

Linked-Hybrid

Structural system analysis

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Background

Completion Date: Spring 2009

Area: 220,000sqm(2,368,060sq ft)

Primary Use: Towers 1-8: Residential, Tower9: Hotel

Other Use: Retail, Office, Public Space

Owner/Developer: Modern Green Development Co.Ltd.

Architect: Steven Holl Architects

Associate Architect: Beijing Capital Engineering Architecture Design Co,Ltd

Structural Engineer: Guy Nordenson and Associates, China Academy of Building Research

MEP: Transsolar ClimateEngineering, Beijing Capital Engineering Architecture Design Co,Ltd, Cosentini Associates

Contractor: Beijing Construction Engineering Group



1 Architect

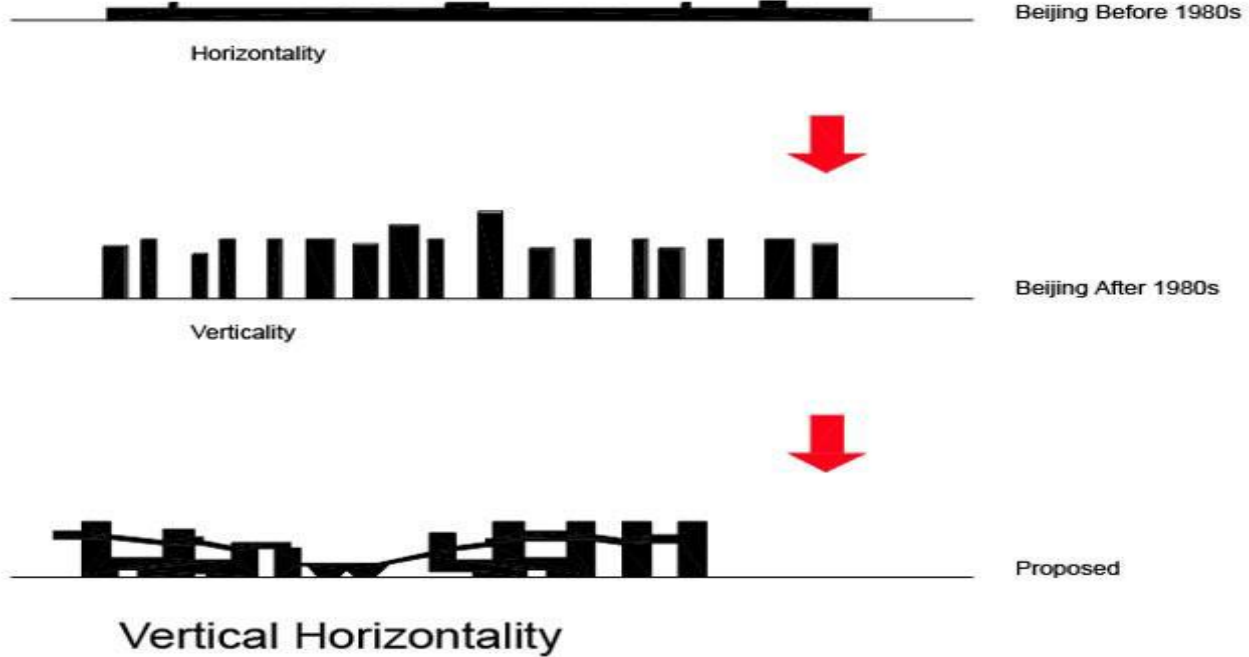
Steven Holl (born December 9, 1947) is an American architect and watercolorist, perhaps best known for the 2003 Simmons Hall at MIT in Cambridge, Massachusetts, the celebrated 2007 Bloch Building addition to the Nelson-Atkins Museum of Art in Kansas City, Missouri, and the praised 2009 Linked Hybrid mixed-use complex in Beijing, China.



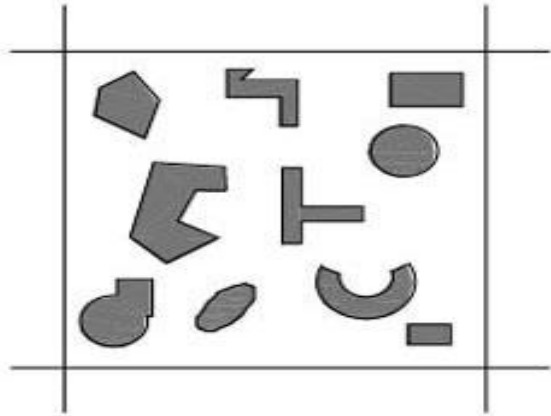
2 Program & Function

The design for a mini-city consisted of nine towers connected by sky bridges at the upper floors. The 2.4M SF program included 750 apartments, public green space, commercial zones, hotel, cinemateque, kindergarten, Montessori school, and underground parking.

