THE SHARD

structural case study

Sarah Fletcher - Nick Michl - Nikki O'Donnell - Landon Parker - Jordan Taylor

Fall 2018 - ARCH 631 - Nichols

THE SHARD

CONTENTS

- INTRODUCTION....3
- PROJECT DESCRIPTION....4
- STRUCTURAL OVERVIEW....7
- FOUNDATION SYSTEM OVERVIEW....24
- LATERAL STRUCTURE....16
- HOW SYSTEM RESPONDS TO LATERAL LOADING....35
- MULTIFRAME ANALYSIS....38
- CONSTRUCTION....39
- REFERENCES....42

INTRODUCTION

Architect:

Renzo Piano

Owner:

State of Qatar / Sellar Property Group

Developer:

Sellar Property Group

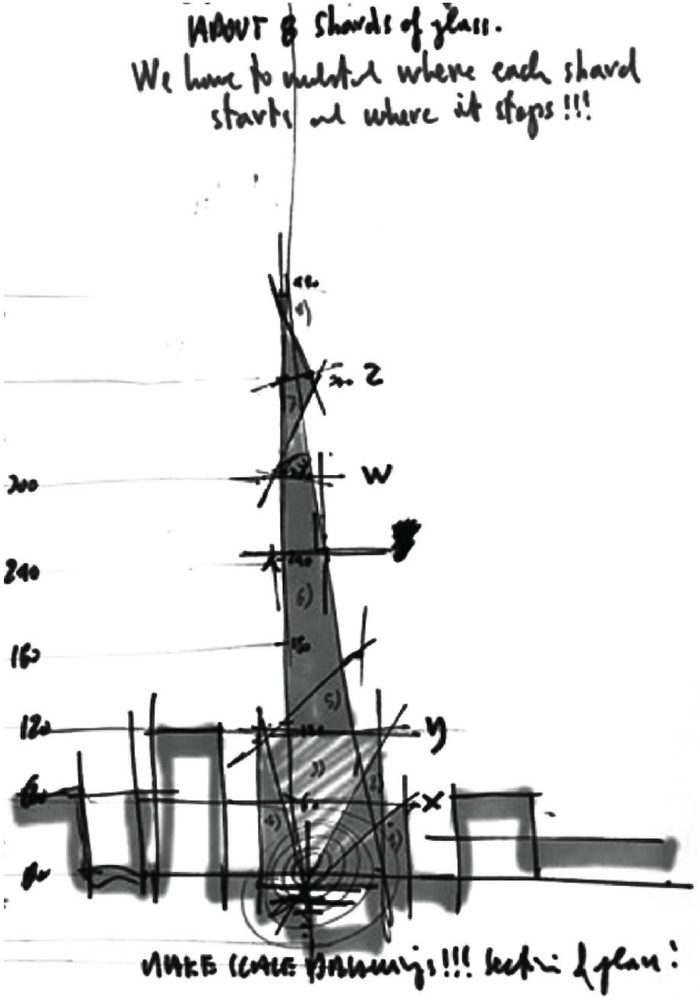
Structural Engineer:

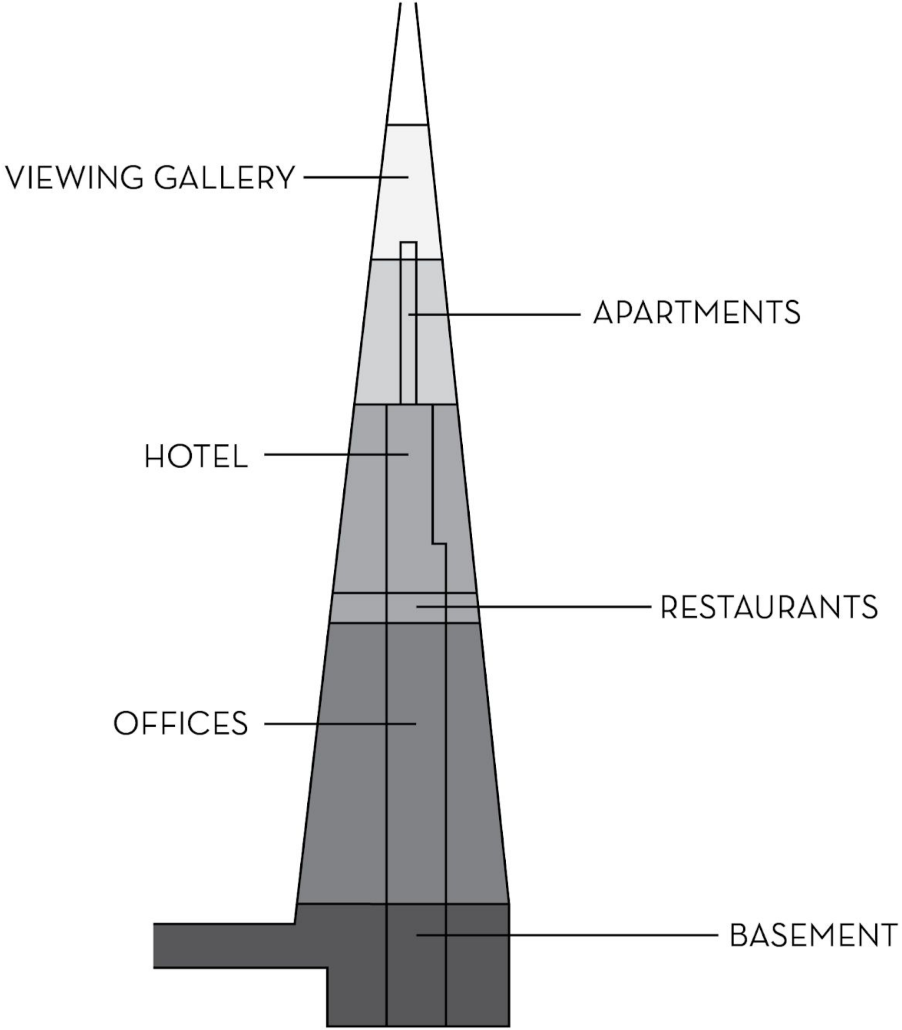
WSP Global

Sellar had the intent of redeveloping the southwork towers that once lay in the plot where the Shard stands today. The tower is a multi-function building designed by the world renounded architect, Renzo Piano. The structure is the fifth tallest in London standing at 1,016 feet tall. The Shard encompasses 72 habitable floors that sum to 1.4 million square feet. The building serves as residence for a variety of functions. The building proves its importance with a unique hyrid structural system utilizing steel and concrete.

PROJECT DESCRIPTION

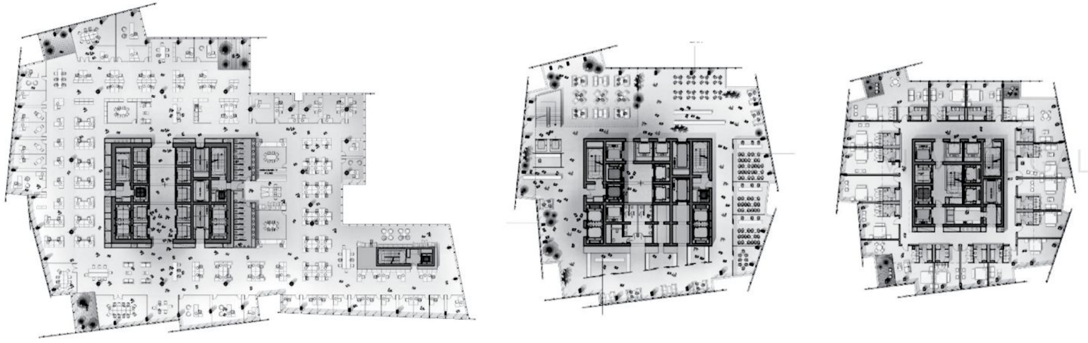
Piano compared the scultpure to “a shard of glass through the heart of historic London”. He included 11,000 panes of that reflect the forever changing sky above. The structure was designed to be energy efficient as it stores a radiator, has sustainable glazing system, and includes wind openings with a mechanically functioning facade.

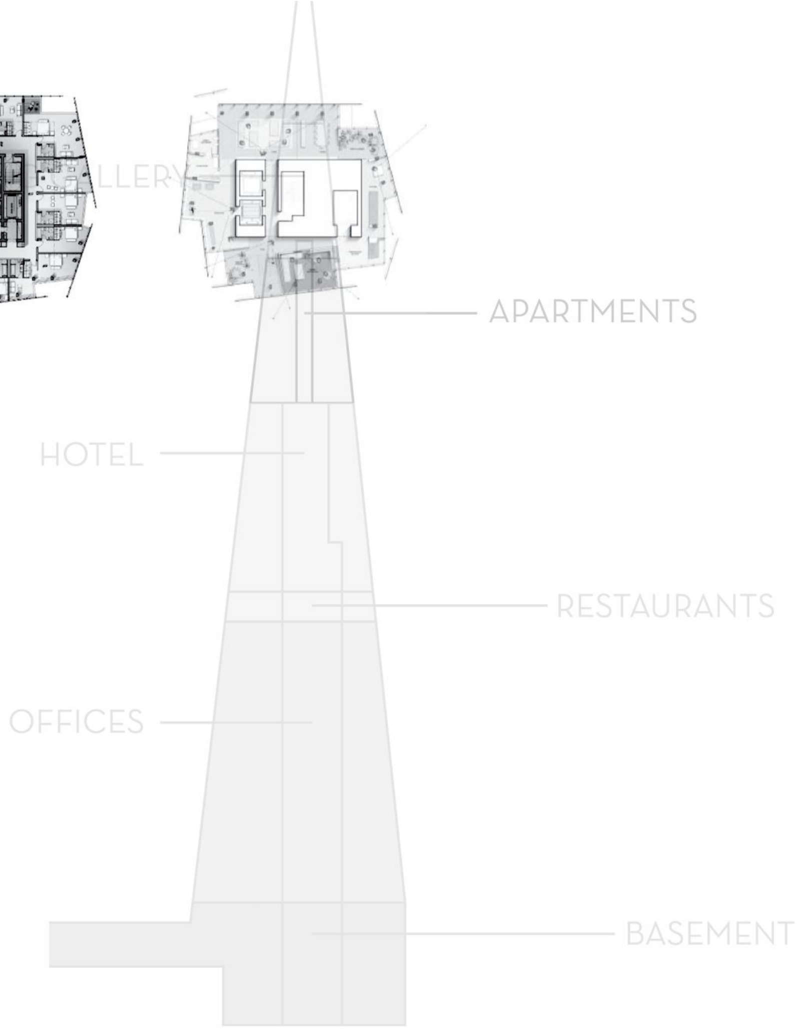




The project consists of several floor types based on program. Floors 0-40 are privately owned business offices, floors 41 through 65 contain the restaurants, hotel and private residences. Floors 66 through 72 contain the “view from The Shard” tourist attraction with 2 viewing decks.

