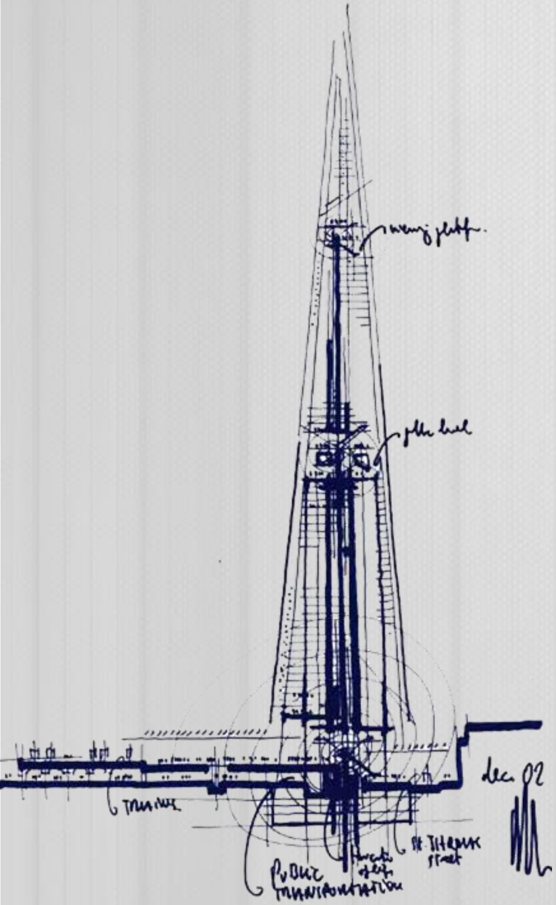


The Shard at London Bridge

Structure Case Study by:

Leslie Tijerina - Adrian Silvas - Hardik Jariwala

Azadeh Mahmoudi - Saideh Sadri - Behzad Yaghmaei

ARCH-631 / Dr. Anne Nichols

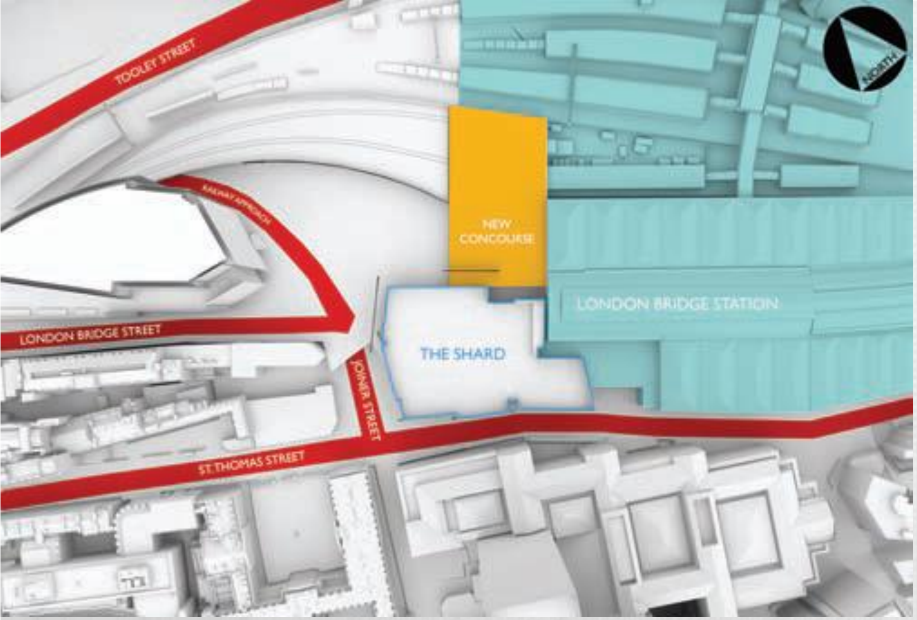
Fall 2016

THE SHARD

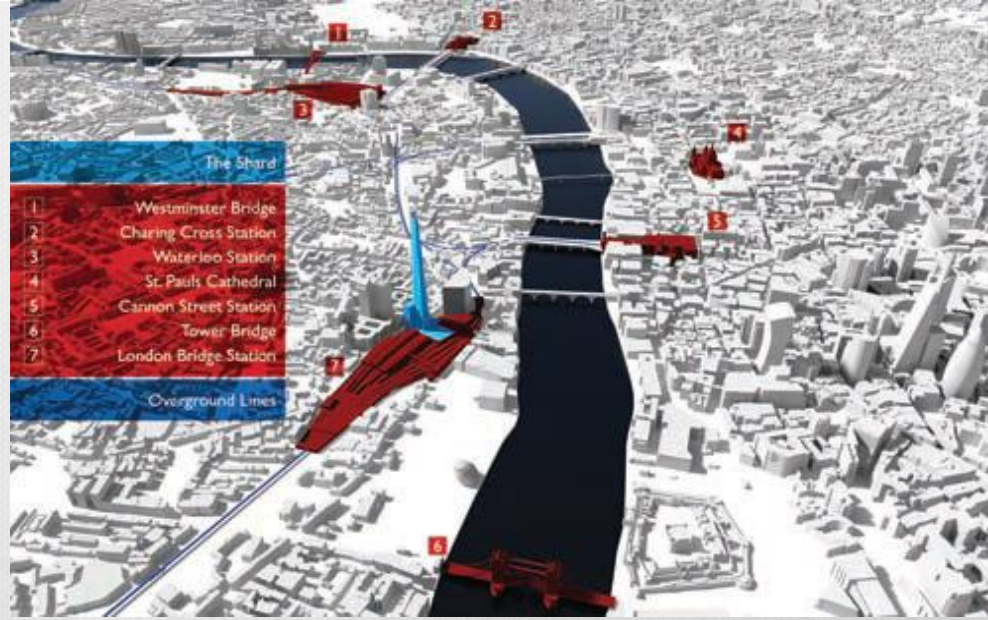
CONTENT

INTRODUCTION

Client: Teighmore Ltd c/o Sellar Property Group
Location: London
Project Year: 2009 - 2012
Project Area: 1,200,000 sq ft
Height: 1,016 ft (310 m)
Project Costs: £435 Million
Lead Architect: Renzo Piano Building Workshop & Adamson Associates
Structural Engineer: WSP Cantor Seinuk

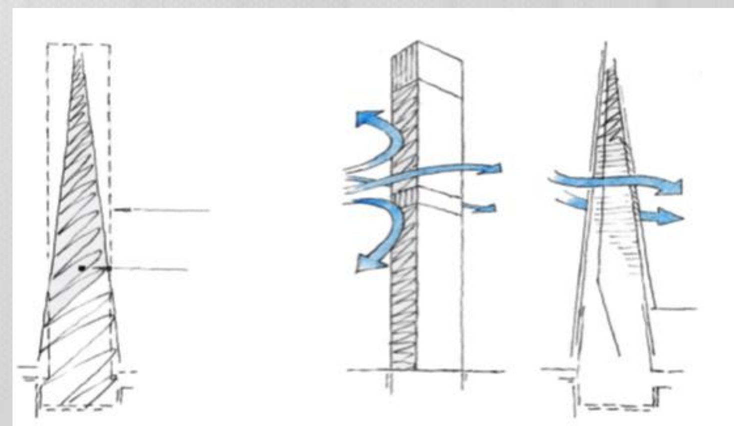


Located in the center of a transportation hub, The Shard's aims to sympathize with urbanscape.

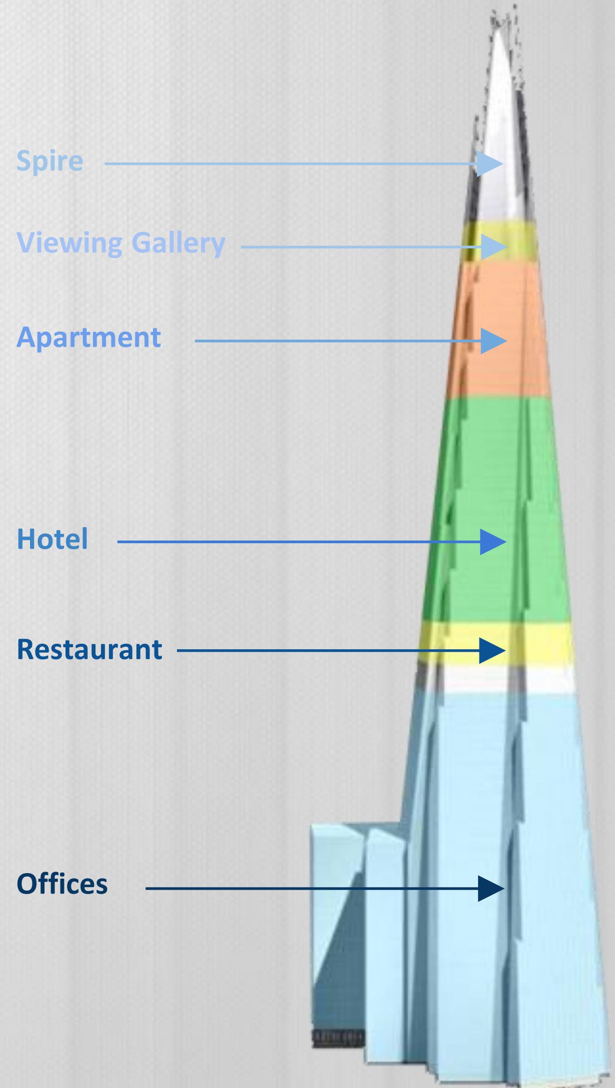


The goal for the design was to accentuate the urban and create a structure that would blend with the skyline.

DESIGN CONCEPT



Since the schematic design process, geographic conditions were designed for.



PROJECT REQUIREMENTS

Residential
62,000 sq ft

Offices
594,000 sq ft

Hotel
192,000 sq ft

Retail
61,000 sq ft

Gross Internal Area	1,367,000 sq ft
Area of Facade	600,000 sq ft
Population	8,000
Lifts	44
Car Parking Spaces	48

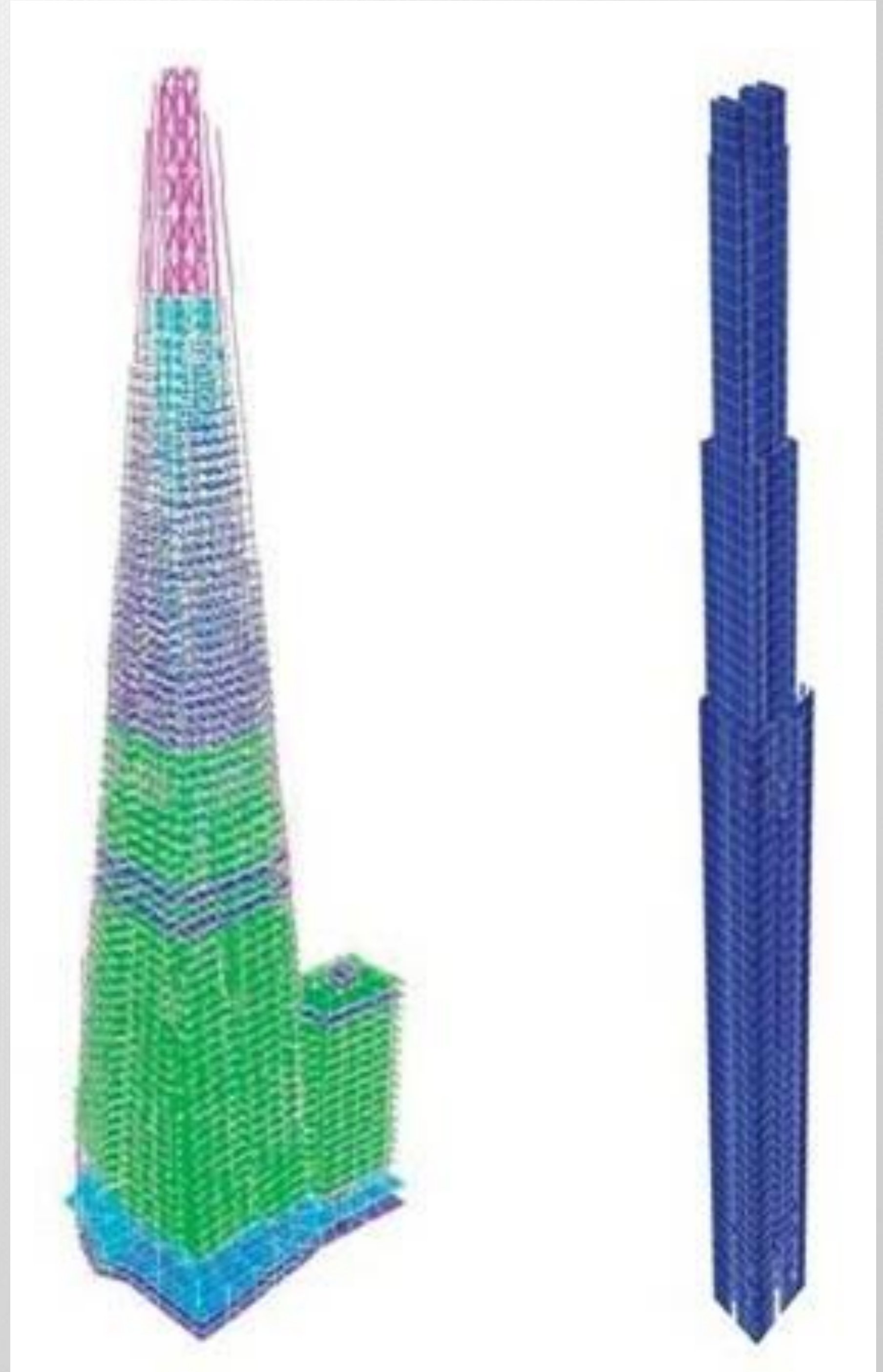
Volume of Concrete	580,000 sq ft
Weight of Steel	11,000 tons
Glass Panels	11,000

MAIN STRUCTURE

- The structural system of the tower is a combination of different systems. It consists of concrete cores, composite floors, and steel structural members.