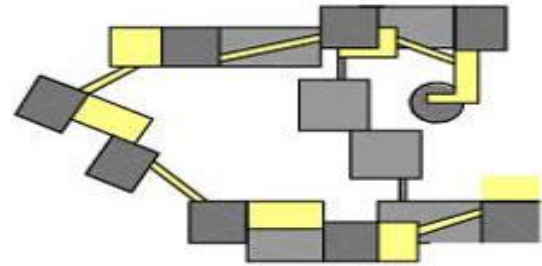
Space



a. Program

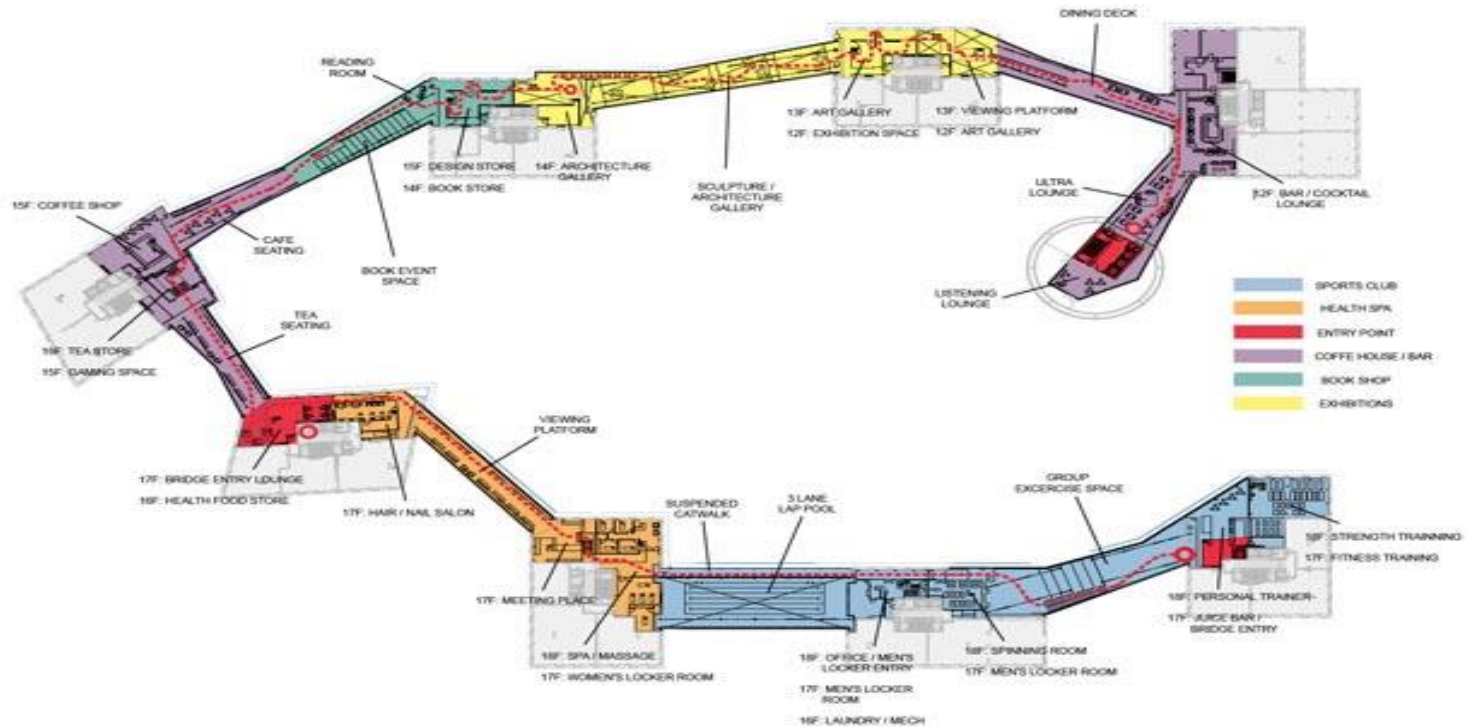


City of Objects

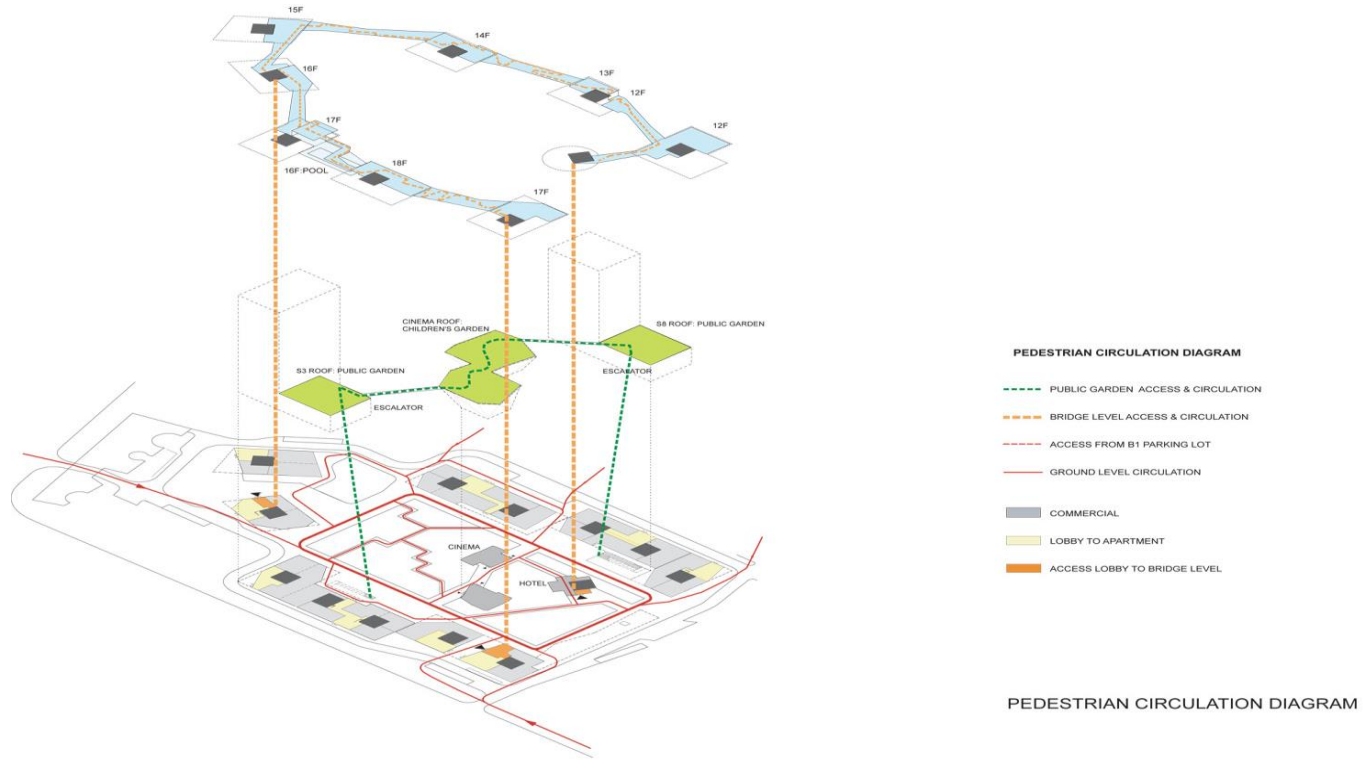


City of Spaces

a. Program



b. Function



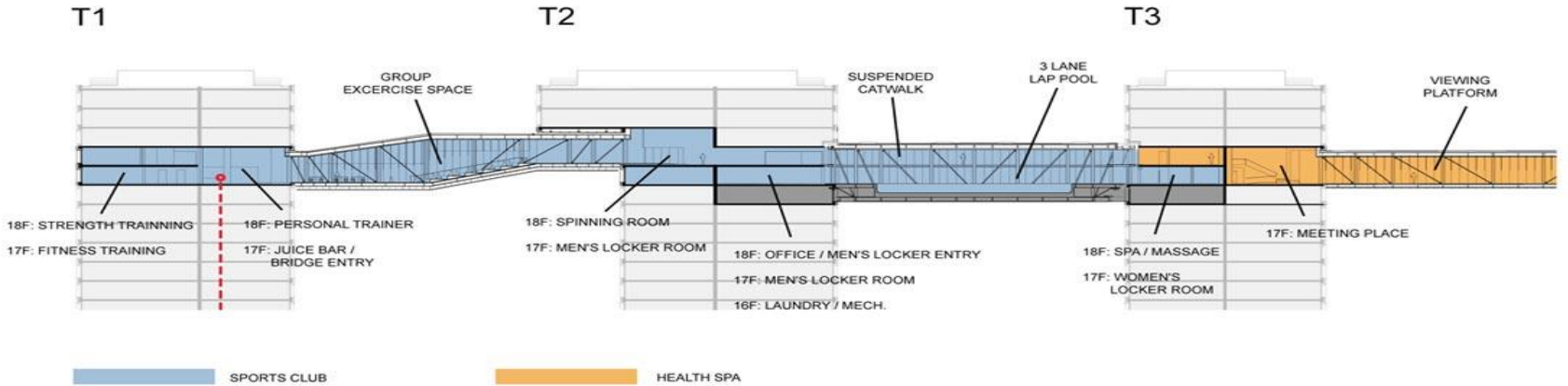
b. Function



3 Unique part of design

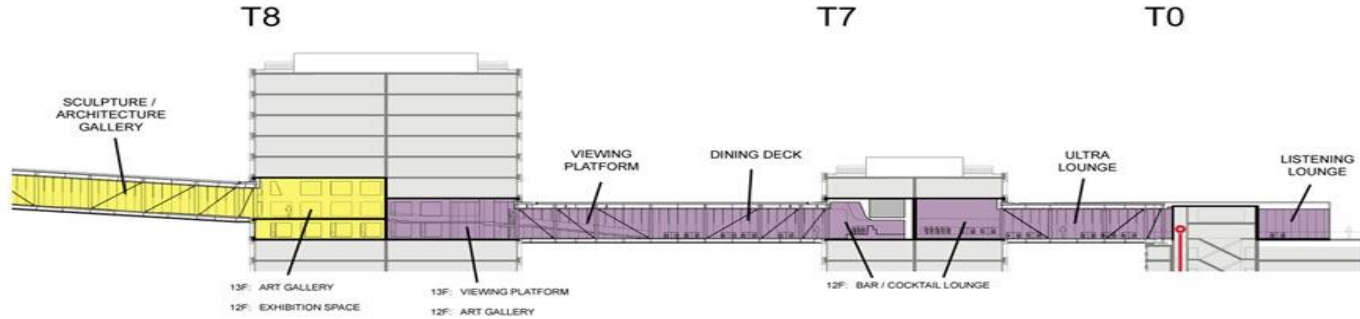
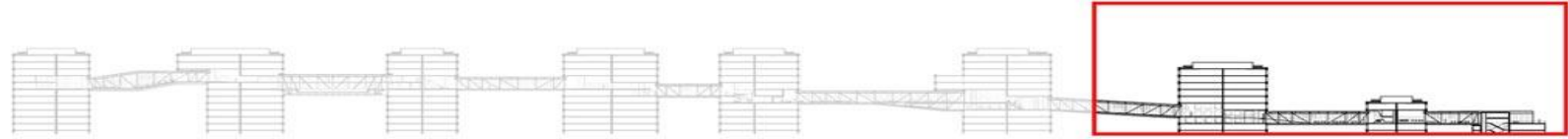
Inspired by *dancers*, the famous painter Matisse's work now collected in modern art museum in New York, Steven Holl designed this project. Beijing "hutong" and "siheyuan" are also important factors for this project. The most unique design in this project is sky-walk, which provides splendid public space. The concept of this design is "mini city". The use of diagonal bracing can effectively resist the lateral loads from earthquake and also make the facades of the building more beautiful and unique.





Section through the ring (1 of 3)

(1) Unique part of design
 ---Skywalk

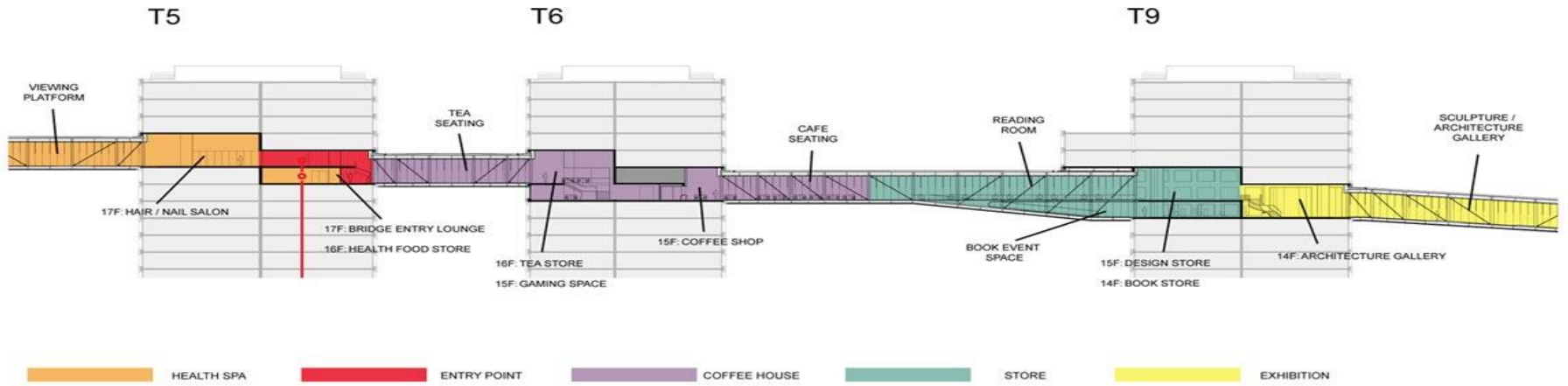
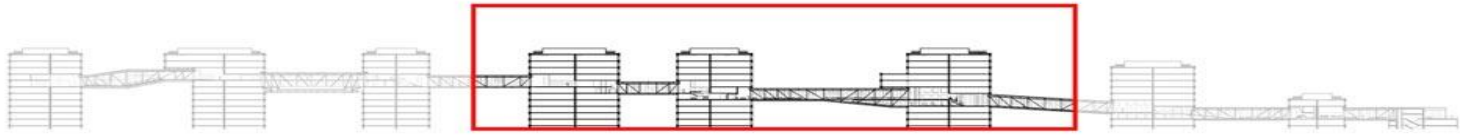


