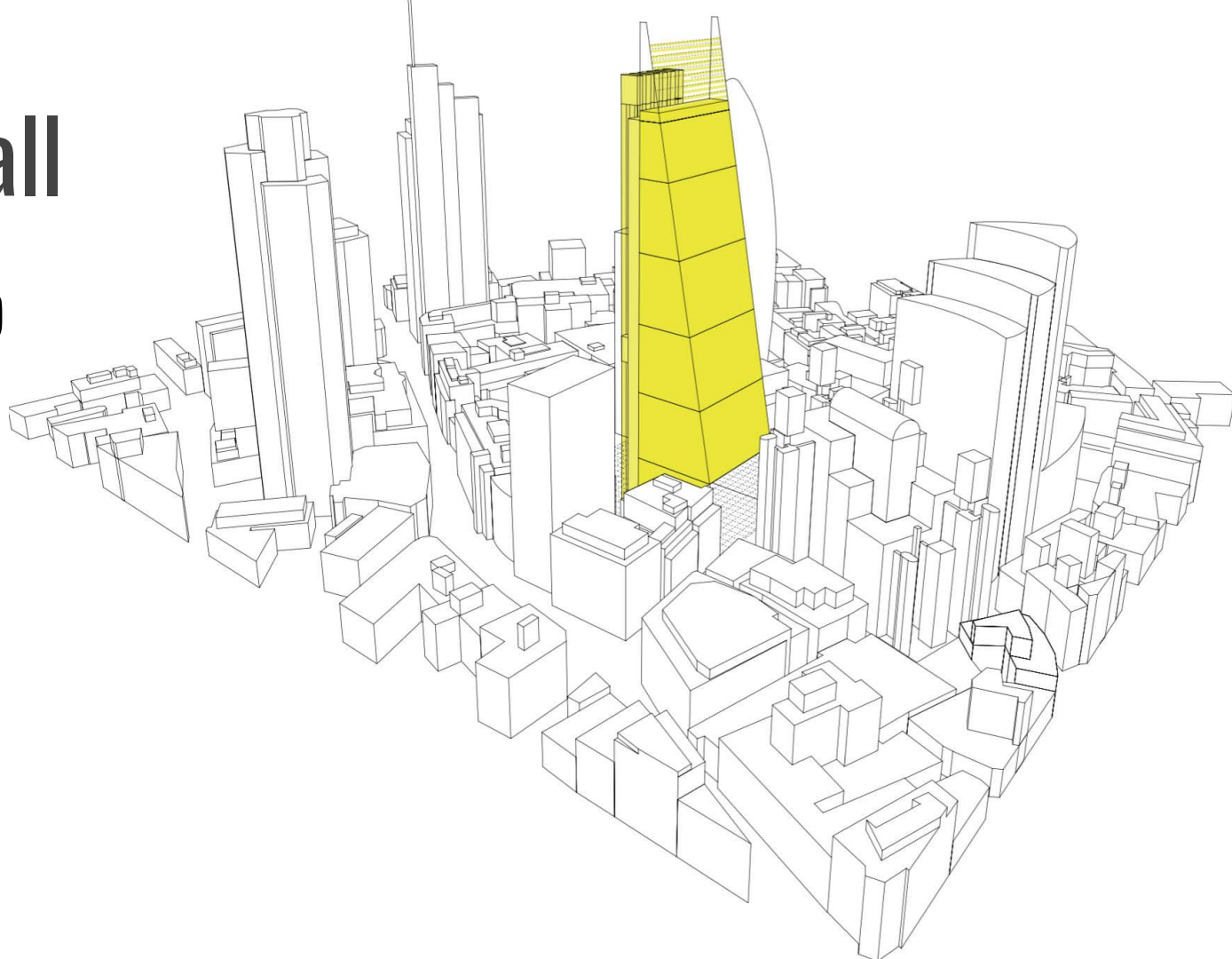


# Leadenhall

ARCH 631

(The Cheese Grater)



## Team members:

Seul Ki Hong

Xiwen Ma

Shiduo Lang

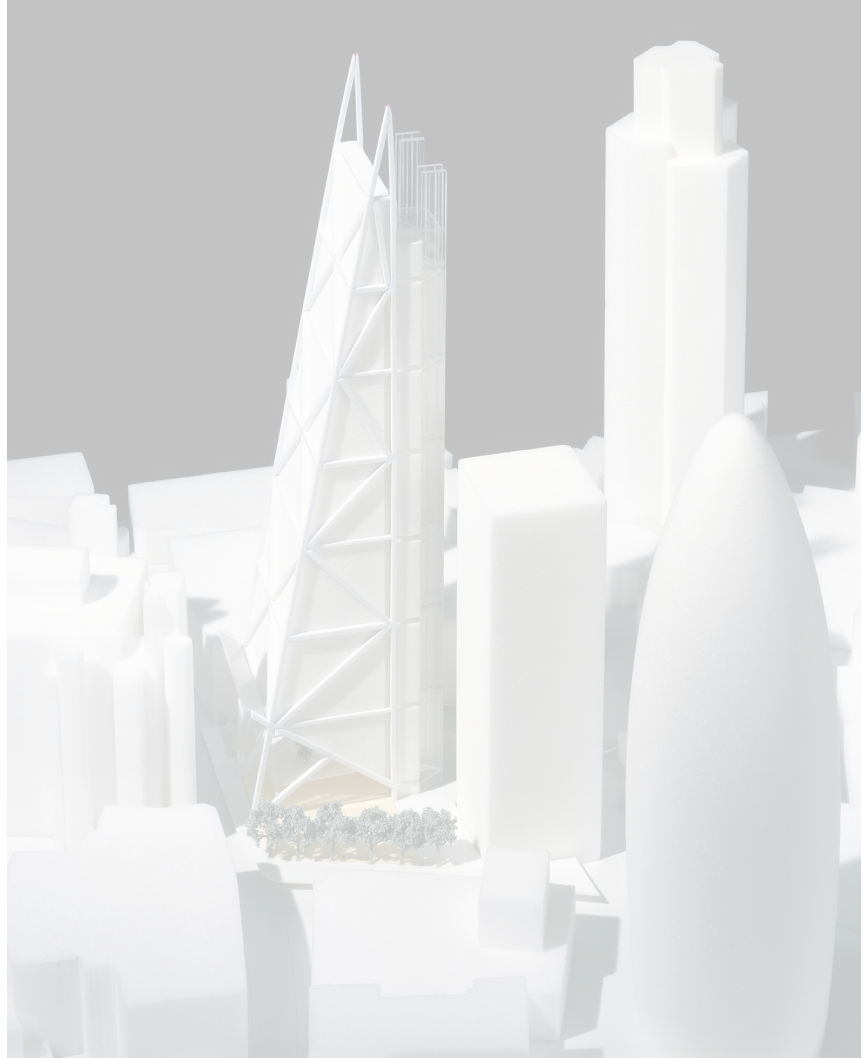
Junhao Ma

Yiming Du

Xiaolei Wang

# Contents

- **Introduction**
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  - Building Design
- **Body**
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  - Load transfer mechanism
  - Lateral Loads + Resistance
  - Material
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- **Conclusion**
- **References**



# Overview

- **Project:** The Leadenhall Building
- **Location:** London, UK
- **Completed:** June 2013
- **Architects:** Rogers Stirk Harbour + Partner
- **Structural Engineer:** Arup
- **Height:** 225 m (48 stories)
- **Gross Internal Area :** 84,424 m<sup>2</sup>
- **Primary Use:** Office and business



# Architects/Structural Engineer

- **Richard Rogers**
- Born in Florence, Italy in 1933. Graduated from Yale University in America in 1962. English Architect. Designed the Hong Kong and Shanghai Banking Corporation Limited (HSBC), Millennium Dome in London. Designed Centre National d'art et de Culture Georges Pompidou (Centre Georges Pompidou) with Renzo Piano and Gianfranco Franchini. One of the most influential architects in the last 30 years. Master of High-Tech building style.
- **Engineer and Construction**
- LAING O'ROURKE – CONTRACTOR (Team)





# Building Design

- **Architectural Image** :The Cheesegrater
- The inclined form was constructed depended on the view management framework.

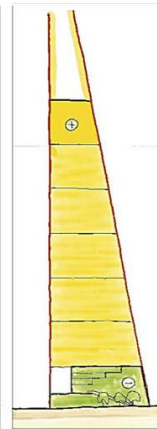
- The ground floor stilts about 15m in order to provide more communication spaces for people and reduce the sight block of historical buildings.
- This Cheesegrater not only shows response to the impact on the view of Sir Christopher Wren's St Paul's Cathedral and the potential public realm, but also try to establish a positive communication and relationships between historical buildings and modern buildings in the site.



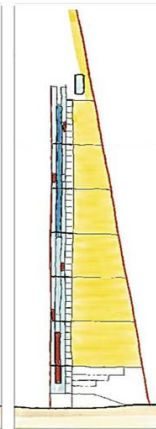
Site profile



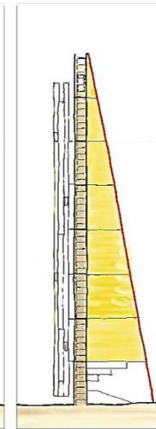
Envelope for potential development



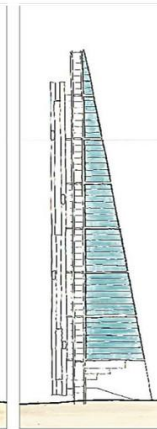
Public realm



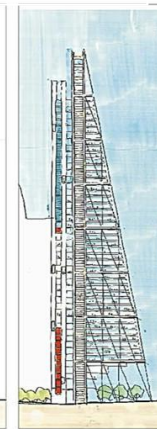
Northern support core



Ladderframe



Offices



Envelope

# Building Design

- **A tapering, perimeter-braced diagrid structure**
- Start 2011.10 --end of 2013
- Architects and engineers use 3D model in order to ensure the construction.
- They've run the complete simulation and "built" the The Leadenhall Building in a virtual world 37 times.