- The Shard Tower has about 54,000 cubic metric tons of concrete and the steel system has a weight of about 11,000 tons.

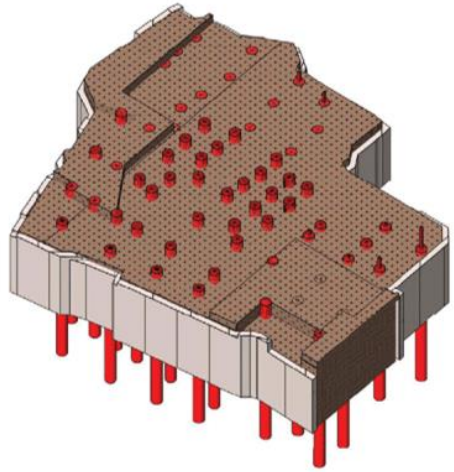
- The core of the tower was made by slip forming. The core was constructed at a rate of at least 3 meters per day.
- The steel columns are aligned with the slope of the Shard Tower.
- The size, weight, and spacing of the columns get smaller the higher they go up in floors. .



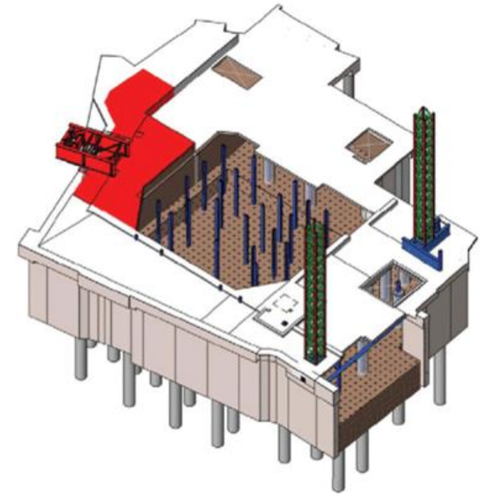
THE SHARD

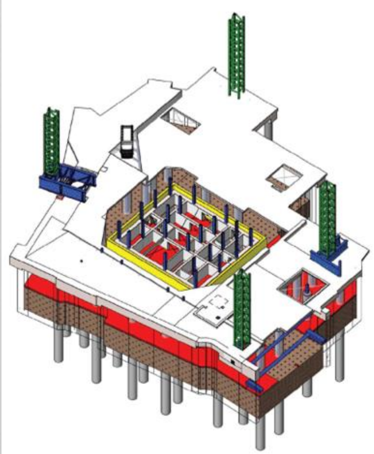
MAIN STRUCTURE

Step one
The secant pile wall is installed around the perimeter along with the plunge piles and columns.

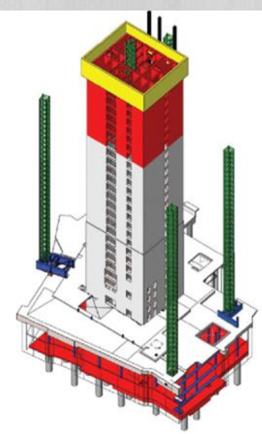


Step two
The ground floor slab of the building is cast and excavation begins down to level two of the basement.





Step three
The floor slab at basement level two is cast and the slipform for core construction erected to "jump start" the core. As the core goes up excavation below basement level two continues.



Step four
As the core construction continues, the raft foundation is cast at basement level three (the lower red level in the picture) before the concrete walls between the base of the core and the raft are installed.

MAIN STRUCTURE

- The Shard Tower's spire was pre-constructed due to the height of the building and the strength of the high winds at that level.
- The weight of each component of the spire had to be calculated so that they did not surpass the tonnage limit of the crane.
- Total weight was about 530 tons
- Units were about 3 meters wide and bolted together.

COMPONENTS

•The floor framing in the Shard was altered with height; the office levels were designed in steel, while the hotel and residences were framed in concrete. The transition did not exactly match the change of use; steel construction was continued up to level 40- six floors above lowest part of hotel.

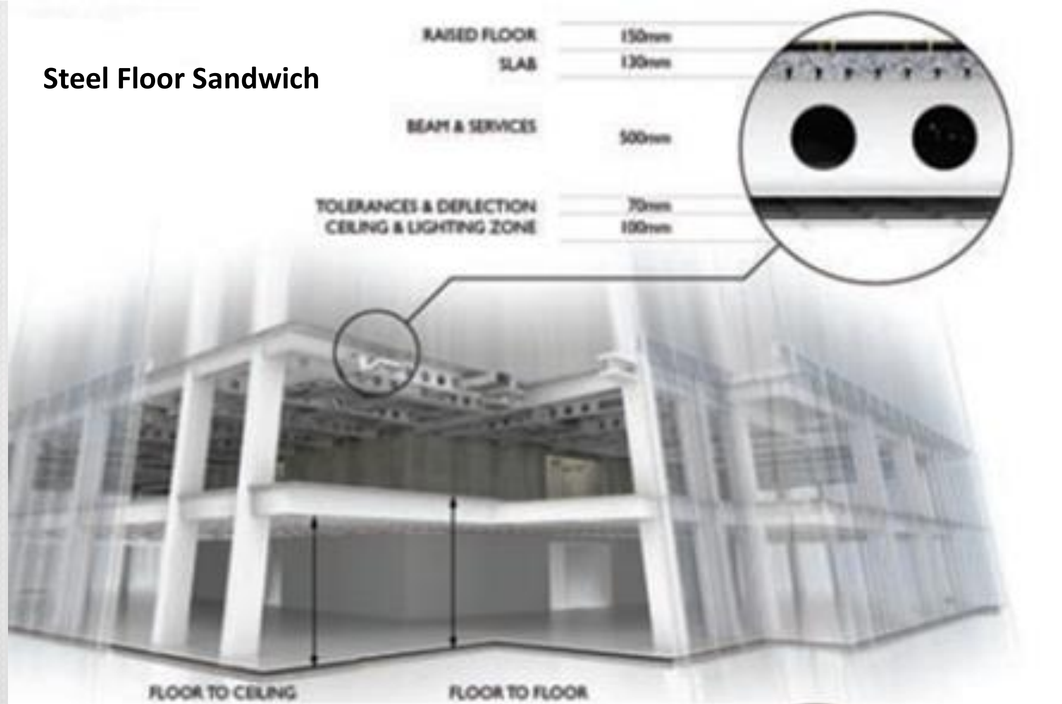
• The reason for this mismatch was related to the span between perimeter columns and the low allowable deflections of the glass façade.

• The composite edge beams achieved the required performance with a span of 6 but in the concrete levels, the maximum perimeter column spacing was 3m because down-stand beams were not preferred.

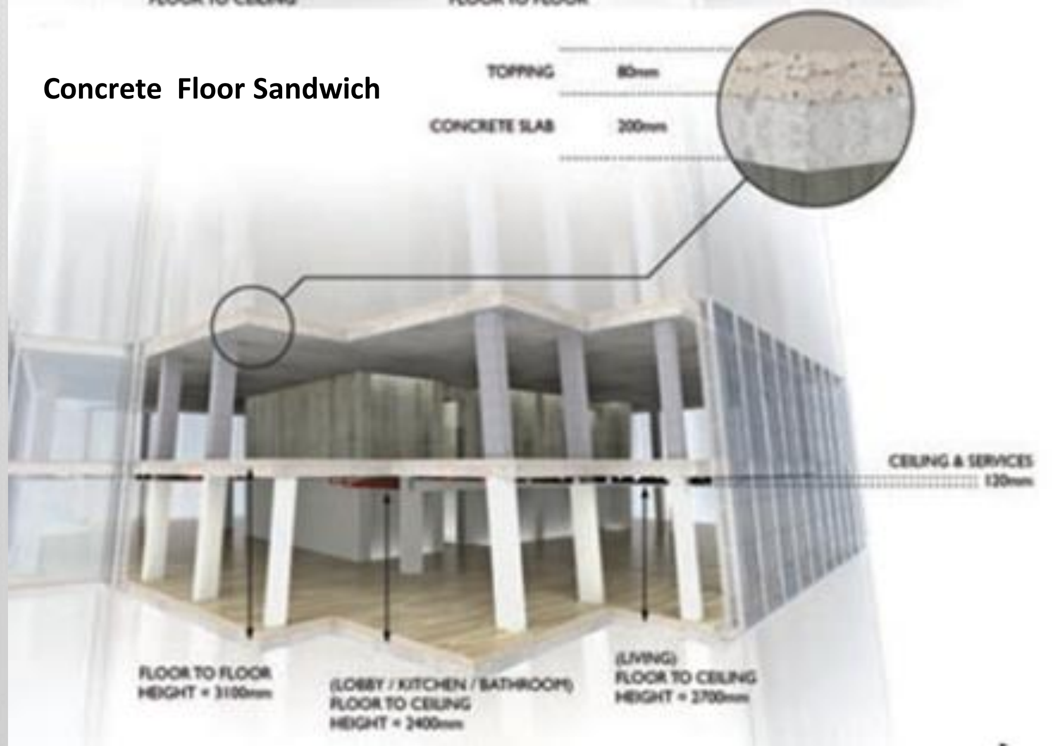
• Transfer structures were needed in order to achieve the reduction in spacing, and these took the form of three-storey high vierendeel frames at the top of the steel levels (i.e. from level 37 to level 40).

Floors

Steel Floor Sandwich



Concrete Floor Sandwich



COMPONENTS

• The façade of the building was recognized as its most distinctive feature.

• The architect desired a very clear appearance, without the common green tinge that is often seen.

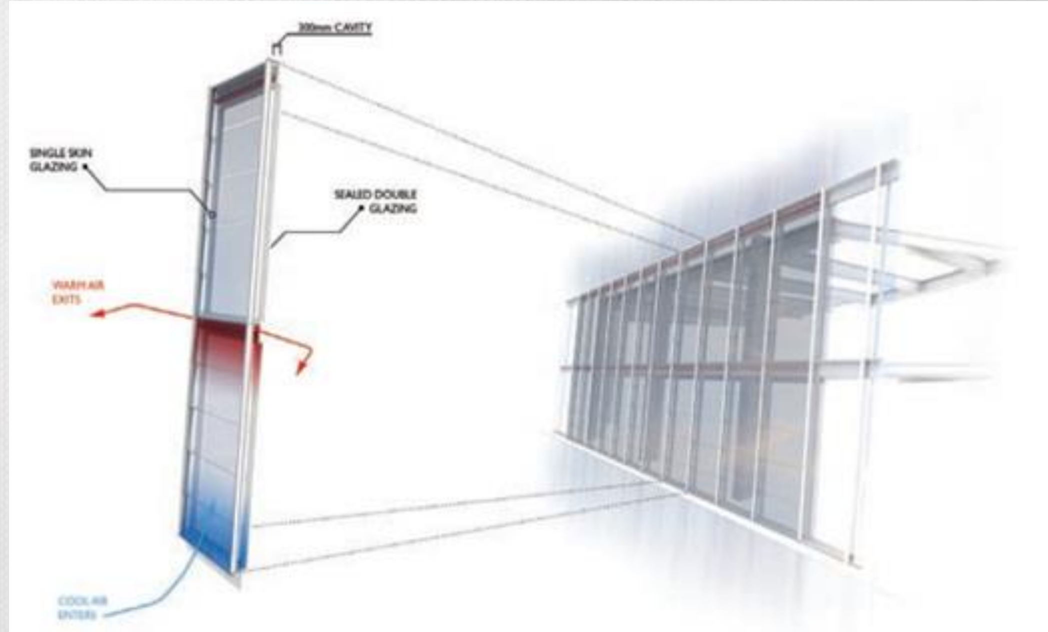
• Triple-glazed panels were produced, with a single skin on the outside and a sealed double-glazed unit inside. The shards were extended beyond the edges of the floor plates as “wing walls”, providing additional visual definition to the separate façade planes.

• The outer cavity is 300 mm wide and is ventilated at each floor level. When the air in the cavity is heated by the sun, it rises and exists through the vent at the top of the panel, drawing cool air in at the bottom.

• In addition, the cavity contains a roller blind, operated by the building management system (BMS) to further reduce solar gain.

• Users of the shard can lift a blind to see the view, but after a short time the BMS lowers it again.

• For office floors, it is possible to open the outer façade slightly in the winter gardens to admit fresh air, although the opening mechanism is connected to the BMS. If the temperature is too low, or the wind speed is too high, the window cannot be opened.



Safety detail at perimeter

Facade Safety Detail At Perimeter

A unique prefabricated edge detail was provided to the steel floors, with steel tubes installed on a plate to enable immediate installation of safety barriers to the perimeter of the building

COMPONENTS

"The Spire"

• The 'Spire' is the 60m tall pinnacle at top of the tower, containing the public viewing gallery.

• The concrete core stops at level 72 and continues as a steel mast.

• The solid floors are replaced by open grids and the shards stop at different levels.

