State of Practice of Seismic Design in Korea

Taejin Kim, Ph.D and PE in Structural Engineering

Feb. 10th, 2025

TISE Technical Innovation TI Structural Engineers
www.tistructure.com

Short Bio – Dr. Taejin KIM

- Current Affiliation
  - CEO of TI Structural Engineers, Seoul, Korea
- Education
  - **Ph.D**, Dept. of Civil Engineering, University of California at Berkeley, USA
  - **M.S**, Department of Architecture, Seoul National University, Korea
  - **B.S**, Department of Architecture, Seoul National University, Korea
- Professional Registration
  - Registered Professional Engineer (Architectural Structures), Korea
  - Architectural Engineer, Korea
- Employment History
  - Chief Executive Officer, TI Structural Engineers, Korea
  - President, Chang Minwoo Structural Consultants, Korea
  - Research Scientist, State University of New York at Buffalo, USA
  - Assistant Professor (Full-Time Instructor), Sungkyunkwan University, Korea
  - Postdoctoral Researcher, University of California at Berkeley, USA
  - Senior Engineer, Chang Minwoo Structural Consultants, Korea
  - Engineer, SAC International, Ltd. Architects-Consulting Engineers, Korea
- Professional Affiliations
  - Vice President, Korean Structural Engineers Association (KSEA)
  - Vice President(former), Korean Society of Steel Construction (KSSC)
  - Vice President(former), Earthquake Engineering Society of Korea (EESK)
  - Vice President(former), Council on Tall Building and Urban Habitat Korea (CTBUH-Korea)

Dr. Shakhzod Takhirov, UC Berkeley

Structural Design of Lotte World Tower

Türkiye-Syria Earthquake Reconnaissance

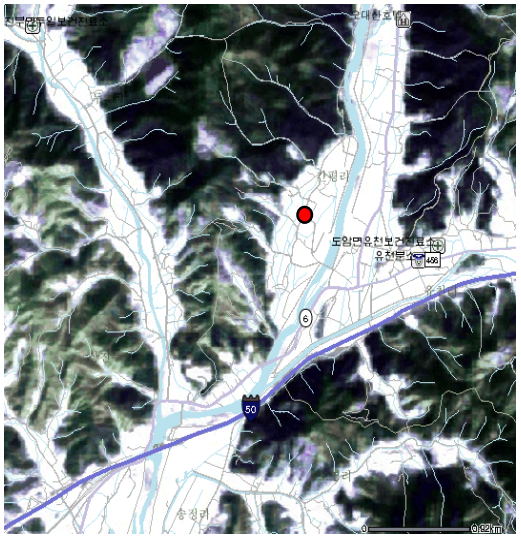
Presentation Topics

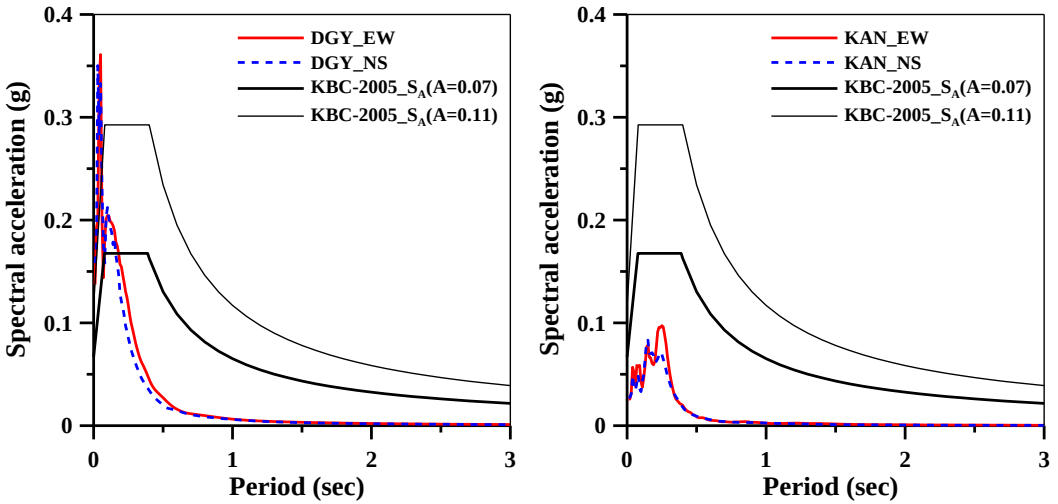
- Recent Earthquakes in Korea
- Seismicity of Korea
- Basis of Seismic Design Codes in Korea
- Structural Steel for Seismic Design
- Structural Design of Tallest Building in Korea

Recent Earthquakes in Korea

2007.1.20 오대산지진

- 진앙: 37.6889˚N, 128.5841˚E
- 깊이: 10 ~ 15km (추정: 13.1 km)
- 규모: M_L=4.8 (m_b=4.3)
- 진도
  - 진도 V : 강릉, 평창
  - 진도 IV : 속초, 춘천, 원주, 영월, 태백, 삼척
  - 진도 III : 철원, 경기 동부지역, 충북 북부, 경북 북부지역
  - 진도 II : 서울, 경기 서부, 충남, 충남 남부, 전북, 전남, 경북 남부지역(포항, 추풍령), 경남





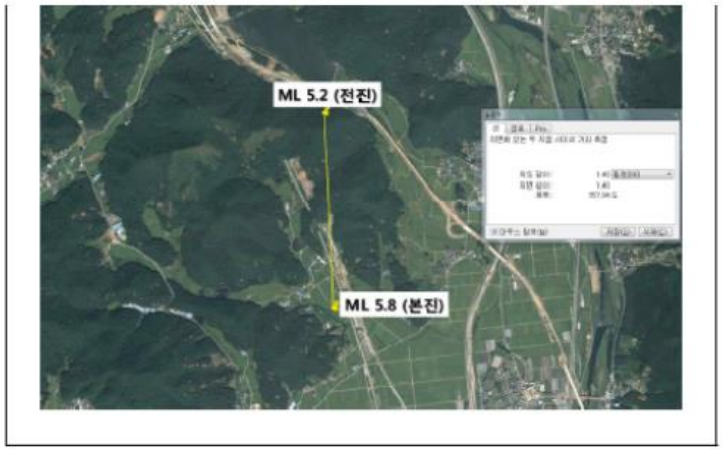
2007.1.20 오대산지진

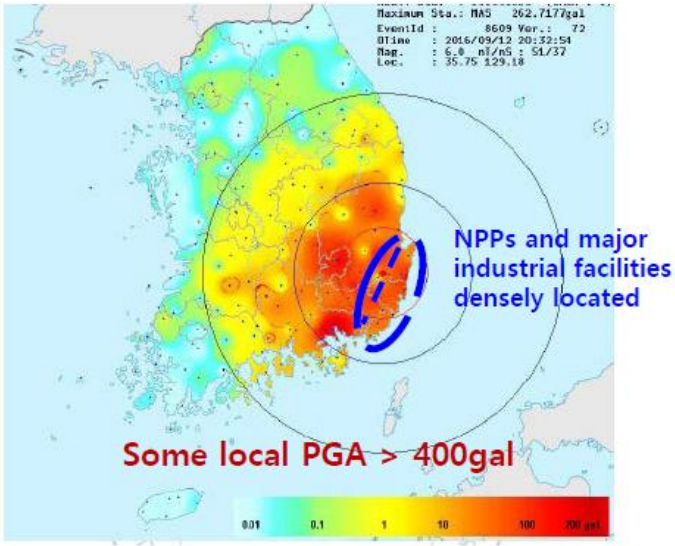




2016.9.12 경주지진

The first (pre-) shock: M_L 5.2, 19:44
The main shock: M_L 5.8 (M_W 5.4), 20:32
Focal depth: 13km





: Shake map (PGA) caused by the 912 M5.8 Gyeong-Ju

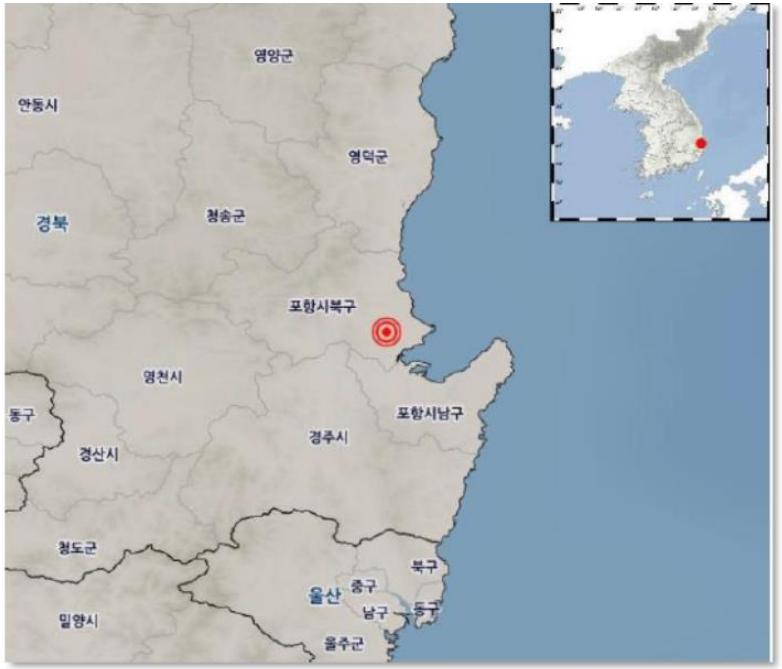
이철호, 최근 포항/경주 지진의 지진공학 및 구조공학적 비교분석 및 시사점, 한국강구조학회, 2018.2.21

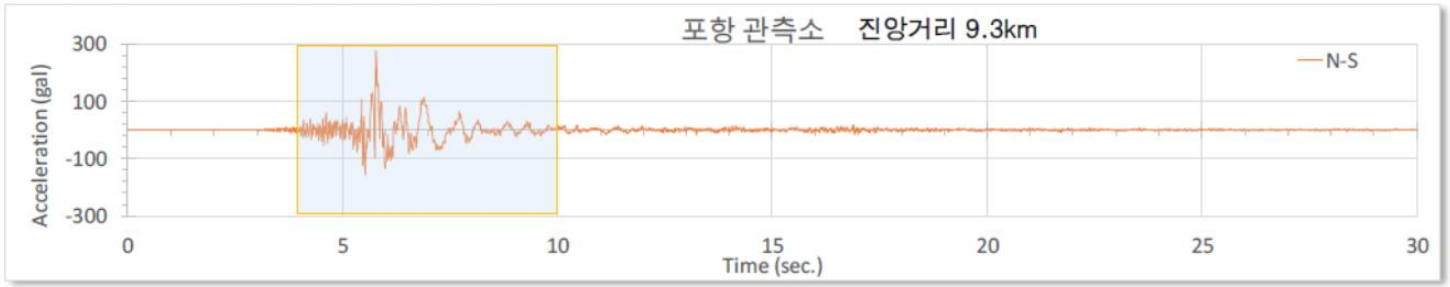
2016.9.12 경주지진

박광순, 경주지진 이후, 우리는 무엇을 준비할 것인가? 한국방재학회, 2017.2.17

2017.11.15 포항지진

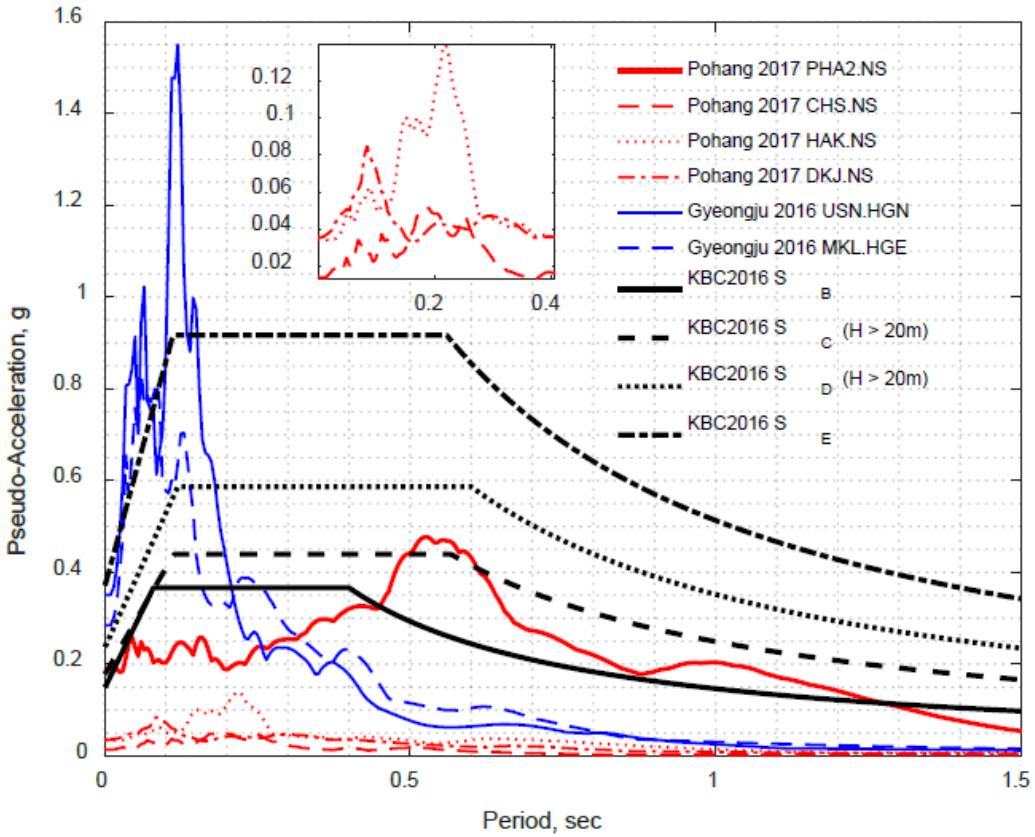
- 2017년 11월 15일, 수요일
  14시 29분 31초 (KST)
- 진앙: 36.10°N, 129.37°E
  경북 포항시 북구 북쪽 6km 지역,
  진원 깊이 3.5 km.
- M_L 5.4: 계측된 국내 지진 중에서
  2번째로 큰 지진 (2016 경주
  지진이 최대 지진 M_L 5.8)
- 강진지속시간: 약 4~6 초.





정성훈, 포항 지진의 개요, 한국지진공학회, 2018.1.26

2017.11.15 포항지진

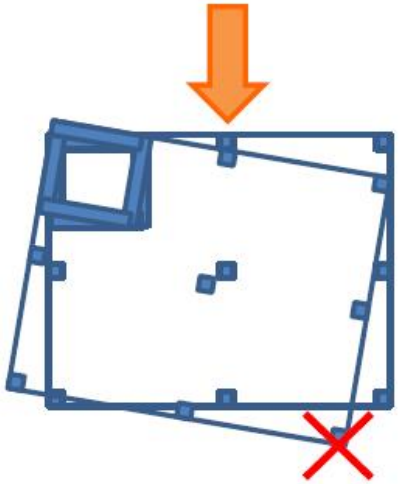


: Comparison of response spectra from the 2017 Pohang and 2016 Gyeongju EQs and design spectrum of KBC2016

이철호, 최근 포항/경주 지진의 지진공학 및 구조공학적 비교분석 및 시사점, 한국강구조학회, 2018.2.21

2017.11.15 포항지진

❑ 과도한 평면 비정형성 – 내진설계에 대한 이해부족



정성훈, 포항 지진의 개요, 한국지진공학회, 2018.1.26

2017.11.15 포항지진

- 내진설계 오류: 기둥의 취성파괴, 연약층
- 구조설계 기준 미준수: 구조안전에 대한 책임감 결여

정성훈, 포항 지진의 개요, 한국지진공학회, 2018.1.26

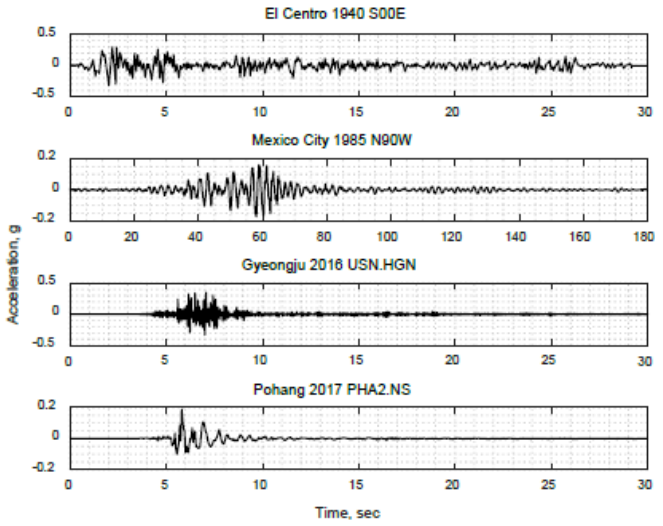
2017.11.15 포항지진

❑ 내진보강 미적용 교사동

정성훈, 포항 지진의 개요, 한국지진공학회, 2018.1.26

경주지진 vs 포항지진

출처: 2018 이철호



"1/6 time scale"

"20-40층 (2-4초)"