PROJECT DESCRIPTION





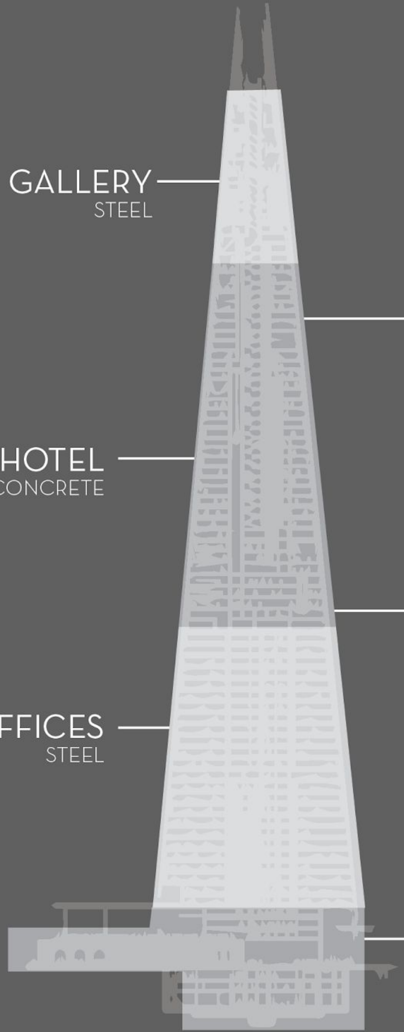
The horizontal layout is planned in a way deemed simple by the project team. Rather than a traditional squared or right angled grid, the beams were set orthogonally to the façade planes. Additionally, the beam spans, as well as flooring spans decrease in length as the structure rises. The perimeter spans reduced from 6m in the steel floors to 3m in the concrete floors and again to 1.5m at the top of the spire.
3m in the concrete fl oors and again to 1.5m
at the top of the spire

PROJECT DESCRIPTION

STRUCTURE

THE SHARD

OVERVIEW........8
VERTICAL SYSTEM........9
HYBRID SYSTEM........10
LOWER STEEL FRAME........12
MIDDLE CONCRETE SECTION........15
TOP STEEL FRAME........20
FACADE OVERVIEW........22



The Shard is a unique infrastructure because of its hybrid system that accommodates for the various functions throughout the elevation. The building uses a combination of composite steel frames, post-tensioned concrete floors, and a mass core that has a role of ensuring stability. The lengthy structure contains 54,000 cubic metric tons of concrete, while the steel system sums up to weigh 11,000 tons.

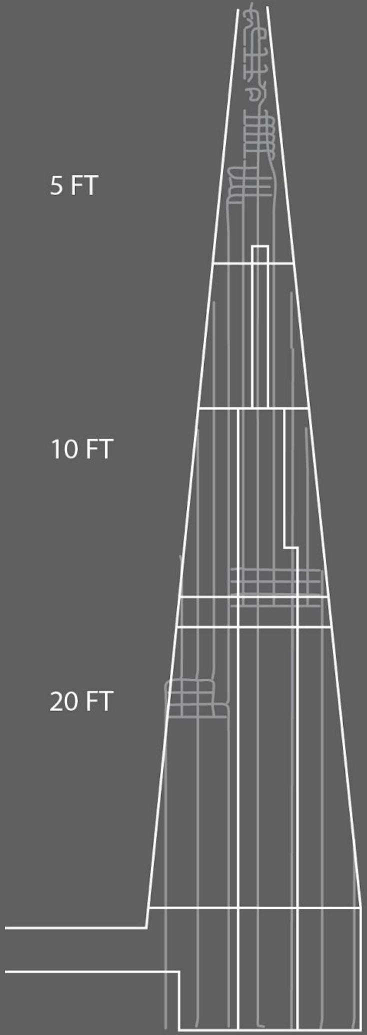
STRUCTURAL OVERVIEW

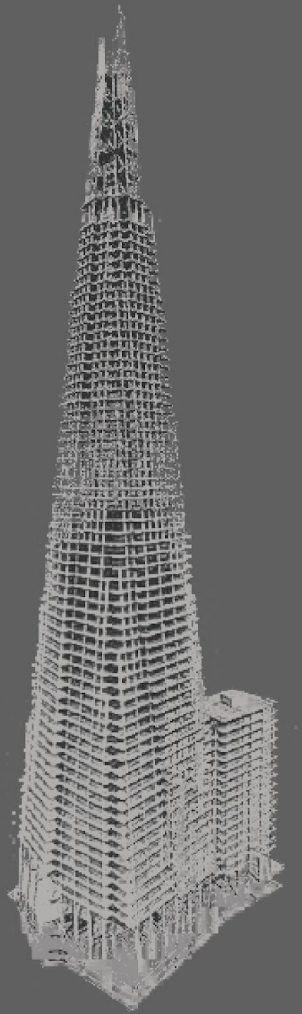
The vertical system within The Shard is composed of columns that shrink in size and reduce in spacing as the elevation extends upward. The vertical elements mimic the facade angle as they extend.

Column spacing

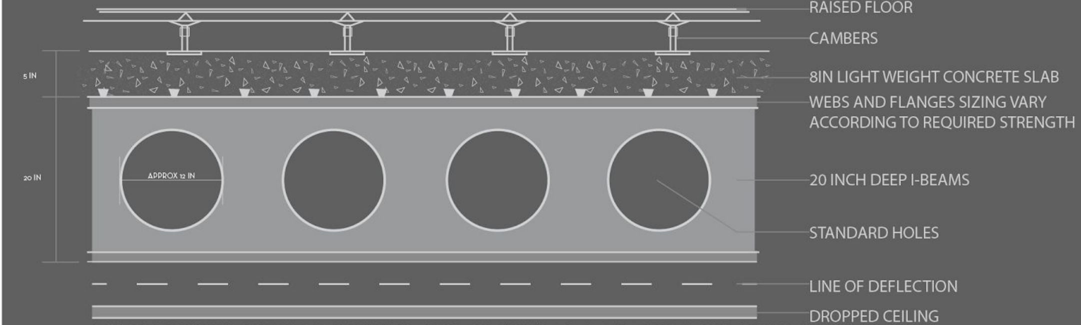
Base and office levels
19.7’
Hotel and apartment levels
9.8’
Radiator
4.9’

STRUCTURAL OVERVIEW



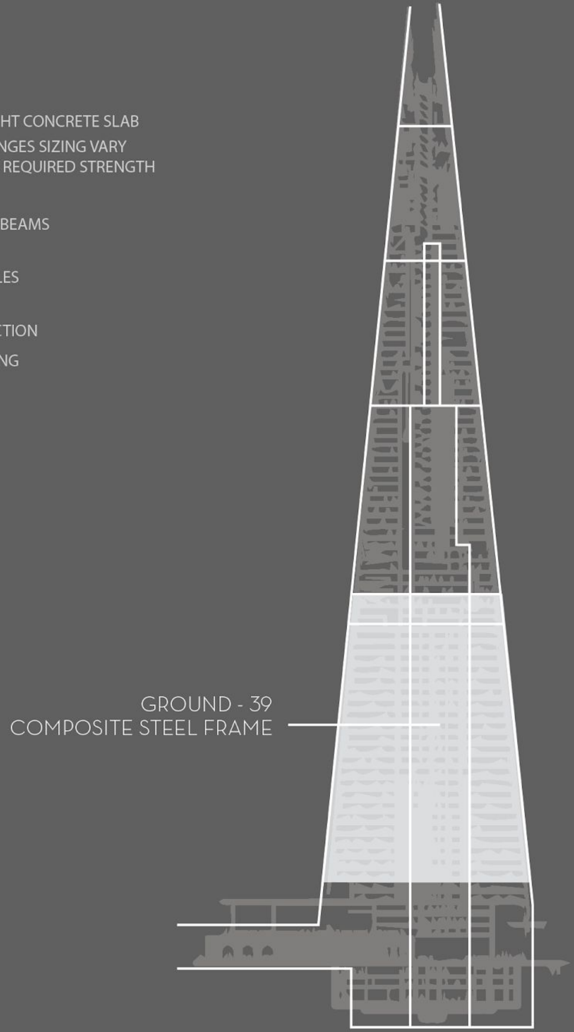


STEEL-CONCFRETE-STEEL: COUNCIL ON TALL BUILDINGS AND URBAN HABITAT / KAMRAN MOAZAMI, JOHN PARKER, RODOLFO GIANNI



STEEL-CONCFRETE-STEEL: COUNCIL ON TALL BUILDINGS AND URBAN HABITAT / KAMRAN MOAZAMI, JOHN PARKER, RODOLFO GIANNI

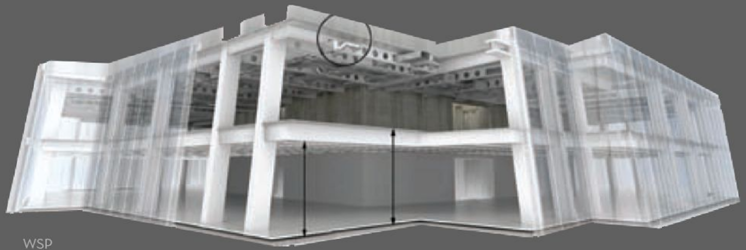
The foundation and basement levels, up to level 39 serve as offices and lower retail. The engineers decided to use a steel frame with deep beams to enable further spacing within the columns.
A majority of the steel used within the building exists within the lower office levels of the building (ground-39). The sections contains 15,000 pieces of structural steel and weighs 12,000 tons. This steel structure is made using 20 inch deep I beams that acquire standard holes for system pass throughs. On top of the beams is a lightweight concrete slab measuring 5 inches thick. They were designed to span up to 50 feet (from perimeter to core) for spatial adaptability in offices. The joints that connected the cladding and the floor plates utilized compact plate girders. The utilization of these girders was specified for low depths on the facade. This was a desire by the architect to take advantage of the sun penetration. Additionally, the floor that sits on these open beams are raised on cambers.