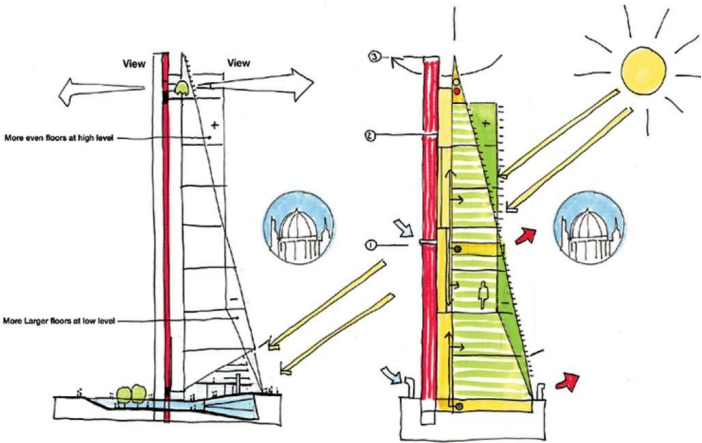
# Building Design

- **Off-site prefabrication**
- Prefabricated offsite and assembled in the tightest of spaces
- The total site is only 3 m (10 feet) wider than the building.
- It is not construction but “Some assembly required” on a monumental scale.

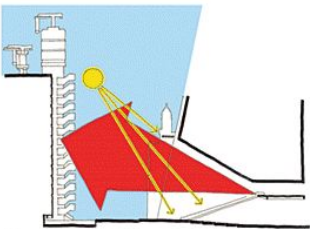


# Building Layout

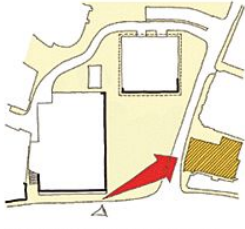
## Building Diagrams



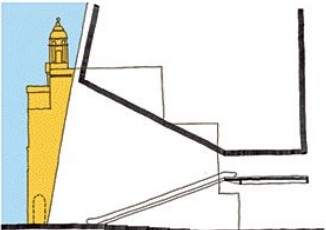
Sunshine Analysis



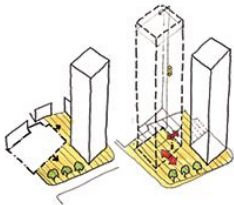
The creation of a public space



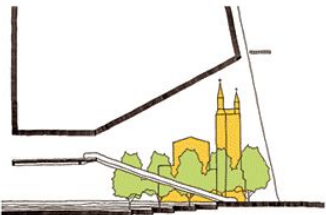
Existing plan: St. Andrew Undershaft becomes visible on emergence into St. Helen's Square



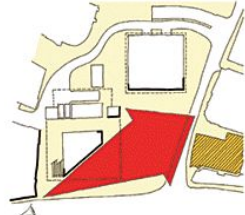
Proposed building profile respects the listed façade of 144 Leadenhall Street by Lutyens



Create public space within building footprint at low level

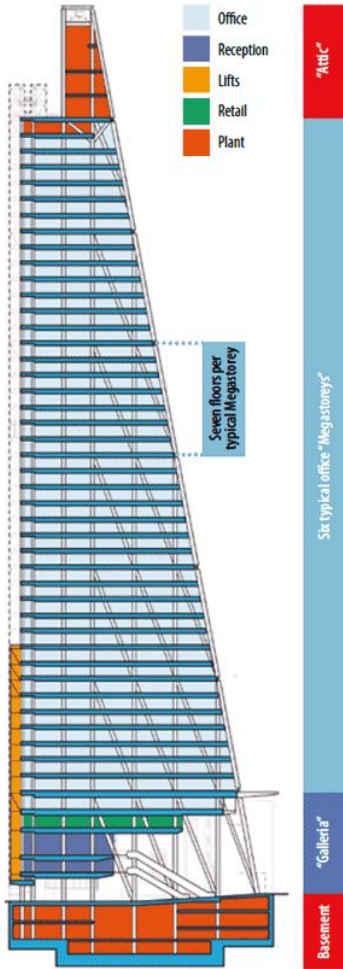


Eroded lower levels reveal the presence of St. Andrew Undershaft



Proposed plan enhances the visibility and presence of the listed church

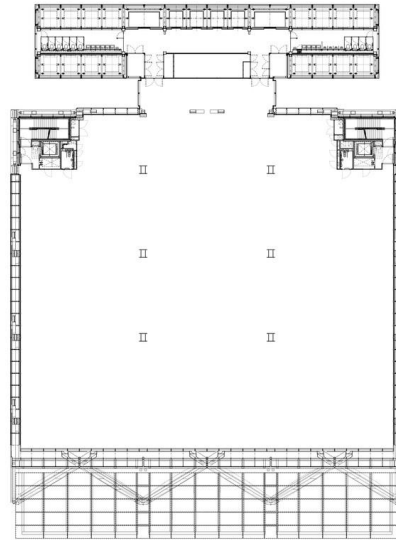
Progress diagram



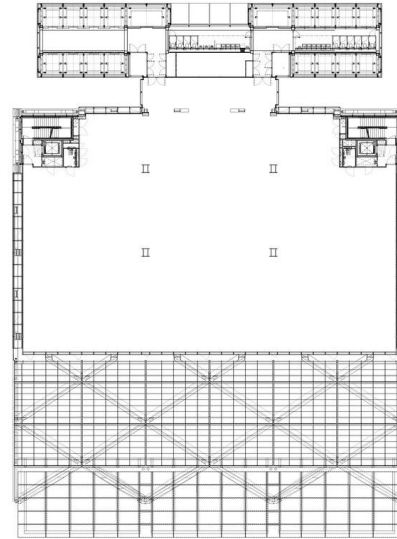
Function

# Building Layout

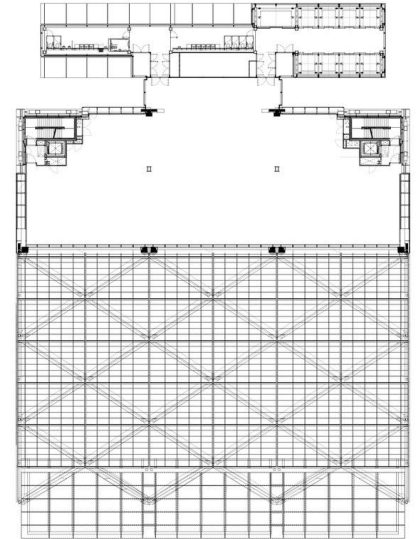
- The lower levels of the building
- Recessed for a large public space
- The office floors
- Rectangular floor plates
- Getting smaller in depth by 750mm towards the apex
- Connected to the structure tube at every floor level without additional vertical elements.



6th floor



22nd floor

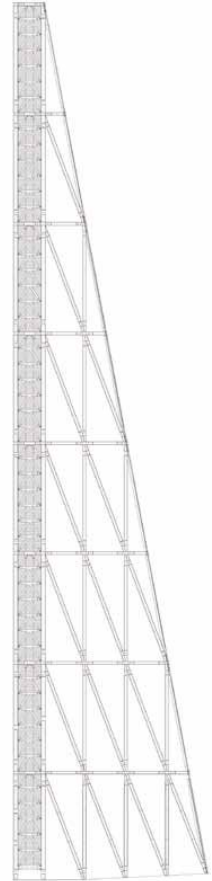
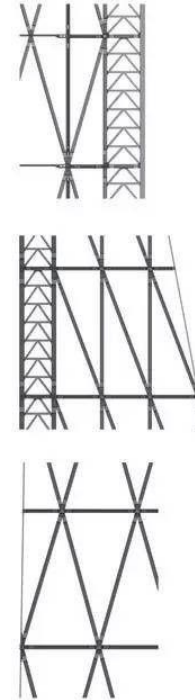
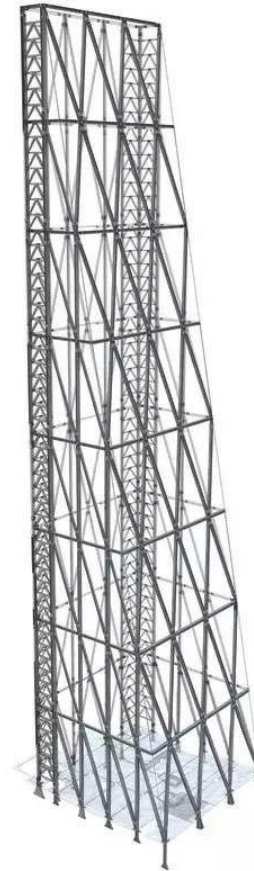


