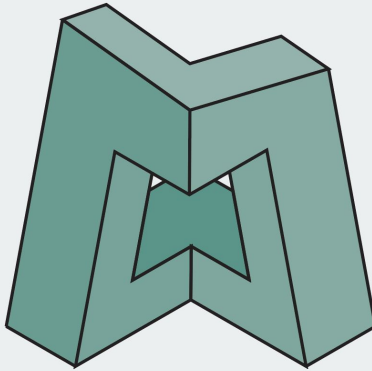




CCTV HEADQUARTERS



ARCH 631 Spring 2018
Daniel | Edith | Mckenzie | Rafael

CCTV HEADQUARTERS



Introduction

Architect: OMA Rem Koolhaas

Main Structural Engineer: Arup

Structural Engineer: Architecture Design Institute of East China

Main Contractor: China State Construction and Engineering Corporation

Developer/Owner: China Central Television



Introduction

Location: Beijing, China

Construction Started: 2004

Completed Year: 2012

Number of floor: 51 (3 below ground)

Height: 768 ft

Floor area: 4188012 ft



Phases

Due to the complex form , the project fell outside codes for buildings in China

-Series of rigorous meetings

- Intense approval process

-3 Physical Tests

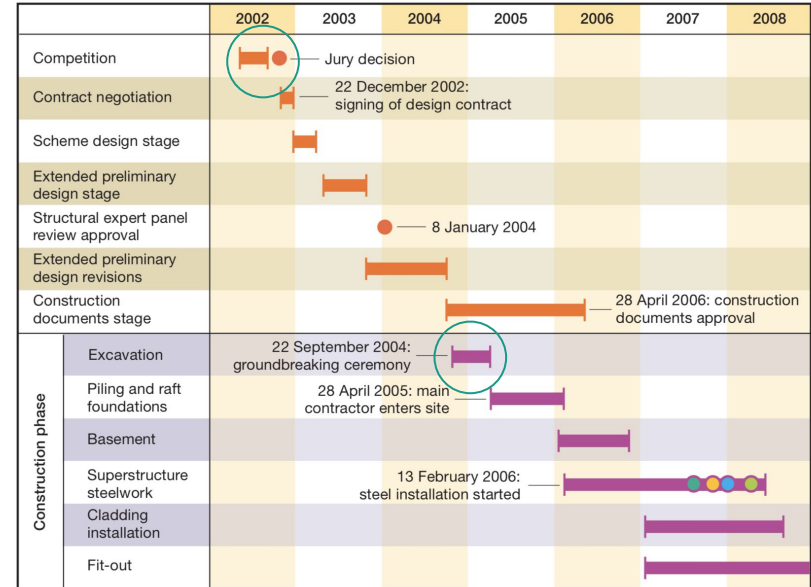
Joint Test

Composite Columns Test

Shaking Table Test

~largest most complex model tested

~corroborate the computer model



- 1 August 2007: construction of Overhang starts
- 8 December 2007: connection of Overhang
- 26 December 2007: Overhang connection ceremony
- 27 March 2008: topping-out ceremony