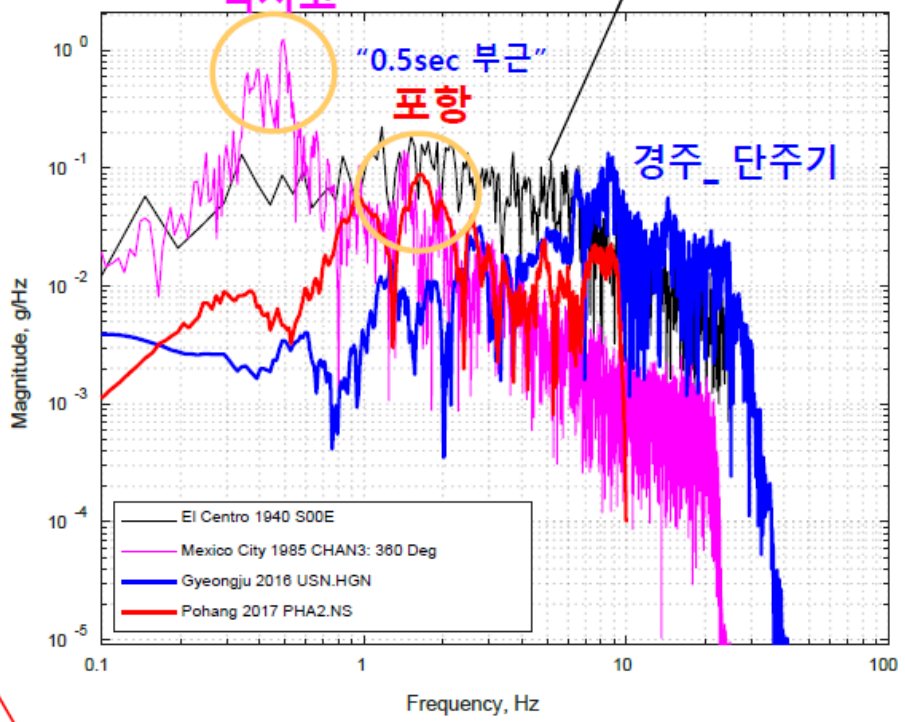
엘센트로_ 상대적으로 균등

멕시코

"0.5sec 부근"

포항

경주_ 단주기



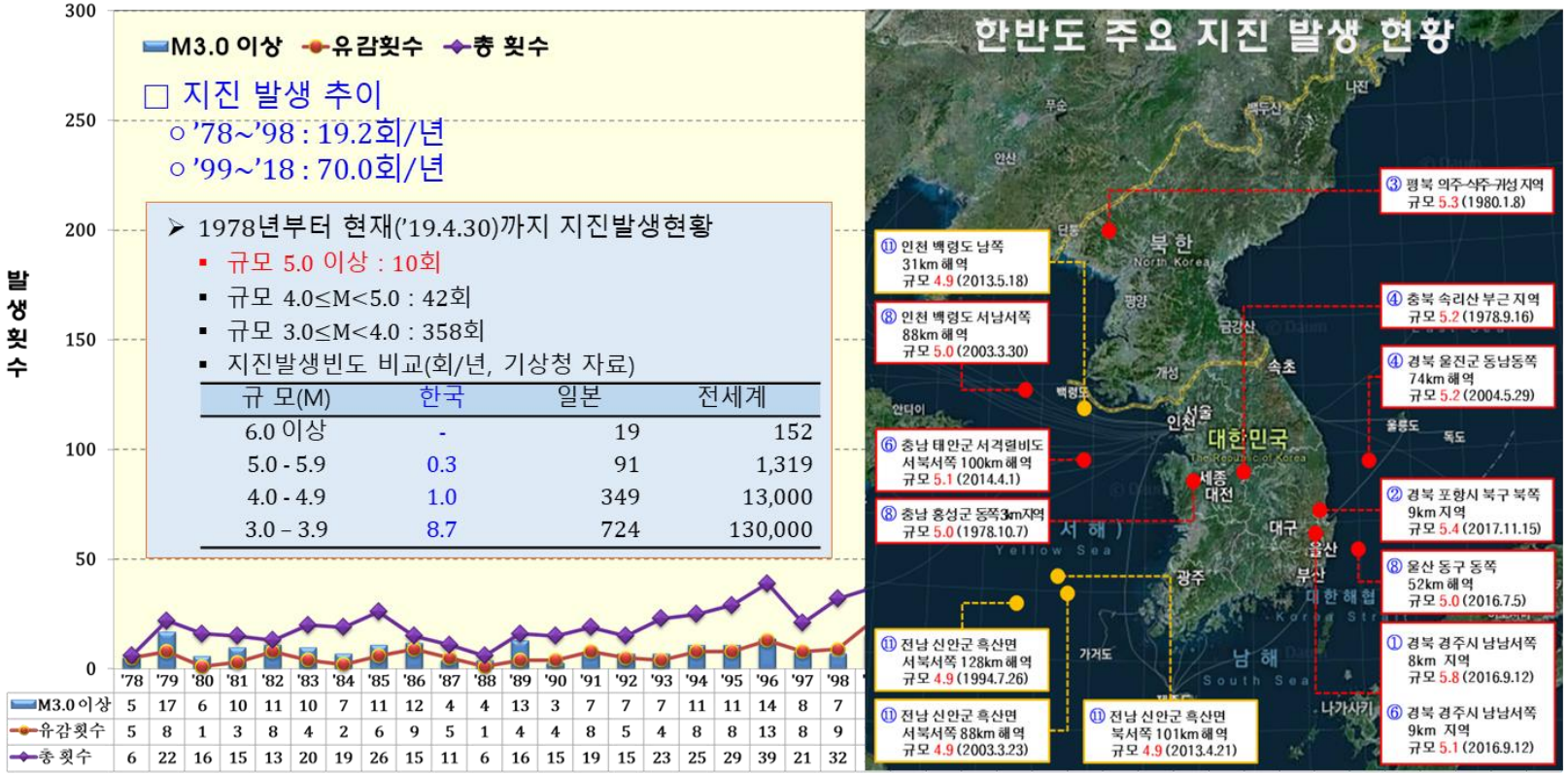
	El Centro 1940 — S00E	Mexico City 1985 — CHAN3: 360 Deg
Magnitude, Mw	6.9	8.1
Epi-distance, km	16.9	400
PGA, g	0.34	0.17
Remarks	standard earthquake	far-field earthquake (nearly harmonic)

"원거리대지진/매립지 지진동 증폭"

: Time histories and frequency spectra for selected accelerograms

Seismicity of Korea

Number of Earthquake Occurrences



내진보강사업 적정성 검토 및 지원 연구 최종보고회 발표자료, 2019.5.10, 한국시설안전공단/한국지진공학회

한반도의 지진 - 국내 활성단층과 최대지진 규모

- **지진규모와 단층길이**

✓ 규모 7.3 구마모토 지진: 약 50km 활성단층 운동(파쇄)

규모	단층 길이	규모와 에너지
5	1 km	
6	수 km	규모 1증가 → 에너지 32배
7	수십 km	규모 2증가 → 에너지 1000배
8	≈ 100 km	
9	수백 km	규모 4증가 → 에너지 백만 배

- **한반도의 활성단층**

✓ 현재 확인된 활성단층은10여 개

✓ 최대길이는 약 1.5km (대부분 1km 이하)

- **최대 잠재지진 추정의 불확실성**

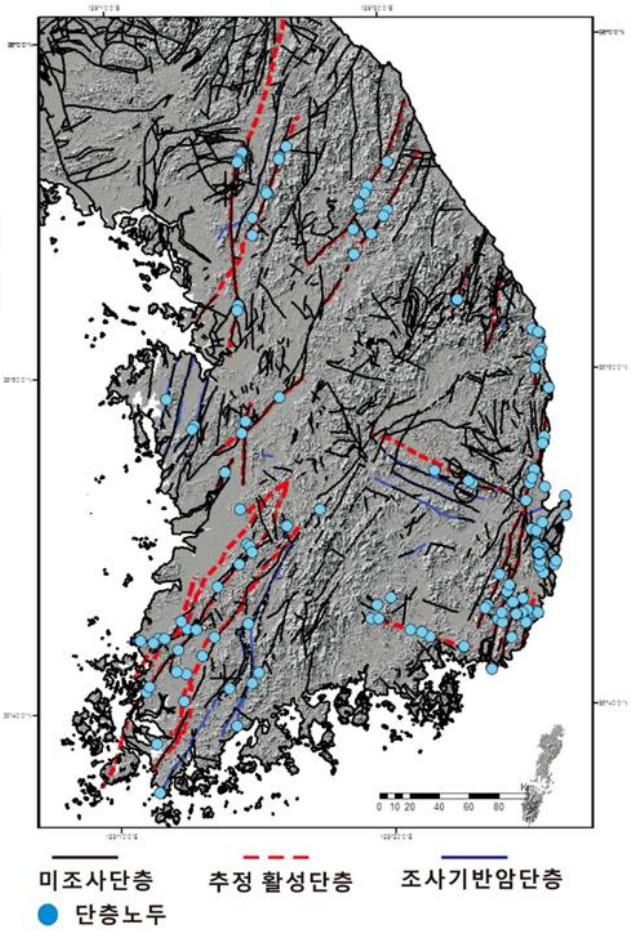
✓ 개발로 인한 지표의 단층흔적 소멸

✓ 접근 제한으로 연장선 확인 불가능

✓ 향후 수 km 이상의 단층 발견 가능성 고려

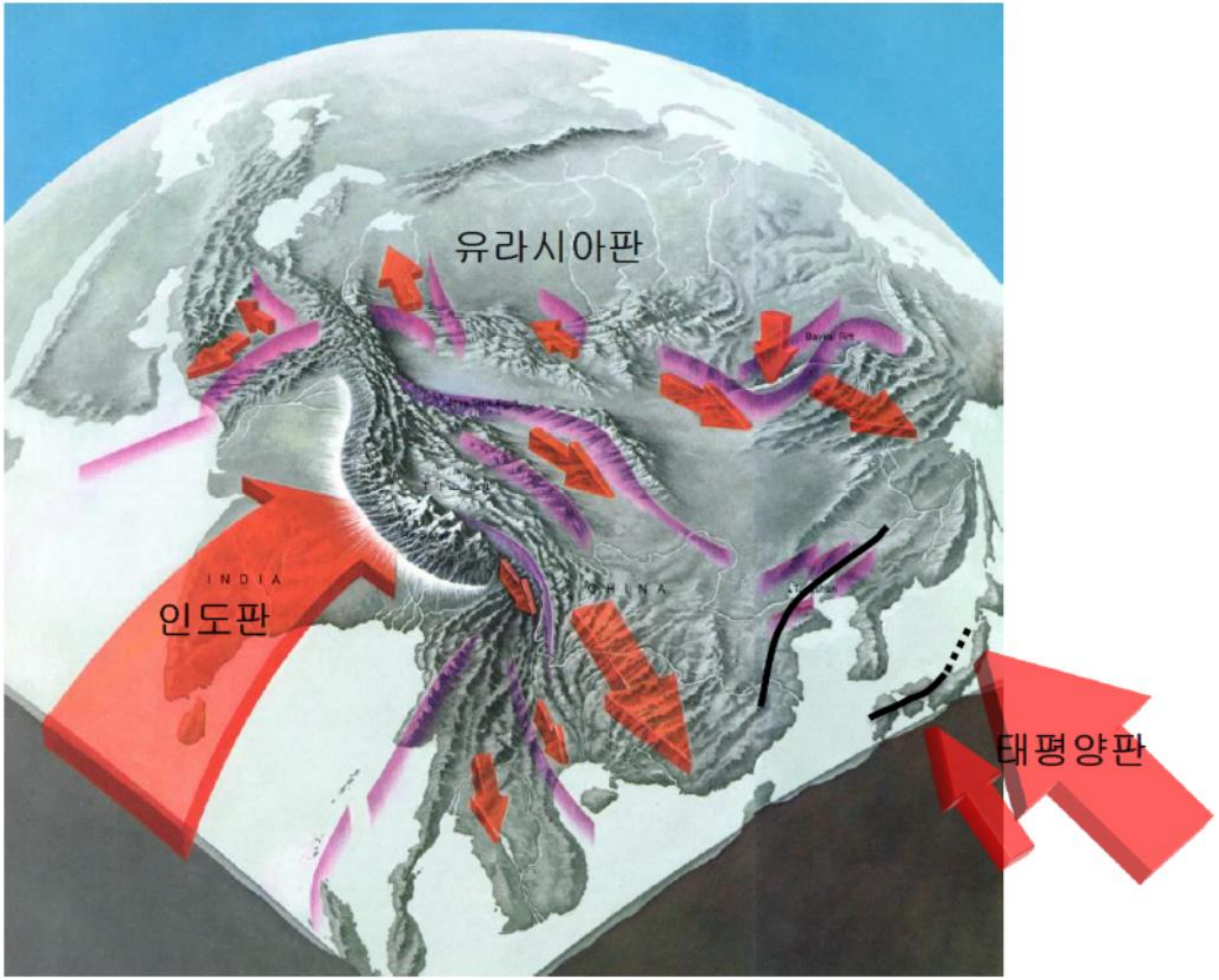
→ 최대규모 7.0에 상응하는 지진하중 도출

이철호, 2017



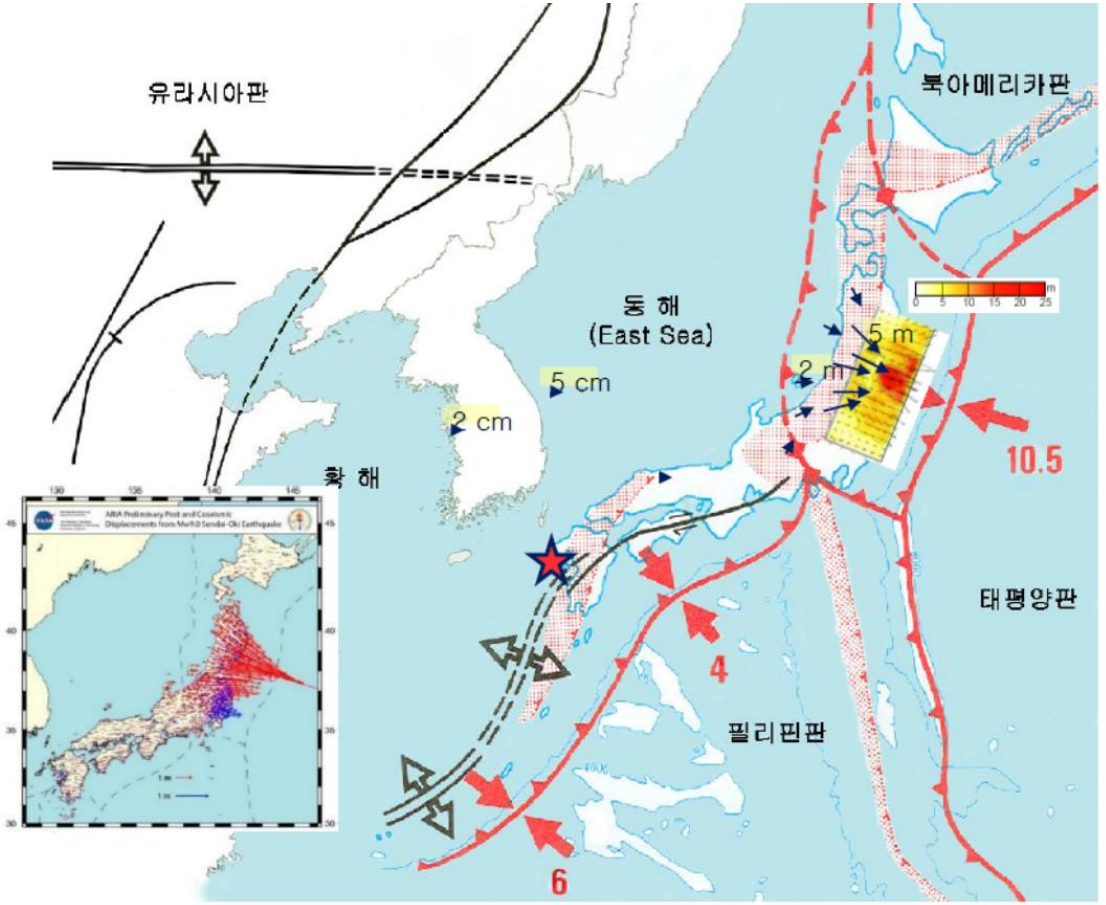
한국지질자원연구원, 2012

한반도 주변의 응력 분포



지헌철, 한반도의 지진학적 환경과 경주 지진의 의미, 2016.12.9

동일본 대지진으로 인한 한반도의 지각 이동



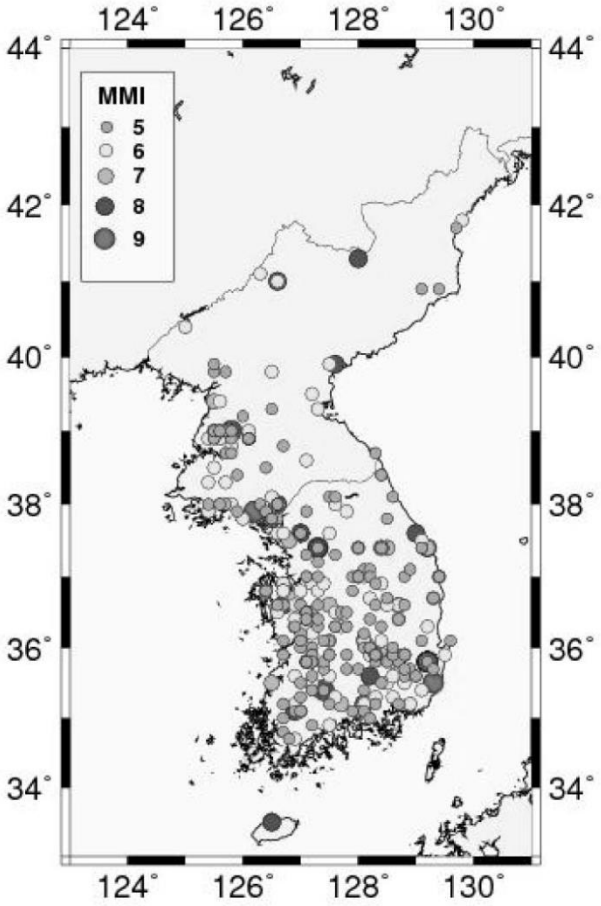
참조 : 제 35회 과총포럼, 한반도 지진과 원자력 안전(2011 3. 23.)

