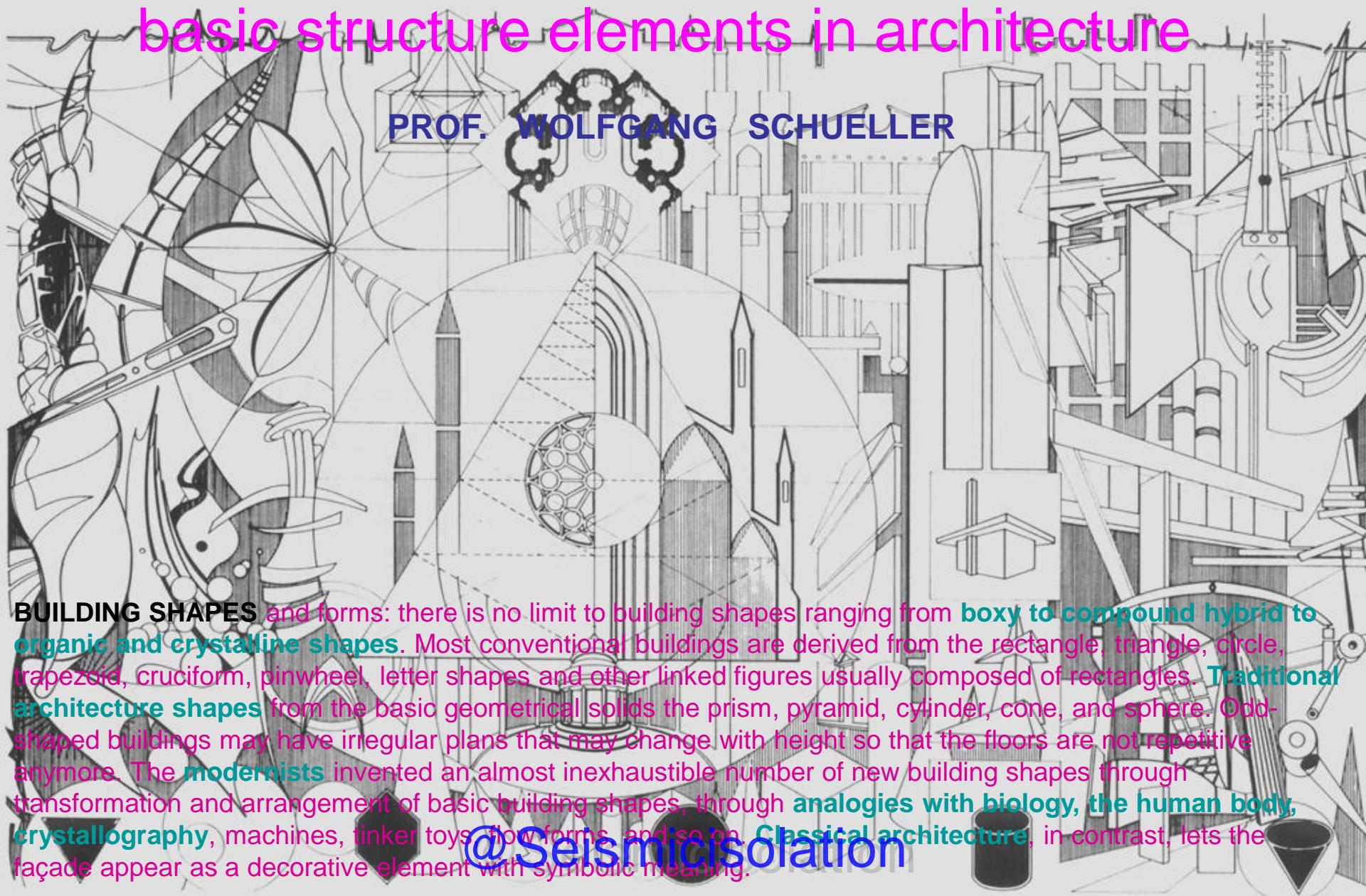


Building Structures as Architecture

basic structure elements in architecture

PROF. WOLFGANG SCHUELLER



BUILDING SHAPES and forms: there is no limit to building shapes ranging from **boxy to compound hybrid to organic and crystalline shapes**. Most conventional buildings are derived from the rectangle, triangle, circle, trapezoid, cruciform, pinwheel, letter shapes and other linked figures usually composed of rectangles. **Traditional architecture shapes** from the basic geometrical solids the prism, pyramid, cylinder, cone, and sphere. Odd-shaped buildings may have irregular plans that may change with height so that the floors are not repetitive anymore. The **modernists** invented an almost inexhaustible number of new building shapes through transformation and arrangement of basic building shapes, through **analogies with biology, the human body, crystallography, machines, tinker toys, flow forms, and so on**. Classical architecture, in contrast, lets the façade appear as a decorative element with symbolic meaning.

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A. GENERAL CONCPTS OF BUILDING SUPPORT STRUCTURES

B. BUILDING STRUCTURE ELEMENTS: **beams, columns, frames, arches, surfaces, free form**

A. GENERAL CONCPTS OF BUILDING SUPPORT STRUCTURES

Structure is a necessary part of live; it establishes order.

It relates various entities or all the parts of a whole displaying some pattern of organization and lack of randomness. It occurs at any scale, ranging from the molecular structure of material to the laws of the universe.

THE PURPOSE OF BUILDING STRUCTURE

**support structure
ordering system
space maker
form giver**

The richness of structures can only be suggested by the wealth of building structure types, ranging from the **long-span stadium** to the **massive building block** to the **slender tower**, from structures above or below ground or in water to structures in outer space. They range from simple symmetrical to complex asymmetrical forms, from boxes to terraced and inverted stepped buildings, from low-rise to high-rise buildings, and so on.

Classification of support structures according to:

A1 Building structure type and use

e.g. apartment buildings, factories, gymnasiums, arenas, multi-use

A.2 Building structure as support (local and global scale)

A.3 Structure systems: rigid systems, flexible systems, composite systems

horizontal-span structures

vertical-span structures

A.4 Structural behavior:

loads, force-flow, stress, force and form

A.5 Building structure as geometry

STRUCTURE as an ordering system

STRUCTURE as a form giver

STRUCTURE as art

A.6 Building vs. Structure vs. Architecture:

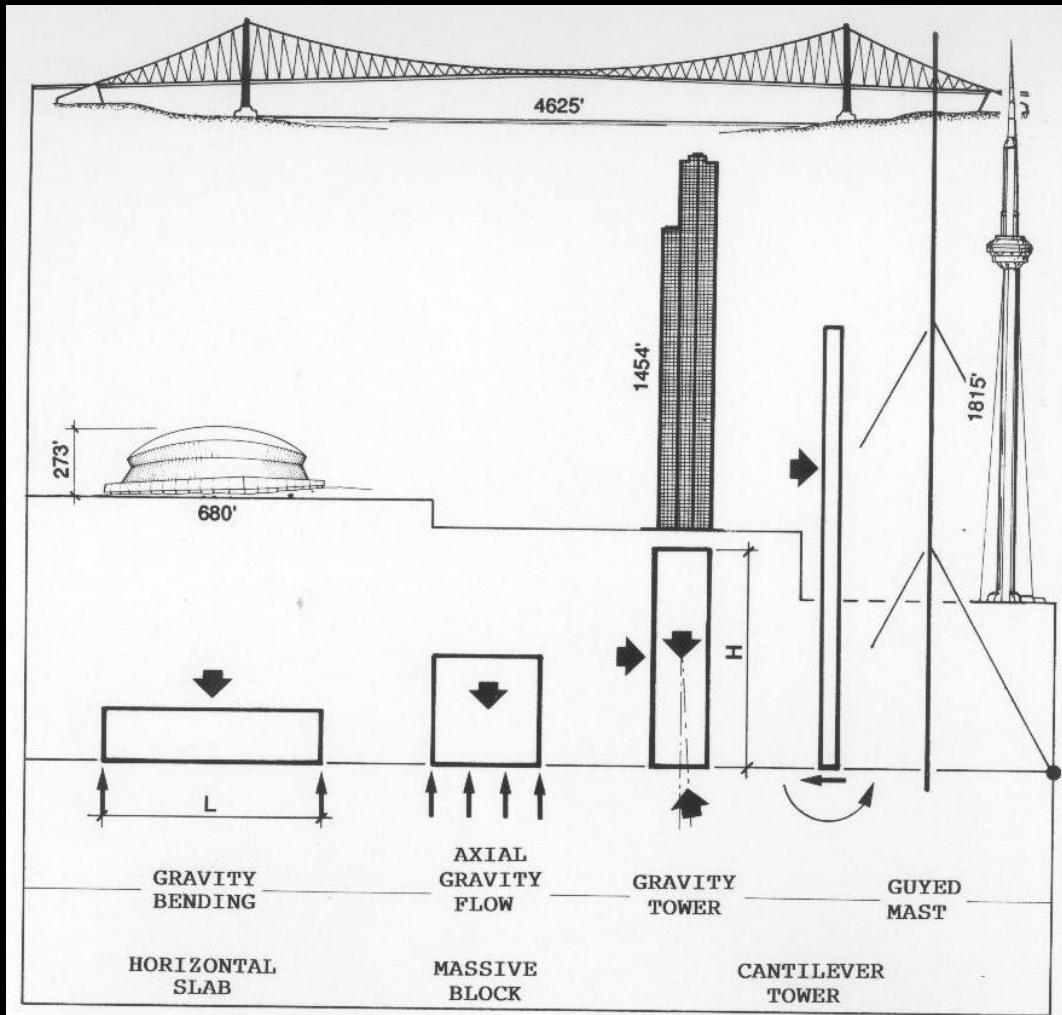
expression of structure: hidden vs. exposed, innovative vs. standard construction

structure is necessary for buildings but not for architecture:
without structure there is no building,
but architecture as an idea does not require structure

A.7 Structure as detail

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A1. Building STRUCTURE Types and Building USE



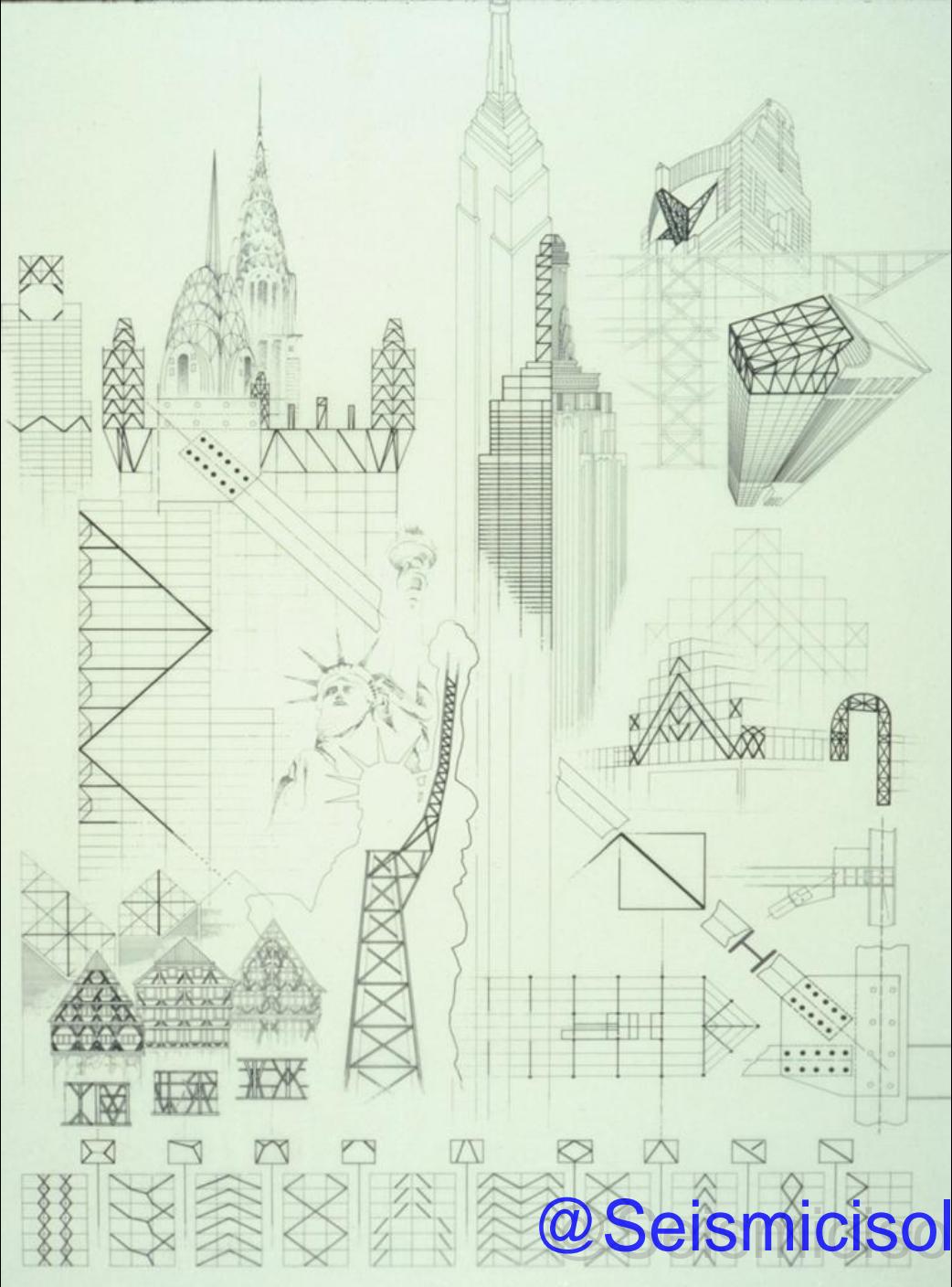
Single volume with large spans – cellular subdivision with multiple small spans – long-span stadiums vs. massive buildings
vs. vertical slabs vs. high-rise towers

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A2. Building **STRUCTURE** as *support* (*local and global scale*)

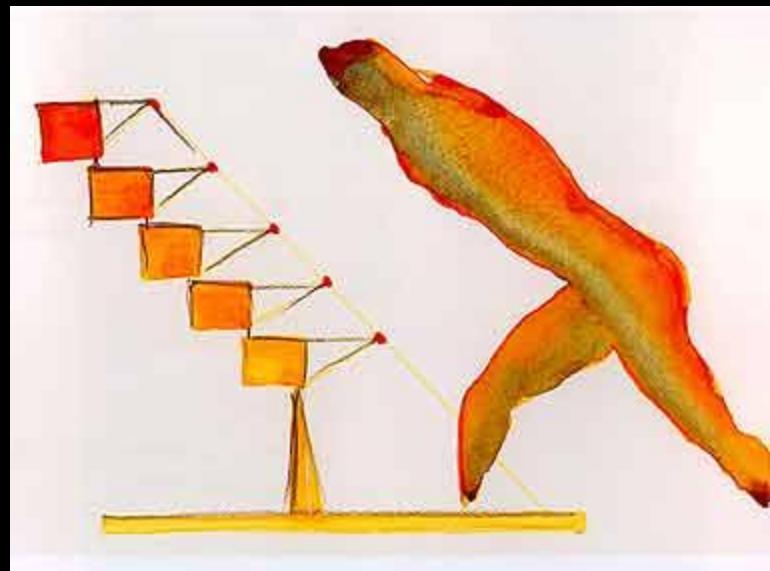
Structure holds the building up so it does not collapse or deform excessively; it makes the building and spaces within the building possible. Structure gives support to the material and therefore is necessary.

BUILDING and **STRUCTURE** are inseparable and intimately related to each other. The external loads that act on buildings cause internal forces in building support structures. The forces flow along the structure members to the ground, requiring foundations as transition structures to the comparatively weak soil. The members must be strong and stiff enough to resist the internal forces. In other words, **BUILDING SUPPORT STRUCTURES** have to provide the necessary **STRENGTH** and **STIFFNESS** to resist the vertical forces of gravity and the lateral forces due to wind and earthquakes to guide them safely to the ground. In addition to strength and stiffness, **STABILITY** is a necessity for structures to maintain their shape. **SAFETY** is a basic requirement of building design!



**Example of support structure:
study of **wall trusses** in context
of various building types**

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Sculpture: **Running Torso**, 1995,
Santiago Calatrava

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A3. STRUCTURE Systems

Every building consists of the **load-bearing structure** and the **non-load-bearing portion**.

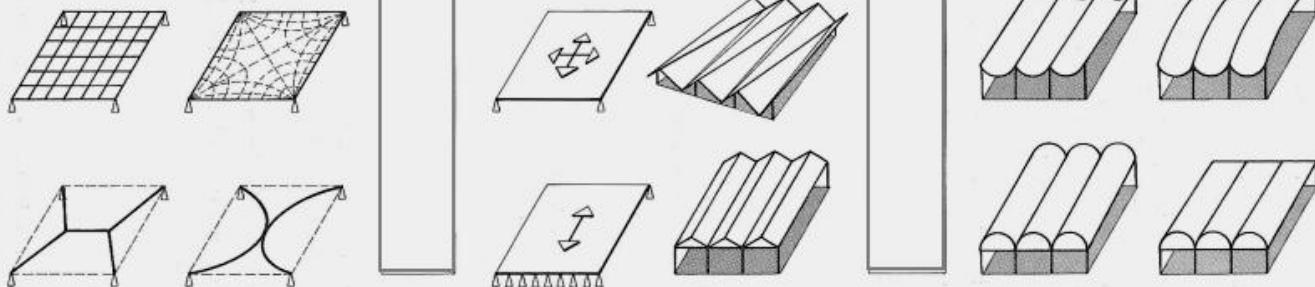
The main load bearing structure, in turn, is subdivided into:

- **Gravity structure** consisting of floor/roof framing, slabs, trusses, columns, walls, foundations
- **Lateral force-resisting structure** consisting of walls, frames, trusses, diaphragms, foundations

Support structures may be classified as,

- **Horizontal-span structure systems:**
floor and roof structure
enclosure structures
- **Vertical building structure systems:**
walls, frames cores, etc.
tall buildings

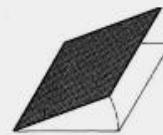
SURFACE FORMS



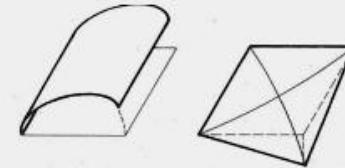
BASIC
STRUCTURAL
ELEMENTS



STRAIGHT SURFACE ELEMENTS



CURVED SURFACE ELEMENTS

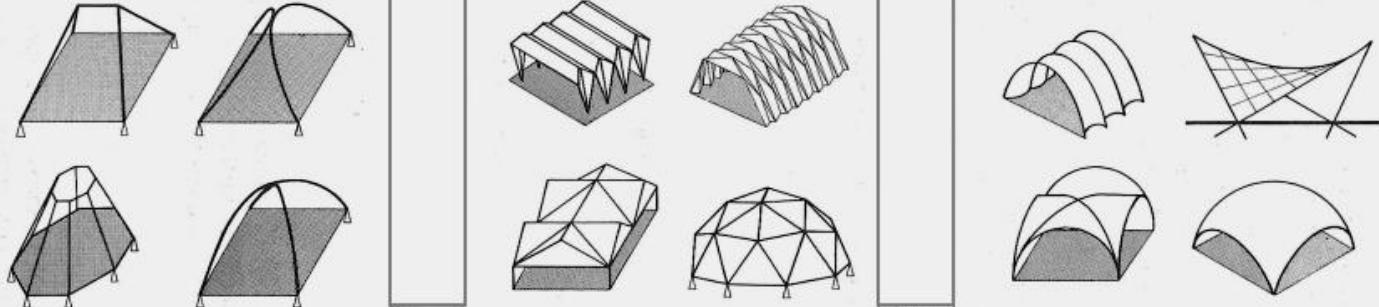


STRAIGHT vs. CURVED MEMBERS

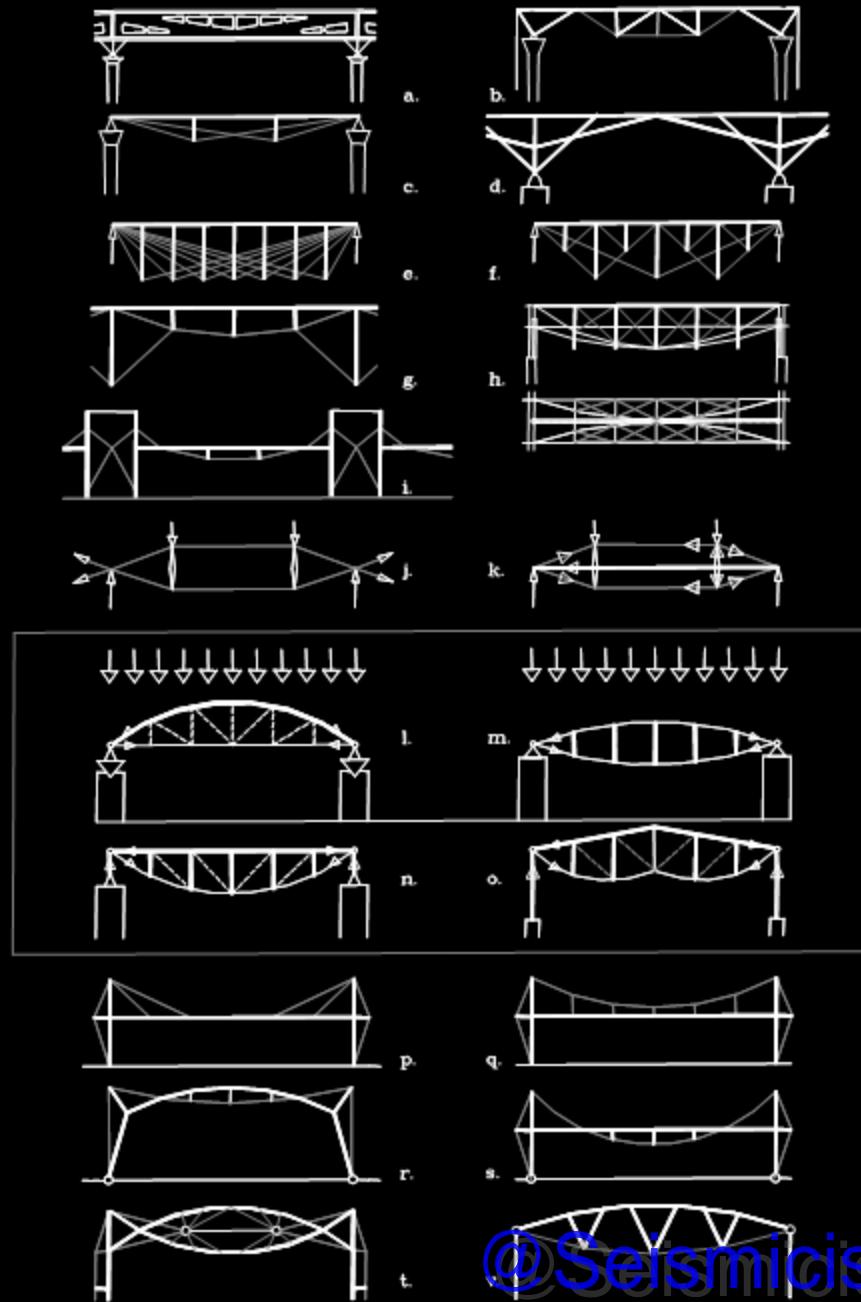
HORIZONTAL vs. INCLINED PLATES

SINGLE vs. DOUBLE CURVED SHELLS

SPATIAL FORMS



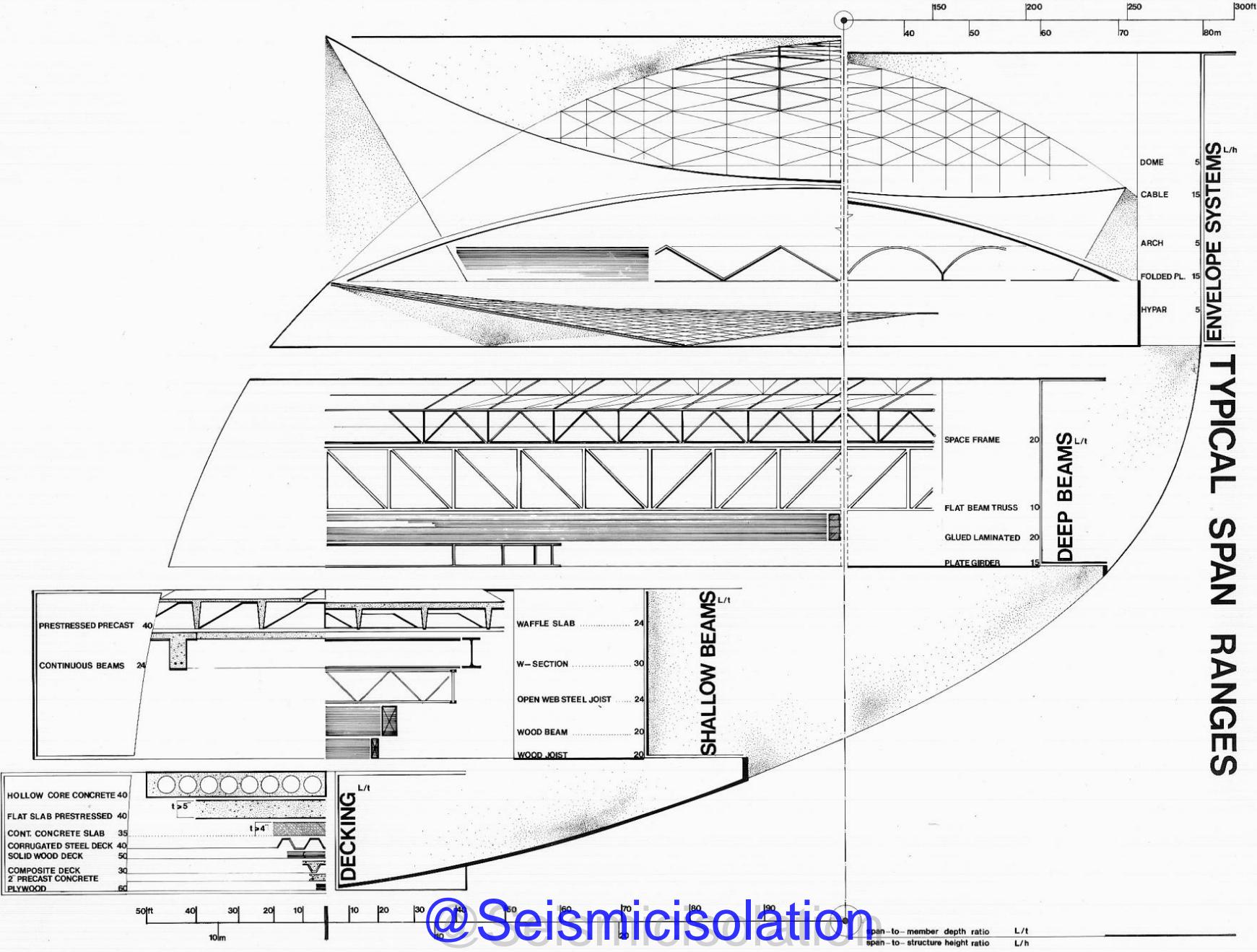
HORIZONTAL – SPAN BUILDING STRUCTURES: rigid systems
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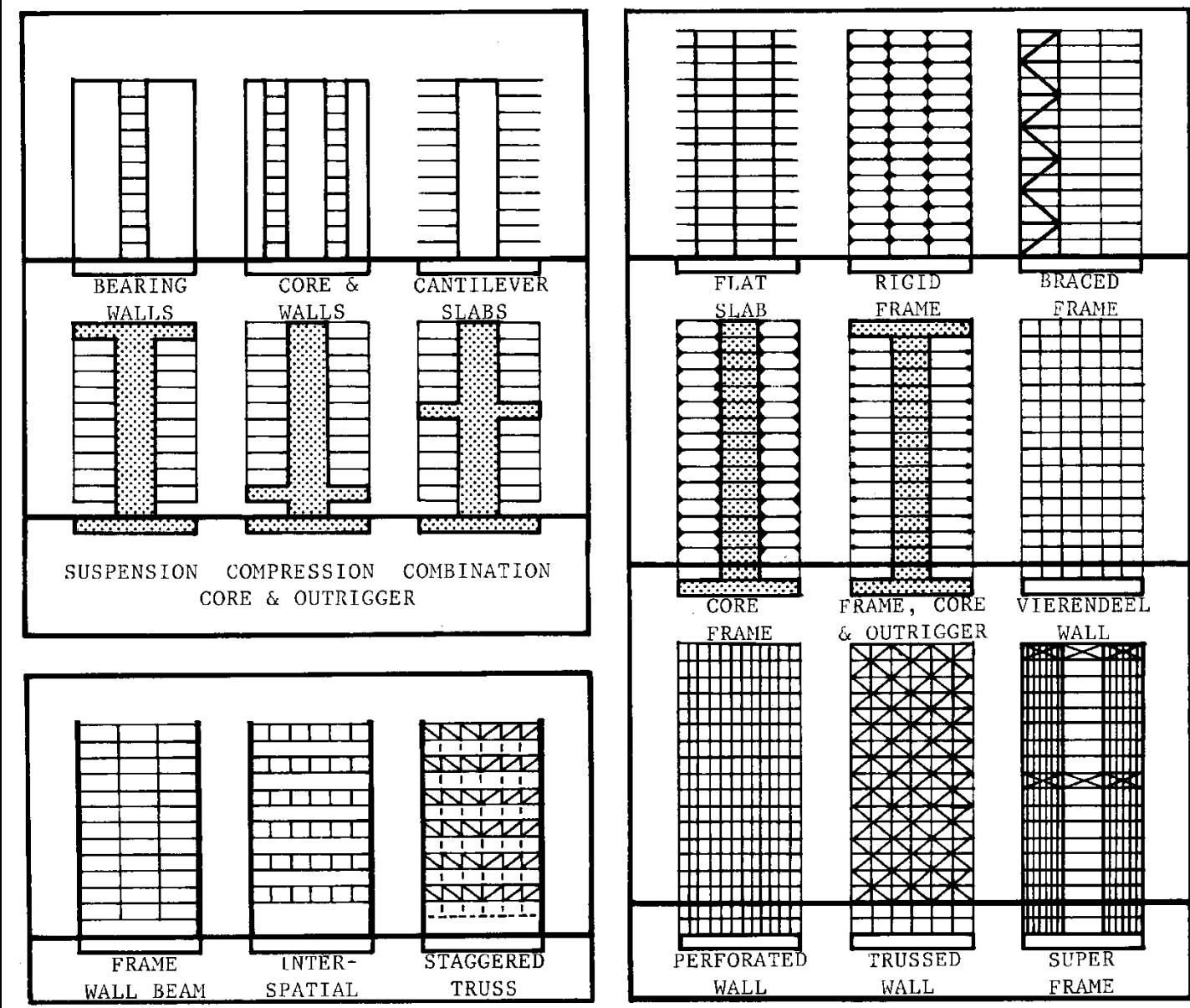


Cable-supported structures

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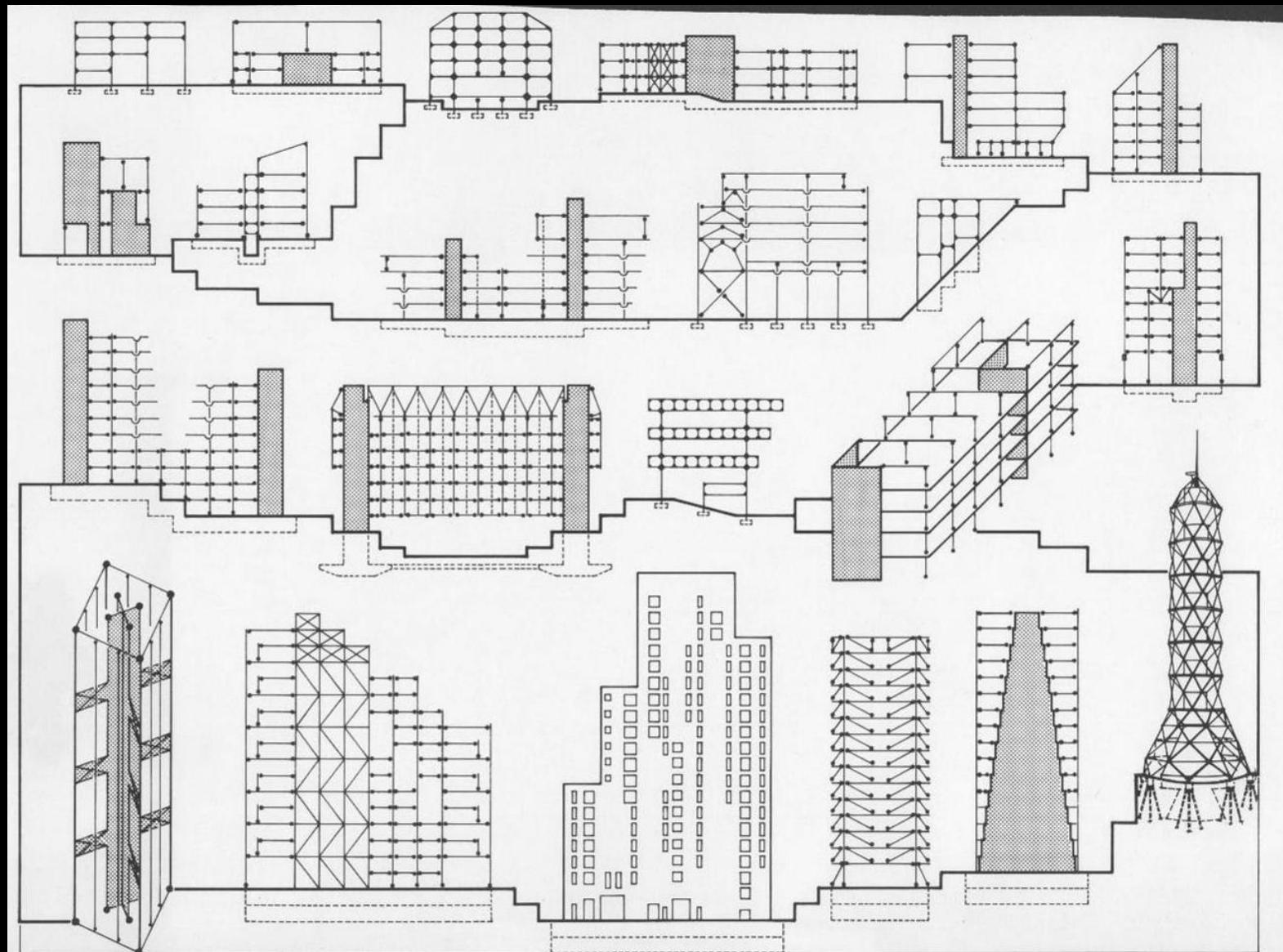
TYPICAL SPAN RANGES





VERTICAL-SPAN BUILDING STRUCTURE SYSTEMS

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Examples of **VERTICAL-SPAN BUILDING STRUCTURES**

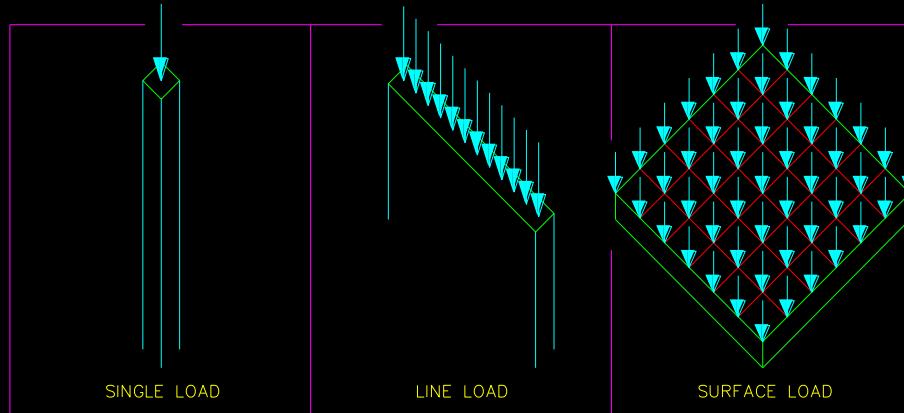
A4. STRUCTURE Behavior

LOADS: gravity, lateral loads (wind, seismic)
external vs. internal forces (force flow along members)

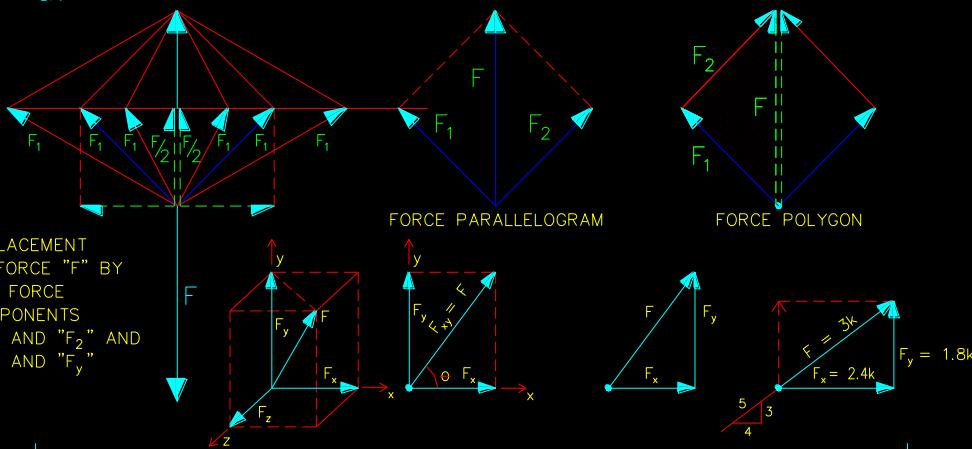
PROPERTIES OF FORCES

FORCE FLOW: -- path to the ground where foundations make the transition possible to the weak soil -- stresses (intensity of force flow, blood pressure) depend on: member shape, material, size, structure, connections

RESPONSE OF STRUCTURE TO LOADING



a.



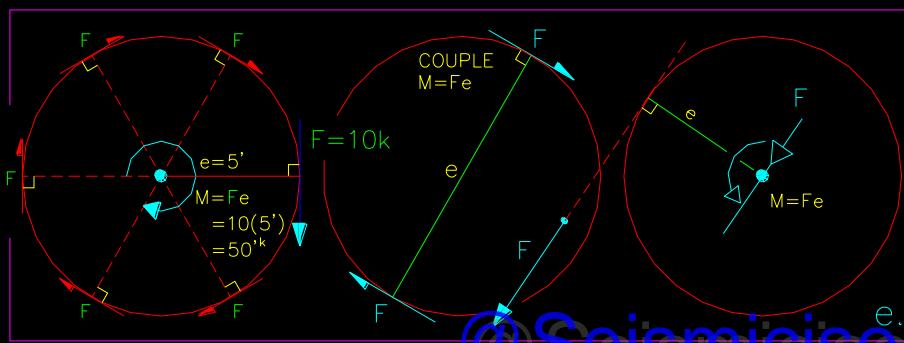
b.

c.

d.