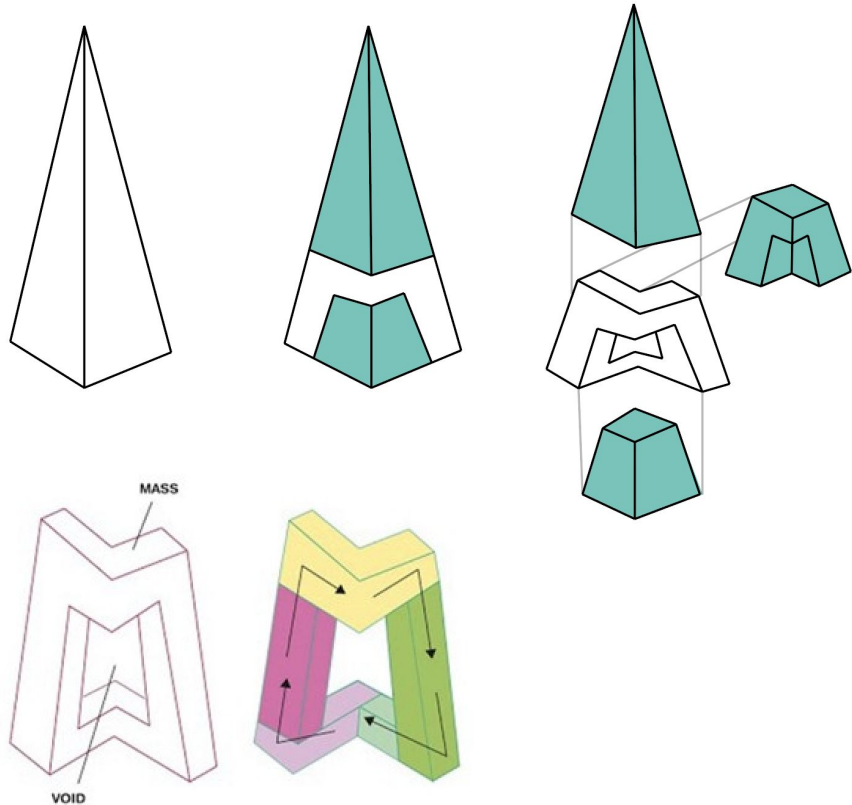
Geometry

Continuous loop/Mobius strip

L-shaped

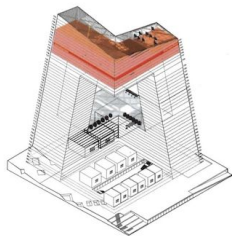
Cantilever Overhang

Diagonal Structural Grid System

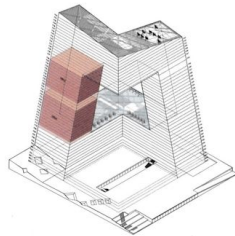




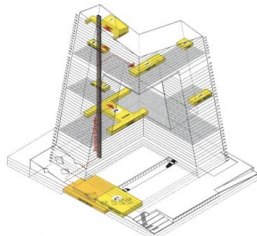
Program



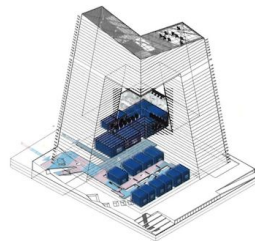
ADMINISTRATION



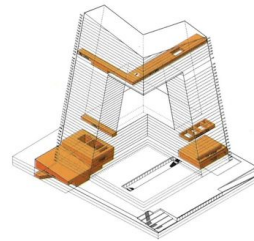
BUSINESS



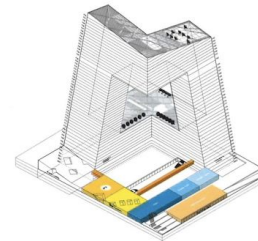
CANTEENS



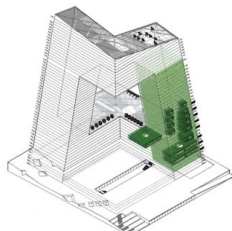
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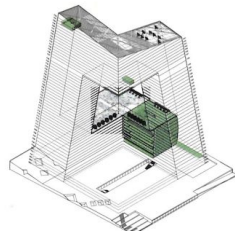
LOBBY



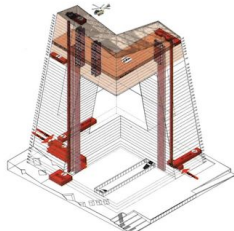
FUN AREAS



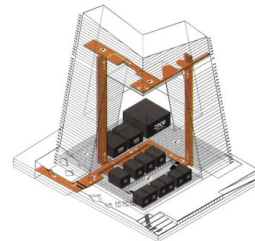
NEWS &
BROADCAST



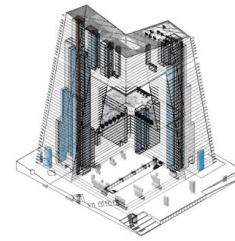
BROADCASTING
TRANSMISSION



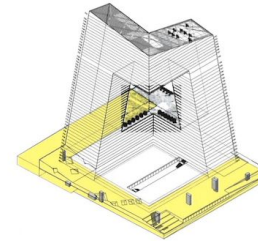
VIP AREAS



VISITOR CIRCULATION



CORES



PARKING

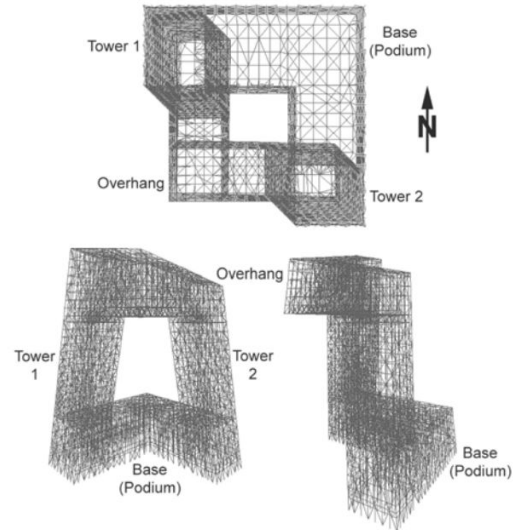
Structural Concept

3 story basement, 9 story base, 2 towers, 9-13 story overhang (36 stories above ground) joined as a 'continuous tube'

Towers slope in 6 degrees each direction

External diagrid solution for high seismic area as well as solution to connect full loop

Transparency of structure expressed through facade





Seismic Requirements

ARUP proposed a performance based design approach to set the following:

Basic Targets for a Seismic Event

1. No structural damage when subjected to an earthquake of level 1 with an average return period of 50 years
2. Repair structural damage when subjected to an earthquake of level 2 by return period of 475 years
3. Accepted but forecast severe structural damage collapse when the building is subjected to an earthquake of level 3, for an average return period of 2500 years

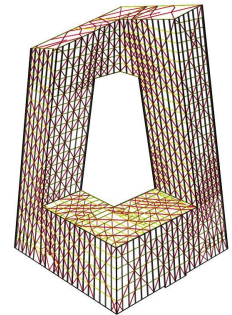
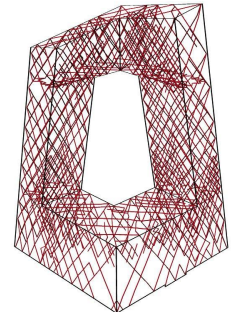
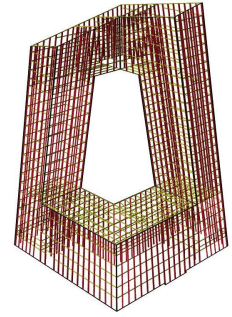
Super-structure

All sides of facade are fully braced through combination of regular column grid/edge beams and the diagonal bracing system

Stepped and oriented vertical cores within towers including elevators, risers, and stairs

TWO story support trusses at mid height of towers to support vertical columns that should not be carried directly to the ground

TWO story transfer deck supports vertical columns in overhand moving load to external load structure





Super-structure

Stiff floor plate diaphragm used every two stories

Towers gain primary stiffness through braced tube system - allowed them to be built safely when not yet connected

Same phenomenon for cantilever parts as they are being built from either end before connected

Regular pattern of steel/SRC behind main tube structure/perimeter beams and optimized to allow change in plate thickness in more necessary areas

Diagonal Grid System (Diagrid)