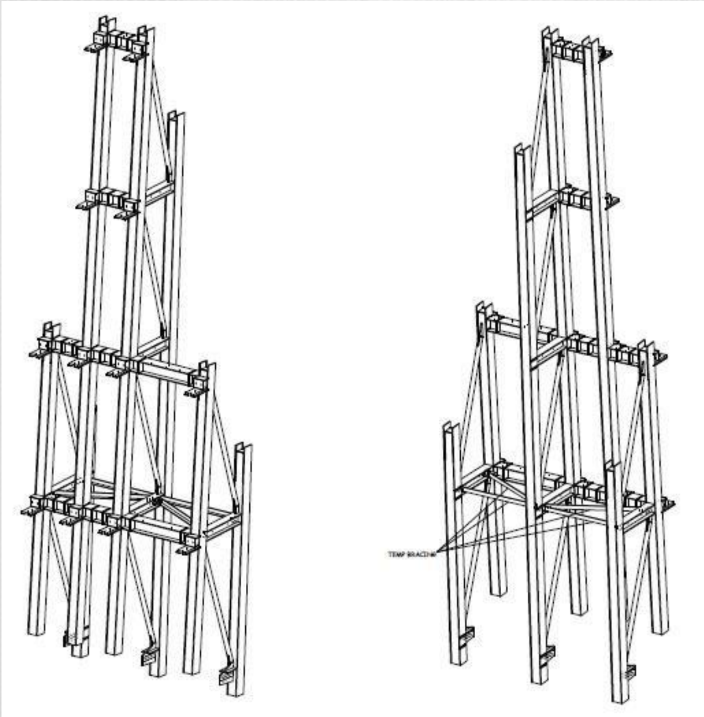
• The spire comprises a central steel mast to provide stability, floor plates every third level and the 'shards' themselves.

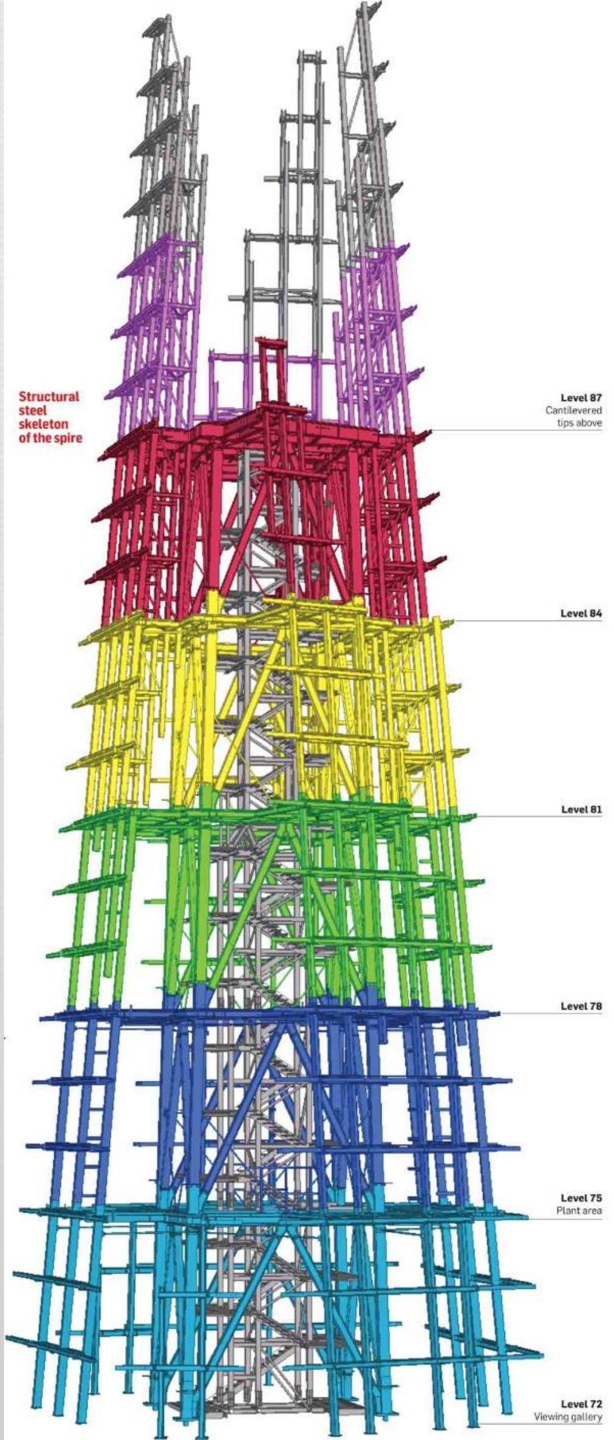
• The shards extend past the top floor plate by up to 18 m and are supported by cantilevering trusses.

• The compression booms are restrained by U-frame action from the trusses acting together with the frames in the plane of the facade.

• The wind tunnel test on the spire checked the structure for any resonant or 'galloping' effects from wind gusts.

The Spire



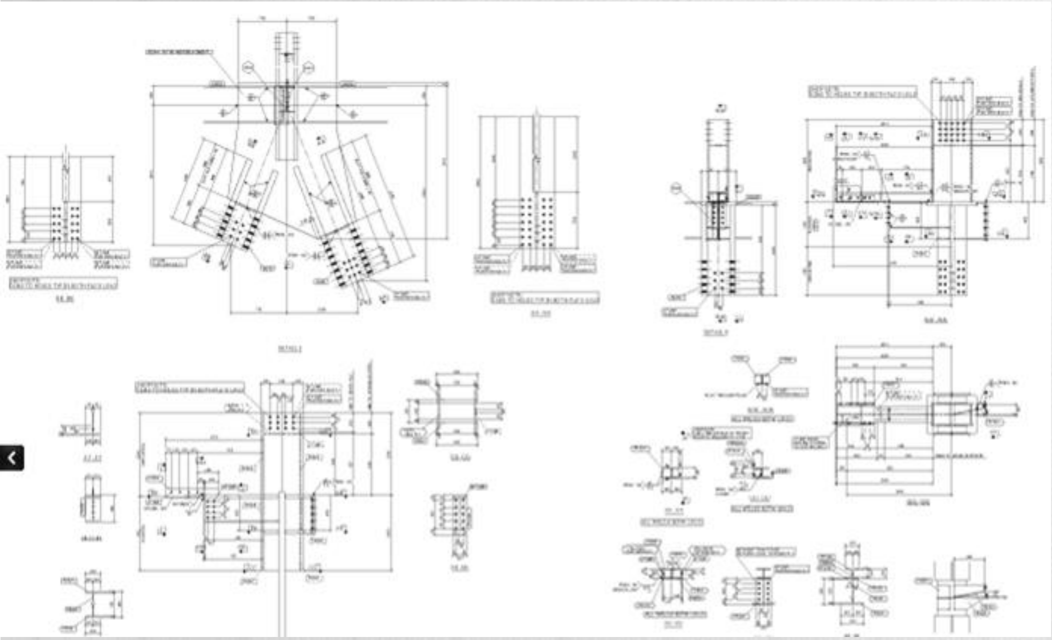


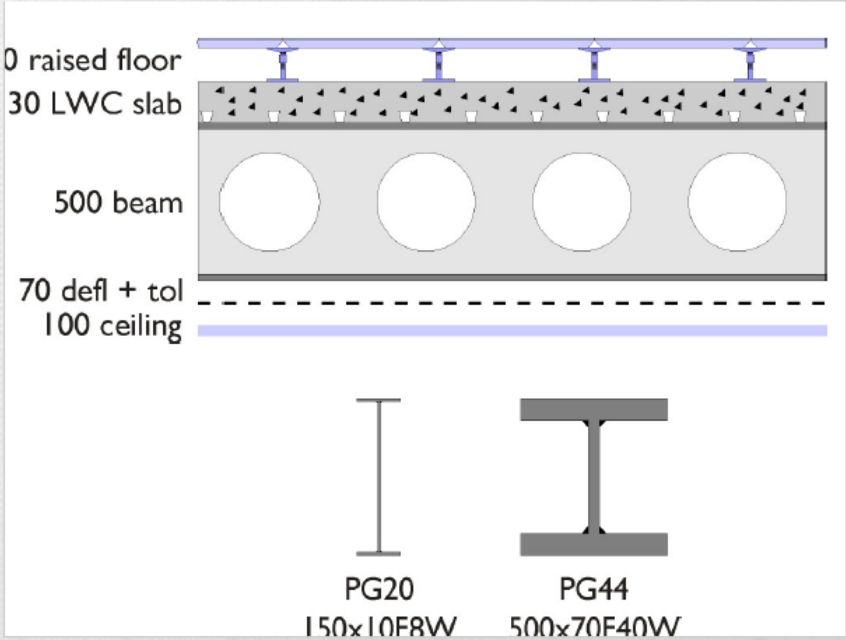
THE SHARD

CONNECTIONS

- Where bolted connections couldn't be avoided, the architect worked with the steelwork contractor to dress the connections with cover plates. For example, on the connection between the vertical, horizontal and diagonal bracing Severfield-Reeve produced curved plates.

- Other connections were dressed with filler after erection, and over-coating such as those on the wing walls, which have flush welds or hidden connections.



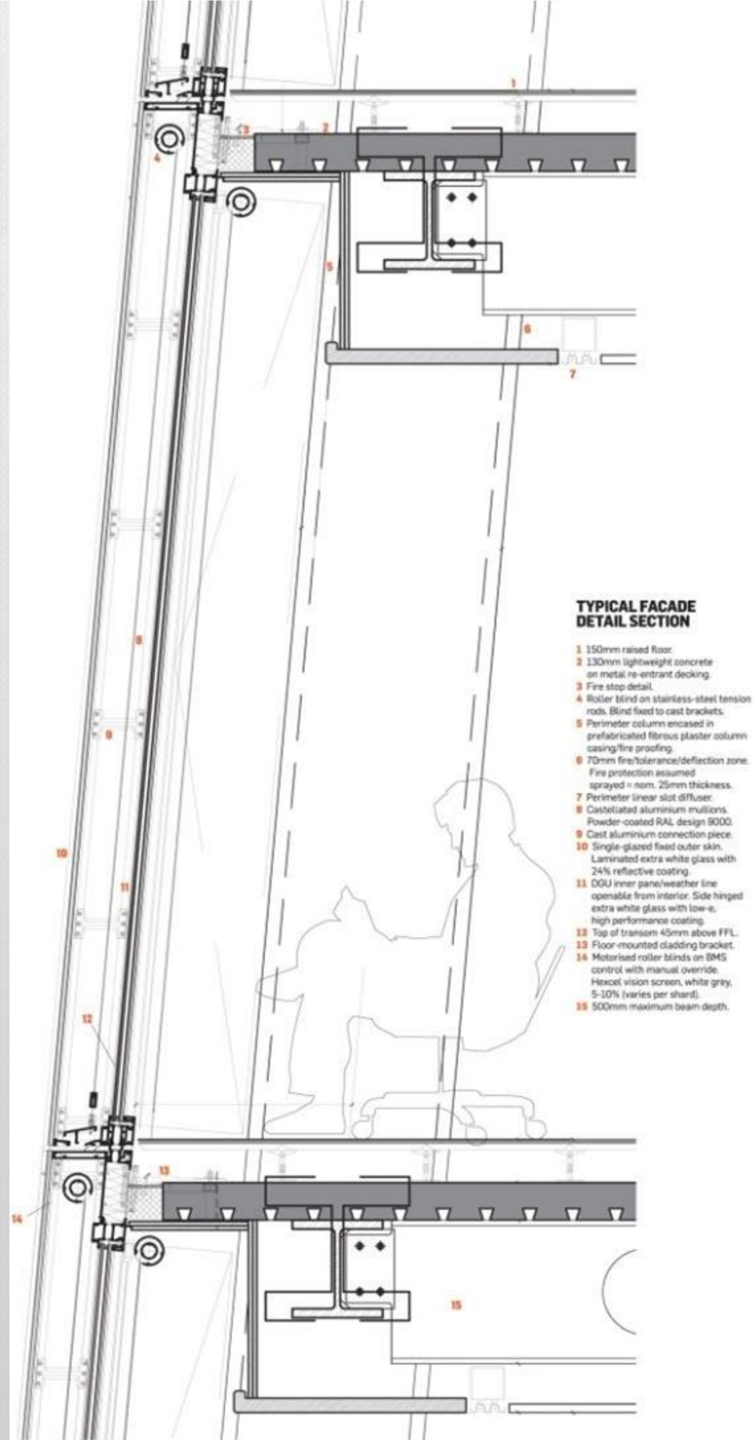


CONNECTIONS

- “They went to a lot of trouble to minimise the size of connections and make the welding neat,” says John Parker technical director of engineer WSP.
- The spire has a steel stair supported by a steel core structure built in three-storey units. The stair extends from floor 67 to 87. It wraps around the central core and is tied to the structure at landings on every third floor.

THE SHARD

CONNECTIONS



DESCRIPTION OF LOADS

The Shard tower includes 5800 m^2 of residential, 17800 m^2 Hotel, 55200 m^2 office space and 5600 m^2 retail stores. This volume contains 54000 m^3 concrete as well as about 11,000 to 12,500 tons of structural steel.

The weight of live objects and movable parts such as furniture, as well as wind load and seismic load (lateral loads which we will discuss it in a different section) are considered live load.

All this mass creates a dead load that needs to be calculated.