Properties of Forces

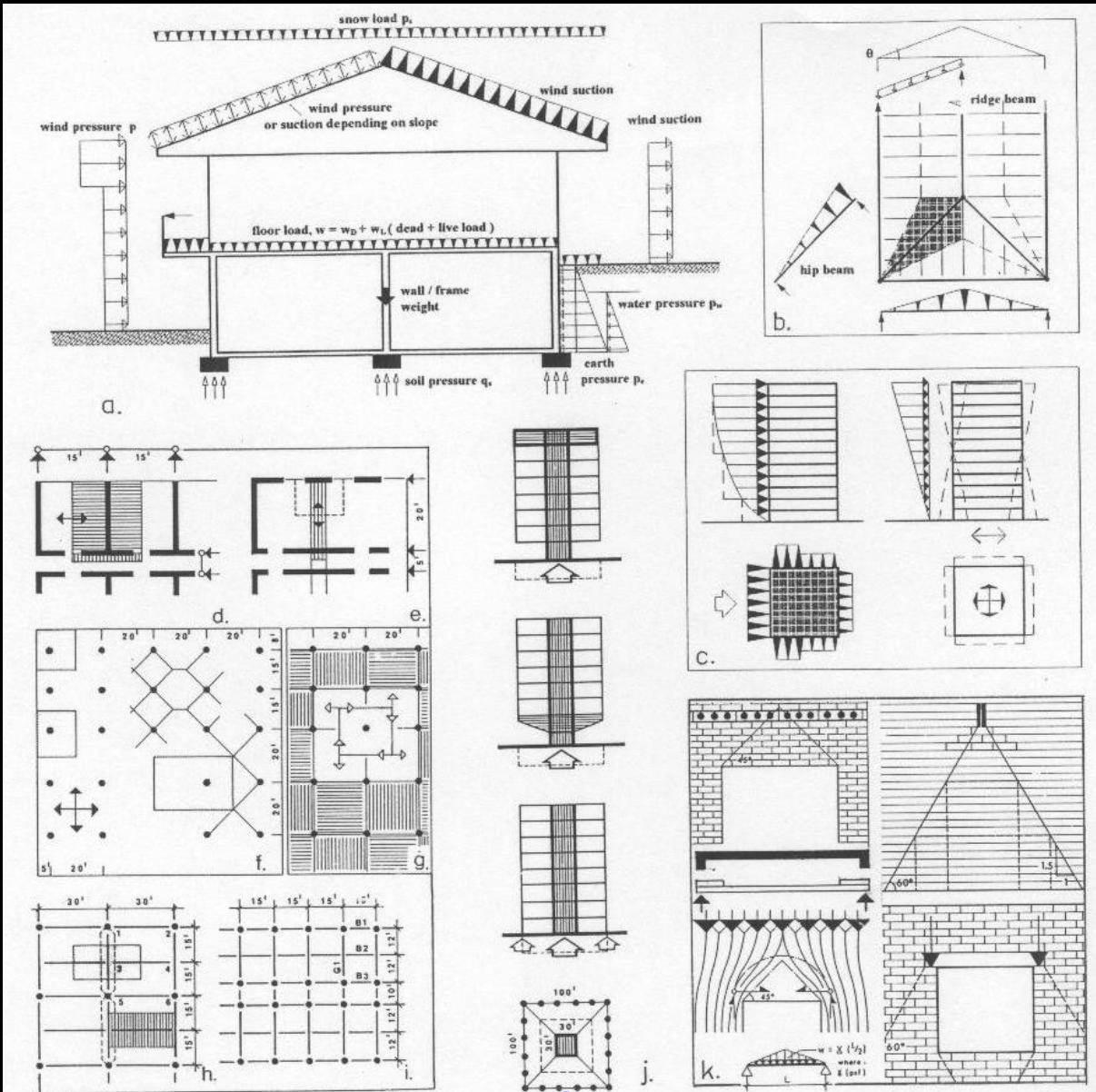
- **magnitude**
- **direction**
- **location**



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Common building loads

on global and local scale

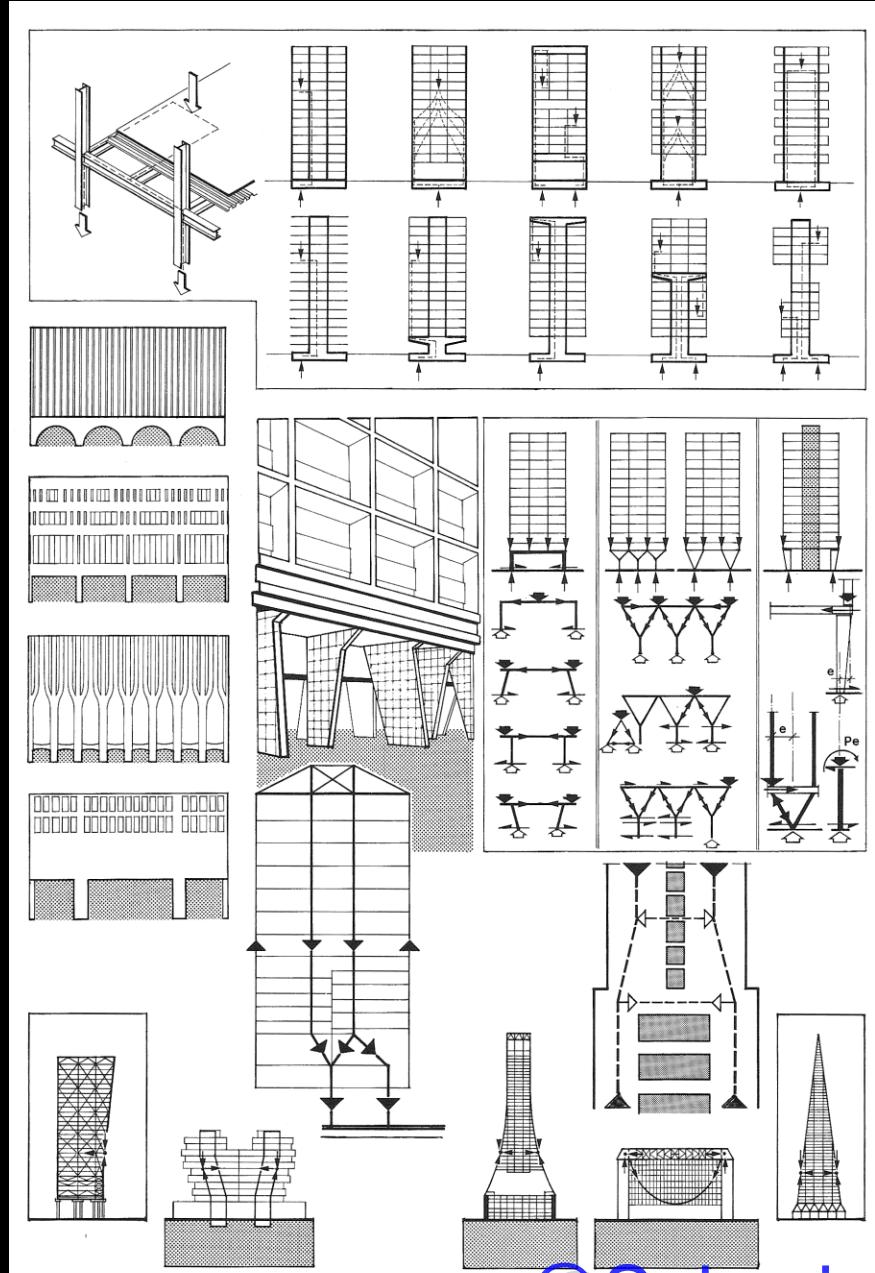


Gravity loads

- Beam loads
- Column loads
- Floor loads
- Roof loads

Lateral Loads

- Wind load
- Earthquake loads

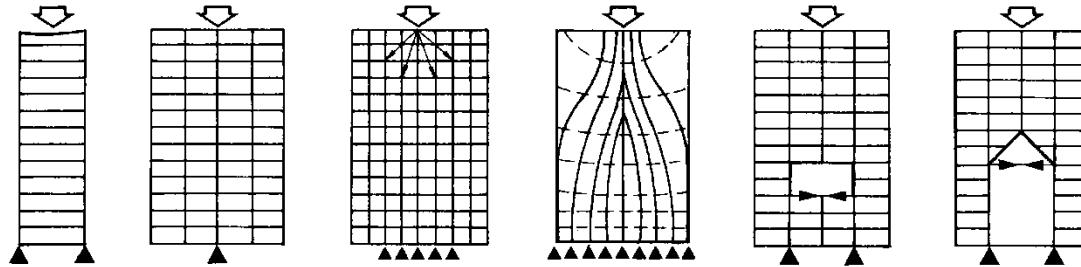


FORCE FLOW

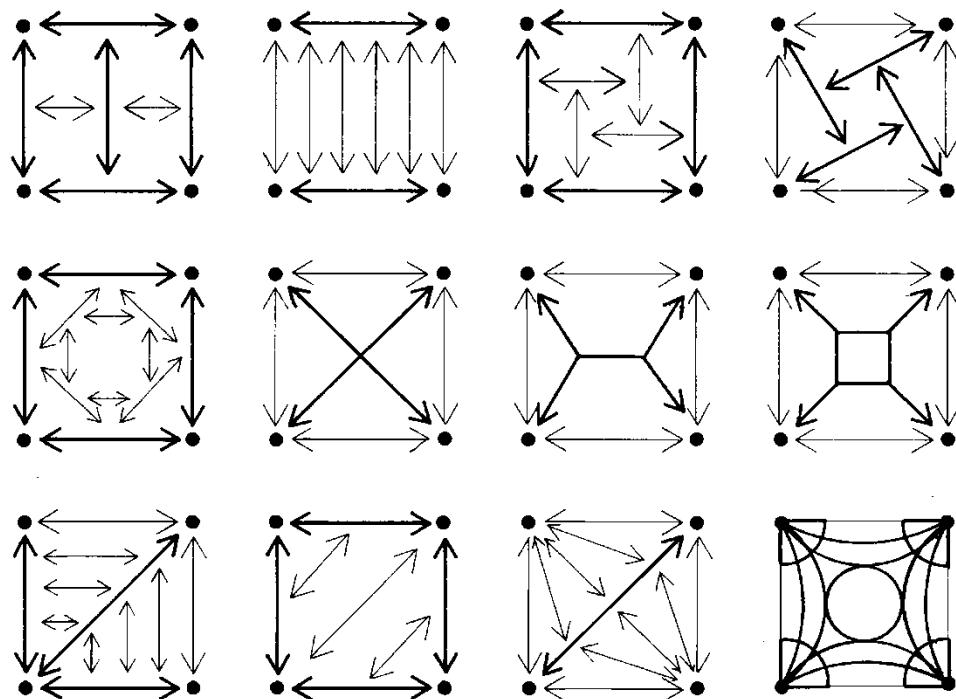
Vertical gravity force flow

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FORCE FLOW



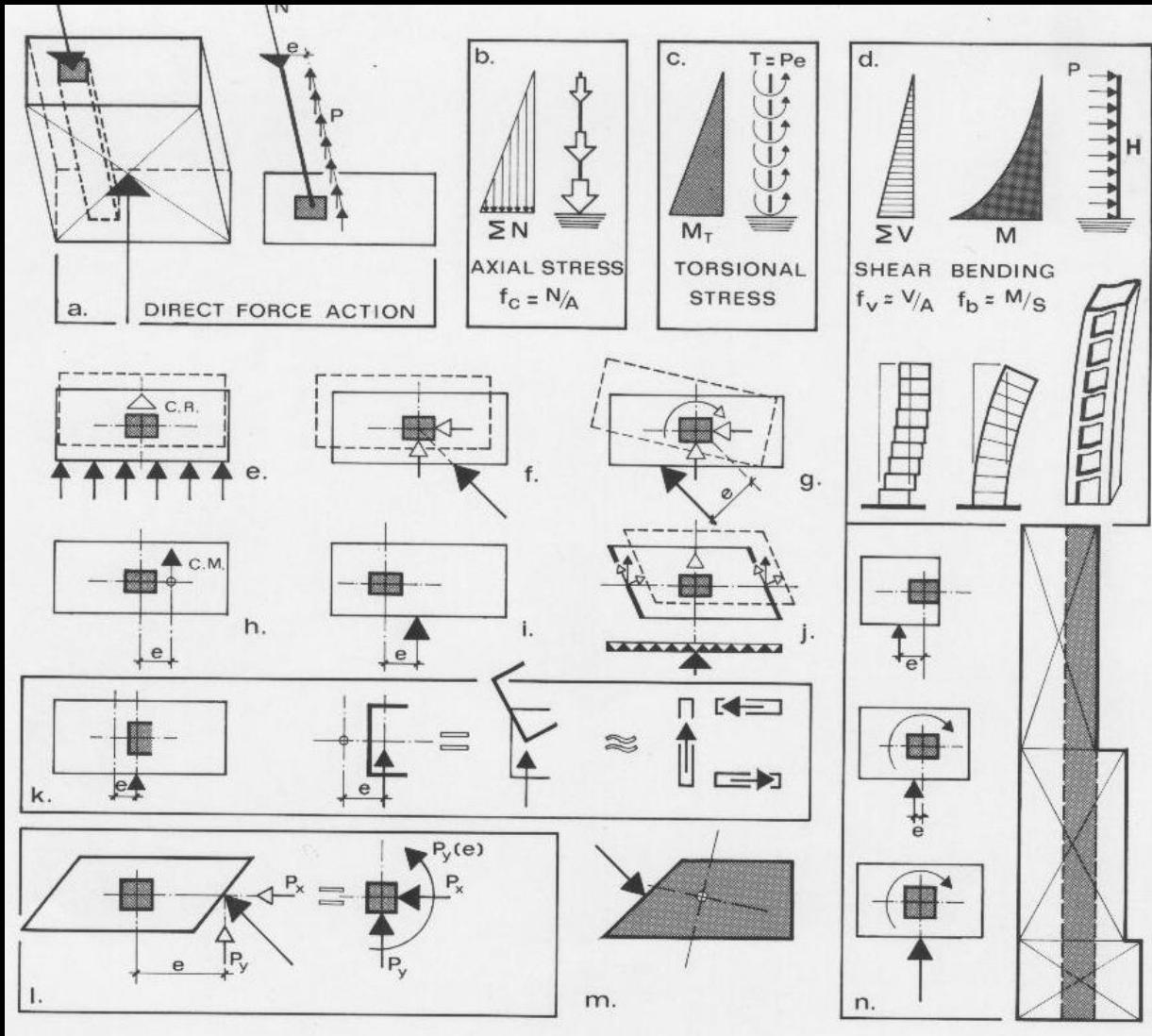
a. V E R T I C A L F O R C E F L O W



b. H O R I Z O N T A L F O R C E F L O W

Vertical gravity force flow

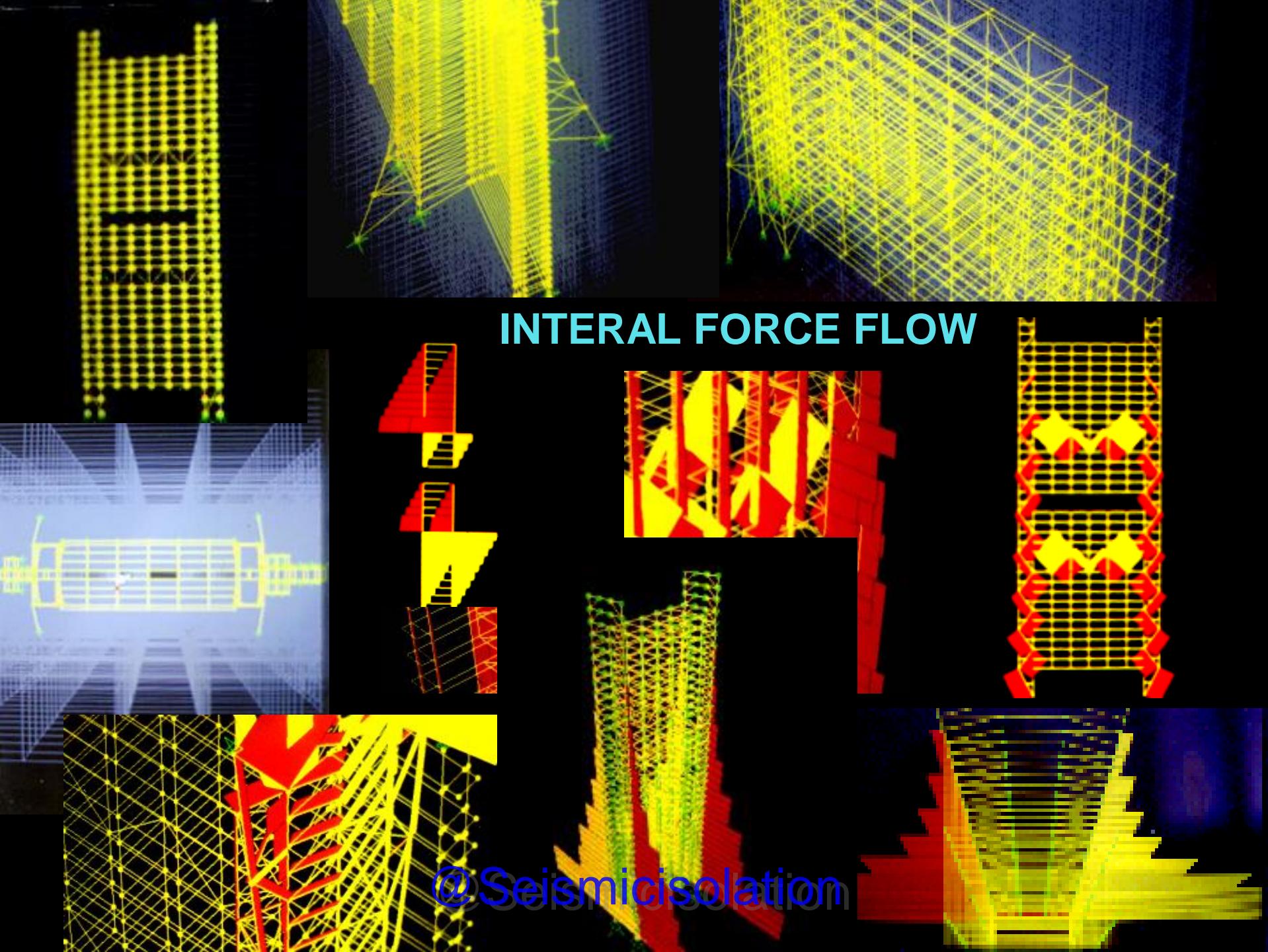
Horizontal gravity force flow



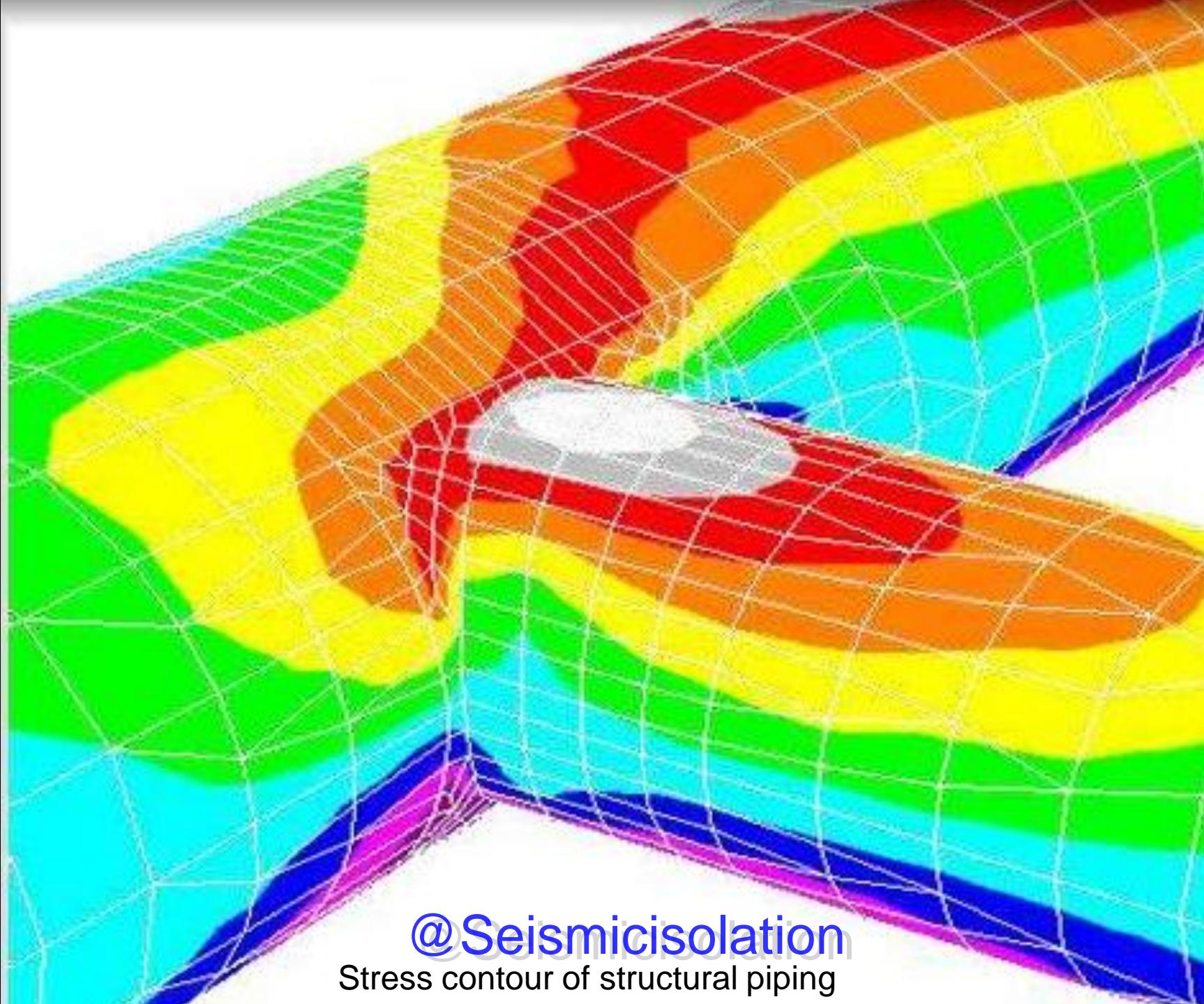
LATERAL FORCE FLOW

the effect of asymmetry on seismic isolation

INTERAL FORCE FLOW



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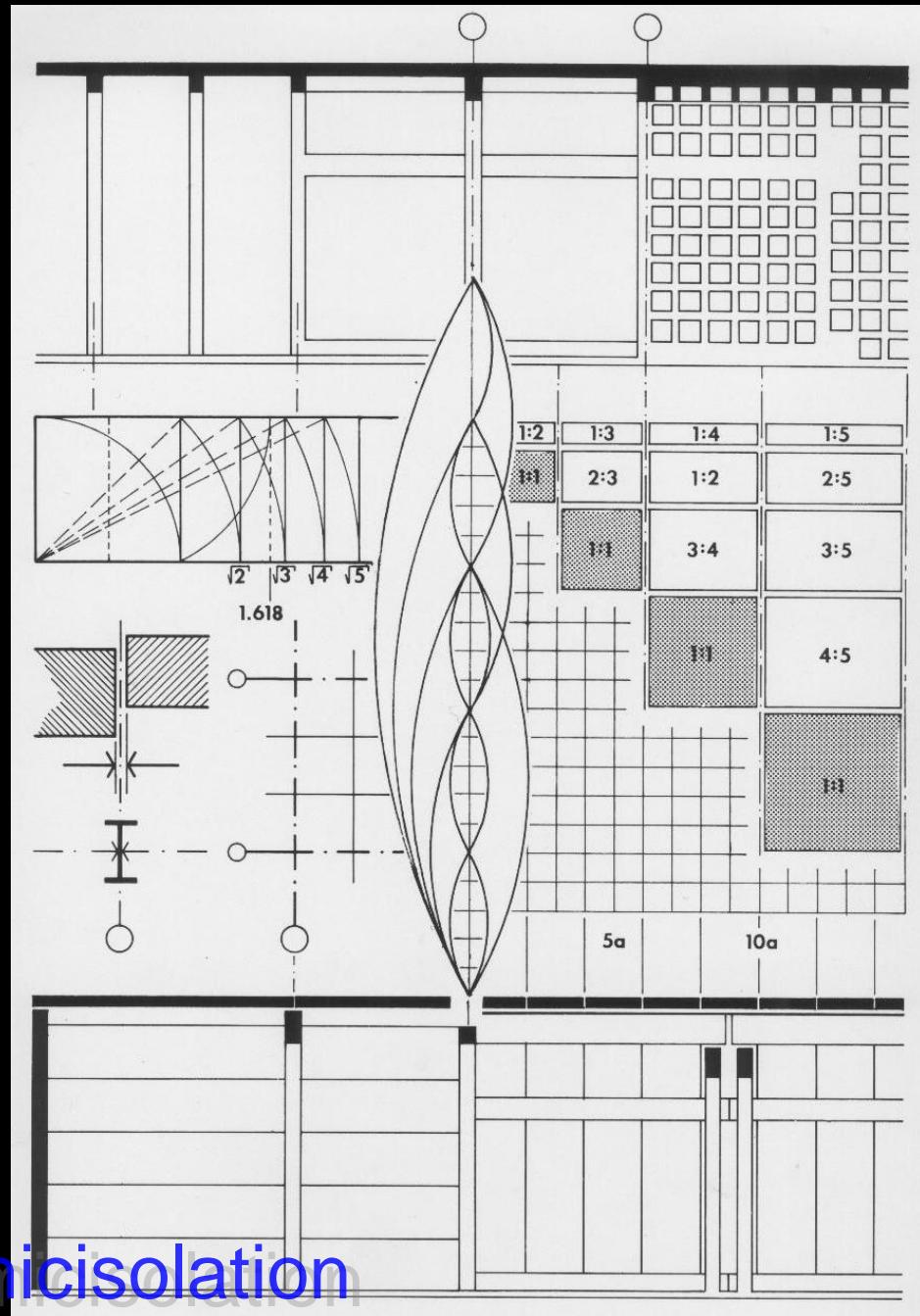


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Stress contour of structural piping

A5. STRUCTURE

as GEOMETRY:

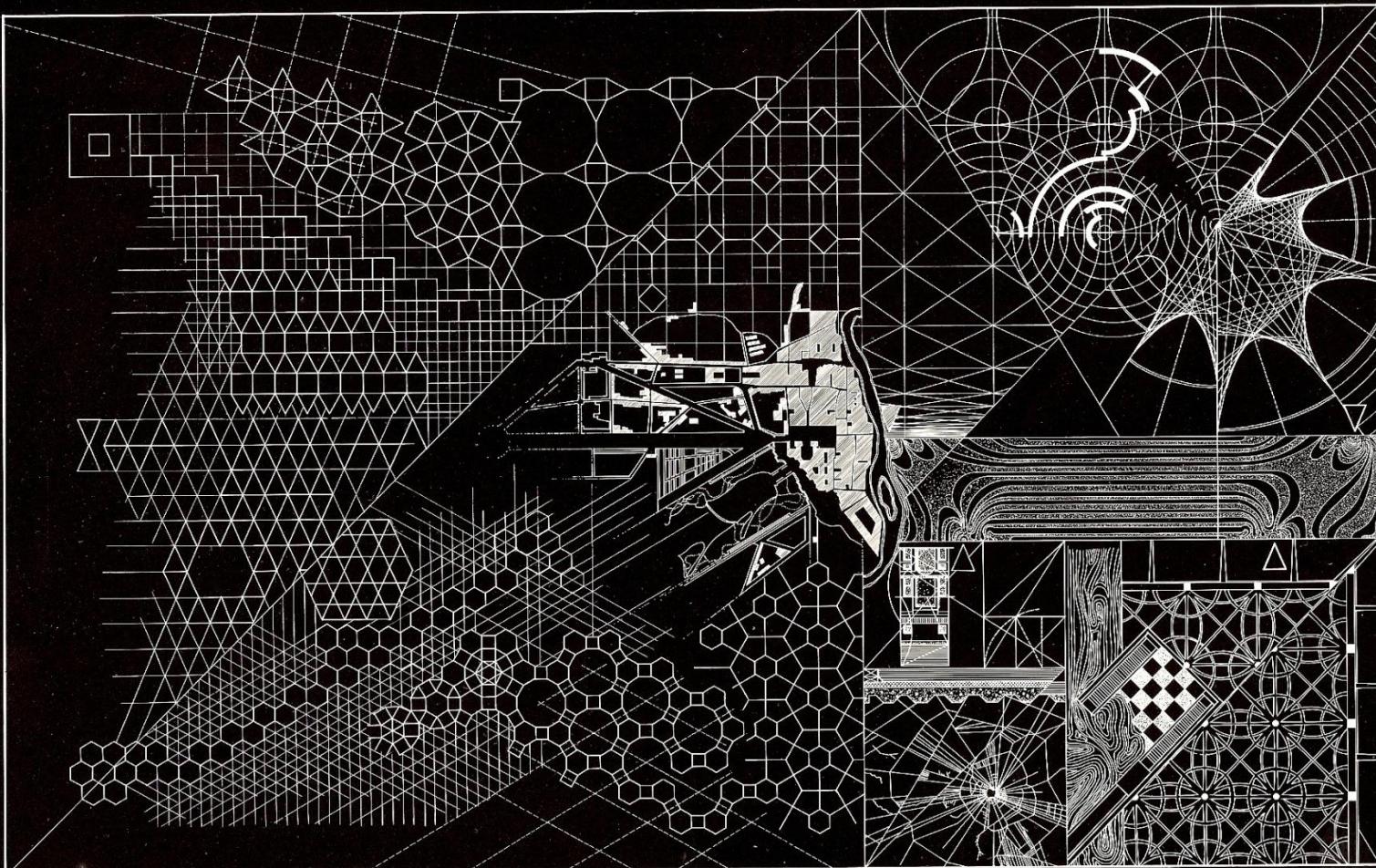
- ordering system
- form giver
- art





BUILDING SHAPES and forms: there is no limit to building shapes ranging from **boxy to compound hybrid to organic crystalline shapes**. Most conventional buildings are derived from the rectangle, triangle, circle, trapezoid, cruciform letter shapes and other linked figures usually composed of rectangles. **Traditional architecture shapes** from the basic geometrical solids the prism, pyramid, cylinder, cone, and sphere. Odd-shaped buildings may have irregular plans that change with height so that the floors are not repetitive anymore. The **modernists** invented an almost inexhaustible range of new building shapes through transformation and arrangement of basic building shapes, through **analogies with biology, human body, crystallography**, machines, tinker toys, flow forms, and so on. **Classical architecture**, in contrast, leaves shapes appear as a decorative element with symbolic meaning.

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Geometrical
Systems
Architecture



Daniel Libeskind . BERLICITY EDGE
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Project: Museum of Art Miami, 2009, Jacques Herzog and Pierre de Meuron.

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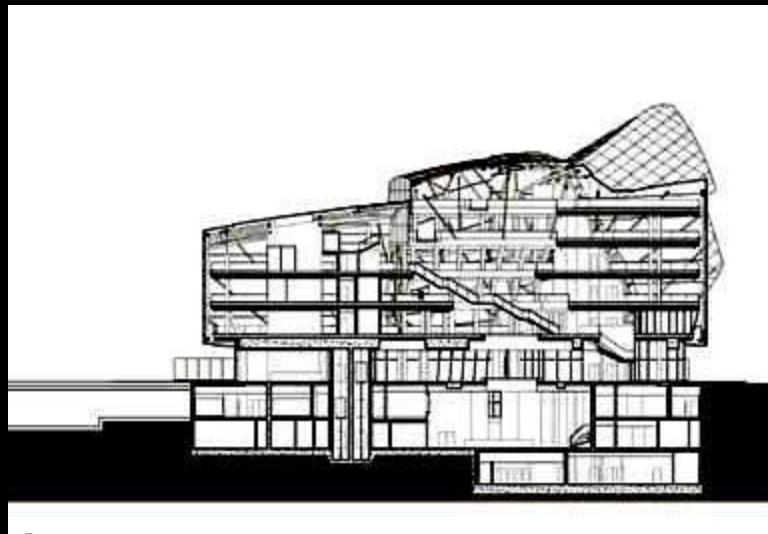
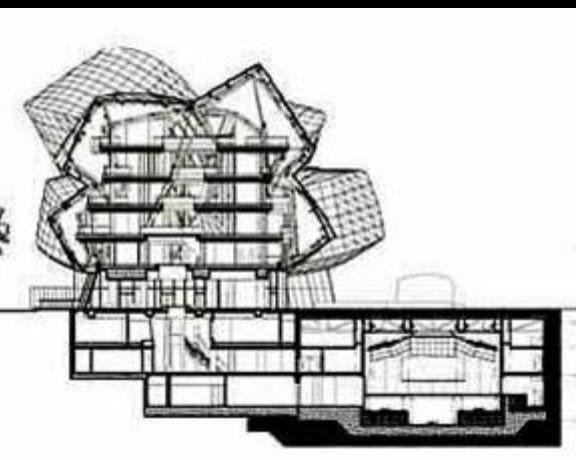
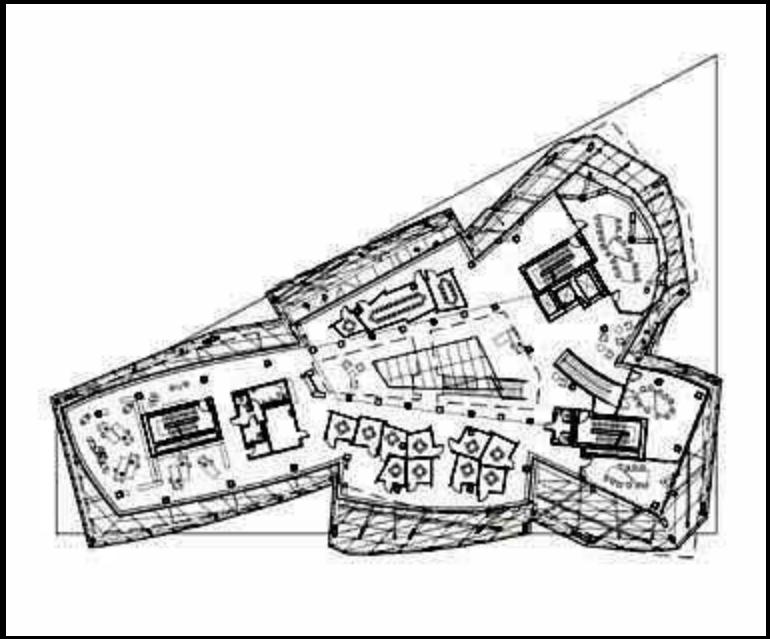
The Novartis campus , Basel, Switzerland, 2009, Frank Gehry



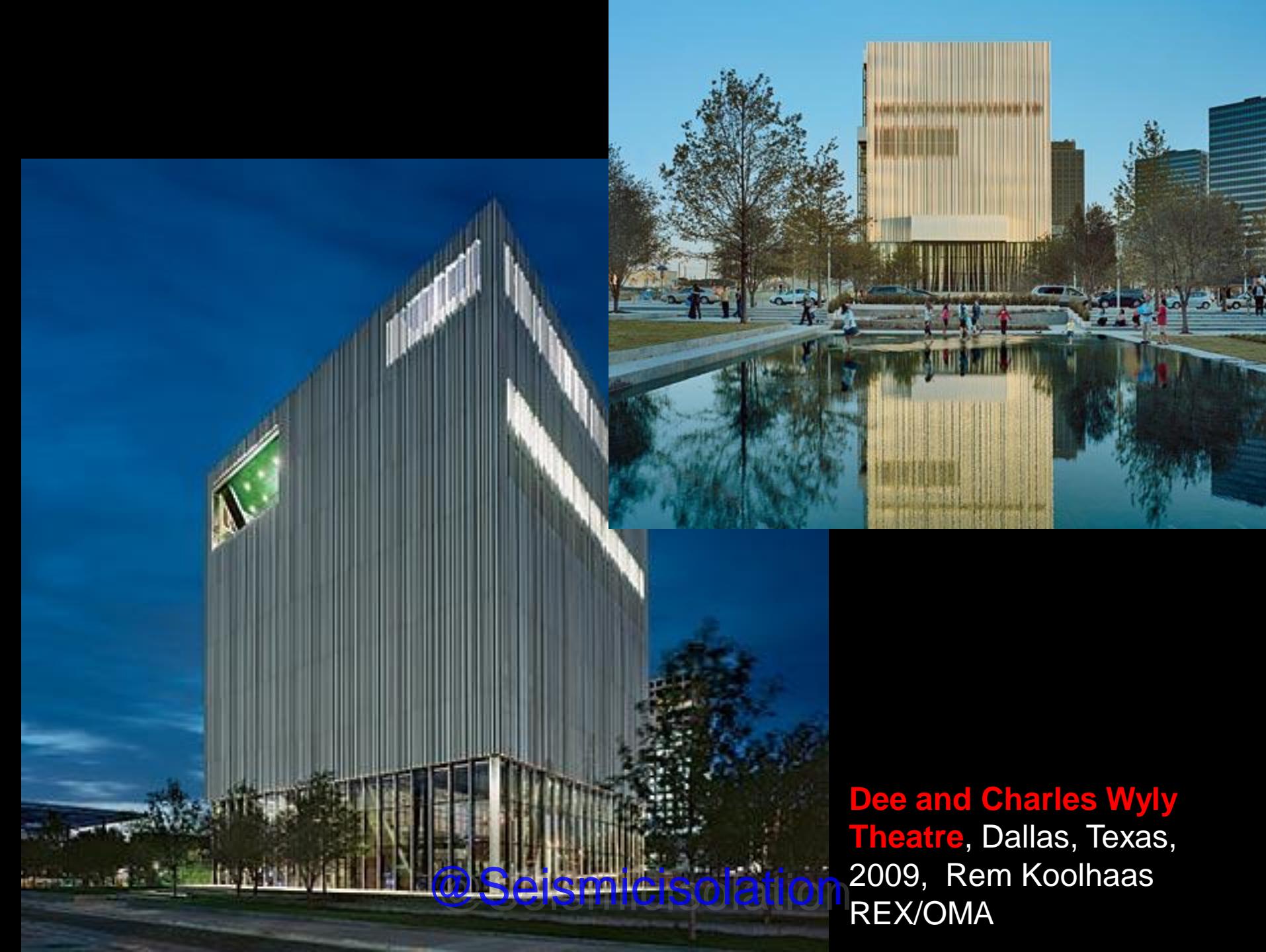
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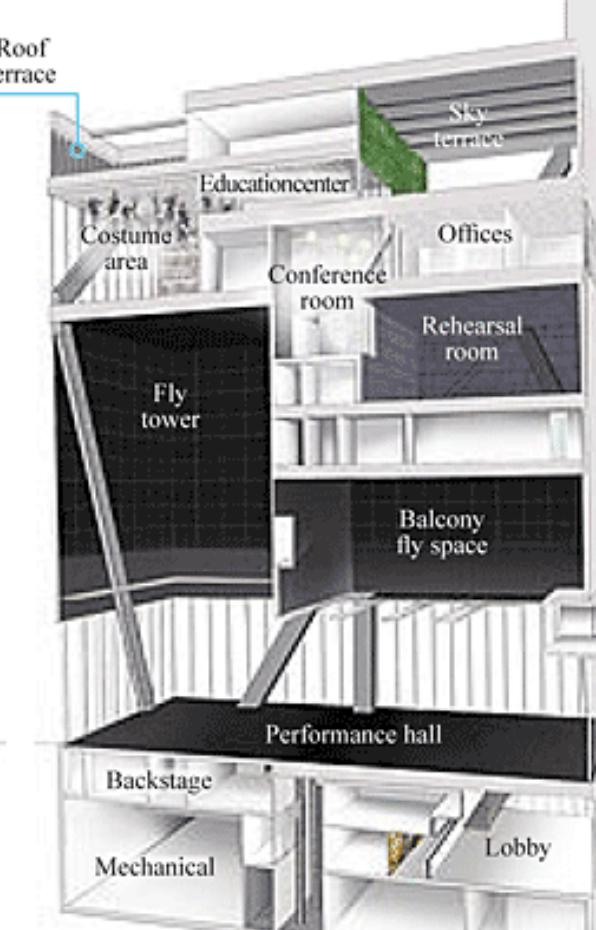
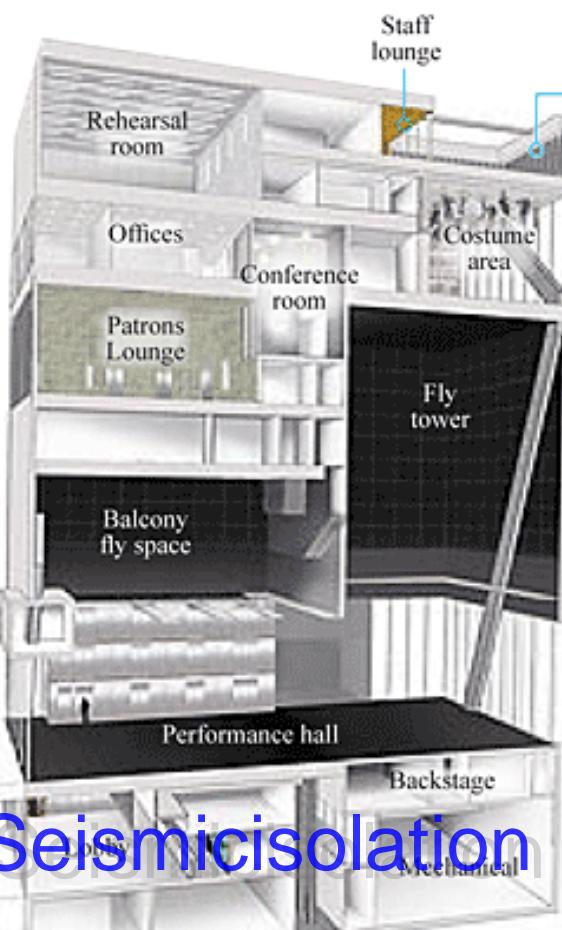
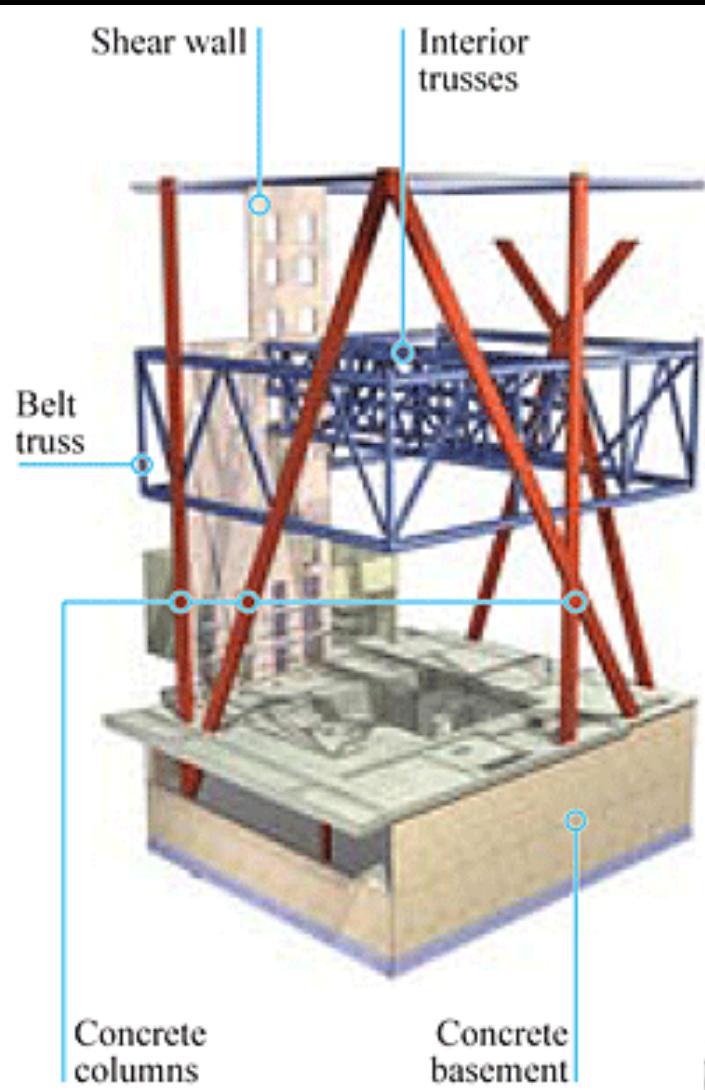


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**Dee and Charles Wyly
Theatre**, Dallas, Texas,
2009, Rem Koolhaas
REX/OMA

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STRUCTURE as *ordering system*, it functions as a spatial and dimensional organizer besides identifying assembly or construction systems.
geometry vs. composition, dimensional coordination (grids, surface subdivision, mathematics, etc.):

- Beijing Jian Wai SOHO Beijing, Riken Yamamoto
- Langen Foundation, Hombroich, Germany, 2004, Ando
- Buckminster Fuller geodesic dome, US Expo Montreal, 1967
- tree houses, Rotterdam, Piet Blom
- capsule tower, Tokyo, 1972, Kurokawa
- Daniel Libeskind, city edge
- bus shelter, Aachen, Germany, 1996, Peter Eisenman
- CCTV Headquarters and TVCC Building, Beijing, Rem Koolhaas
- National Swimming Center in Beijing, 2007, Arup, space frame cells
- Beijing Olympic Stadium, called the “nest”, Herzog and De Meuron, Arup Eng
- Guggenheim Museum, Bilbao, 1997, Frank Gehry
- Fisher Center, Bard College, NY, Frank Gehry
- UFA Palace Dresden (German Architecture Price 1999), COOP Himmelblau
- Phare Tower, La Défense, Paris, 2006, Thom Mayne (Morphosis, LA)



Beijing Jian Wai SOHO, Beijing, 2011, Riken Yamamoto
Seismic isolation



Langen Foundation, Hombroich, 2001, Germany, Ando
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Buckminster Fuller geodesic dome, U.S. Pavilion at Expo 67, Montreal, three-quarter sphere with 250 ft diameter and a height of 200 ft, double-layer space frame

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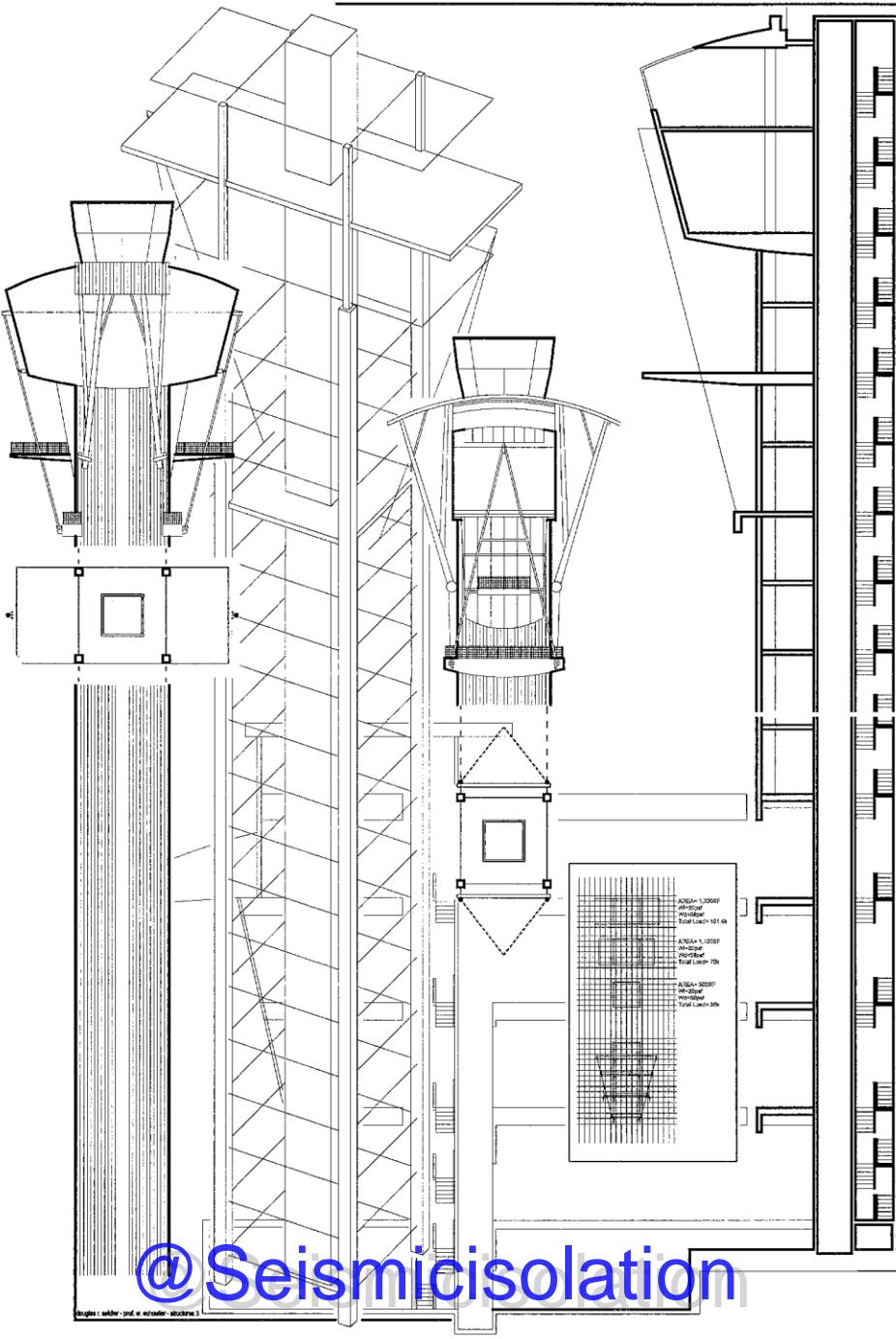
Cube (tree) houses, Rotterdam, Piet Blom, 1984. The houses look like a tree because the architect turned the cubes 45 degrees and put them on a pole. The 32 attached houses together look like a stone forest. The complex is built at a pedestrian bridge crossing a traffic road.