Load follows diagonals and transferring gravity and lateral loads to the ground

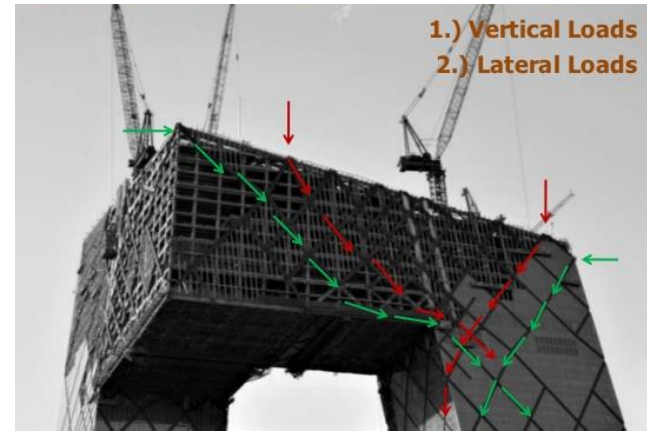
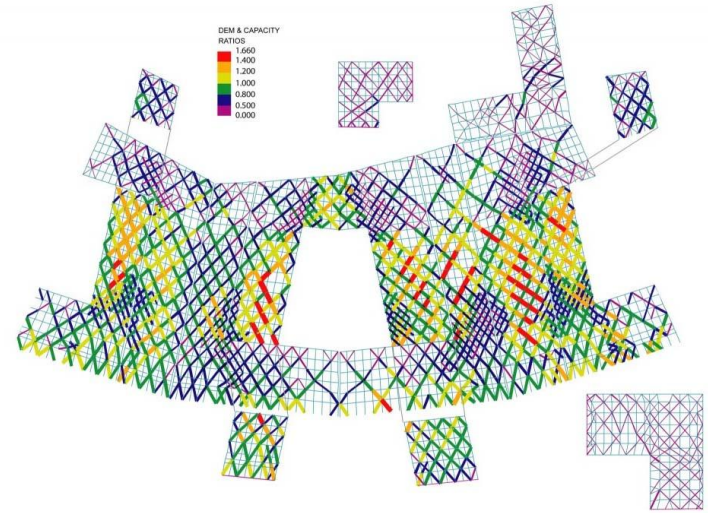
Combination of columns, bracing, and diagonals in one

In-place welding of nodes

Configure optimal angles

Column (max bending rigidity): 90

Diagonals (max shear rigidity): 35



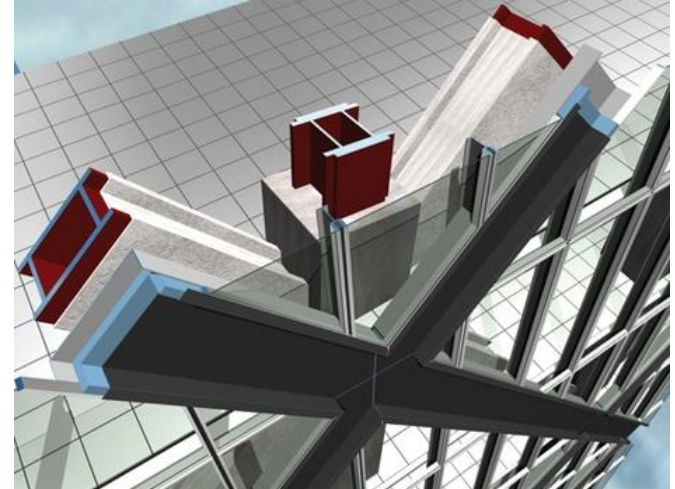
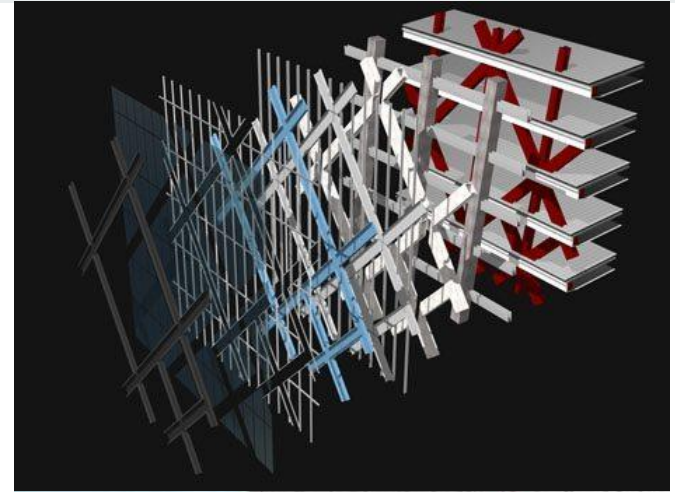
Exoskeleton/Facade

Facade bracing expresses pattern of forces within the structure

Determined through iterative analysis

Facade installation began when structure reached mid-height

Load of facade taken into account as well the extra safety measures needed for sloped facade



Transfer Structures

Due to slope of towers, internal vertical columns cannot be continuous

Select plant floors house two story deep trusses to transfer loads

Connect to internal cores and external columns at singular pin-joint locations to prevent outrigging

Also located in overhang to support internal columns

Forces in truss diagonals carried only by the flanges at connections

Webs stop short of the chords to simplify construction

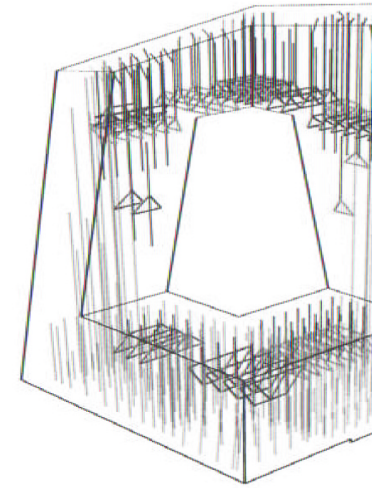
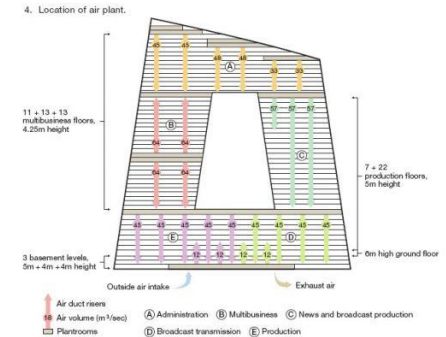