40th floor



# Structure

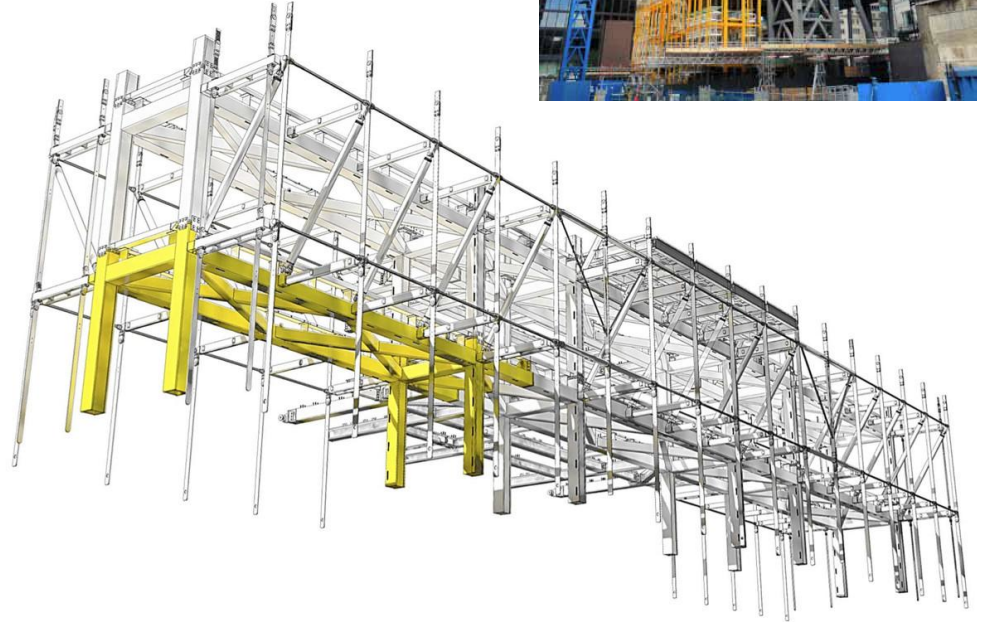
- A tapering, perimeter-braced diagrid structure
- Architects and engineers get rid of the concrete, and replace it with steel. Floors are **only** parts which use **concrete**. Instead of having a massive central core, they planned a steel exposed-skeleton.
- The frame structure encloses the building on all four sides and is divided longitudinally into eight large areas, each seven stories high, with exterior-installed curtain walls with ventilation function.
- The northmost core tube is designed with herringbone support to increase its stability while the rest parts are K-shaped.



# Structure

## North core

- The support function areas
- The self-supporting core connects back to the mainframe
- Not required to be over-clad with fire protection → visible steelwork.

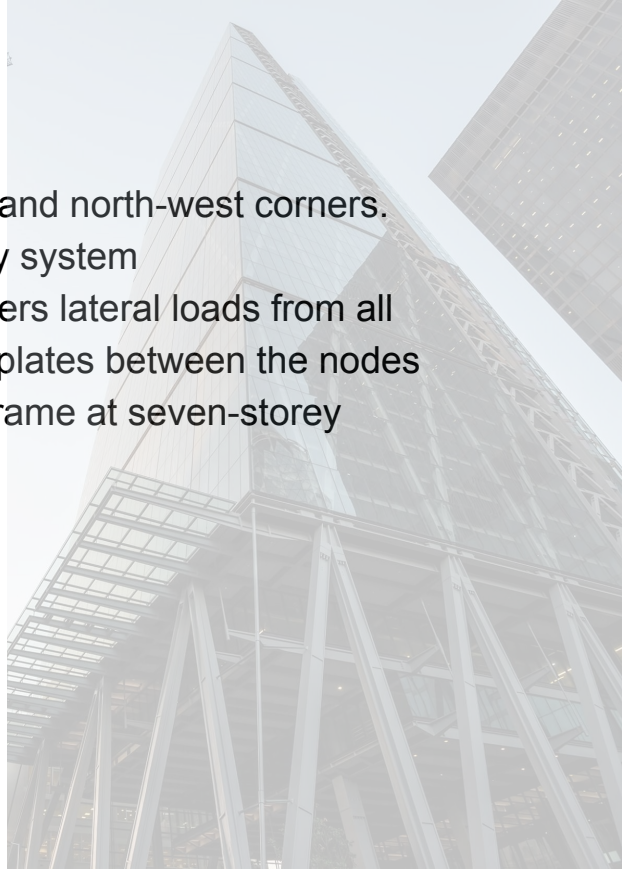




# Structure

## K-bracing

- On the north-east and north-west corners.
- Secondary stability system
- The bracing transfers lateral loads from all intermediate floor plates between the nodes back to the main frame at seven-storey intervals.



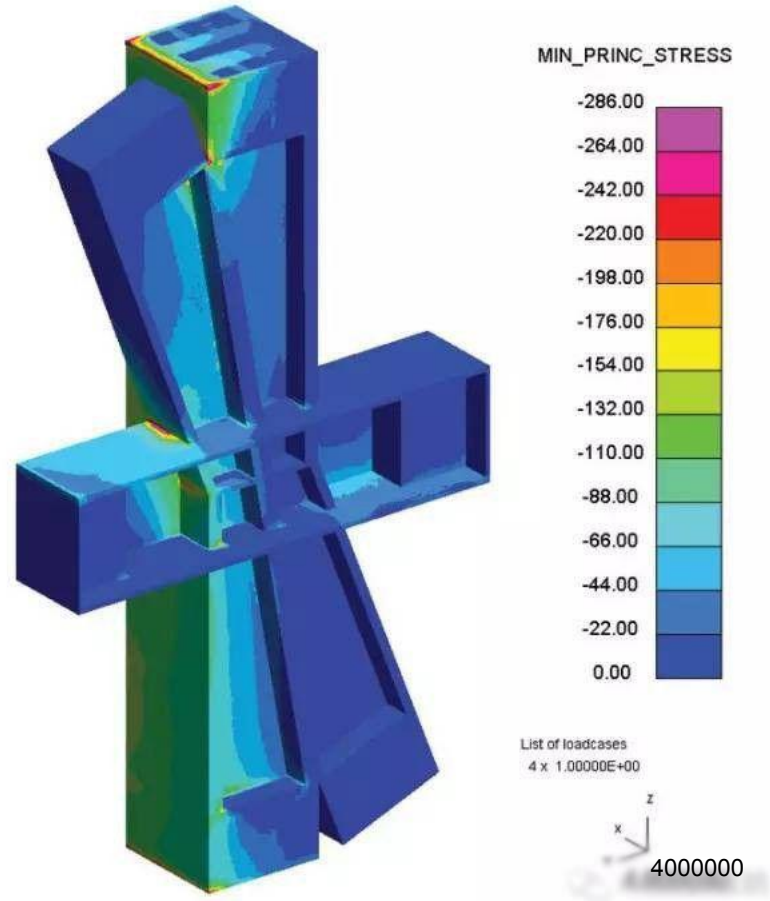
# Building Construction

- Fastest pieces of large-scale construction in U.K
- A planned completion timescale of just 11 months
- Construction site - extra ordinarily tight
  - Footprint reaching right up to the perimeter
  - No storage, space to work on site
- Every part had to be prefabricated and ready for installation.
- Most of the construction work for the building done in factories and workshops



# Joint detail

- The key point of the structure design is the design of connection joints of the the external mega-frame.
- Connections transfer 6,000 tons (forces) in at least three different directions.
- Typically, six elements come together at each joint in a variety of angles within the mega frame
- Prefabricated nodes & Instead of site welding





# Joint detail

- The nodes' bolts are high strength, threaded pre-tensioned bars up to 76mm in diameter, whose prestress is less than 200 tons.
- The connections are made within the profile of the members and transfer their pre stress to the members' ends via plated bolt boxes situated between the flanges of the main steelwork beams and columns.
- All connections on the mega-frame can be done with this bolt-on "cross" structure without affecting the exterior

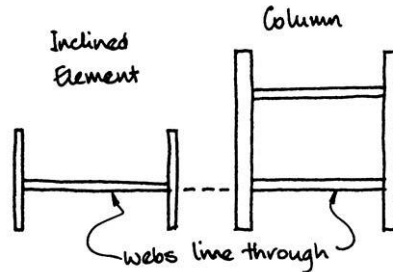
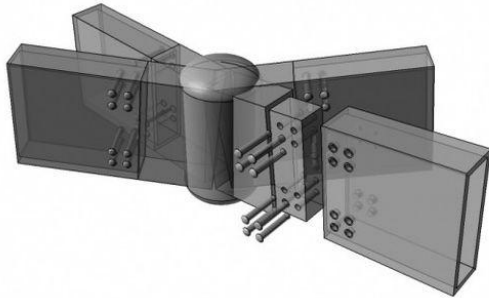
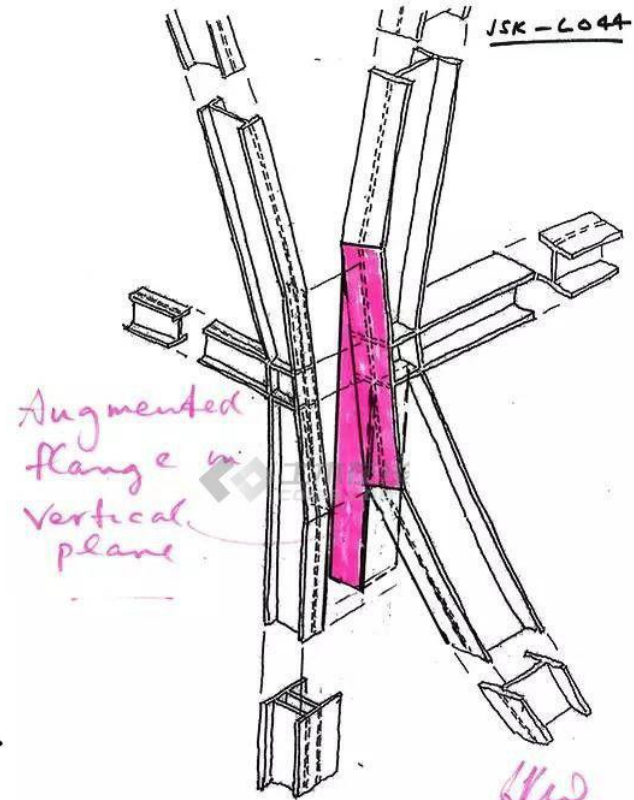
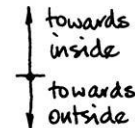