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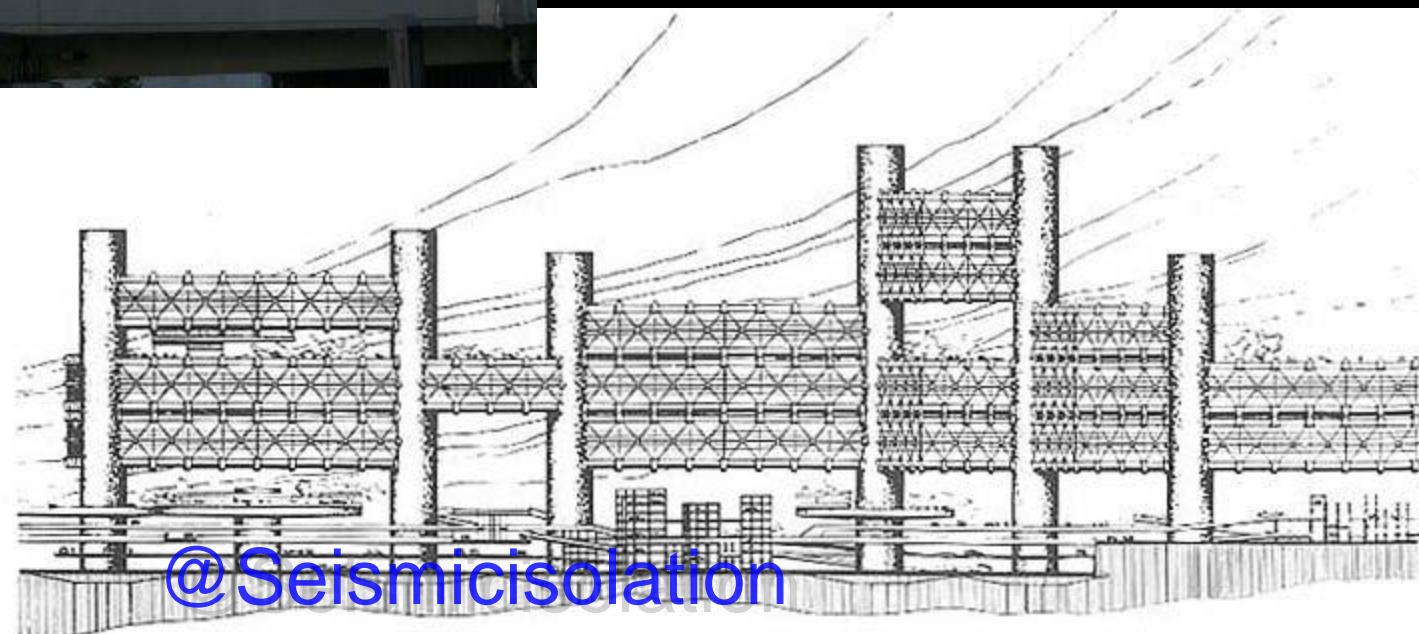
Restaurant Tower (46 m),
called “Bierpinsel”, Steglitz,
Berlin, 1976, Ralph Schüler
and Ursulina Schüler-Witte



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Kisho Kurokawa, Nakagin Capsule Tower, Tokyo, Japan, 1972, The 14-story high Tower has 140 capsules stacked at angles around a central core. Kurokawa developed the technology to install the capsule units into the concrete core with only 4 high-tension bolts, as well as making the units detachable and replaceable.



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**Bus shelter, Aachen, 1996,
Peter Eisenman**



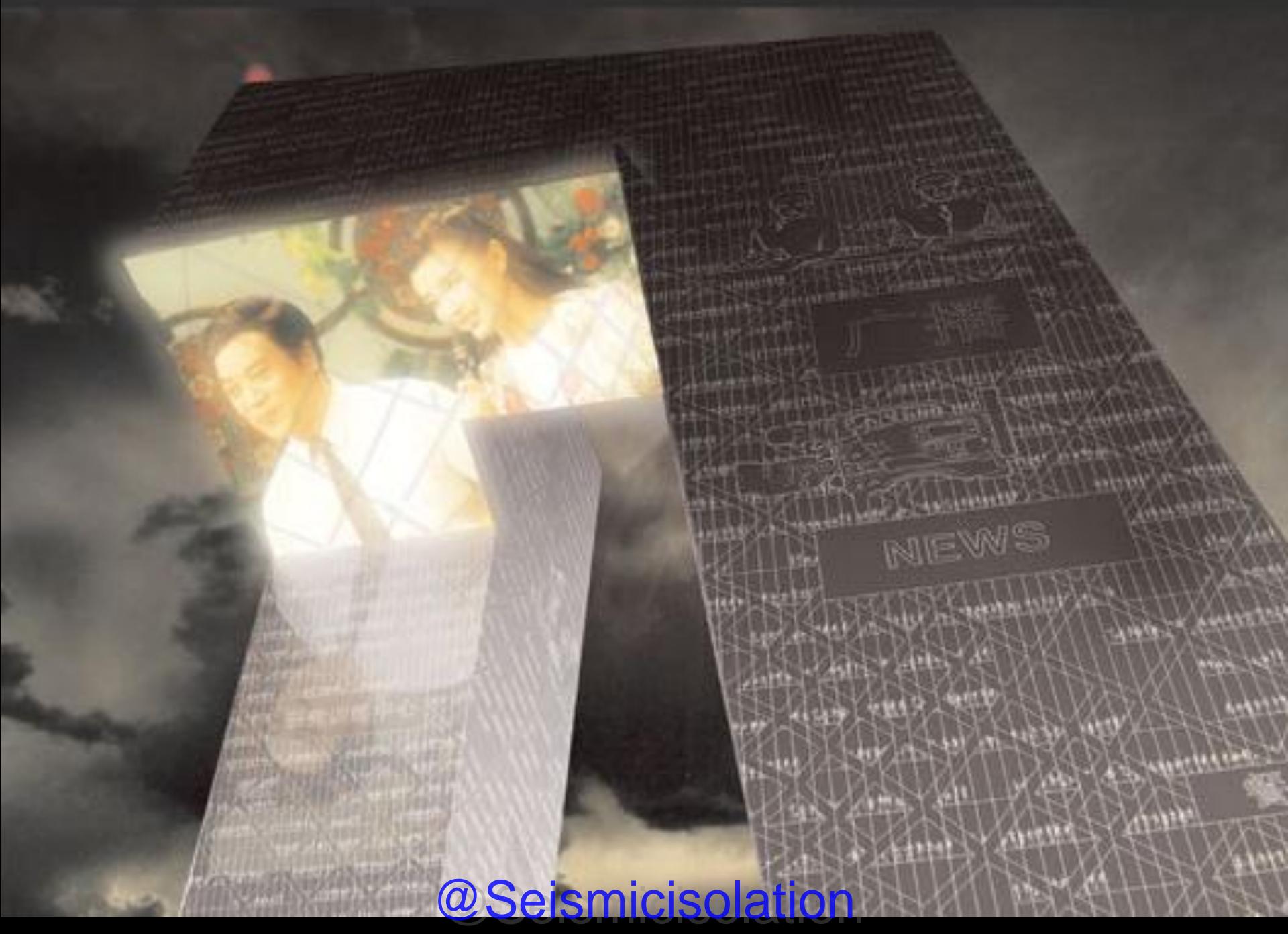
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CCTV Headquarters and TVCC Building, Beijing, 2008, Rem Koolhaas and Ole Scheeren



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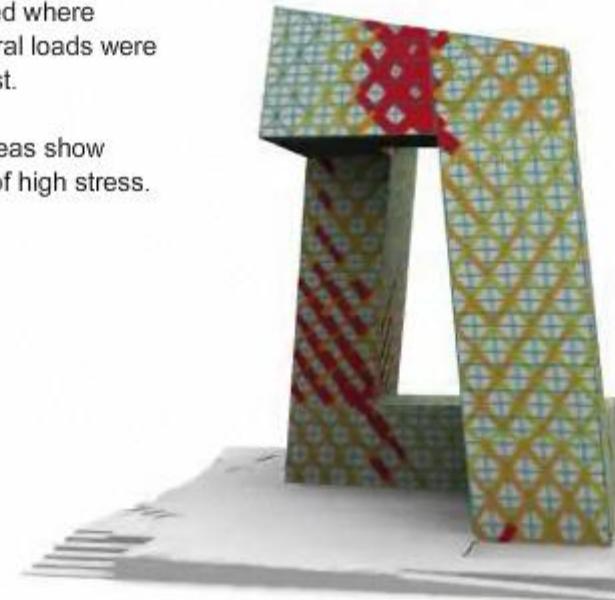
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To arrive at this pattern, building engineers began by applying a uniform series of diagonal braces to a model of the structure's surface.



A computer model revealed where structural loads were greatest.

Red areas show areas of high stress.



A computer model revealed where structural loads were greatest.

Red areas show areas of high stress.



The pattern of steel members was adjusted to provide support where necessary.

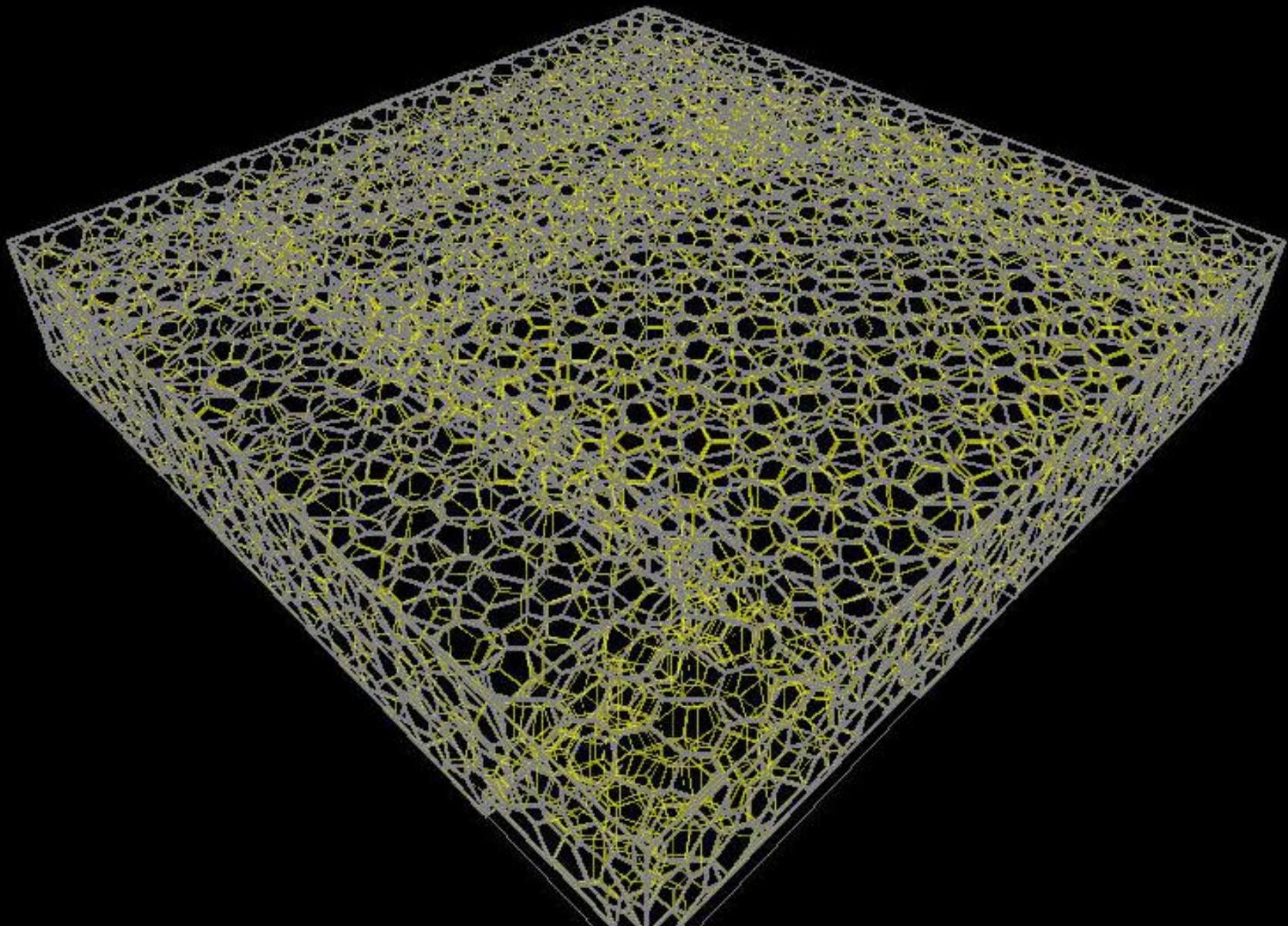


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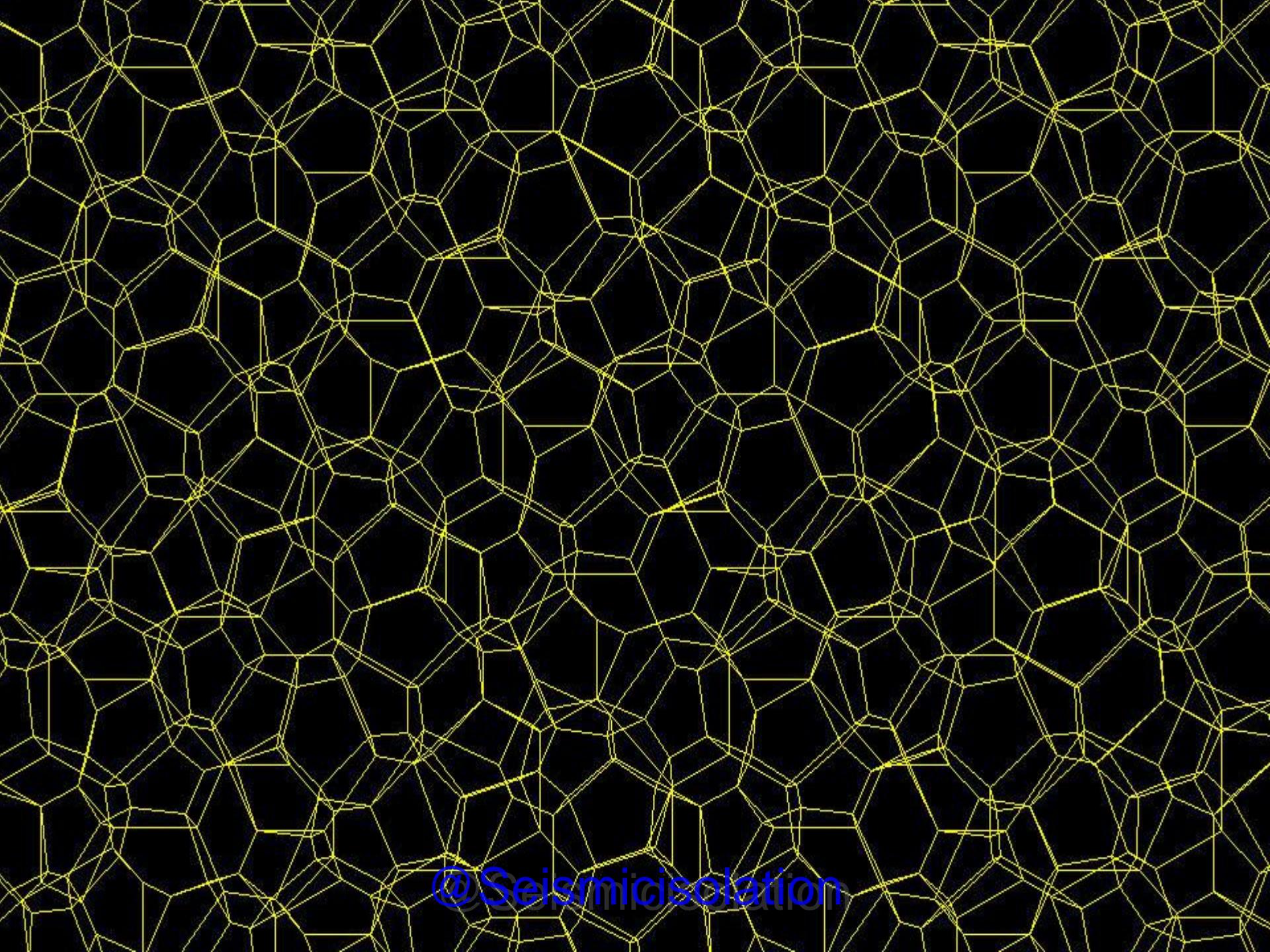
National Swimming Center in Beijing, 2007, Arup, space frame cells



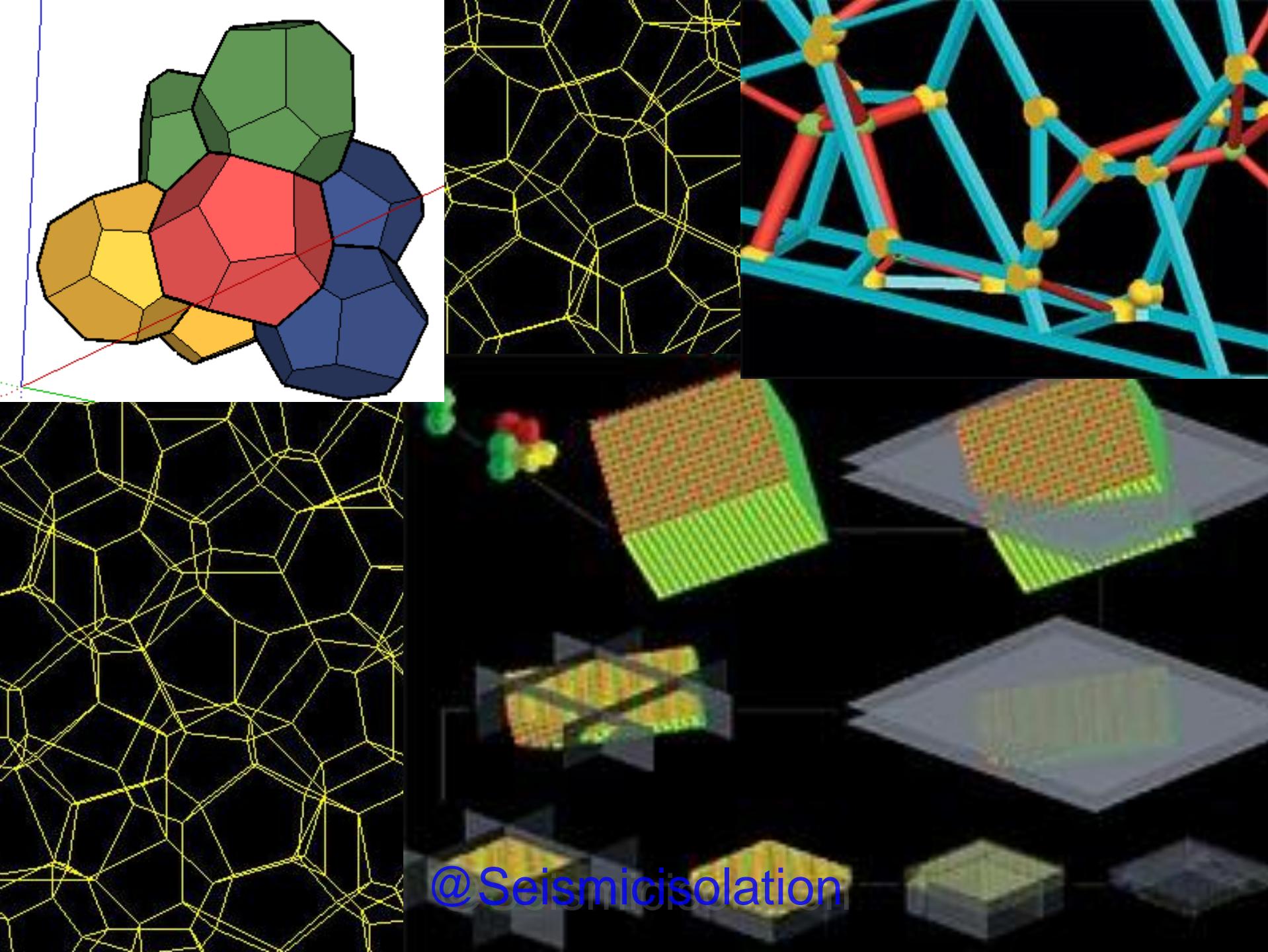
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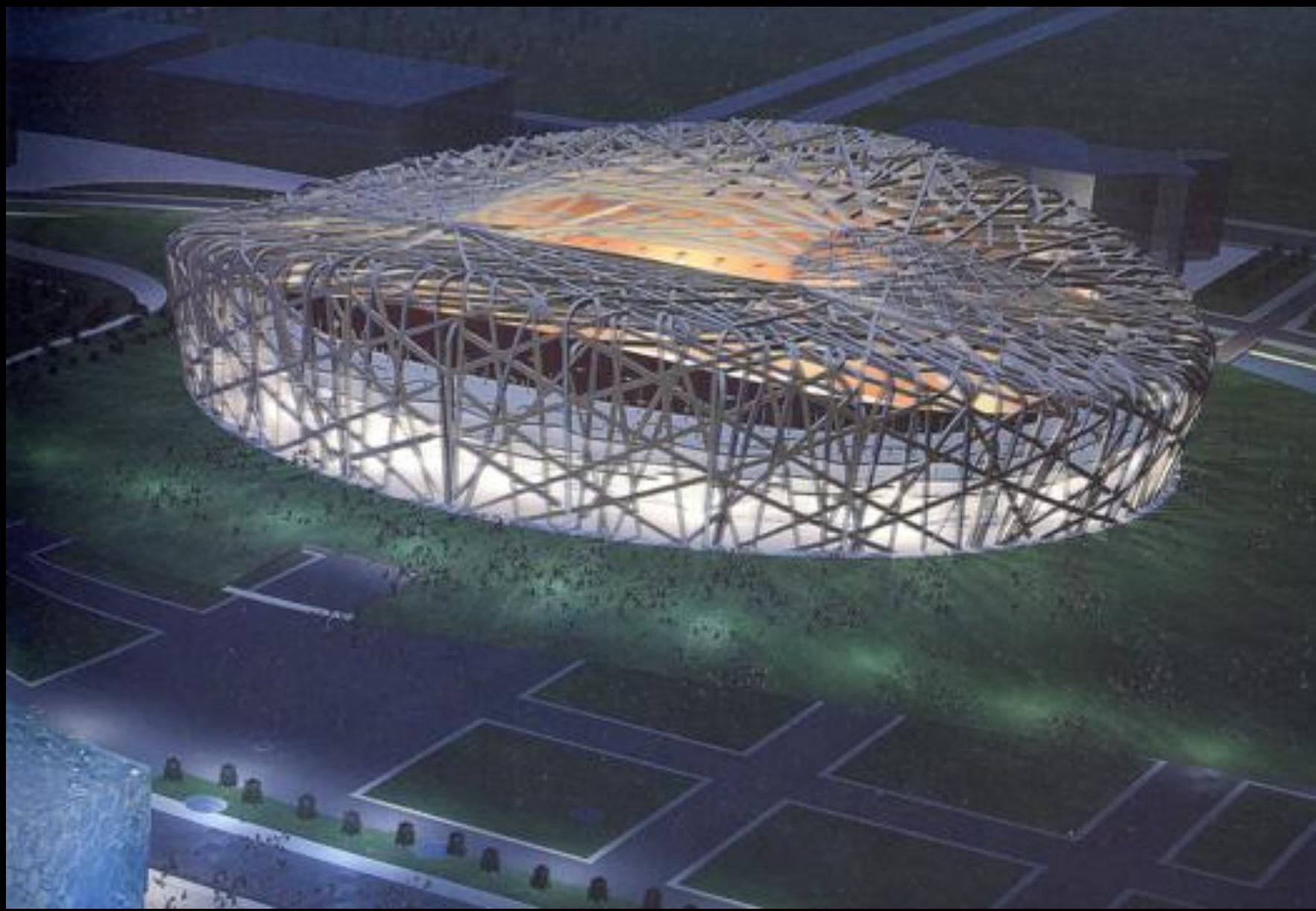
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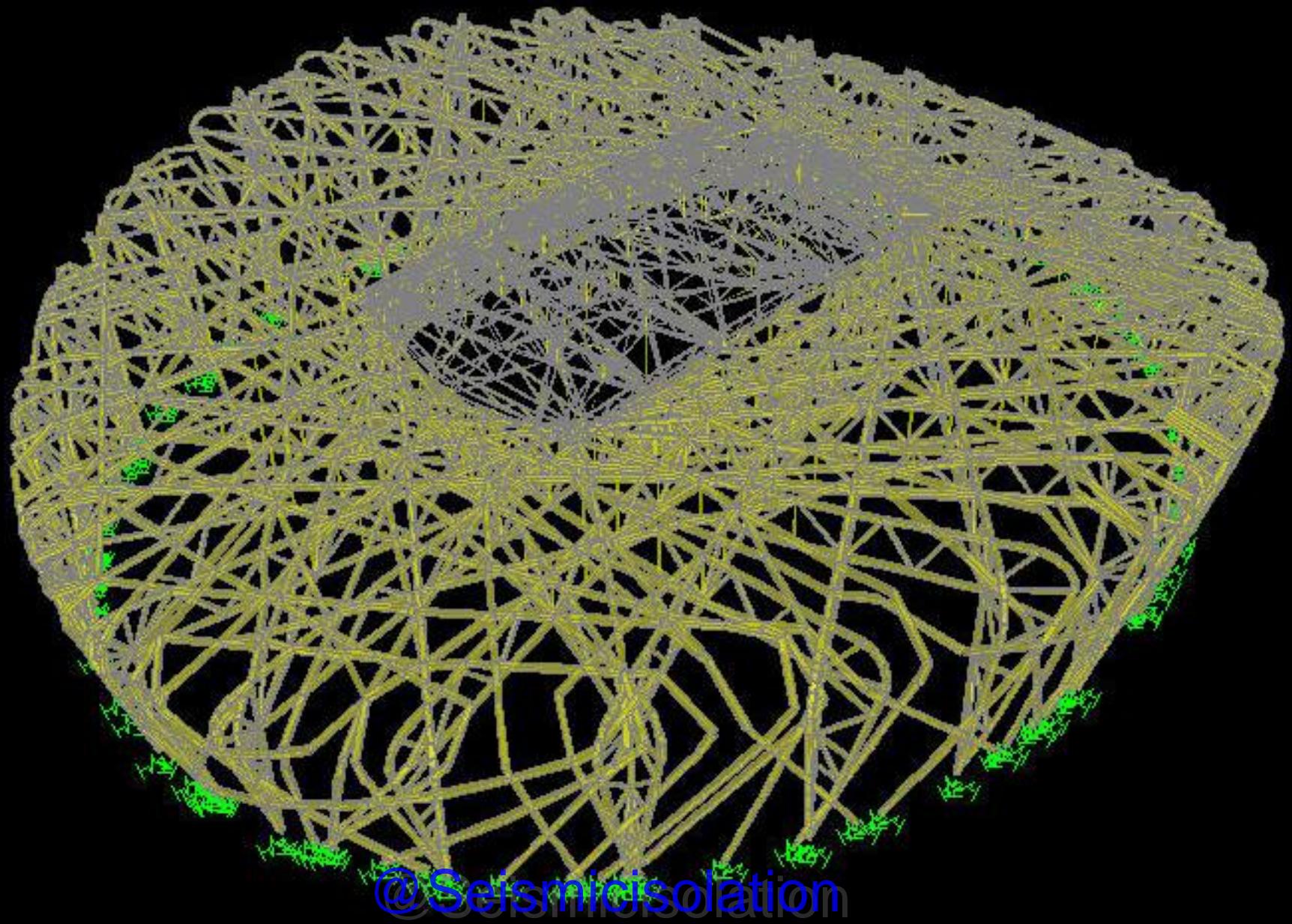
Beijing Olympic Stadium, called the “nest” 2008 Herzog and De Meuron, Arup Eng
©Seismicisolation



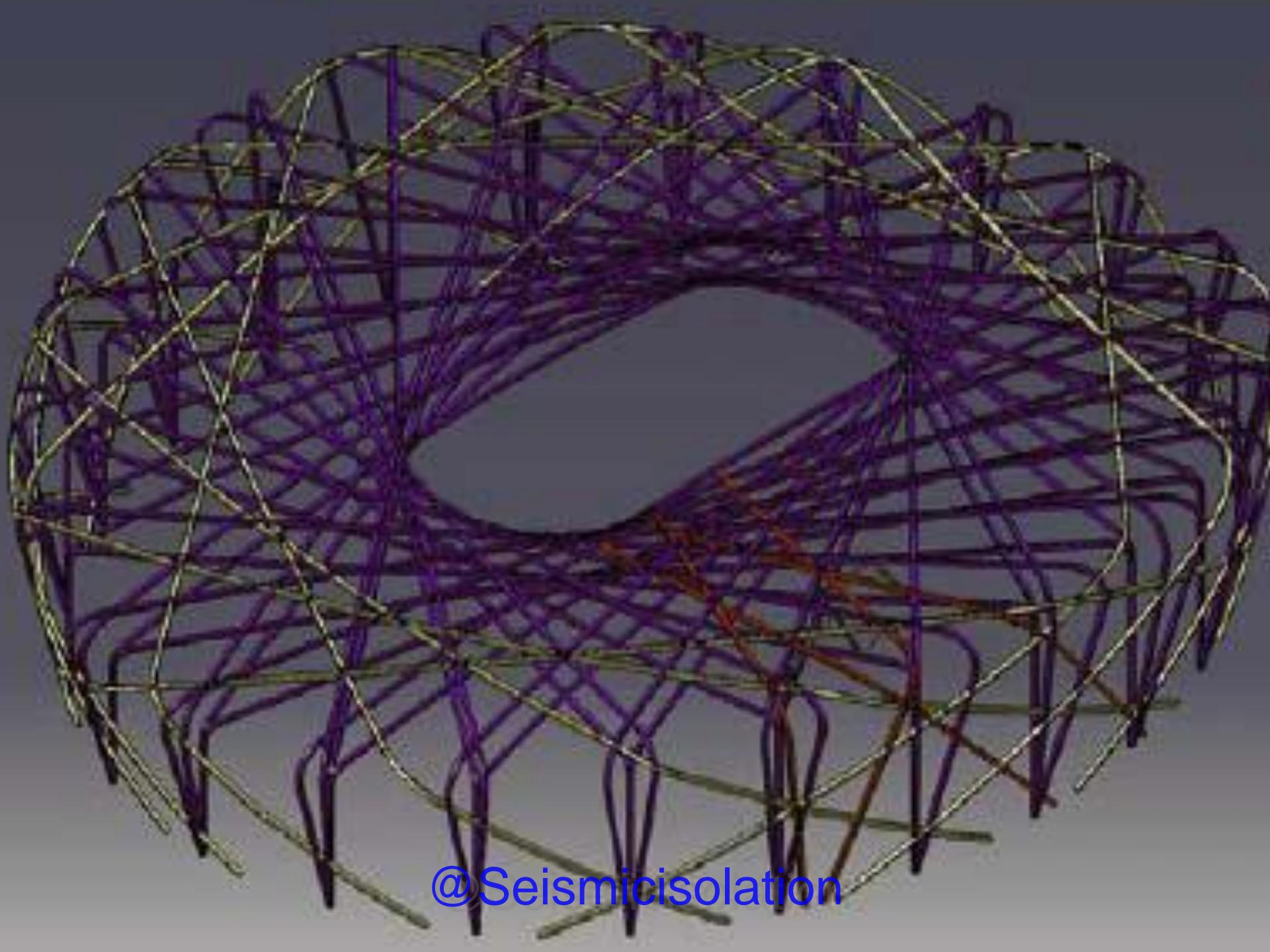
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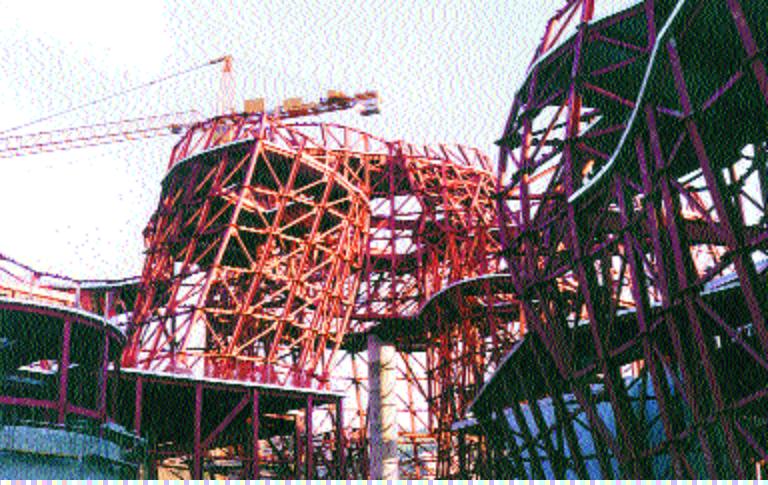
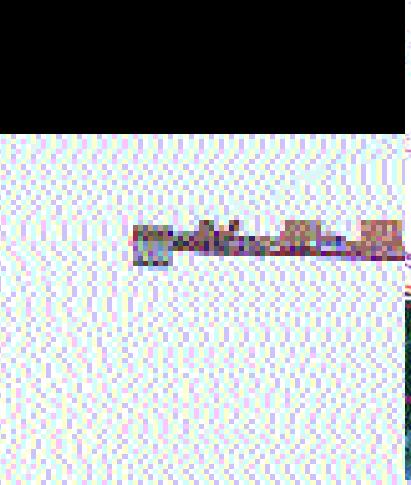
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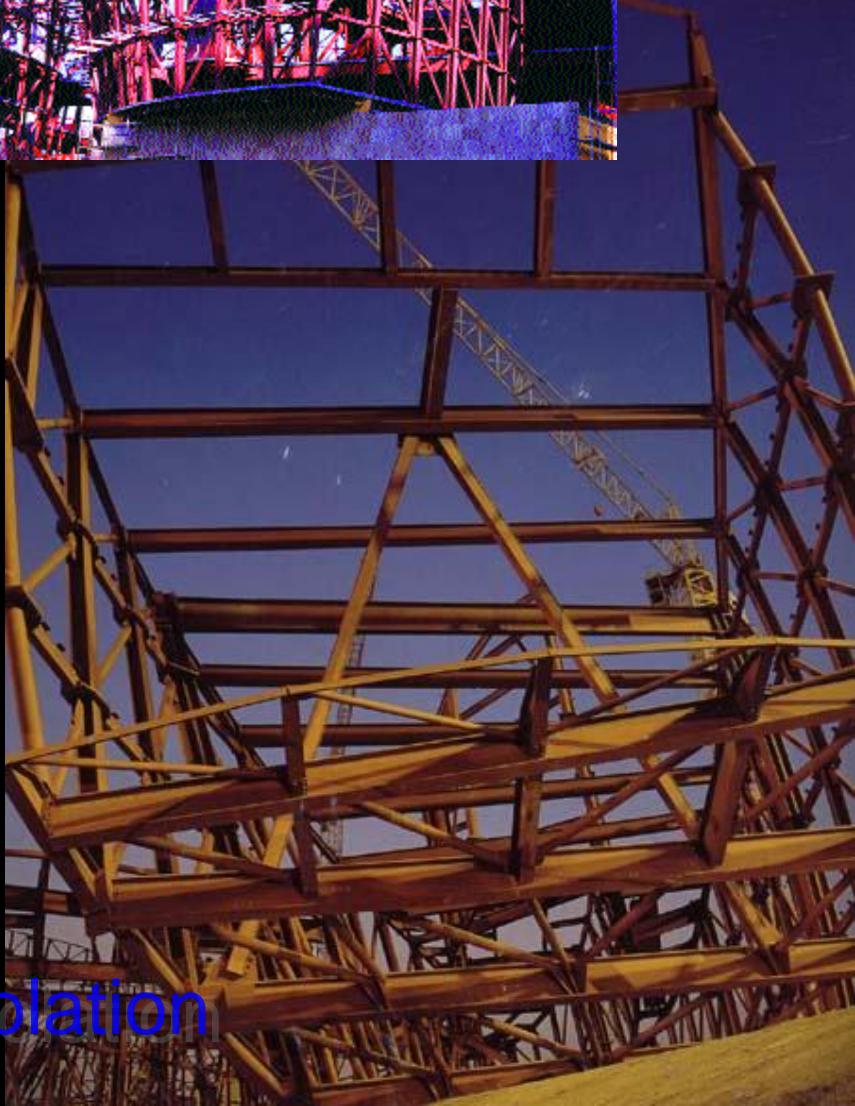
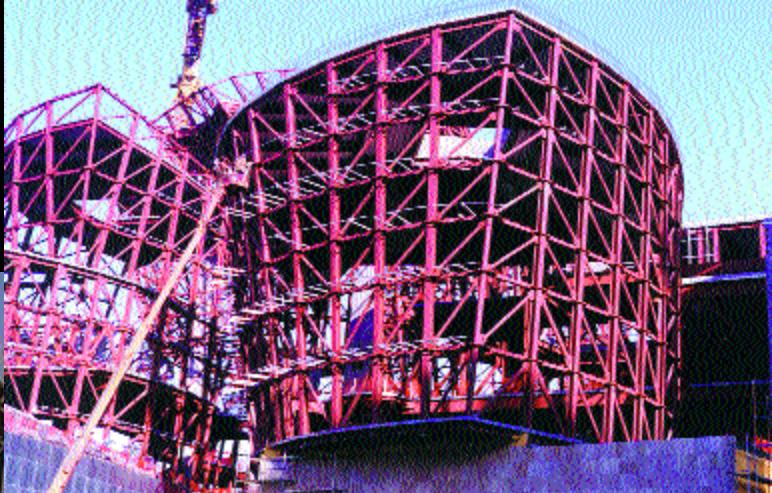
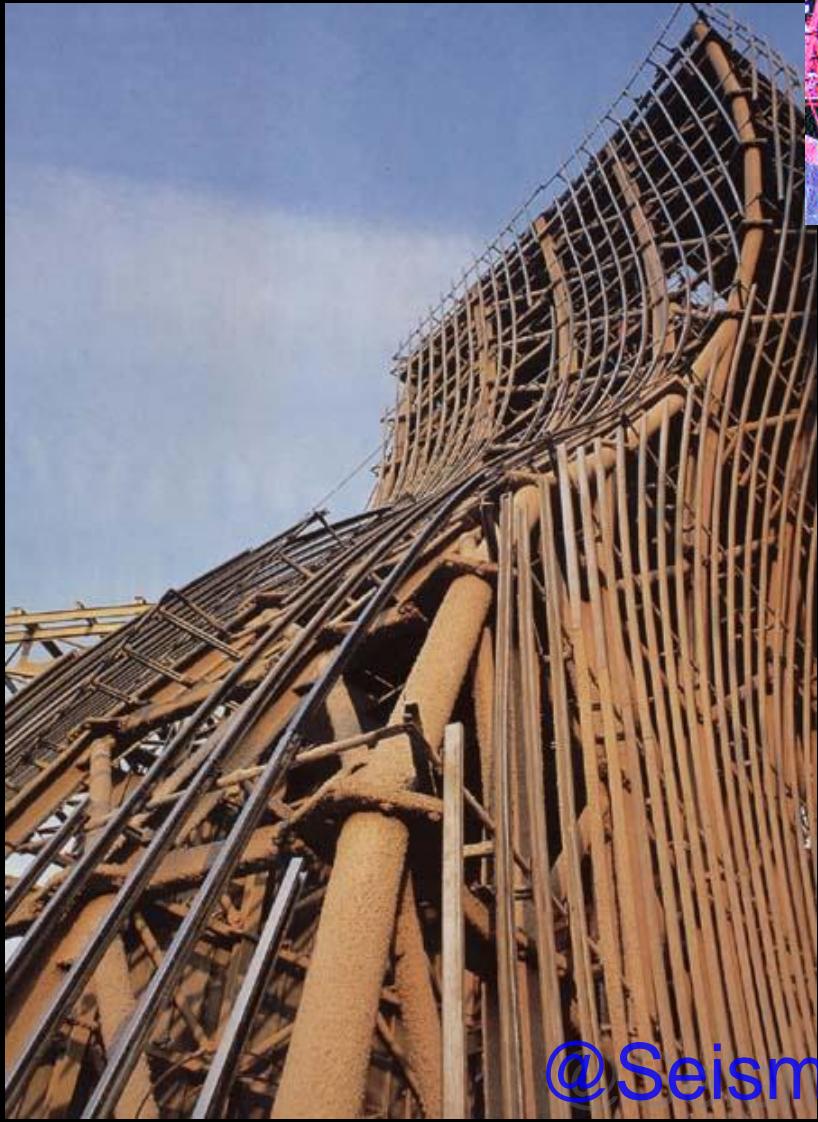
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Guggenheim Museum, Bilbao, 1997, Frank Gehry, SOM
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Fisher Center, Bard College, NY,
2003, Frank Gehry