EXHIBITION

BAR / LOUNGE

Section through the ring (2 of 3)

(1) Unique part of design
---Skywalk



Section through the ring (3 of 3)

(1) Unique part of design
 ---Skywalk

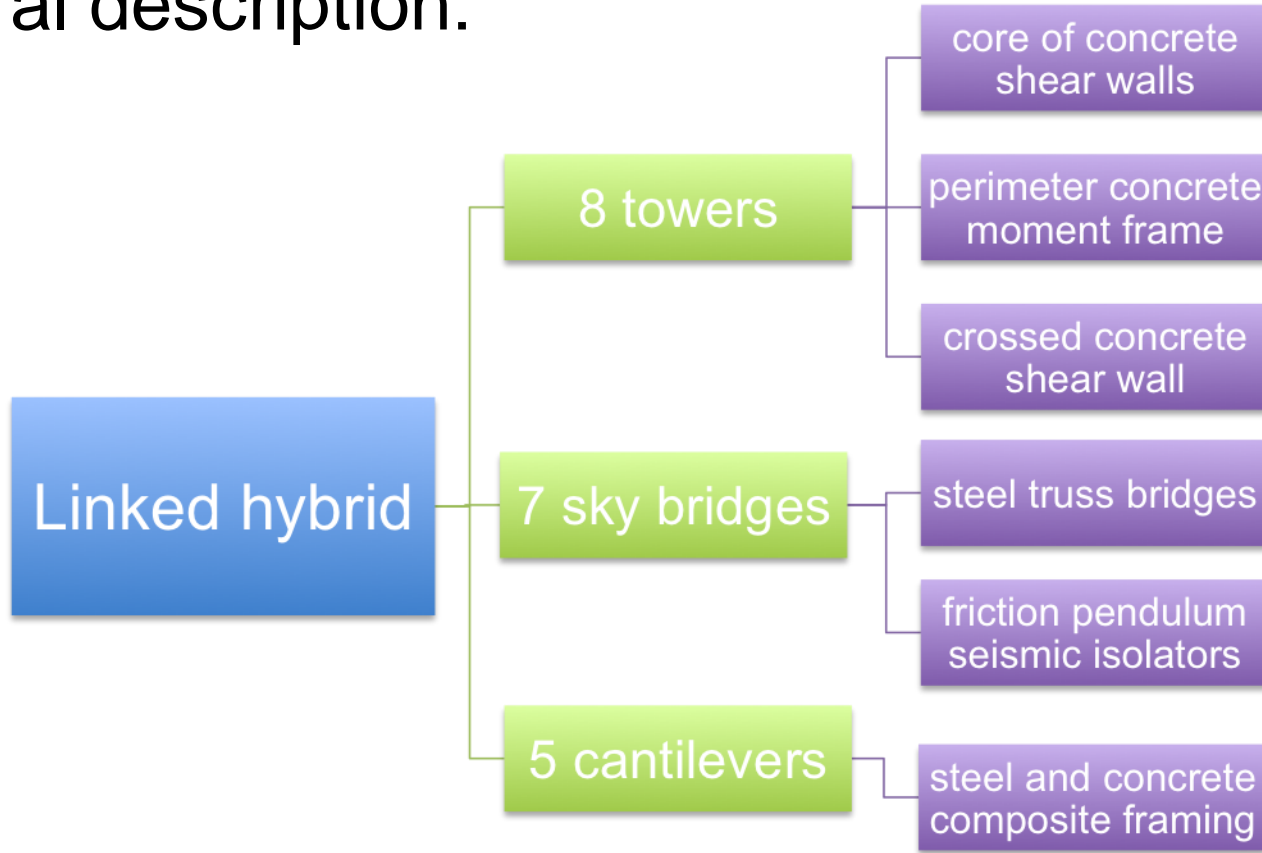


(2) Unique part of design
--- Diagonal bracing

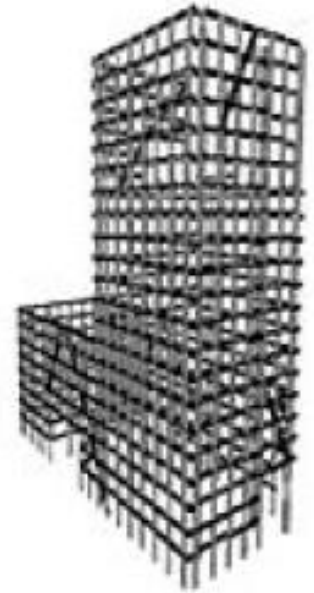
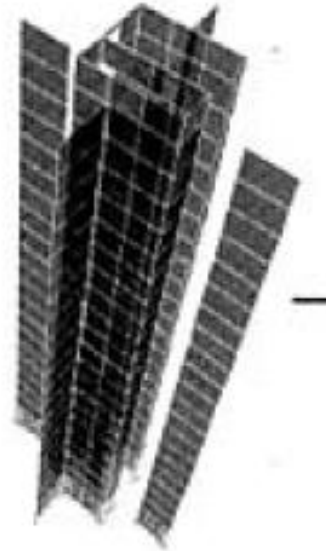
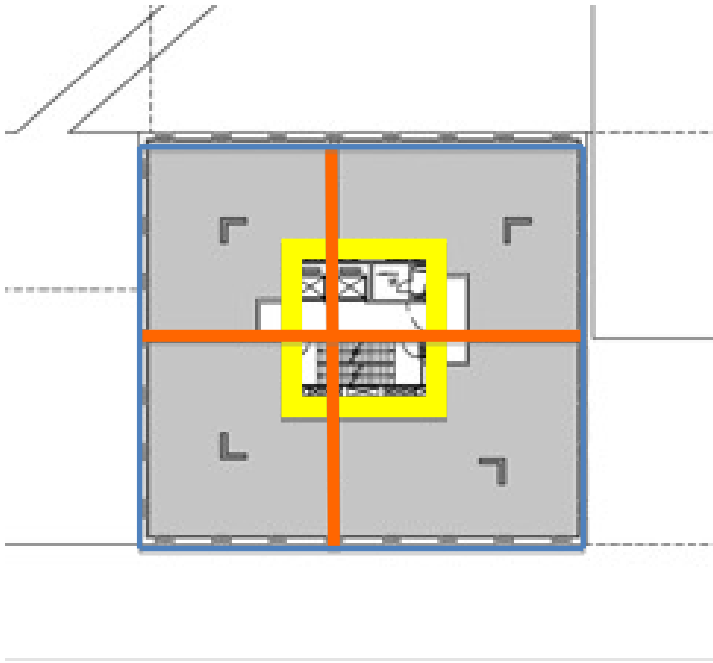
Main Structural System



General description:

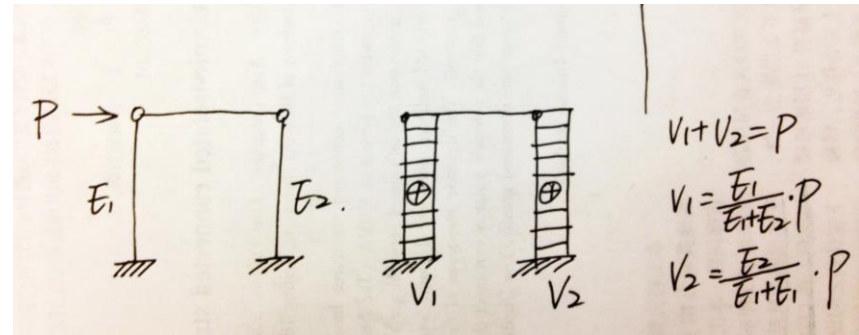
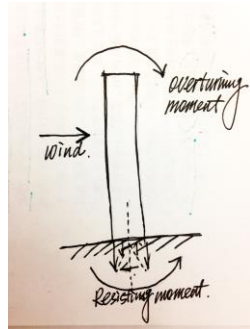
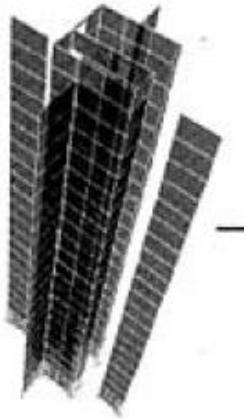


Tower: 2 systems to resist lateral load



1. Core of concrete shear walls & crossed shear walls

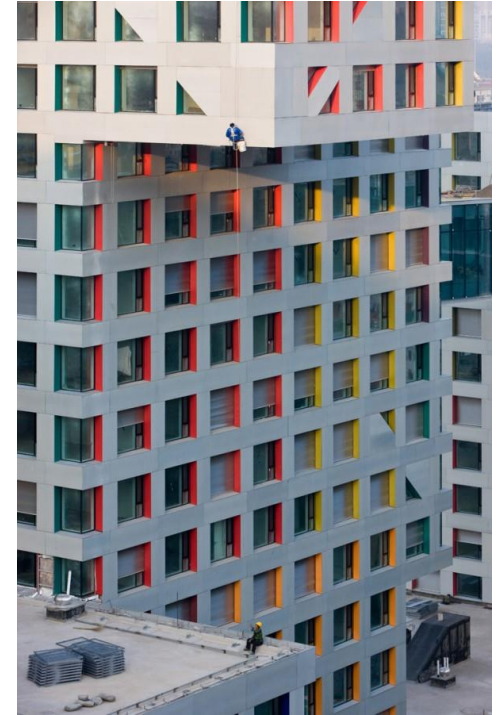
The rectangular tube can be viewed as 4 shear walls. They can increase the stiffness of the structure obviously. Thus, it stabilizes the building mainly with regard to horizontal forces like wind and earthquake.