Figure 1



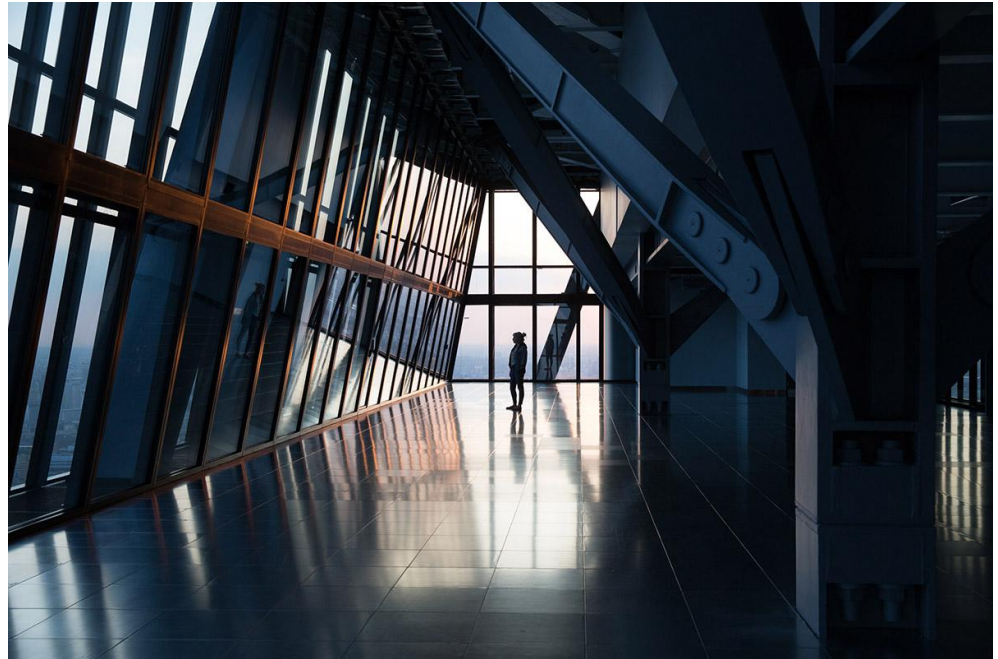
122 LEADENHALL ST - ARUP JOB  
SSK/151 EXPLODED VIEW ON NODE 6 30.3.2006 (SPACES NOT SHOWN)

# Joint detail

- Engineers designed large 16-20t nodes (see box below), typically measuring 6m × 3m, which connect straight mega frame members.
- The nodes provide the geometrically complex transitions between the different elements through welded joints between carefully orientated plates.

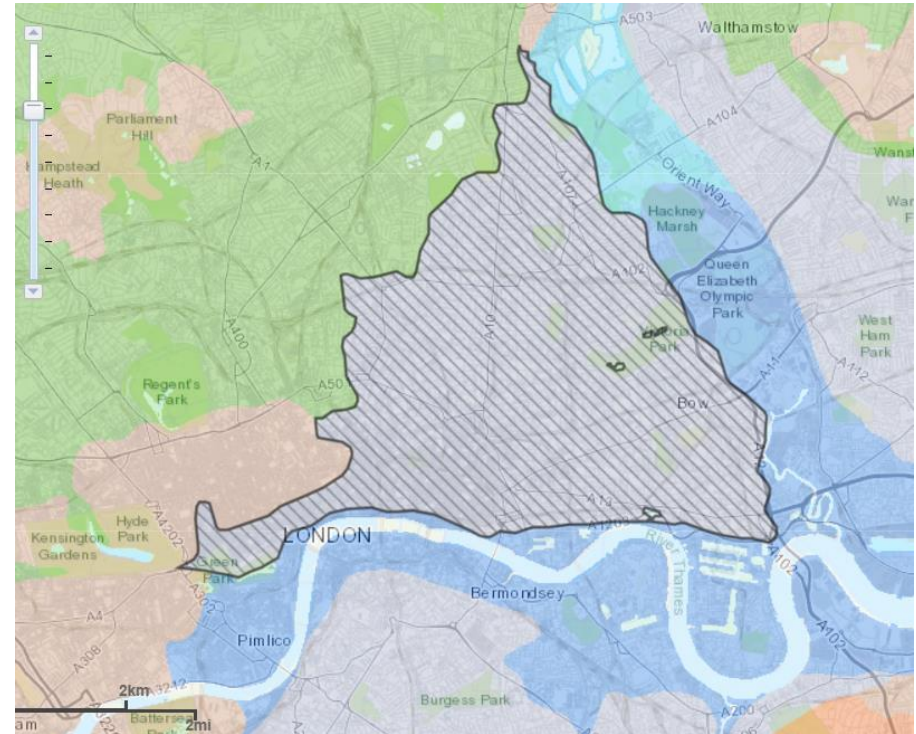


- These joints and the structure are not only functional but also aesthetic.



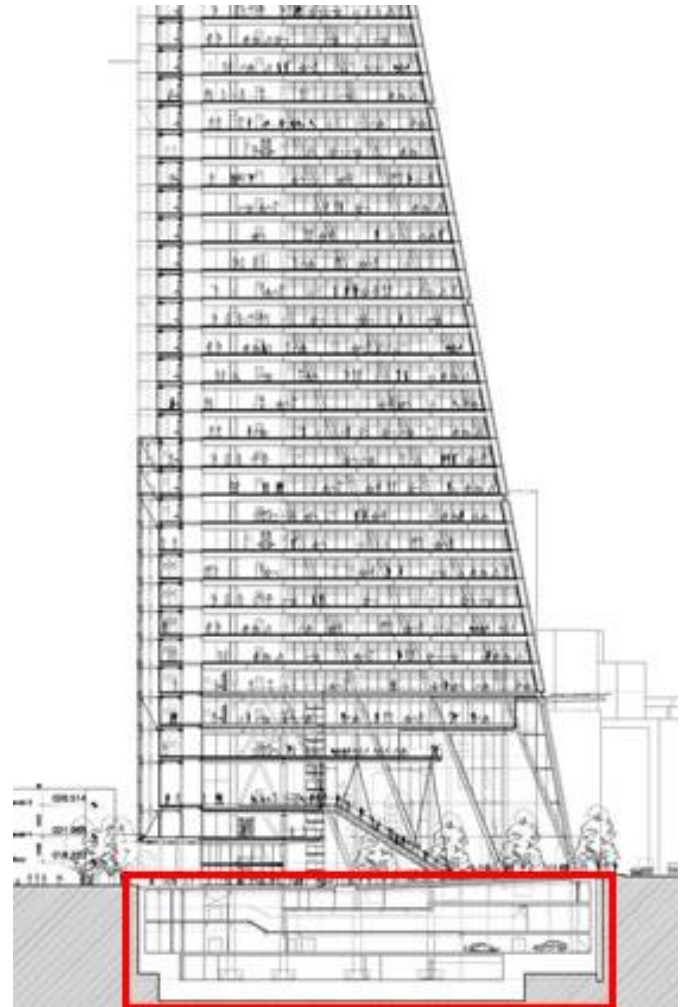
# Soil analysis

- Soil type: Loamy soils with naturally high groundwater.
- Description:
- 'Light' soils have more sand grains and are described as sandy, while 'heavy' soils have few sand grains but a lot of extremely small particles and are described as clayey. Loamy soils have a mix of sand, silt and clay-sized particles and are intermediate in character. Soils that have a surface layer that is dominantly organic are described as Peaty.
- In low-lying sites, permeable soils are often affected by high groundwater that has drained from the surrounding landscape. They are described as naturally wet.
- Water protection:
- Soils are mostly drained. Shallow groundwater and marginal ditches to most fields mean that the water resource is vulnerable to pollution from nutrients, pesticides and wastes applied to the land



# Basement Foundation

- The 14-story 1960s P&O building that previously occupied the site had a three-story basement, but the new building required more volume below ground, so a fourth level was introduced.
- To avoid undermining adjacent perimeter structures, the extra basement level was confined to the site's central area while the third basement level foundation slab was designed so that, together with some minor temporary works, it could be built first and give support to adjacent structures. This minimized the temporary works needed to construct the lowest basement story.
- The perimeter mega-frame columns to the east, west and south sides are supported on new retaining walls cast on the insides of existing perimeter structures. Large base plates and columns are cast into the new retaining walls at first or second basement level, so as not to impact architectural requirements at ground level.