UFA Palace, Dresden, Germany, 1993, COOP Himmelblau
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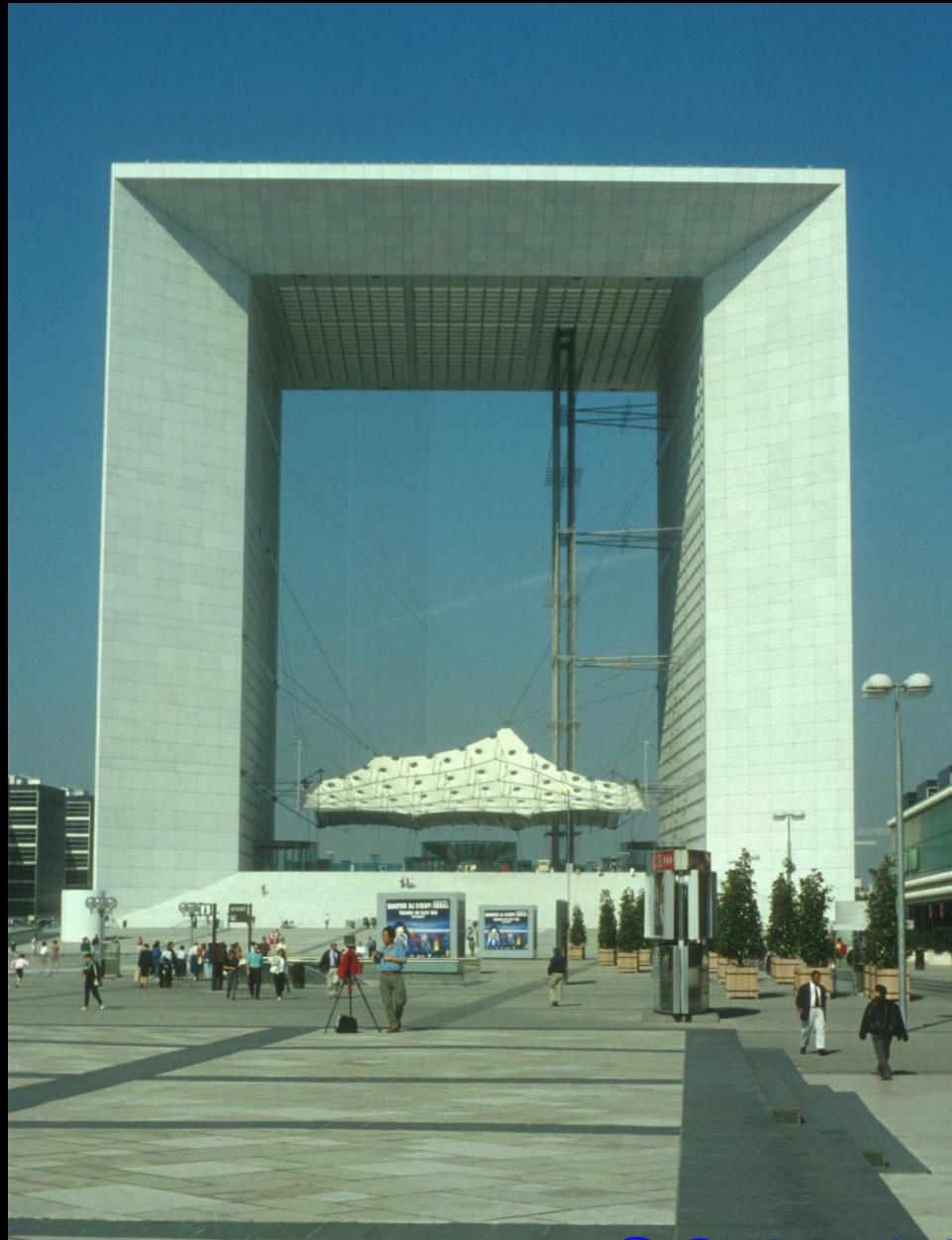
Thom Mayne's (Morphosis, LA) design for the Phare Tower in La Défense, Paris. 2012

STRUCTURE as *form giver*: it defines the spatial configuration and reflects other meanings and is part of esthetics:

- Roman aqueduct, Segovia, Spain
- La Grande Arch, Paris, Fainsilber & P. Rice
- TU Munich, Germany
- Integrated urban buildings, Linkstr. Potsdamer Platz), Richard Rogers, Berlin, 1998
- Mercedes-Benz Museum, Stuttgart, 2006, Ben van Berkel & Caroline Bos, Werner Sobek Ingenieure
- Phaeno Science Center, 2005, Wolfsburg, Zaha Hadid
- BMW Welt Munich, 2007, Coop Himmelblau



Roman aqueduct in Segovia, Spain, 50 AD



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La Grande Arch, Paris, 1989, Fainsilber & P. Rice for the canopy



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Werner-von-Siemens Auditorium, TU Munich , Germany



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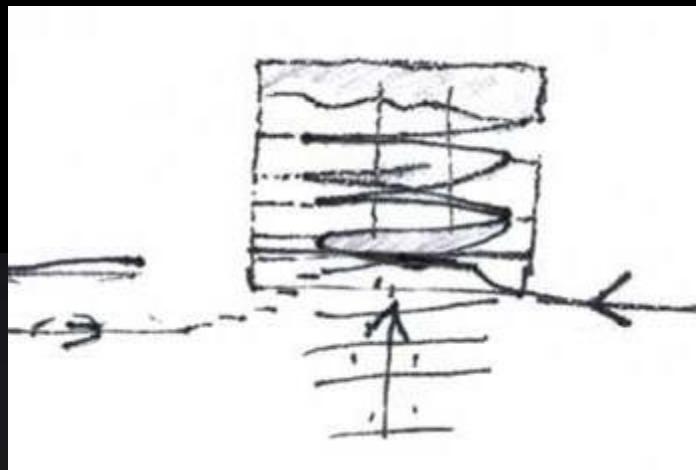
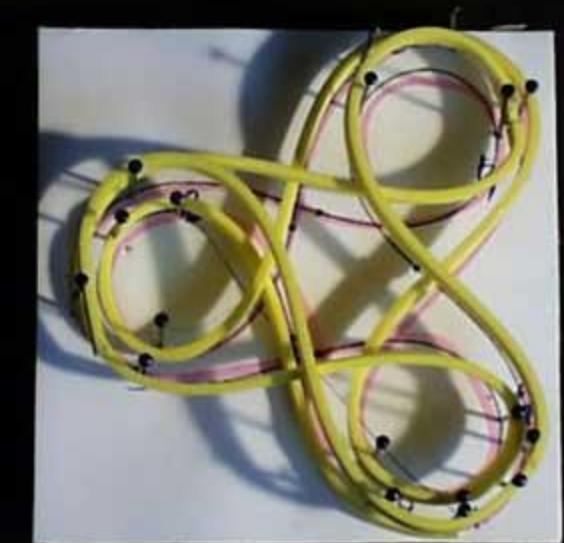
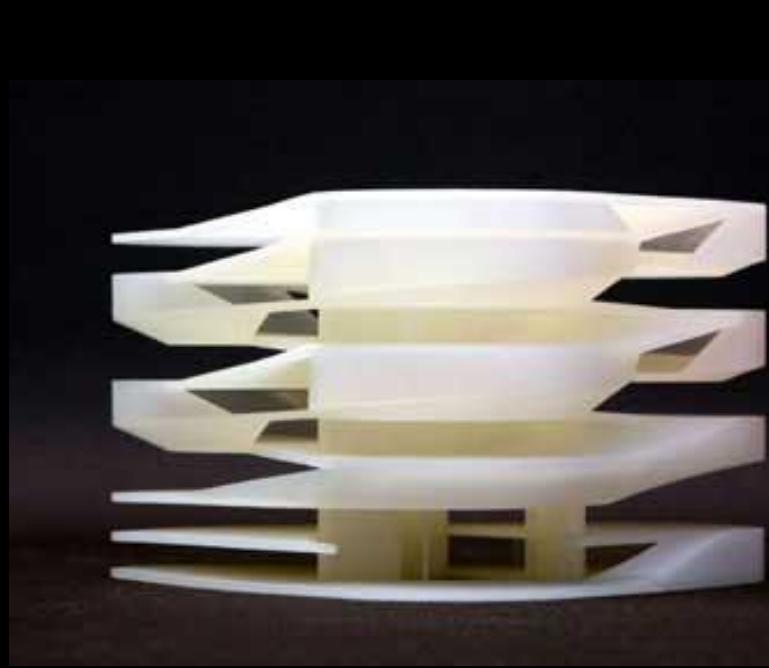


Integrated urban buildings, @Seismicisolation, Richard Rogers, Berlin, 1998

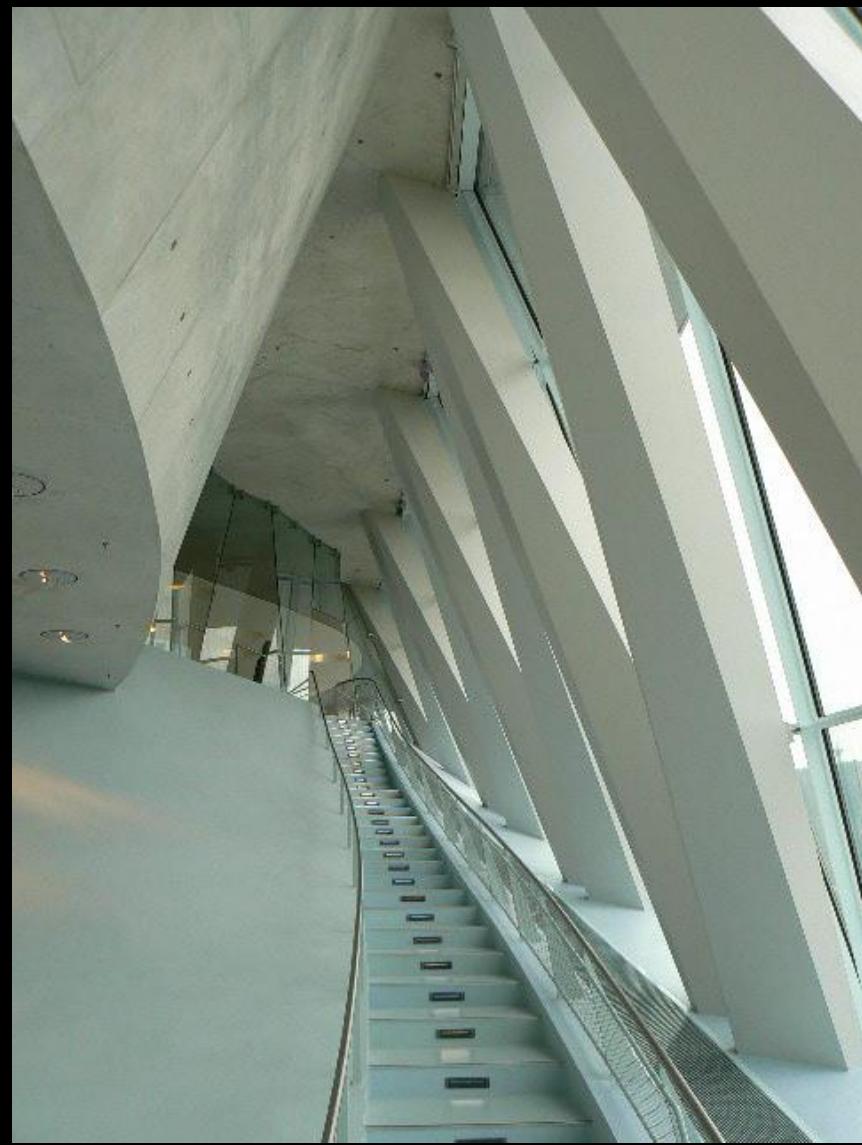
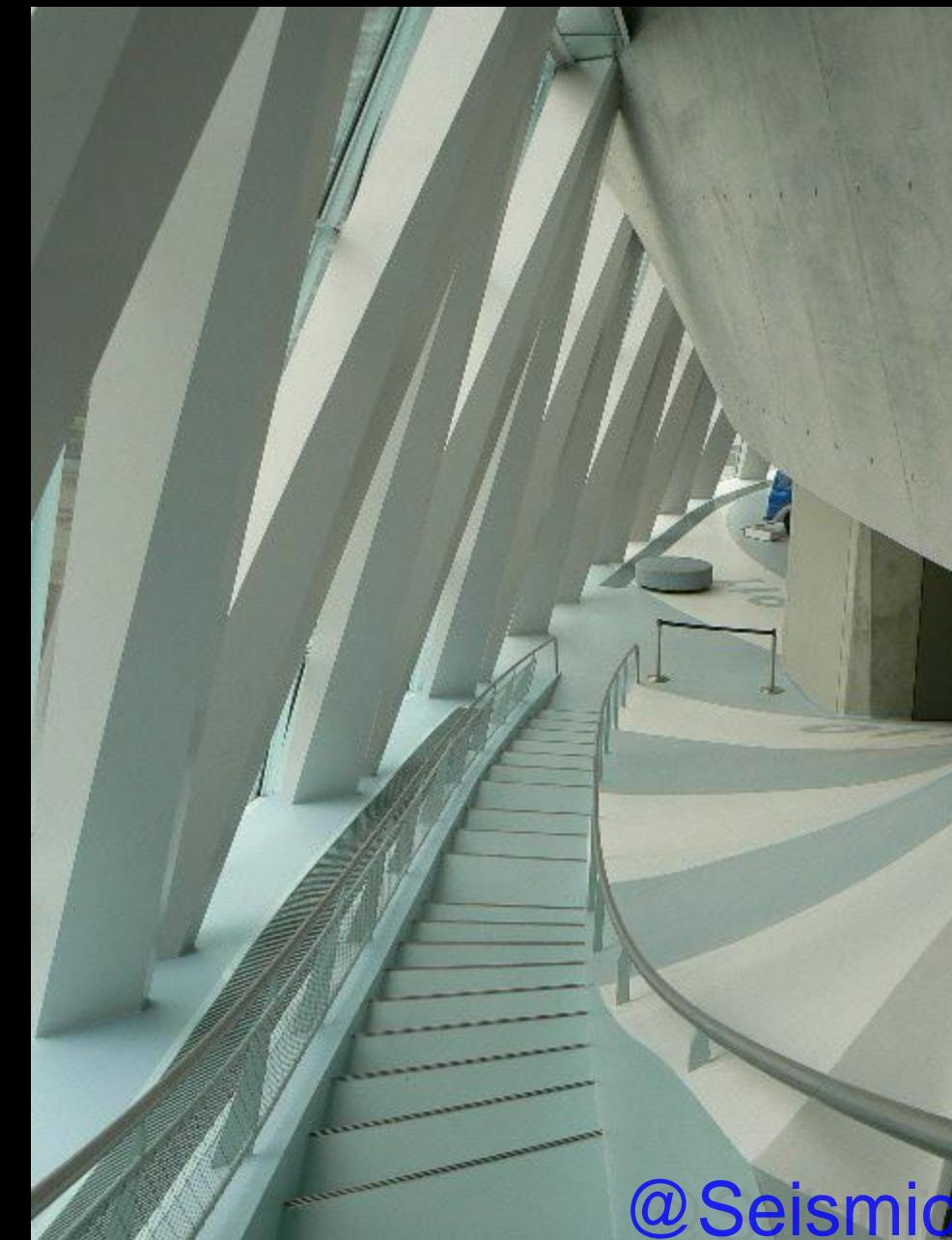


**Mercedes-Benz
Museum,
Stuttgart, 2006,
Ben van Berkel
& Caroline Bos,
Werner Sobek
Ingenieure**

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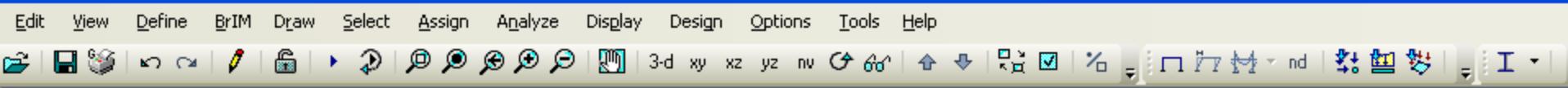
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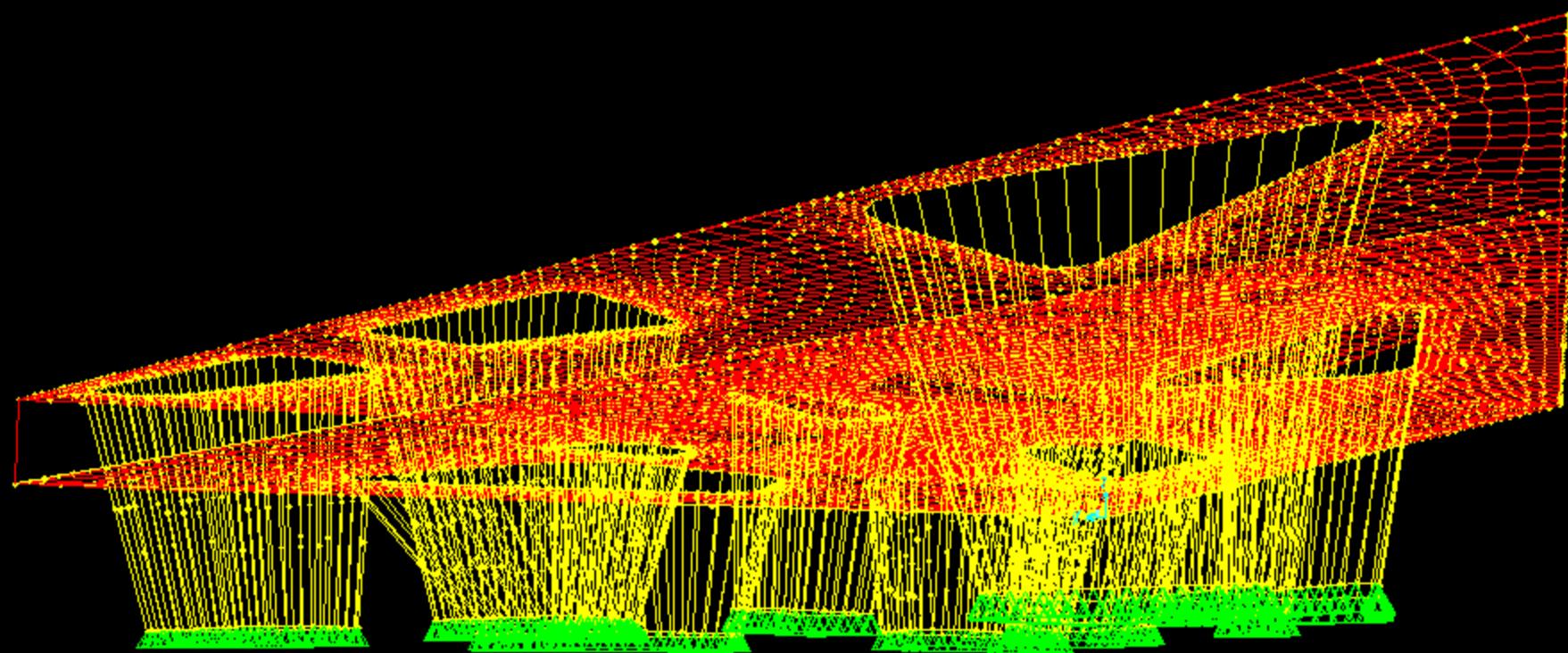
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Phaeno Science Center, 2005, Wolfsburg, Zaha Hadid



3-D View

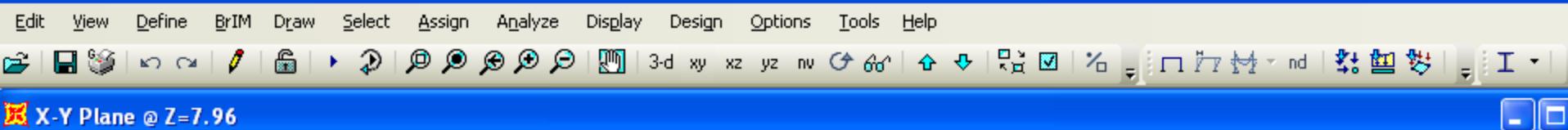


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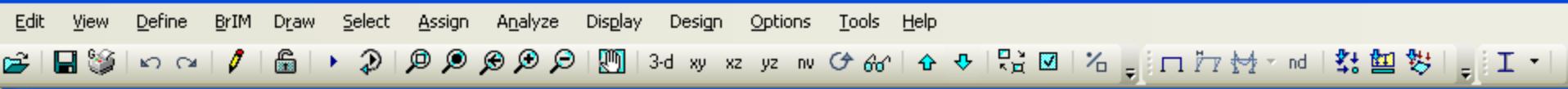
View

X0.00 Y0.00 Z0.00

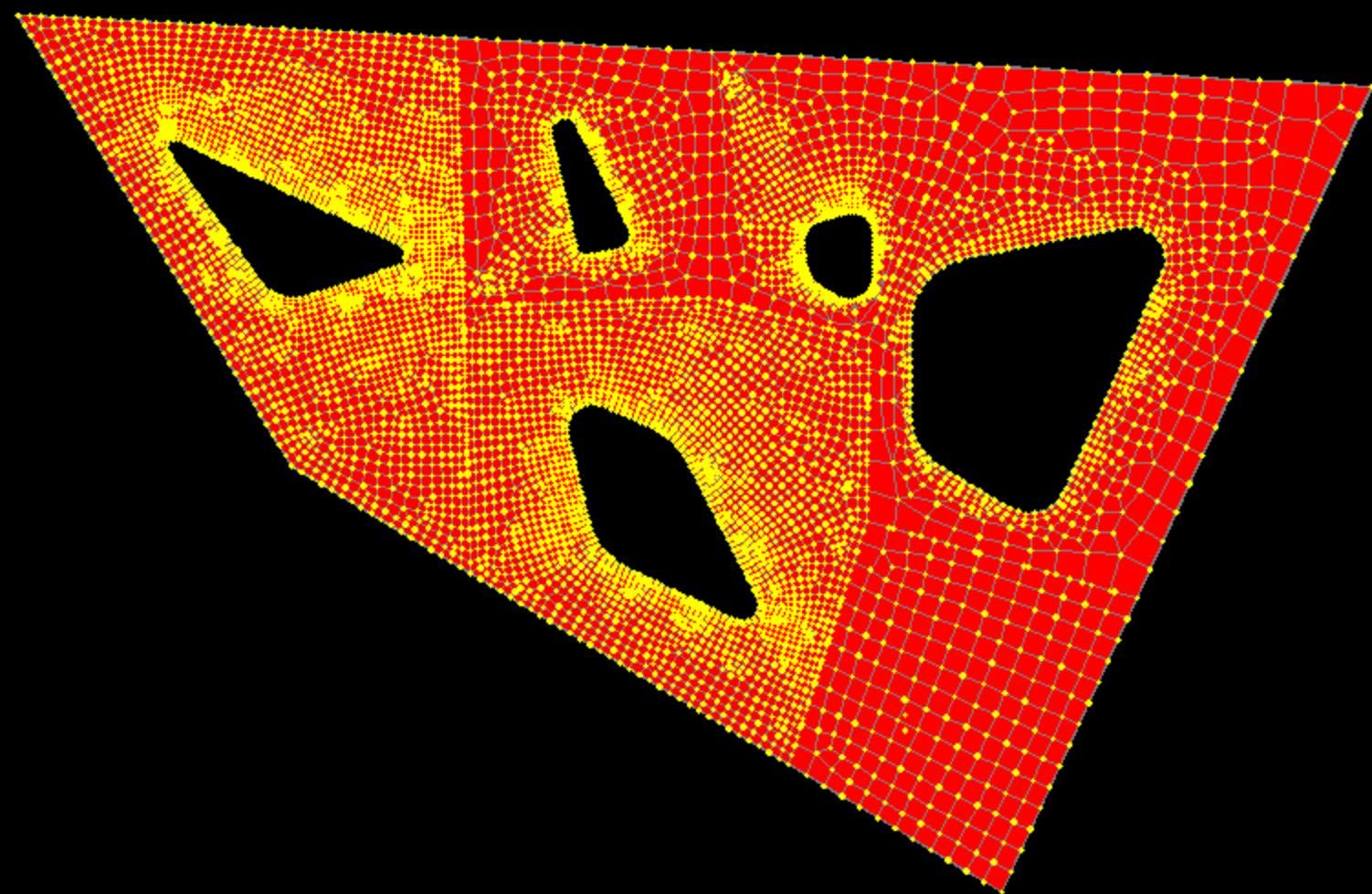
GLOBAL Friday, May 22,



@Seismicisolation



X-Y Plane @ Z=0



@Seismicisolation

Plane @ Z=0

X-27.99 Y8.03 Z0.00

GLOBAL KN, m, C



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BMW Welt, Munich, 2007, Himmelblau, Bollinger + Grohmann



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STRUCTURE as *art*

The experimentation with structures is also reflected by the **constructivist art of modernism** and was first articulated particularly by the dreams of designers such as the pioneers **Antoine Pevsner** and **Naum Gabo** at the early part of this century in Russia, and later by **Alexander Calder's** kinetic art and **Kenneth Snelson's** tensegrity sculptures.

- Flamingo Sculpture, Chicago, 1974, Calder, in front of Mies van der Rohe Building
- Calder in the National Gallery of Art, East Wing, Washington, 1978, I.M. Pei
- Experiments with structure, Russian Constructivism (3 slides)
- Kenneth Snelson's tensegrity tower, double-layer tensegrity dome
- Stradelhofen Station, Zurich, 1990, Santiago Calatrava, (2 slides)
- Earth sculpture, MUDAM, Luxembourg, 2007
- Chairs (2 slides)
- Shizuoka Press & Broadcasting Center, Tokyo, 1967, K. Tange



**Calder Flamingo
Sculpture, Chicago, 1974,
in front of Mies van der
Rohe building**

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© BRUNO FOLGERT

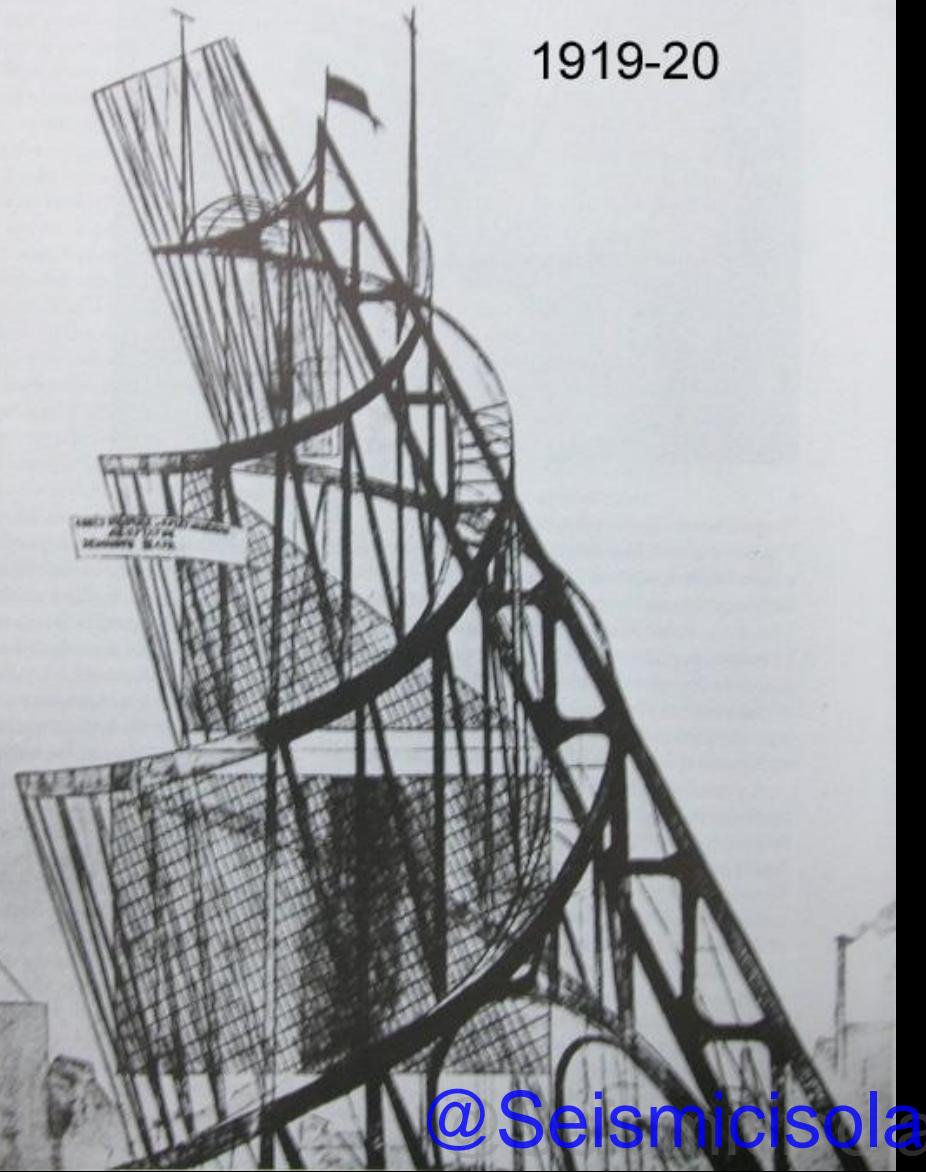


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Calder in the National Gallery of Art, East Wing, Washington, 1978, I.M. Pei

Vladimir Tatlin

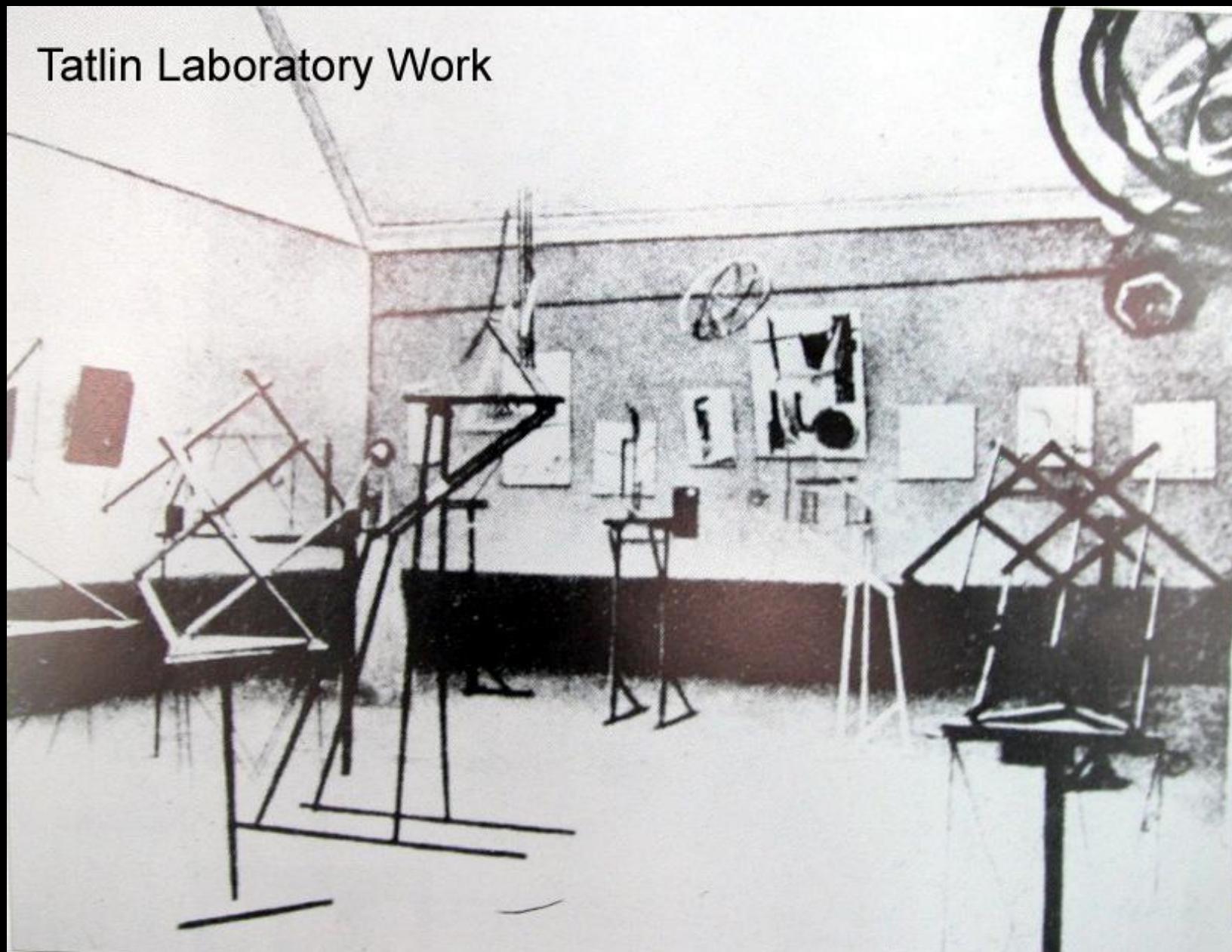
1919-20



Experiments with structure,
Russian Constructivism

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Tatlin Laboratory Work



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Experiments with structure, Russian Constructivism



*Non-right
solids*

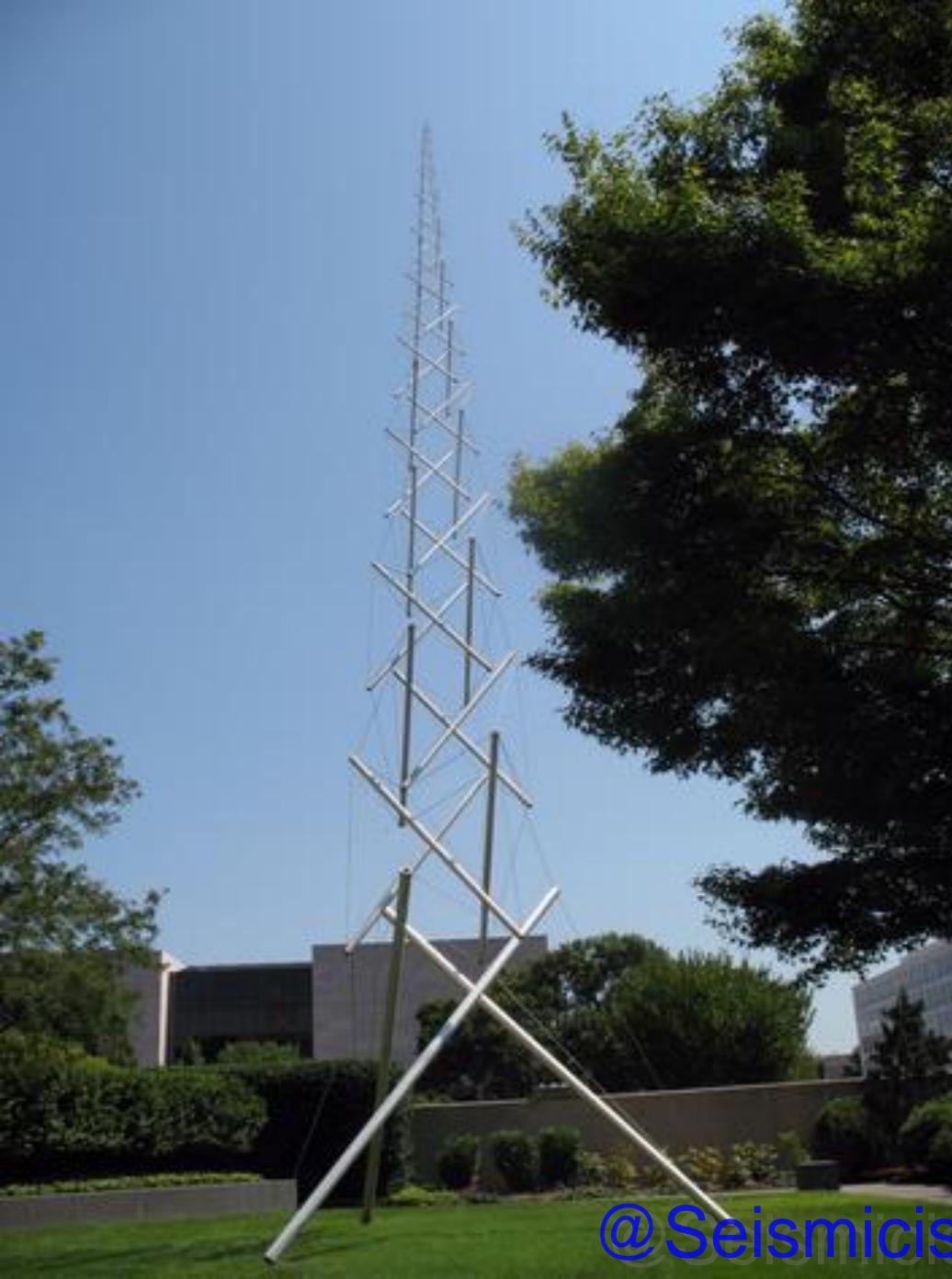
Fundamentals of Constructivism

Experiments @Seismicisolation
with structure, Russian Constructivism

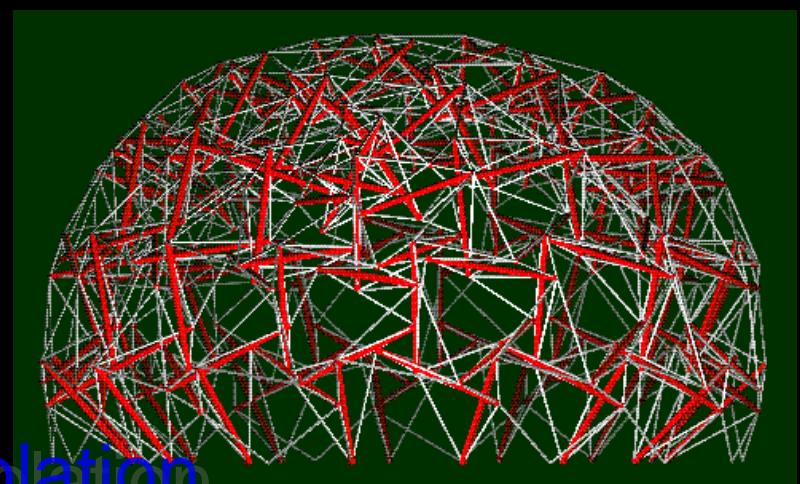


**SHIZUOKA PRESS &
BROADCASTING CENTER,**
Tôkyô, 1967, Kenzo Tange

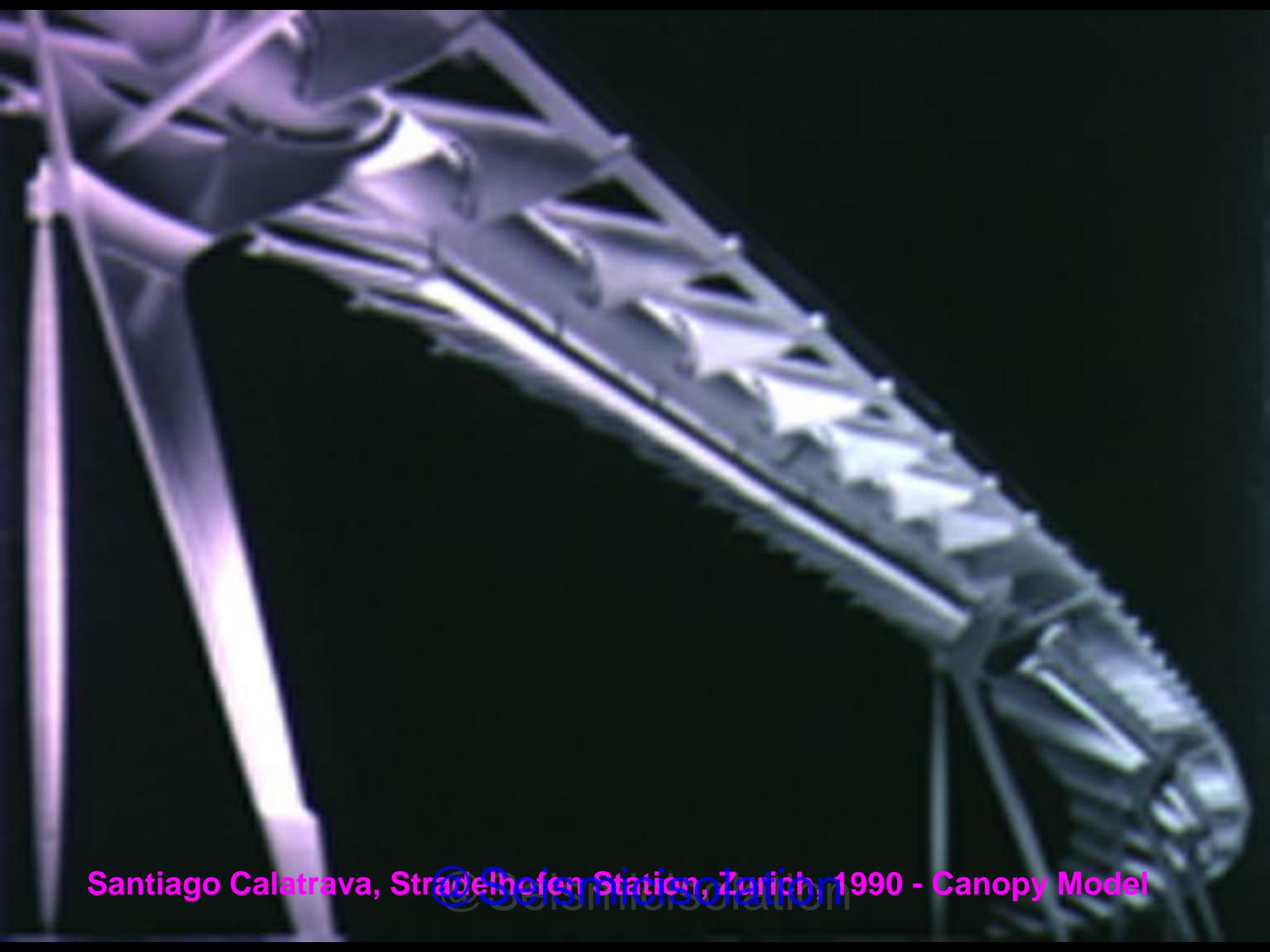
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Kenneth Snelson's **tensegrity tower**, 1968, double-layer tensegrity dome