2. perimeter concrete moment frame

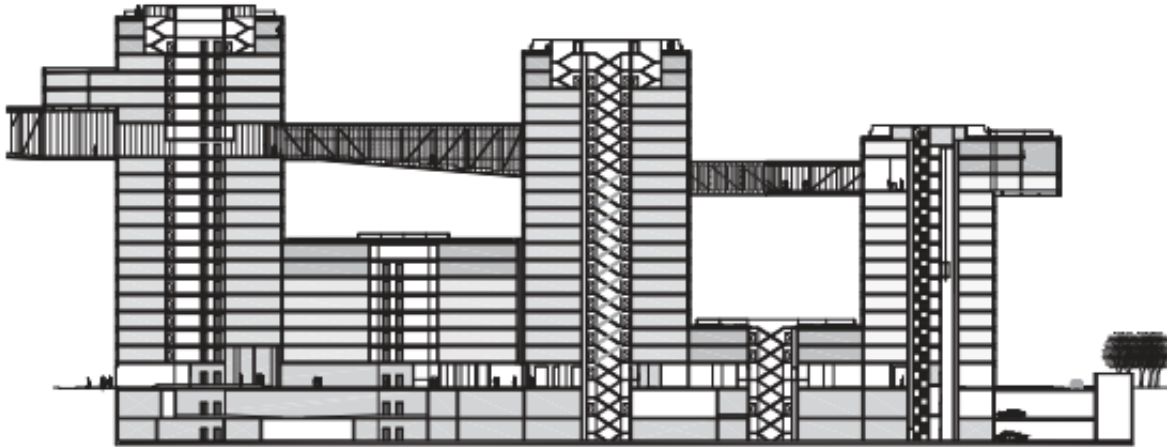
In the area of the (inevitable) openings, special reinforcement is required. Normal high rise buildings can be fully stabilized by the reinforced concrete core. For higher ones, one makes also use of the façade.

In this case, the perimeter concrete moment frame is the second way to resist lateral load.



Sky bridges:

In order to span the great distance required and also to achieve the utmost transparency, the bridges utilize a pair of parallel steel trusses.

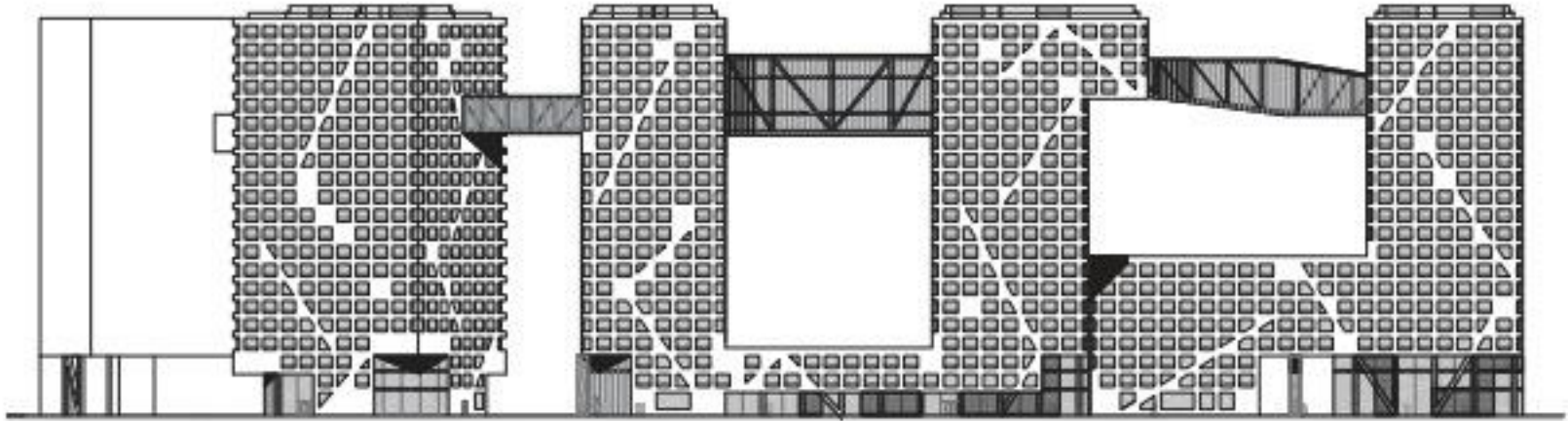


Trusses: the most efficient form to resist flexure

Trusses are triangular frame works in which the members are subjected to essentially axial forces due to externally applied load.

Steel members subjected to axial forces are generally more efficient than members in flexure since the cross section is nearly uniformly stressed.

The connections between vertical and horizontal truss members were made rigid to form a complete three-dimensional rigid Vierendeel frame. This provides additional stiffness and redundancy to the bridge structure and allows for the removal of the center panel diagonal members.



The frame is a grid of uniform dimension interspersed with diagonal members. These diagonals occur on an ad hoc basis where required for building cantilevers, overhangs and overall stiffness. These bracing members were added around the perimeter of the towers to increase torsional rigidity.

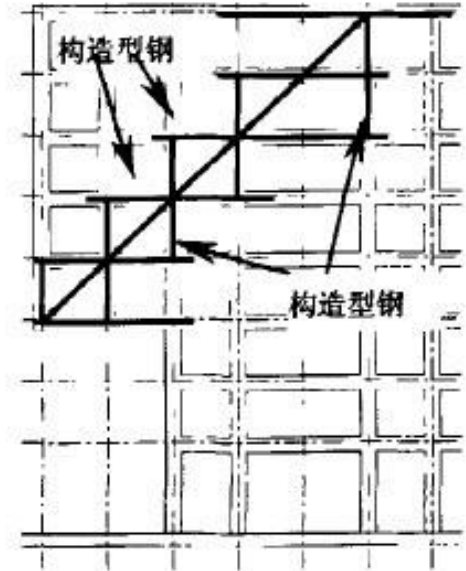
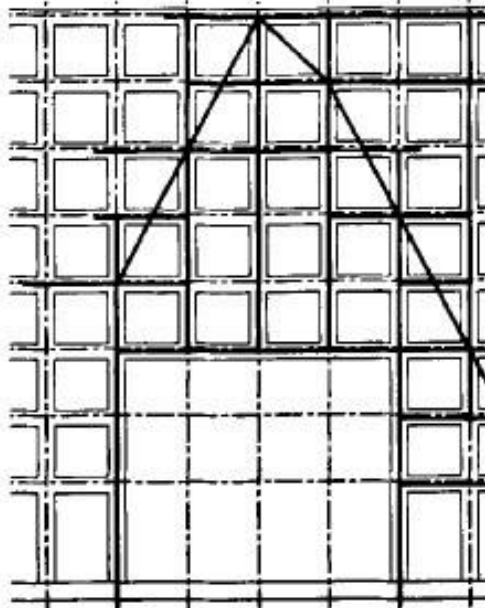
Diagonal bracing

Due to its complex form, Linked hybrid have very complicated force transfer system. In order to solve the problem of force transformation in building's high rise part, the design of structure adopted the space trusses transform system, installing diagonal bracing in appropriate structural section.

Mainly in two situation:

1, integral transform trusses with diagonal bracing over big openings

2, double-side overhanging integral transform trusses with diagonal bracing in corner openings

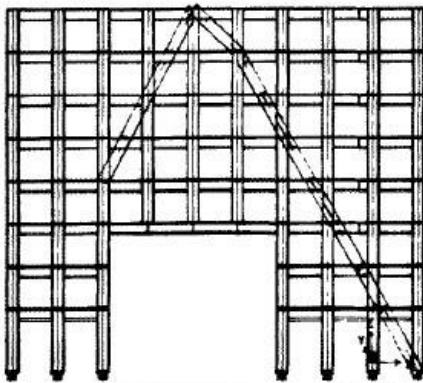
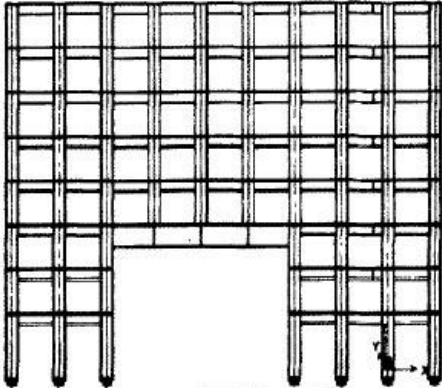


Compare of normal beam transform and integral transform of space trusses with diagonal bracing