출처 : https://forum.kofst.or.kr/dataroom/pds.html?mode=view&uid=61&no=35&gubun=2&page=3&code=tb_board_04&r_url=/dataroom/pds.html

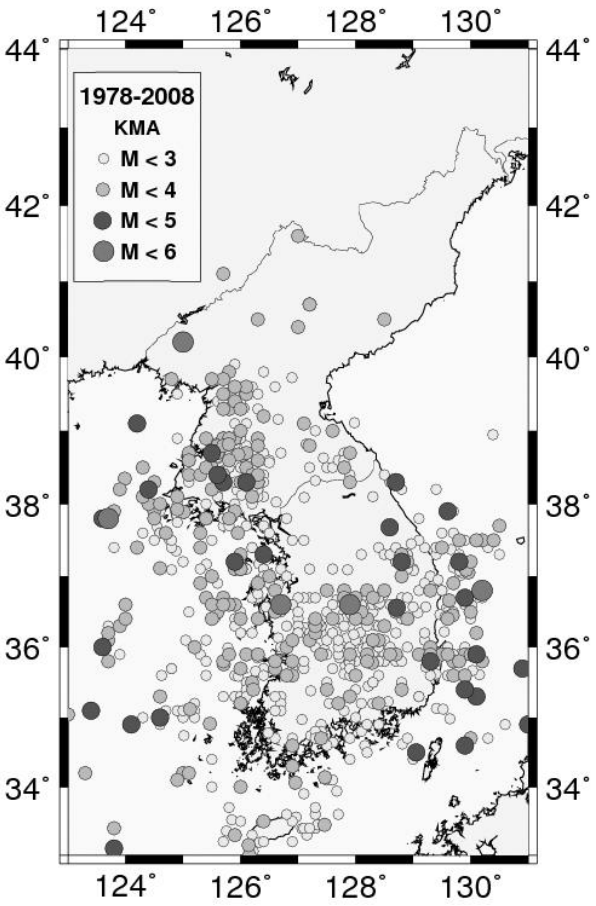
지헌철, 한반도의 지진학적 환경과 경주 지진의 의미, 2016.12.9

Basis of Seismic Design Codes in Korea

Historical vs. Instrumental Earthquakes



Epicentral Distribution of the Historical Earthquakes 2 A.D.-1904



Epicentral Distribution of the Instrumental Earthquakes 1978 - 2008

- Historic documents
- The Annals of the Choson Dynasty (1392 AD – 1910 AD)
  - 389 events greater than or equal to V on MMI scale
  - Over 45 events greater than or equal to VII on MMI
  - Maximum intensity IX on MMI
- Large uncertainty in the seismic hazard assessment
- 1st seismic hazard maps for the development of seismic codes in 1997

Seismic Hazard Maps

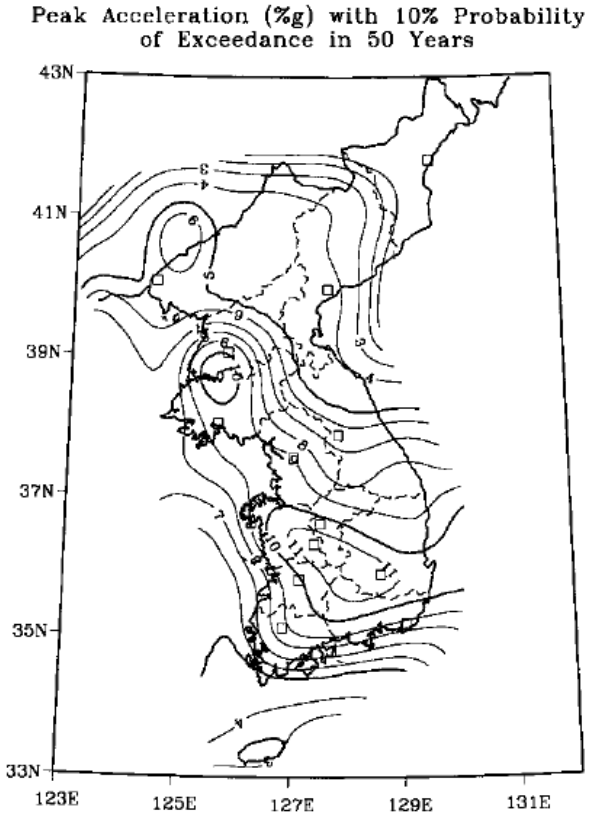


Figure 1. Seismic hazard map of 10% probability of exceedance in 50 years

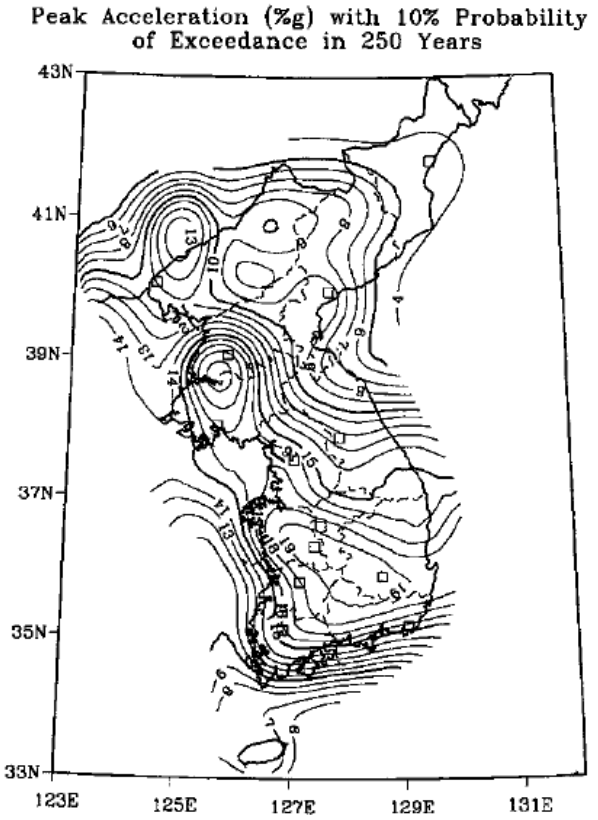


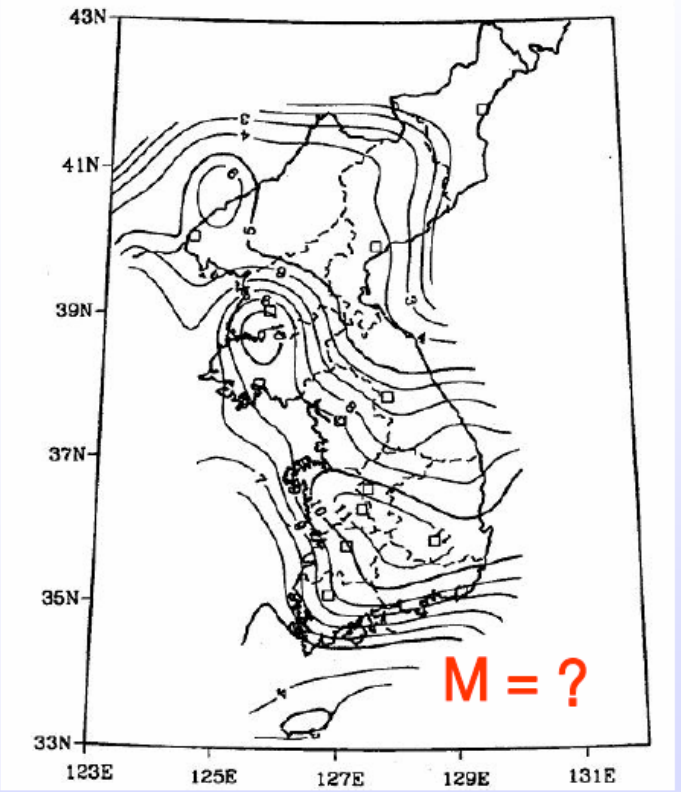
Figure 2. Seismic hazard map of 10% probability of exceedance in 250 years

Design Earthquake Level

Seismic region	Regional seismic coefficient	Administrative district	
I	0.11g	City	Seoul, Incheon, Gwangju, Busan, Daegu, Daejon, Ulsan
		Province	Gyunggi, Chungcheong, Jeonbuk, Kyoungsang, Southern Kangwon, Northeastern Jeonnam
II	0.07g	Province	Northern Gangwon, Cheju, Southeastern Jeonnam

Return period (yr)	50	100	200	500	1000	2400
Importance factor	0.4	0.57	0.7	1.0	1.4	2.0

(Using regional seismic coefficient and importance factor)



(Using seismic hazard map, return period : 500 years)

Seismic Building Design Codes

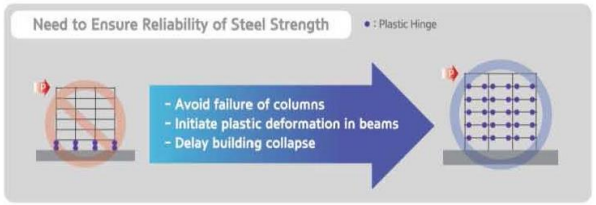
Design Code	1988	2000	2005	2009
Reference Code	ATC 3-06, UBC 85	similar to 1998	IBC 2000	similar to 2005
Design Base Shear	$V = \frac{AIS}{1.2\sqrt{T}R} W$ $\leq \frac{1.75AI}{R} W$ or $V \leq \frac{1.5AIS}{R} W$	$V = \frac{AIS}{1.2\sqrt{T}R} W$ $\leq \frac{1.75AI}{R} W$	$V = \frac{S_{D1}}{(R/I_e)T} W$ $\leq \frac{S_{DS}}{R/I_e} W$	$V = \frac{S_{D1}}{(R/I_e)T} W$ $\leq \frac{S_{DS}}{R/I_e} W$
Seismicity in Seoul	0.12g	0.11g	0.11g	0.22g
Return Period (year)	500	500	500	2400
Site Coefficient	3 groups	4 groups (S1, S2, S3, S4)	5 groups (SA, SB, SC, SD, SE)	5 groups (SA, SB, SC, SD, SE)

Structural Steel for Seismic Design

Properties of High Performance Steel

Performance Criteria for Seismic Design

Ductile Design Concept : **Strong Column - Weak Beam**



- A pronounced stress-strain plateau at the yield stress
- A large inelastic strain capability

  ① Upper limit on yield strength ⇒ Reliability of steel strength

	Yield Point (Fy, MPa)
SN400[1] / SHN400	235 ≤ Y.P. ≤ 355
SN490[1] / SHN490	325 ≤ Y.P. ≤ 445

1) for thickness ≤ 40 mm

  ② Limitation of Yield Ratio

- Good weldability

  : a guaranteed maximum carbon equivalent (CE%)

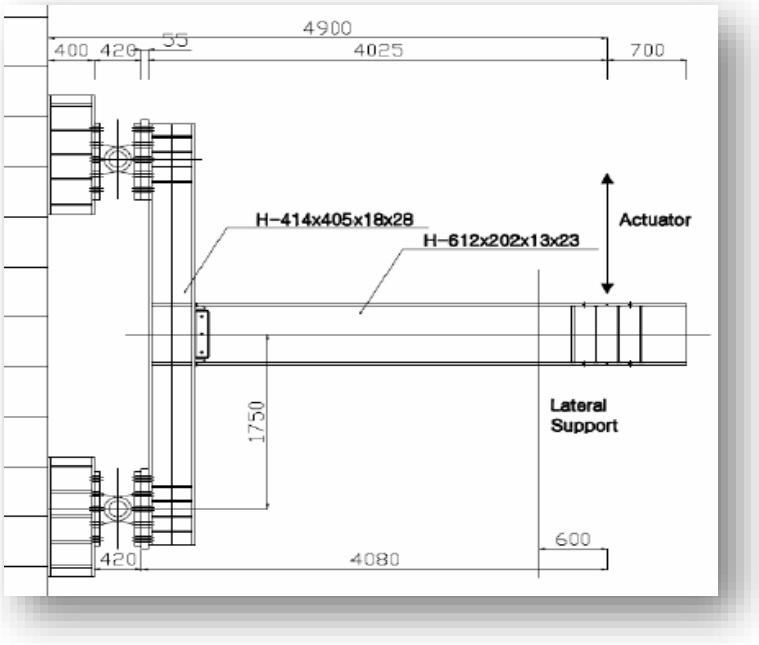
- Toughness

Expected Material Strength

Specification	Material Grade		Ry	Rt
KBC 2009	SS400		1.3	1.2
	SM400, SM490		1.2	1.2
	SHN490, SN490		**1.1**	**1.1**
AISC 341-10	shape	ASTM A36	1.5	1.2
		ASTM A572/572M Gr. 50 **ASTM A992**	**1.1**	**1.1**
	plate	ASTM A36	1.3	1.2
		ASTM A572/572M Gr. 50	1.1	1.2

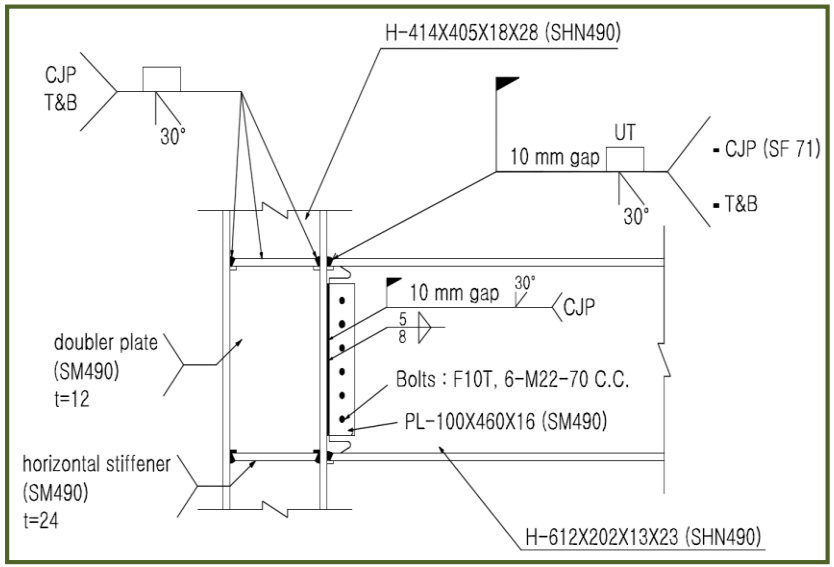
Test Specimens and Set Up

Specimens for the experiments			
Name	**Connection Type**	**Steel**	**Section Size**
JR1	WUF-B	SM490	Beam: H-612x202x13x23 Column: H-414x405x18x28
JR2		SHN490	
JR3	WUF-W	SM490	
JR4		SHN490	

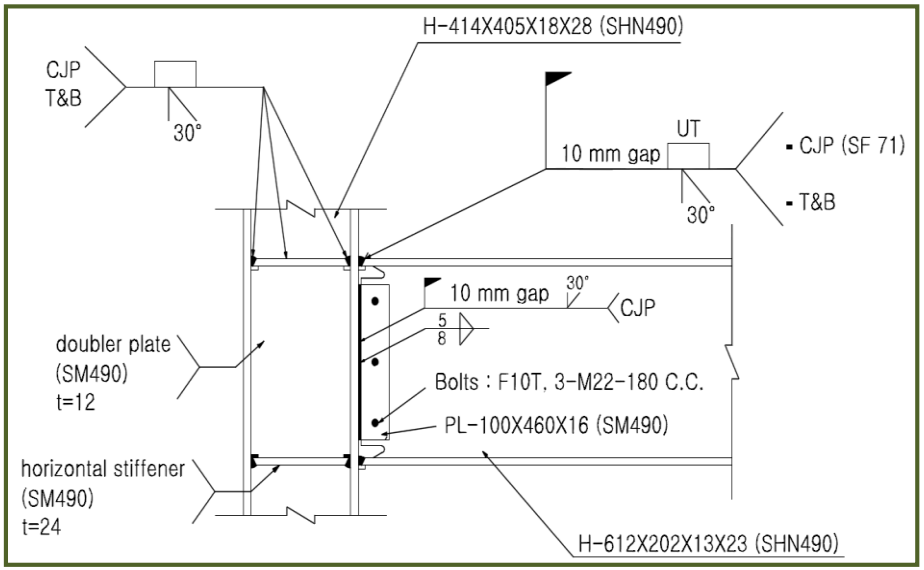


- The depth of the beam is typical for low-to-midrise steel buildings in Korea,
- The column section was determined considering the strong column-weak beam theory
- Loading (Disp. Control) protocol was based on AISC Seismic Provision, 2005.

Test Specimen Design



JR2 (WUF-B, SHN490)

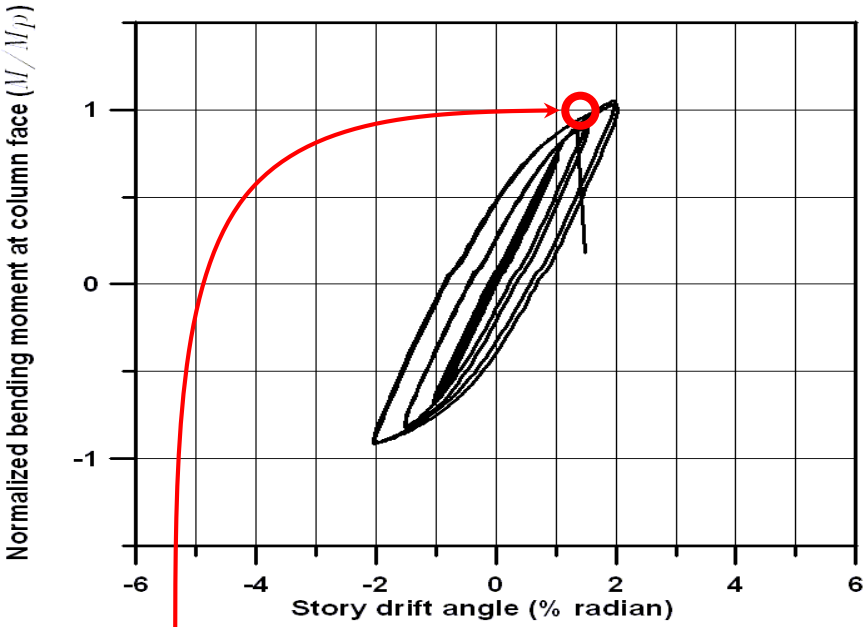


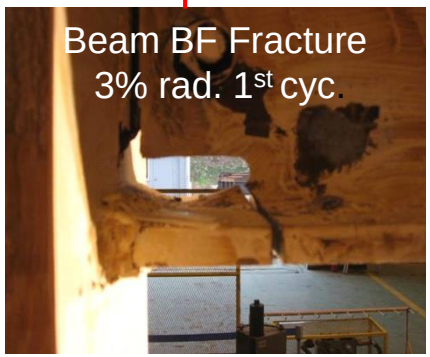
JR4 (WUF-W, SHN490)

- Weld access holes were fabricated according to FEMA350
- Horizontal stiffener is added to prevent the local flange buckling of the column
- The panel zone is stiffened by doubler plate to reduce the shear deformation.