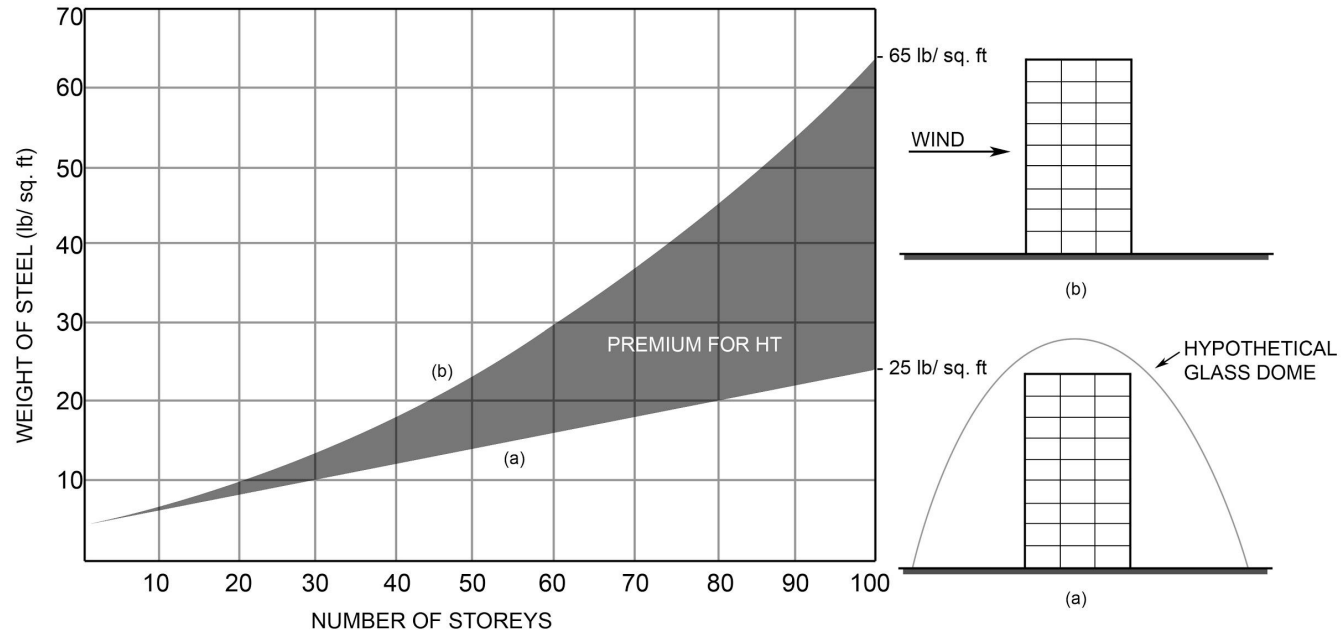


# Load Transfer Mechanism

## Dead load

Most material used in the Leadenhall is steel and they compose the major part of dead load. The total steel using is 18,000 tons.

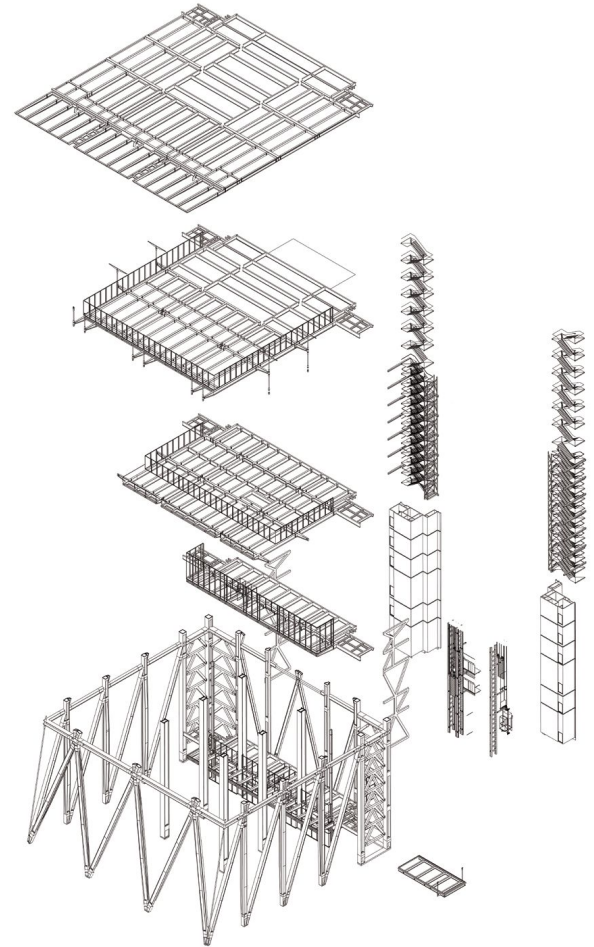
Structural Height Premium for structural steel buildings. The lower curve represents theoretical designs for gravity loads exclusively; the upper curve incorporates additional structural material required for resisting lateral wind and seismic loading (diagram adapted from diagram of Yasmin Khan, 'Engineering Architecture: the vision of Fazlur R. Khan')





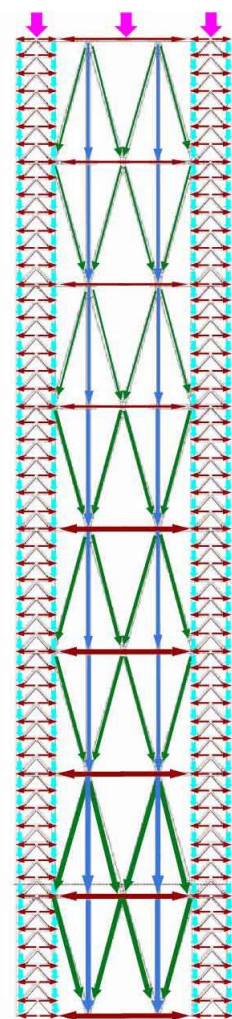
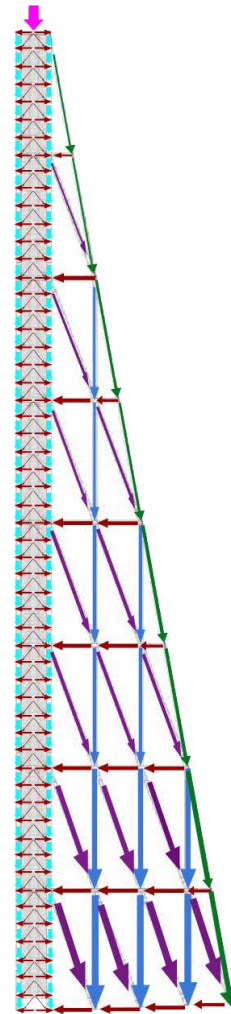
# Load Transfer Mechanism

- The main structure of the building has only six internal columns, and the span of the grid is 16m deep and 10.5m long, creating such a clear and flexible floor space.
- The expressed structure, triangulated mega-frame is divided into eight proportion, and each of them works like what the design team terms mega-levels of 28m high, each containing seven floors, apart from the first, which is five floors.



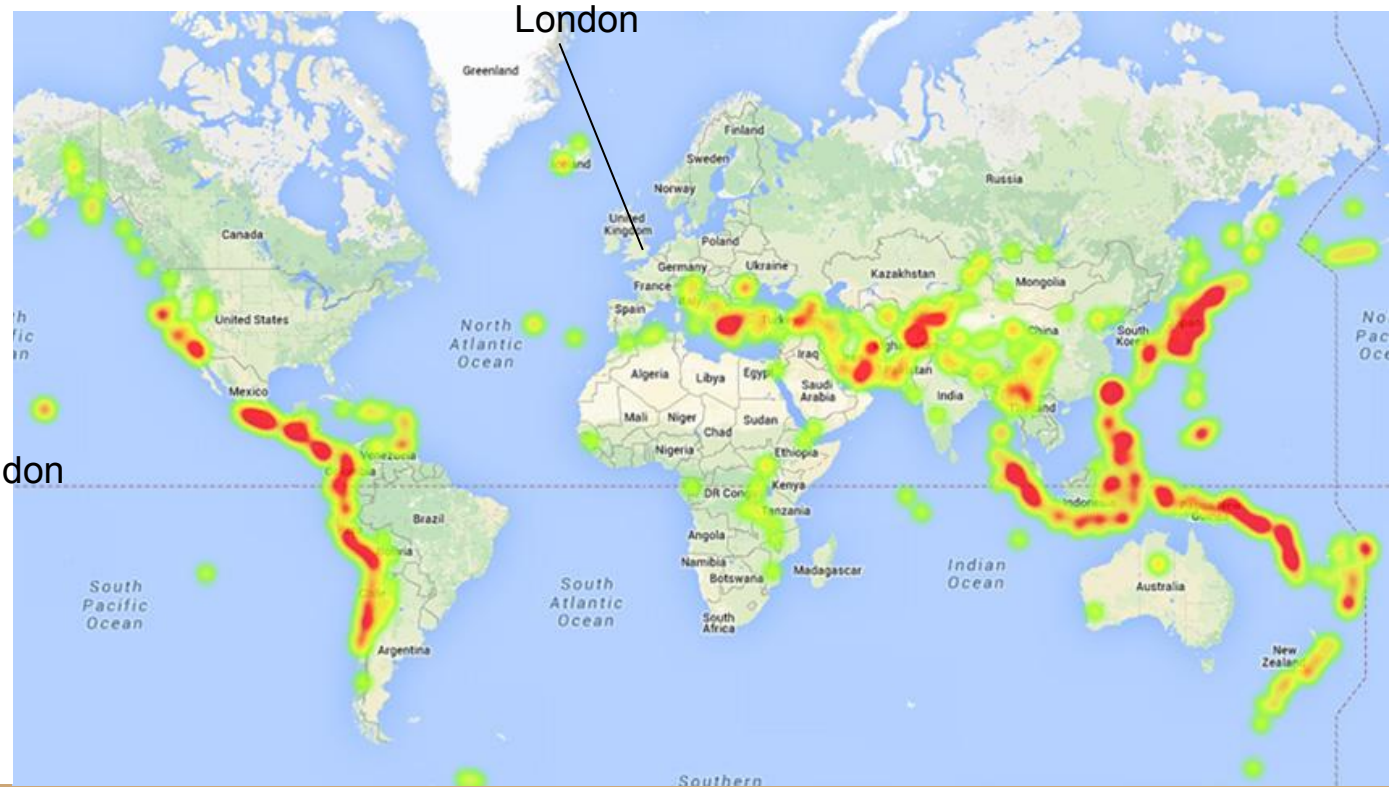
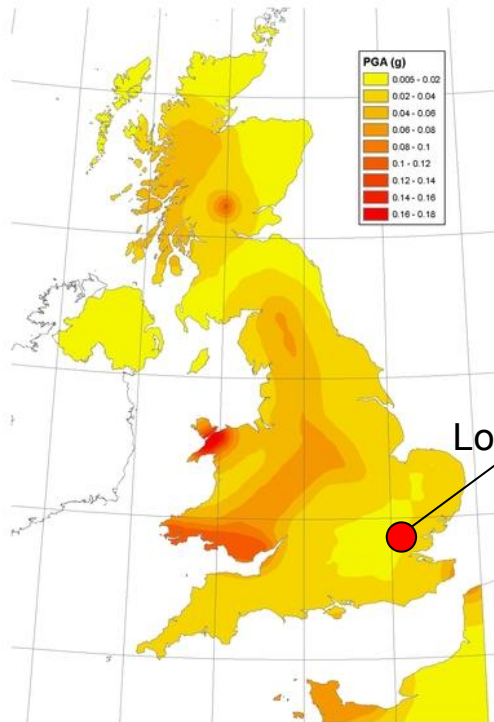
# Load Transfer Mechanism