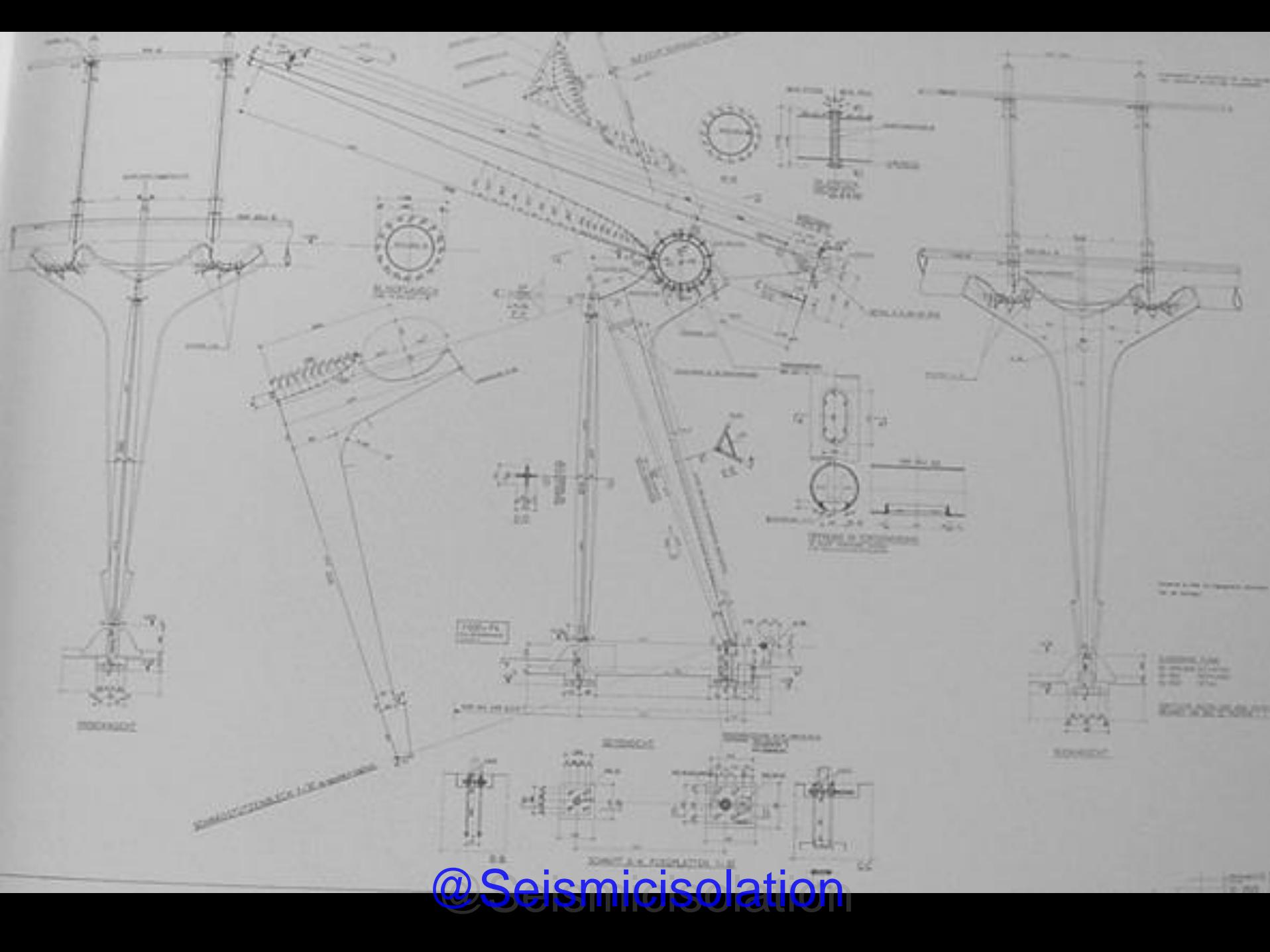
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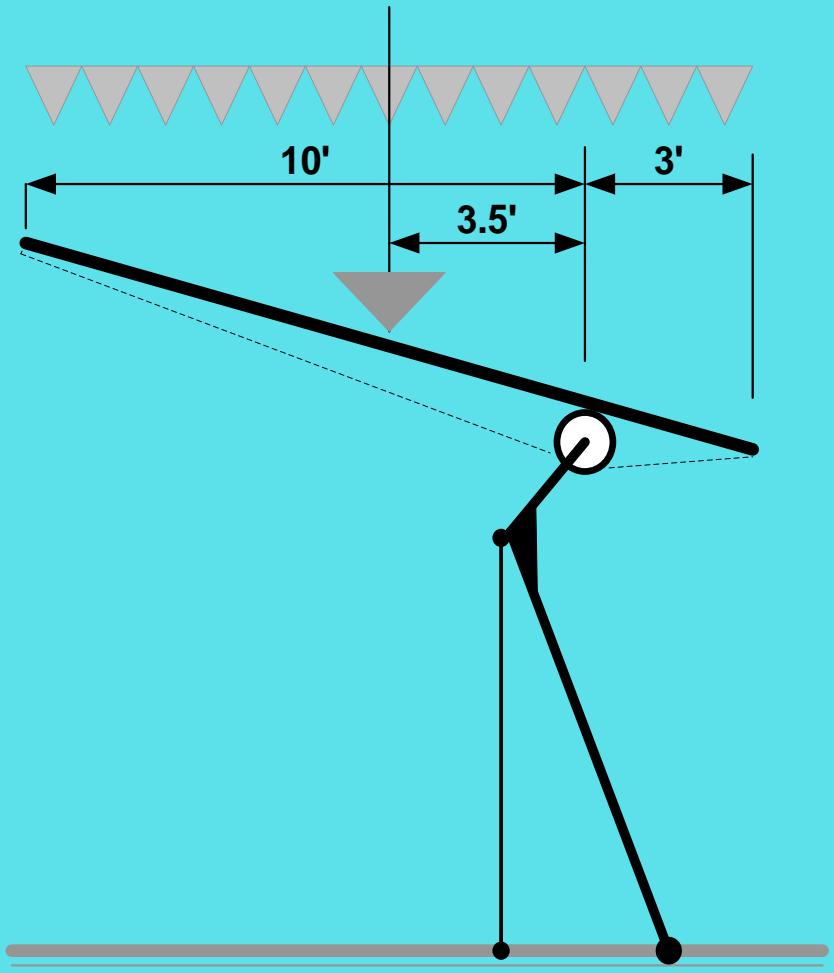
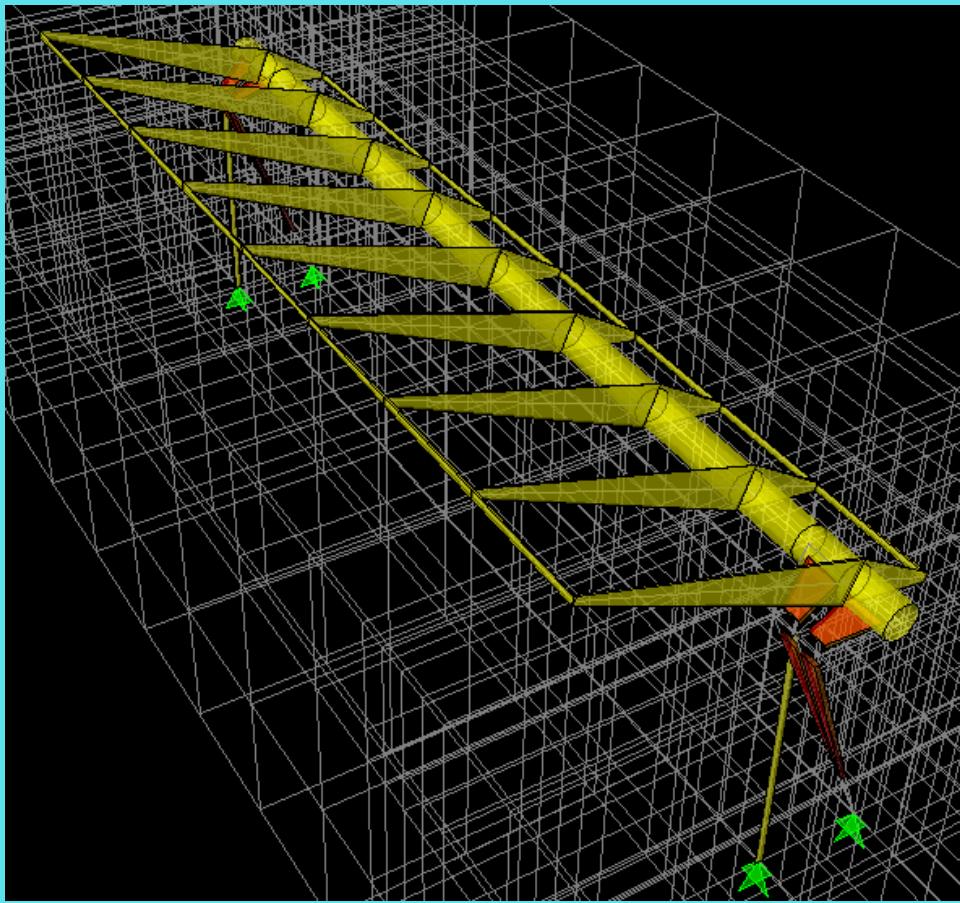
Santiago Calatrava, Stradelhofen Station, Zurich 1990 - Canopy Model
© Design is isolation



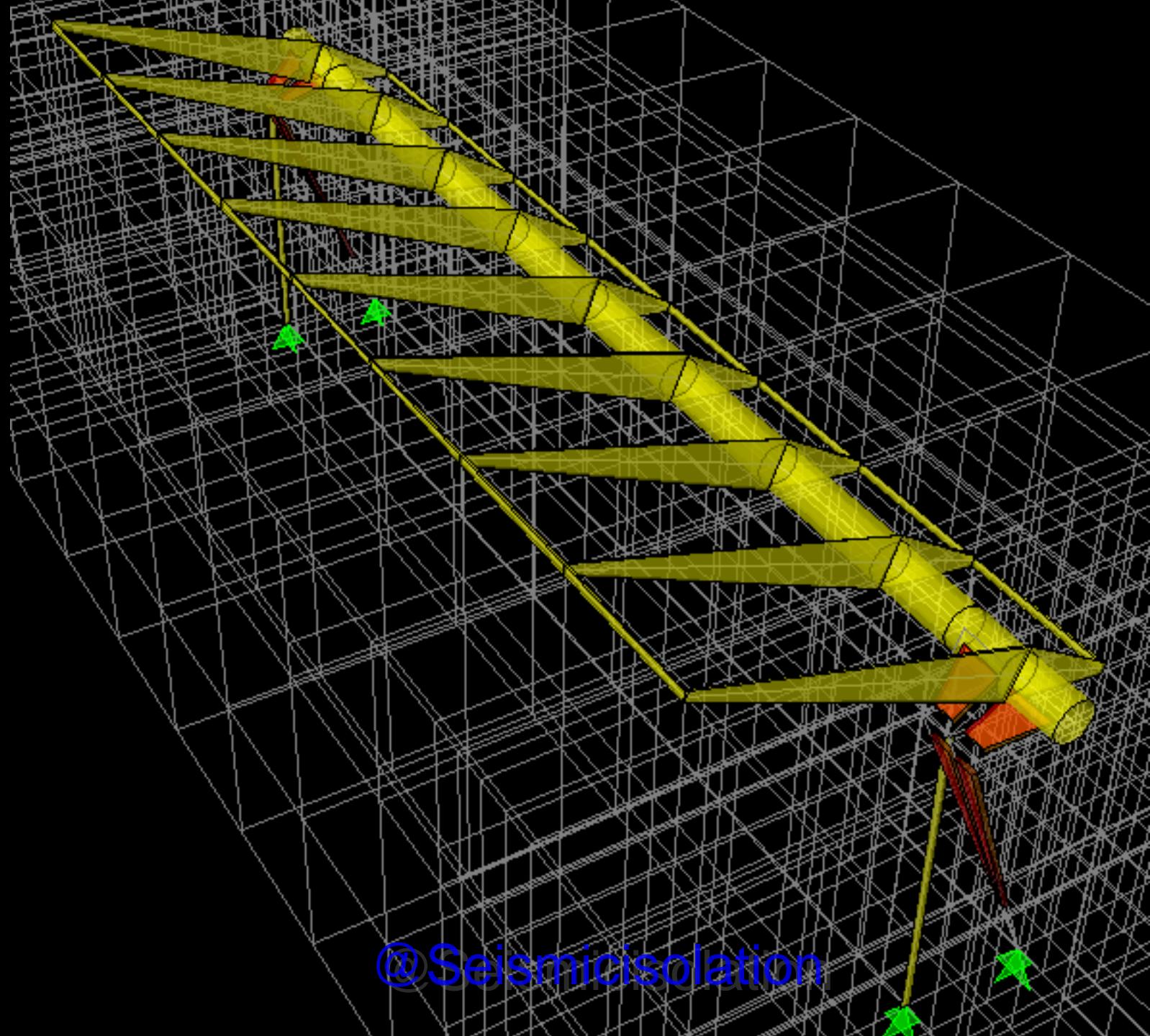
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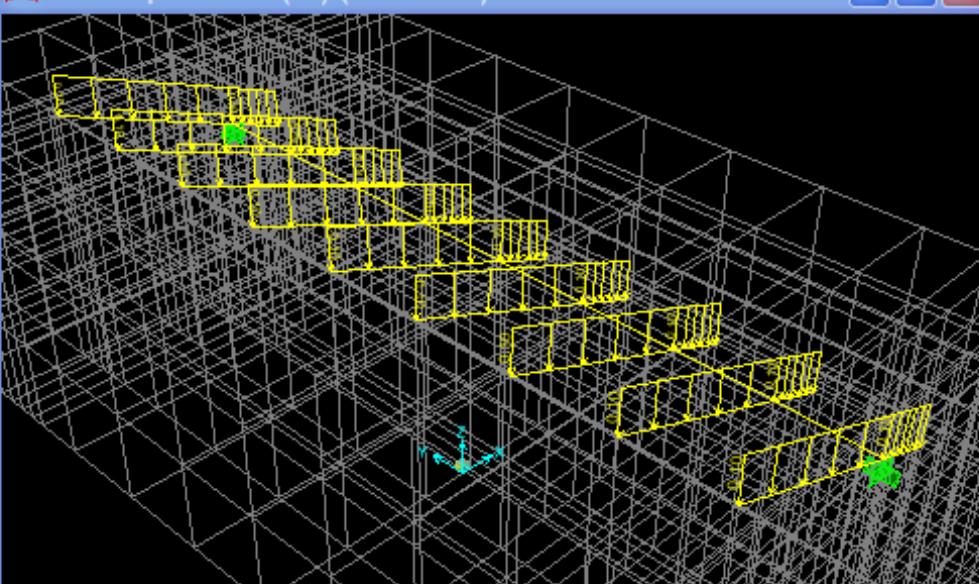


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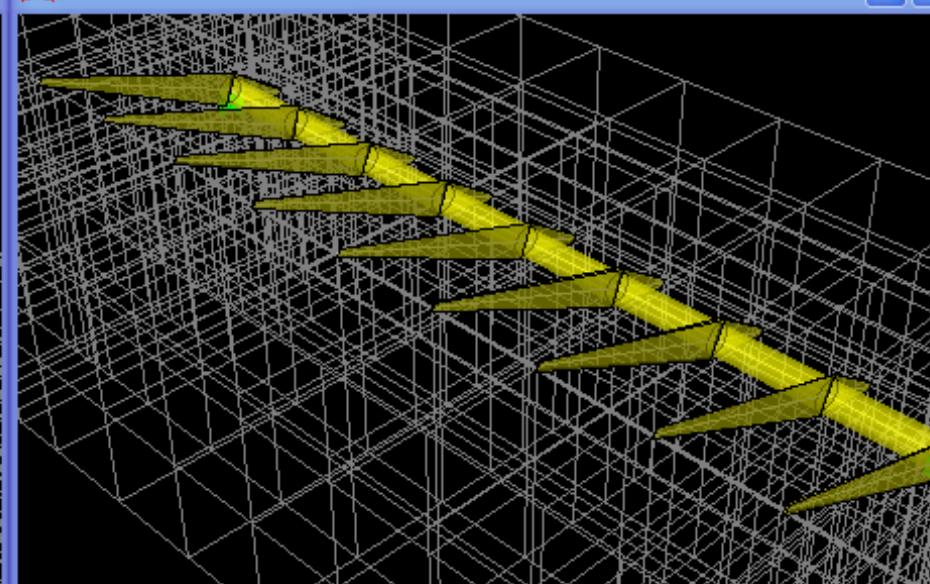
Edit View Define Draw Select Assign Analyze Display Design Options Help



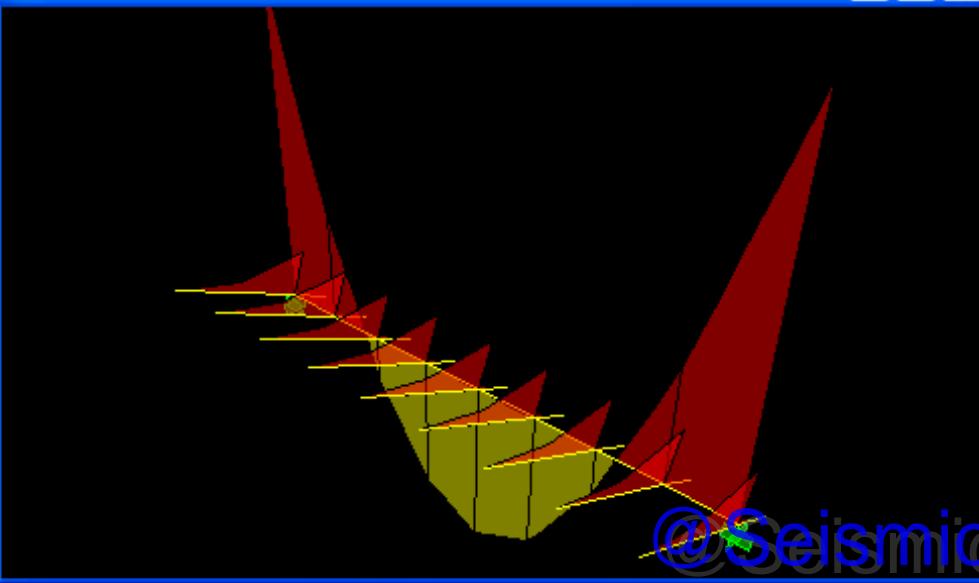
Frame Span Loads (DL) (As Defined)



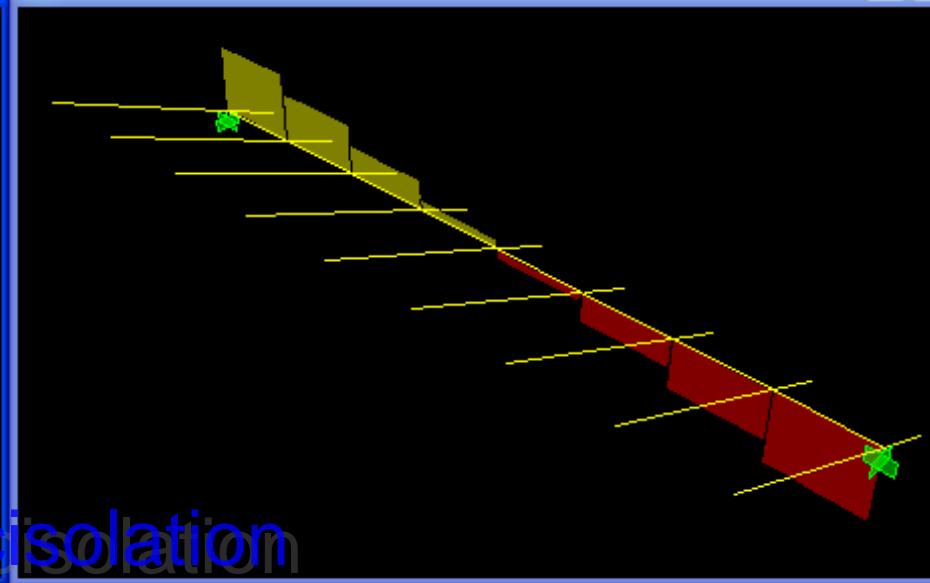
3-D View



Moment 3-3 Diagram (COMB1)



Torsion Diagram (COMB1)



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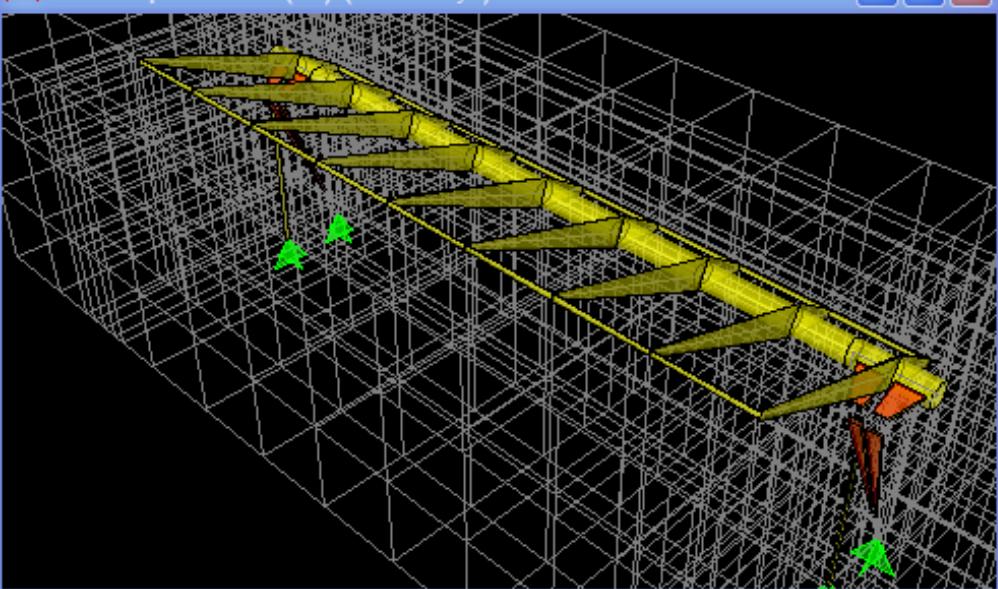
Click on any Frame Element for detailed diagram

GLOBAL Kip, ft, F

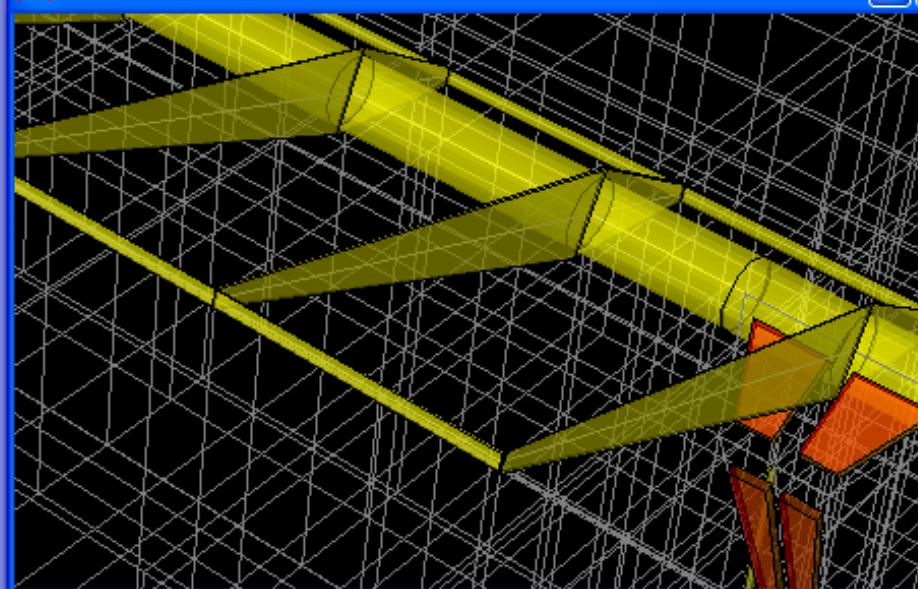
Edit View Define Draw Select Assign Analyze Display Design Options Help



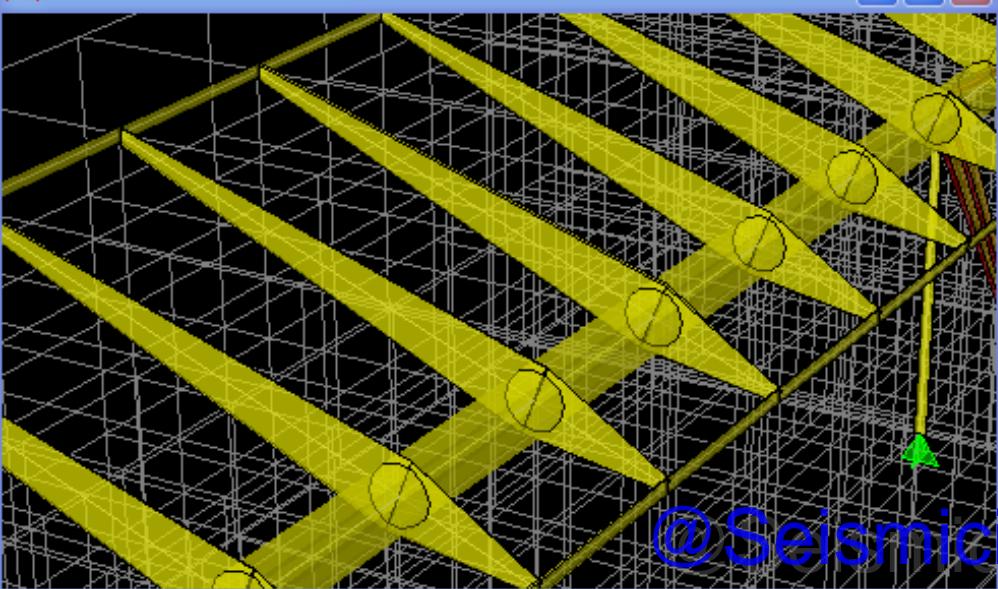
Frame Span Loads (DL) (Local CSys)



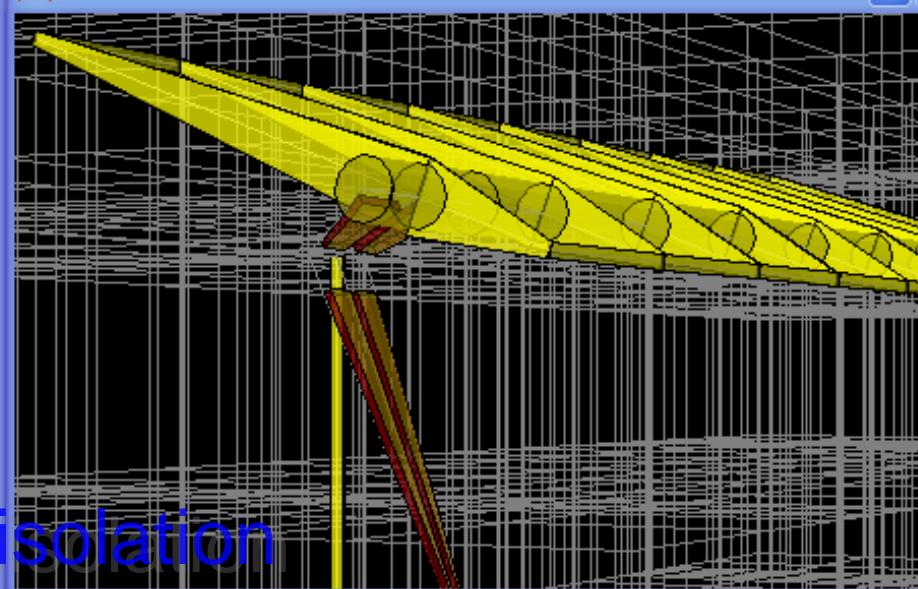
3-D View



3-D View

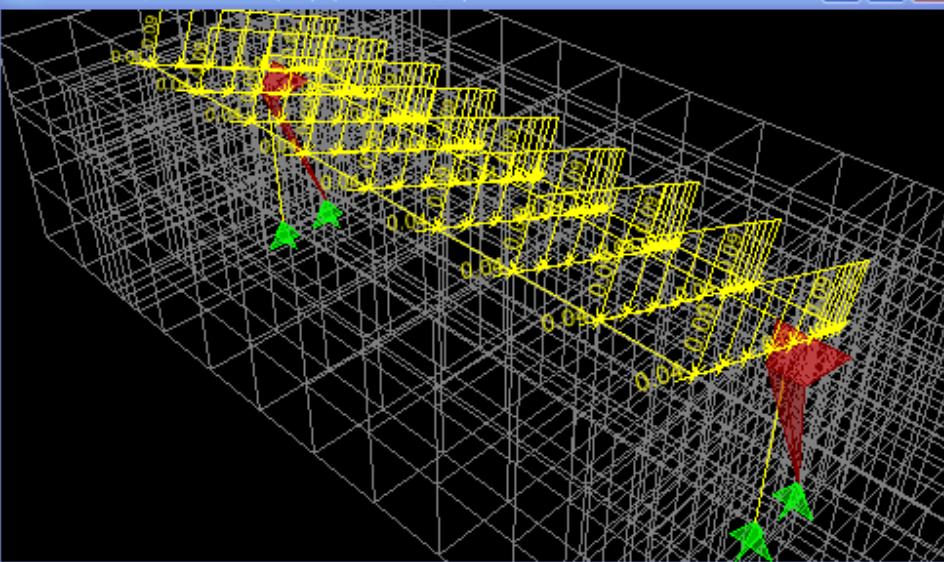


3-D View

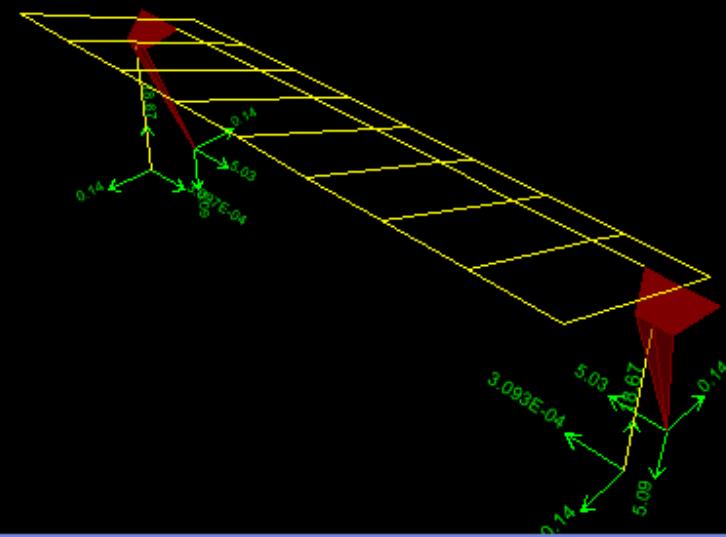


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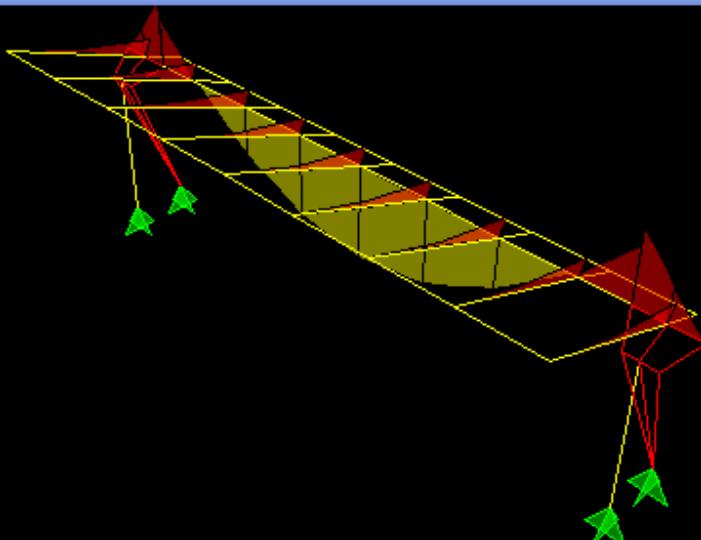
Frame Span Loads (DL) (Local CSys)



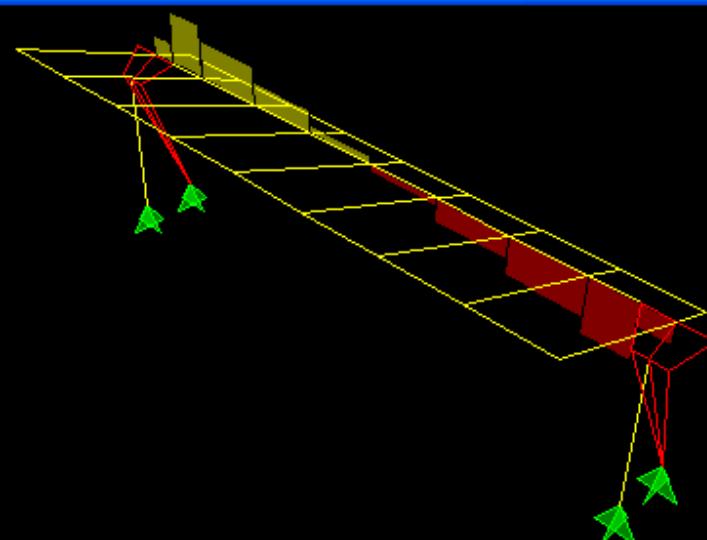
Restraint Reactions (COMB1)



Moment 3-3 Diagram (COMB1)



Torsion Diagram (COMB1)



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Earth sculpture, MUDAM, Luxembourg, 2007
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Chairs, MUDAM, Museum of Modern Art, Luxembourg, 2007, I.M. Pei



Chaise by Le Corbusier,
chairs by Marcel Breuer
(late 1920s)
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A6. STRUCTURE vs. BUILDING vs. ARCHITECTURE

Structure is necessary for buildings but not for architecture, without structure no building, but architecture as an idea does not require structure (i.e. design philosophy).

EXPRESSION of STRUCTURE:

- *hidden structure* vs. *exposed structure*
- *decorative structure* (post-modern) vs. *tectonic structure*
- *innovative structures* vs. *standard construction*

- **Cathedral of Learning**, at the University of Pittsburgh
- **Tsinghua University building**, Beijing, 2005 (2 slides)
- **Holocaust Memorial Museum**, Washington, 1993, James Ingo Freed
- **New Beijing Planetarium**, 2005, Amphibian Arc, Nanchi Wang (4 slides)
- **Jewish Museum**, Berlin, 2000, Daniel Libeskind (2 slides)
- **Rock and Roll Hall of Fame** and Museum, Cleveland, 1995, I. M. Pei (3 slides)
- The fractal space of Moshe Safdie's **Habitat 67** in Montreal, Canada
- **Administration Building**, Ningbo Institute of Technology, Zhejiang University, Ningbo, Qingyun Ma
- **Ningbo Institute of Technology Campus Library**, Zhejiang University, Ningbo, MADA spam, 2002
- **Crédit Lyonnais Tower** (120m), Christian de Portzamparc
- **Tour Lilleurope** (115m), Claude Vasconi
- Highrise apartment tower, Malmö, Sweden, 2003, Calatrava – based on a **turning torso sculpture**
- **Palau de les Arts**, Valencia Opera House, 2005, Santiago



**Cathedral of Learning,
at University of Pittsburgh, 1926,
Charles Klauder**

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Tsinghua University building,
Beijing, 2005

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Holocaust Memorial Museum, Washington, 1993, James Ingo Freed



New Beijing Planeta@Seismicisolation- Nanchi Wang

A close-up photograph of a modern building's exterior. The facade features a curved, grid-patterned cladding system made of light-colored panels. A large, light-colored cylindrical pipe runs vertically along the left side of the frame. The sky is visible in the background, showing a mix of blue and white clouds.

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Jewish Museum, Berlin, 2000,
Daniel Libeskind

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Rock and Roll Hall of Fame and Museum, Cleveland, 1995, I. M. Pei
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The fractal space of Moshe Safdie's **Habitat 67** in Montreal, Canada, 1967
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Administration Building, Ningbo Institute of Technology,
Zhejiang University, 2002, Ningbo, Qingyun Ma

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Ningbo Institute of Technology Campus Library, Zhejiang
University, Ningbo, MADA Spain, 2005

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Credit Lyonnais Tower (120 m), Lille, France, 1994, Christian de Portzamparc





Tour Lilleurope (115m, 25 stories), Lille, France, 1995, Claude Vasconi

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Apartment Tower, Malmö, Sweden, 2003, Santiago Calatrava, based in form on the sculpture turning torso



Palau de les Arts, Valencia Opera House, 2005, Santiago Calatrava

A7. STRUCTURE as *Detail*: articulation of the facade detail as material

- Museum of Science, la Villette, Paris, Fainsilber
- Atlanta mall, Elbasani & Logan
- Ningbo downtown, Qingyun Ma
- Dresdner Bank, Verwaltungszentrum, Dittrichring 5-9, Leipzig (2 slides)
- MUDAM, Luxembourg, 2006, I.M. Pei
- Marta Herford, Herford, 2006, Frank Gehry
- Architectural Institute, Rotterdam, Netherland, Joe Coenen
- The new San Francisco Federal Building, Thom Mayne (Morphosis)
- Boston Convention Center, Vinoly and LeMessurier, 2005 (2 slides)
- Pompidou Center, Paris (1977), *Piano and Rogers*
- Glass-tree structure, Berlin
- Glass structure, Beijing
- Canopies Staatsgalerie, Stuttgart, Stirling (2 slides)
- Peek & Cloppenburg, Koeln, Renzo Piano, 2005 (2 slides)

The devil (or god according to Mies) is in the detail!

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**Museum of Science and
Technology, Parc de la Villette,
Paris, 1986, Fainsilber/Rice**

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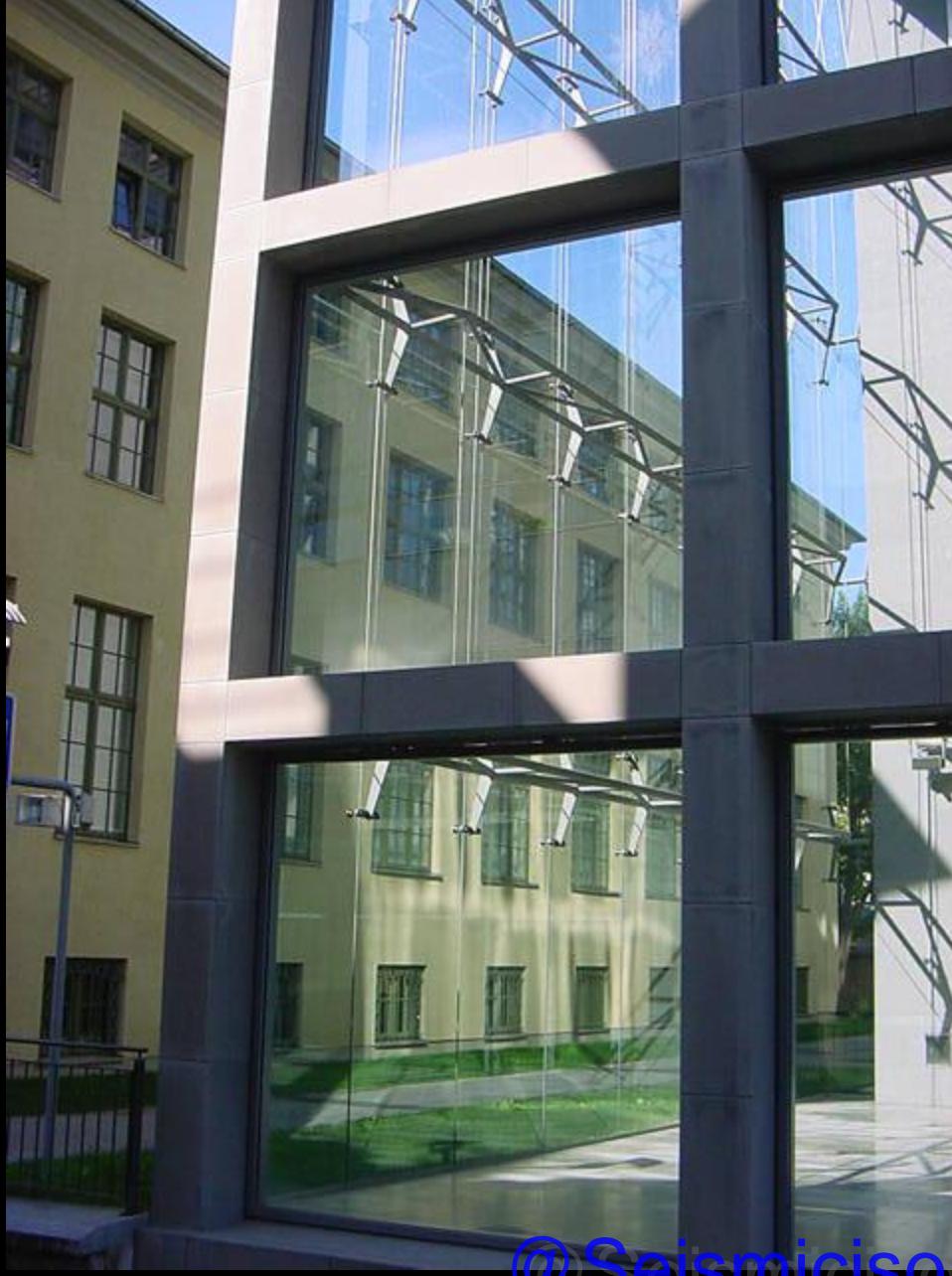
Atlanta mall, Elbasani & Logan

@Seismicisolation



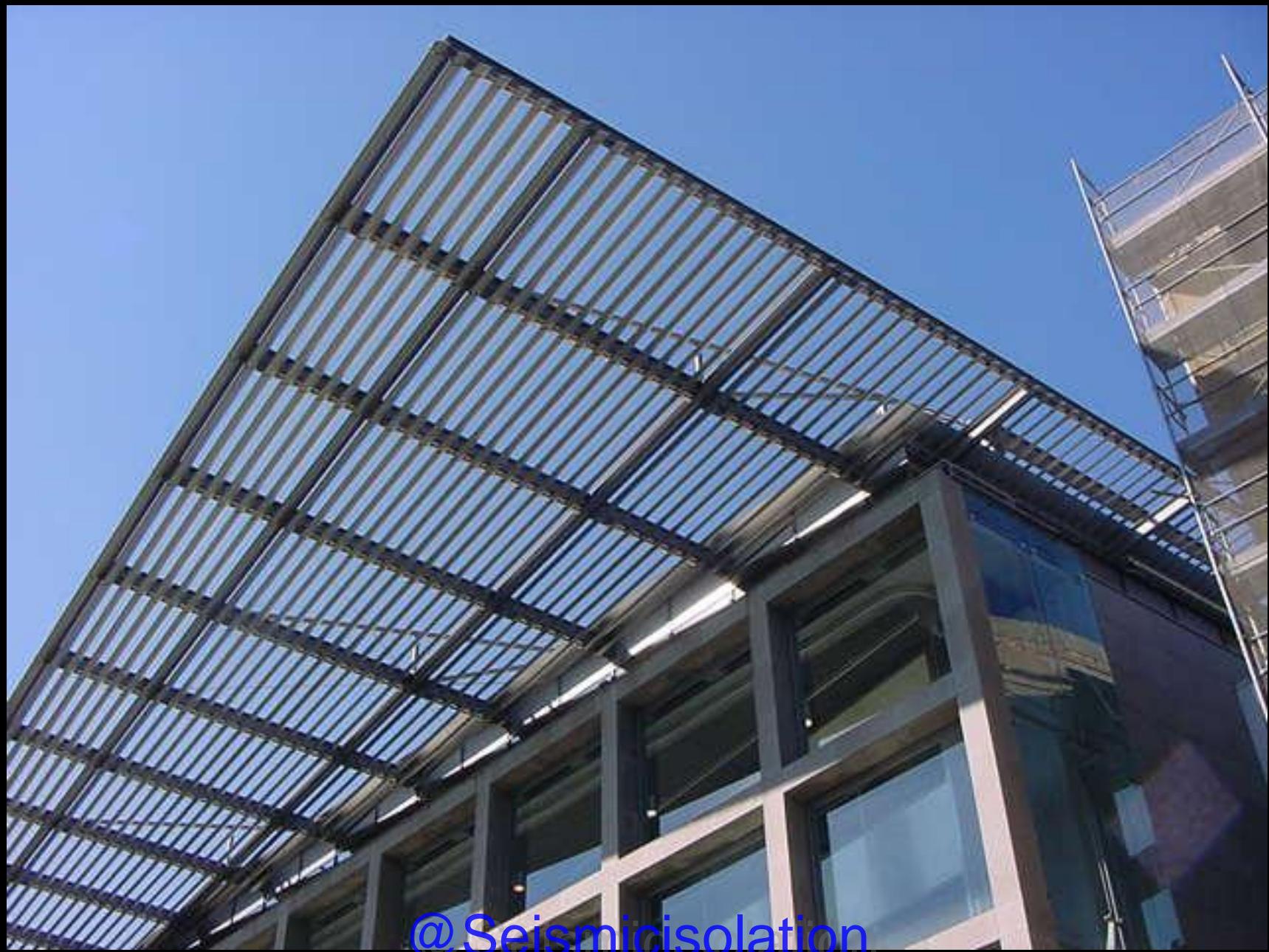
Ningbo downtown, 2002,
Qingyun Ma

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Dresdner Bank,
Verwaltungszentrum,
Leipzig, 1997, Engel und
Zimmermann Arch

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**MUDAM, Luxembourg,
2006, I.M. Pei**

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MARTa, Herford, 2005, Frank Gehry, Bollinger & Grohmann
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The Netherlands Architectural
Institute, Rotterdam, 1993, Jo
Coenen Arch

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The new San
Francisco Federal
Building, 2007, Thom
Mayne of Morphosis

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Supported on columns spaced 90' by 180' apart, the roof features exposed trusses and purlins in addition to a network of catwalks and rigging supports for use by exhibitors. The exhibit hall also features lower 35' roofs on the side of the central exhibition space that are supported by sloping steel "tree" columns resting on 7'-tall concrete pedestals. This arrangement minimizes the impact of structure on the exhibit hall floor while simultaneously providing a system that resists lateral forces on the building. A continuous ribbon of clerestory glazing just below the eaves of the roof combines with careful detailing of all exposed connections to create a roof structure that floats above the building.