Figure 6. Transfer trusses



Natural Frequencies & Mode Shapes

Due to complex geometry, natural frequency analyzed with 3-dimensional modes

1st mode mainly lateral with two towers bent

2nd mode sees bending in the cantilever as well

3rd mode sees torsion on towers and cantilever

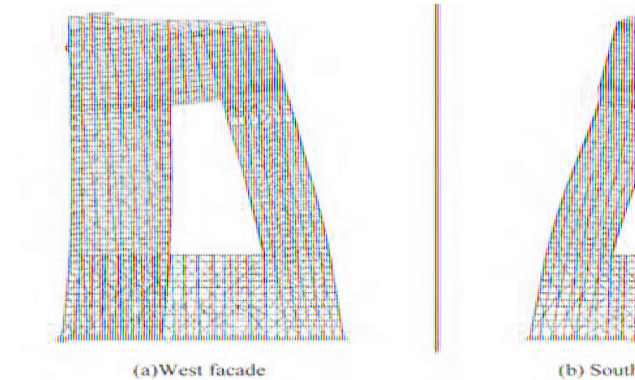


Figure 3. The first bending mode.

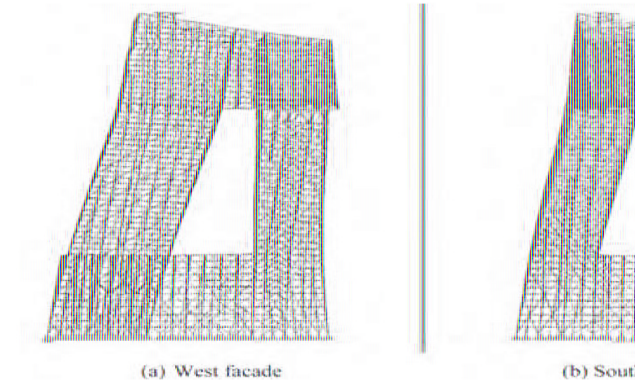


Figure 4. The second bending mode.



Building Code

Chinese design codes treated as legal documents, relieving engineers of legal responsibilities

Chinese code for seismic design (GB50011-2001) sets scope of applicability and limits heights

Buildings exceeding code go through seismic design expert panel review

Height is compliant but geometry not

Panel of 12 prominent engineers and academics reviewed seismic resistance, structural damage control, and life safety

Approved in January 2004 after 3 meetings and a final presentation

Testing Practices

In addition to various computer simulations, physical testing was required for approval process

Butterfly plate - 1:5 scale model of joint for performance in cyclical loading and confirmation of yield location

Composite column - 1:5 model for concerns that high steel ratio would result in ductility

Shake table: 1:35 full model under various seismic events



Figure 7. Shake table test model

Excavation

Strict construction regulations so soil could only be removed at night

Groundwater level was above the max excavation depth; dewatered wells

Up to 42,400 cubic feet of soil was removed each day

190 days of excavation

Largest single continuous concrete pour in China



8. Preparation of foundation raft.

Foundation/Substructure

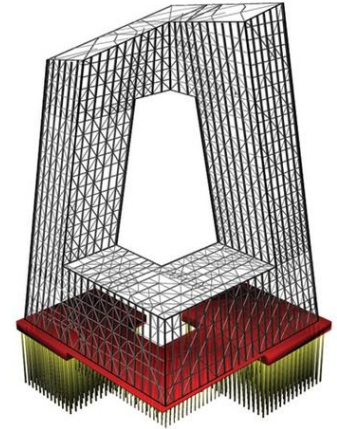
Towers are supported on separate **piled raft foundations**

370 reinforced concrete **bored piles** beneath each tower

1242 piles were installed

Centre of the raft is close to the centre of the load at the bottom of each tower for no permanent tension in the piles

Certain piles were designed for tension especially designed for severe **earthquakes**



Foundation/Substructure

A traditional raft is used in the basement with more tension piles between columns locations to resist uplift due to water pressure

the foundation design required that the load be redistributed across the pile cap

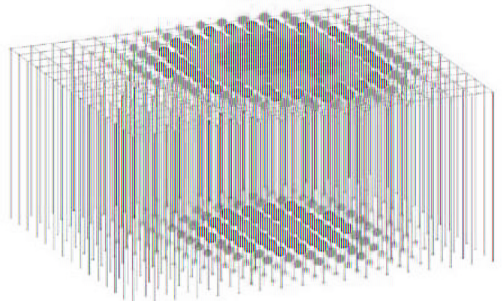
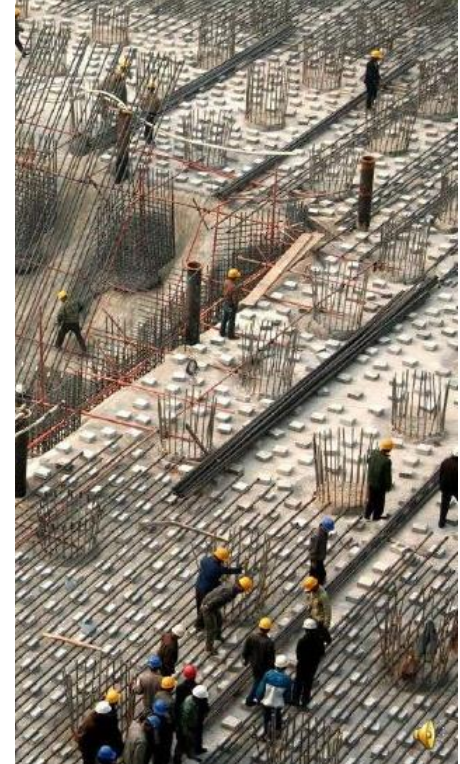