Load from concrete part=12701.41 kips

Load from steel parts=2486.9005 kips

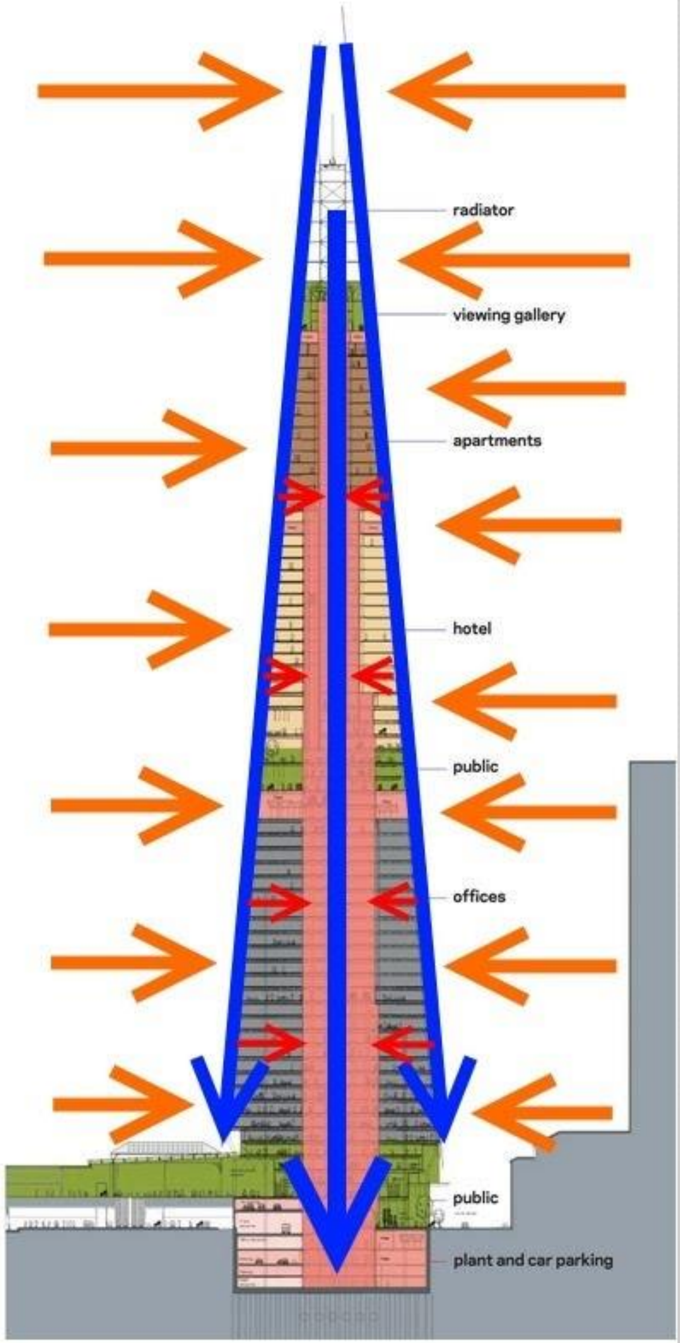
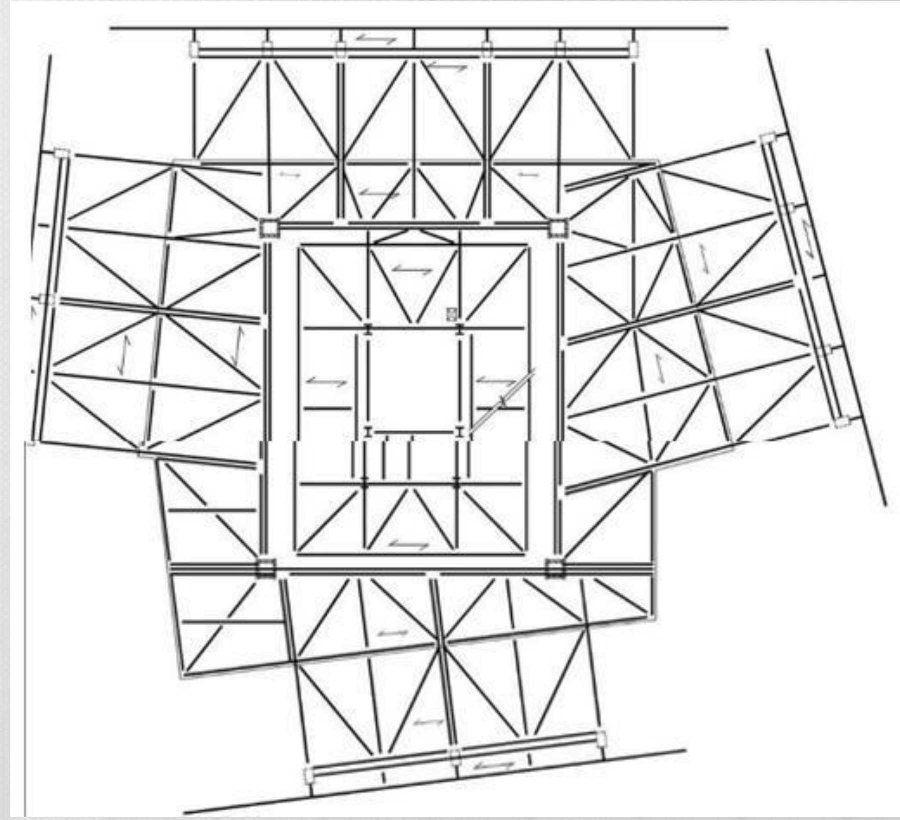


Figure 3: Section of the Shard - Vertical and Horizontal Loads Diagram

DESCRIPTION OF LOADS

TRANSFER OF LOADS

USING VIERENDEEL TRUSSES



At the junction of the main tower with the backpack(the office space extension which is 19 stories high), the spacing of columns was increased to 12m. The reason is because they wanted to avoid a wall of columns interrupt the office spaces. Here, they used simple but very large trusses.

In order to make it as efficient as possible, the change in perimeter column spacing from 6m to 3m was achieved by using Vierendeel trusses.

DESCRIPTION OF LOADS

Diagrid

The beams for the steel framed floors were set orthogonally to the shards (façade planes) rather than being arranged at right angles to the core walls. The perimeter spans were 6m in the steel floors, but 3m in the concrete floors. At the top of the spire reduced to 1.5m.

DESCRIPTION OF LOADS

Loading the columns at ground level

COLUMNS

They chose cranked, y shaped perimeter columns at first, but then changed their
decision to the simplicity of direct line. Because it was better both aesthetically and economically.

DESCRIPTION OF LOADS

Glass Spire

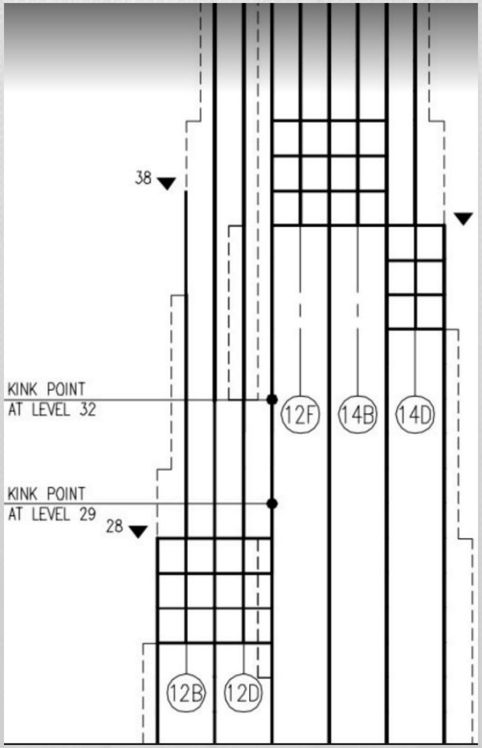
sits at the top of the Shard
contains 530 tons of structural steel.

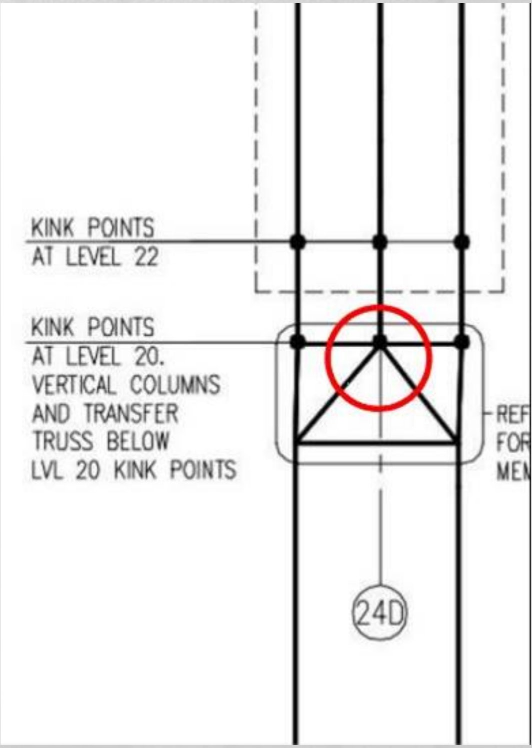
Its height is 60m and has 23 stories. It is located on top of middle concrete part, and assembled 300m up in the air, over the top of the highest point of the concrete core, where wind speed can be as much as 100 mph. The spire is the focal point of the tower.

The Shard's spire was pre-assembled on a North Yorkshire airfield by the steel design and erection team Severfield Rowen. The firm used the exercise to create 3D models of the spire at every part of its construction, and create a 'building guide' with detailed day-by-day instructions for the team to build it on top of The Shard © Mace

DESCRIPTION OF LOADS

Tapering and Kink points





From the outside, it looks like that the tower has an uninterrupted taper from base to the top, while in fact it is not true.

In some parts of the office levels, the perimeter columns rise vertically for several floors before gaining the slope of 6 degree. In one location the slope is reversed for some of the levels. These are the places we call "Kink points" that substantial horizontal forces are produced, and from there transfers from the steel struts and ties, back to the core.

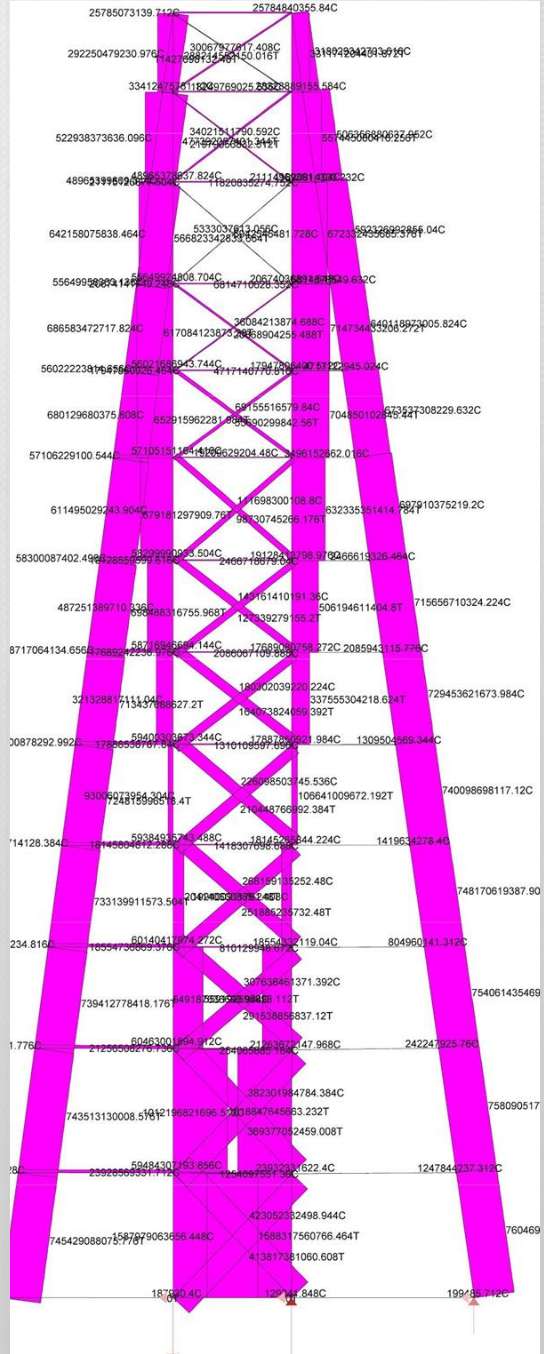
Multiframe Analysis

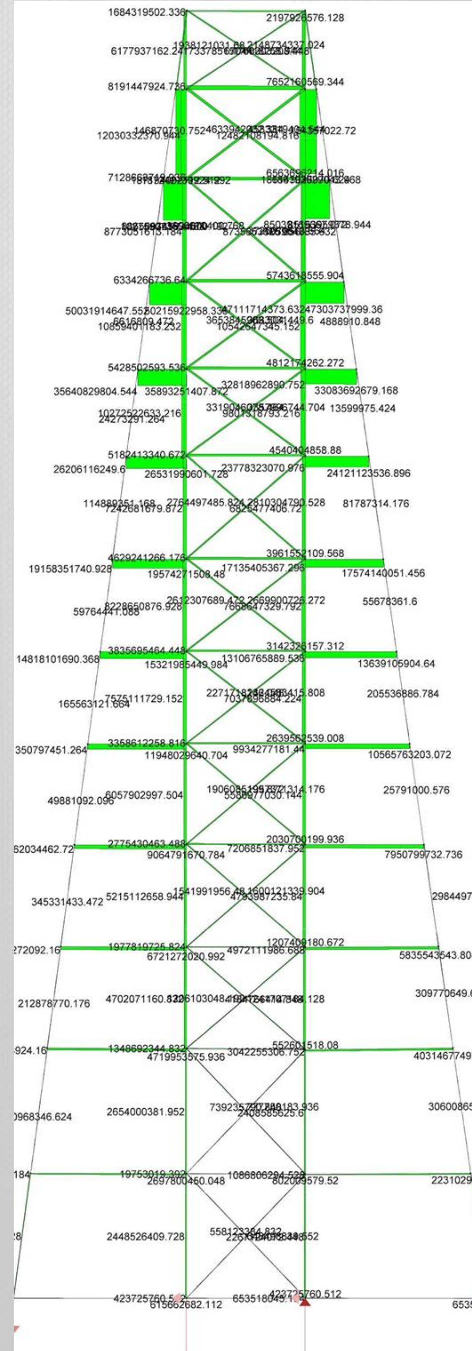
Forces and Shear

The relative magnitudes of the total

Dead loads: 2.15×10^8 lb
Live loads: 9.60×10^7 lb
and Horizontal loads: 6.08×10^8 lb

respectively. These numbers imply that the structural systems for this building must resist extremely high external and internal loads due to its grand scale and unusual geometry.