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Boston Convention Center, Vinoly and LeMessurier, 2005



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Pompidou Center, Paris, 1977, Piano and Rogers



Expansion of **Printing Office** Berlin, 1997, BEHSA Partner; glass-tree structure



Glass structure, Beijing

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State Gallery, Stuttgart, Germany, 1984, James Sterling Arch, canopies

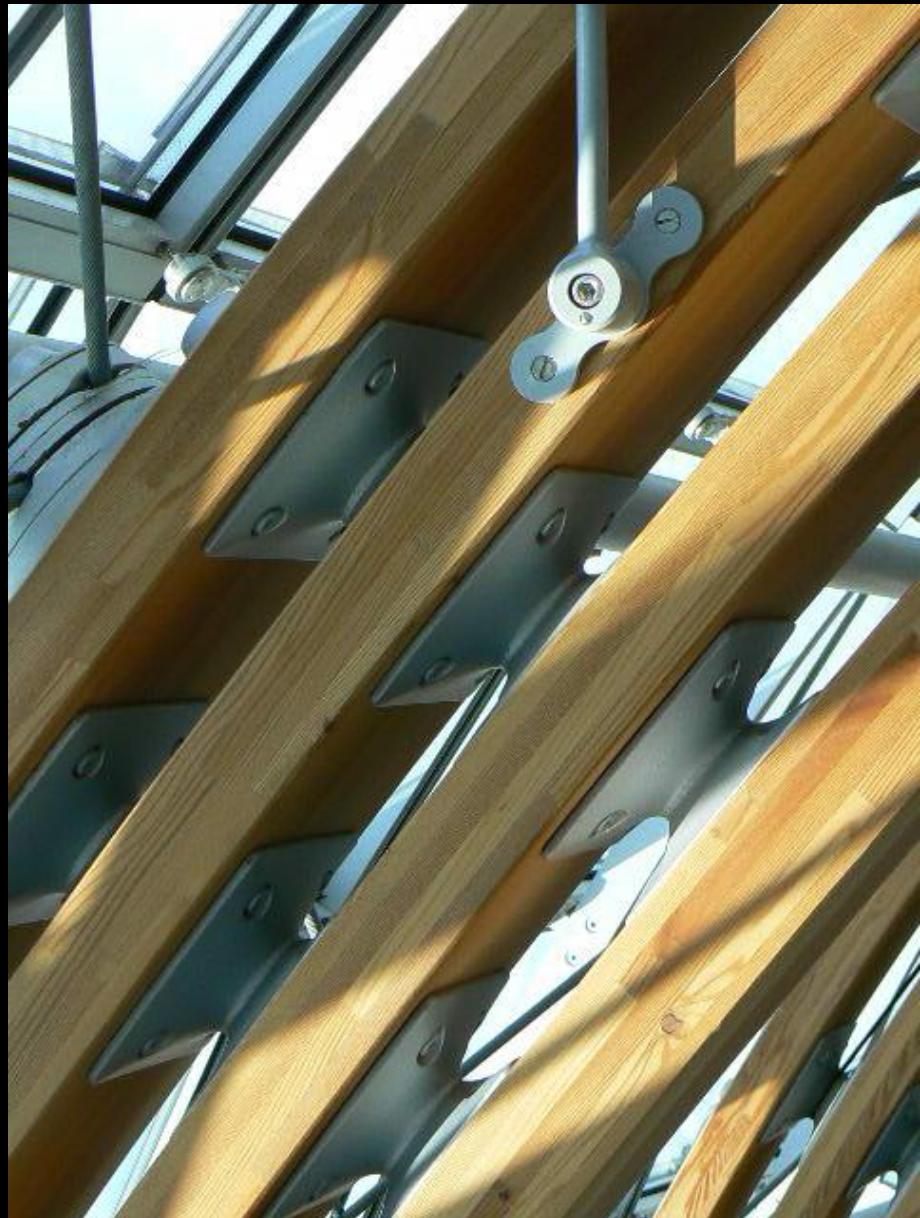


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Peek &
Cloppenburg,
Cologne, 2005,
Renzo Piano

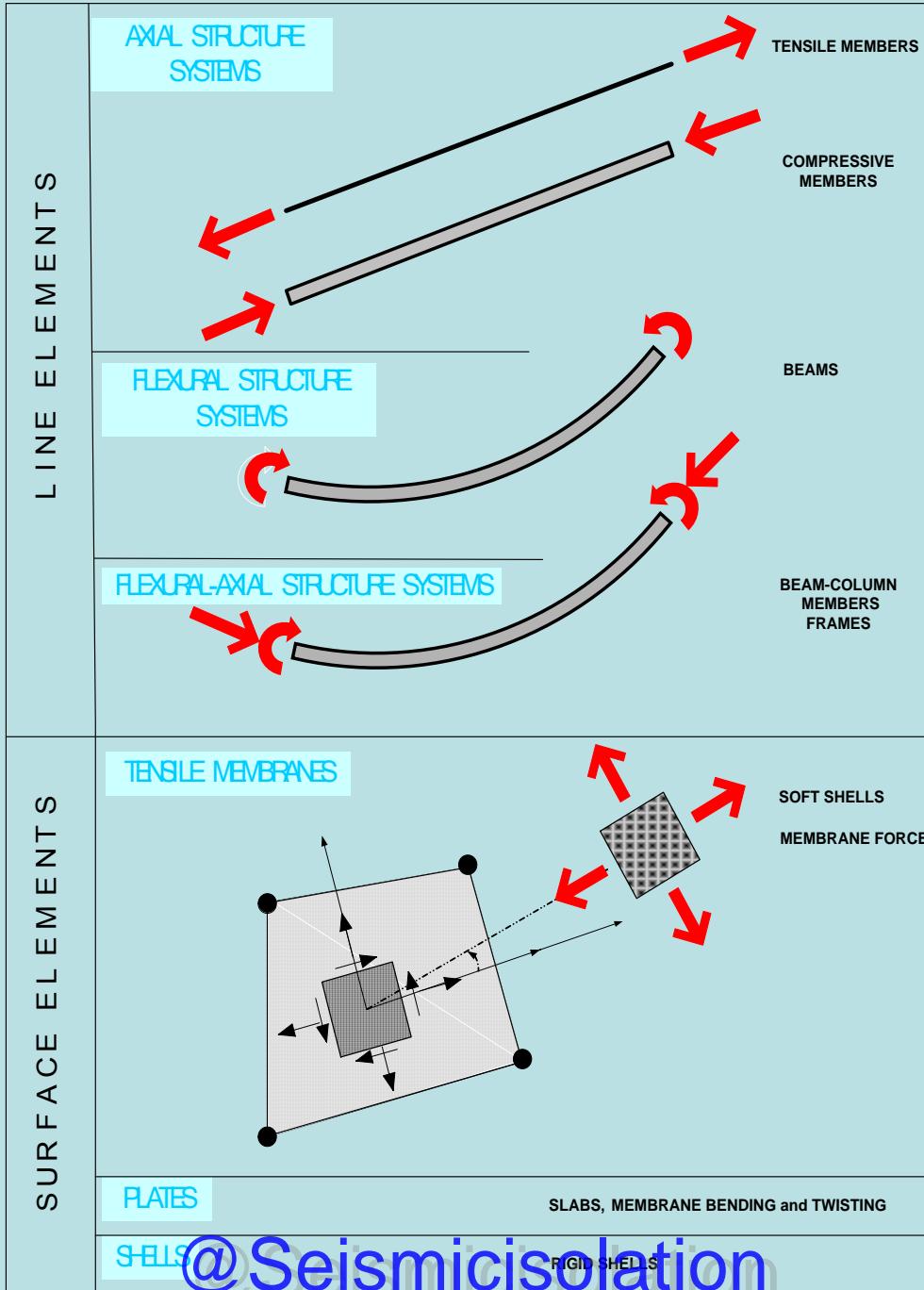
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B. BUILDING STRUCTURE ELEMENTS

- **Line elements:** beams, columns, cables, frames, arches
- **Space frames**
- **Surface elements:** walls, slabs (floors), shells, tensile membranes
- **Tensegrity,**
- **Hybrid systems**
- **Free form**



BEAMS: straight/inclined, solid/composite, arrangement/density, scale, building as beam, the vertical beam:

- **Museum Nuremberg, Germany**
- **Library University of Halle (?)**
- **Petersbogen (shopping center, university library, casino, etc.), Leipzig**
- **New National Gallery, Berlin, 1968, Mies**
- **Pedestrian bridge, Nuremberg, Germany**
- **Documentation Center Nazi Party Rally Grounds, Nuremberg, 2001, Guenther Domenig Architect**
- **Chongqing Airport Terminal, China**
- **Theater, Berlin, Renzo Piano, 1998**
- **Merzedes-Benz Zentrale, Berlin, 2000, Lamm, Weber, Donath & Partner , (2 slides)**
- **Bridge connecting two buildings, Berlin**
- **Integrated urban buildings, Potsdamer Platz, Richard Rogers, Berlin, 1998**
- **UNESCO stair, Paris, Breuer and Nervi**
- **Everson Museum, Syracuse, NY, 1968, I. M. Pei**
- **Lille Grand Palais, Rem Koolhaas**
- **Hirshorn (sculpture) museum, Washington**
- **Story beam, Berlin**
- **Everson Museum, Syracuse, NY, 1968, I. M. Pei**
- **Central Plaza, Kuala Lumpur, Malaysia, Ken Yeang**

Atrium, Germanisches Museum, Nuremberg, Germany

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Library @ Seismic isolation
University of Halle, Germany



Petersbogen shopping center, Leipzig, 2001, HPP Henrich-Petschnigg
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New National Gallery, Berlin, 1968, Mies van der Rohe



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Pedestrian bridge, Nuremberg, Germany



**Documentation Center Nazi
Party Rally Grounds,
Nuremberg, 2001, Guenther
Domenig Architect**

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Chongqing Airport Terminal, 2005, Llewelyn Davies Yeang and Arup
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Debis Theater, Berlin, 1998, Renzo Piano



Debis Theater, Berlin, 1998, Renzo Piano
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**Mercedes-Benz Center am
Salzufer, Berlin, 2000, Lamm,
Weber, Donath und Partner**

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Bridge connecting two buildings, Berlin



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Integrated urban buildings, Linkstr. Potsdamer Platz, Richard Rogers, Berlin, 1998



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UNESCO stair, Paris, 1957, Breuer and Nervi



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Everson Museum, Syracuse, NY, 1968, I. M. Pei



Grand Palais, Lille, France, 1995, Rem Koolhaas/Ove Arup

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Hirshorn Museum @Seismicisolation
Washington, 1974, Gordon Bunshaft/ SOM

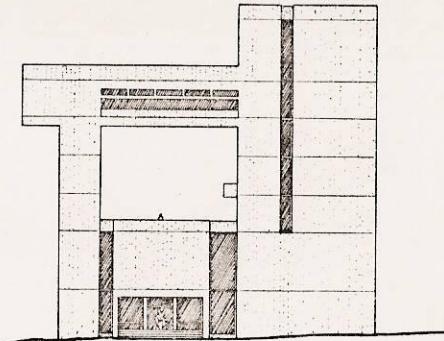
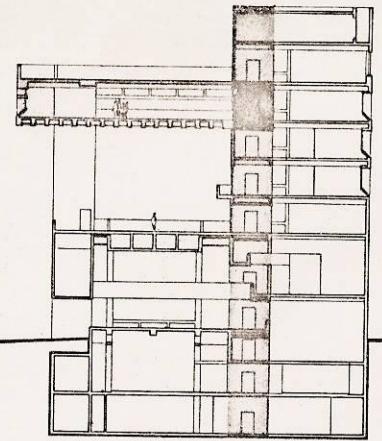


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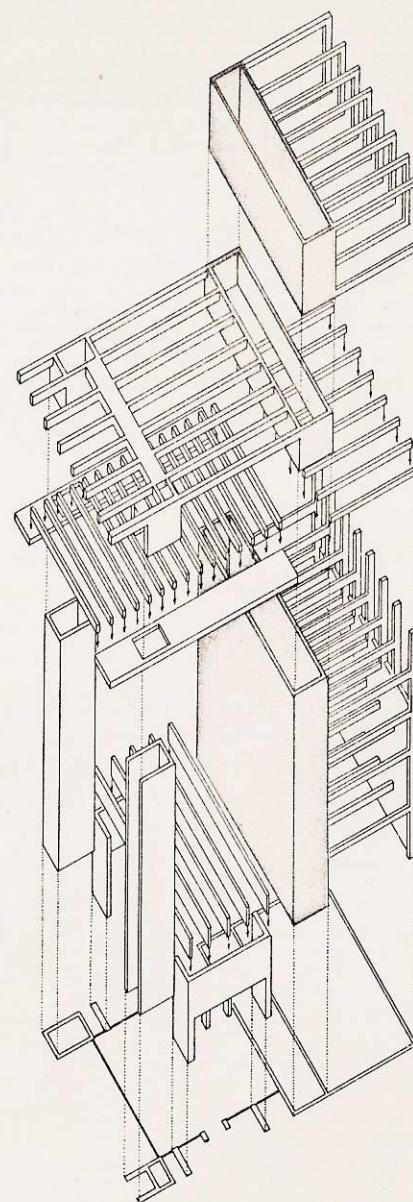


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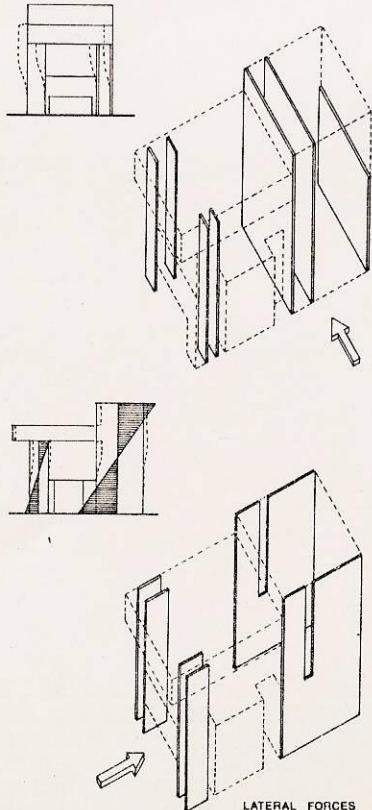
Landesvertretung von Baden-Wuertemberg, Berlin, 2000, Dietrich Bangert



SECTION + ELEVATION
0 10 20



GRAVITY FORCE FLOW



LATERAL FORCES

HERBERT F. JOHNSON MUSEUM OF ART
I.M. PEI and PARTNERS

JERRY DIVIS YOUNG APRIL 11, 1981

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Everson Museum, Syracuse, NY, 1968, I. M. Pei



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Central Plaza, Kuala Lumpur,
Malaysia, 1996, Ken Yeang
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COLUMNS: power of column as: space maker, sign in landscape, facade columns, space articulation, scale, etc.

- **Acropolis**, Athens, 650 - 480 B.C.
- **Bourges cathedral**, Bourges, France
- **St. Lorenz**, Nuremberg, Germany
- **Theater Erfurt**, 2003, Joerg Friedrich Arch
- **Pop Museum**, Rotterdam, The Netherlands, 1992, Rem Koolhaas Arch
- **Sichuan University**, Chengdu, College for Basic Studies, 2002 (2 slides)
- **Government building**, Berlin, Germany, Schultes
- **Shopping center**, Berlin, Boehm
- **Study of façade columns**, visual analysis
- **Luxemborg Philharmonie**, Luxembourg City, 2006, Atelier Christian De Portzamparc (2 slides)
- **LA Control Tower**, Los Angeles, USA, Katherine Diamond
- Samsung Life Insurance Jong-Re Building, Seoul, 1999, Rafael Vinoly



Acropolis, Athens, 650 - 480 B.C

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Bourges cathedral, 13th cent, Bourges, France



**St. Lorenz, 15th. cent,
Nuremberg, Germany**

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Museum of Modern Literature, Marbach, Germany, 2006, David Chipperfield Architects



Pinakothek der Moderne, Munich , 2002,
Stephan Braunfels

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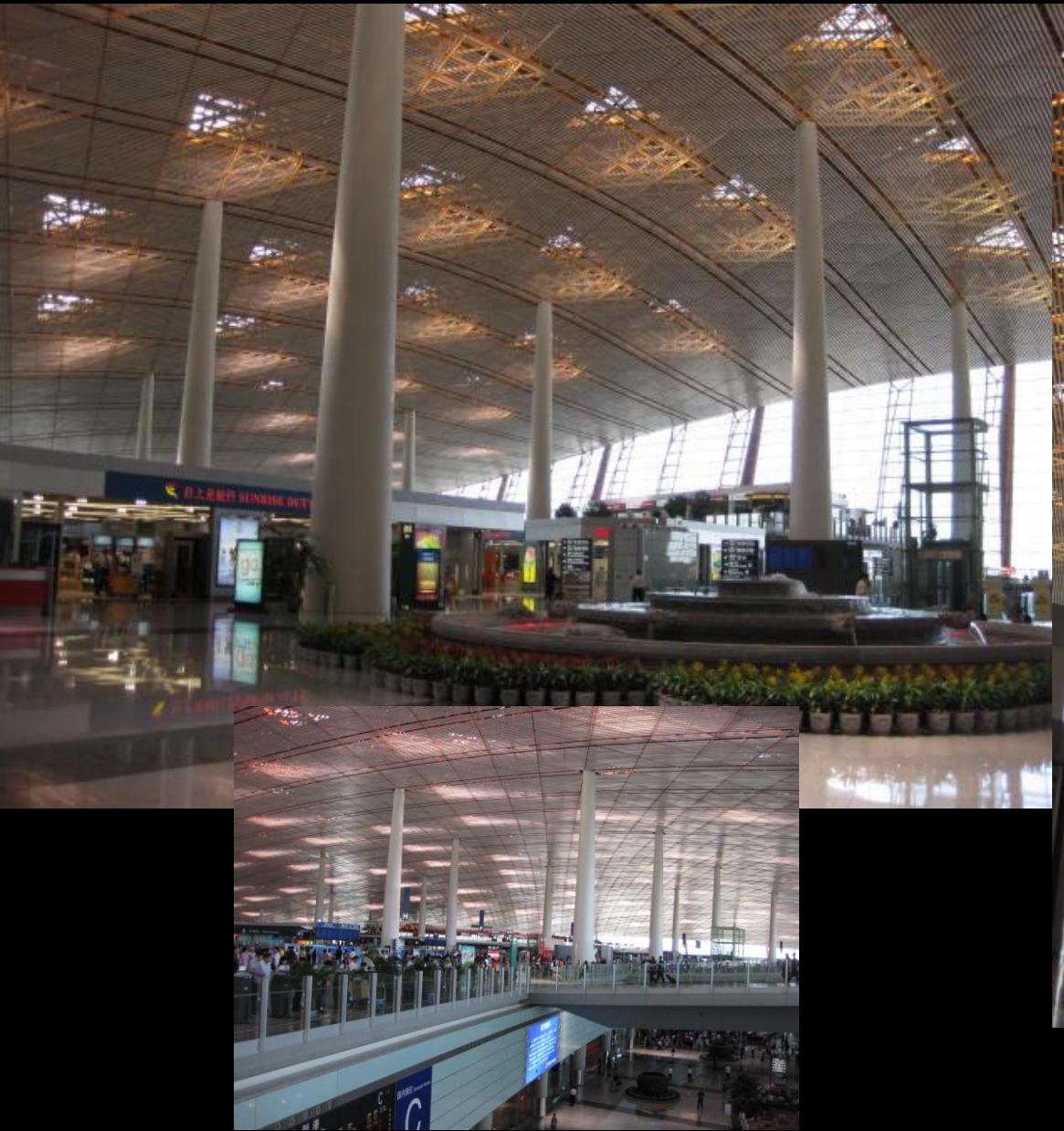


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Theater Erfurt, 2003, Joerg Friedrich Arch, foyer



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Kunst Hal, Rotterdam, The Netherlands, 1992, Rem Koolhaas Arch



Beijing Capital International Airport, Terminal 3, 2008, Foster and Partners, Arup
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**College for Basic Studies,
Sichuan University, 2000,
Chengdu**

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**Government building, Berlin,
Germany, 2001, Axel Schultes**

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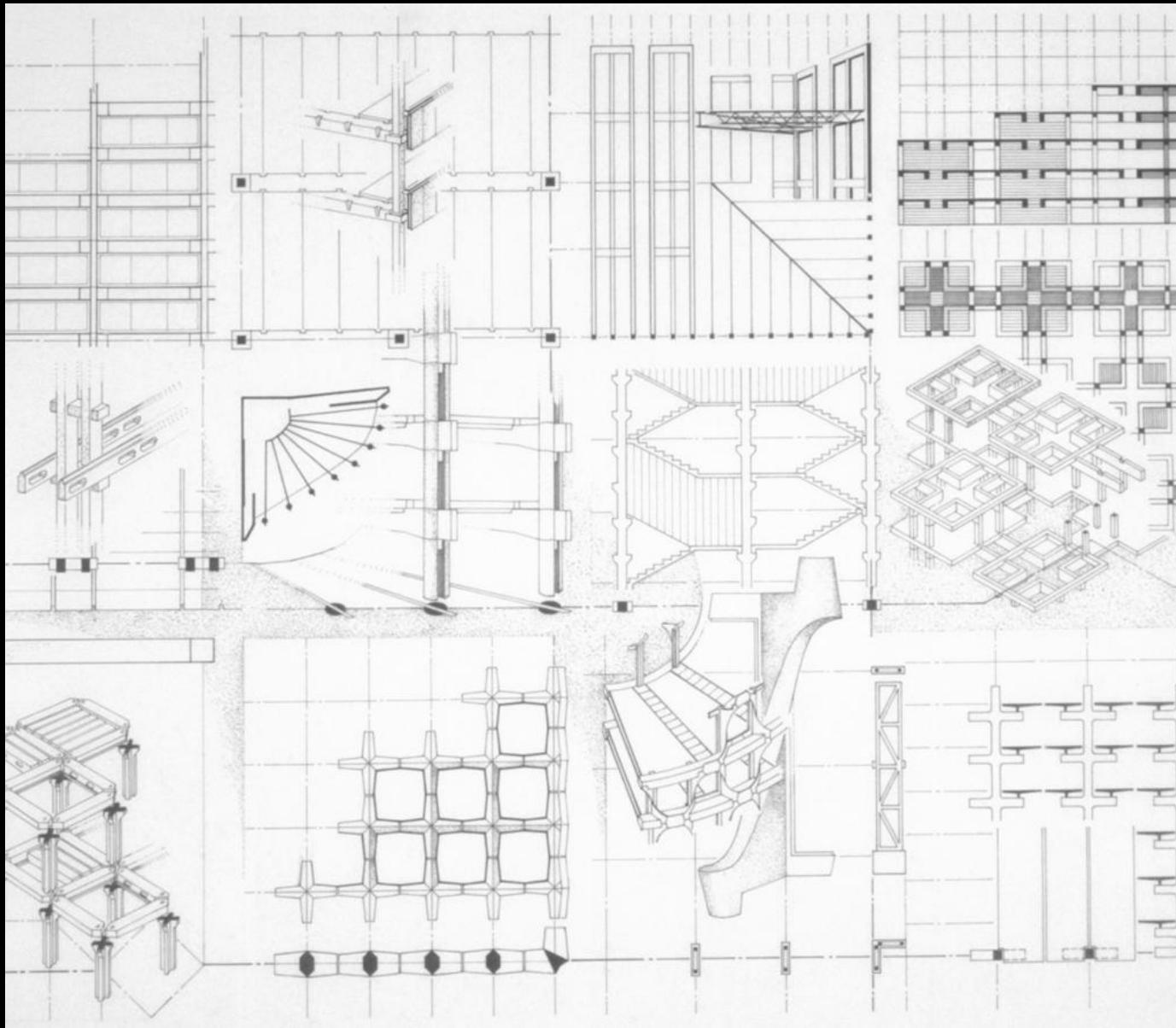
Treptow Crematorium, Berlin, 1997, Axel Schultes
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Peek & Cloppenburg Department Store, Berlin, 1995, Gottfried Böhm
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Luxemborg Philharmonie, Luxembourg City, Luxembourg, 2006, Atelier Christian De Portzamparc



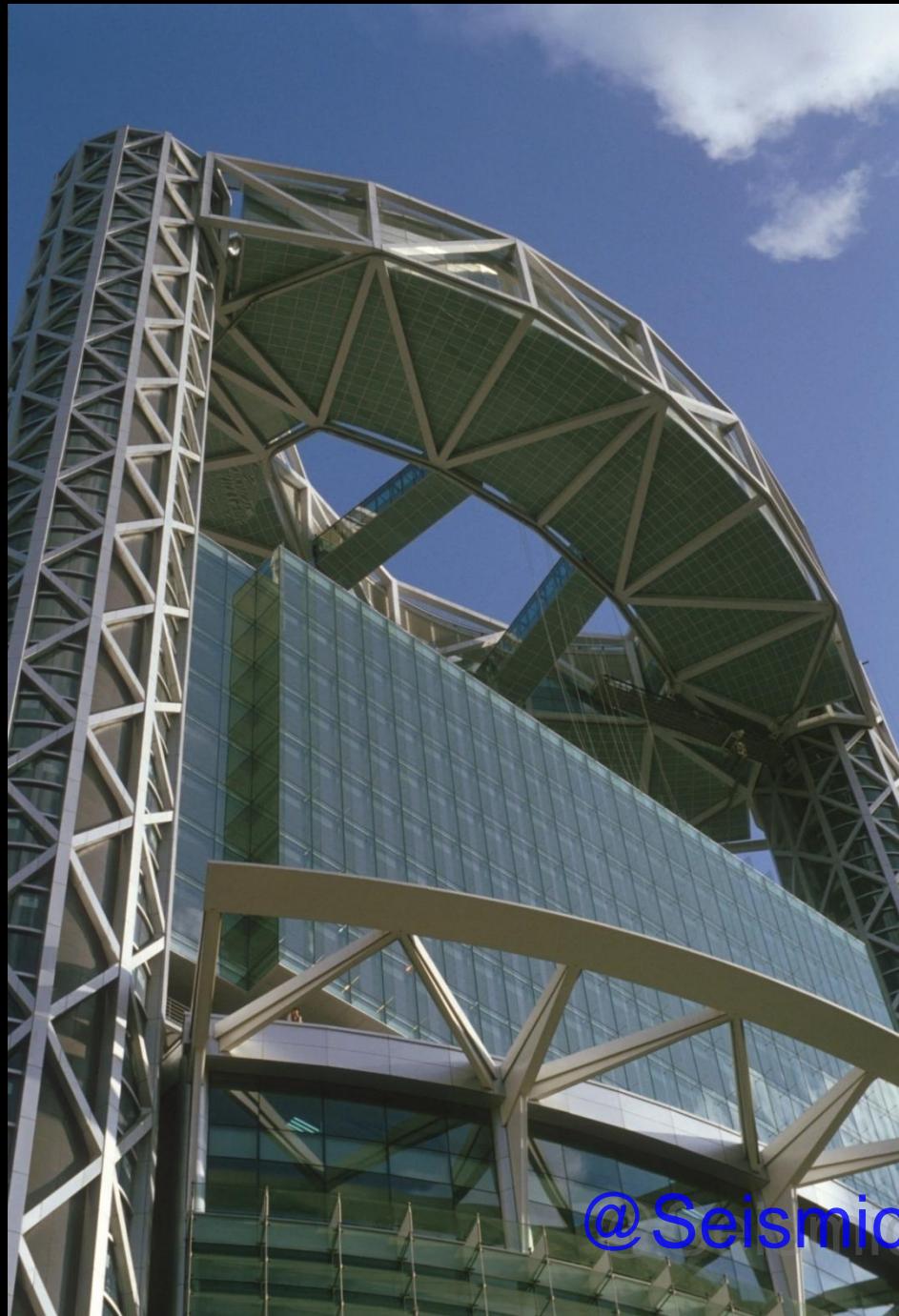
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LAX Control Tower, Los Angeles,
1996, Katherine Diamond





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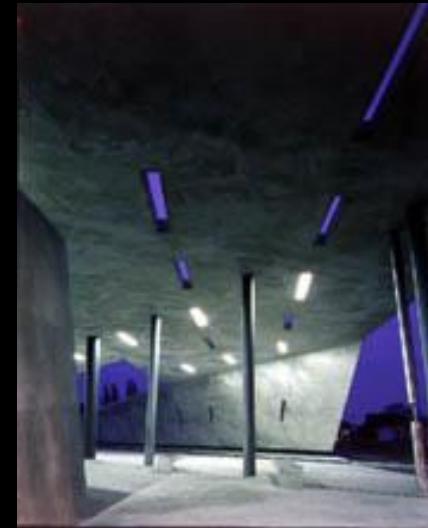
Samsung Life Insurance Jong-Re
solution Seoul, 1999, Rafael Vinoly

INCLINED COLUMNS (*beam-columns*):

lateral thrust: visual analysis, tree columns, cantilever columns, etc.

bone-shaped columns, human thighbone

- **Interchange Terminal Hoenheim-Nord, Strassbourg, 2002, Zaha Hadid**
- Erasmusbridge, Rotterdam, 1996, Ben Van Berkel
- **Mensa Dining Hall, Karlsruhe, 2007, Jürgen Mayer H**
- **Hannover EXPO 2000, Thomas Herzog und Julius Natterer**
- **Subway station Munich 2, Germany**
- **Stansted Airport, London, Norman Foster**
- **Chongqing Airport Terminal, China**
- **World Trade Center, Amsterdam, 2003, Kohn, Pedersen & Fox (2 slides)**
- **Petersbogen (shopping center, university library, casino, etc.), Leipzig**
- **Satolas Airport TGV Train Station, Lyons, France, 1995, Santiago Calatrava**
- **Airport Madrid, Spain, Richard Rogers, 2005 (2 slides)**
- **City Center, Bremen, 1964, Germany, R. Rainer and U. Finsterwalder**



Interchange Terminal Hoenheim-Nord, Strasbourg, 2002, Zaha Hadid
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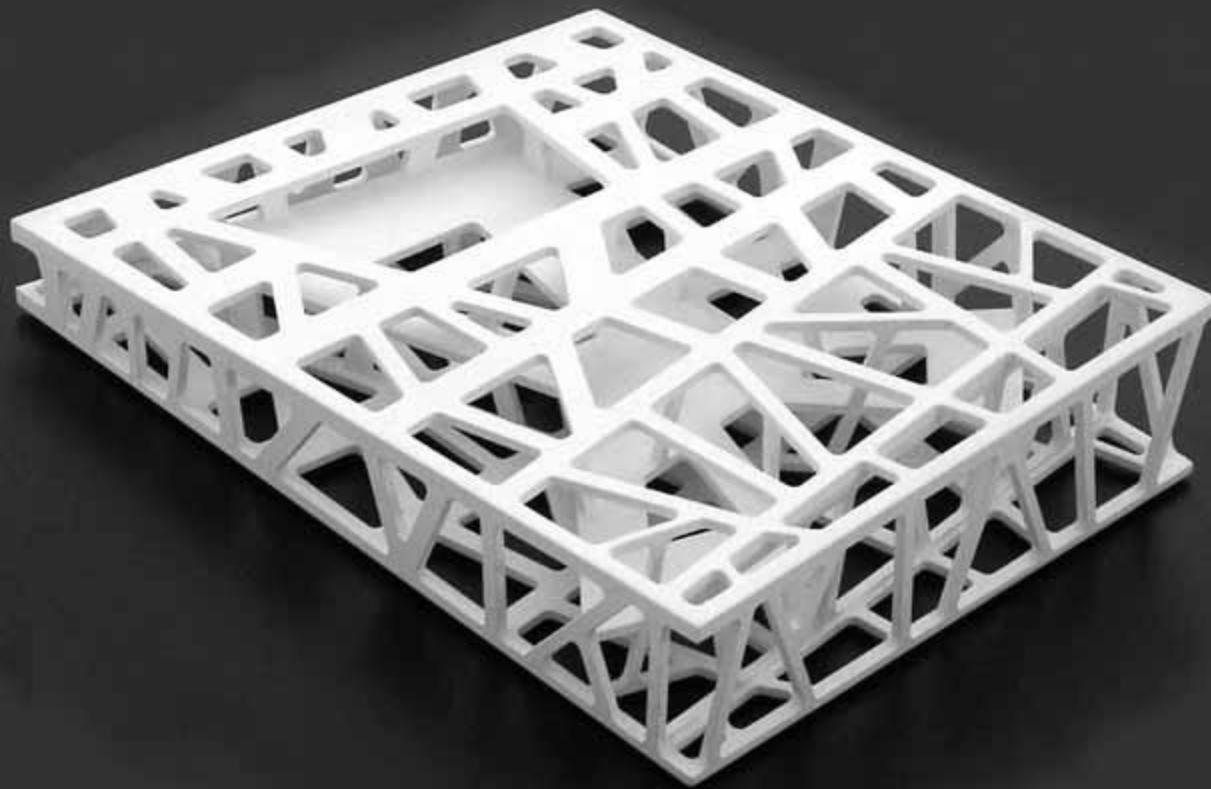
Erasmusbridge, Rotterdam, 1996, Ben Van Berkel
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Dining Hall Karlsruhe, Hochschule Karlsruhe, 2007, Jürgen Mayer H, ARUP
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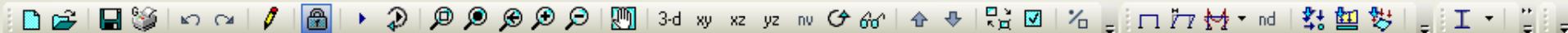


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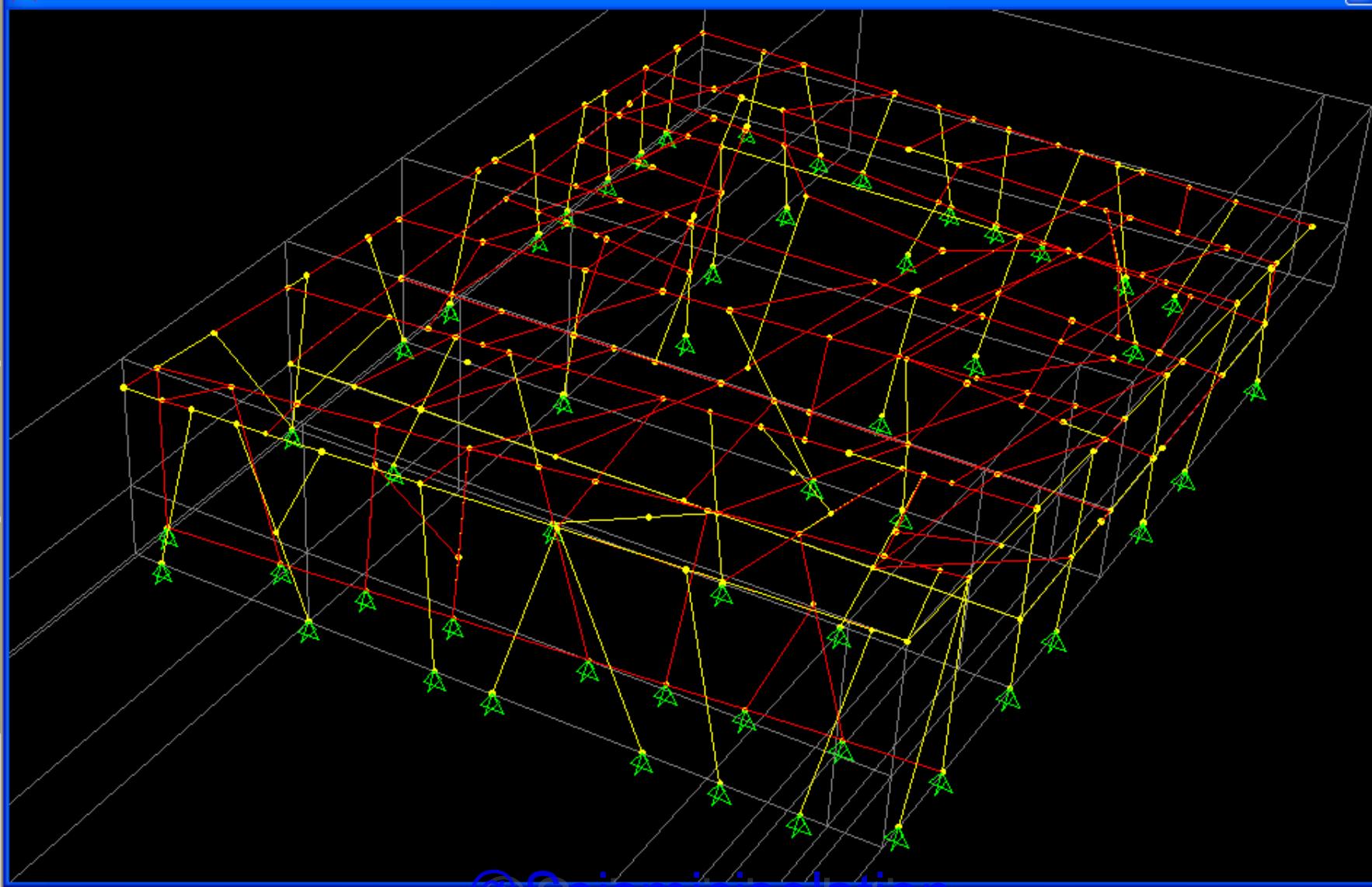


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3-D View



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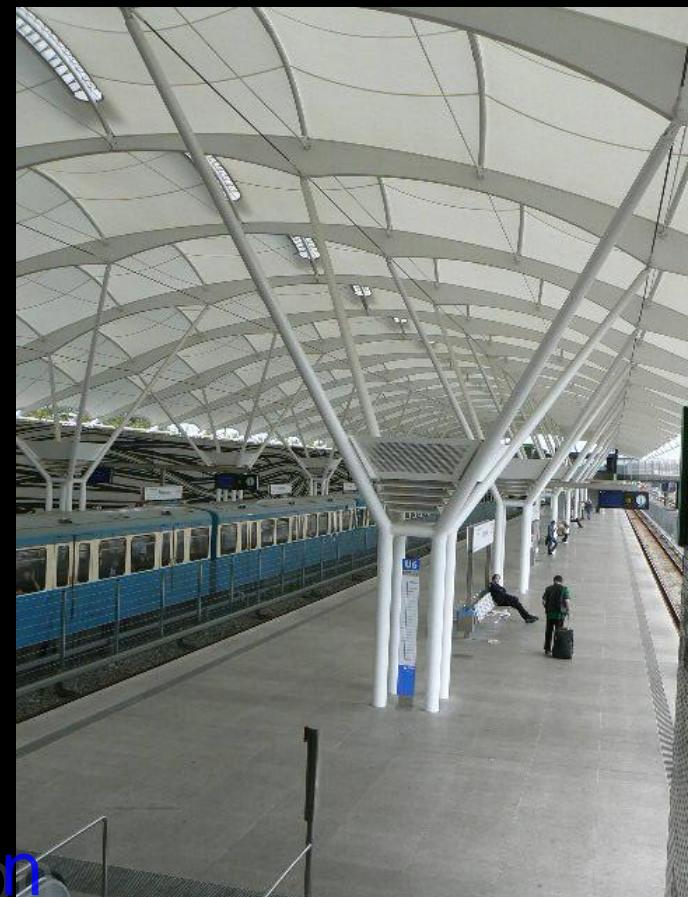
EN

3:59 AM



Hannover EXPO 2000, Thomas Herzog und Julius Natterer

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Subway Station to Allians Stadium, Froettmanning,
Munich, Munich, 2004, Peter Bohn Arch.