转换梁模型

斜撑模型

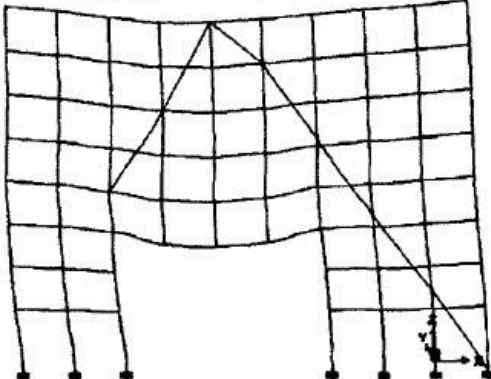
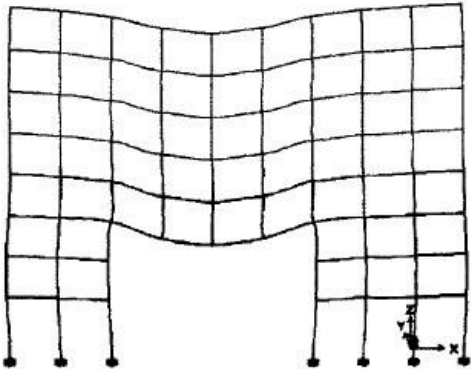
模型图



model

重力荷载下挠度

deflection under gravity load



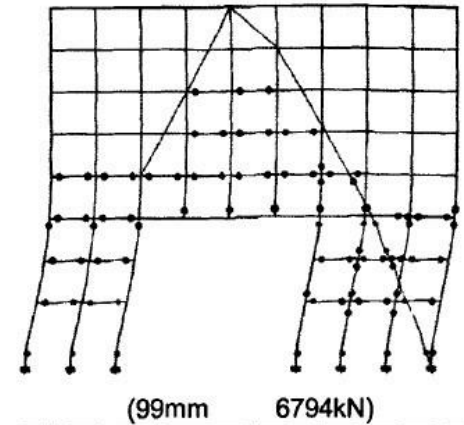
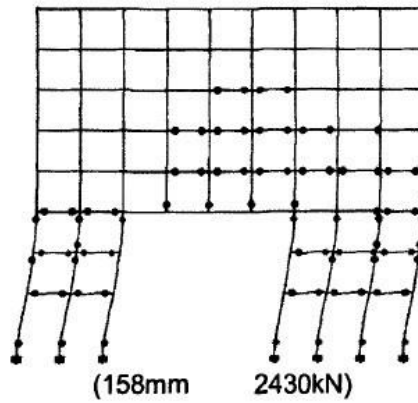
-4.05mm

-2.71mm

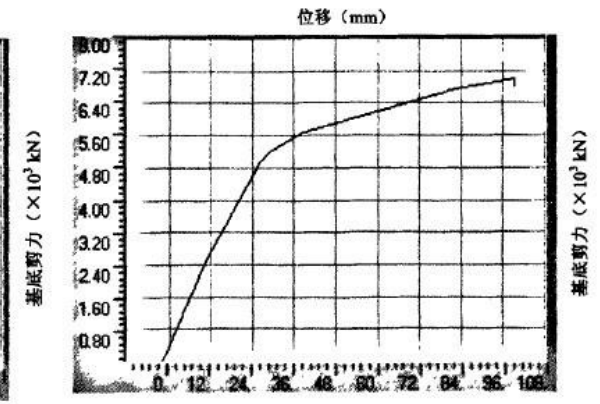
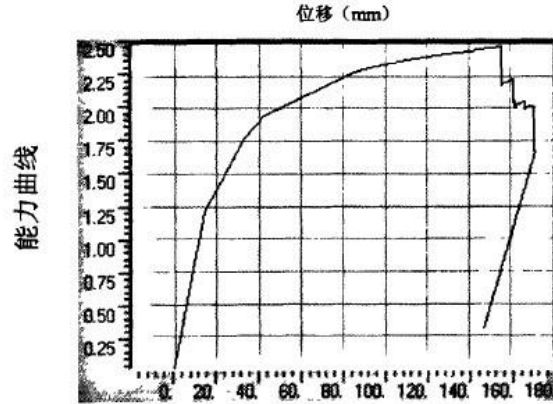
Compare of normal beam transform and integral transform of space trusses with diagonal bracing

deflection under lateral load

破坏状态及塑性铰



capacity diagram



The compare analysis results shows the max deflection of system with diagonal bracing are smaller than normal structural system, approximately 1/1.5, that means the diagonal bracing effectively increased the vertical stiffness of structure, decreased the structural deflection.

The resistance capacity increased like 1.8 times than normal structure when facing lateral loads.

Overhanging and diagonal bracing

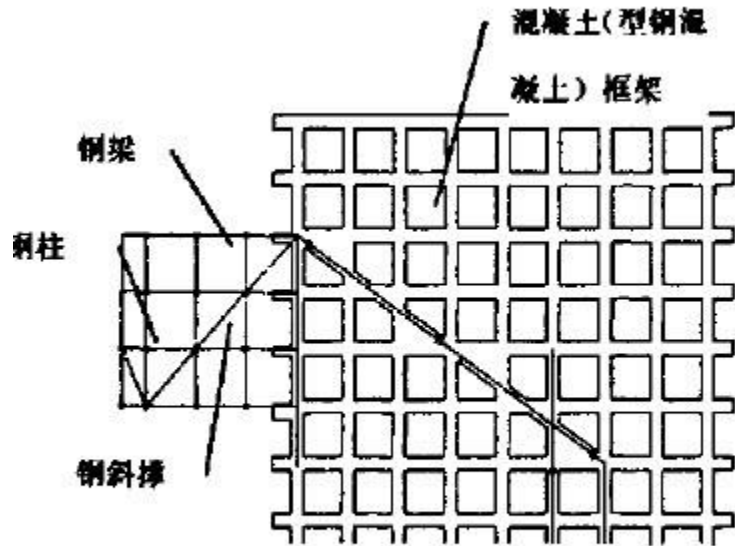


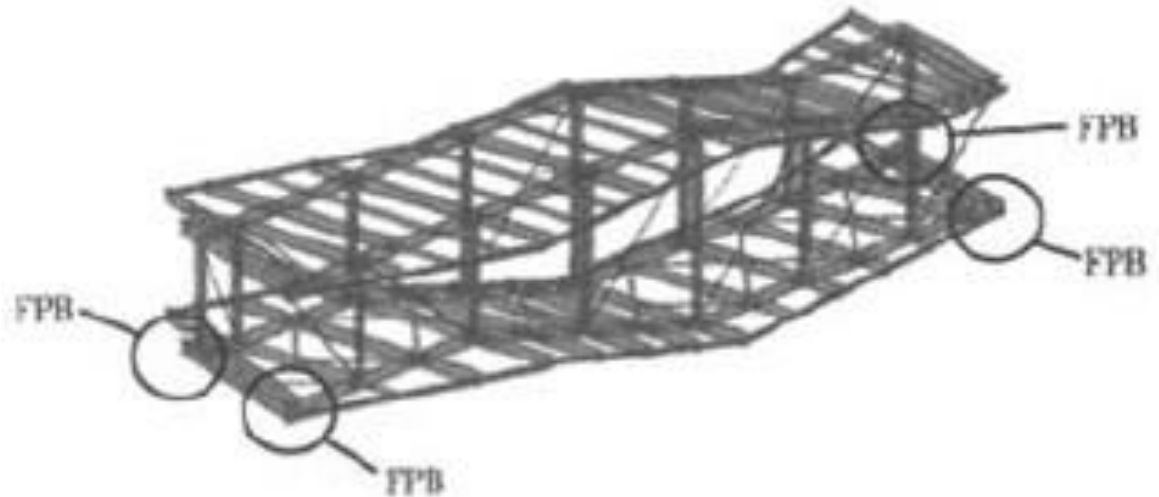
图9 悬挑结构布置示意

Diagonal bracing played an important role in overhanging structure, they take the tension force and the moment produced by overhanging gravity loads. with this diagonal bracing, these overturning force transfer from overhanging to main building. the core tube and shear wall increased the stiffness of building and the capacity of main building to resist these moment.

SEISMIC

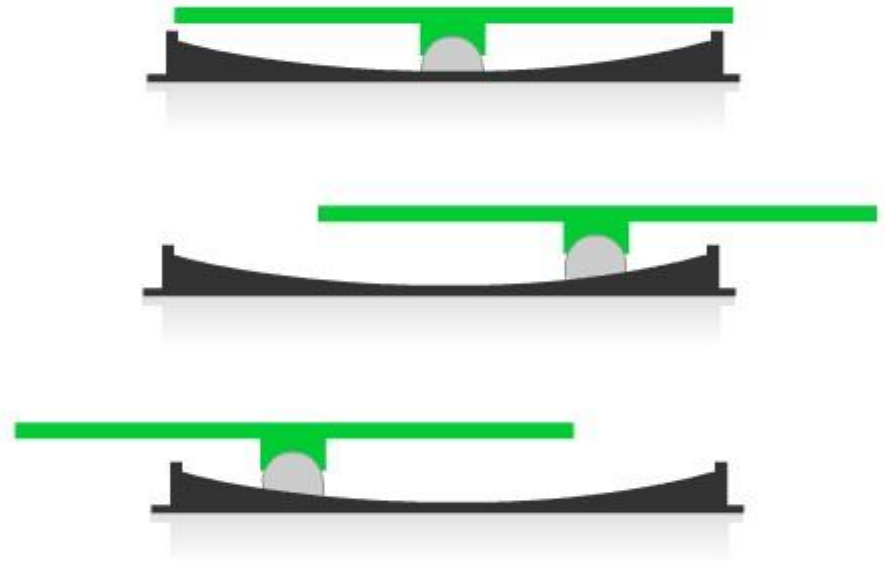
Friction pendulum bearing

Linked Hibrid use friction pendulum bearings between aerial bridge and main building, in order to decrease the torsion effect and mass eccentric caused by aerial bridge during an earthquake.



Friction pendulum bearing

The bridges are light and glass enclosed. In order to protect them from the effects of significant tower movement under an extreme seismic event, it was decided to isolate both sides of the bridges. The system selected was a "friction pendulum isolator" which is provided by Earthquake Protection Systems of California. The isolators are shaped with a radius to achieve a described period of vibration that will minimize the shear transfer by reducing the resonance. In an earthquake, the bridges will move up to 40cm relative to the buildings, sparing them, and the buildings of the effects of lateral forces.



WIND LOAD

Wind Load Calculation

According to <Building Structure Code> of China, formula for calculating wind load in Beijing is $W_K = \beta_z \mu_s \mu_z \omega_0$

β_z : factor of wind fluttering effect in height z.

μ_s : factor of building form when consider wind load.

μ_z : factor of wind pressure related to height.

ω_0 : basic wind pressure

Each factor can checked by related table.