PG20
150X10F8W

PG44
500X70F40W

STRUCTURAL OVERVIEW

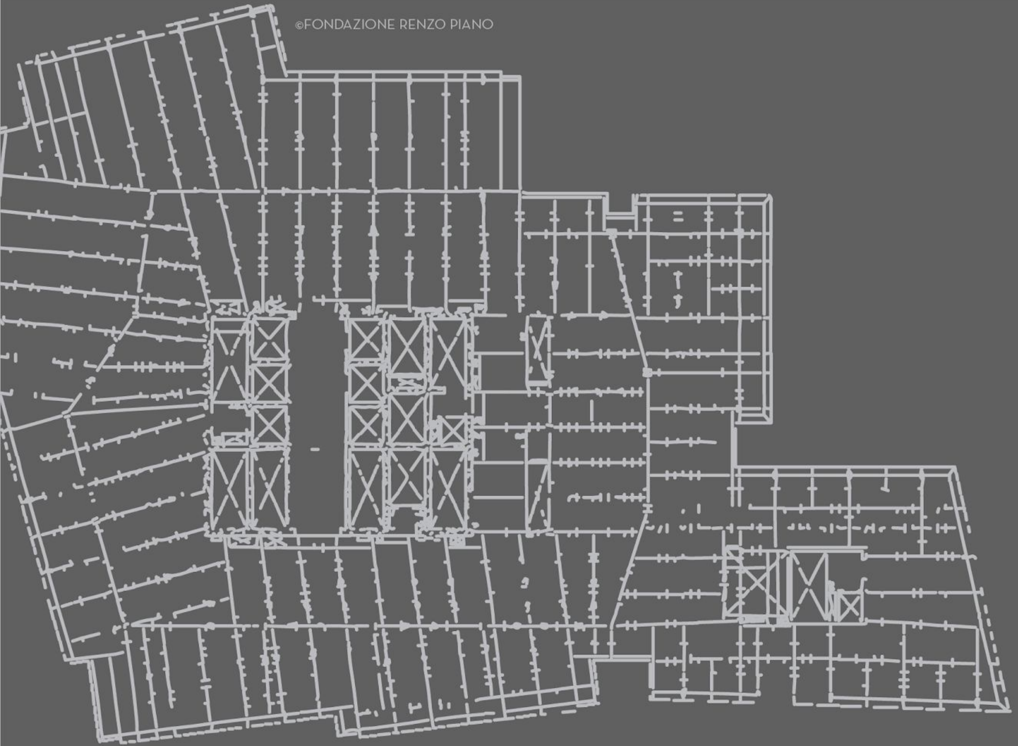


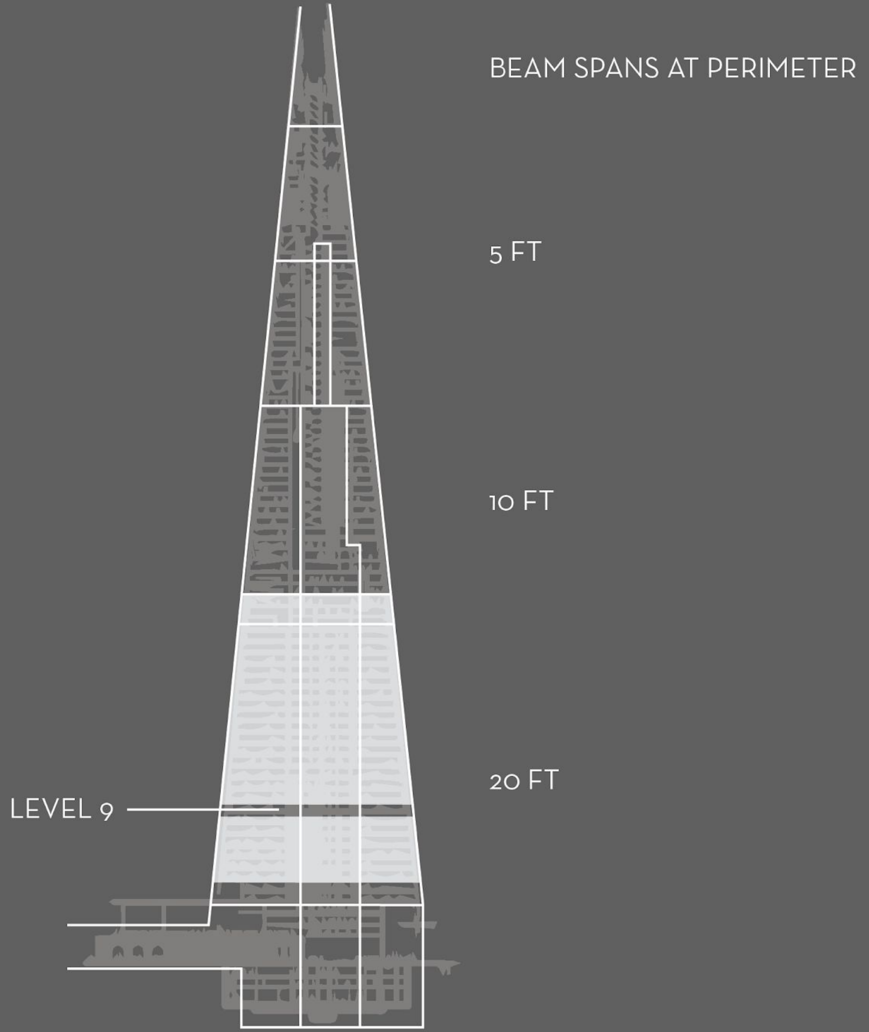
WSP

WSP

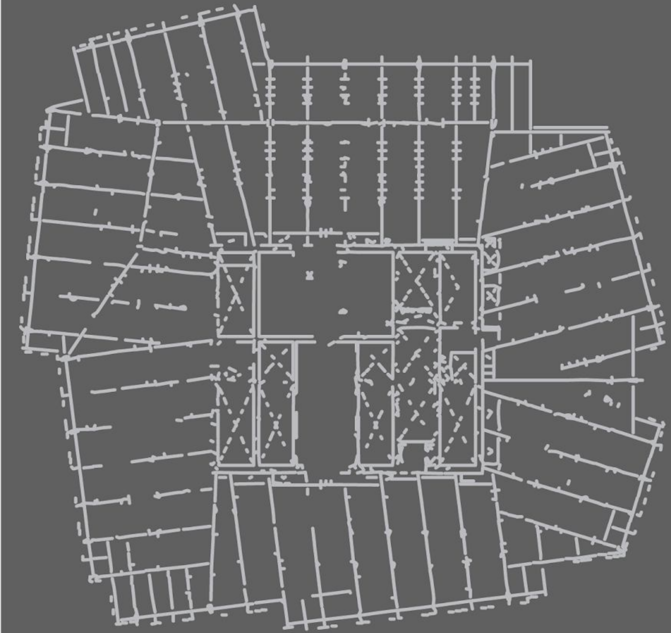
© Daniel Taylor via CTBUH

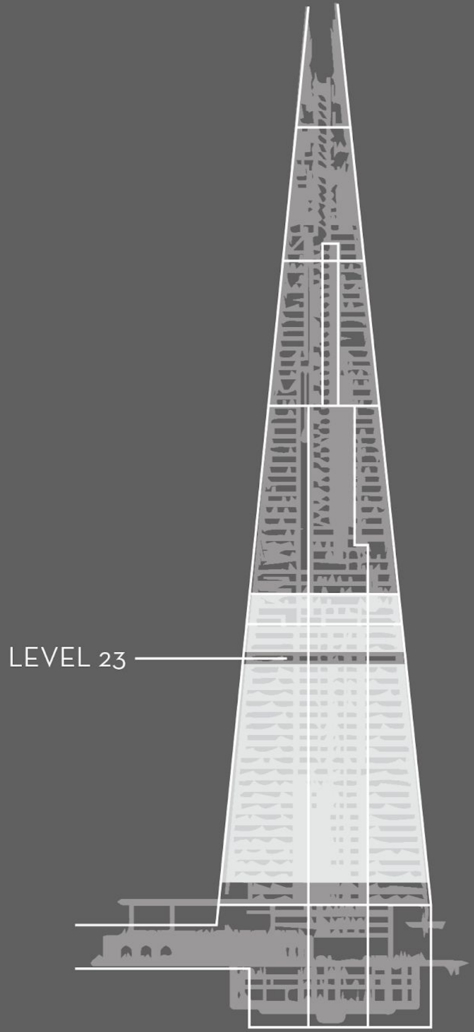
STRUCTURAL OVERVIEW





STRUCTURAL OVERVIEW





STRUCTURAL OVERVIEW

KENNEDY WATTS PATERNERSHIP

PHOTO BY LEE MAWDSLEY

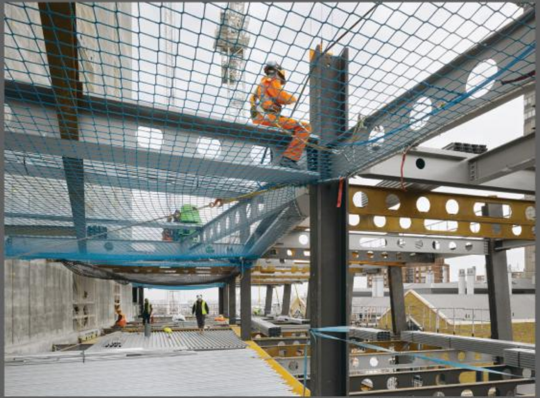


PHOTO BY LEE MAWDSLEY

PHOTO BY LEE MAWDSLEY

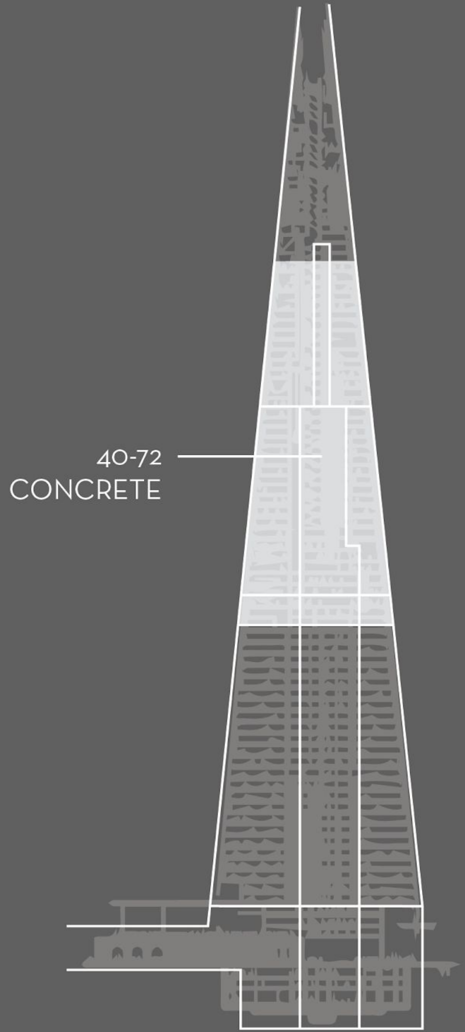
Bolted and welded connections support the exterior framing and are the major connection types for connecting the elements to the concrete core.