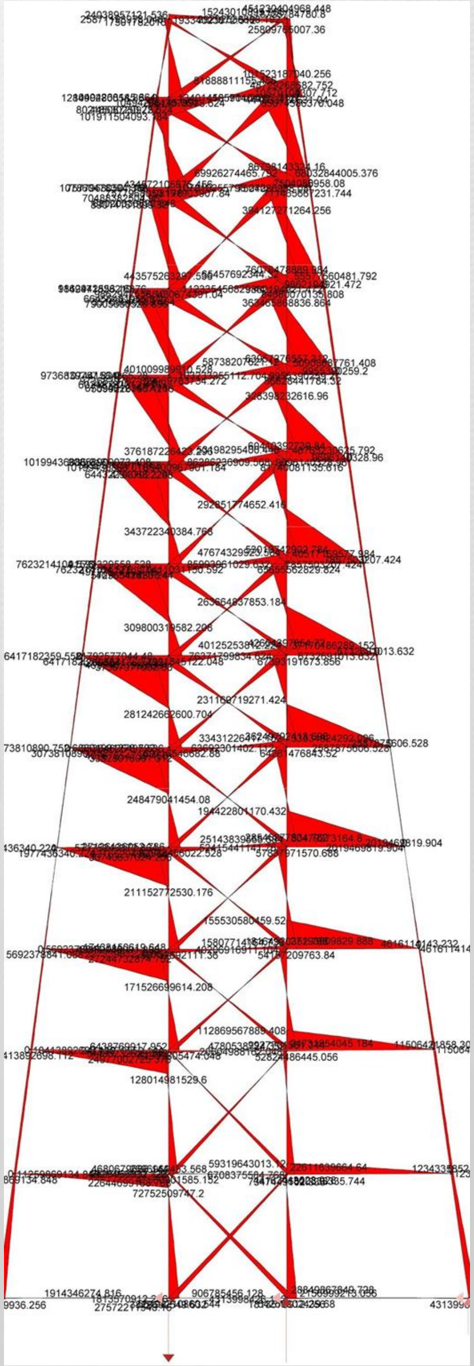
Multiframe Analysis

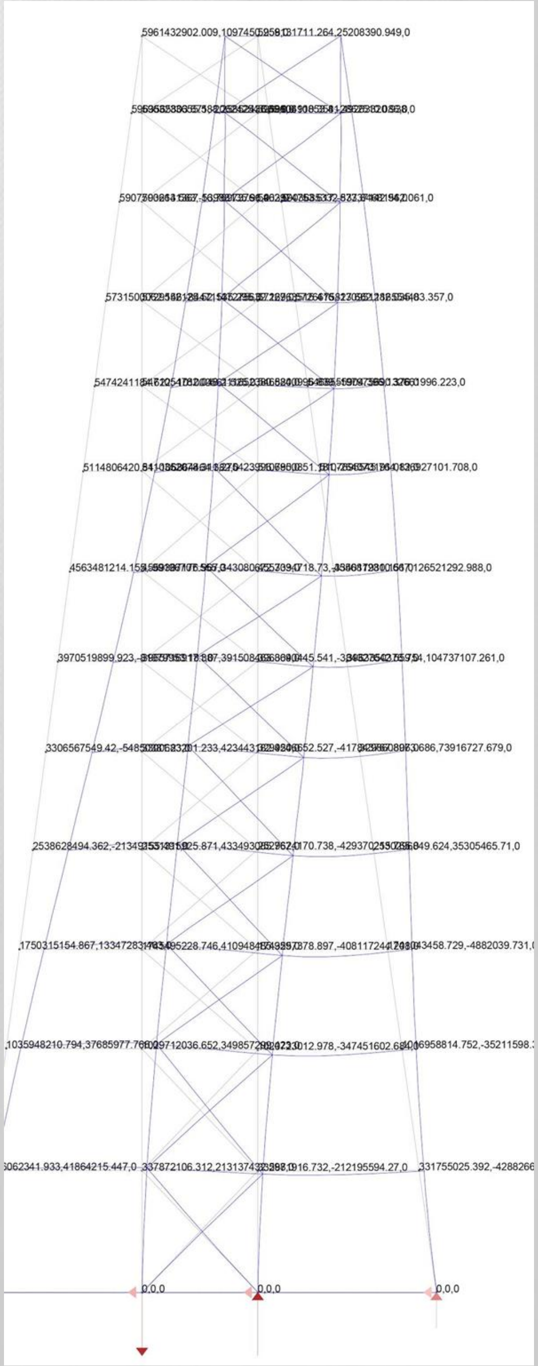
Moment and Deflection

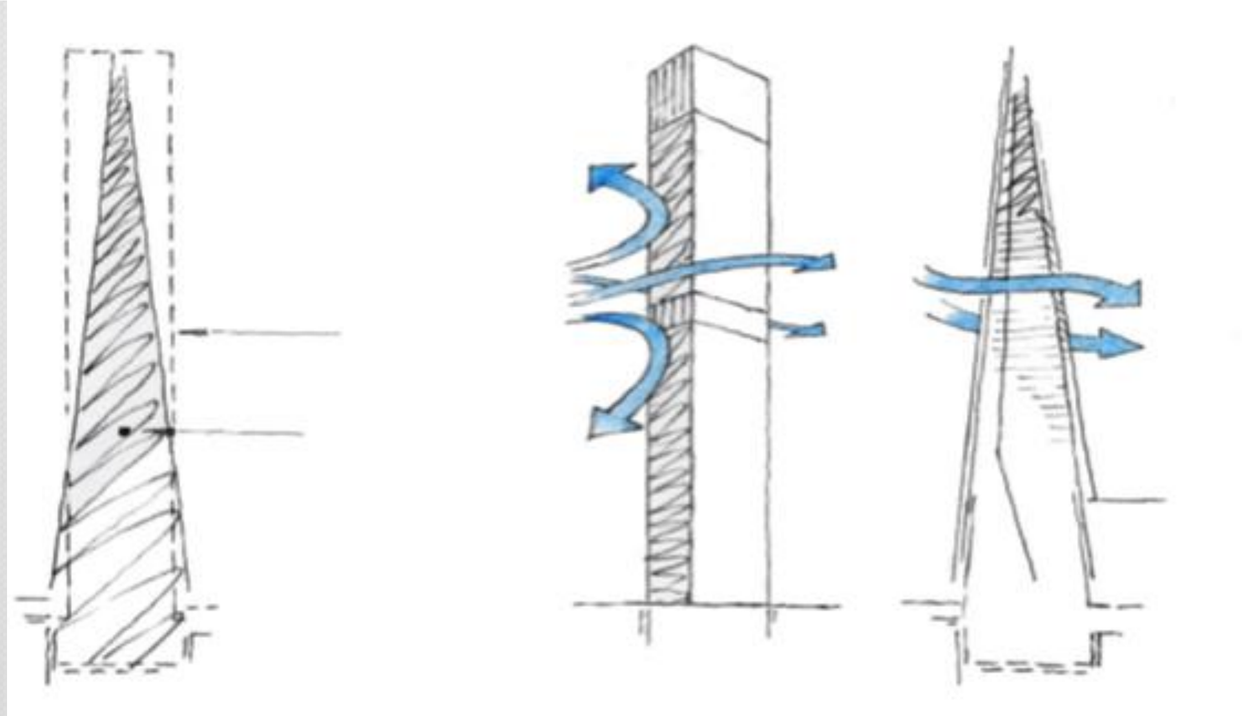
The relative magnitudes of the total

Dead loads: 2.15×10^8 lb
Live loads: 9.60×10^7 lb
and Horizontal loads: 6.08×10^8 lb

respectively. These numbers imply that the structural systems for this building must resist extremely high external and internal loads due to its grand scale and unusual geometry.







THE SHARD

LATERAL SYSTEMS

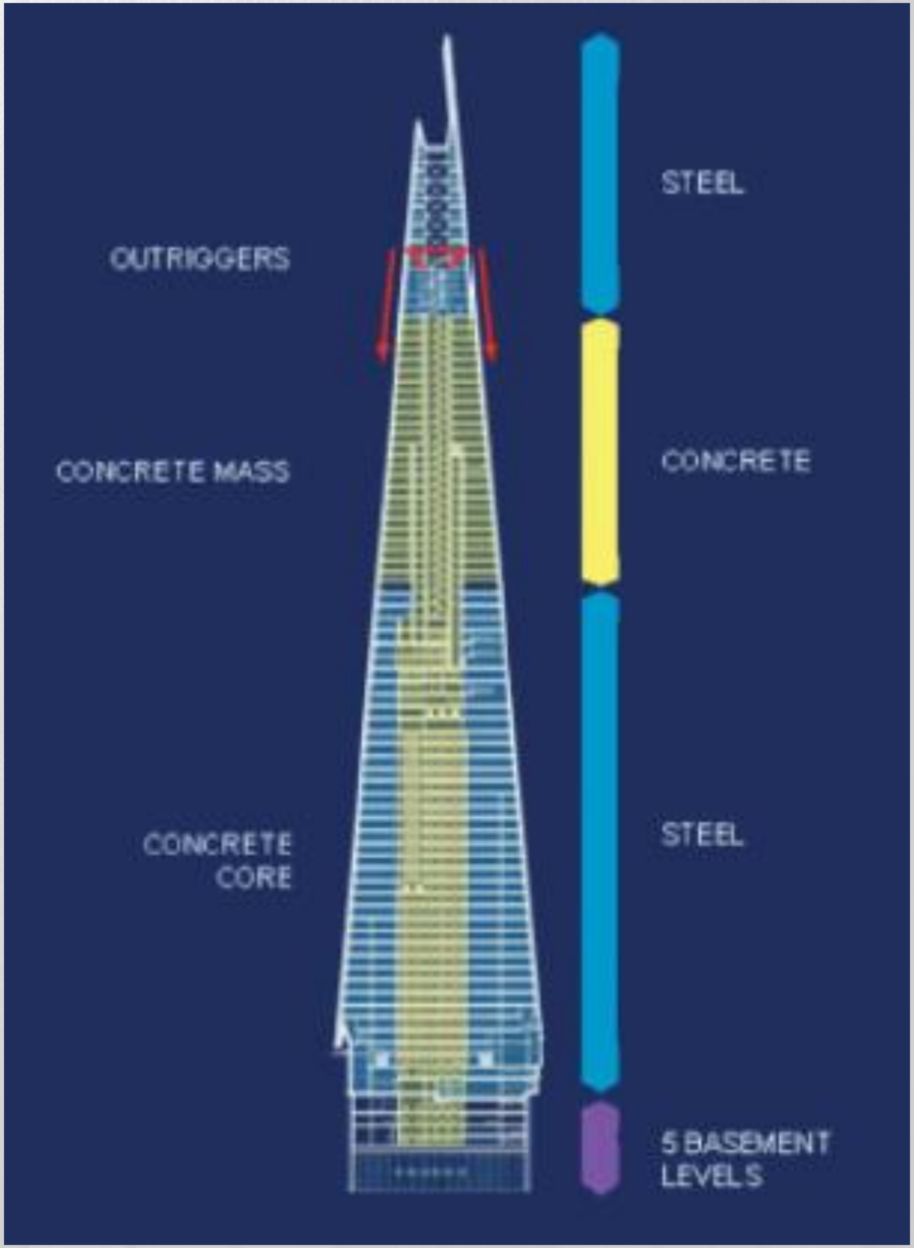
Lateral Consideration During Schematic Design:

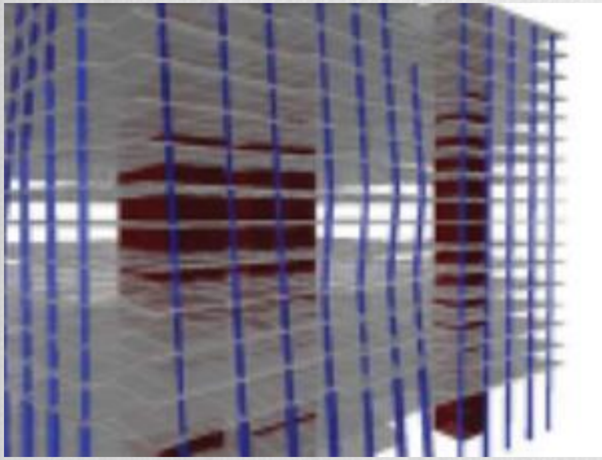
- Center of gravity would be closer to the ground
- Designed like an average rectilinear tower, the building would face significant swaying and vibrations from wind loads and would require exterior lateral bracing.
- Prism design decreases the affected wind area and helps wind redirect more effectively with minimal lateral movement
- Structure also extends below the ground level, and in result, gives more stability to the high rise.