Table: Basic wind pressure w_0

City	Height (m)	Wind pressure (kN/m ²)		
		n=10	n=50	n=100
Beijing	54	0.3	0.45	0.5

In this table, n represent the return period, normally, we took 50 years in wind load calculation. According to this table, the basic wind pressure w_0 in beijing is 0.45.

Table: factor of wind pressure related to height μ_z

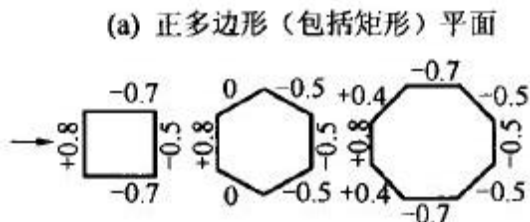
Height(m)	Ground rough level			
	A	B	C	D
5	1.09	1.00	0.65	0.51
10	1.28	1.00	0.65	0.51
15	1.42	1.13	0.65	0.51
20	1.52	1.23	0.74	0.51
30	1.67	1.39	0.88	0.51
40	1.79	1.52	1.00	0.60
50	1.89	1.62	1.10	0.69
60	1.97	1.71	1.20	0.77

This table shows the factor of wind pressure related to different height.

Table: factor of wind pressure μ_z

In our case, Linked-hybrid located in Beijing which have the ground rough level of C, we picked five different height in T1 building to analysis the wind load, and get the factor of wind pressure in these height.

Height(m)	13.70	25.90	38.10	50.30	66.00
μ_z	0.65	0.88	1.00	1.10	1.28



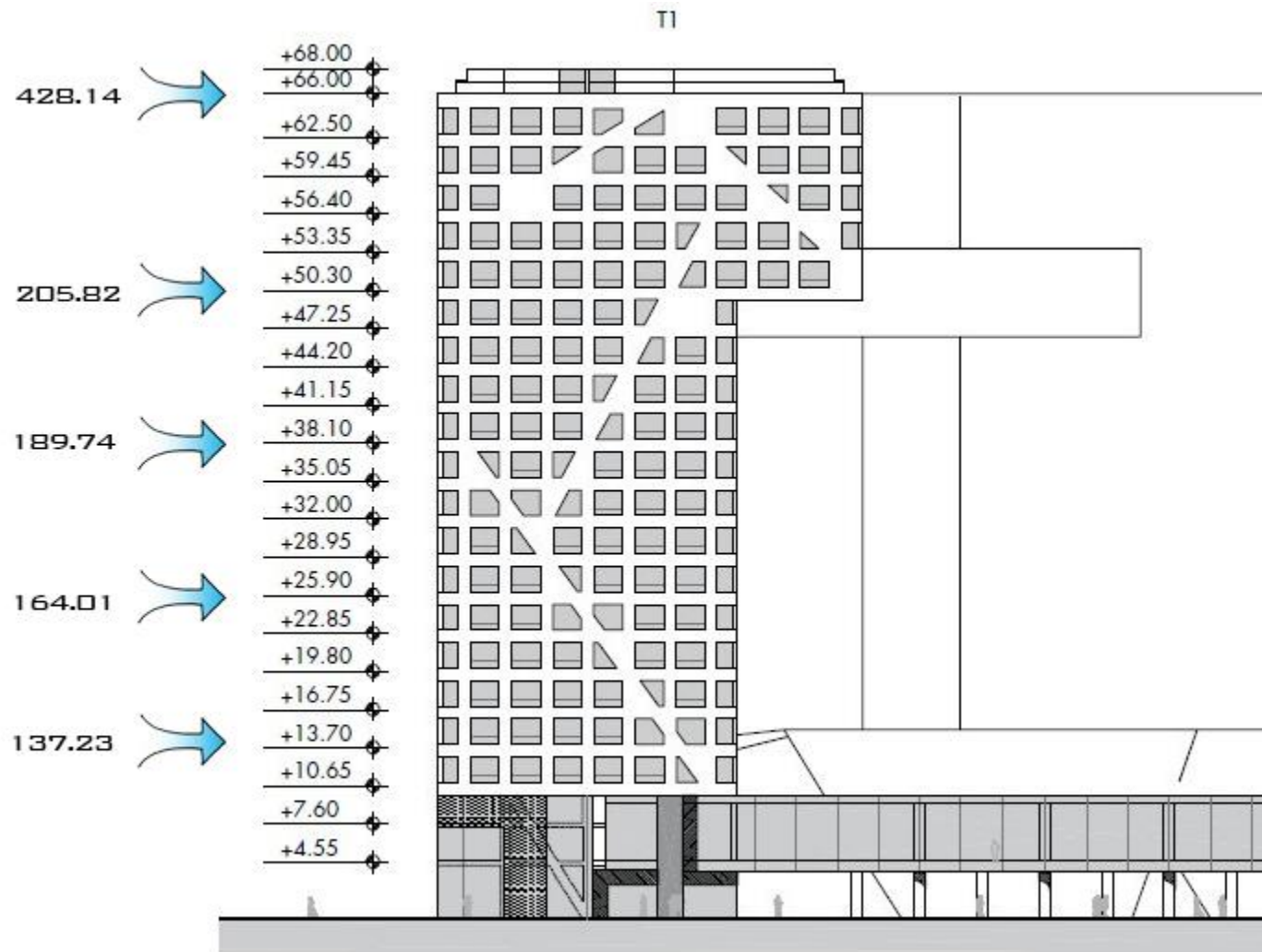
Factor of building form μ_s
 $\mu_s = 0.5 + 0.8 = 1.3$

T1 building wind load Standard values

By using this formula, we convert wind load as concentrated load act on each frame level, H represent the frame level height from ground, A as the area facing the wind load.

The process of calculation are as follow:

Floor	β_z	μ_s	Height	μ_z	w_0	A	W_K	$P_K = W_K A$
			(m)		(kN/m ²)	(m ²)		(kN)
22	1.0	1.3	66.00	1.28	0.45	570.85	0.75	428.14
17	1.0	1.3	50.30	1.10	0.45	321.59	0.64	205.82
13	1.0	1.3	38.10	1.00	0.45	321.59	0.59	189.74
9	1.0	1.3	25.90	0.88	0.45	321.59	0.51	164.01
5	1.0	1.3	13.70	0.65	0.45	361.13	0.38	137.23



wind load diagram

Seismic force

- $V=ZICW/R_w$
- Z:0.3 zone3 from table 16-l
- I:1.0 for standard occupancy as defined in Table 16-k
- C:2.75
- R_w : 5.5 concrete shear from table 16-N

	Z	I	C	W	R_w	$V=ZICW/R_w(t)$
T1	0.3	1.0	2.75	22849.7	5.5	3427.46
T7	0.3	1.0	2.75	17537.2	5.5	2630.58
T8	0.3	1.0	2.75	20234	5.5	3035.1

Aerial bridge profile

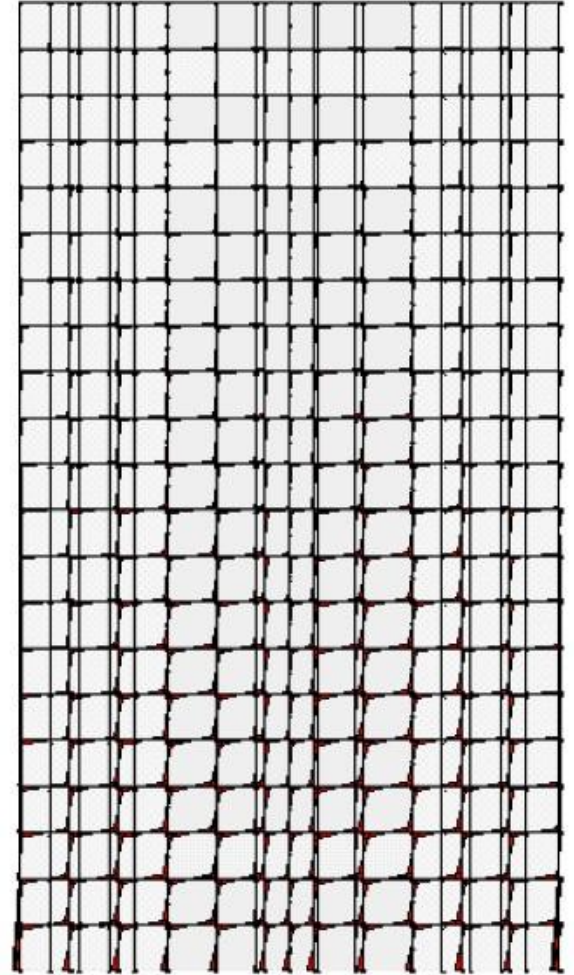
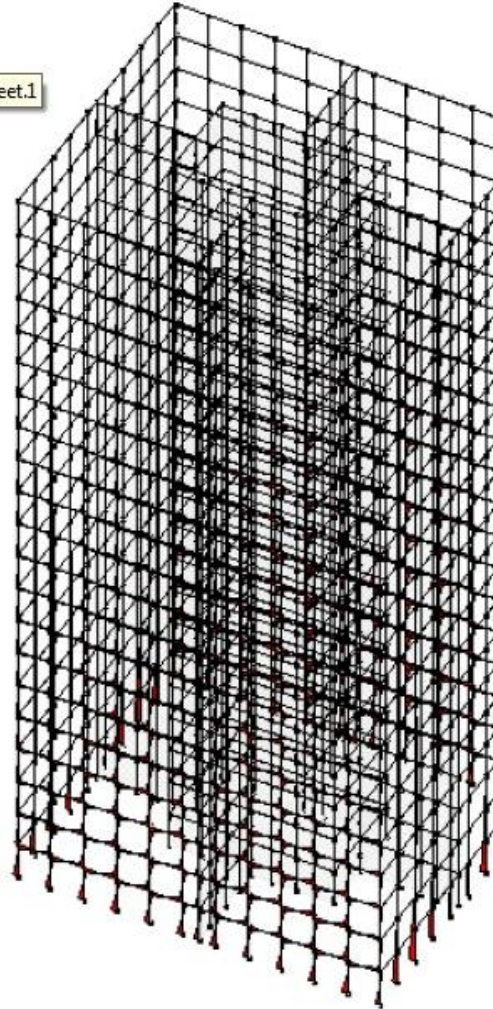
	Total weight(t)	t/m	t/m ²	Length(m)	Width(m)	Height(m)
B78	76	2.2	0.73	35.244	3.057	4.84