- The superstructure arrangement led to very high loads under the mega-frame at the edge of the site, as well as under the six internal columns.
- The loads are supported by large diameter bored piles founded in the London clay.
- Because of the mega-frame located at the very edge of the site, these large-perimeter piles must be eccentric to the building.
- The mega-frame are linked to the internal column piles via a 2.7-meter-thick raft slab covering most of the site.
- Because of the building shape, this thickness reduces to the south where the column loads are considerably less.
- As the advantage of the tapering, perimeter-braced diagrid structure, loads reduce from the basement level to the top level. In this way the whole structure system can bear more loads.



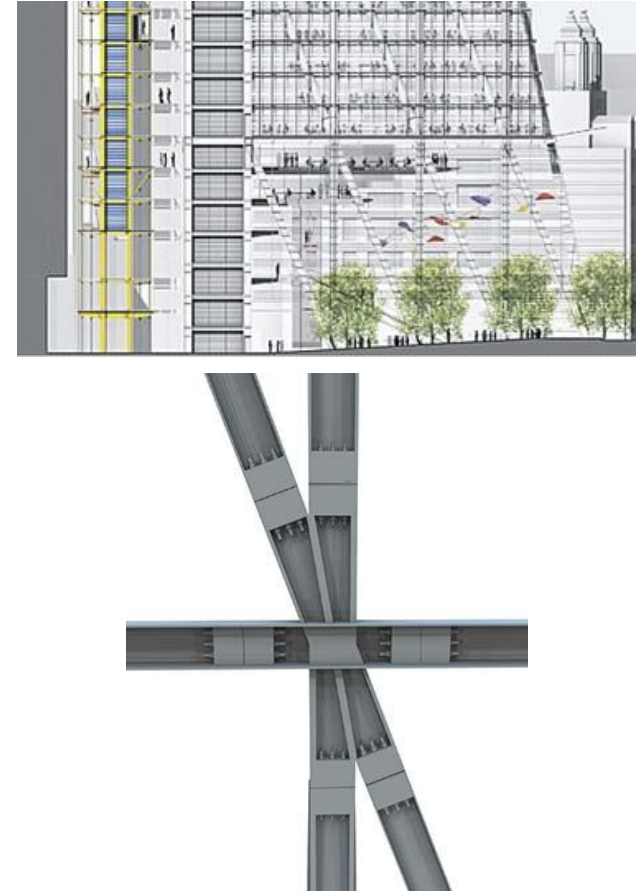
# Lateral design-seismic load

World earthquake danger zone



# Lateral design-seismic load

- The PGA (peak ground acceleration) in London is 0.02 - 0.04.
  - Converting it to US. seismic zone is zone 0.
  - it means London is more safer than Texas about happening earthquake.
1. Disadvantage of seismic
    - The bottom overhead construction in ground floor, no diaphragma in over 4 stories high.
    - No shear-wall
  2. Advantage of seismic
    - Steel is good material to be stable in Short-period earthquake.
    - This structure have the natural seismic Joint
    - The exterior truss tube.





# Lateral design-wind load

- $$F_w = p_d A$$
$$= 1/2 \rho v^2 A$$

where

$F_w$  = wind force (N)

$A$  = surface area (m<sup>2</sup>)

$p_d$  = dynamic pressure/wind load (Pa)

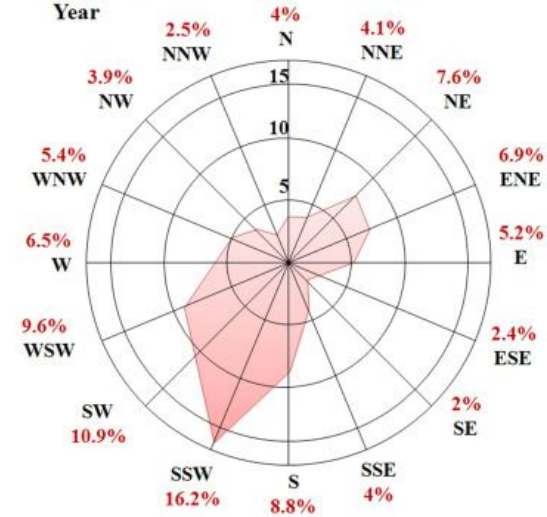
$\rho$  = density of air (kg/m<sup>3</sup>)

$v$  = wind velocity (m/s)

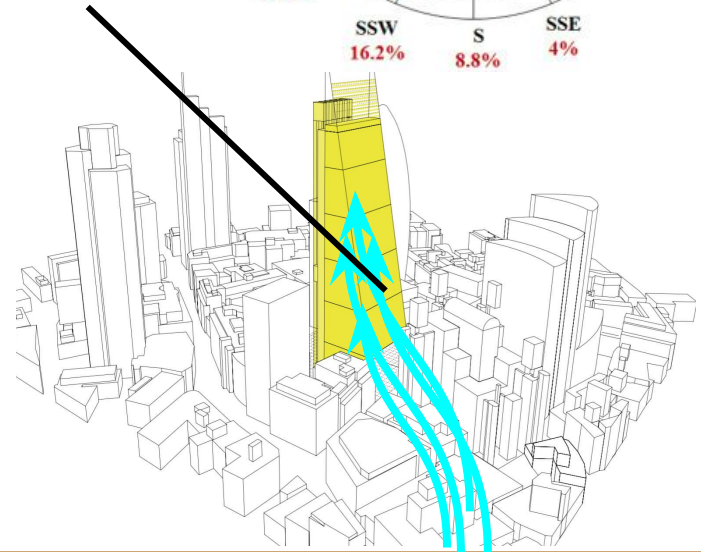
- The most important wind is from SSW and north west side and It makes to structural design for wind load resistance in this direction. However, the wind speed is not too much, convert to **MPH** is **33.5**.

- $v=15\text{m/s}$
- $\rho =1.2\text{kg/m}^3$
- $p_d/Lw=135 \text{ Pa}$  (N/m<sup>2</sup>)

Wind direction distribution in (%)

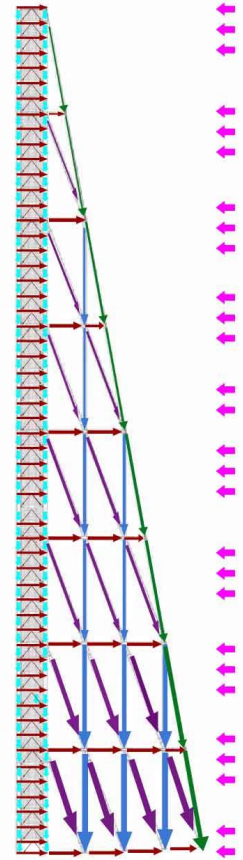
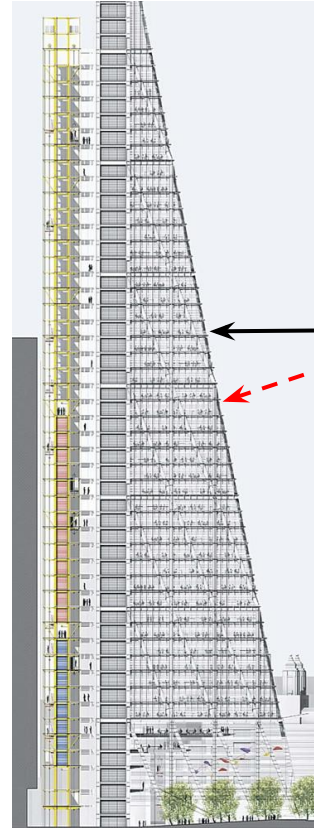
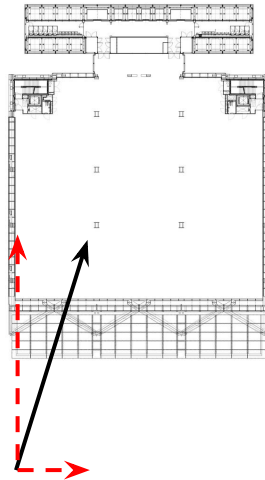