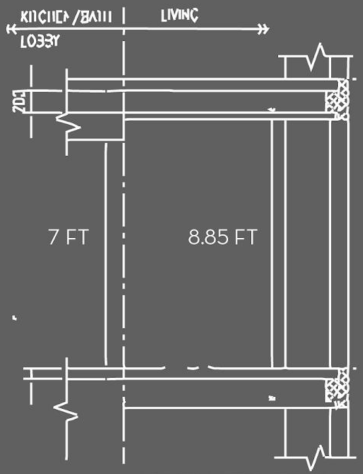
STRUCTURAL OVERVIEW

The levels that sit upon the steel framed base (40-72) house the restaurants, hotel, and apartments. These spatial functions called for concrete construction. The engineers chose concrete because of the thin slab that maximized the amount of levels allowed by code. The concrete also served a purpose of acoustic barriers, enabled to building to be within the regulations of residential code. The use of concrete eliminated the need for further damping systems,

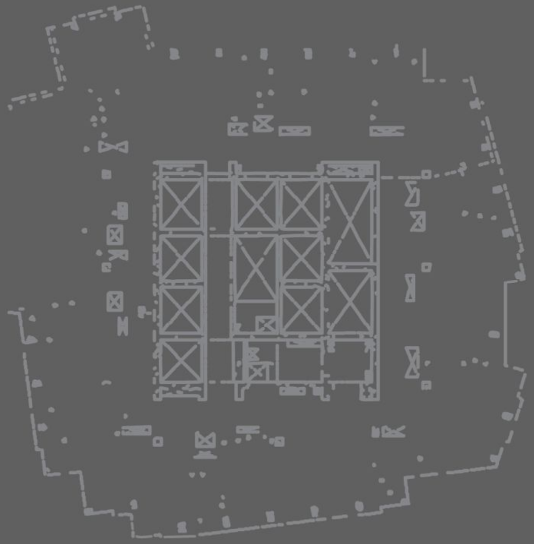
In the following concrete levels, the restaurant, hotel, and apartment complexes reside. 8-inch thick post tensioned concrete slabs were utilized in normal weight concrete. They were designed to reach spans of 30 feet (from perimeter to core). The thin slabs were desirable, as the team wanted to be efficient in maximizing the number of floors enabled by code.

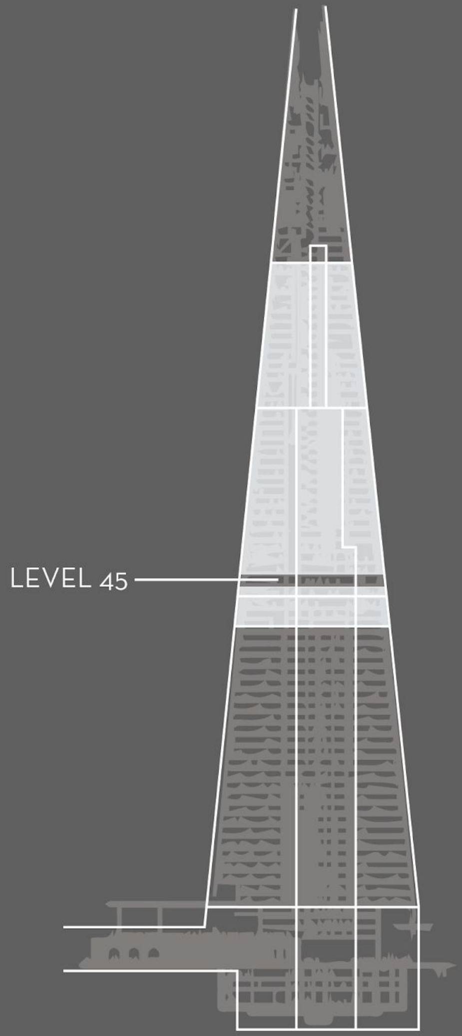
STRUCTURAL OVERVIEW



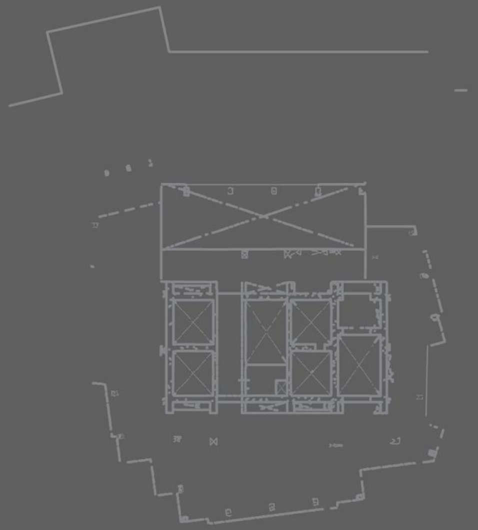


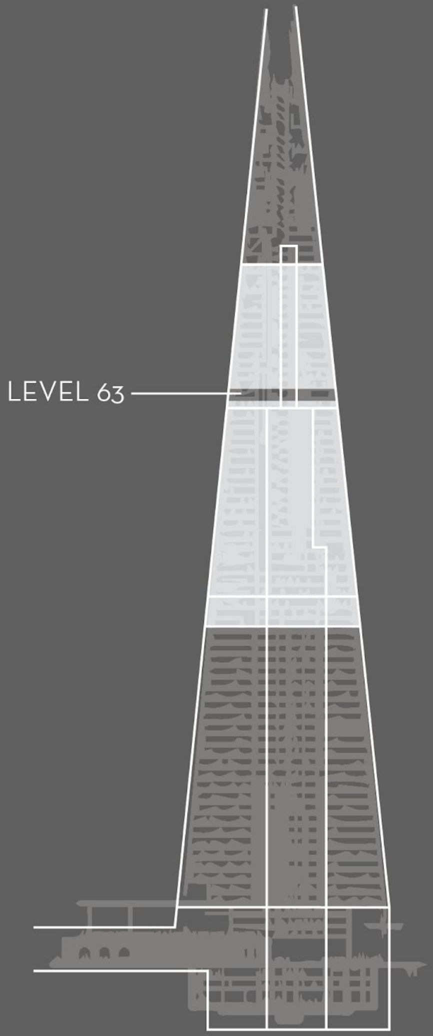
KENNEDY WATTS PATERNERSHIP





STRUCTURAL OVERVIEW



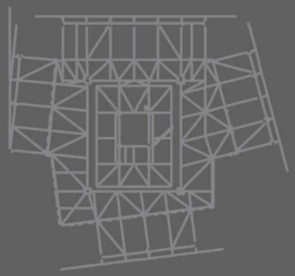


STRUCTURAL OVERVIEW

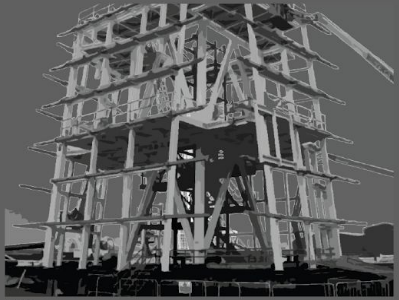

WSP

STRUCTURAL OVERVIEW


SELLAR PROPERTY GROUP



WSP

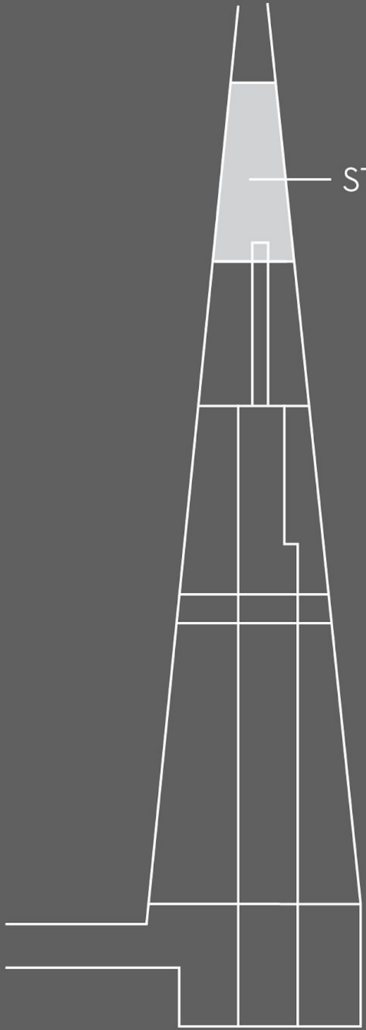


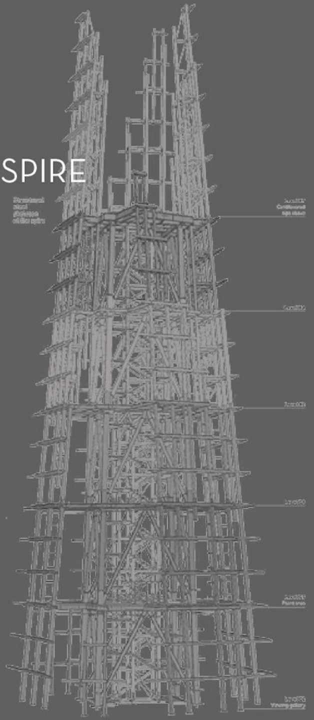
WSP

Above the hotel and residential quarters is the viewing deck and additional areas for systems. These levels are the last of the inhabitable, and combine to make the area referred to as The Spire. The framing on the top levels consist of a centrally located mast that supports access decks to the system plant. The skyscraper is topped off with another steel frame that utilized a vierendeel truss system paired with 1 inch rod bracing elements. This truss serves a purpose of realigning the columns to match the concrete struture below. It additionally was intended to maximize the column spacing on lower floors for an adaptable open space. The spire is composed of 460 exposed steel that weighs 530 tons. This system transfers loads and is located within the 4 floors that support the top of the tower.

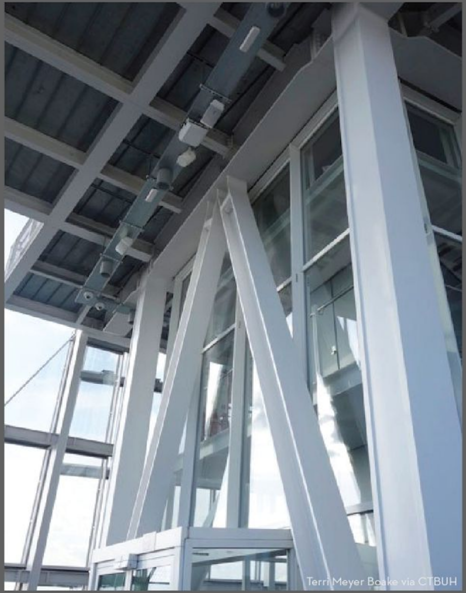
At this level, the grid spacing is roughly 5 FT. apart. The connections are bolted elements.