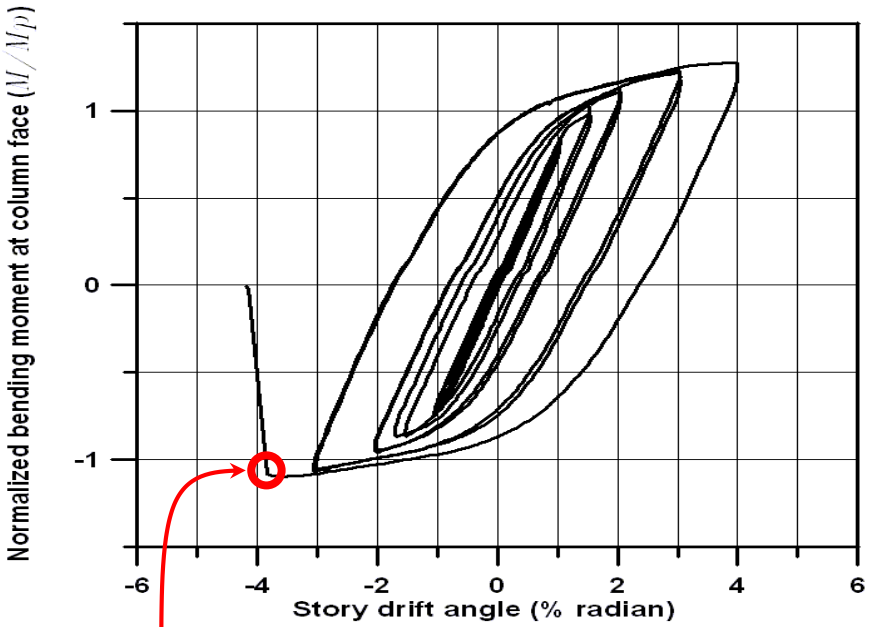
Connection Test Result

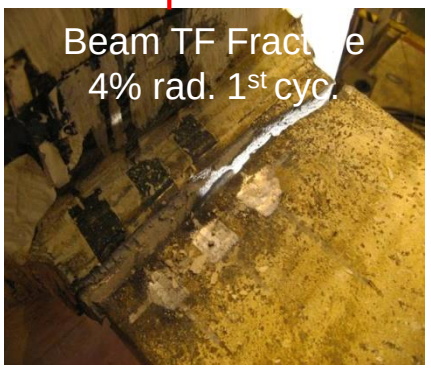
JR1(SM490)

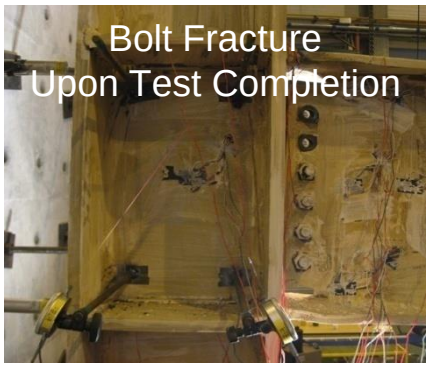




JR2(SHN490)







Summary of Test Results

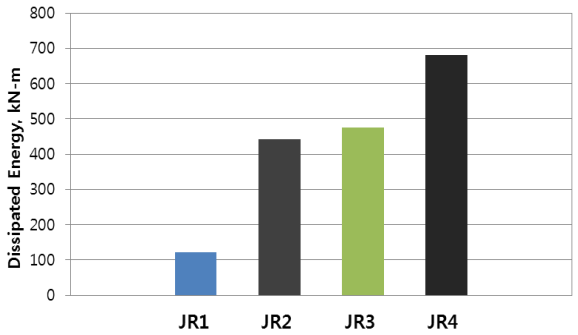
Specimen	Type	Steel	Failure Mode	$\frac{M_{max}}{M_p}$	θ_{pq} (% rad.)	Energy (kN-mm)
JR1	WUF-B	SM490	Beam BF Fracture near Weld Access Hole	1.05	2.0	121,000
JR2		SHN490	Beam TF HAZ Fracture	1.23	3.0	443,000
JR3	WUF-W	SM490	Beam TF HAZ Fracture	1.22	3.0	475,000
JR4		SHN490	Beam TF HAZ Fracture	1.17	4.0	681,000

Design Implication from Test Results

Specimen	Type	Steel	Interstory Drift	Suggested Frame System
JR1	WUF-B	SM490	2%	Intermediate
JR2		SHN490	3%	Intermediate
JR3	WUF-W	SM490	3%	Intermediate
JR4		SHN490	4%	Special

Interstory drift demand according to AISC,

- *Ordinary Moment Frame (OMF): 1%*
- *Intermediate Moment Frame (IMF): 2%*
- *Special Moment Frame (SMF): 4%*



Comparison of Energy Dissipation

MAK Tower Project

Site Location

· Ulaanbaatar, Mongolia.

Used

· Office, Retail

Height

· 190m (1 story below and 43 story above the ground)

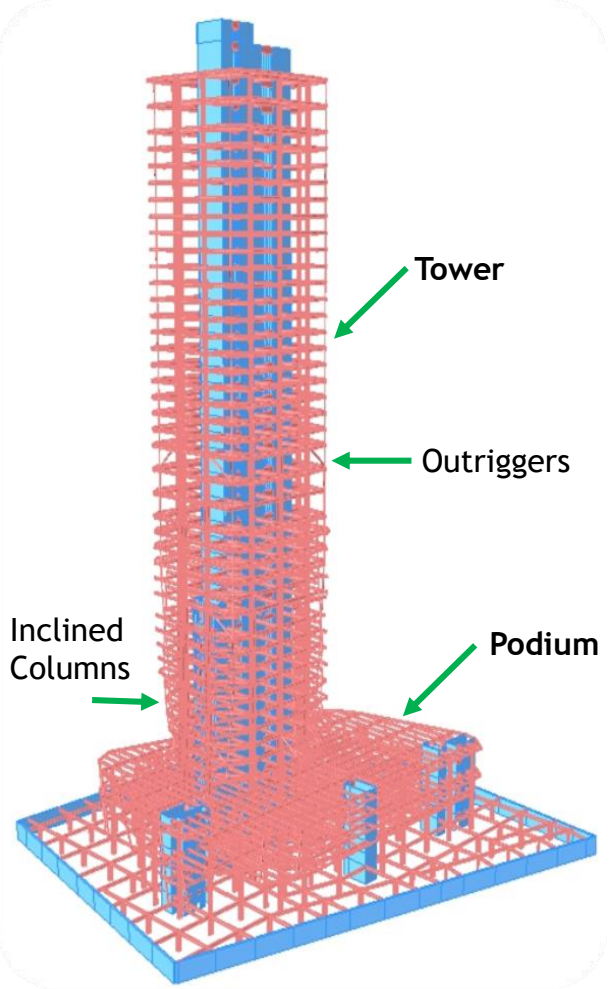
Structural System

· Steel Special Moment Frame + RC Core wall

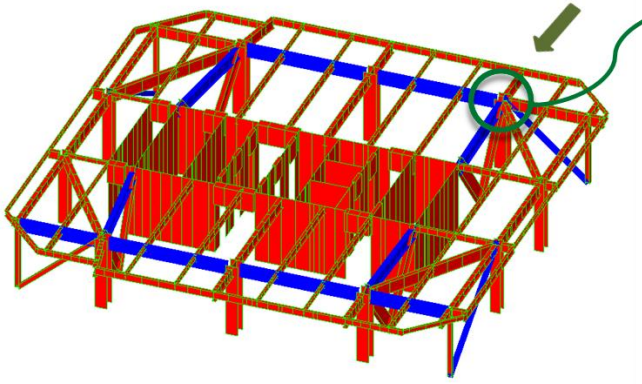
Design & Construction Company

· Architectural Design : Seohan Architecture
· Structural Design : Chang Minwoo Structural Consultants
· Gen. Contractor: Lotte E&C

Design Issues on Beam-Column Connections



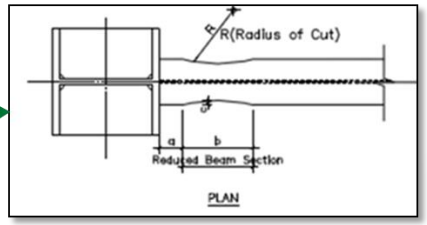
- Large Steel Beam-Column Connections
  (BH-900x500x40x40, H-900x300x16x28)
- Weak-axis/Skew Connections
- Weld Access Hole Geometry
- Flange Field Weld vs. Shop Weld with Bracket

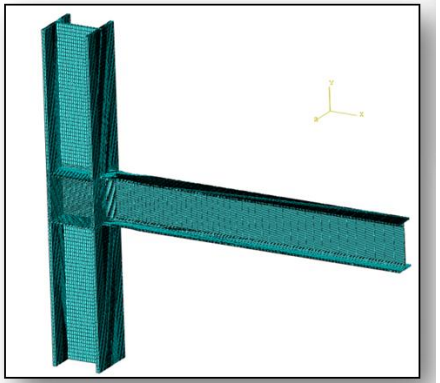


20F (Outrigger floor)

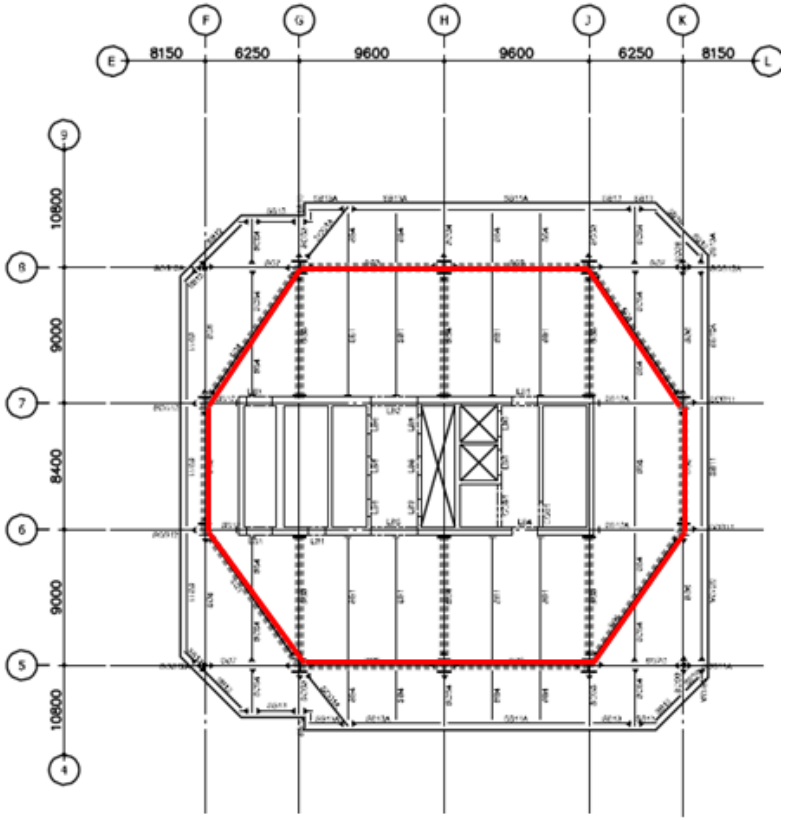
보: BH-900x300x20x35 (SN490)

기둥: BH-900x900x50x80 (SM490 TMC)





Seismic Force Resisting System

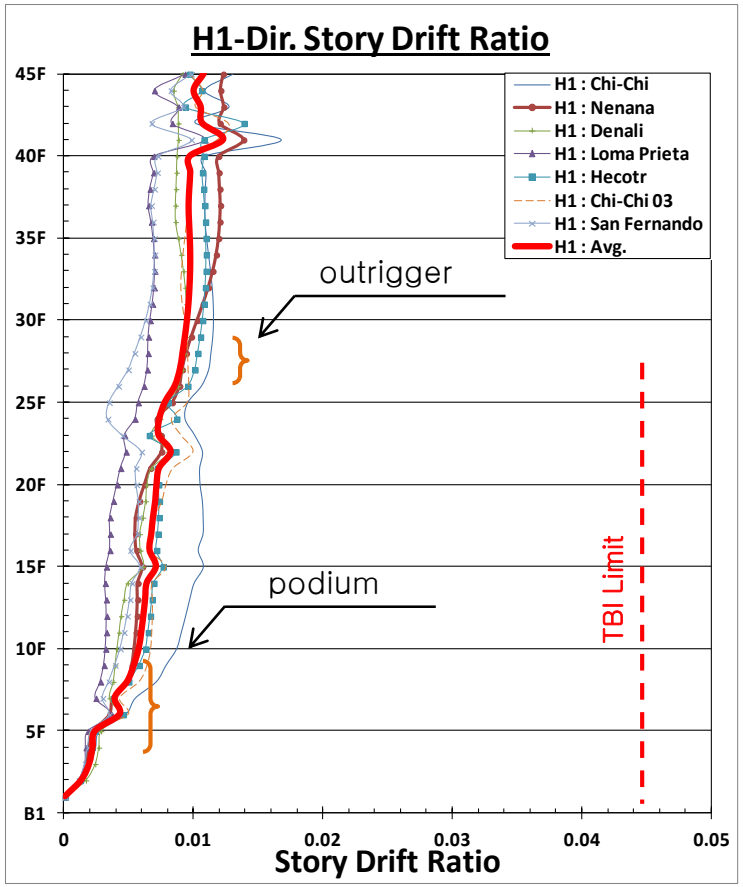


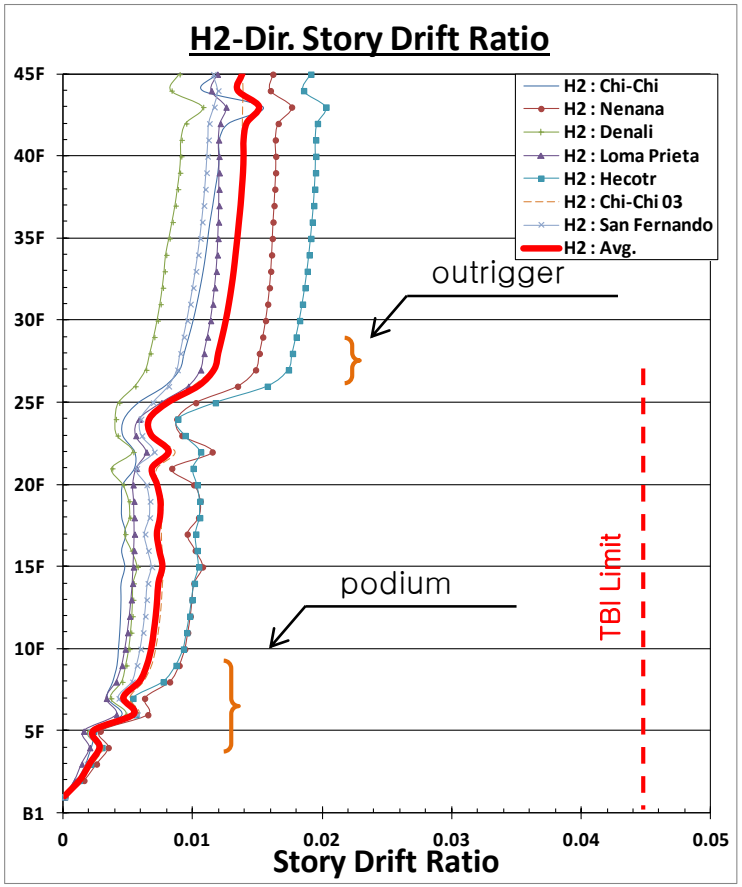
Key Plan for Special Moment Frame

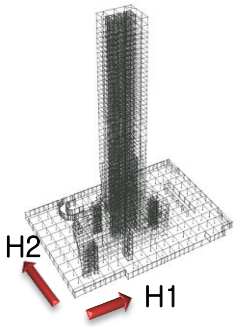
Type	D	B	tw	tf	Steel
H	496	199	9	14	**SHN490**
H	500	200	10	16	**SHN490**
H	482	300	11	15	**SHN490**
H	488	300	11	18	**SHN490**
H	612	202	13	23	**SHN490**
H	582	300	12	17	**SHN490**
H	588	300	12	20	**SHN490**
H	594	302	14	23	**SHN490**
H	692	300	13	20	**SHN490**
H	800	300	14	26	**SHN490**
H	900	300	16	28	**SHN490**
BH	600	300	15	30	**SN490**
BH	600	300	20	40	**SN490**
BH	800	300	30	40	**SN490**
BH	900	300	20	35	**SN490**
BH	900	350	30	40	**SN490**
BH	900	500	40	40	**SN490**

- Dual system with special moment frames selected per IBC 2006.
- Korean Building Code (KBC 2009) used for steel frame design