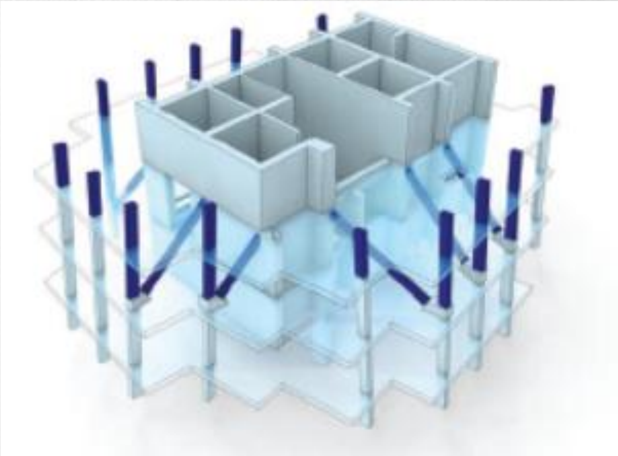
LATERAL SYSTEMS

Layering of Structural Materials

- Building is composed of four material layers vertically.
- Layering of structural materials give stability where needed.
- The concrete section from levels 41 to 69 provides mass dampers to minimize oscillations and stiffness to the building.
- A concrete core running provides lateral stability.
- Provides vertical rigidity and allows for minimal floor plates shift.



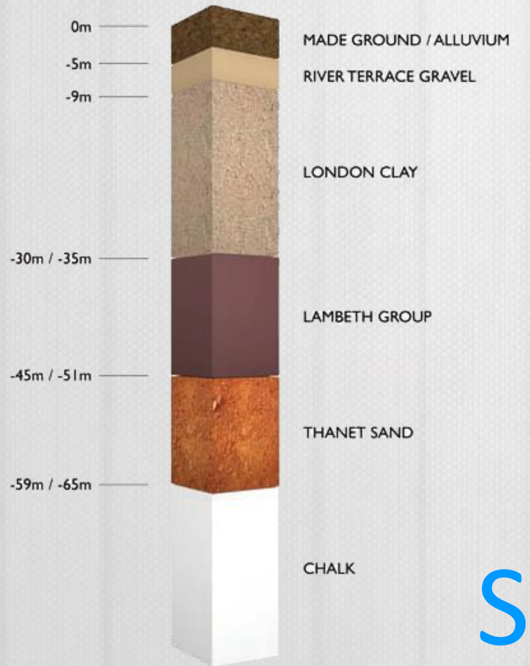




LATERAL SYSTEMS

Structural Systems to Reduce Lateral Movement

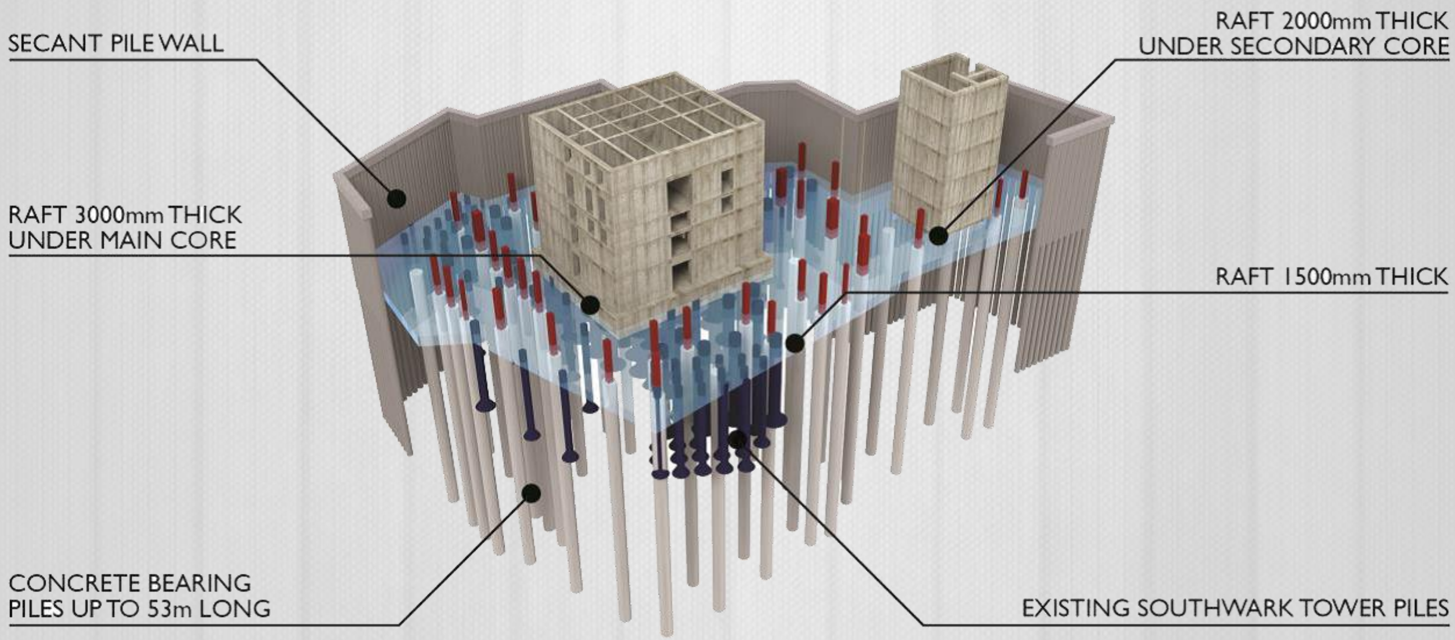
- Majority of the lateral stability come from the concrete core.
- Staggered lifts provide multiple points of support and balances the lateral forces applied.
- Lateral stiffness is also provided by placing perimeter columns throughout the entire structure .
- Hat trusses serve as buttresses, but also give rigidity to each floor and reduces drifting of floor plates.
- helped keep lateral accelerations below the recommended. These trusses also provide lateral bracing within the building. By doing so,
- No visible lateral bracing is needed on the façade.
- Allows for maximum glass on the façade and provides a sleek design look.

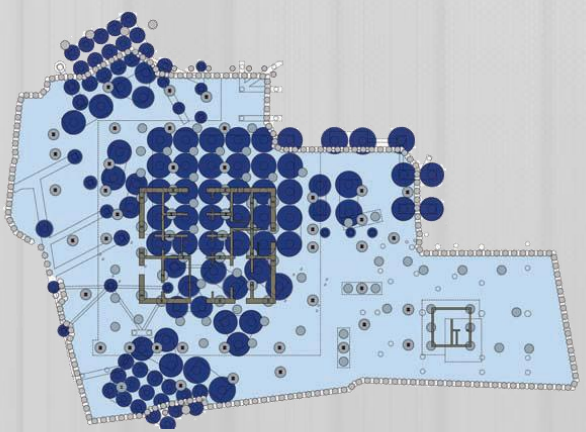


SOIL ANALYSIS

- London has a geology typical soil at this area.
- The water table is at the top of the gravel.
- Tectonic plate under neath ground layers effect was to make the eastern piles a few metres deeper.

Description





FOUNDATION

- Movement monitoring, vibration, ground water and reuse of old piles were taken into account in designing foundation.

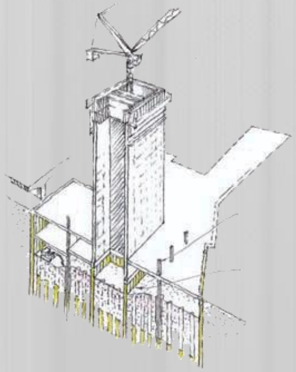
- Top-Down construction methodology was used in construction.

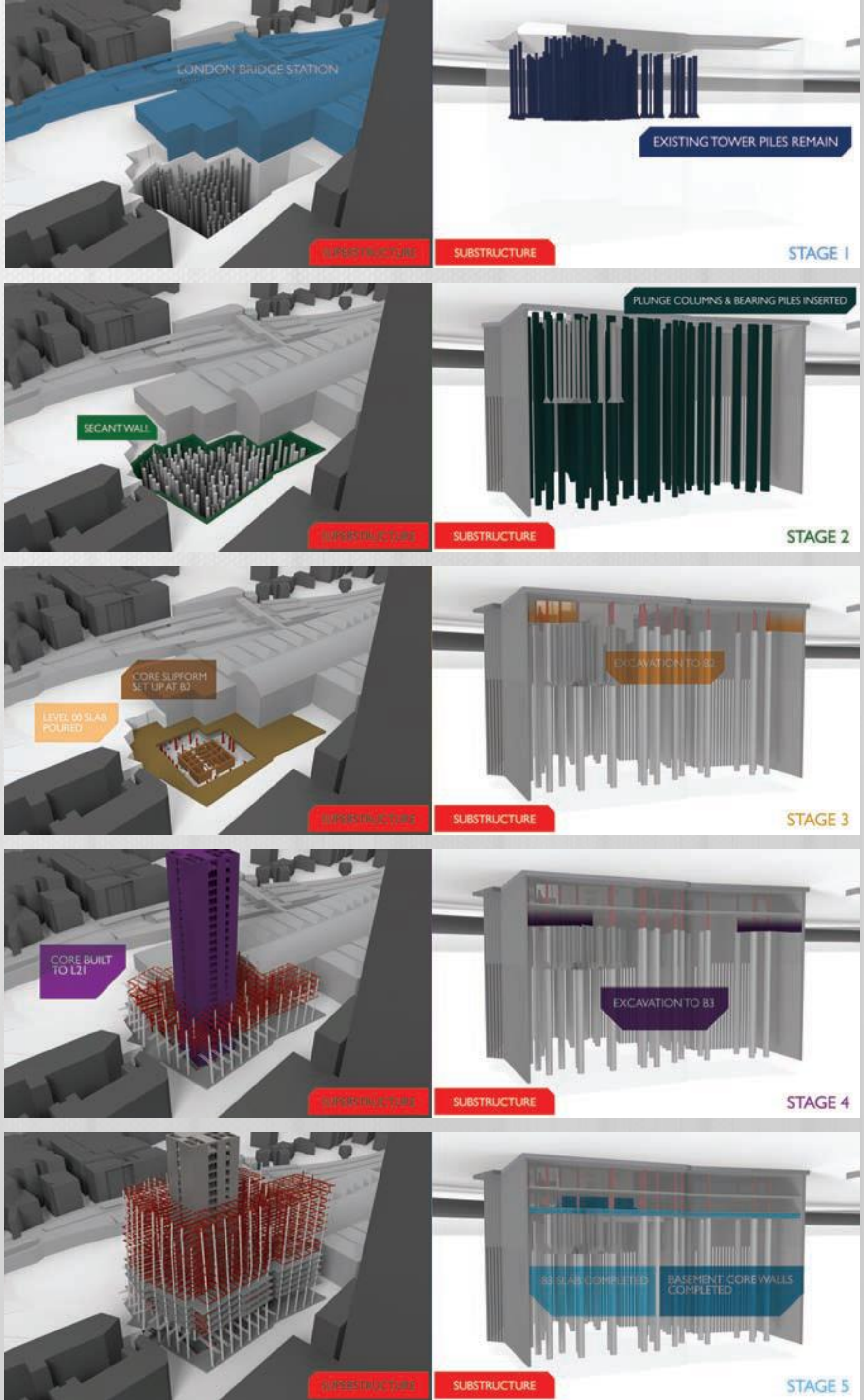
- Plunged columns used to supported core and Top-down slabs.

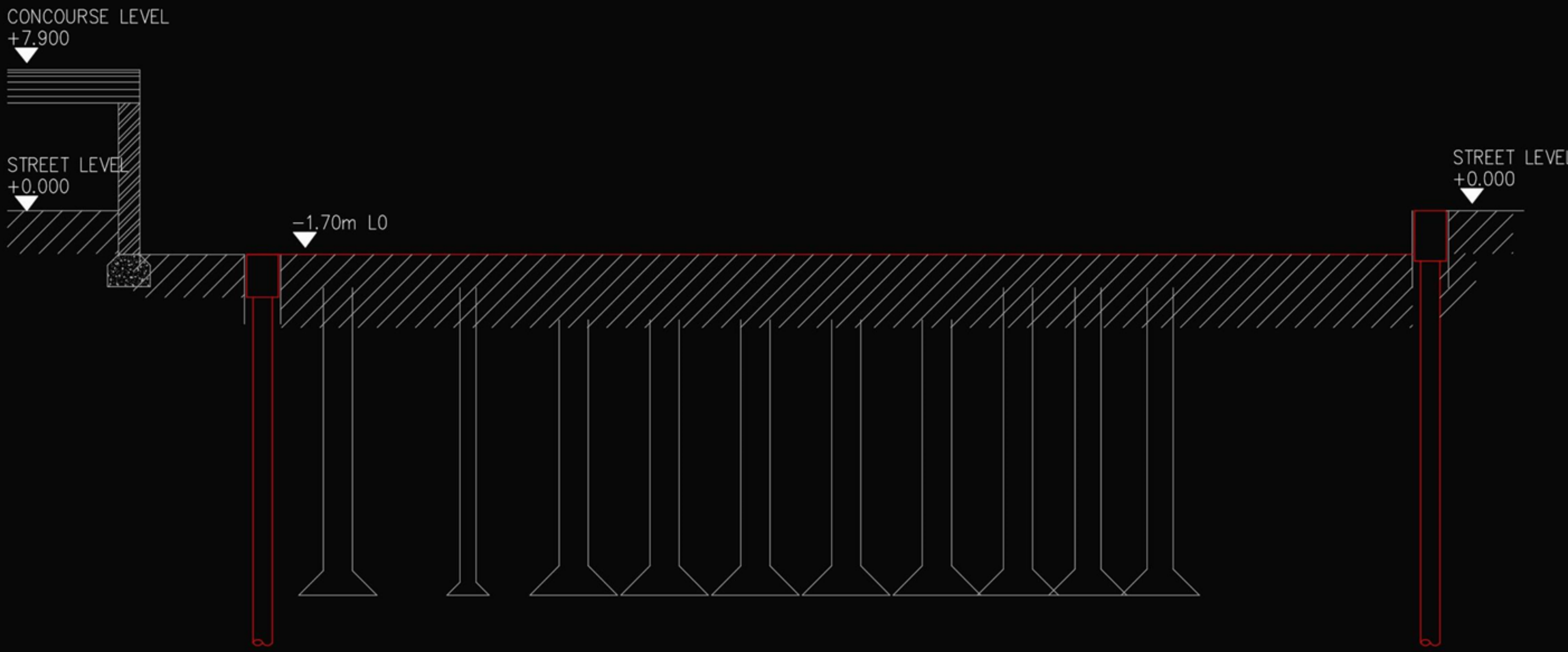
- The slab underneath the core has 3m thickness with four layers of reinforcement in each direction to provide stiffness.