Main direction of wind



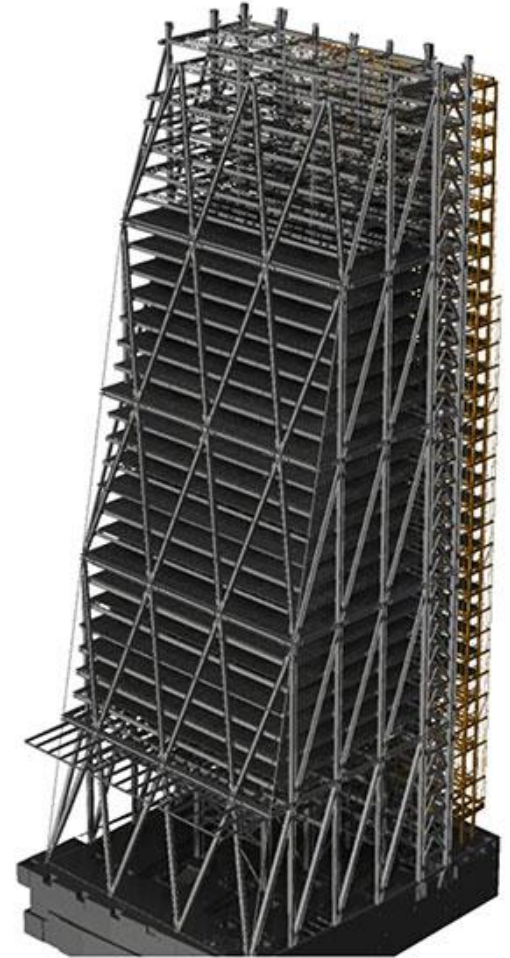
# Lateral design-wind load

- The Tapered and inward sloped facade is good way to reduce wind loads.
- Wind speed will be decomposed and part of it does not work on wind load press.
- The reduce of load is more than 2%, not too much but useful.



# Lateral design-wind load-conclusion

- Both of seismic and wind load are not the primal design concern for London is not in the major seismic zone and there are no big wind here.
- The exterior truss provide a very stiff ring or tube about building so that they have the capacity to carry any direction lateral loads. Especially in the leadenhall building, the diagrids connected with the horizontal floor beams generate stable triangles.
- The tarped facade reduce the wind load.



# Material

## Steel:

- 11252 pieces of steel
- 18000 tonnes
- sprayed prior to site assembly with a marine standard, epoxy intumescent coating in layers of 3-12mm, depending on the thickness of the steel
- Structure contains 500 tons of paint
- 90 minutes of fire protection

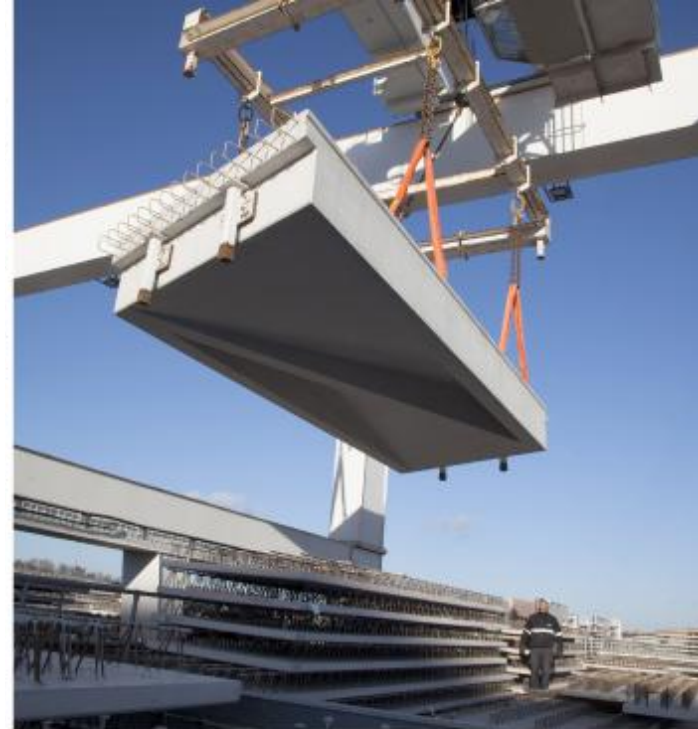




# Material

## Precast concrete components:

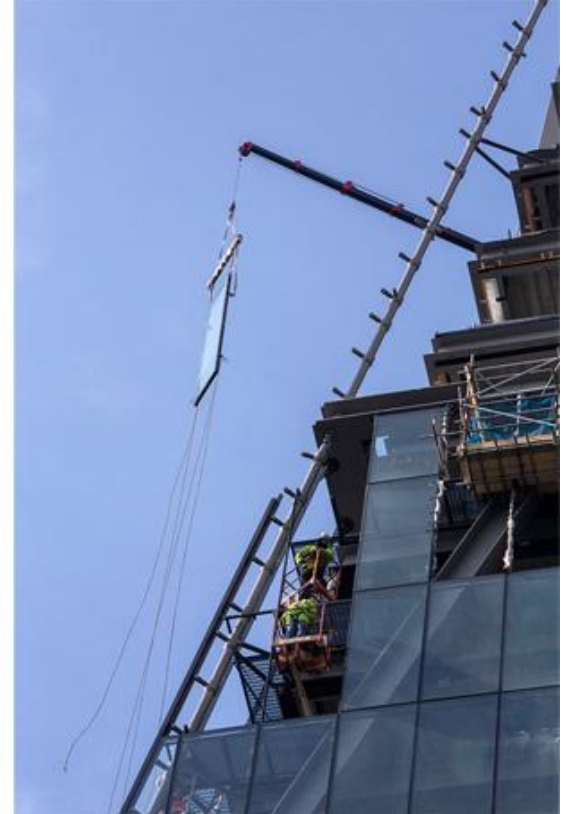
- precast planks above Level 5
- 150-millimeter-deep concrete slab over 700-millimeter-deep fabricated steel beams.



# Material

## Glass:

- Facades require the highest comfort criteria in relation to heat loss, daylight, glare control and solar gain
- the facade is supplemented with an internal layer of double-glazing, forming a cavity which incorporates the structural frame
- The external glazing incorporates vents at node levels to allow outside air to enter and discharge from the cavity



# Summary

- The Leadenhall Building seems to be a miracle in construction history for its unique building method. 80% of the elements pre-assembled off site (DFMA). This included integration of trades such as for the North Core tables, and the development of a new lightweight precast flooring solution.
- This building is a great example to build a tall skyscraper in a limited area. A ladder, stair-shape solve the problem easily and create a breathing public for London city.
- Like many modern buildings, environmentally sustainability is an important part during the design process. Inside the building, all Modric stainless steel door fittings made from 62% recycled material, but also 95% of the material can be recycled at the end of the products life.

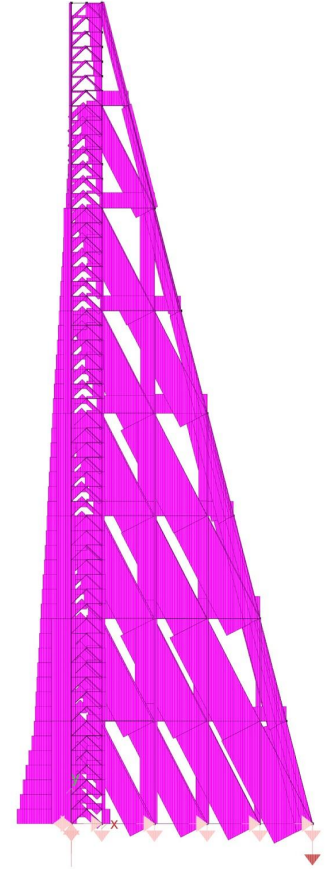
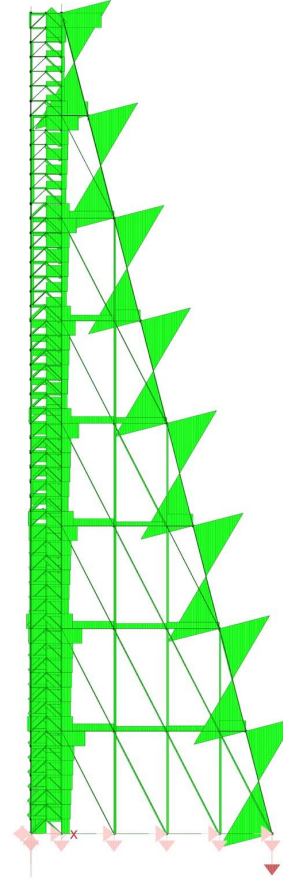
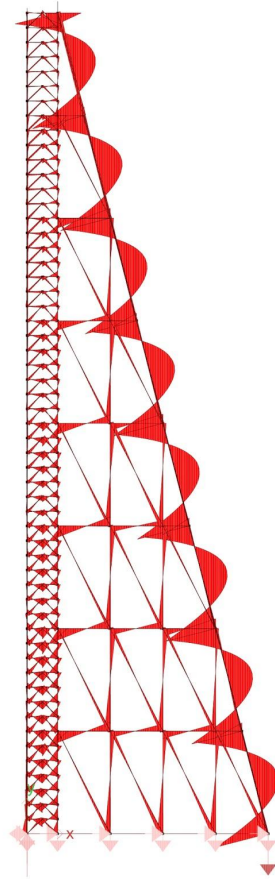