STRUCTURAL OVERVIEW

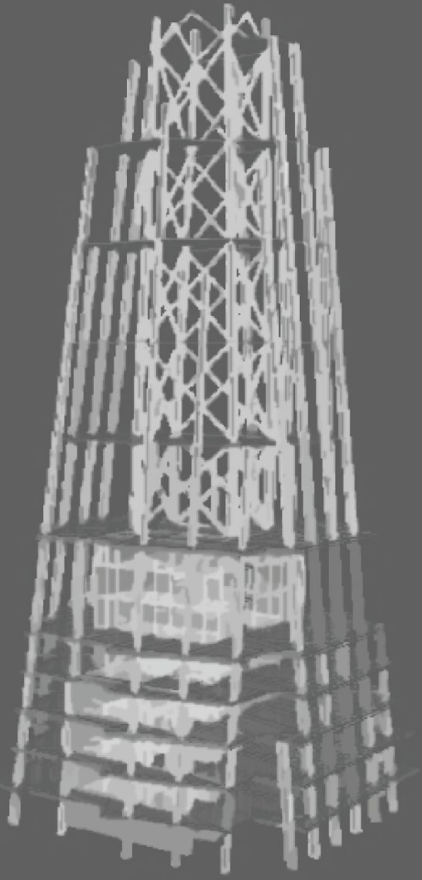




©FONDAZIONE RENZO PIANO

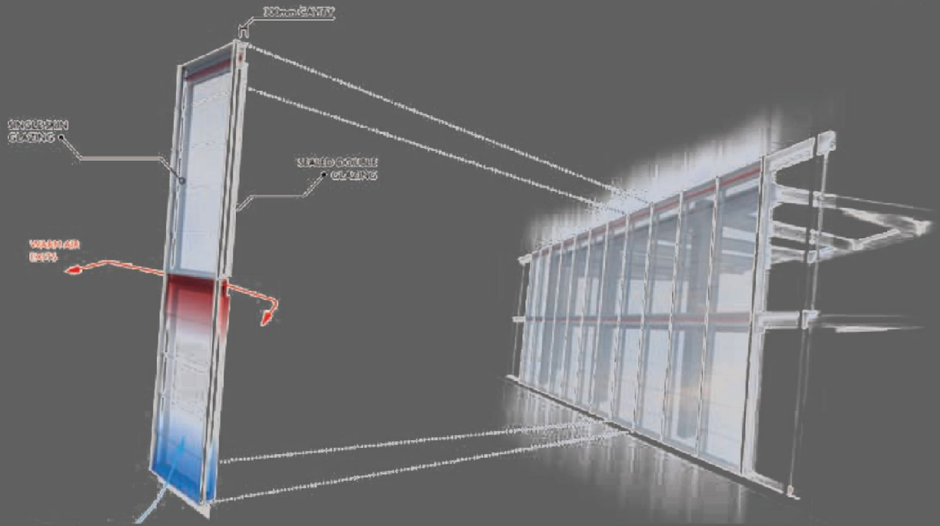


STEEL-CONCFRETE-STEEL: COUNCIL ON TALL BUILDINGS AND URBAN HABITAT / KAMRAN MOAZAMI, JOHN PARKER, RODOLFO GIANNI



STEEL-CONCFRETE-STEEL: COUNCIL ON TALL BUILDINGS AND URBAN HABITAT / KAMRAN MOAZAMI, JOHN PARKER, RODOLFO GIANNI

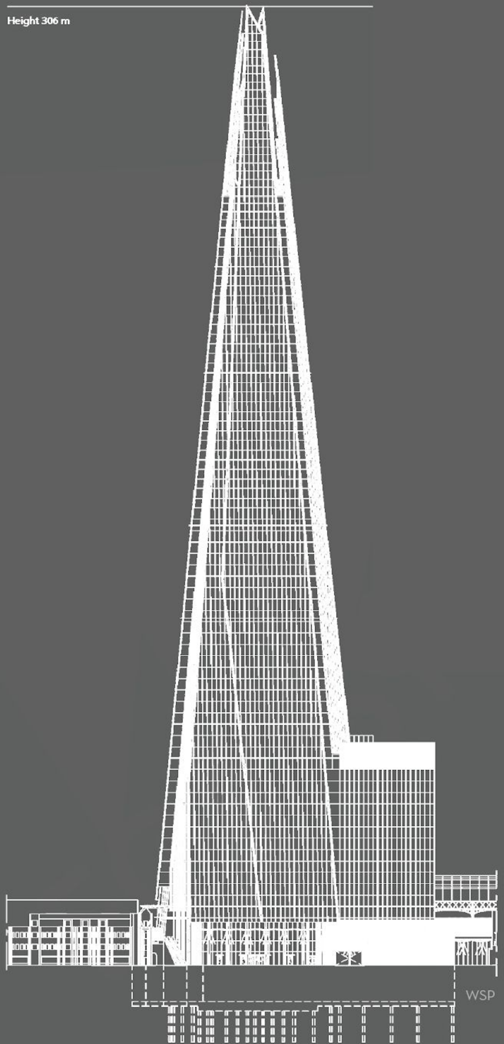
STRUCTURAL OVERVIEW



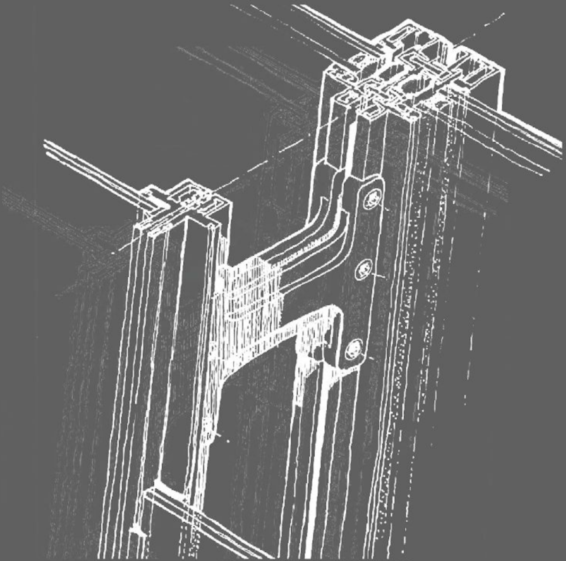
WSP

The facade of The Shard is one main defining factors of the unique superstructure. The facade was designed in a way to reflect the city like a shard of glass. Additionally, a main goal of the team was creating a low energy Glass paint consuming building. Glass paint was carefully created and utilized to aid in efficiency and reflection. The facade is also double skinned, which significantly reduced the amount of heat gain. The Shard's glazing system is covered in 11,000 angled glass elemented.

STRUCTURAL OVERVIEW

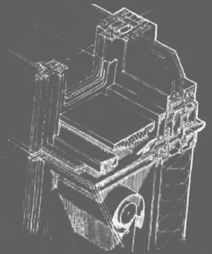


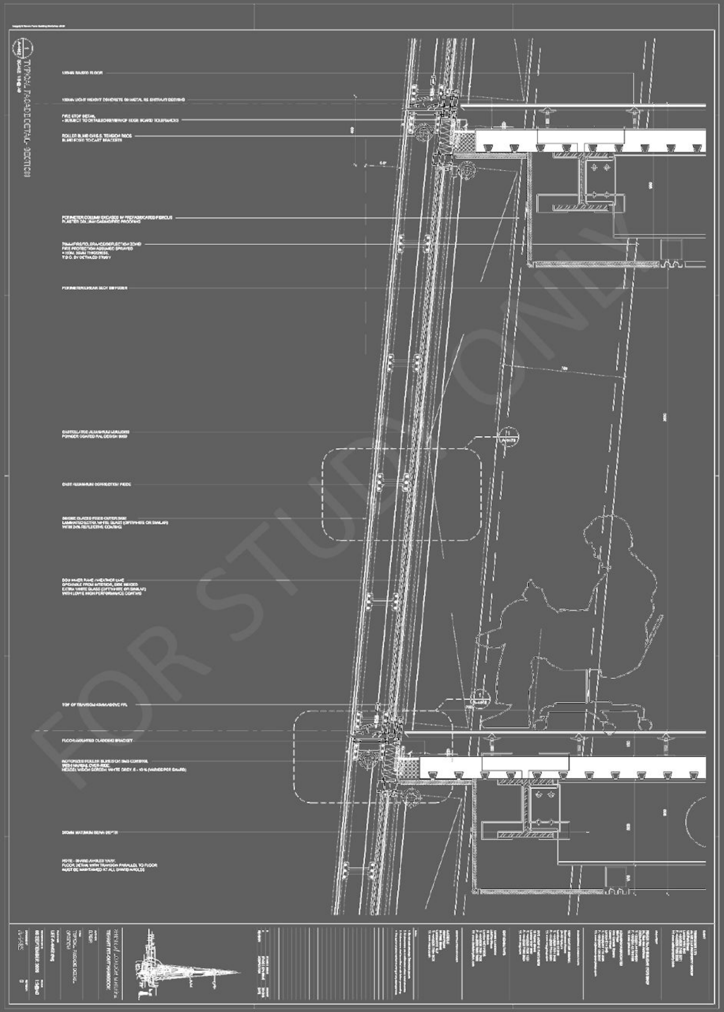
WSP



FACADE

The glass panels are triple glazed and supported by a series of vertical trusses. The glazing system is connected to the infrastructure through the extended flooring systems.





STRUCTURAL OVERVIEW

PHOTO BY LEE MAWDSLEY

PHOTO BY LEE MAWDSLEY

FACADE

The glass panels are triple glazed and supported by a series of vertical trusses. The glazing system is connected to the infrastructure through the extended flooring systems.