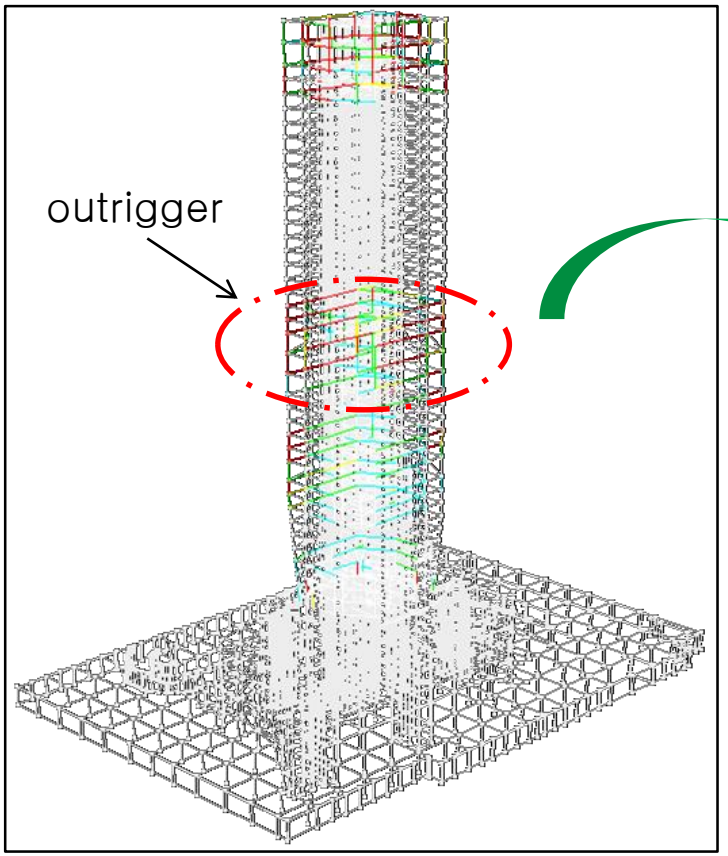
Nonlinear Response History Analysis



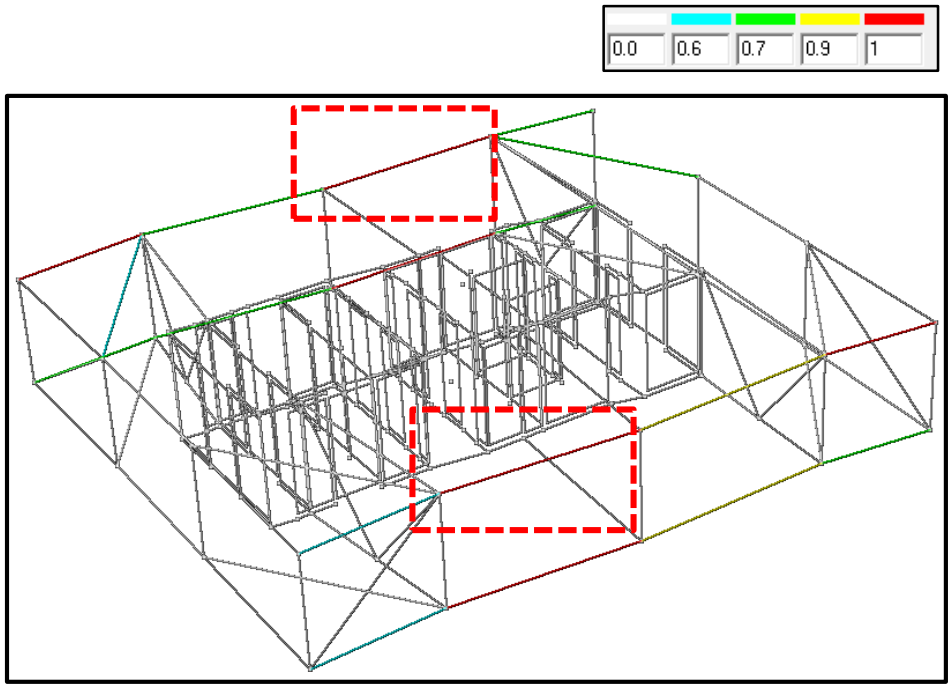




Nonlinear Response History Analysis



Plastic Zone



Structural Design of Tallest Building in Korea

LOTTE WORLD TOWER

Height
555 m (1,821 ft)

Floor Count
123 above ground
6 below ground

Floor Area
304,081 m^2

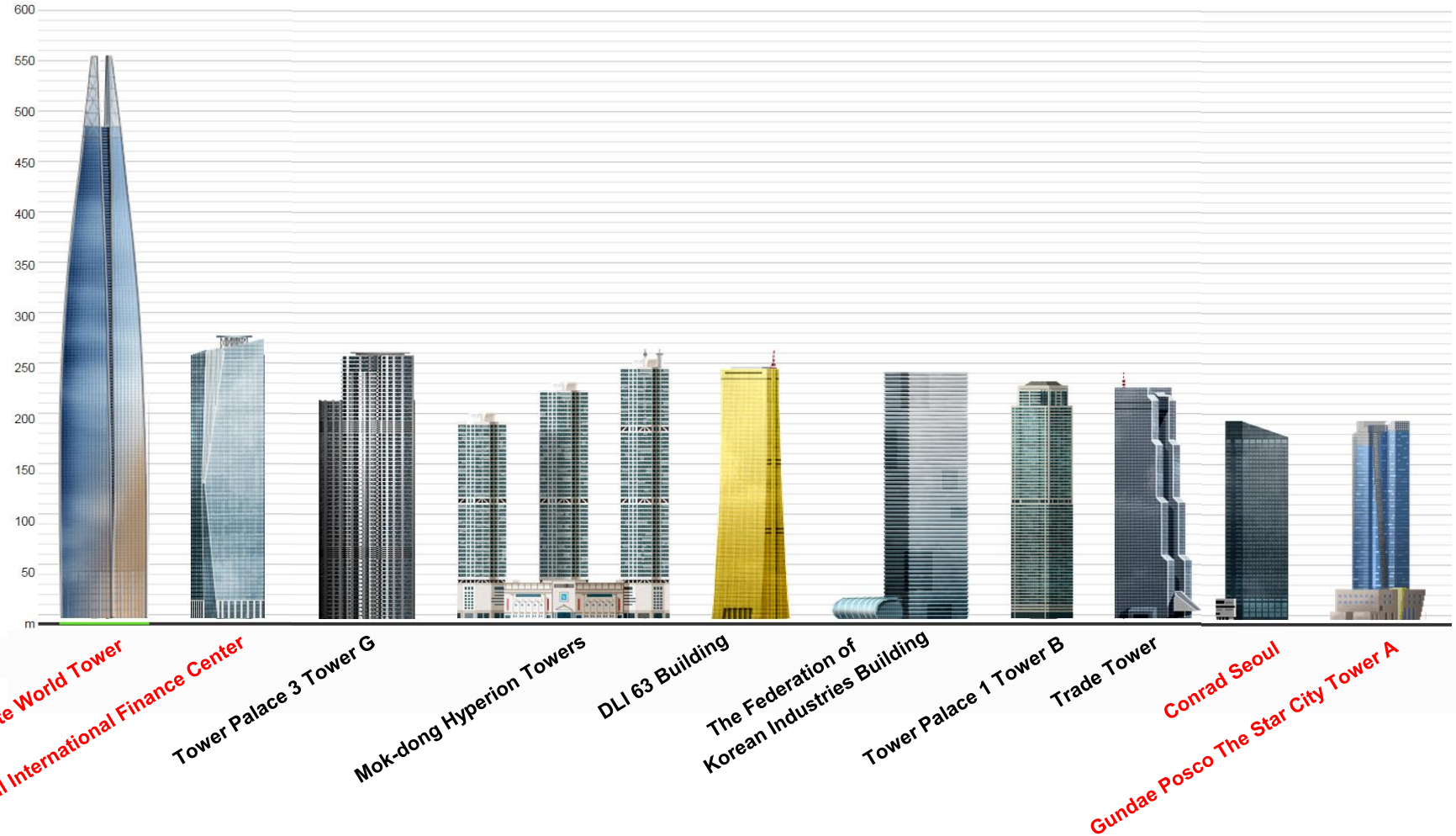
Client
Lotte Corporation

Architect
BAUM(AOR)
KPF(SD, DD)

Structural Engineer
Chang Minwoo(EOR)
LERA(SD, DD)
Thornton Tomasetti
(Peer Review)

General Contractor
Lotte E&C

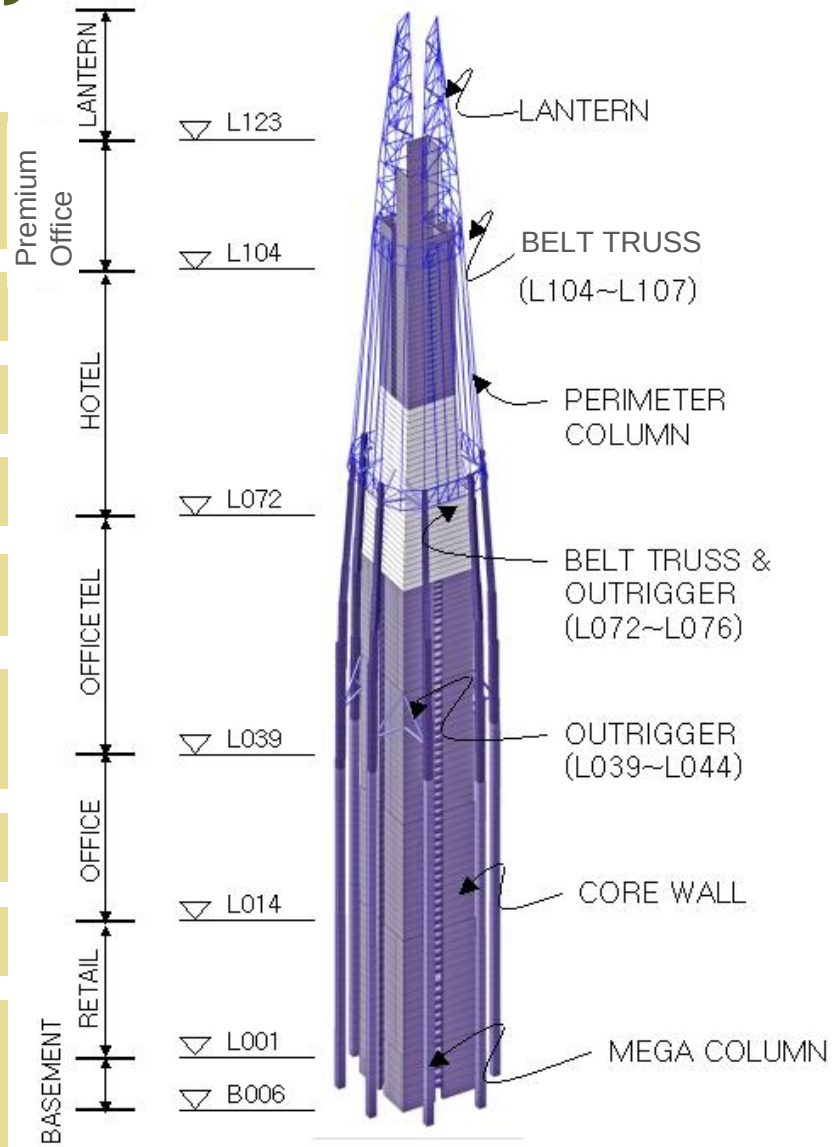
Tall Buildings in Seoul



Courtesy of *SkyscraperPage.com*

Structural System

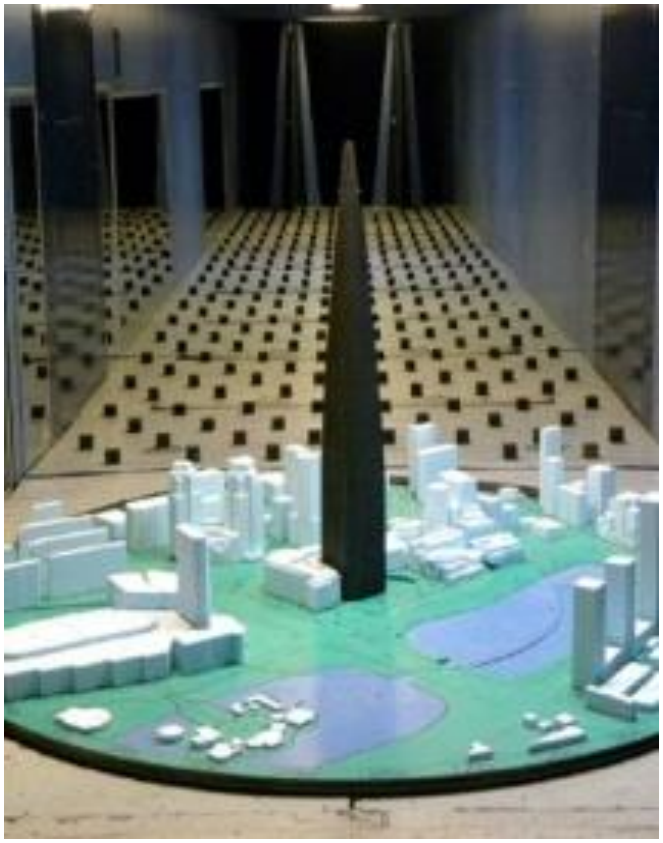
Lateral Resistance System	Core Wall + Outrigger / Belt Truss + Mega Column	
Core Wall	RC Wall (t=2000~500mm)	
Outrigger	Steel (L39~44, L72~76)	
Belt Truss	Steel (L72~76, L104~107)	
Mega Column	RC Mega Column (3.5 x 3.5m^2)	
Slab	Office & Officetel	Steel Beam + Deck Slab
	Hotel	Flat Slab
Foundation	Mat Foundation (t=6500mm)	
Material	Concrete: f_{ck} = 30 ~ 80MPa Rebar: f_y = 400~600MPa Steel: f_y = 235~650MPa	



Lateral Load

- **Wind Load**
  - Code: KBC 2009
  - Exposure: B
  - Basic Wind Speed:
    - V=26 m/s(for drift check)
    - V=30 m/s(for strength design)

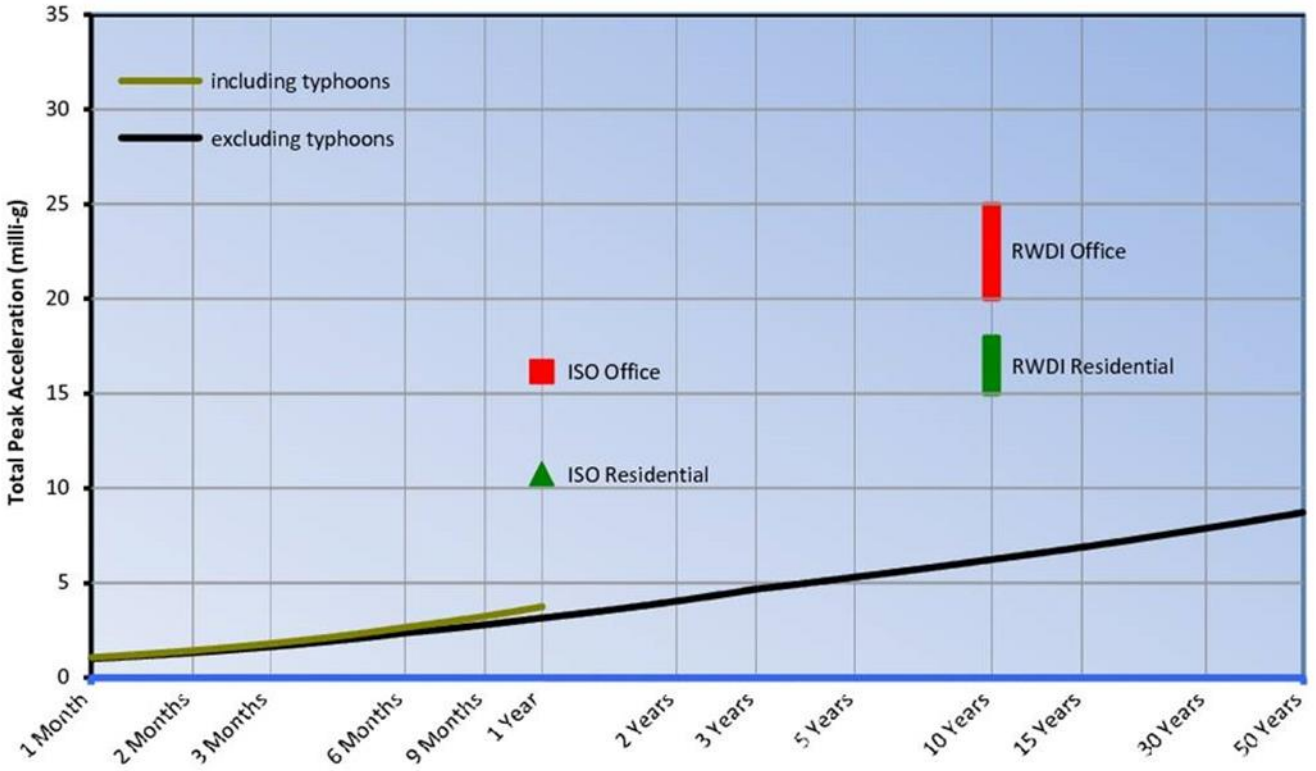
- **Seismic Load**
  - Code: KBC 2009
  - Site Coefficient: S=0.176 (Seoul)
  - Response Modification Factor: 4.0
  - Importance Factor: I_E=1.5
  - Seismic Design Category: C