Main building size

	Height(m)	Width(m)	Length(m)	Weight(t)
T1	66	29.3	38	22849.7
T7	44.2	29	44	17537.2
T8	61.9	36.25	29	20234

Resisting moment under wind load

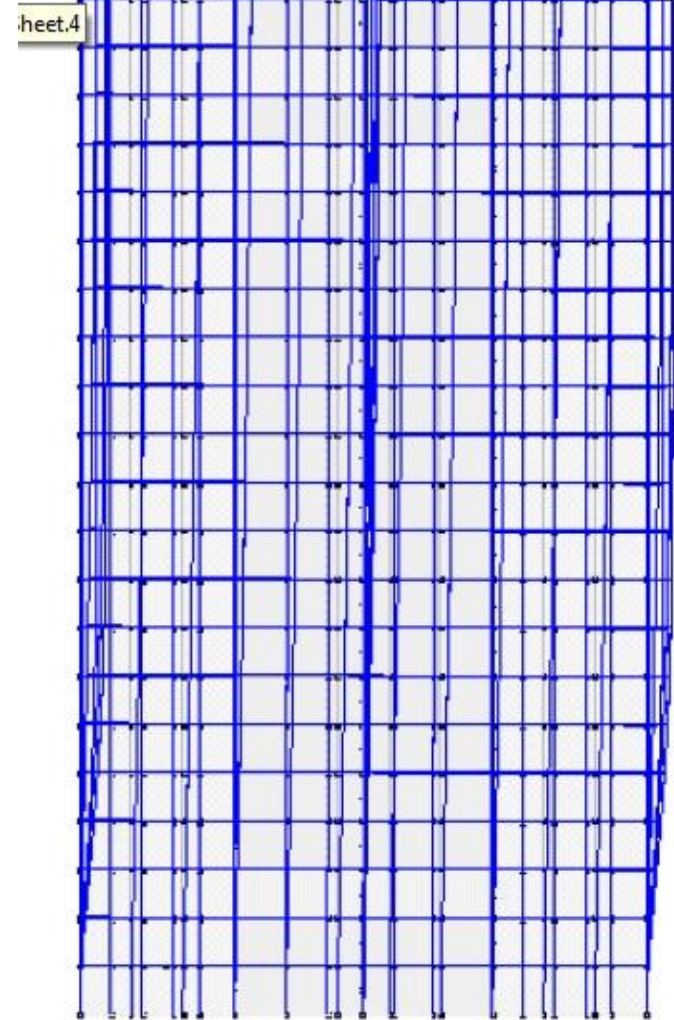
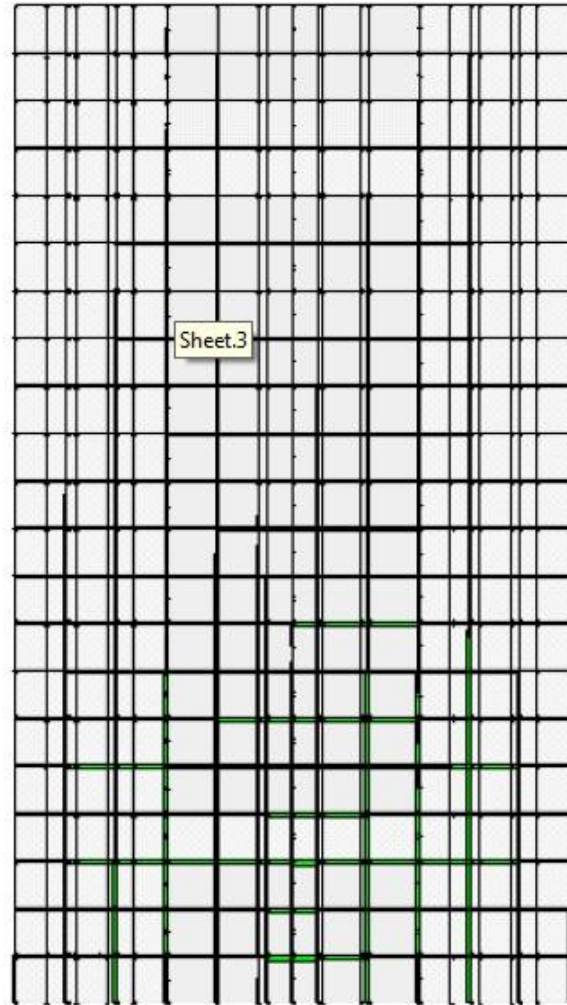
Sheet.1

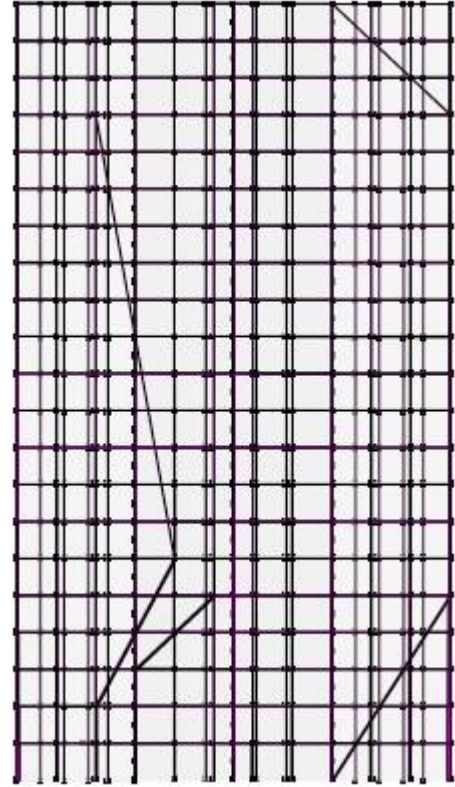
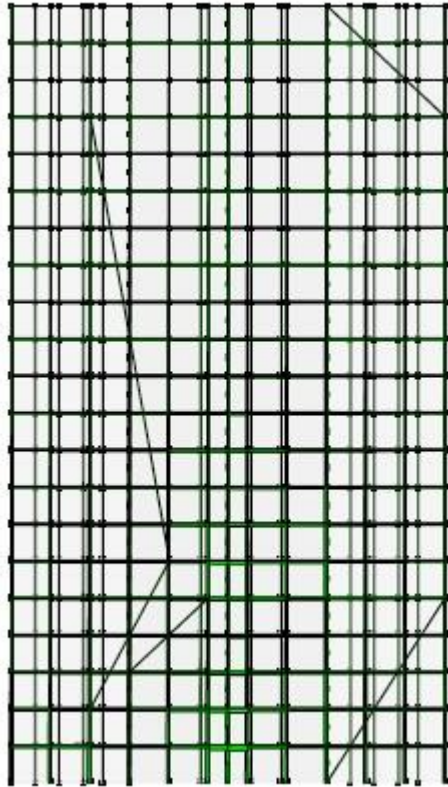
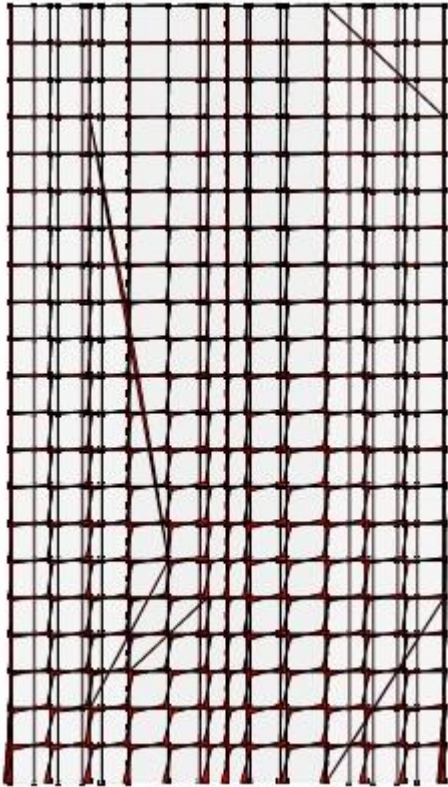


wind speed as 8 level.