Figure 4. Foundation settlement analysis



Columns

Types: SRC Columns and Steel Columns

Challenge: columns on the inside faces of the Towers; huge amount of dead load from the Overhang

Solution: corner columns and brace elements directly below the Overhang were left out until the end of construction

Forcing the dead loads to travel along the diagonals down the adjacent columns; enabling the full capacity of the corner elements to be available for wind and seismic loads



Figure 9. Column embedded in raft

Connections

Butterfly plates used on the face of columns to connect with braces and edge beams

Must behave as “strong joint/weak component”

Extensive modeling and simulations tested largest stress cases and full range of forces for buckling or yield

Cantilever connection facilitated by seven connection pieces in a precise two day process

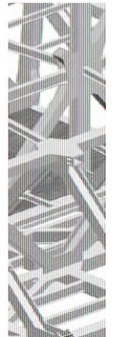
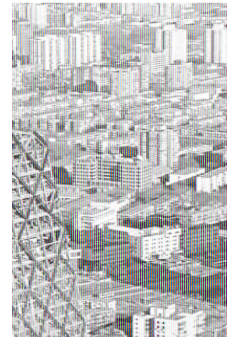
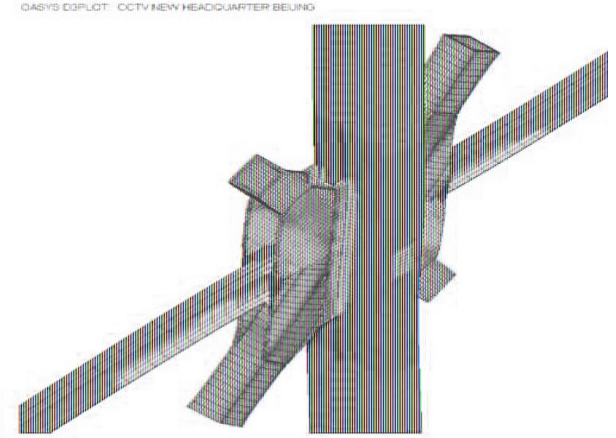


Figure 13. TI

Welding

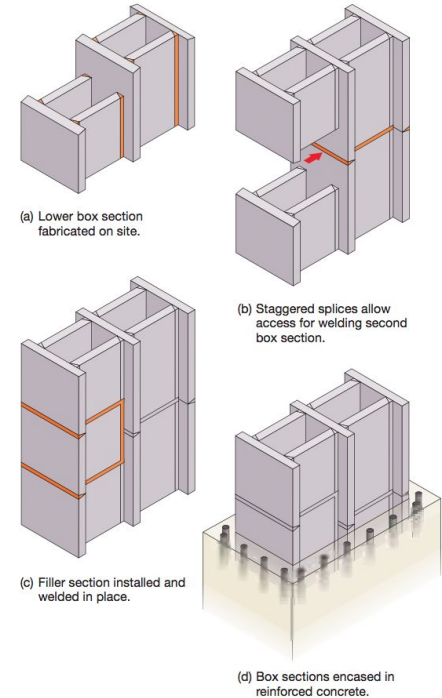
Highly qualified welders; long and complex welding process; high labor cost

Complex sections for a full weld; splices were staggered to reduce the concentrations of weld stresses

At times the volume of the weld reached 15% of the total connection weight

Butt welds at every connection

Onerous material for thick sections



17. Weld process for complex section.

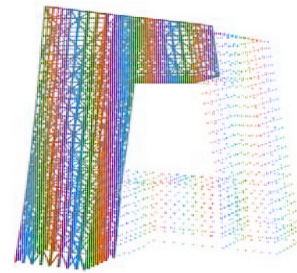
Movement and Presets

Building's deflections and forces during timeline of construction analyzed and taken into account

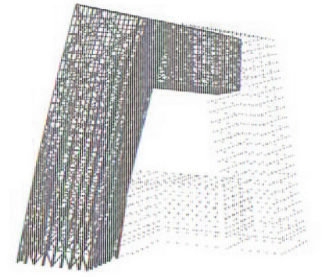
Overhang would deflect 3 meters under dead weight

Towers must be pre-set upwards and backwards to compensate

Careful movement monitoring and prediction used throughout construction



(a) Tower deflects under its own weight.



(b) Preset upwards and backwards.

Figure 11. Basic concept of presetting

Towers

Complexity of crane placement shown to right

Vertical core structure erected 3 stories ahead at all times

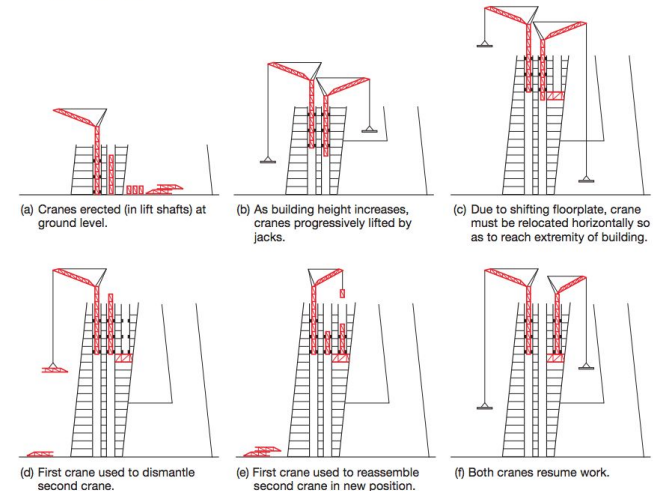
Had to be designed to withstand thermal and wind changes while under construction