HFFB Model

Aeroelastic Model

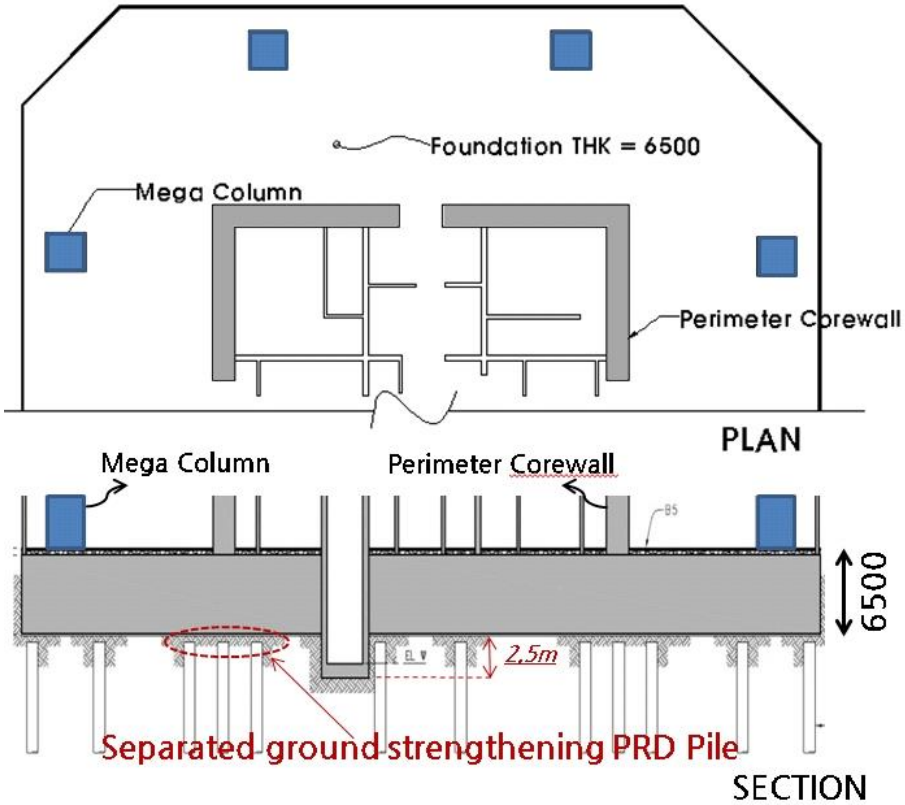
Lateral Load



Response acceleration for wind load

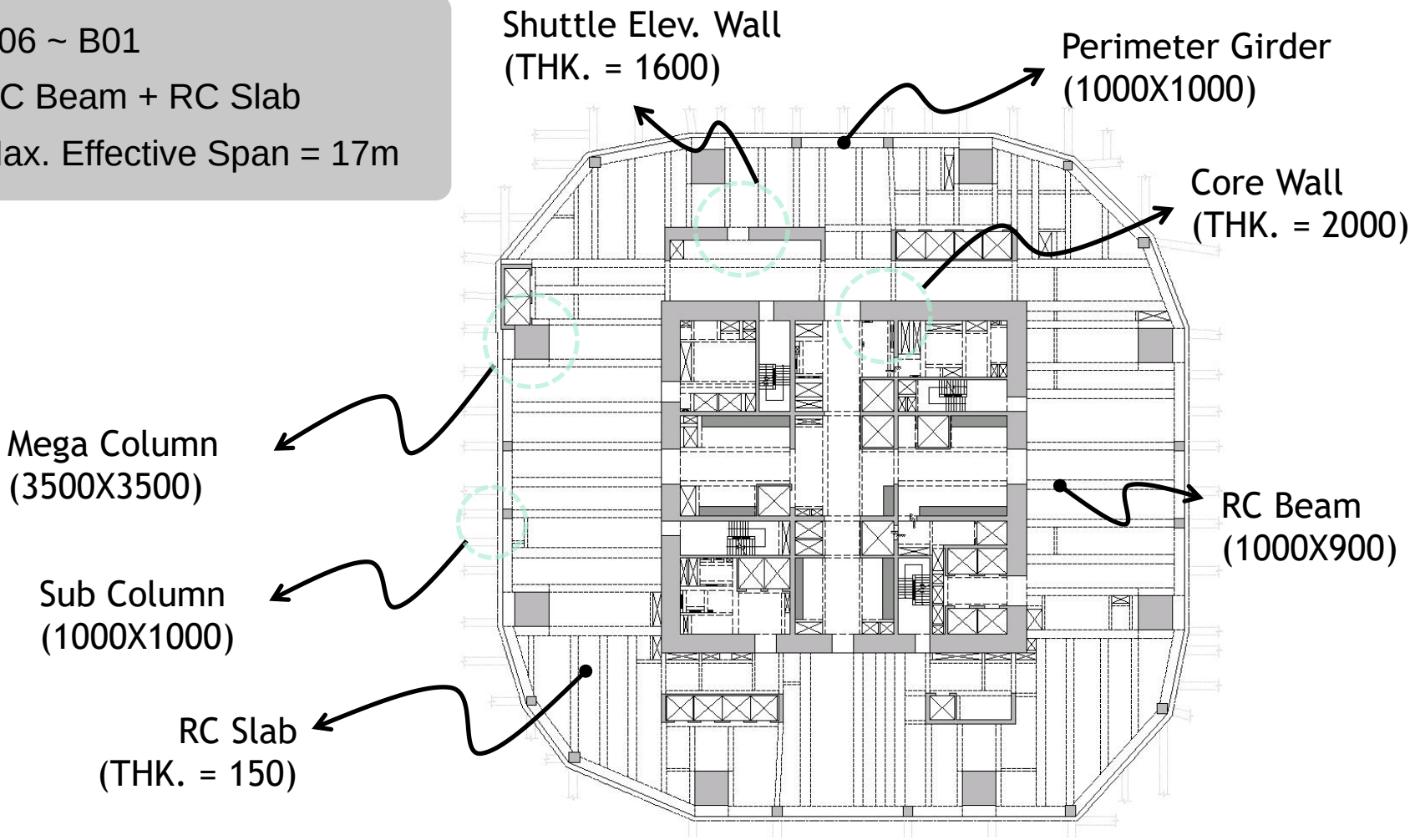
Foundation

- Size : 72m X 72m X 6.5m
- Allowable Bearing : 3,000 kPa
- Reaction : 2,590kPa < 3,000 kPa (O.K)
- f_{ck} = 50 MPa (Low heat- High flexible Concrete)
- Φ1,000 PRD Foundation Reinforcing : To minimize settlement under core walls and mega columns



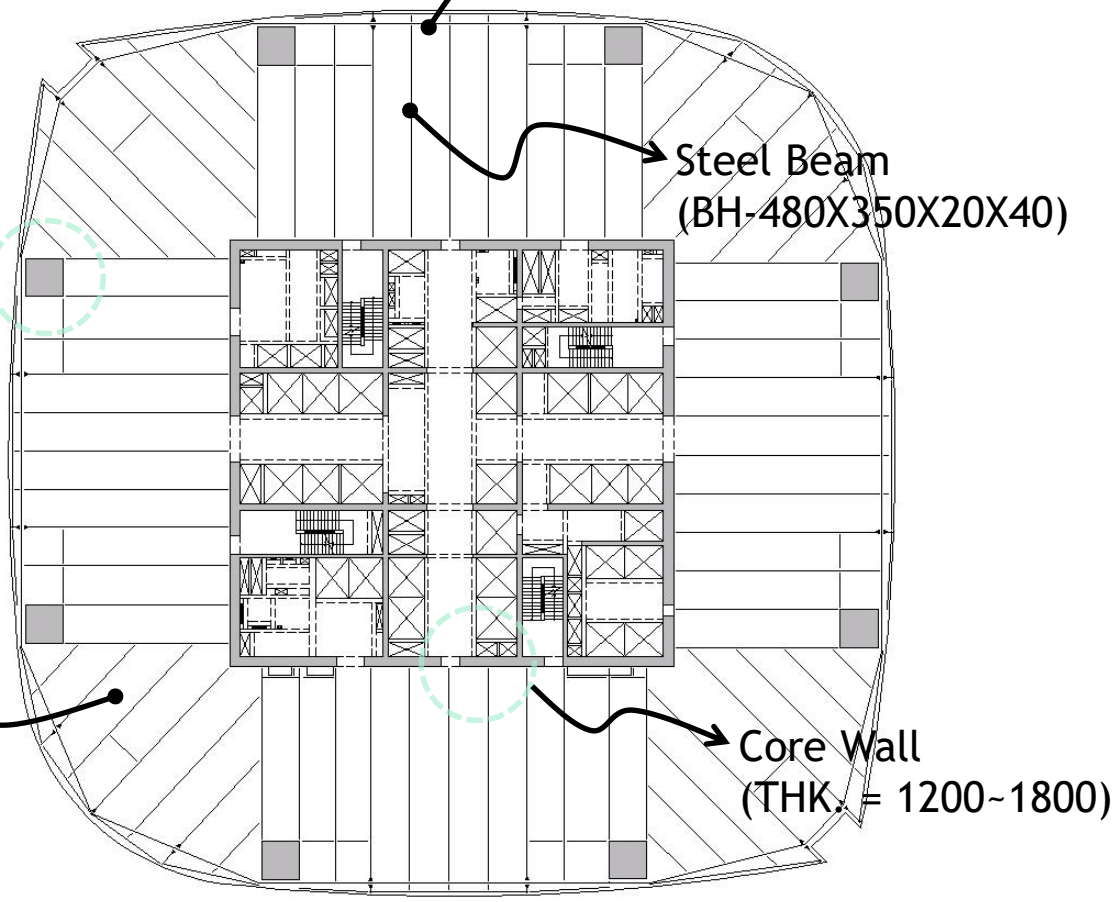
Underground Level

- B06 ~ B01
- RC Beam + RC Slab
- Max. Effective Span = 17m



Office Level

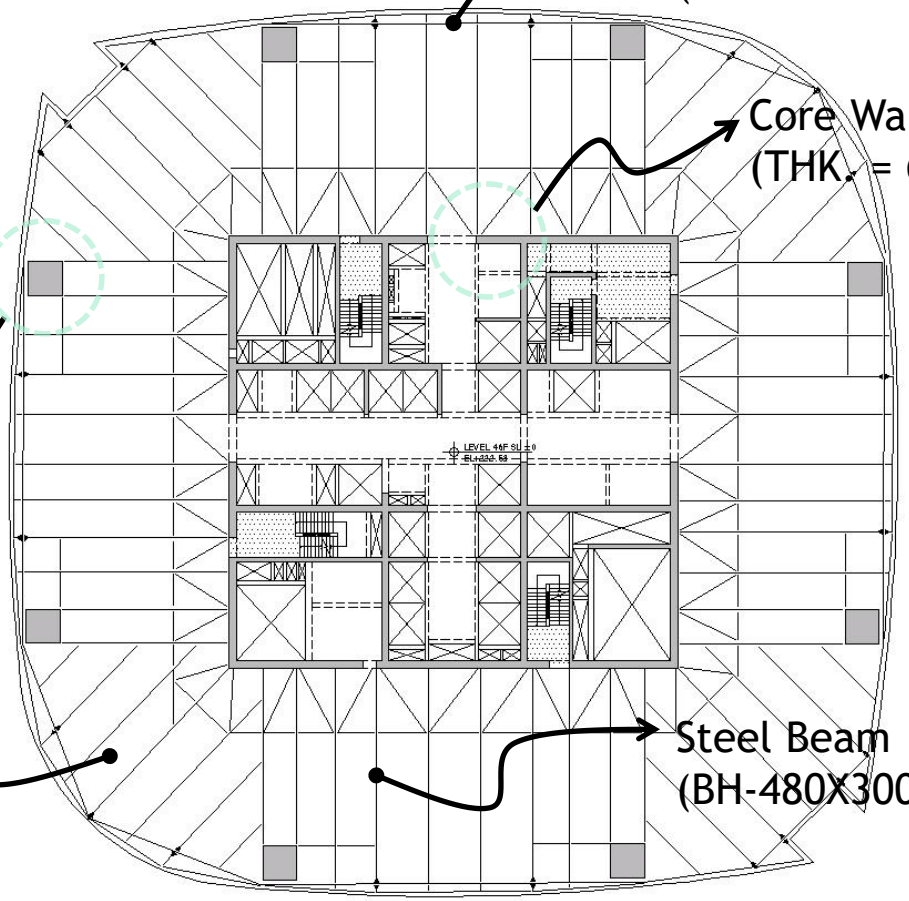
- L013 ~ L038
- Steel Beam + Deck Slab
- Story Height = 4500mm
- Max. Effective Span = 17m



Office Level

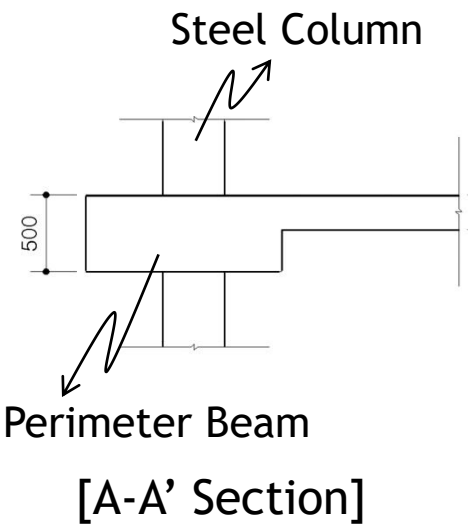
Officetel Level

- L044 ~ L071
- Steel Beam + Deck Slab
- Story Height = 3900mm
- Max. Effective Span = 15m

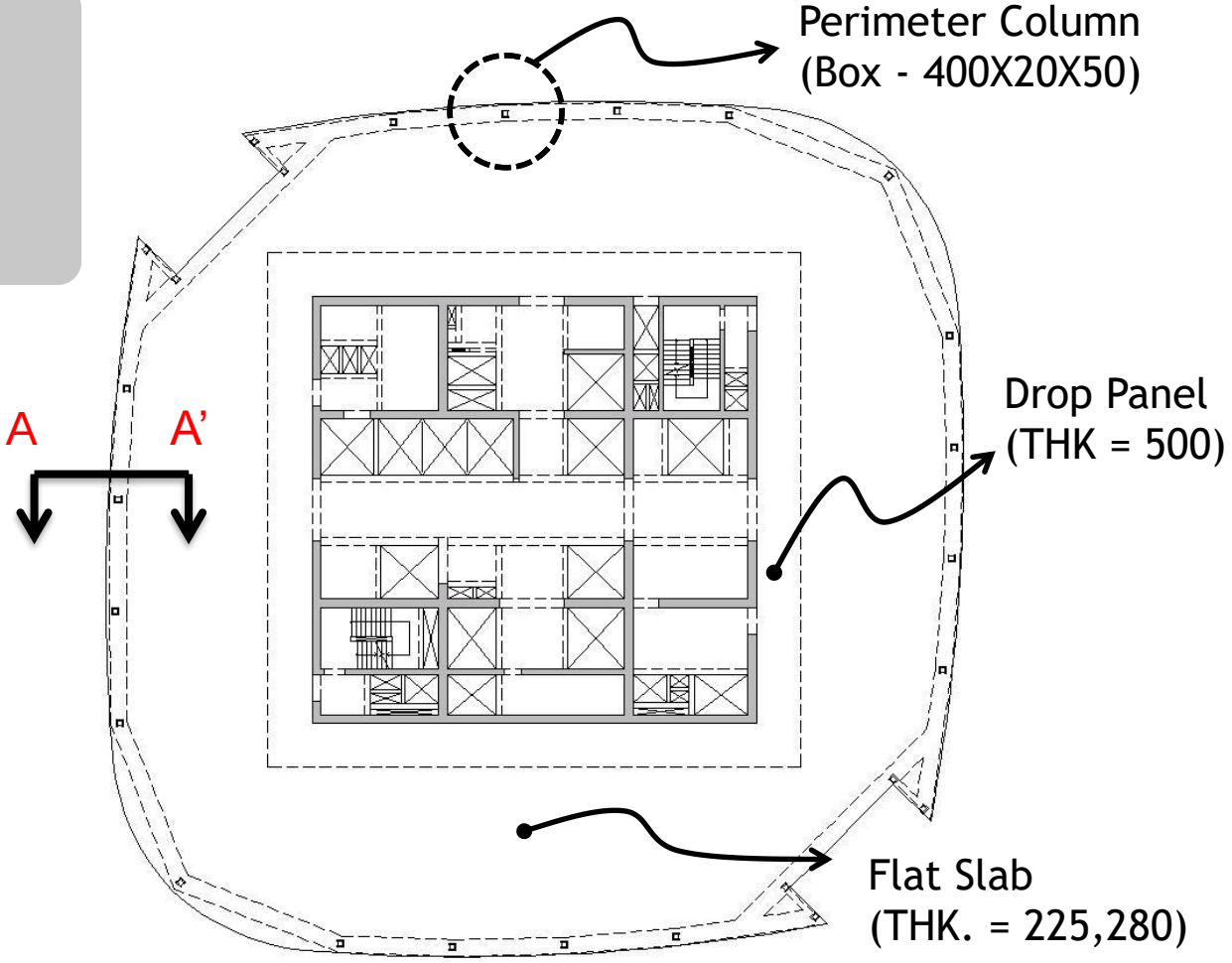


Hotel Level

- L074 ~ L101
- Flat Slab
- Story Height = 3600mm
- Max. Effective Span = 12m

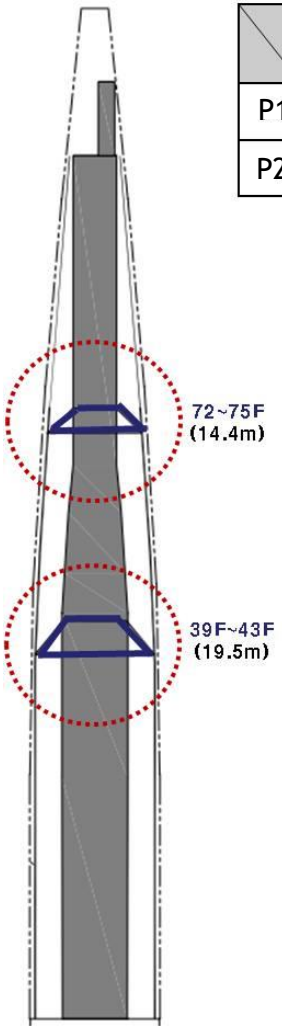


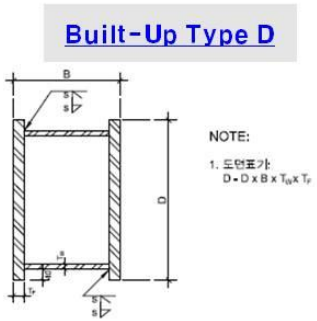
[A-A' Section]