- 1 Shear force under wind load
- 2 deflection under wind load

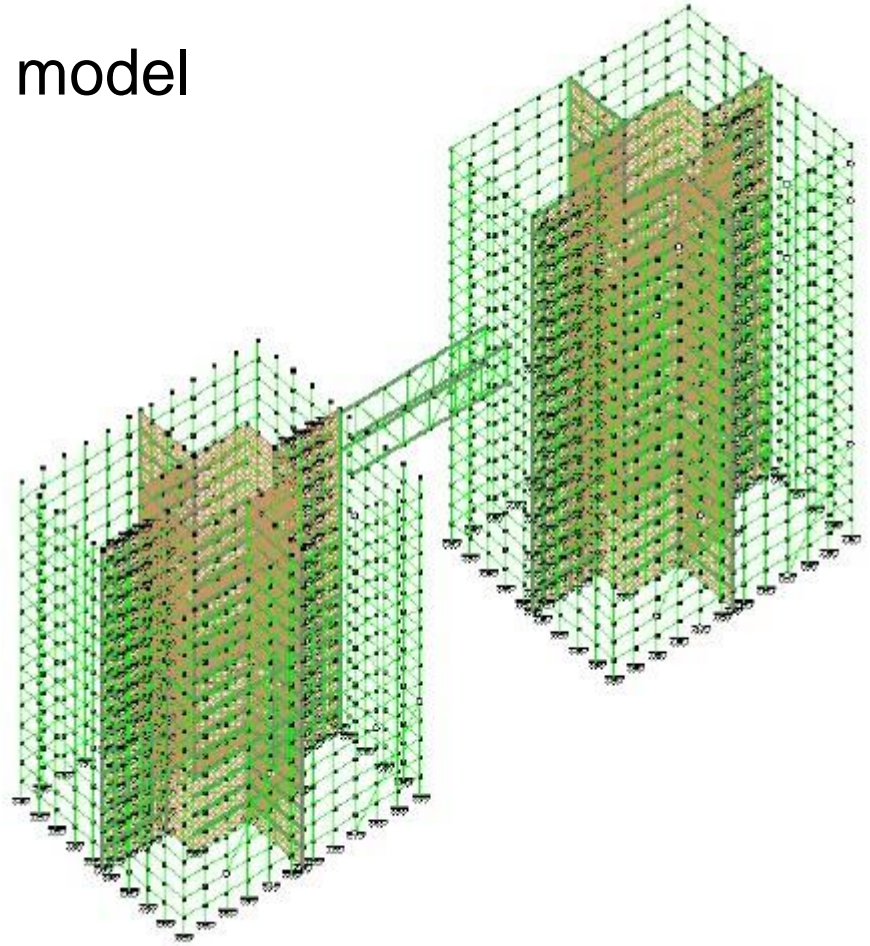
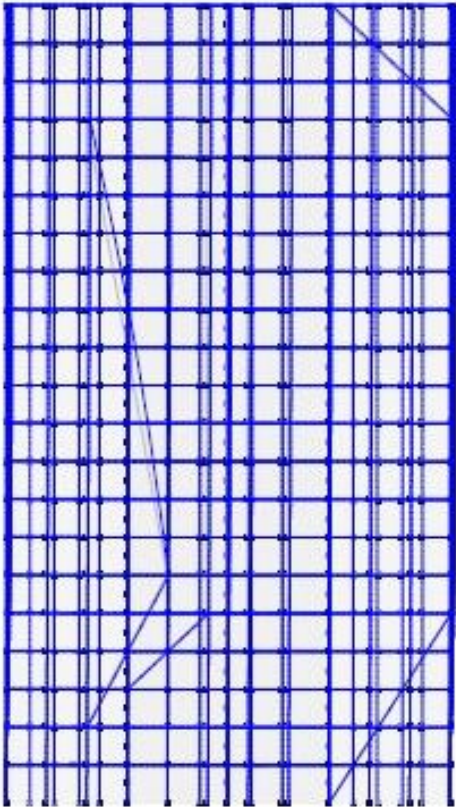
wind speed as 8 level.





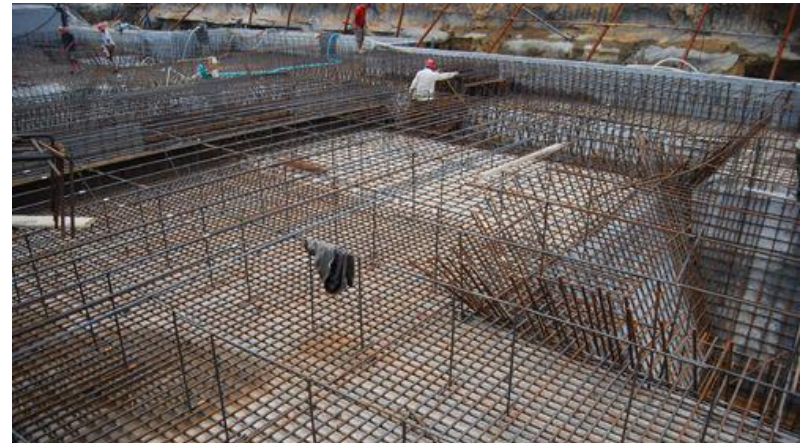
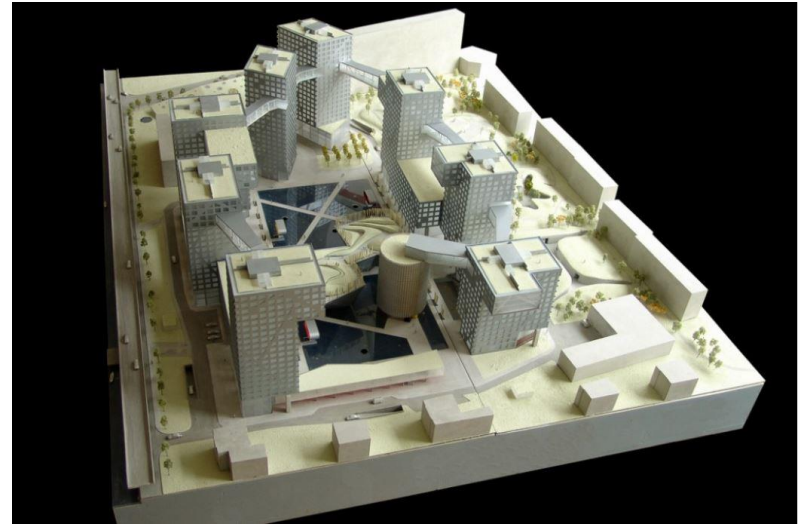
moment, shear force, deflection under wind load (with diagonal bracing)

structural system multi-frame model



Soils and Foundation

The foundation maintains two parts of basement. One part is basements of tall buildings, and another part is a pure basement for parking in middle of base. Soils of Linked Hybrid's base in Beijing is rigid and brittleness. It's hard to handle the complex architectural form and buildings' multiple functions. So designer used raft foundation, which is made of reinforced concrete, to build the basement.



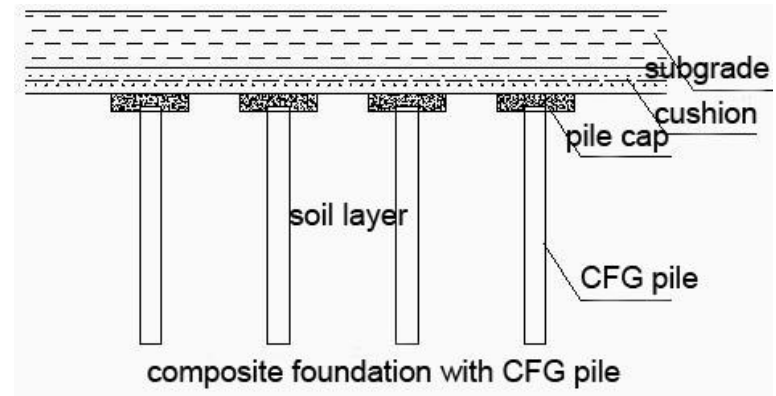
At the same time, the basement is built as an entirety without any deformation seams. Pouring belts after settlement are installed in the connection between basements of tall buildings and the pure basement. Pouring belts after construction are installed in the interior of basements every 40-50 meters.



Anti-floating piles

There are three different foundations in this design.

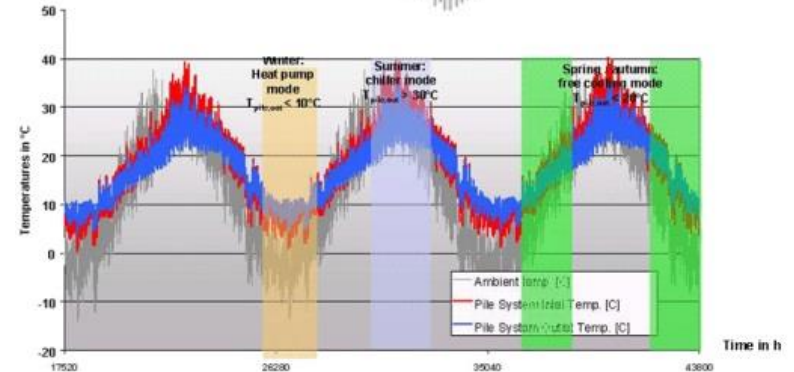
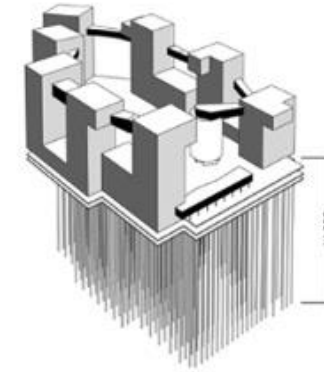
- Natural foundation is used for podium part;
- The pure basement uses natural foundation with firming by anti-floating piles;
- Composite foundation with CFG piles is used for basements of tall buildings.



The pure basement is 210m*83m, and the depth of pit is above 10m. Basing on references of Engineering Geology and Hydrology, building should have anti-floating facility when the depth of pit is more than 2-3m. So additional buoyancy which caused by groundwater has a big influence to the pure basement. Plus since this design use ground source heat pump equipment system to keep buildings temperature stable, there are 600 tube wells at bottom of basement which can reduce the bearing capacity of natural foundation.

So designers arranged anti-floating piles reasonable to make these piles can both be anti-floating and compressive.

Geothermal System with Borehole heat exchanger, cooling tower, chiller(summer) and heat pump(winter) system Temperatures 3rd to 5th year



Reference

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