STRUCTURAL OVERVIEW

THE SHARD

FOUNDATION OVERVIEW.......25

SOIL ANALYSIS.......26

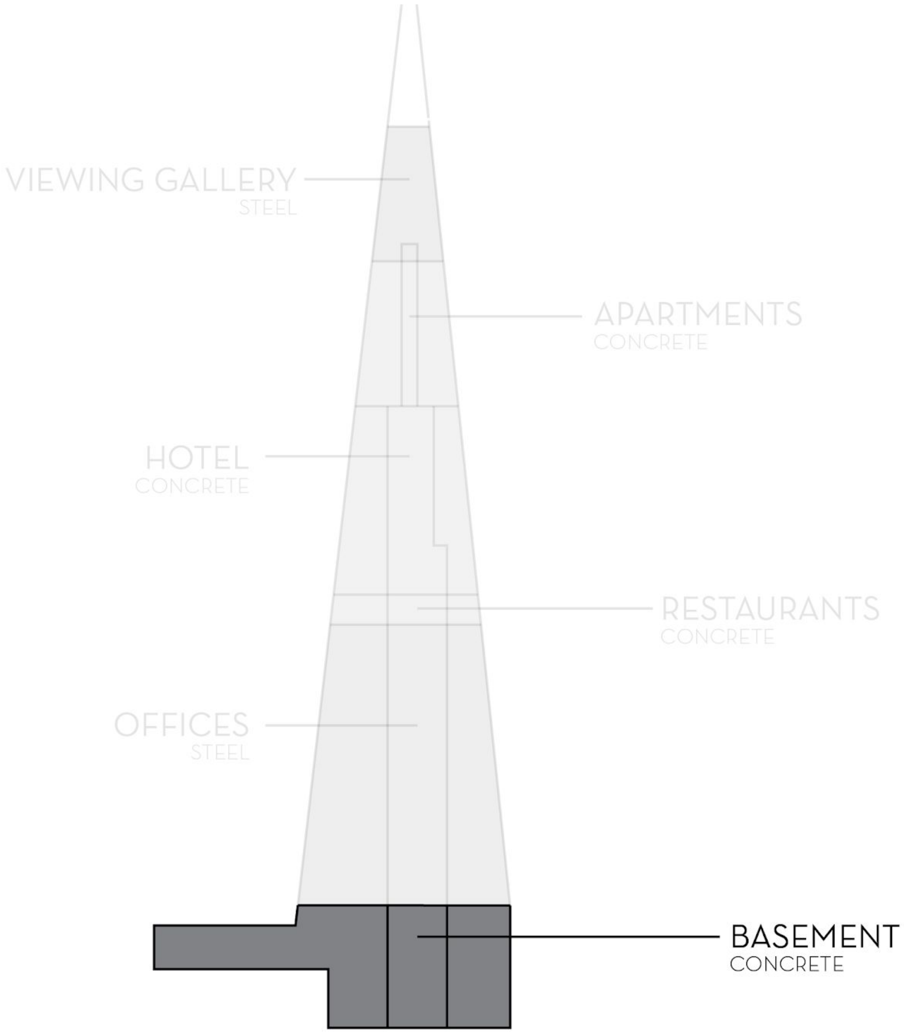
EXCAVATION.......27

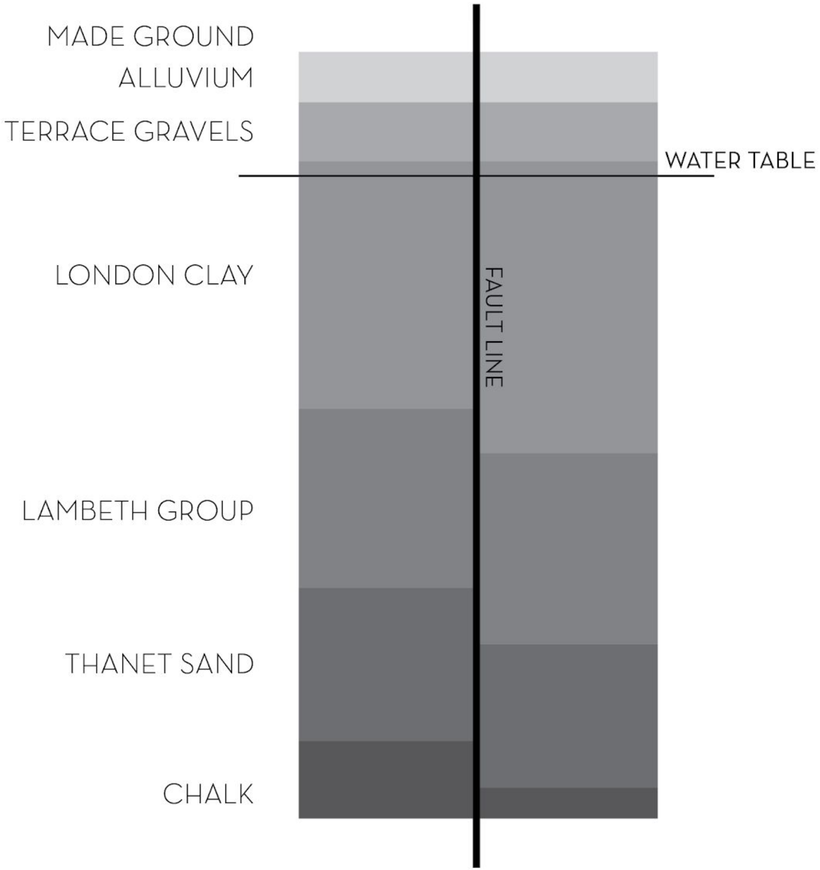
FOUNDATION SLAB.......28

FOUNDATION

Because of the proximity to Guy's Hospital and London Bridge Station, the previous building in its place had to be taken apart floor by floor. The old building's piles were not strong or deep enough to support The Shard and they would be too time consuming and expensive to remove. The new piles had to be planned and driven around the old piles. Also because of this removal of weight, there was a shift in the soil.

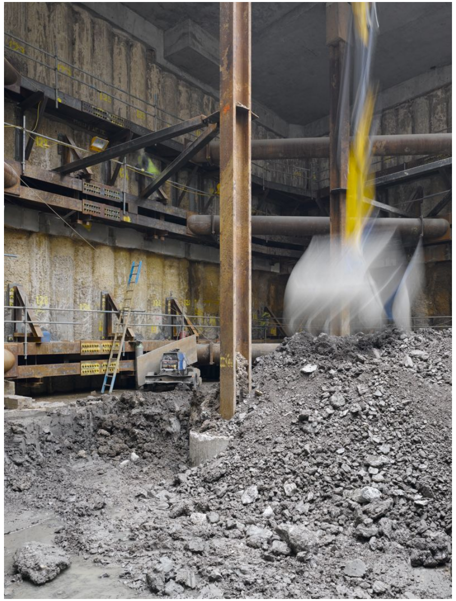
FOUNDATION OVERVIEW

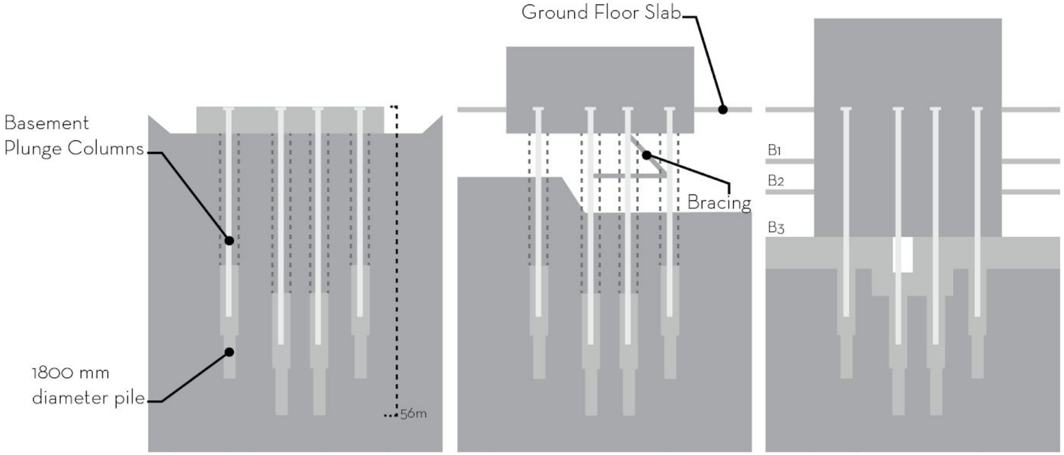




To build this three-level basement, the engineers did a soil analysis. They discovered a fault line under the site running north to south and took soil measurements from each side. There was a slight difference in the elevations of each strata on either side so the piles were adjusted accordingly. There was also ground water found within the gravel layer at -4.8m. They found that the piles would be drilled about 56m, hitting the Thanet Sand layer. The bearing capacity for this strata is 20,000 kN/m^2.

SOIL ANALYSIS





piles and plunge columns driven, construction of core begins

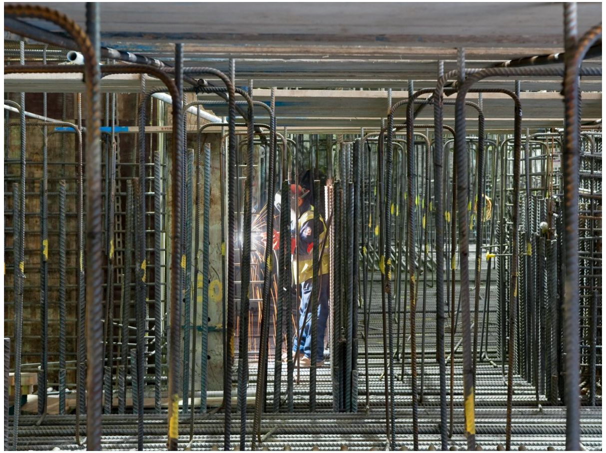
basement excavation begins, bracing of core put in place

foundation is complete, core construction continues

120 concrete and steel piles were driven into ground each one having an overall ultimate capacity of about 41,150 kN. The piles were constructed with top elevation of about 13m below ground level because of the top down construction method. Top down construction is the simultaneous construction of the upper levels of the building while excavating the basement. Plunge columns were used to support the core until the 21st floor when the foundation slab had to be poured.

EXCAVATION

https://www.leemawdsley.co.uk/stories/theshard#first



The foundation slab had to be done in a single pour in order to resume construction on the core as fast as possible. It took 700 truck loads of concrete (5,500 cubic meters) and lots of skilled logistics to complete. The pour took 36 continuous hours to complete and fans were brought in to cool the concrete as it cured so it wouldn't crack. The overall foundation load carries 7,777 lb/sf.