EXCAVATION

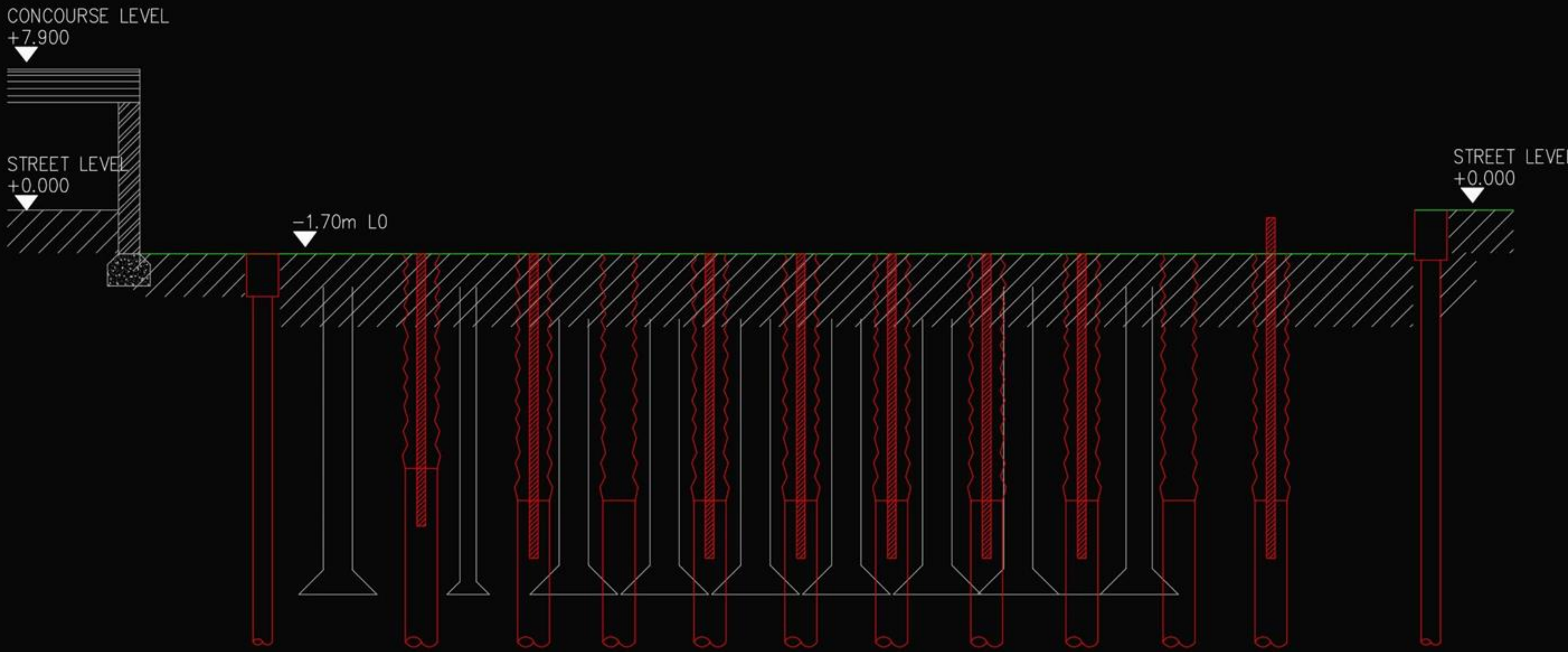
• The ground slab was cast on a slip membrane so that blinding concrete did not adhere to the underside.
• Excavation of two levels of basement then took place beneath the ground floor slab.
• Meanwhile, the slab for level B2 was cast. Excavation continued beneath B2 to formation level.
• The slipform was not allowed to climb above level 21 while the core was supported on plunge columns only.
• The raft slab was installed in a single 5500m3 pour taking 32 hours. Up to this point, all loads were carried on the secant wall and the piles containing plunge columns.