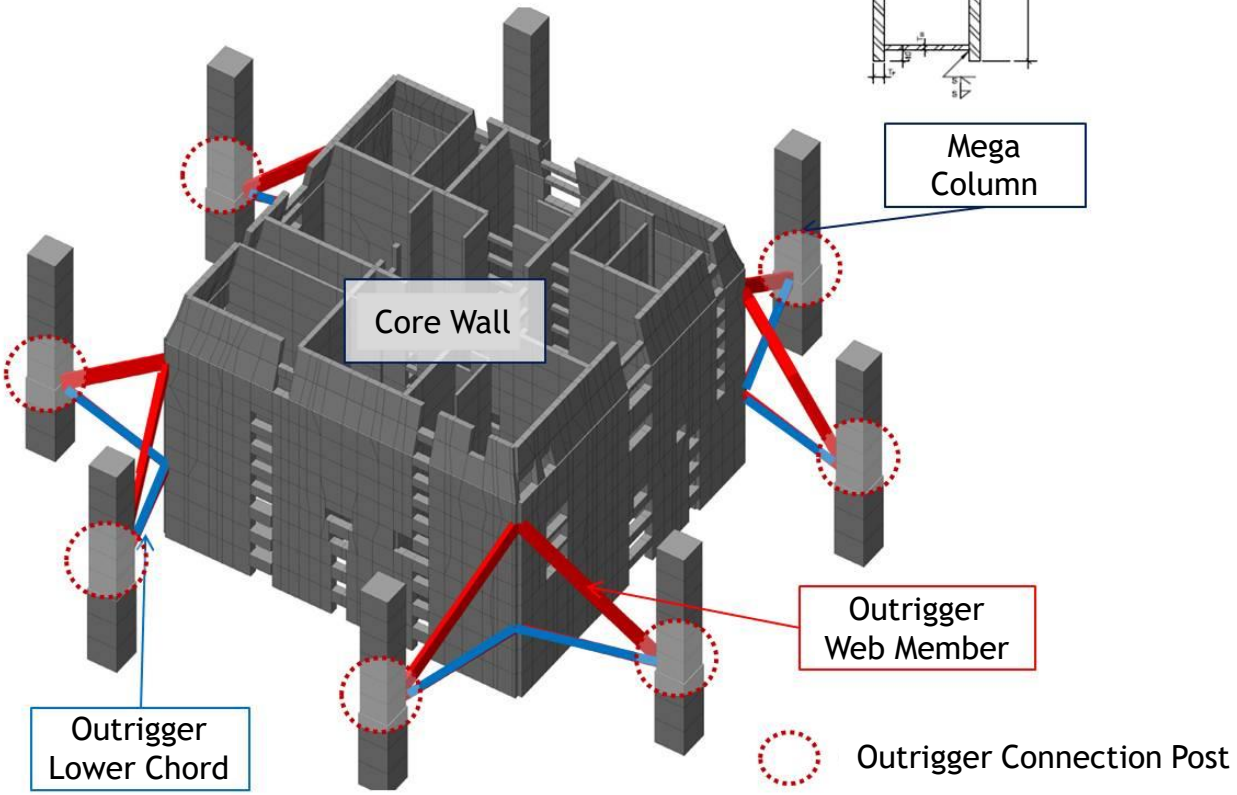


Lateral Resisting System

	Location	Size		Material
		Web	Lower Chord	
P1	39F~44F	□-1,600x500x20x80	□-950x500x20x80	SM570TMC
P2	72F~76F	□-1,600x500x20x80	□-1,000x500x20x80	