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Stanted Airport, London, UK, 1991, Norman Foster/ Arup
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Chongqing Airport Terminal, 2005,
Llewelyn Davies Yeang and Arup
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World Trade Center @ Seismicisolation
Amsterdam, 2003, Kohn, Pedersen & Fox



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Petersbogen shopping @Seismicisolation center, Leipzig, 2001, HPP Henrich-Petschnigg



Satolas Airport TGV Train Station, Lyon, France, 1995, Santiago Calatrava

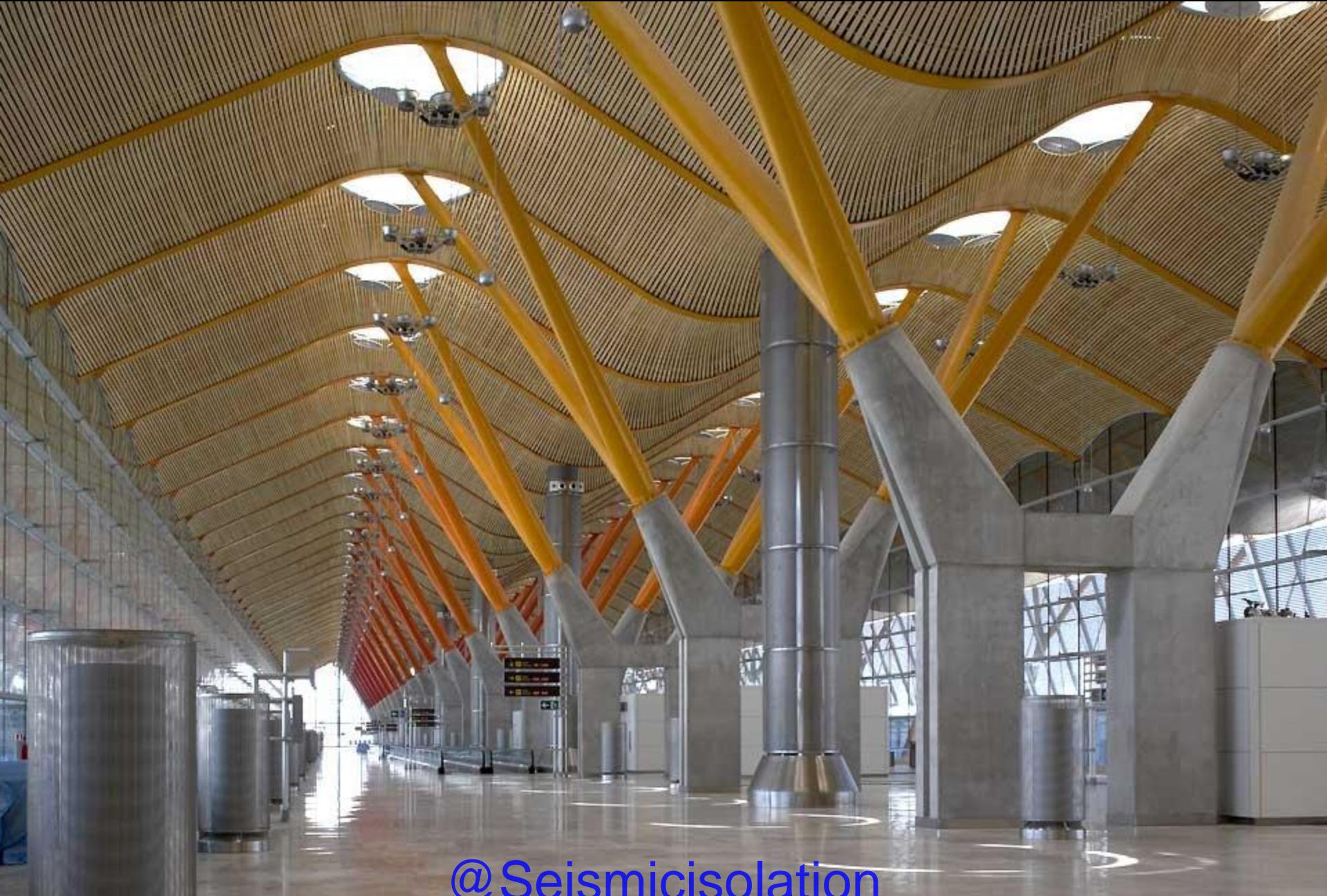


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Airport Madrid,
Spain, Richard
Rogers, 2005

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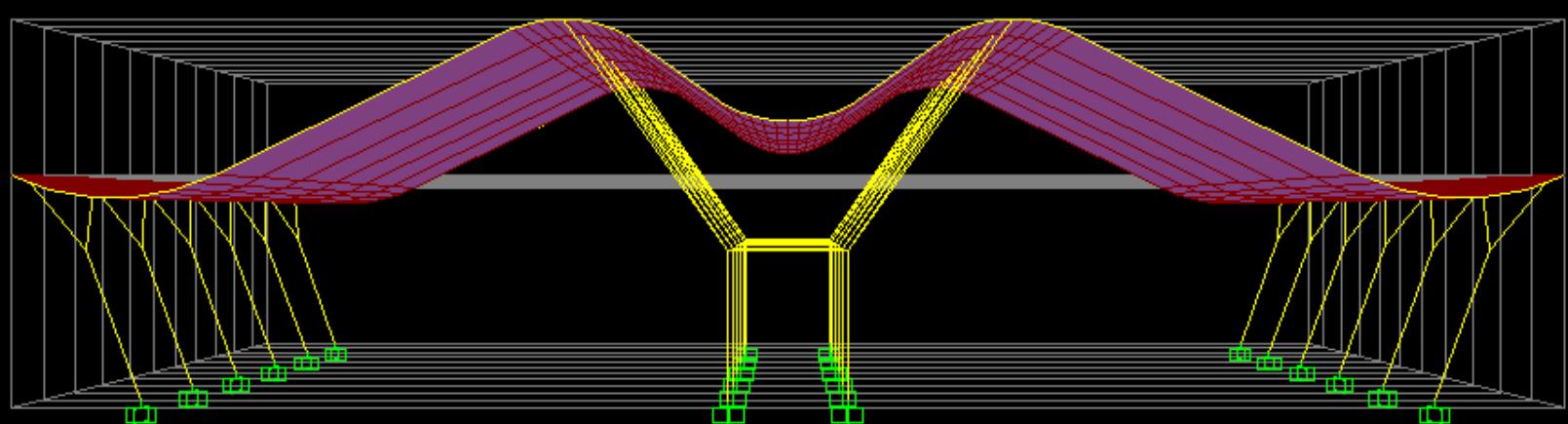
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File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Tools Help



3-D View

X



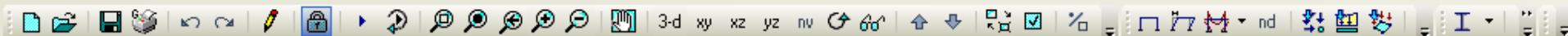
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X0.00 Y0.00 Z0.00

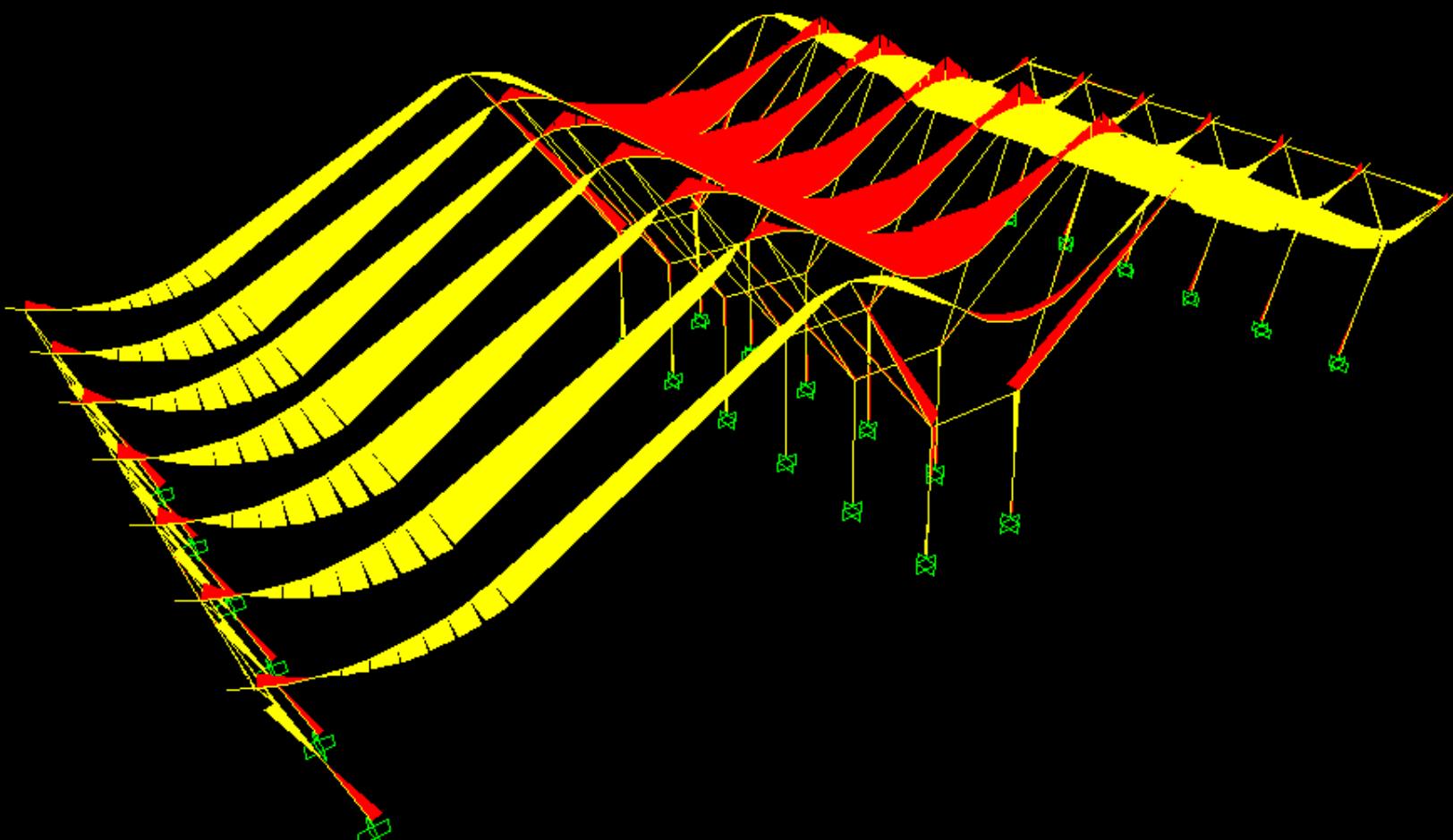
GLOBAL

KN, m, C

File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Tools Help



Moment 3-3 Diagram (D+L)



Right Click on any Frame Element for detailed diagram

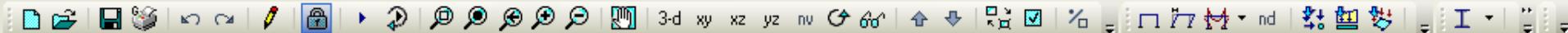
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GLOBAL KN, m, C

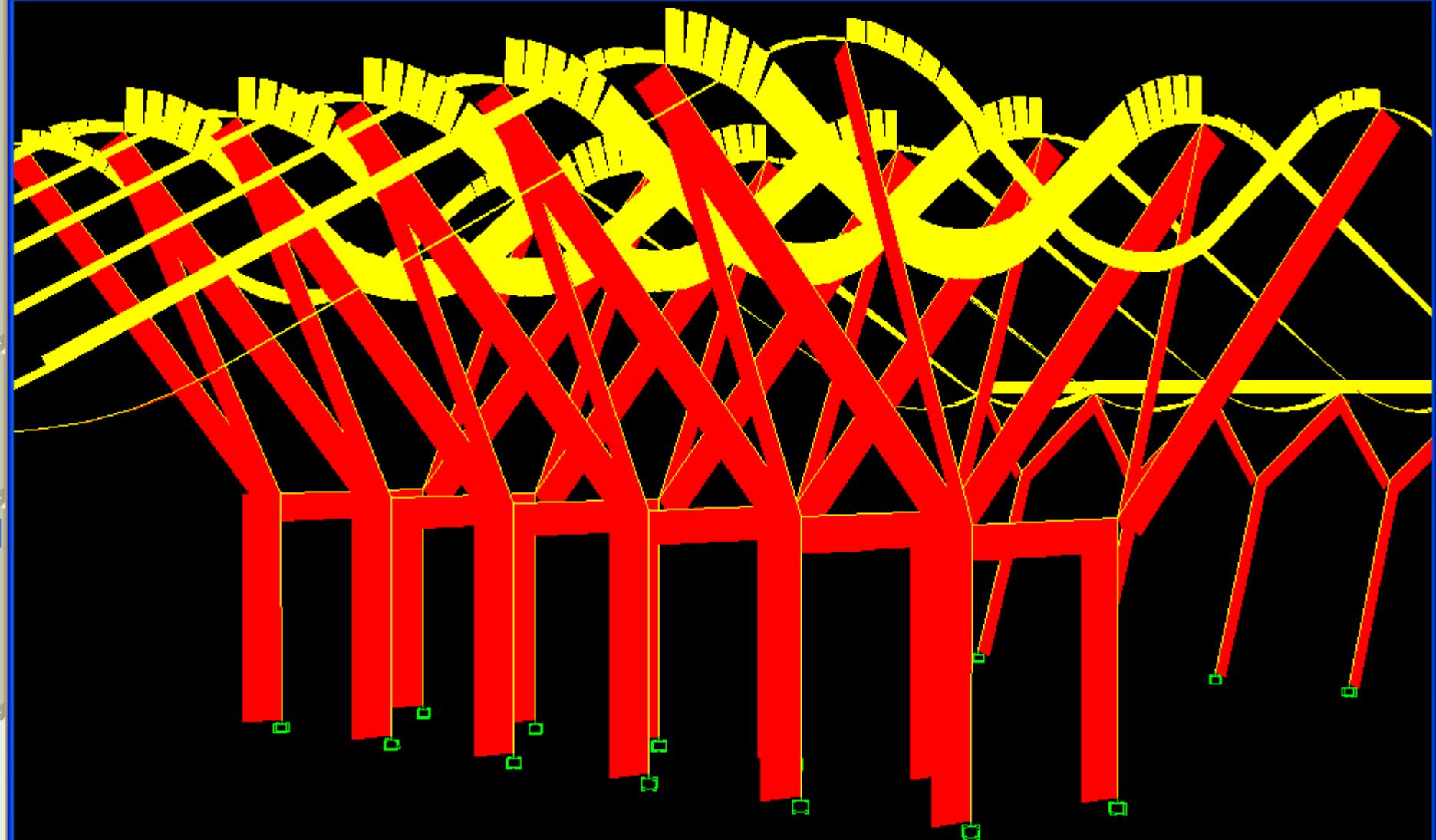


10:23 PM

File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Tools Help



Axial Force Diagram (D+L)



Right Click on any Frame Element for detailed diagram

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GLOBAL KN, m, C

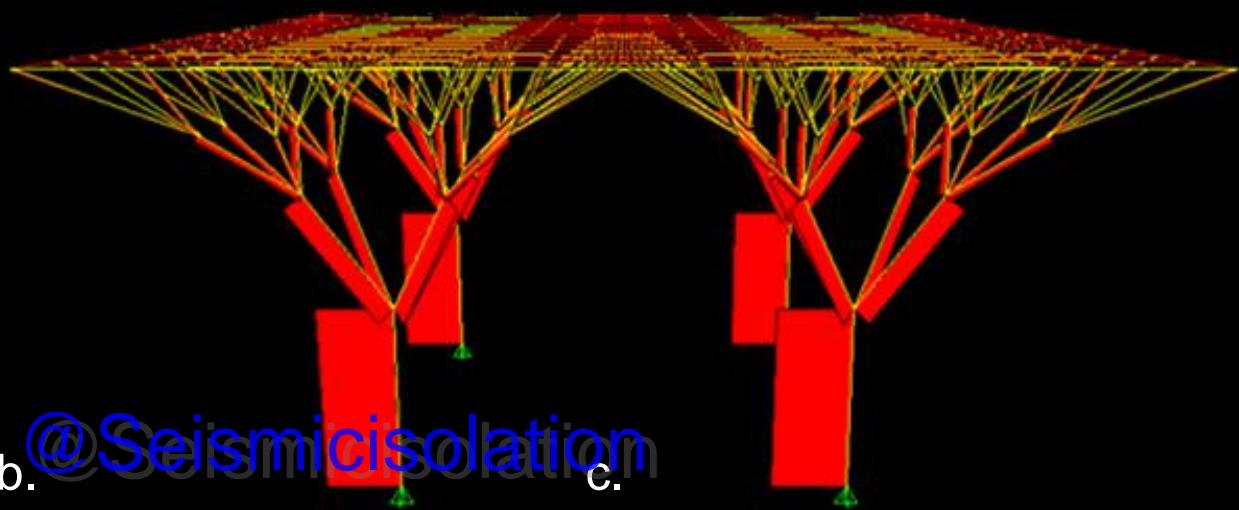
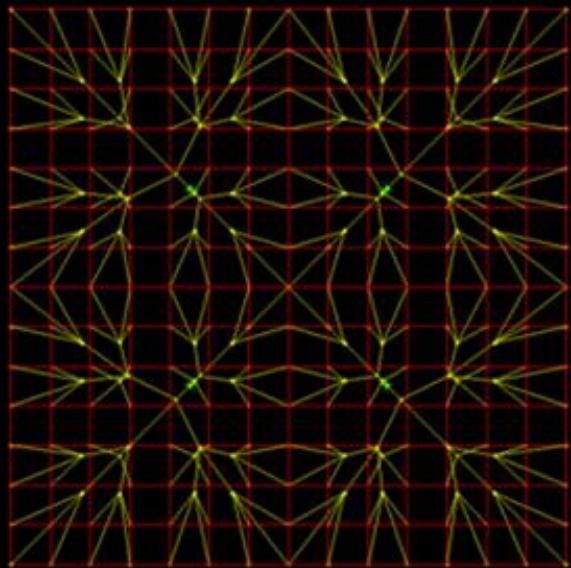
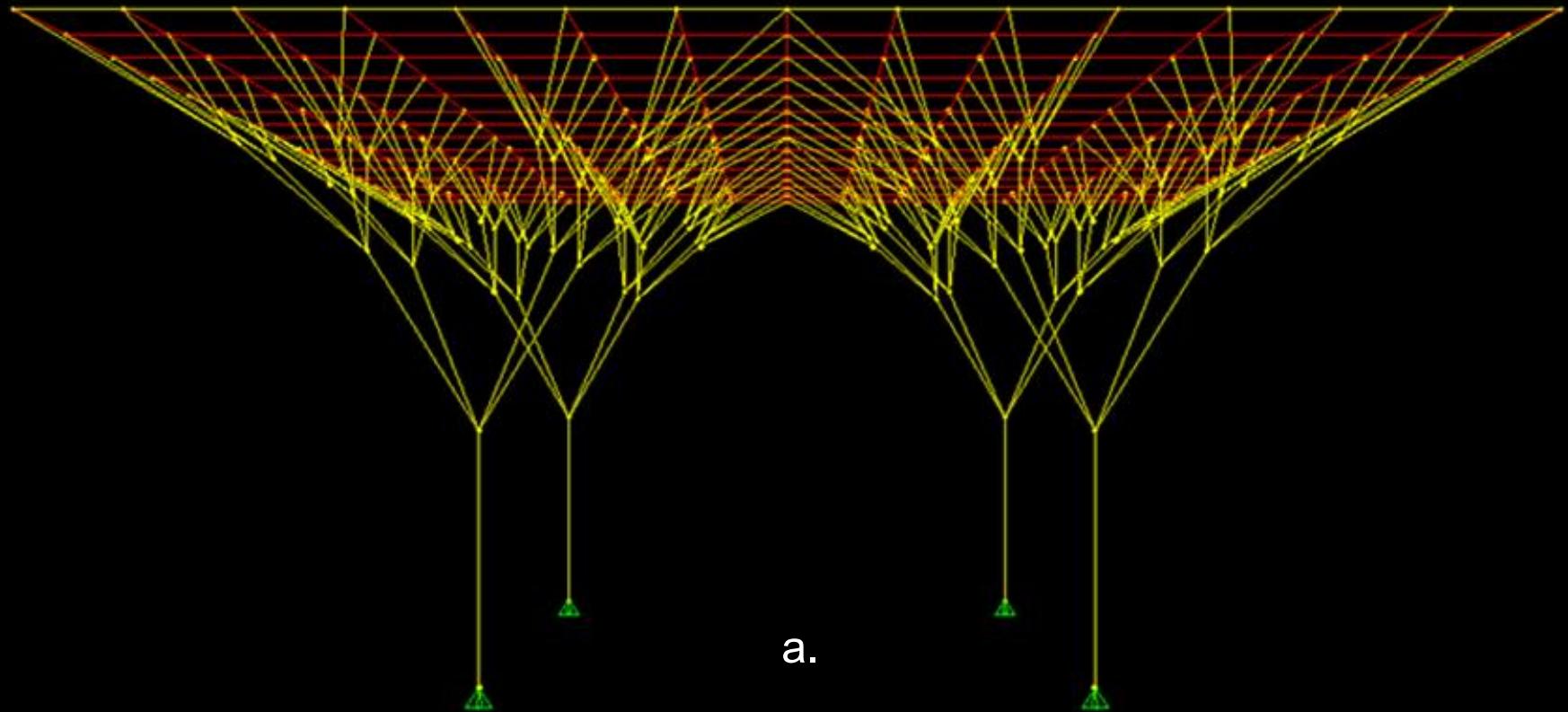


AWD Dome, Bremen, 1964,
Germany, R. Rainer and U.
Finsterwalder

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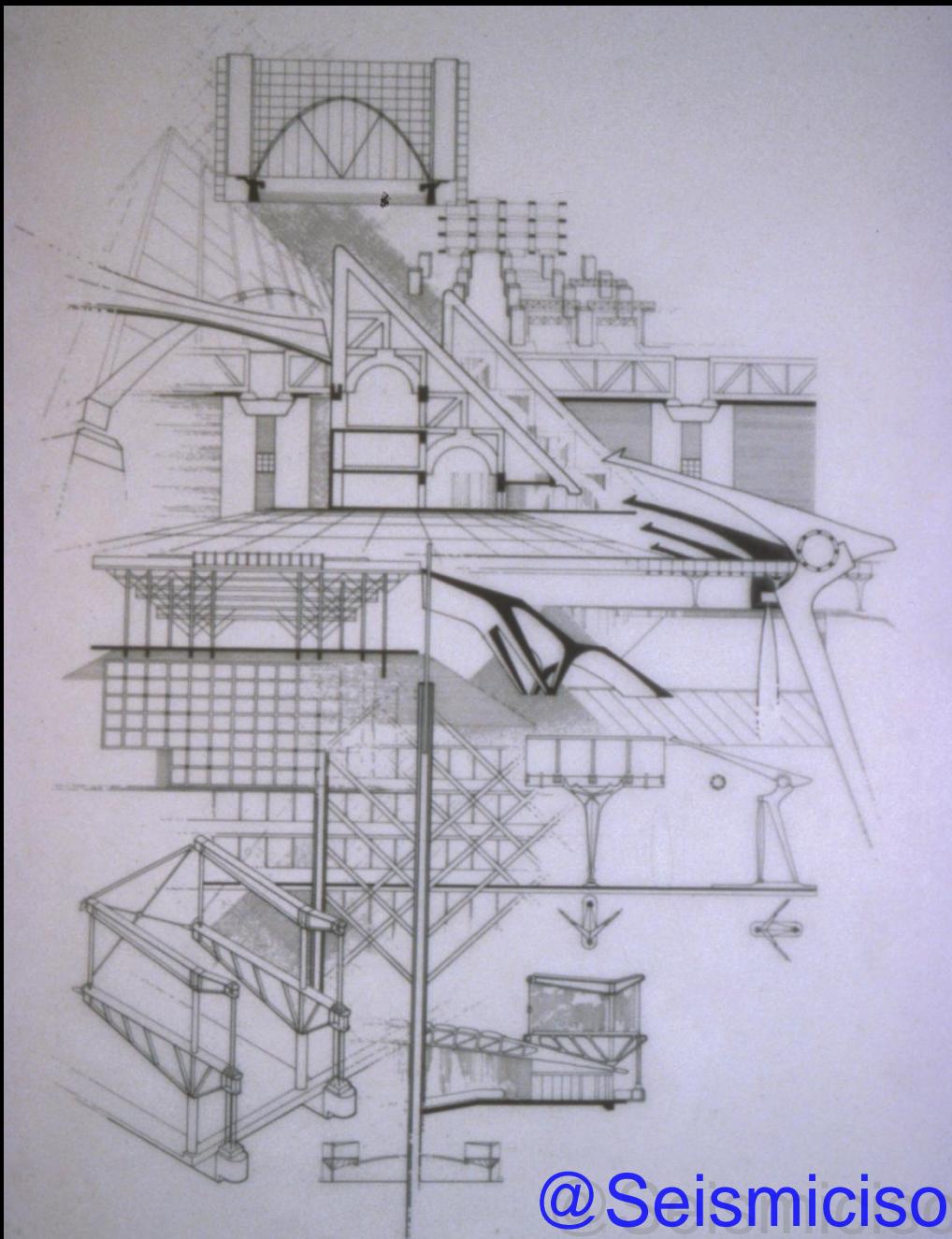
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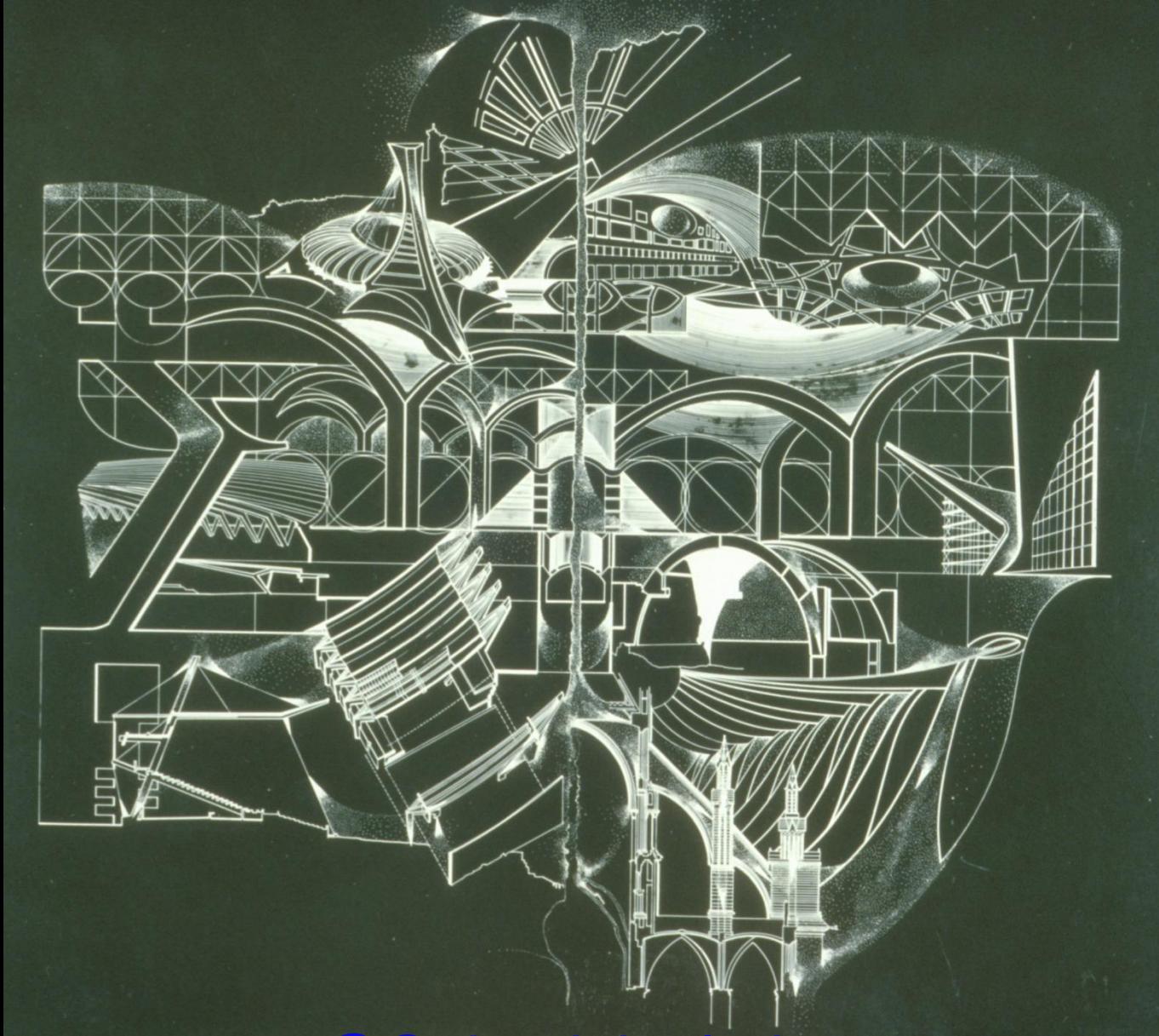
FRAMES

- Visual study of frames, arches and trusses
- Visual analysis of lateral thrust
- Crown Hall, IIT, Chicago, 1956, Mies van der Rohe
- Frankfurt Post Museum, 1990, Behnisch Architekten
- Sainsbury Centre for Visual Arts, Norwich, UK, 1978, Norman Foster
- Willemsbridge, Rotterdam, 1981, C.Veeling
- BMW Plant Leipzig, Central Building, 2004, Zaha Hadid
- Sony Center, Potzdamer Platz, Berlin, 2000, Helmut Jahn Arch., Ove Arup
- Dresden Bank, Verwaltungszentrum, Dittrichring 5-9, Leipzig
- Design Museum, Nuremberg, Germany
- Capital Museum, Beijing, 2001 (2 slides)
- Architectural Institute, Rotterdam, Netherland, Joe Coenen



Visual study of frames, arches
and trusses

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Visual analysis of lateral thrust



Crown Hall, IIT Chicago, 1956, Mies van der Rohe
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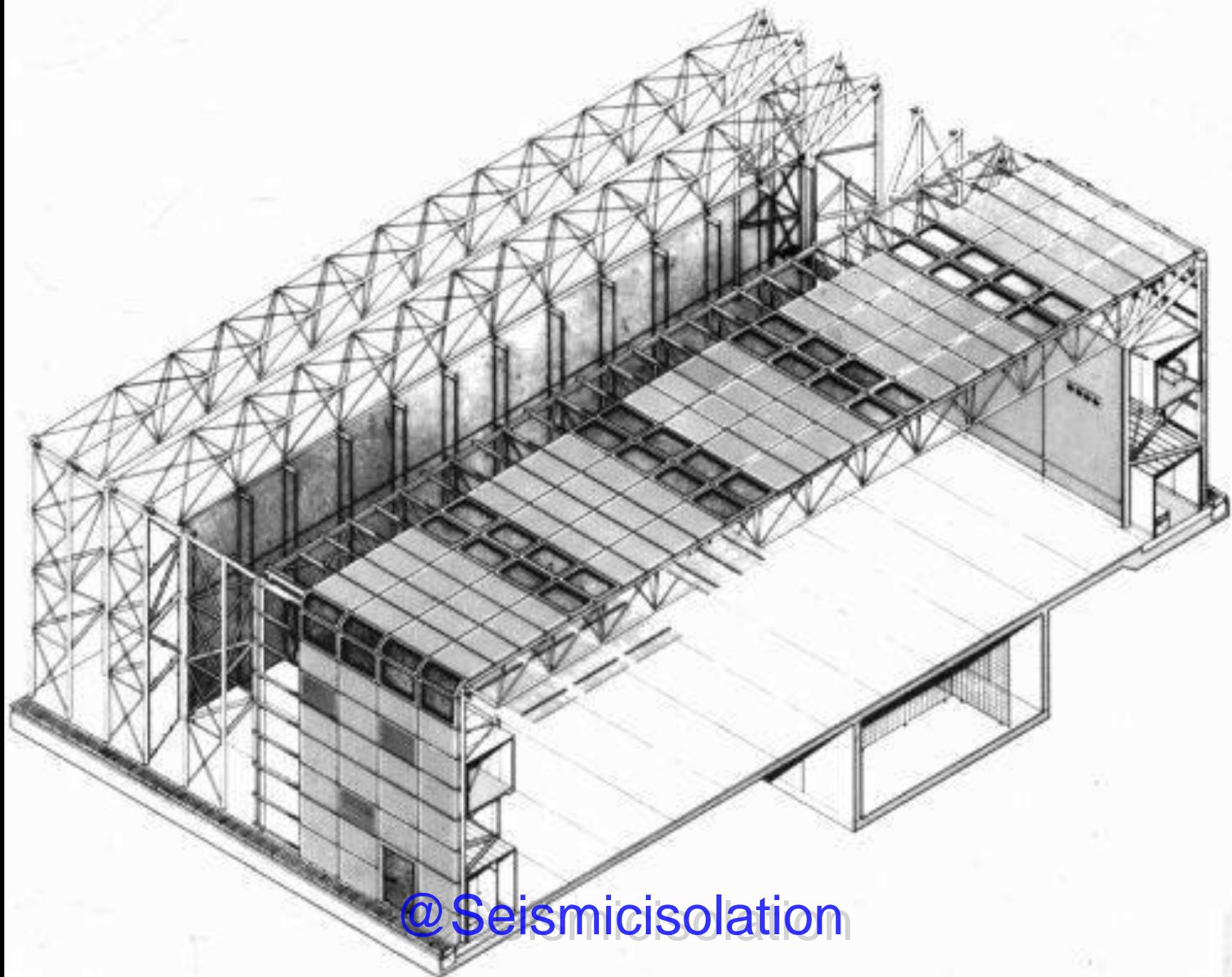


Frankfurt Post Museum, 1990, Behnisch Architekten
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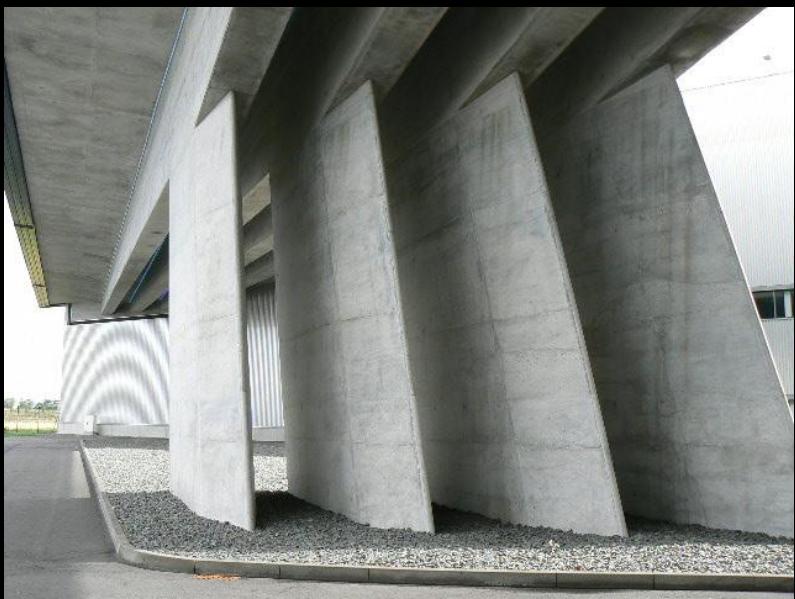
Sainsbury Centre for Visual Arts, Norwich, UK, 1978, Norman Foster



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Willem'sbridge, Rotterdam, 1981, is a double suspension bridge, C.Veeling
@Seismicisolation



BMW Plant Leipzig, Central Building, 2004, Zaha Hadid



Dresdner Bank, Verwaltungszentrum, Leipzig, 1997, Engel und Zimmermann Arch
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Design Museum, [@Seismicisolation](#), Nuremberg, Germany, 2010, Volker Staab

Sony Center, Potsdamer Platz, Berlin, 2000, Helmut Jahn Arch., Ove Arup



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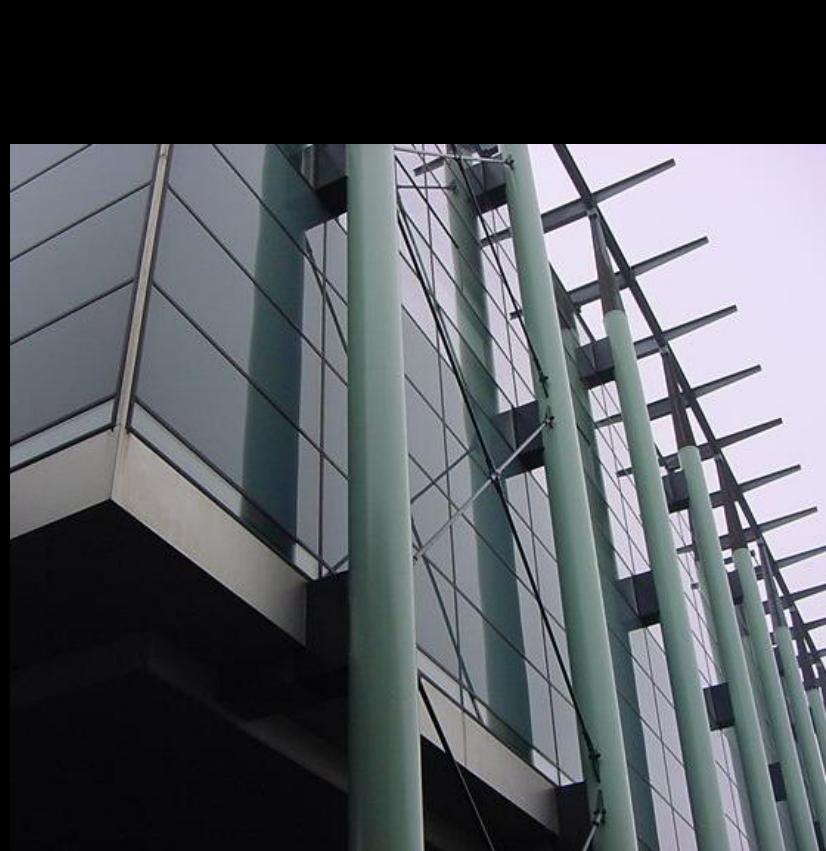


Capital Museum, Beijing, 2001, Jean-Marie Duthilleul + Cui Kai

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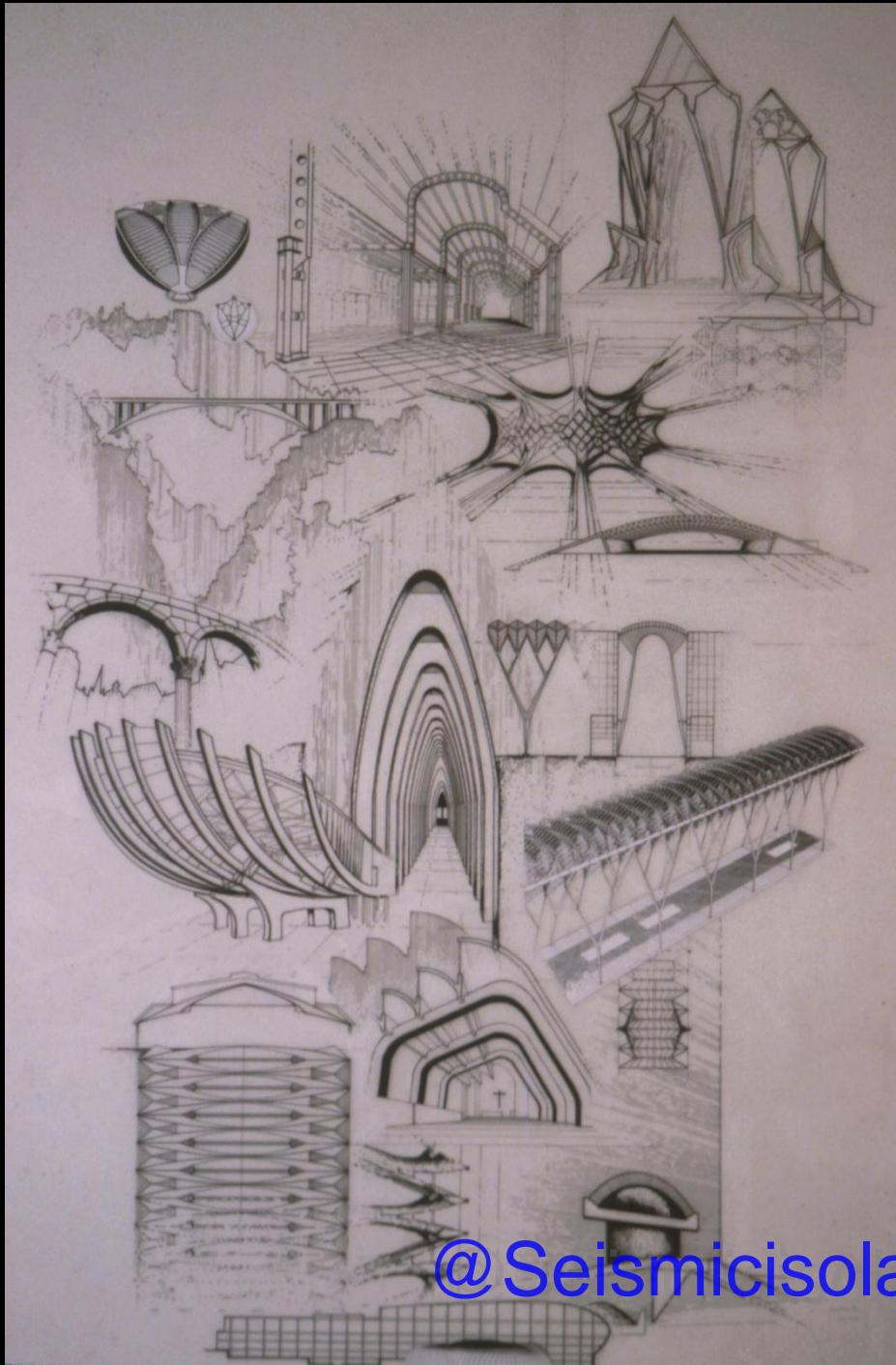


Architectural Institute,
Rotterdam, Netherland, 1993,
Joe Coenen

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ARCHES

- visual analysis of columns (lateral thrust, space interaction through diagonal, principal stress flow)
- Colosseum, Rom, c. 100 AD
- St. Peters, Rom, 16th century. Bramante, Michelangelo, etc.
- Arve River Bridge, 1935, Switzerland, Robert Maillart
- Koeln Medienpark bridge
- Satolas Airport TGV Train Station, Lyons, France, 1995, Santiago Calatrava
- Berlin Stock Exchange, Berlin, Germany, 1999, Nick Grimshaw
- Athens Olympic Sports Complex, 2004, Calatrava
- Rotterdam arch
- Oberbaum bridge, Berlin, Santiago Calatrava, 1995
- Lehrter Bahnhof, Berlin, 2006, von Gerkan, Marg and Partners



visual analysis of arches

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Colosseum, Rom, c. 70 AD



St. Peters, Rom, 16th century, Bramante, Michelangelo, etc.