FOUNDATION SLAB

https://www.leemawdsley.co.uk/stories/theshard#first

THE SHARD

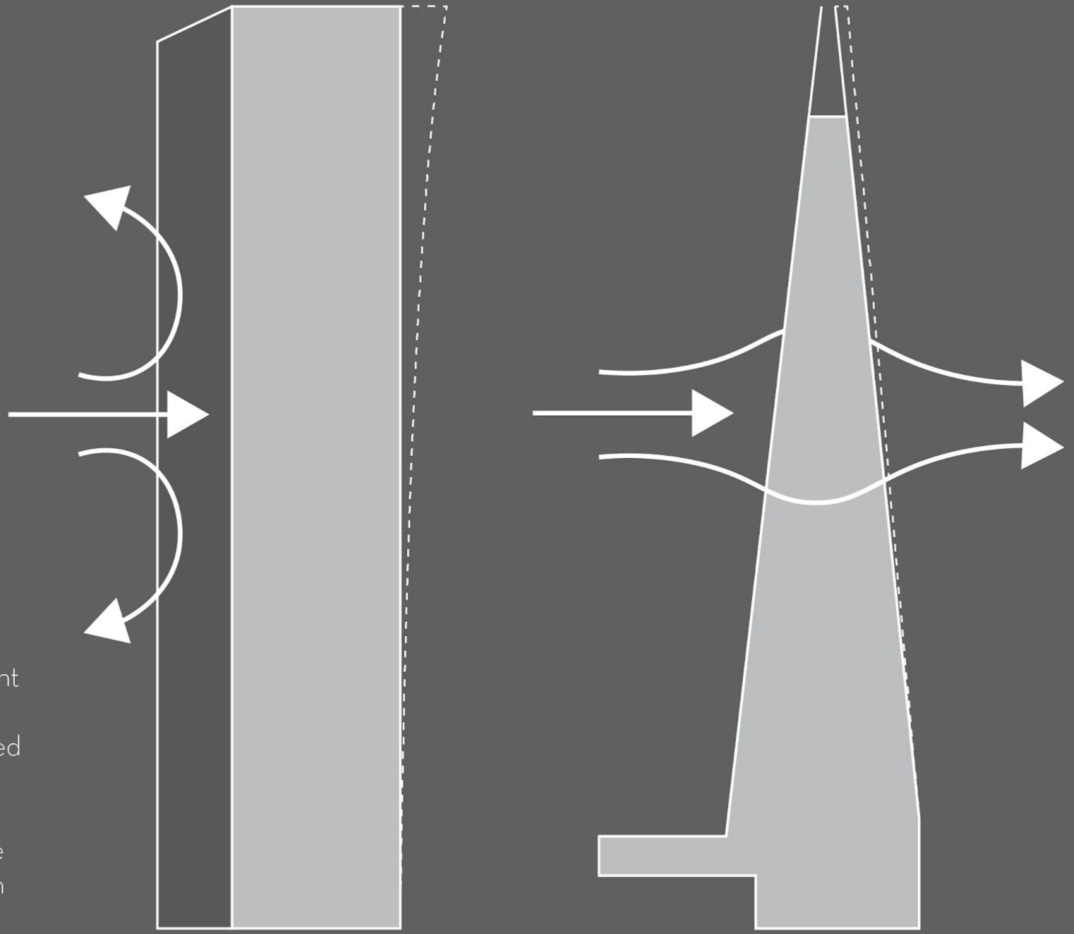
BUILDING PROFILE.......30

SHEAR CORE.......32

BUILT-IN DAMPER.......33

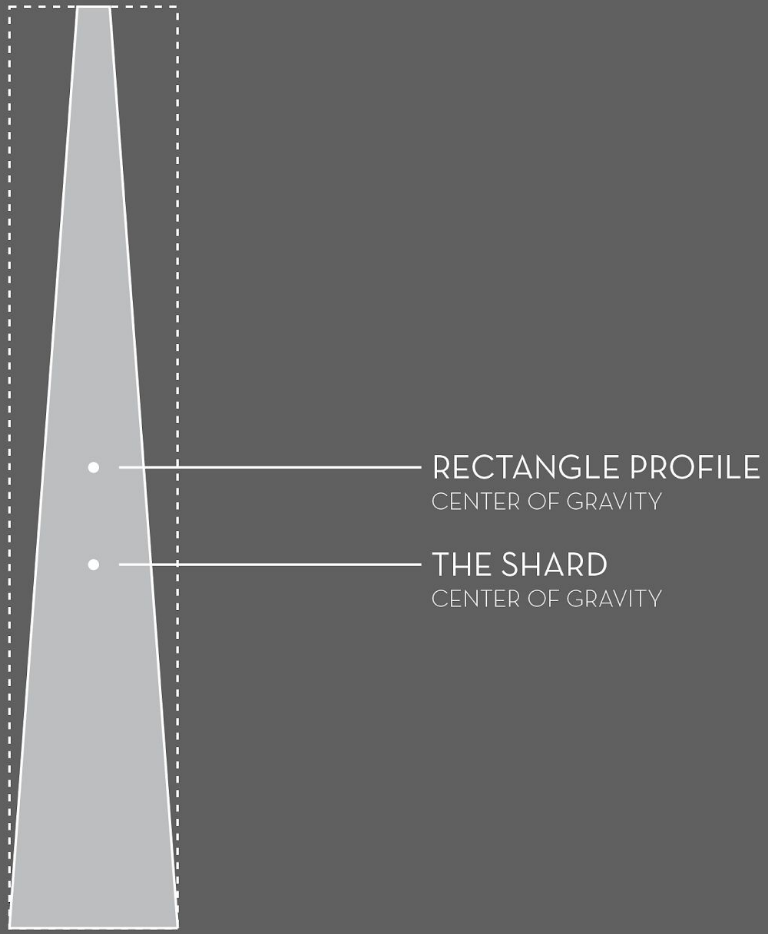
HAT TRUSS.......34

LATERAL STRUCTURE



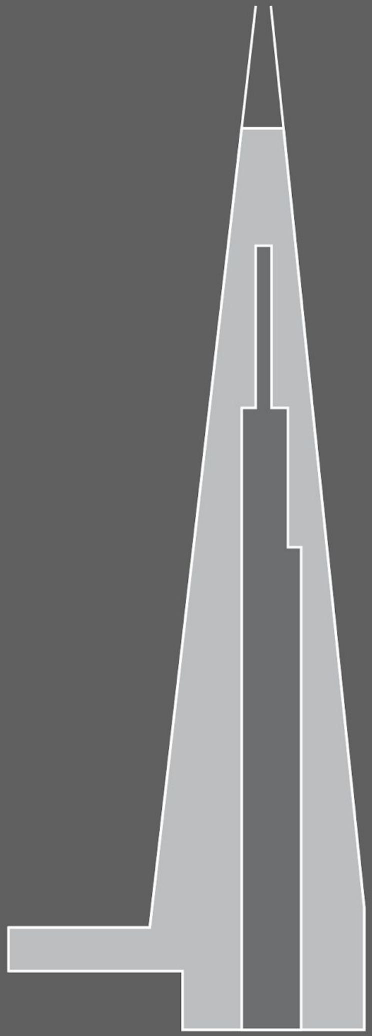
The Shard utilizes many different elements to combat displacement and horizontal acceleration from lateral loads placed on the structure. The first of which is the building profile itself. The tapered design of the project creates a more aerodynamic surface for the wind to interact with, reducing the lateral force on the building created by the wind. With windspeeds recorded at 100mph at the top of the building, the narrowing of the form dramatically helps in the reduction of defelction due to wind loading events.

LATERAL STRUCTURE



Because of the tapered form, The Shard's center of gravity is nearer to the base of the structure as opposed to higher had it been a rectangular form. This interently increases the building's stability and lessens the chance of lateral displacement near the top of the structure from wind.

LATERAL STRUCTURE

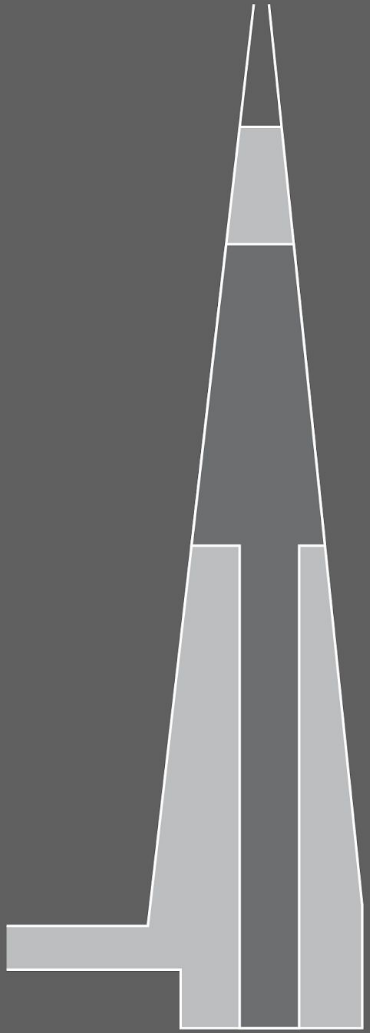


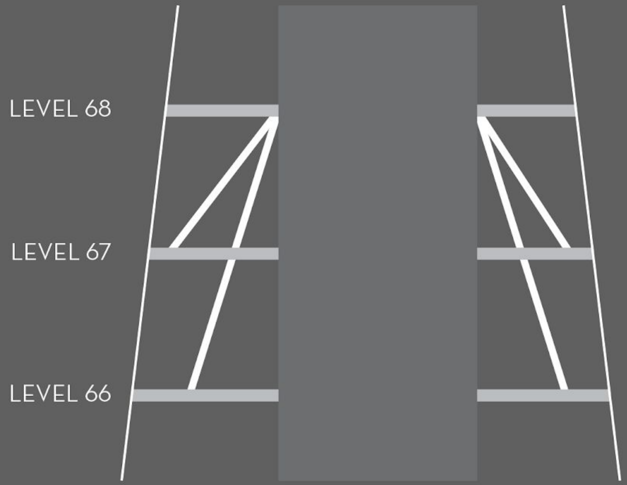
The shear core present in The Shard is perhaps the most vital component in resisting lateral loads. As in most high rise structures, the building features a concrete core that serves as the buildings rigid center, counteracting any lateral force the building experiences. The engineers set a horizontal accelereation limit of 0.15 m/s^2 at the upper floors and the shear core is the main factor that serves in decreasing this acceleration when the building begins to sway due to lateral loading.

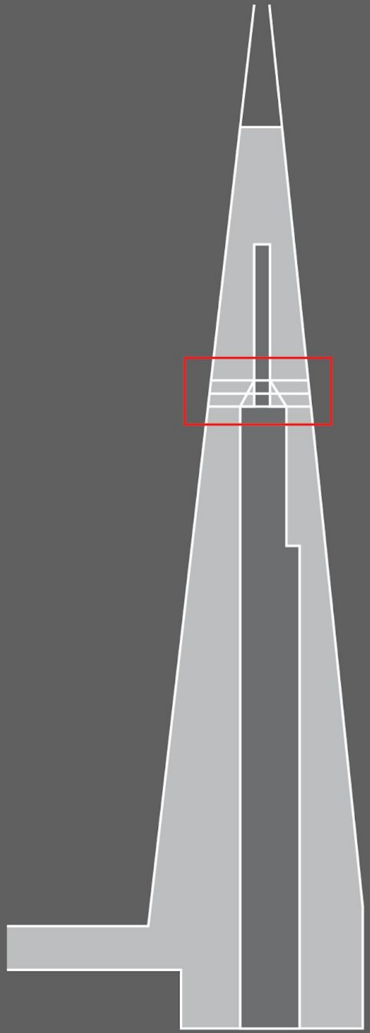
LATERAL STRUCTURE

In most high rise structures, projects often feature a mass tuned damper toward the top of the building that counteracts the force and acceleration when the building begins to sway. Given the nature of construction of The Shard, the massive concrete segment toward the top of the building acts as a "built-in" damper that counteracts sway due to wind or possible seismic loads.

LATERAL STRUCTURE



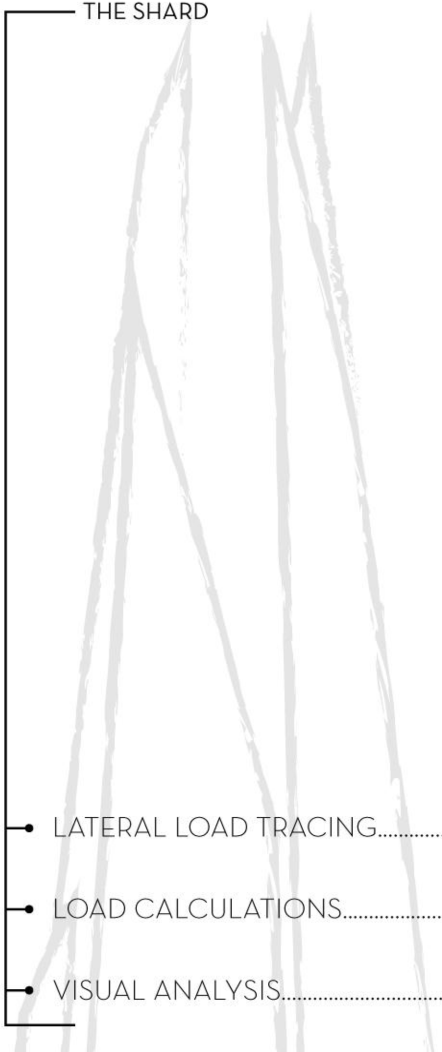




The Shard also features a “hat truss” system constructed from outriggers that begin on Level 66 and extend diagonally through Level 67 that transfers lateral load from the exterior perimeter to the building’s core. This in turn increases the building’s stability, controlling the sway and holds the horizontal acceleration within the perscribed range in order to maintain occupant comfort.