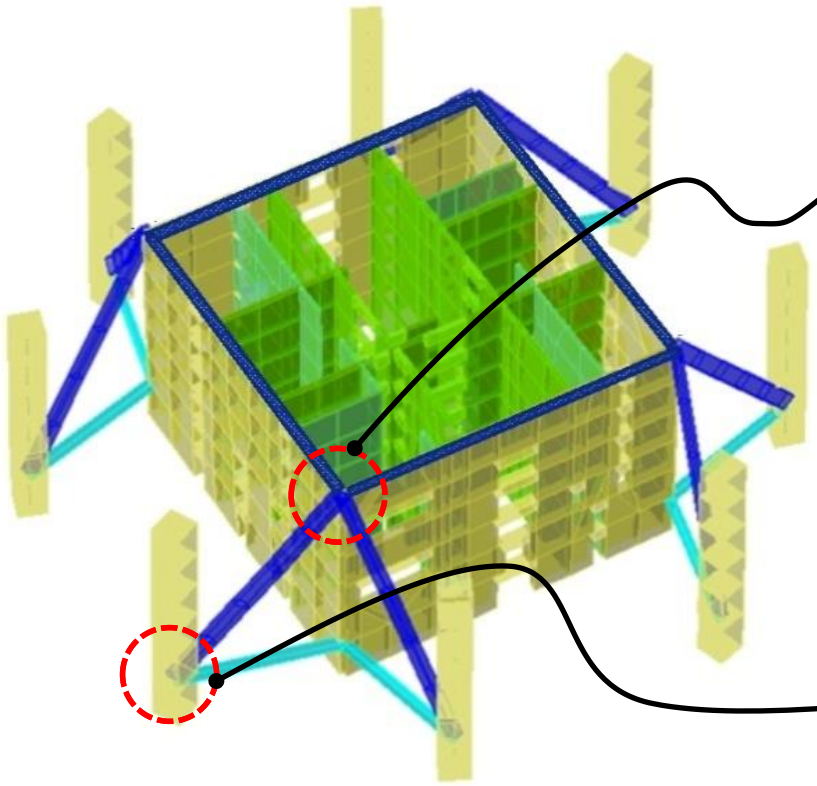


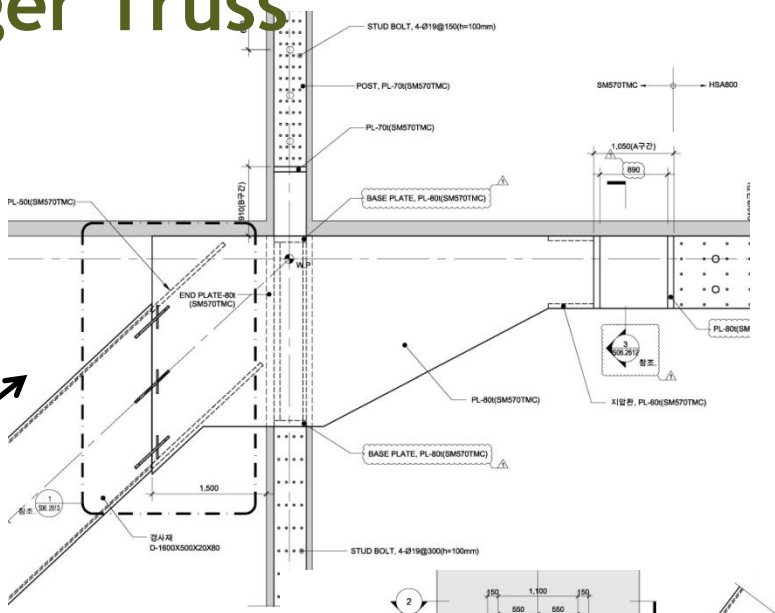


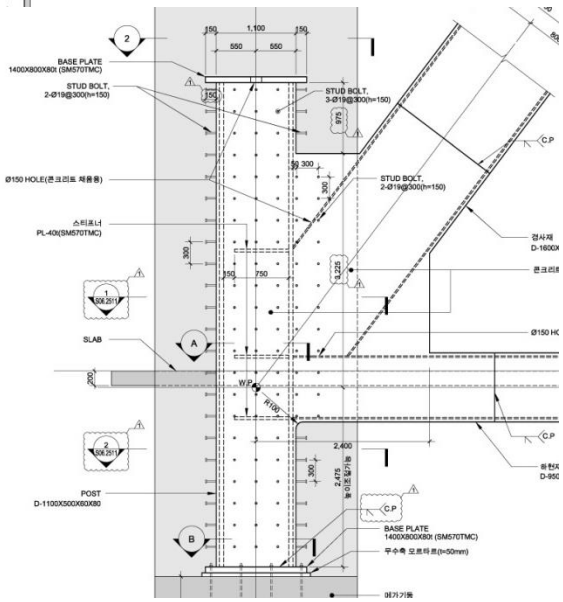


Mega Column

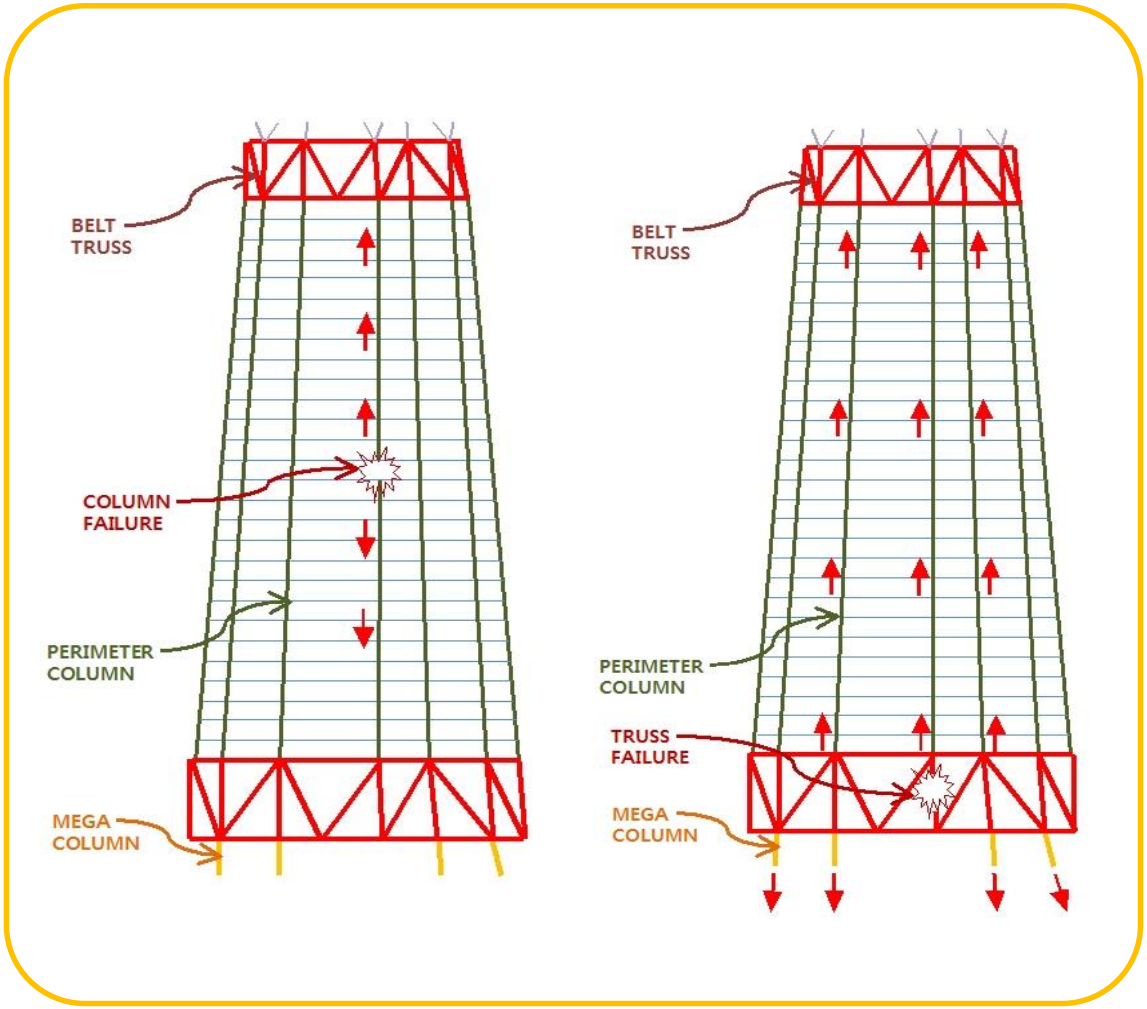
Outrigger Truss



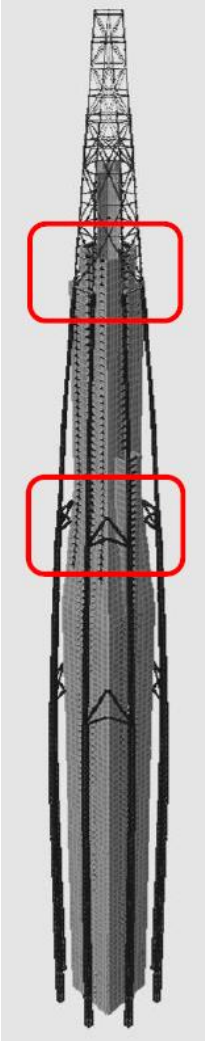




Belt Truss

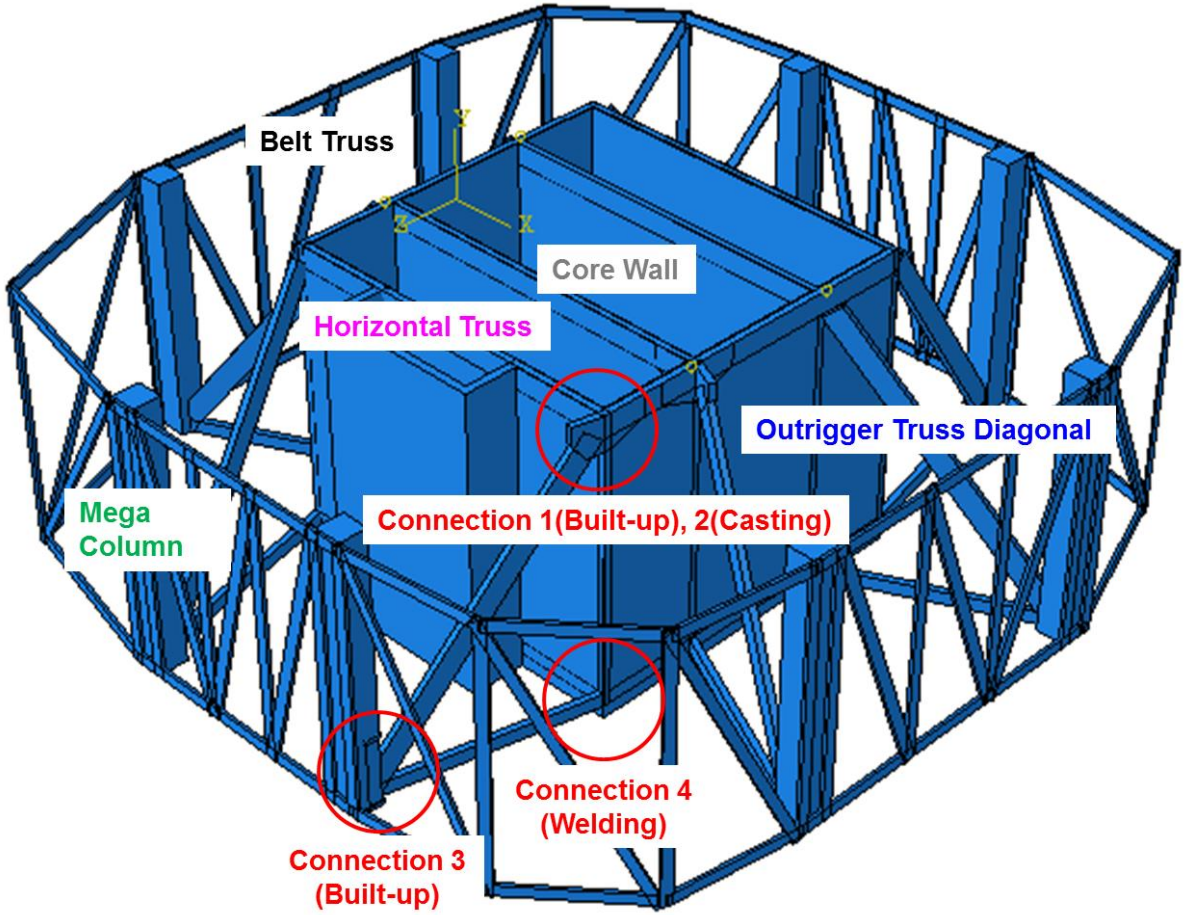

BELT TRUSS
COLUMN FAILURE
PERIMETER COLUMN
MEGA COLUMN
BELT TRUSS
PERIMETER COLUMN
TRUSS FAILURE
MEGA COLUMN

Belt Truss

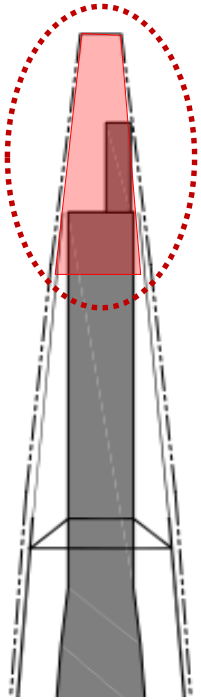


104 ~ 107F
: Belt truss

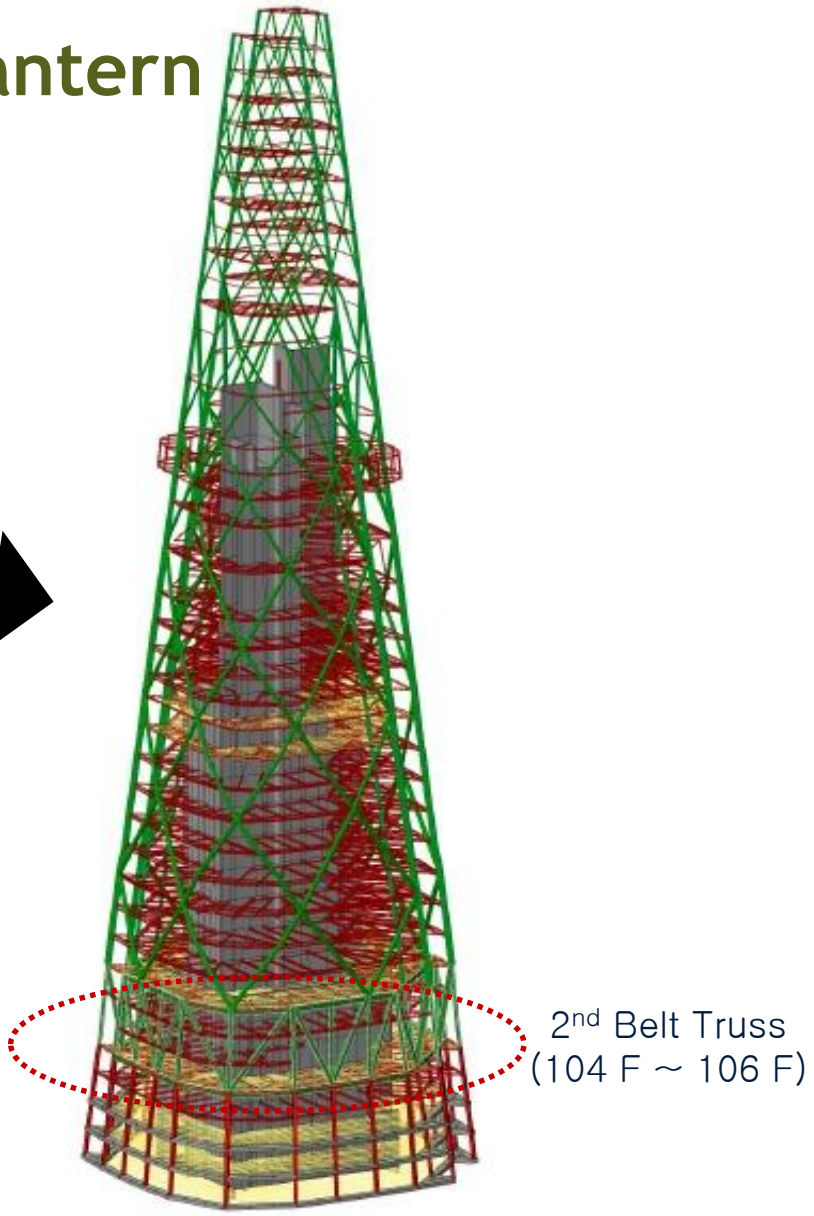
72 ~ 76F
: Outrigger
+ Belt truss



Lantern



107F
~TOP

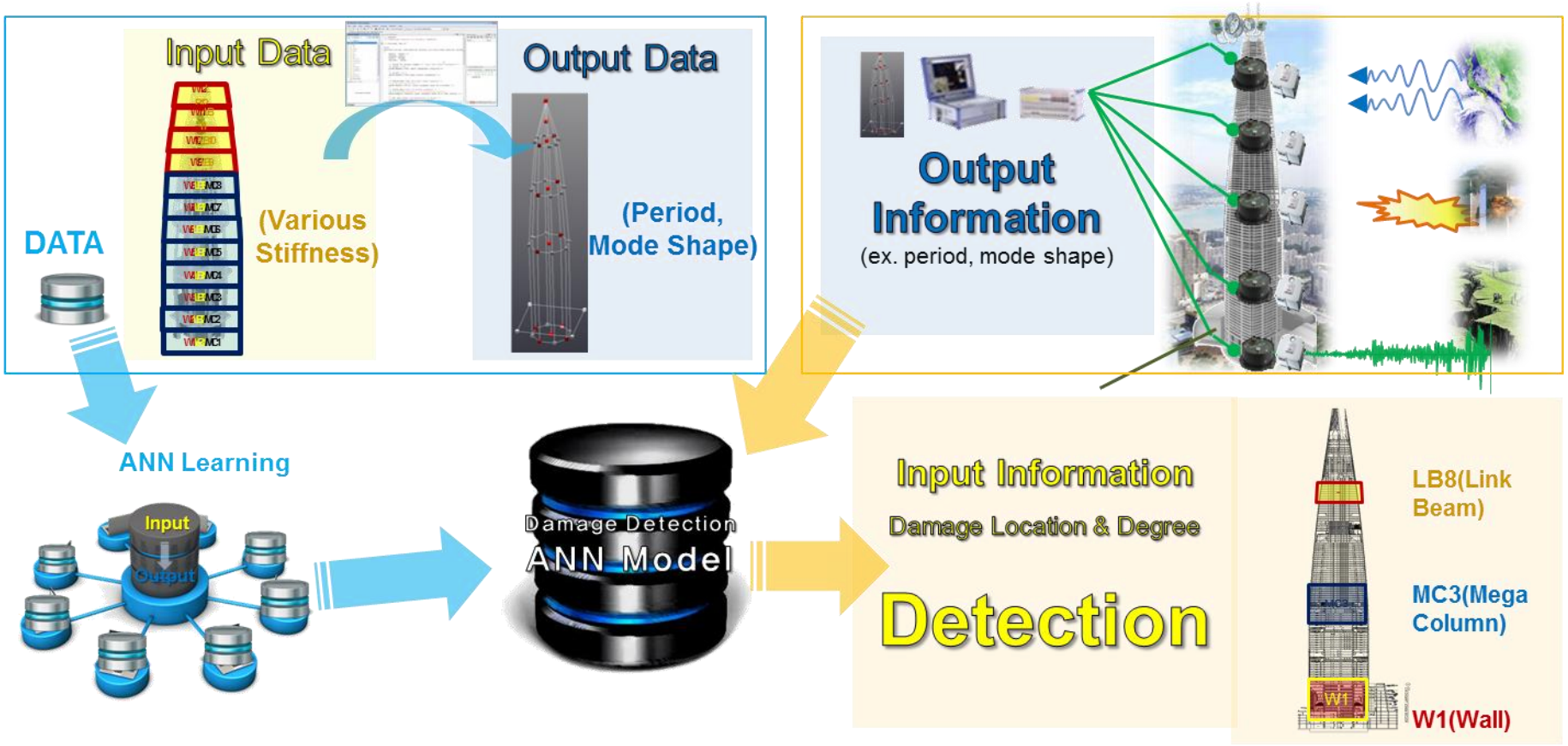


[Lantern: Bracing Elevation]

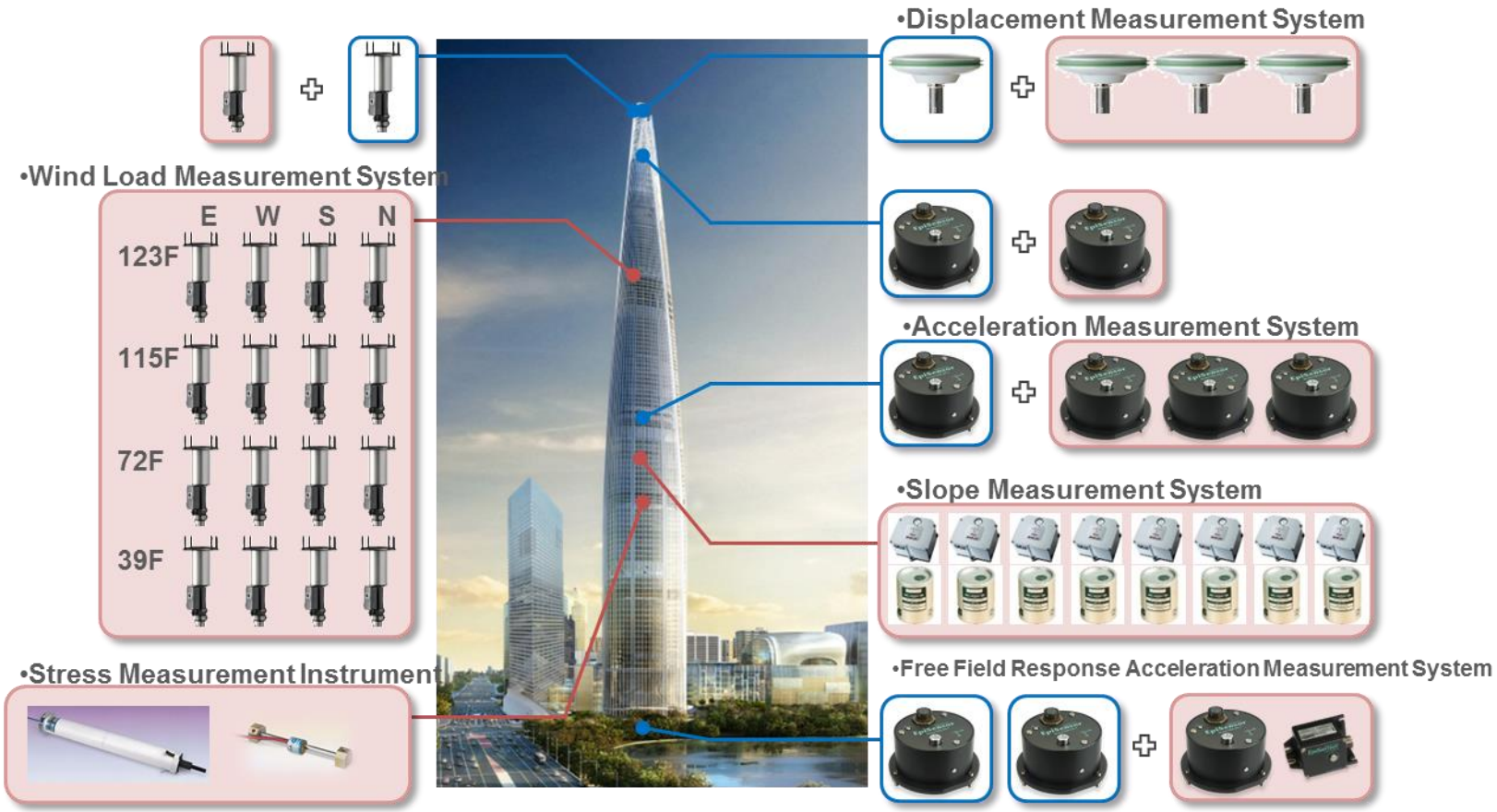
Lantern

Lantern

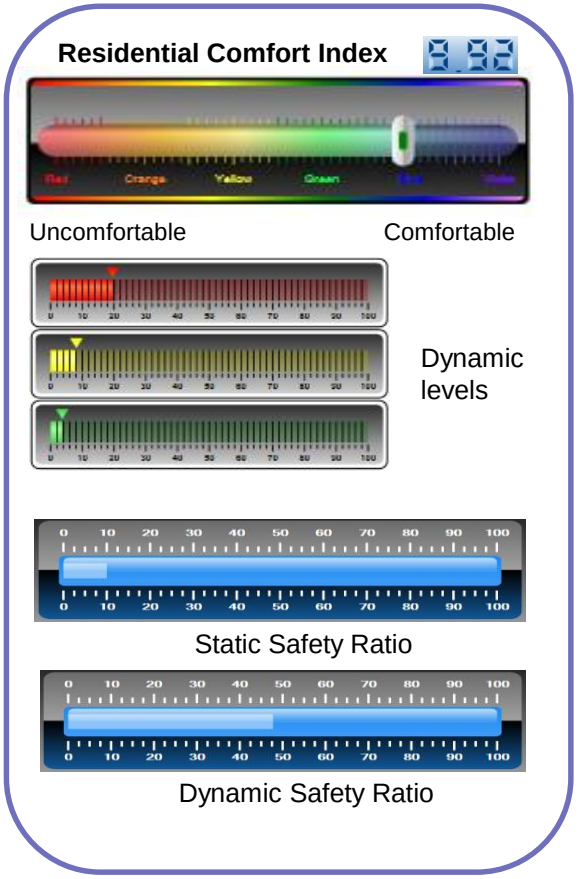
Structural Health Monitoring System

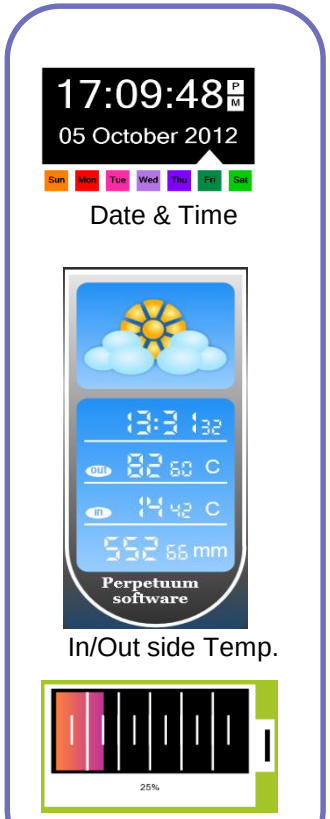


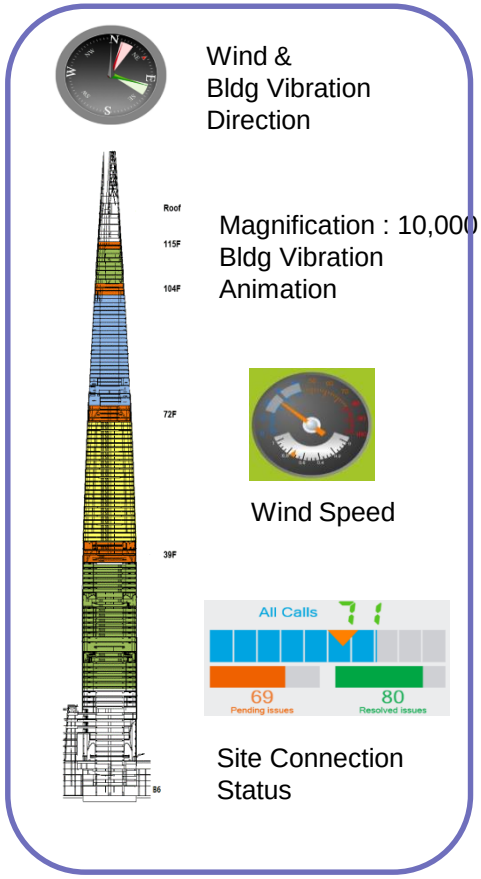
Structural Health Monitoring System



Structural Health Monitoring System

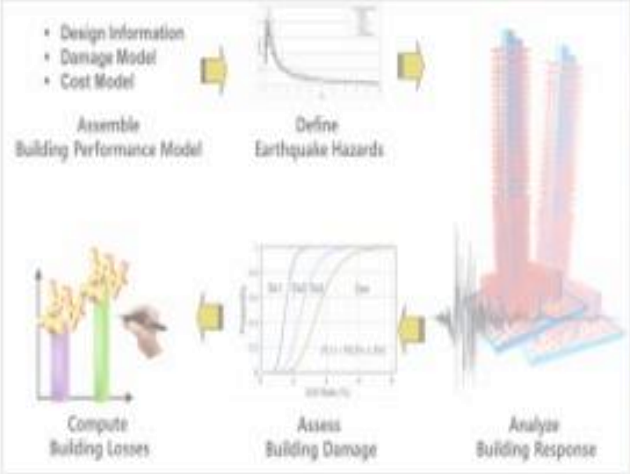


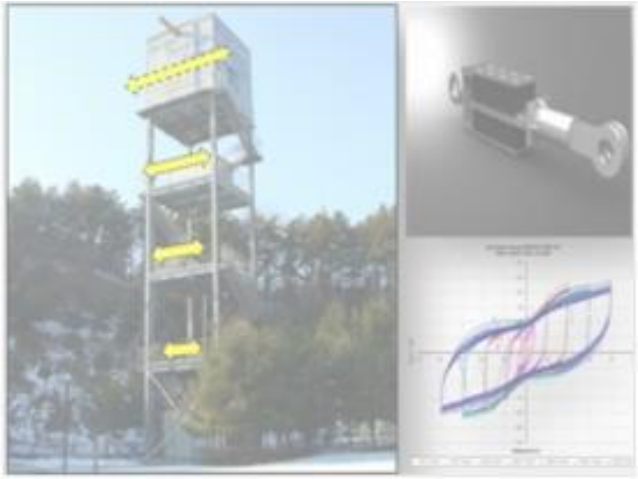


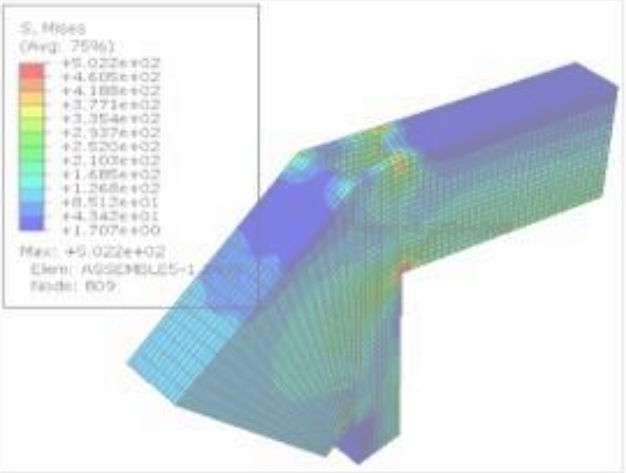


Thank You!

PBD







FEA