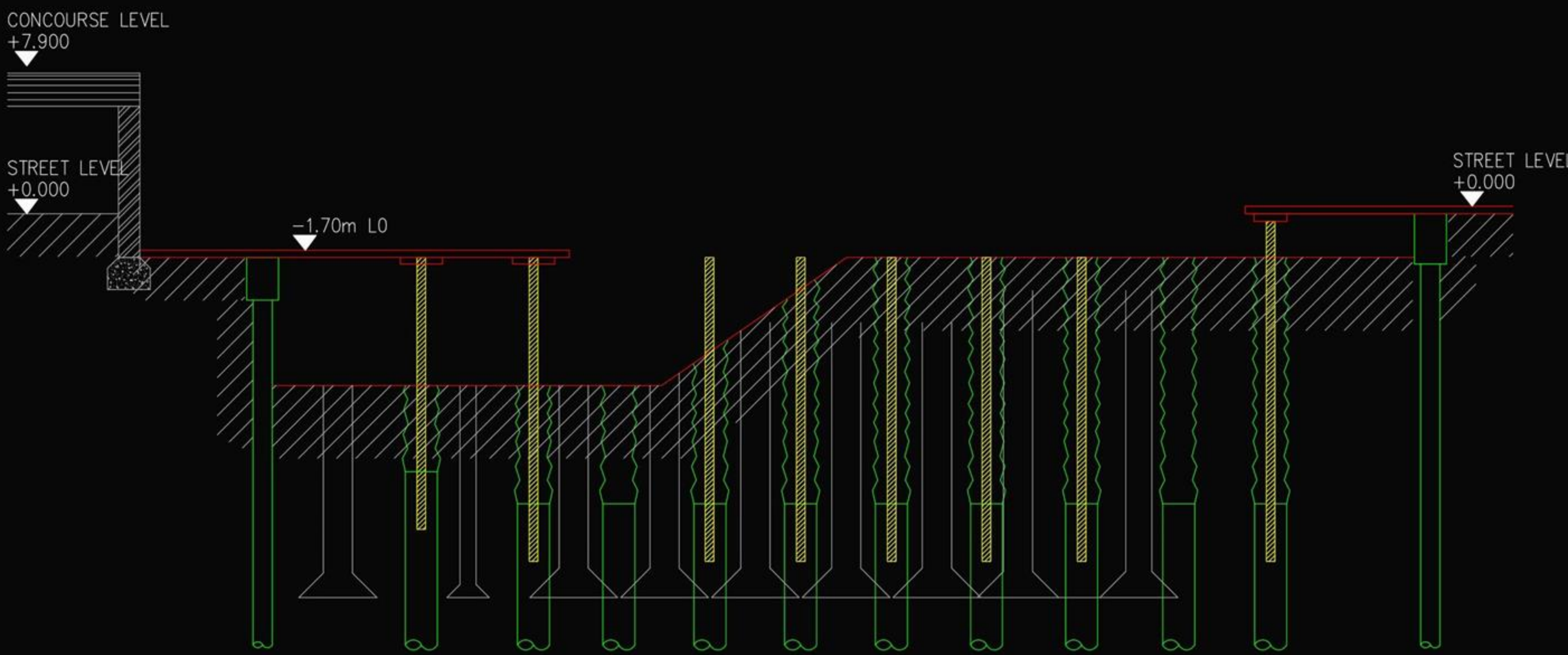




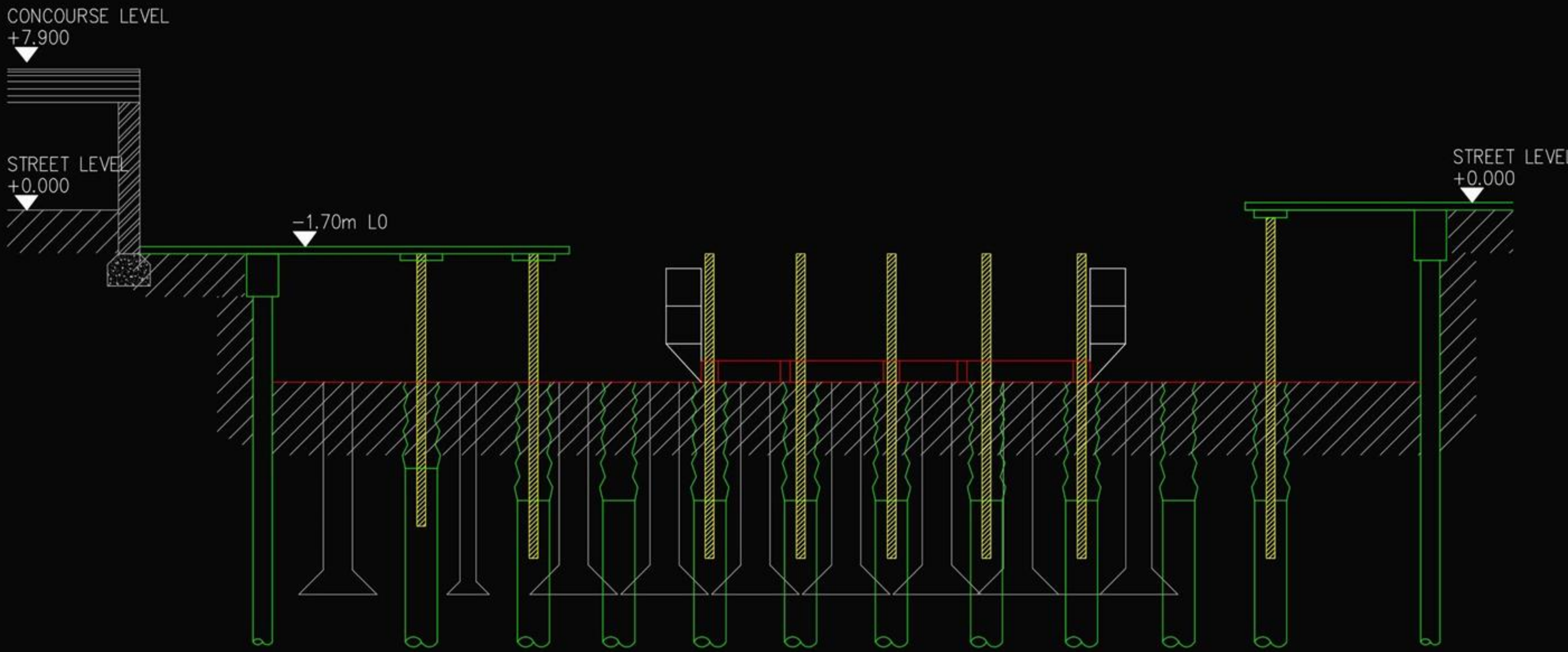
secant piled wall



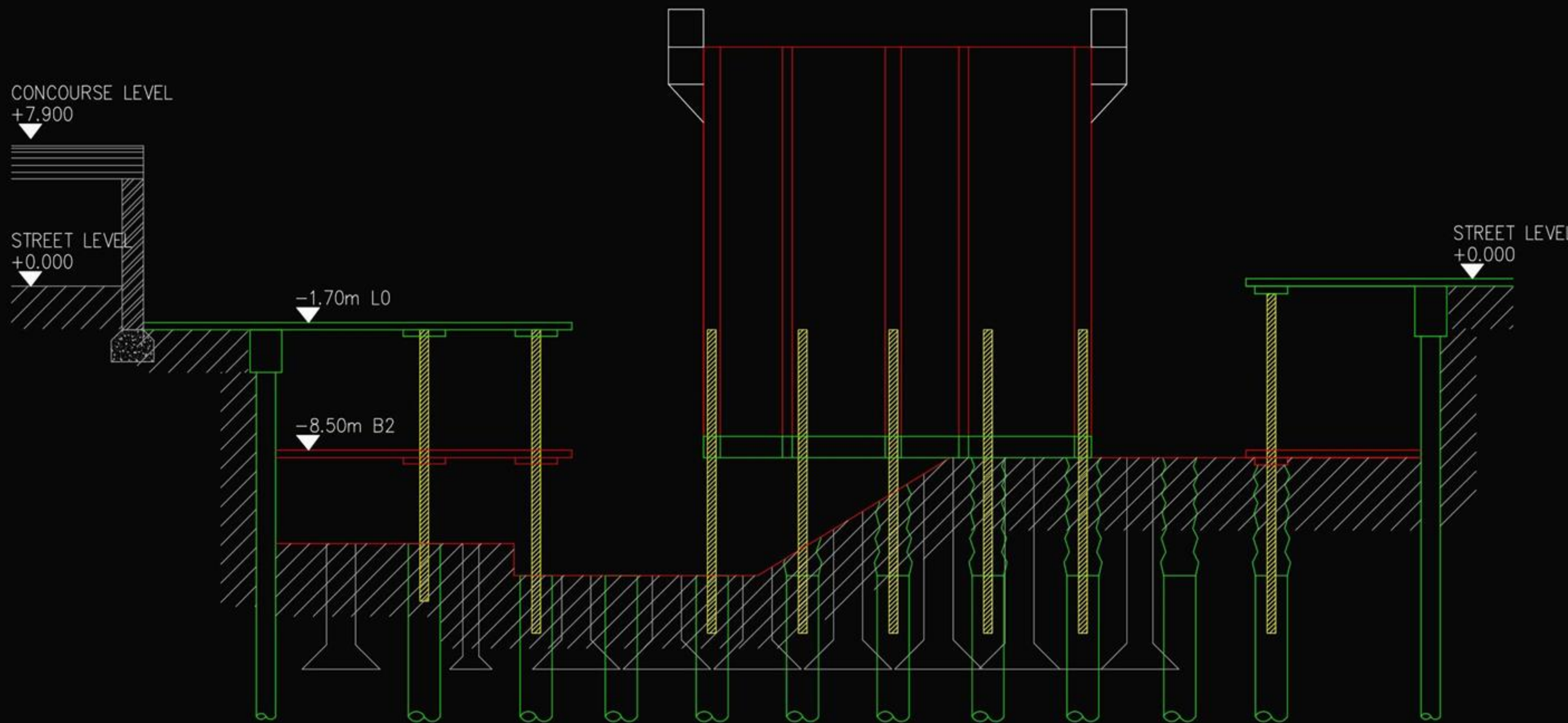
bearing piles and plunge columns



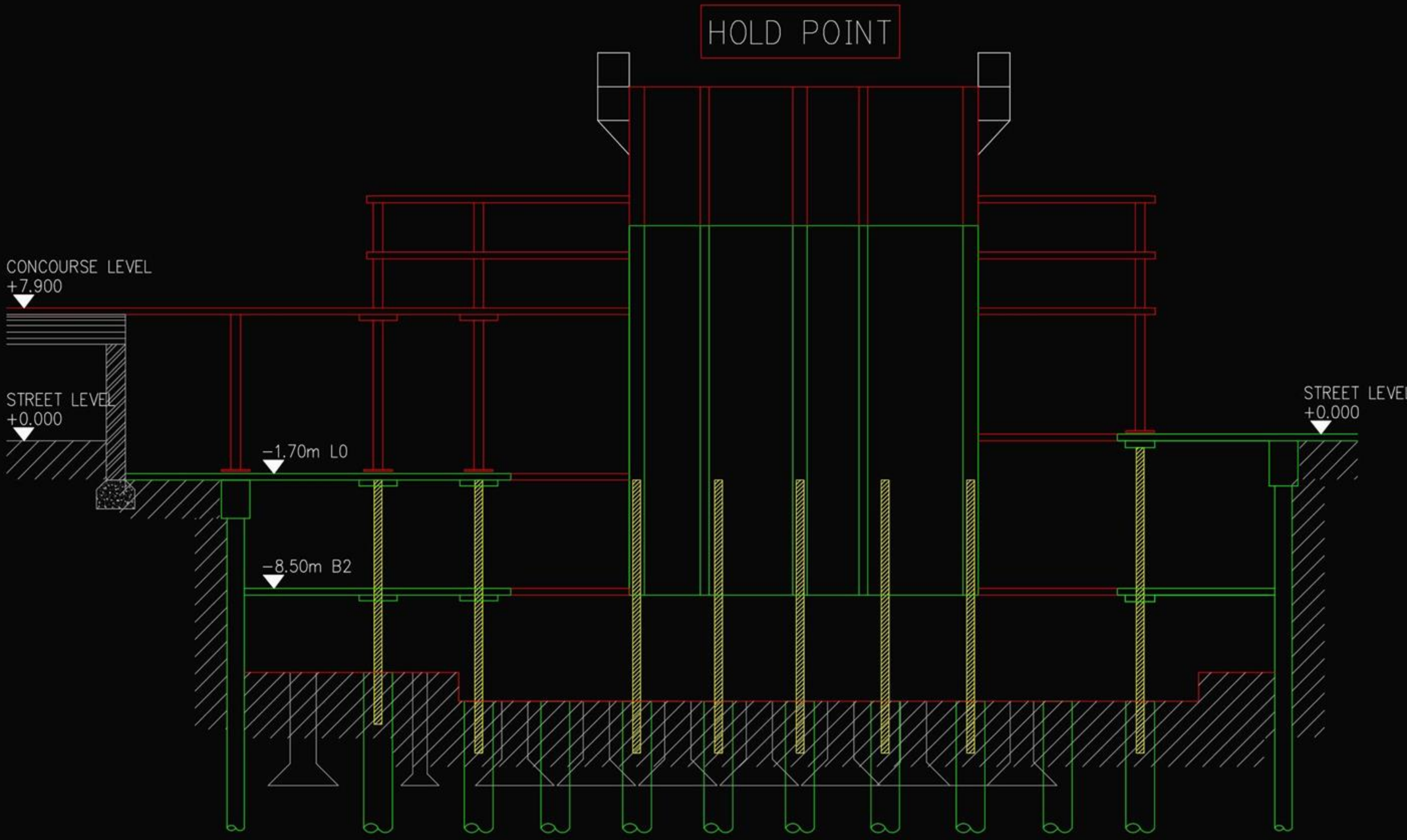
L00 slab; excavation to B2



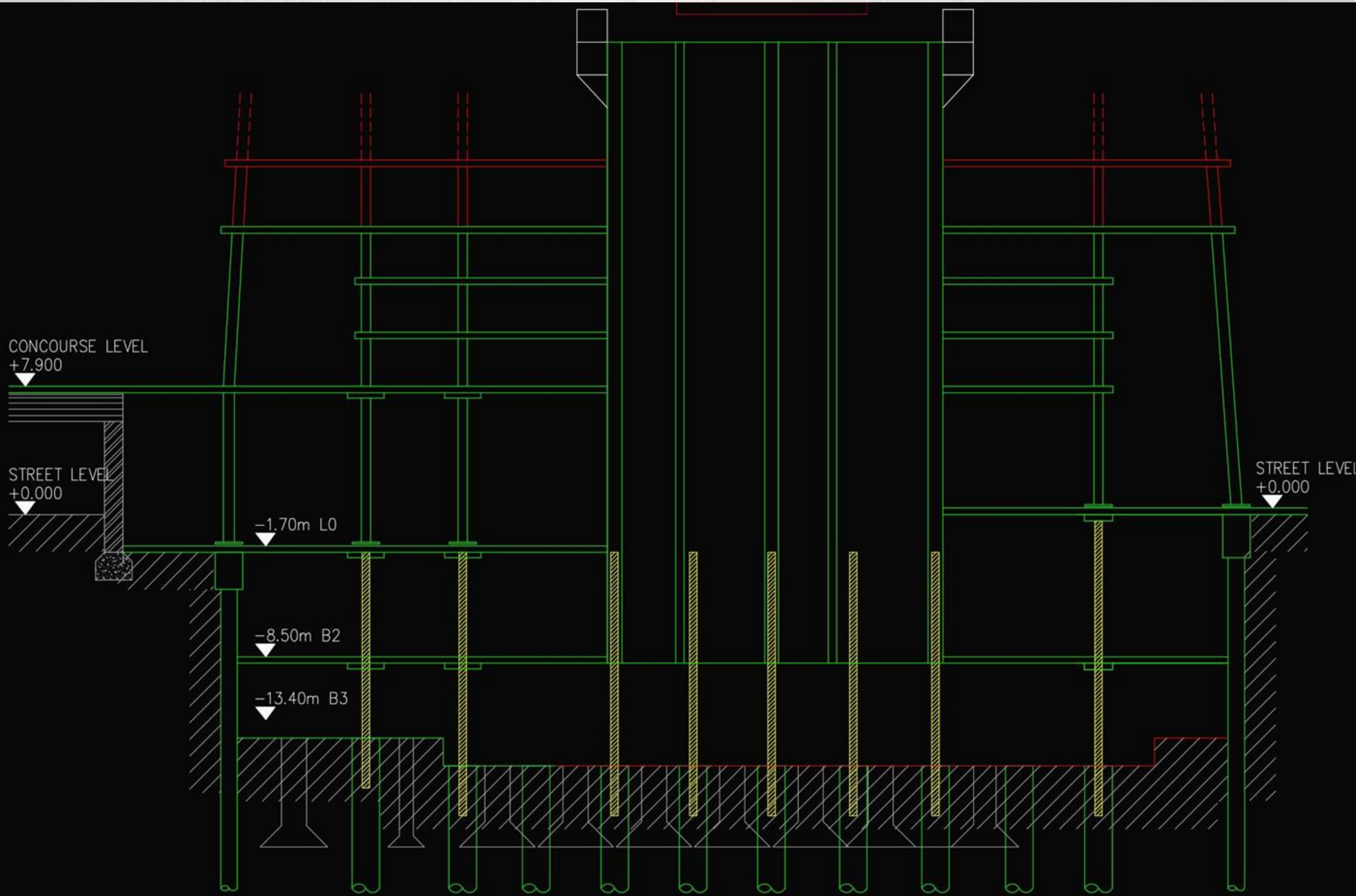
core slipform set up at B2



core slipform started; excavation to B3



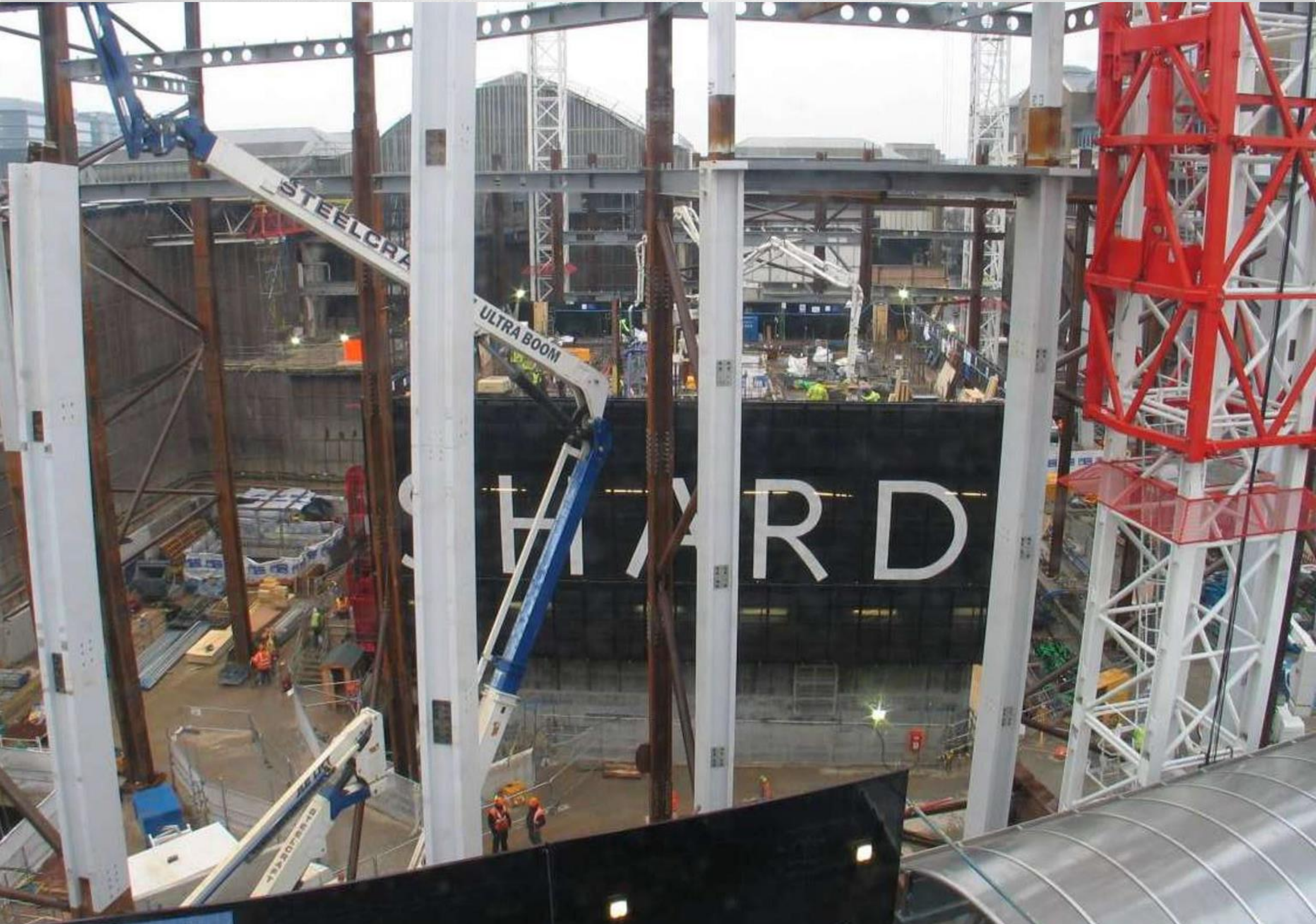
first hold point – L00 and B2 slabs connected



second hold point – full depth excavation


STEELCRAFT


keltbray
keltbray


STEELCRA
ULTRA BOOM
SHARD


STEELCRAFT JLG

THANK YOU