LATERAL STRUCTURE

THE SHARD



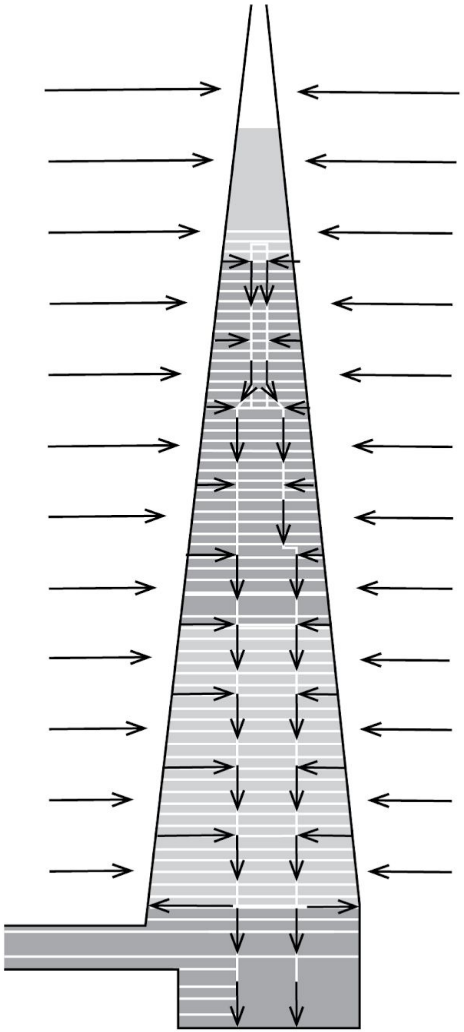
- LATERAL LOAD TRACING....36
- LOAD CALCULATIONS....37
- VISUAL ANALYSIS....38

LATERAL RESPONSE

The lateral loads are transferred:

Through the exterior cladding
To the reinforced floors
Through the outriggers and hat trusses
To the rigid concrete core
To the ground floor and basement

LATERAL LOAD TRACING



$LOAD_{concrete}$ = Concrete Load due to Floor Slabs + Concrete Load due to Core= 1.76×10^8

$LOAD_{glass}$ = Density of Glass x Cubic feet of glass in building = 6.79×10^6

$LOAD_{steel}$ = Density of Steel x CF of steel = 1.77×10^7

$LOAD_{partition}$ = Area per floor x 5 lb/ CF of floor Area = 6×10^6

$LOAD_{equipment}$ = Area per floor x 5lb/CF of Floor Area = 6×10^6

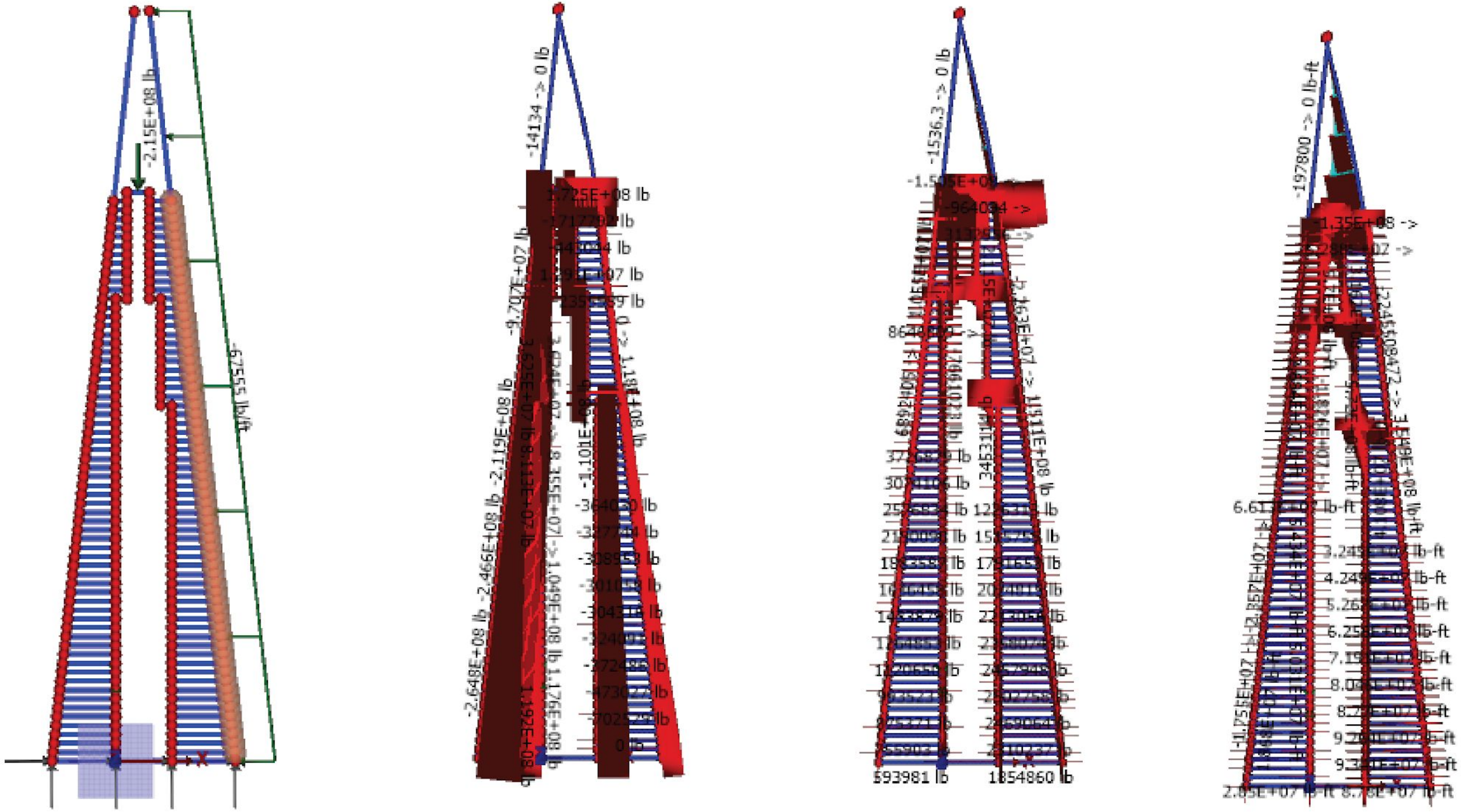
$LOAD_{ceiling}$ = Area per floor x 2lb/ CF of floor Area = 2.4×10^6

Vertical Structure Area = 1.5% of Area per floor x building height = 207,722 CF

Total Dead Load = $LOAD_{concrete}$ + $LOAD_{glass}$ + $LOAD_{partition}$ + $LOAD_{equipment}$ + $LOAD_{ceiling}$ = 2.15×10^8

Max Horizontal Wind Load = Max wind speed in London x Surface Area of Single Face = 6.08×10^6

LOAD CALCULATIONS



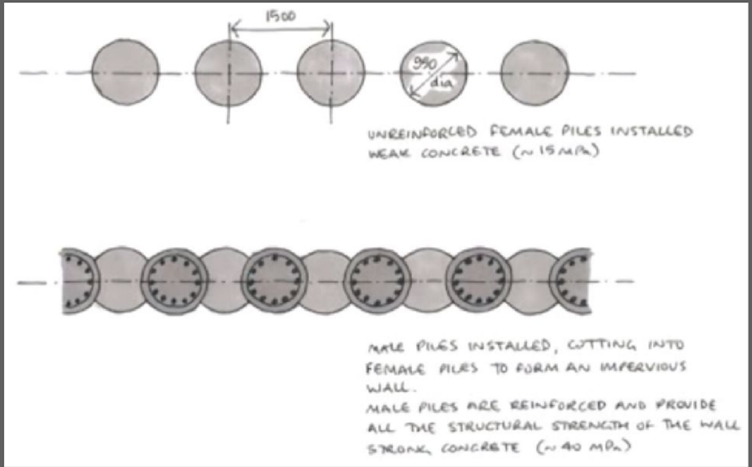
VISUAL ANALYSIS

CONSTRUCTION

THE SHARD

CONSTRUCTION OVERVIEW.....40

SPIRE CONSTRUCTION.....41



Before construction could being, they needed to make sure no water would flood in from the near by River Thames. To prevent this, they construct a secant pile wall system, like a mini dam, made of interlocking concrete piles around the perimeter of the site.

As the building was growing in height, there was a large amount of wind loads experienced on structure as it grew. Around the 50th floor, with 45 to go, was when the wind started to become a problem. Winds would reach 41 mph at over 180 meters up with temperatures dropping below freezing. Protective screens had to be installed in order to continue construction and to protect the workers from frostbite.

CONSTRUCTION

© Mark CH Thompson via CTBUH

The spire sits atop the apartments and is made up of over 1,300 pieces of glass and steel and is over 300 meters (984 feet) above London and is over 60 meters (196 feet) tall. Parts of the spire were preassembled at a steel yard as a way to practice assembling it in three large sections on the ground. These pieces were then taken apart modularly and lifted in 7 ton pieces then reconstructed a top the building.

CONSTRUCTION

https://arstechnica.com/gadgets/2011/12/the-shards-bleeding-edge-anatomy-of-a-21st-century-skyscraper/

https://www.ingenia.org.uk/Ingenia/Articles/89cc651d-72b8-410f-b1a2-5fd5ac894285

https://www.thenbs.com/knowledge/engineering-the-shard

https://www.tekla.com/global-bim-awards-2012/steel-the-shard-london-bridge.html

http://www.engineersjournal.ie/2016/01/26/engineering-the-shard/

http://legacy.skyscrapercenter.com/london/the-shard/451/

https://www.newcivilengineer.com/journals/2014/06/04/c/c/u/ge-jan-2012-pile-test-at-the-shard-london-bridge-beadman-pennington-sharratt.pdf

https://www.leemawdsley.co.uk/stories/theshard#first

http://www.engineersjournal.ie/2016/01/26/engineering-the-shard/

http://www.fondazionerenzopiano.org/it/project/the-shard-london-bridge-tower/#section-drawings-899

https://www.slideshare.net/misschand/the-shard-70431422

https://www.structuremag.org/wp-content/uploads/2014/08/F-LondonBridgeTower-June081.pdf

https://sites.google.com/site/team8assignment2/structural/calculations

REFERENCES