‘L’ shaped connection bridge build from opposite corners until met in the middle at angle



Figure 14. Installation of first connection element

10. Crane slewing process.





Cantilever

Overhand construction began at tower 2 after steelwork for towers were completed to roof level

Five months to construct, cantilevering piece by piece until connected in the center

Forces felt by cantilever in construction within towers until connected and shared

Bottom TWO levels contain 15 transfer trusses - converging in cantilever center with 13-part 3D nodes

Many trial fabrications performed on the ground before actual construction for importance of accuracy

Corner connection used a delay joint which could be tightened when in need of stabilization during final construction

Cantilever

Requirement use of delay joint in the morning of a windless day so that towers would be same temperature and experience minimal movement

Monitoring of tower movement during week before connection in order to format correct lengths of joining members

Continuous steel plate deck (20mm) laid on lowest overhang floor to resist in-plane forces from propping up towers



Construction Issues

Importance of timing during construction of towers

Minimize relative moment between them from wind and thermal effects

Tricky overhang - use of delay joint for finalization

High settlement risk, several pore water spots in soil

Upper and lower bound analyses for flexibility of contractor

Lowest bound = highest stress in overhang when propping towers

Highest bound = highest stress in towers due to bending





Post-Installation Elements

Corner column and brace elements below the overhang added at end of construction to force dead loads through diagonals and down adjacent columns

Other elements added to intersection of towers and podium for full capacity for wind and seismic loads in final condition

Delay joints between towers and base allowed for differential settlement between foundations

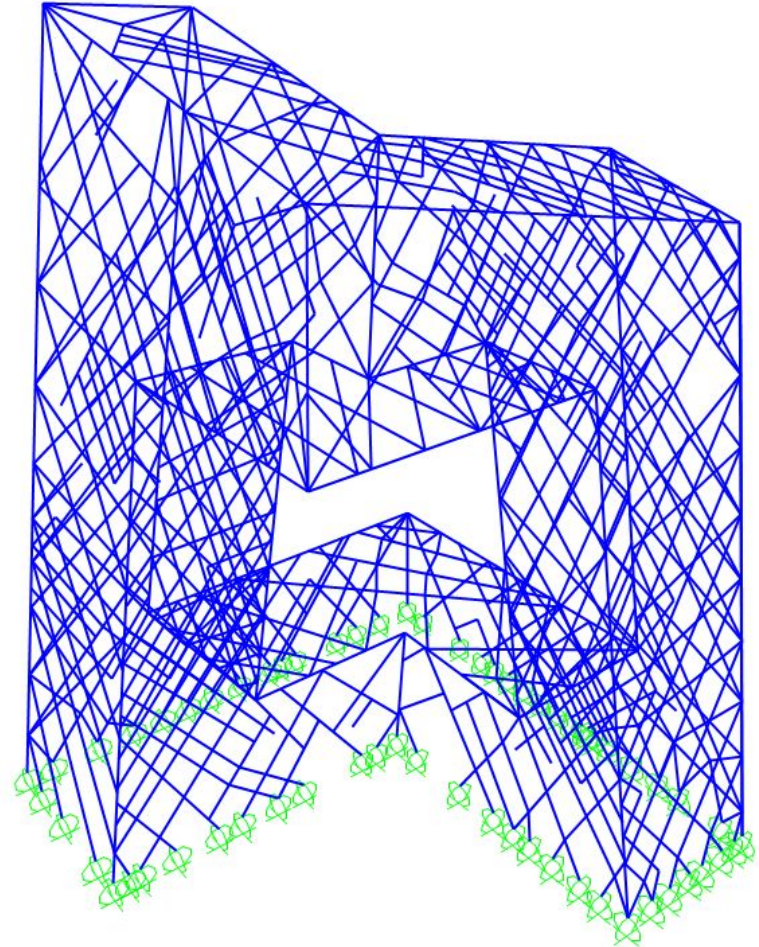
Late cast strips added around basement to controll shrinkage