# Multiframe

Wind load = 5.6 kN/m

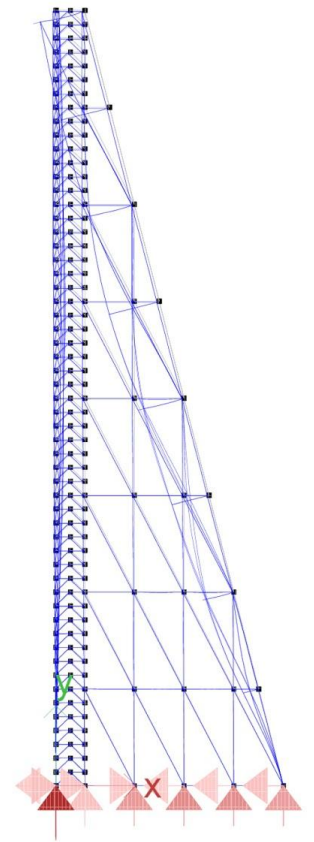
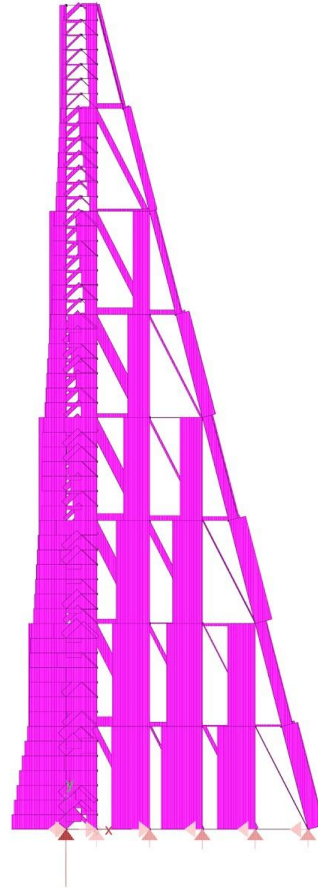
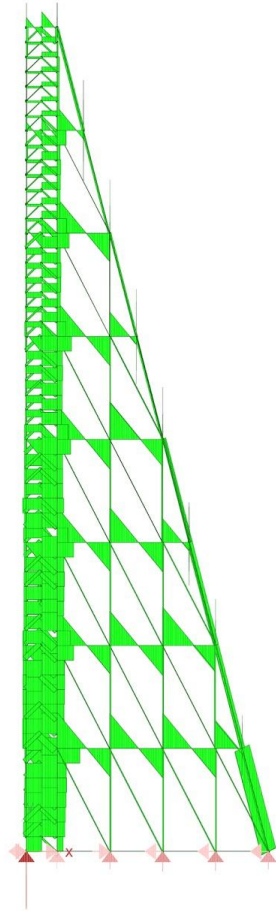
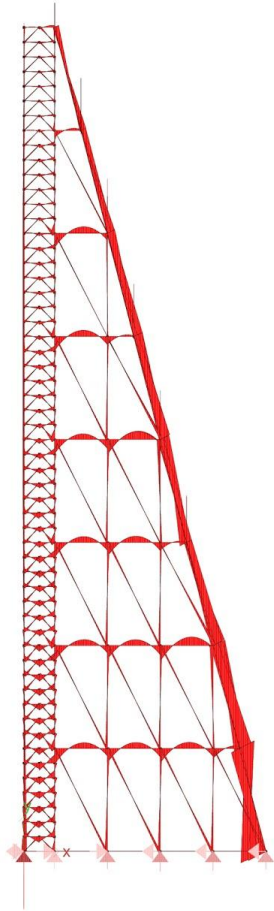
Mmax = 415.44 kN-m

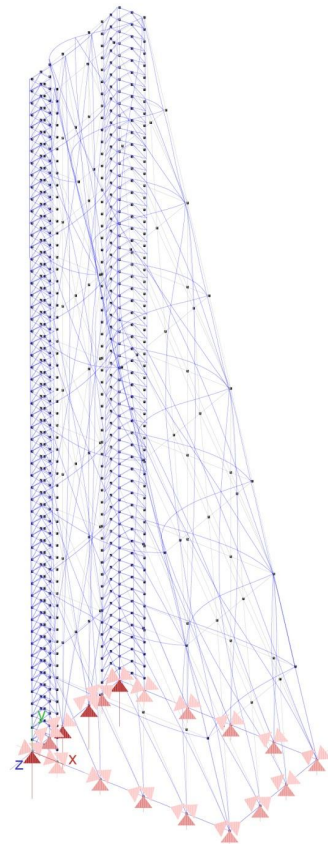
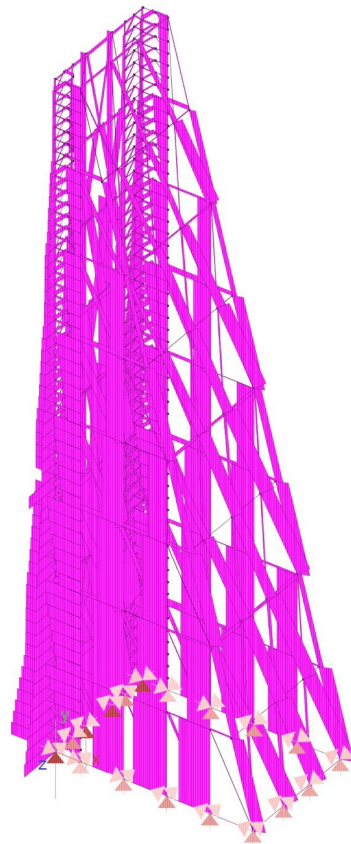
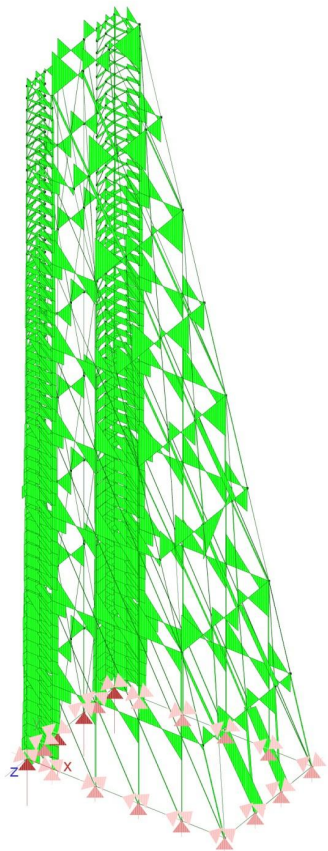
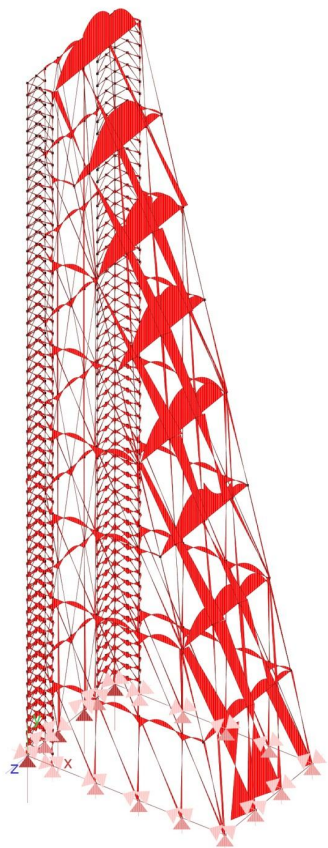
Smax = 818.8 kN



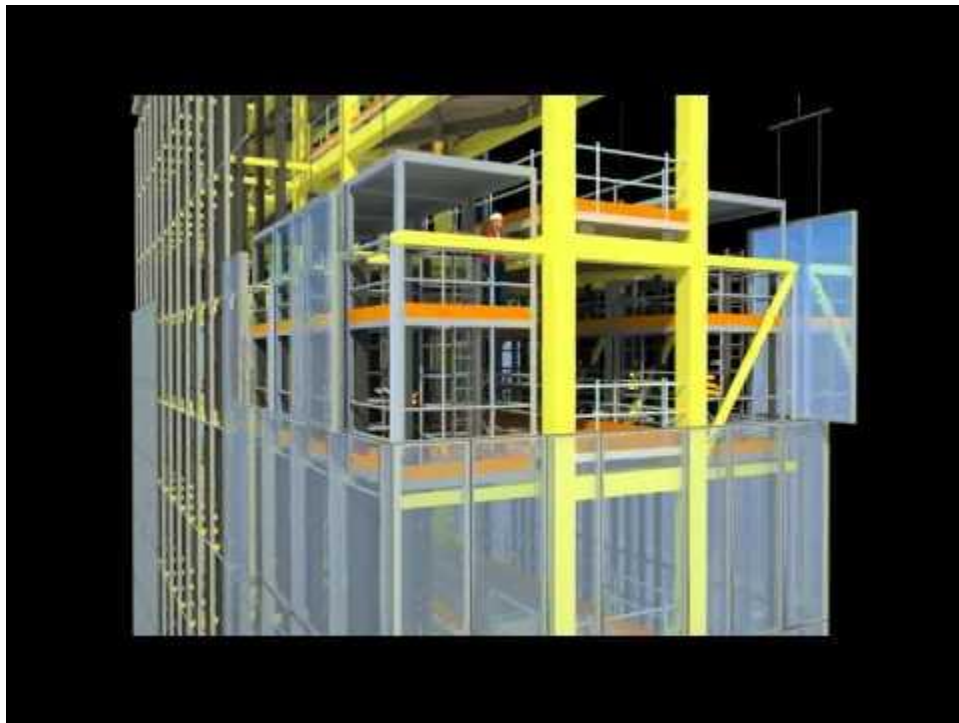


## Dead load





# VIDEO



# Reference

- <http://global.ctbuh.org/resources/papers/download/19-case-study-the-leadenhall-building-london.pdf>
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