performance loads on the building during an earthquake.

2. Three-story steel moment frame building with and is supported by four pilotes.

3. Isolation plane above the bearings.

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Wells Fargo central police station has been constructed with a number of earthquake-resistant features. The exterior walls have X-shaped bracing that enables the building to move as a rigid body. The building rests on 24 foot-high piles, isolating it from the ground, and it has lead dampers to reduce shaking.
Citigroup Center/ 601 Lexington

The City Group Center site was adjacent to St. Peter's church. One of the conditions for building next to the church was for the City Corp to not occupy the corners of their site, which influenced the placement of the building's columns and use of lightweight material. It made the building unstable and vulnerable to wind loads and hurricane wind, so they had to provide a mass damper to balance the forces and stabilize the building in case of strong winds.
TAIPEI 101
WORLD'S LARGEST TUNED MASS DAMPER

High-performance steel and 36 columns support the Taipei 101 altogether including 8 mega-columns. The tuned mass damper weighs a total of 600 tons that has spherical steel pendulum which sways to offset movements in the building.

The mass damper is a heavy block on top of a high rise consist of either solid or liquid that swings like a pendulum in a controlled way to counter the swinging movement produced by winds or earthquakes (feral loads).
Students are given construction documents of several buildings. Focusing on areas of interface between structural system and the building shells, the students are required to create a variety of assembly vignettes which best describe the essential structural concepts.