SAP2000 Model

Complex geometry

Diagrid as main force resisting structure

Rigid Connections in tube, pinned connections to foundation



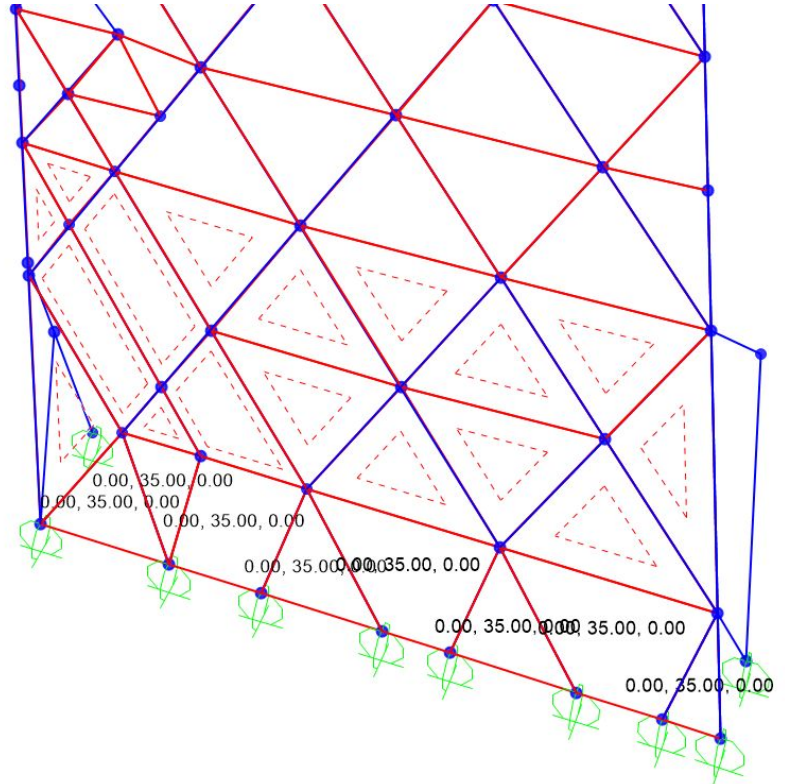
Wind Loading

ASCE 7, Ch 26 and 27 for wind loads

South side is loaded in this example

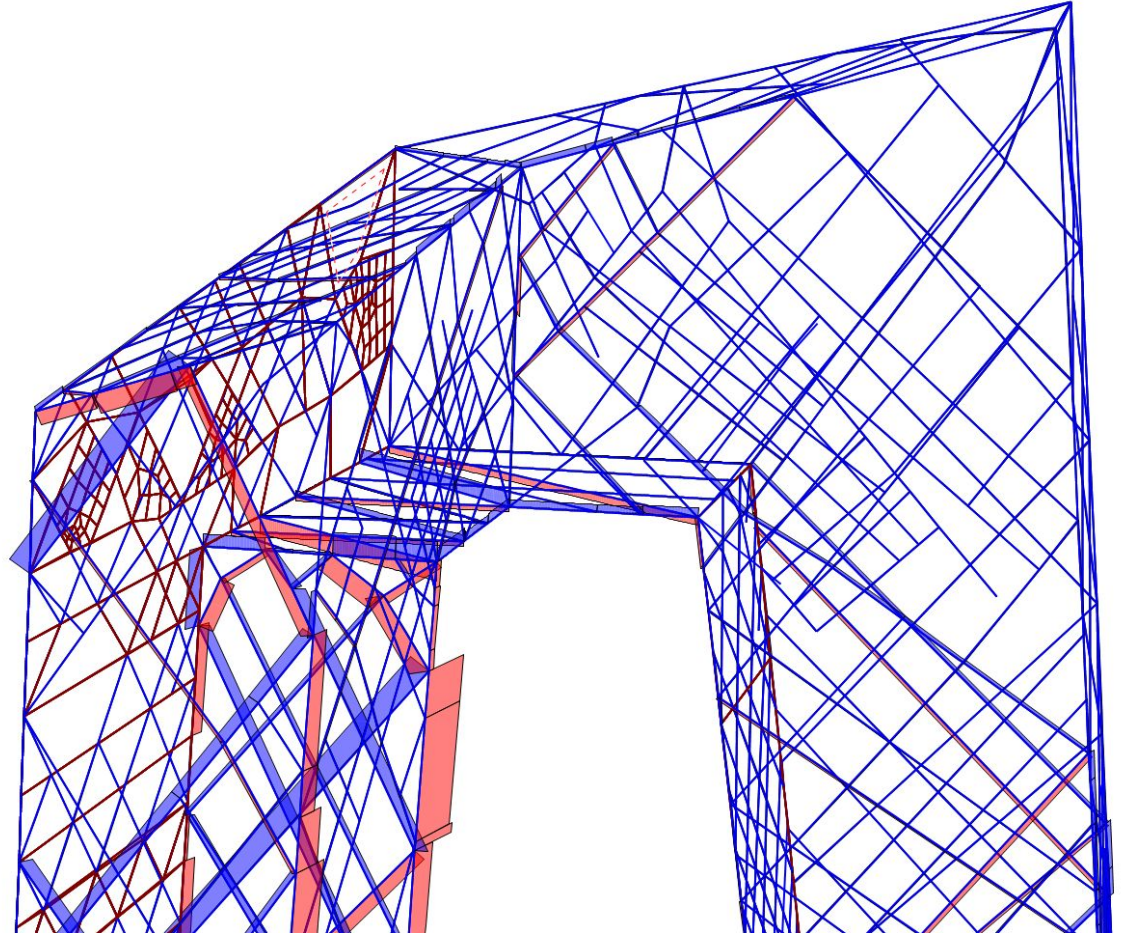
Plate structure utilized to distribute area wind loads