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Arve River Bridge, 1935, Switzerland, Robert Maillart
©Seismicisolation



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Cologne Medienpark bridge



Satolas Airport TGV Train Station, Lyons, France, 1995, Santiago Calatrava
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Berlin Stock Exchange,
Berlin, Germany, 1999,
Nick Grimshaw

Athens Olympic Sports
Complex, 2004, Calatrava

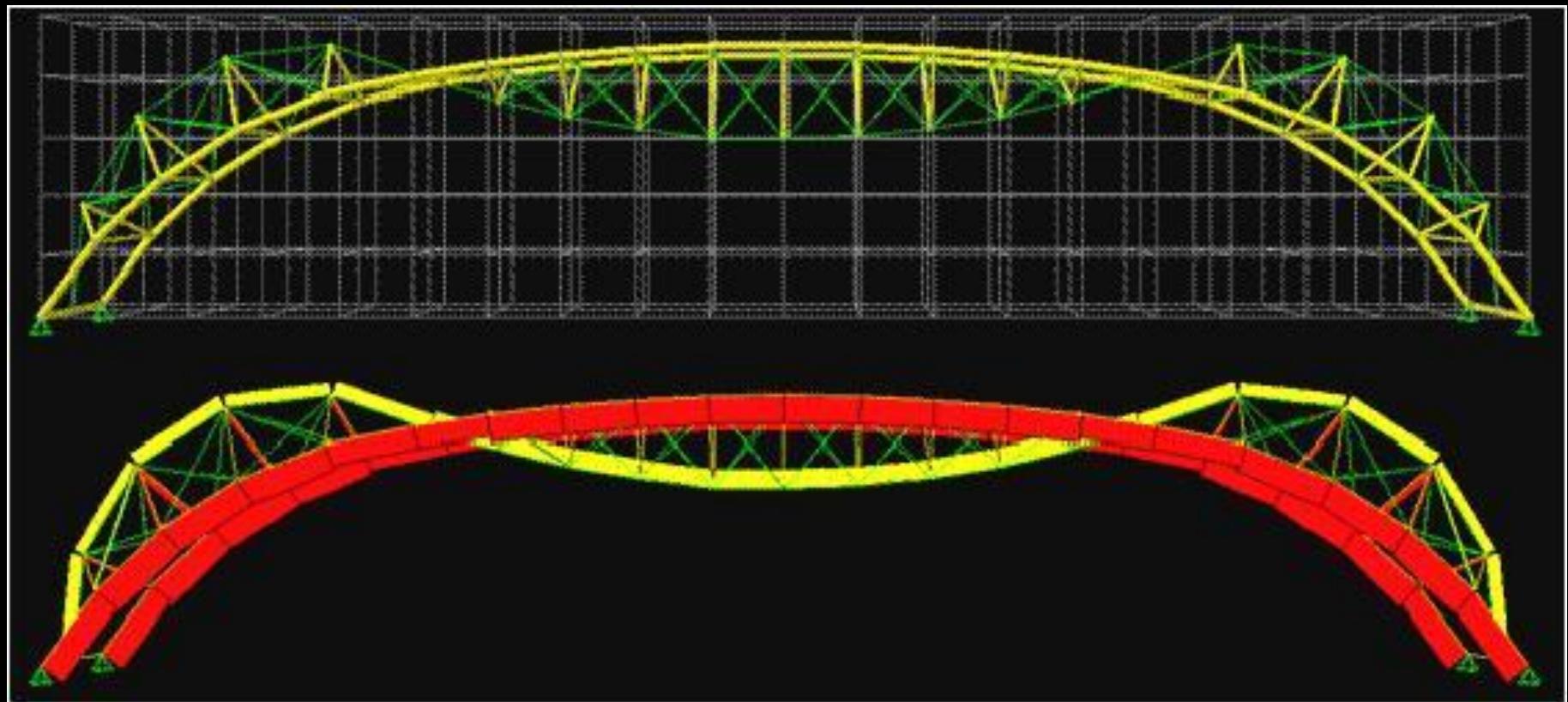


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The Metro station at Blaak, Rotterdam, 1993, Harry Reijnders of Movares; the arch spans 62.5 m, dome diameter 35 m

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Space Truss Arch – Axial Force Flow
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Oberbaumbruecke, Berlin, Santiago Calatrava, 1995



Lehrter Bahnhof, Berlin,
2006, von Gerkan, Marg
and Partners

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CABLES

- **World Trade Center, Amsterdam, 2003, Kohn, Pedersen & Fox**
- **Sony Center, Potzdamer Platz, Berlin, 2000, Helmut Jahn Arch., Ove Arup**
- **The University of Chicago Gerald Ratner Athletics Center, Cesar Pelli, 2004**
- **Incheon International Airport, Seoul, Fentress Bradburn Architects, Denver**
- **Olympic Stadium, Tokyo, 1964, Kenzo Tange, Y. Tsuboi (2 slides)**



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World Trade Center, Amsterdam, 2003 (?), Kohn, Pedersen & Fox



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Sony Center



Sony Center, Potsdamer Platz, Berlin, 2000, Helmut Jahn Arch., Ove Arup
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The University of Chicago **Gerald Ratner Athletics Center**, 2004, Cesar Pelli, OWP/P Struct.
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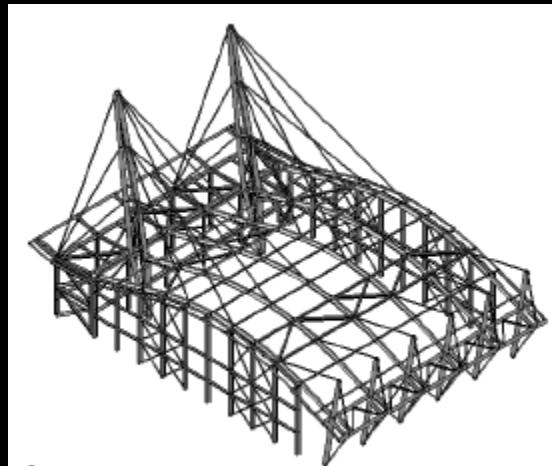
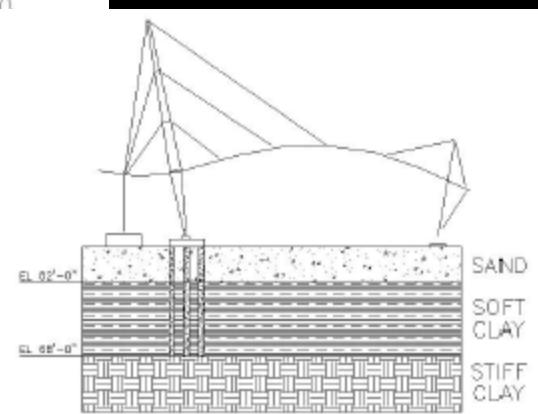
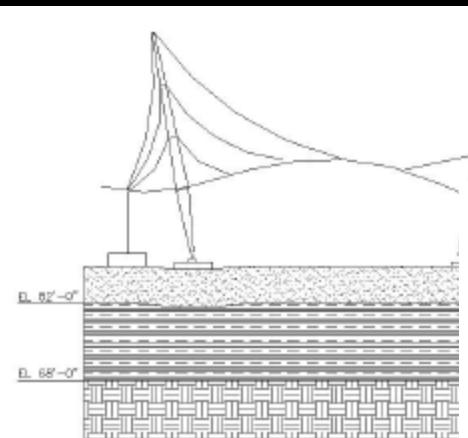
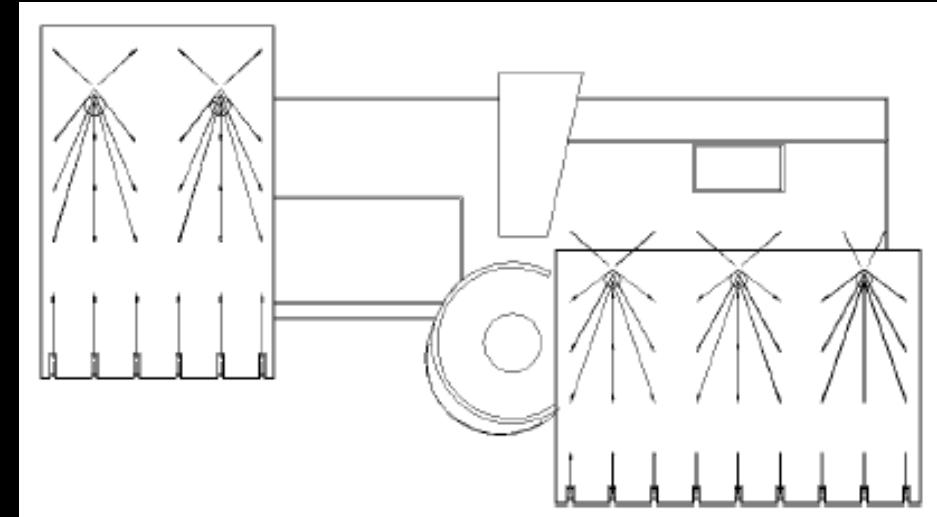
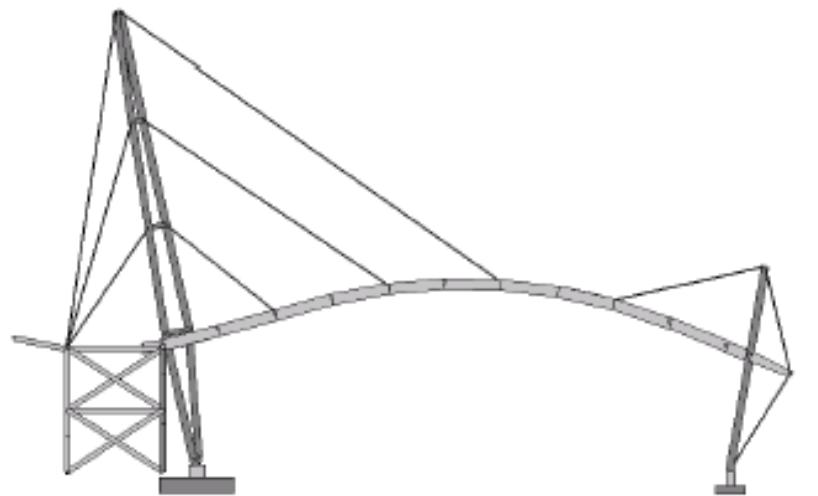


Figure 12 – Settlement Effects
Cable-Supported Structures

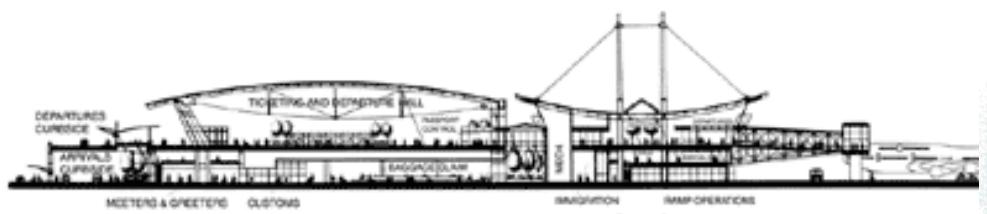
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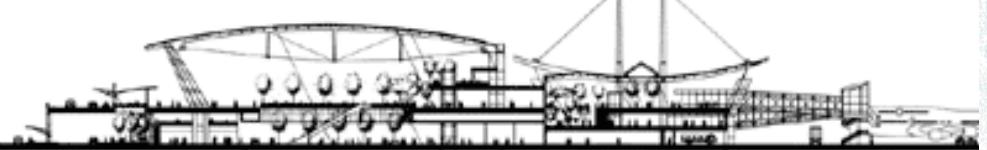
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Incheon International Airport, Seoul, Fentress Bradburn Architects, Denver
© Seismic Isolation



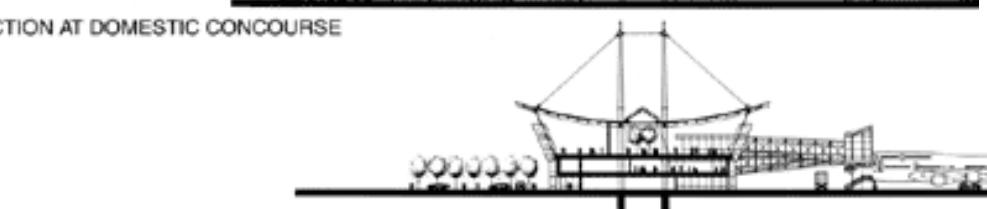
MAIN TERMINAL SECTION



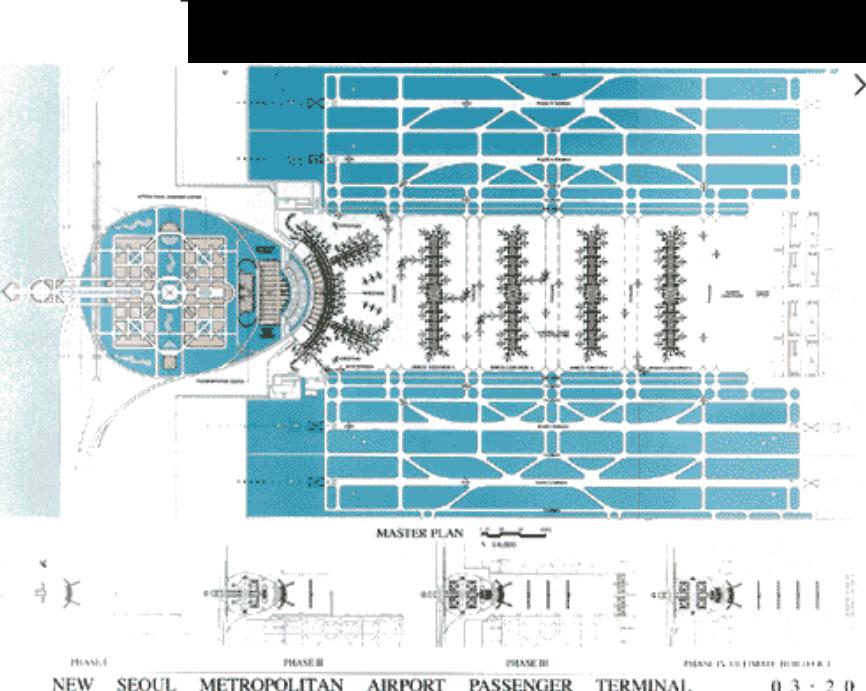
MAIN TERMINAL SECTION AT GREAT HALL



SECTION AT DOMESTIC CONCOURSE



SECTION OF EAST & WEST ENDS OF MAIN CONCOURSE



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Olympic Stadium @ Seismic isolation
Tokyo, 1964, Kenzo Tange, Y. Tsuboi



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SURFACES

ribbed vaulting

Muenster Halberstadt, 14th century, Gothic ribbed vaulting

MUDAM, Museum of Modern Art, Luxembourg, 2007, I.M. Pei

Friedrichstrasse Atrium, 1996, Berlin, Henry N. Cobb

National Grand Theater, Beijing, 2007, Jean Andreu

DG Bank, Berlin, Germany, 2001, Frank Gehry, Schlaich and Bergemann

Reichstag, Berlin, Germany, 1999, Norman Foster, Leonhardt & Andrae



Muenster Halberstadt, 14th century, Gothic ribbed vaulting

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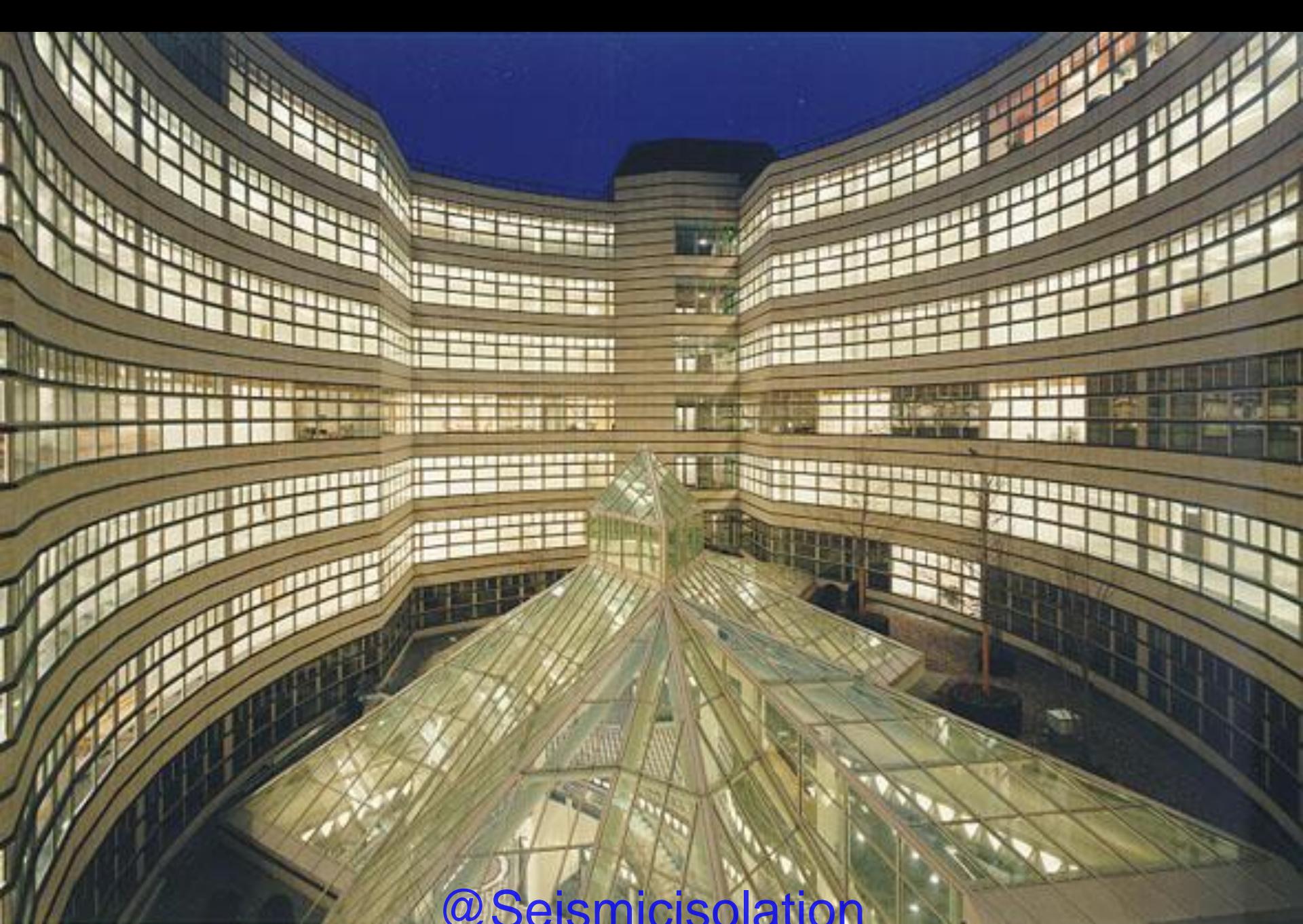


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MUDAM, Museum of Modern Art, Luxembourg, 2007, I.M. Pei



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Friedrichstrasse Atrium 1996 Berlin Henry N Cobb



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National Grand Theater,
Beijing, 2007, Jean Andreu



25 9 4 2001

**DG Bank, Berlin, Germany,
2001, Frank Gehry, Schlaich
and Bergemann**

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**Reichstag, Berlin, Germany,
1999, Norman Foster, Leonhardt
& Andrae**

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rigid shells

Airplane hangar, Orvieto. 1940, Pier Luigi Nervi

Zarzuela Hippodrome Grandstand, 1935. Eduardo Toroja

Notre Dame du Haut, Ronchamp, France, 1955, Le Corbusier

Kimbell Art Museum, Fort Worth, TX, 1972, Louis Kahn

St. Mary Basilica, Tokyo, 1964, Kenzo Tange, Y. Tsuboi

TWA Terminal, New York, 1962, Eero Saarinen

Chrystal Cathedral, Garden Grove, Calif., 1980, Philip Johnson



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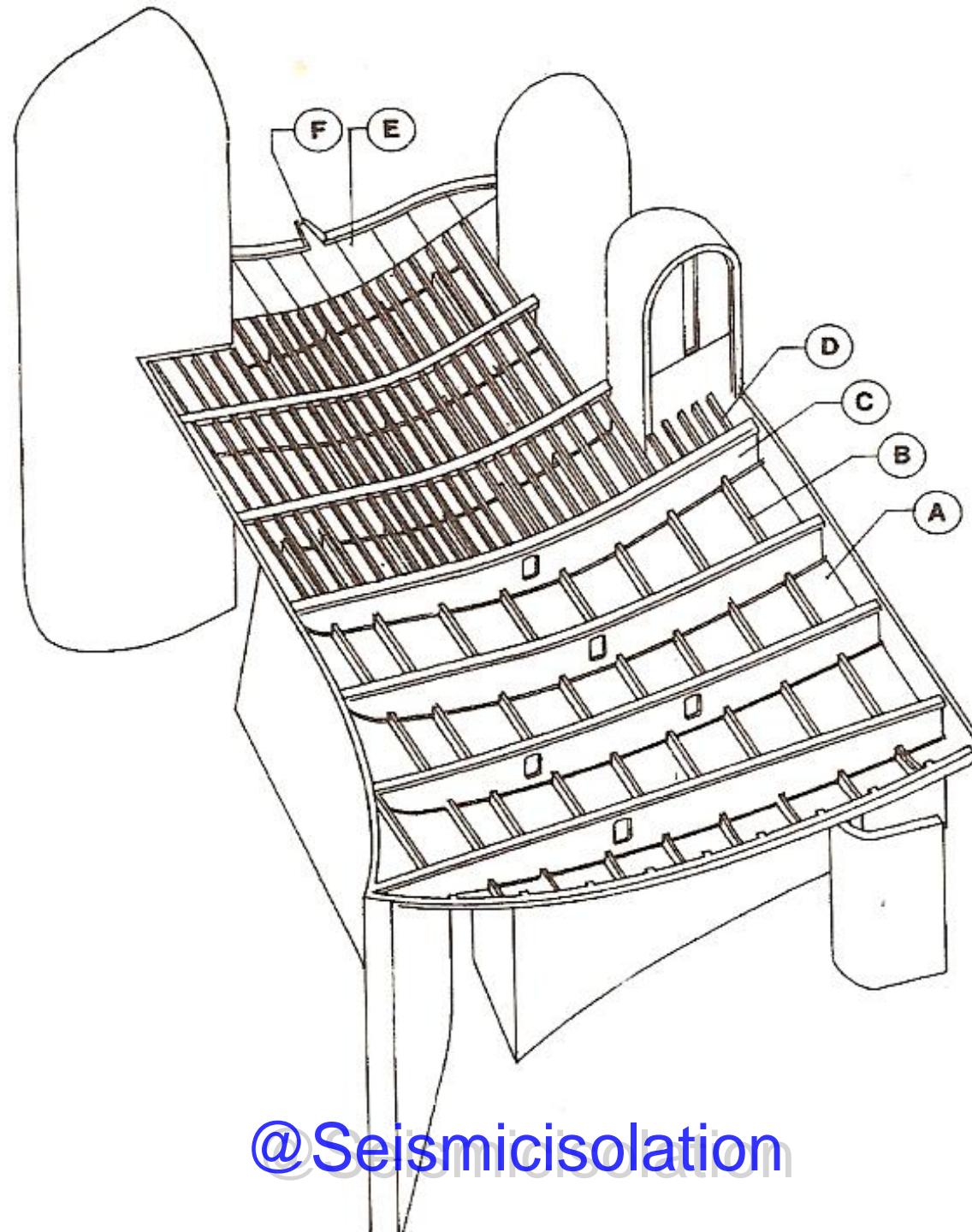
Airplane hangar, Orvieto. 1940, Pier Luigi Nervi



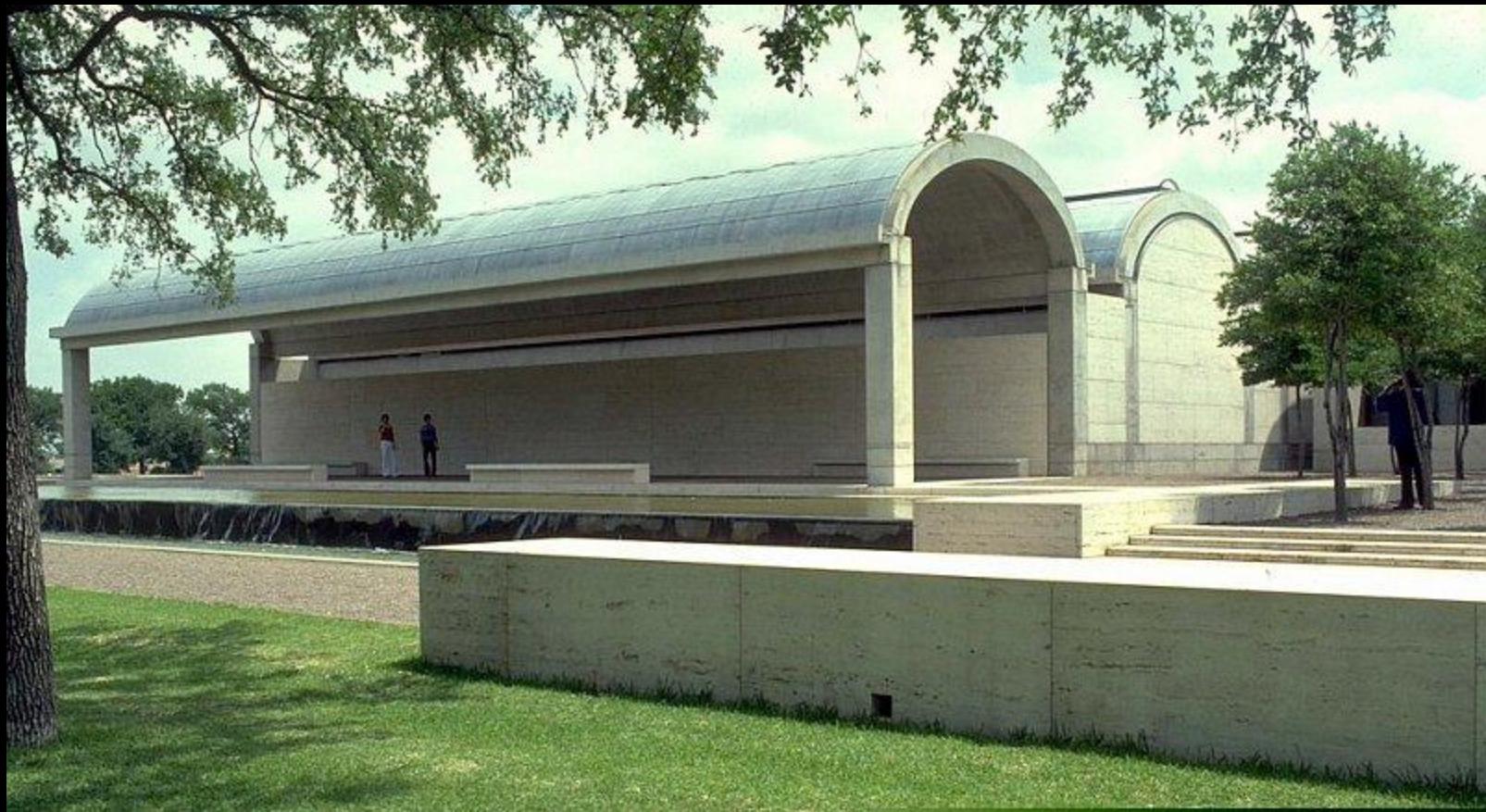
Zarzuela Hippodrome Grandstand, 1935. Eduardo Toroja
@Seismicisolation



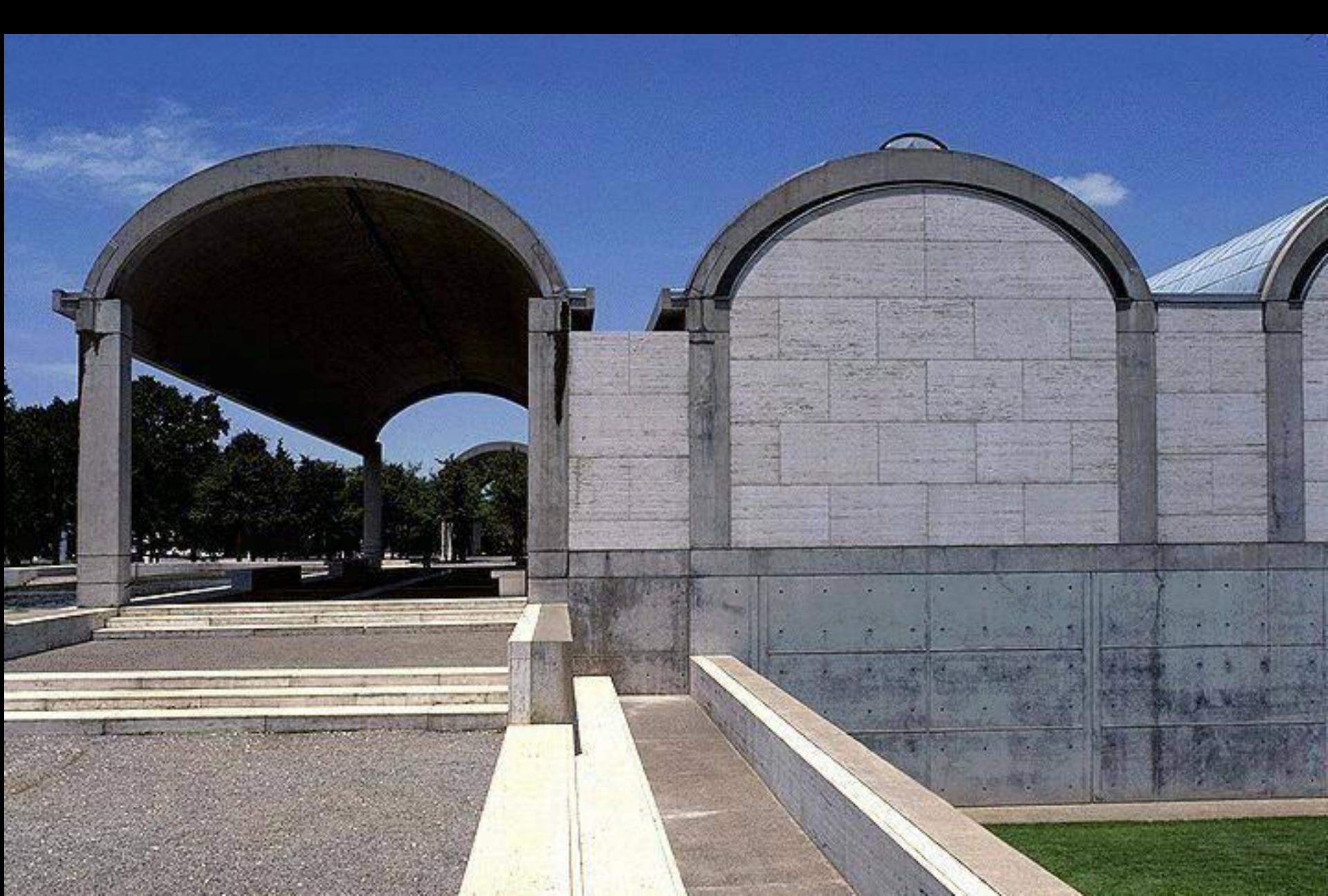
Notre Dame du Haut, Ronchamp, 1955, Le Corbusier



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Kimball Museum, Fort Worth, 1972, Louis Kahn
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Kimbell Art Museum, Fort Worth, TX, 1972, Louis Kahn



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St. Mary Basilica, Tokyo, 1964, Kenzo Tange, Y. Tsuboi

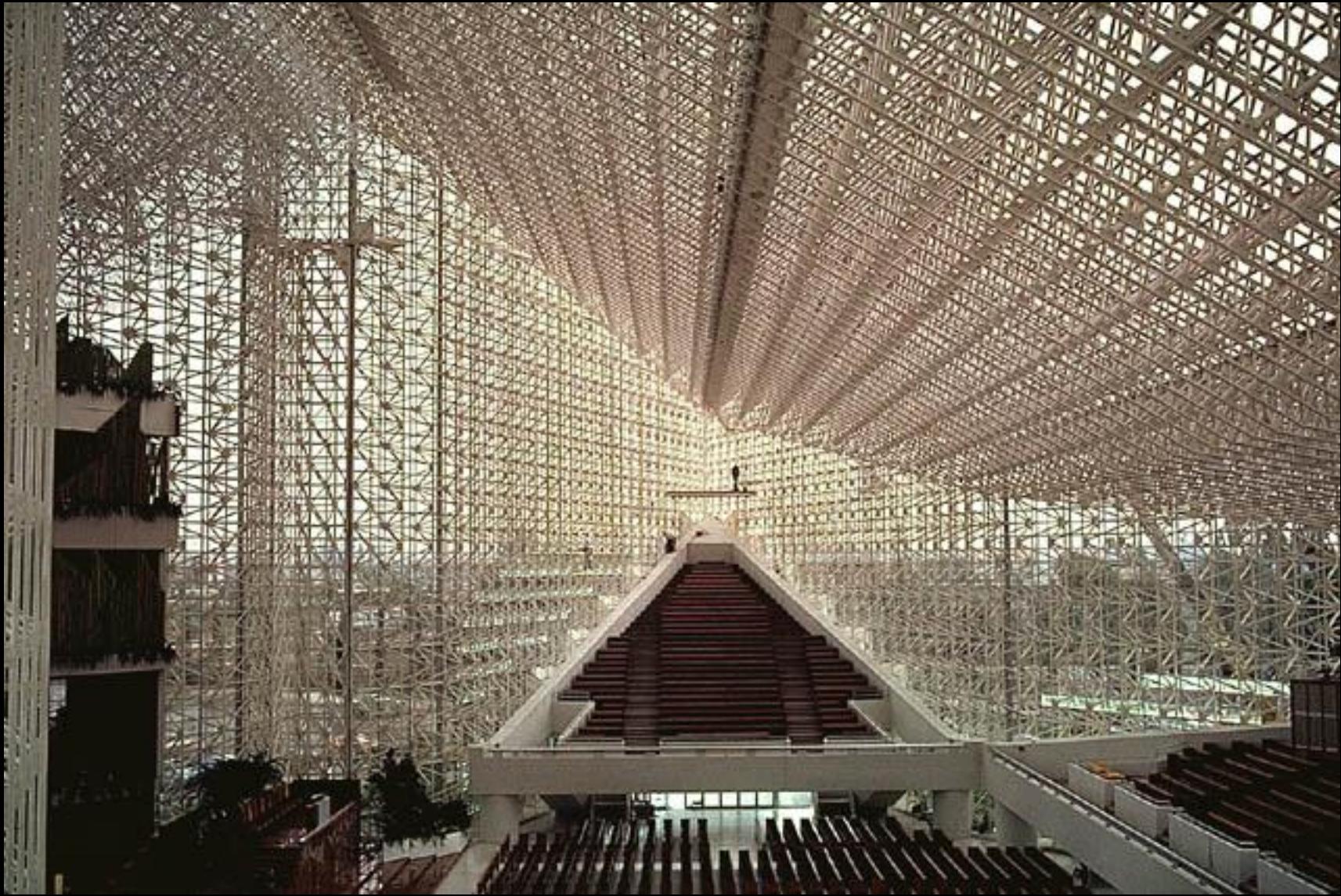


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**TWA Terminal,
New York,
1962, Saarinen**



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Chrystal Cathedral, Garden Grove, Calif., 1980, Philip Johnson
©Seismic Isolation

tensile surfaces

Dulles Airport Terminal, Washington DC, 1962, Eero Saarinen, Fred Severud

Olympic Stadium, Tokyo, 1964, Kenzo Tange, Y. Tsuboi

Trade Hall 26, Hanover, 1996, Thomas Herzog, Schlaich Bergermann

Flexible surface structures

Yeadon pneumatic fabric structures, tennis court

Ice Rink Roof, Munich, 1984, Ackermann und Partner, Schlaich Bergermann

Olympic Stadium, Munich, Germany, 1972, Frei Otto, Leonhardt-Andrae



Dulles Airport Terminal, Washington DC, 1962, Eero Saarinen, Fred Severud



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Olympic Stadium, Tokyo, 1964. Kenzo Tange, Y. Tsuboi
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Trade Hall 26, Hanover, Germany, 1996, Thomas Herzog und Schlaich Bergermann
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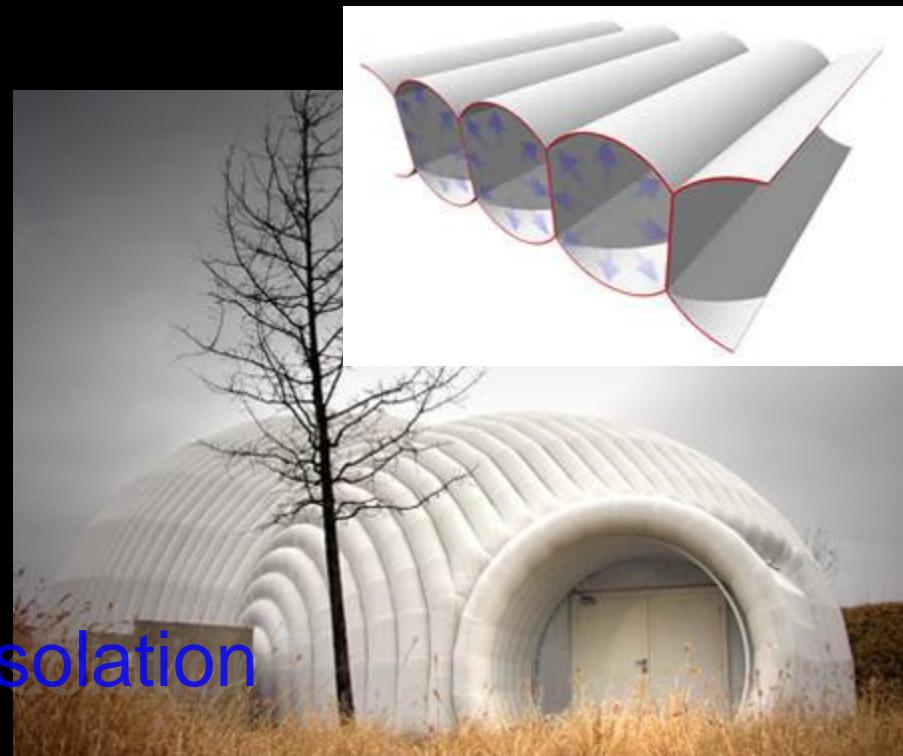
Tensile membrane
structures



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Yeadon fabric structures, tennis court



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Tektoniks

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Ice Rink Roof, Munich, 1984 © Seismosol, Achmann und Partner, Schlaich Bergermann

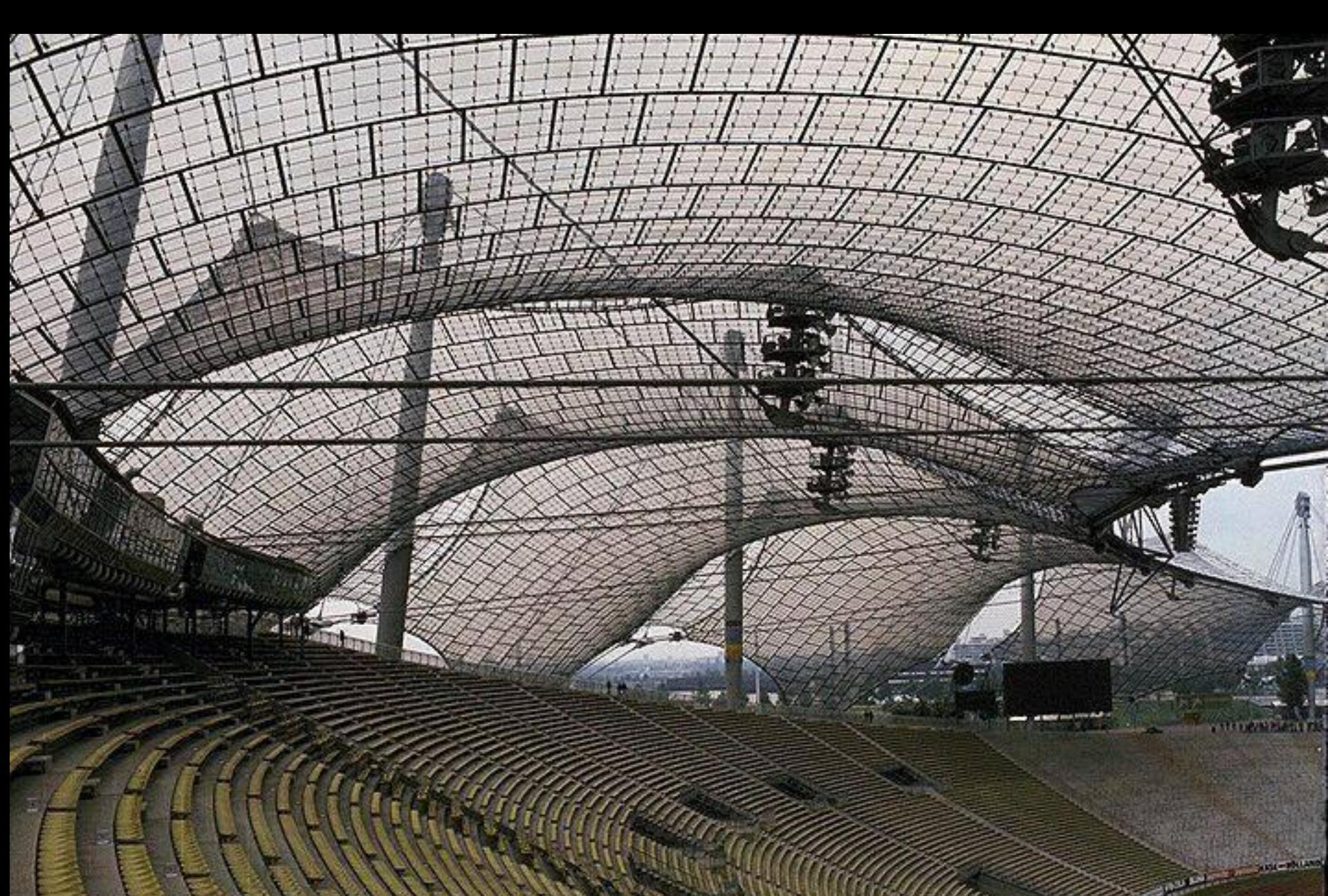
Olympic Stadium, Munich, Germany, 1972, Frei Otto, Leonhardt - Andrae



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Schlumberger Research  @Seismicisolation Center, Cambridge, 1985, Michael Hopkins