Incremental wind loads, up to 55psf at top



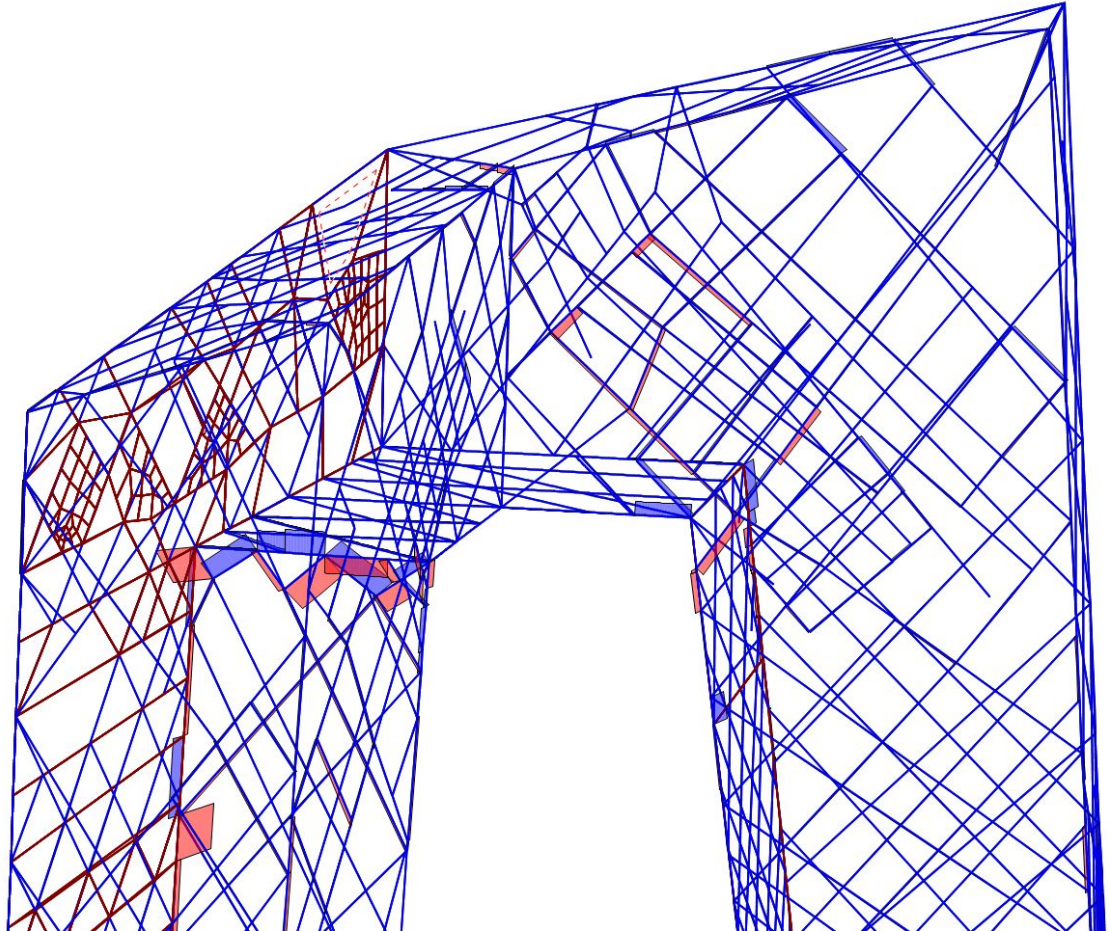


Axial Forces



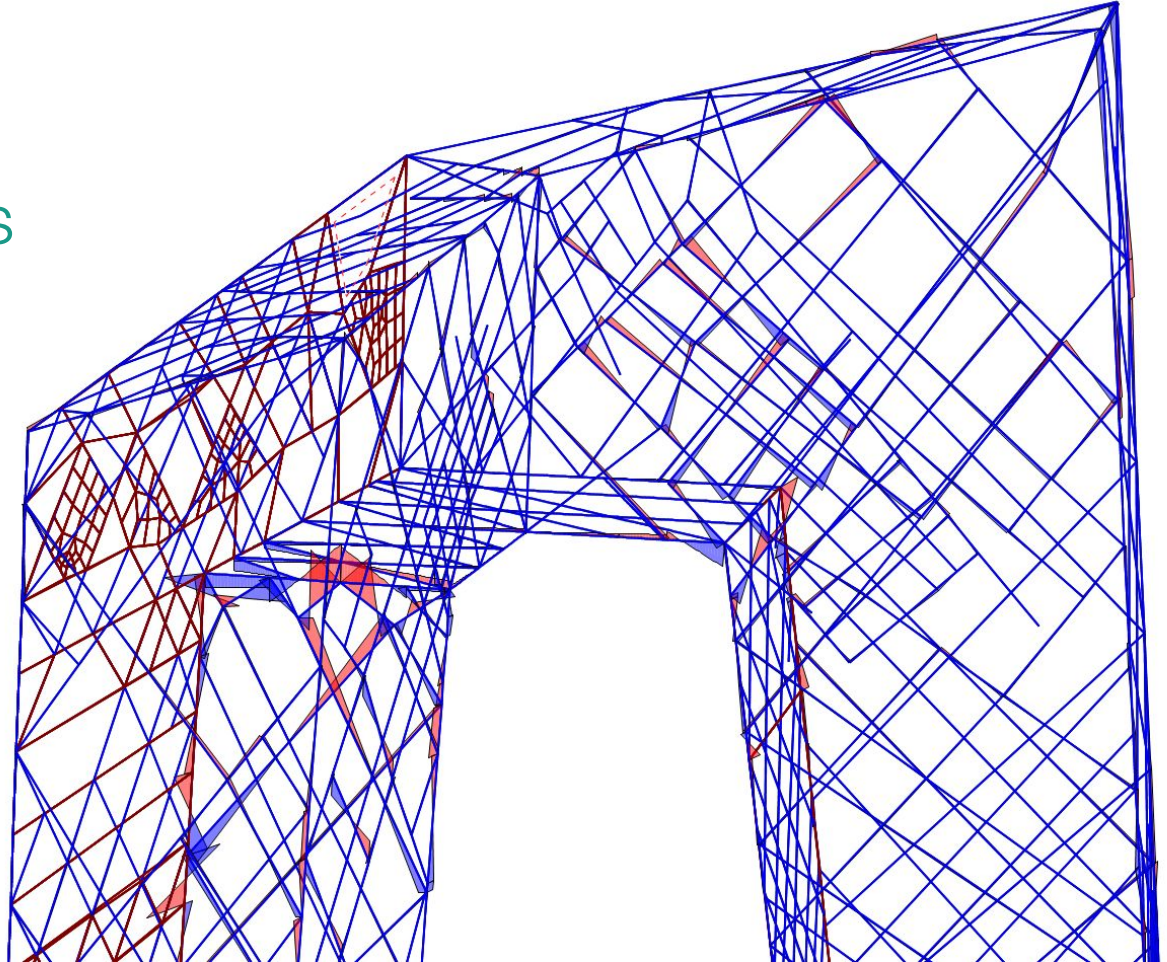


Shear Forces





Bending Moments





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