Design and Construction of High-Rise Buildings with Seismic Isolation System in Indonesia

Ir. Davy Sukamta

Principal of Davy Sukamta & Partners

Experiences

- Principal of Davy Sukamta & Partners
- Past President of HAKI (1999 -2011, 2014-2017)
- Member of advisory team of DKI Jakarta building construction (TABG)

Ir. Davy Sukamta has designed many tall buildings and deep basement structures in his 40 years career, among others the Plaza Indonesia Extension (48-story with 5-level basement) which applied Up-down construction method and saved 11 months of construction time, and Indonesia-1 Tower (303-meter high 63-story with 7-level basement), the first super-tall building fully designed by Indonesian engineers from conceptual design to working drawings and site supervision.
He has authored many papers, many of which were presented in international forums such He has authored many papers, many of which were presented in international forums . His expertise is in seismic design of tall buildings including seismic protective system such as seismic isolation.

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Design & Construction of High-rise Buildings With Seismic Isolation System: Indonesian Experience

Davy Sukamta
Immediate Past President, HAKI
Principal, Davy Sukamta & Partners

Davy Sukamta is the founding principal of Davy Sukamta&Partners – Structural Engineers, based in Jakarta. He is the immediate past president of Indonesian Society of Civil and Structural Engineers (HAKI), serving for five terms.

Graduated from the Catholic University of Parahyangan Bandung in 1981, he has designed more than 300 projects, mostly high-rise buildings with deep basement – among others the 63-story 303 meter-tall Indonesia-1 with 7-level basement structure, currently the first and only supertall building fully designed by Indonesian firm from the conceptual to working drawing phase.

26 7

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He has designed three high-rise buildings with seismic isolation system in Jakarta.

EQ FACTS

Each Year

500,000 earthquakes recorded

104,000 earthquakes felt by people

100 earthquakes causing damage

Earthquake with Most Fatalities

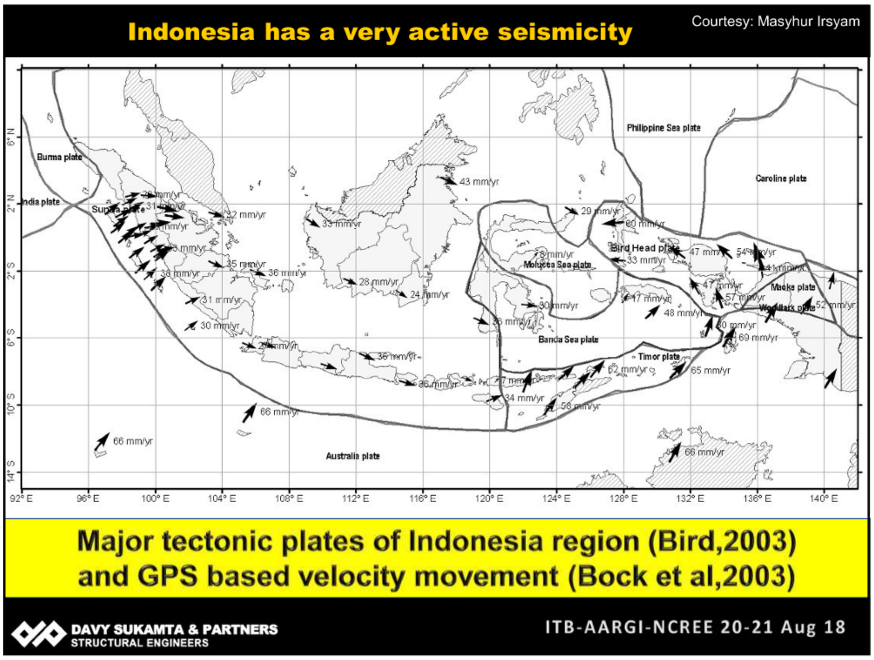
Year 1556, China, 830,000 fatalities
Year 2004, Aceh, 227,898 fatalities
Year 2010, Haiti, 316,000 fatalities

Biggest Eartquakes in History

Chile, 1960, Mw = 9.5

Alaska, 1964, Mw = 9.2

Aceh, 26 December 2004, Mw =9.1


Indonesia has a very active seismicity
Courtesy: Masyhur Irsyam
Burma plate
India plate
Sunda plate
Philippine Sea plate
Caroline plate
Molucca Sea plate
Bird Head plate
Maoke plate
Woodlark plate
Banda Sea plate
Timor plate
Australia plate
Major tectonic plates of Indonesia region (Bird,2003) and GPS based velocity movement (Bock et al,2003)
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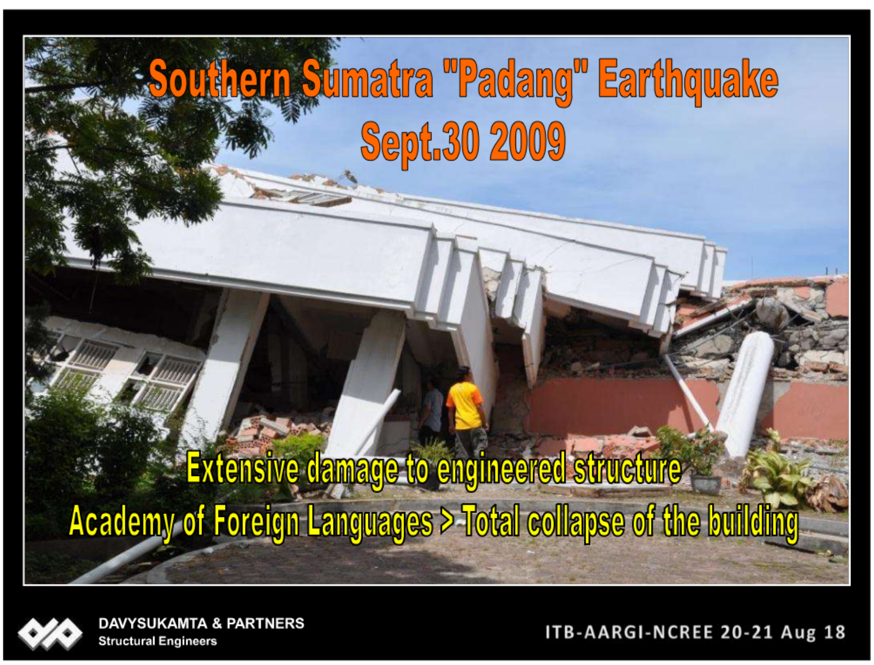
Southern Sumatra "Padang" Earthquake
Sept.30 2009
Extensive damage to engineered structure
Academy of Foreign Languages > Total collapse of the building
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Earthquakes can be Catastrophic and Very Expensive

- Loma Prieta 1989 – $7 Billion
  - $450 Million per Second
- Northridge 1994 - $30 Billion
  - $2 billion per second!
- Kobe 1995 - $150 - $200 Billion
  - $7.5 billion per second!!

Tokohu 2011 - $360 Billion

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SEISMIC PROTECTION SYSTEMS

Seismic resistant design, fixed-base structure

Vibration controlled structure (with dampers)

Seismically isolated structure

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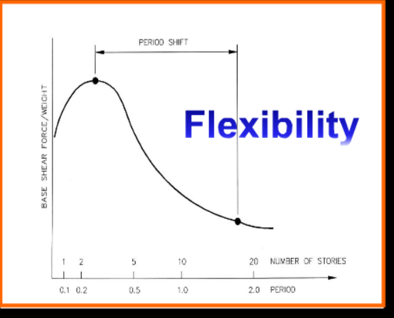
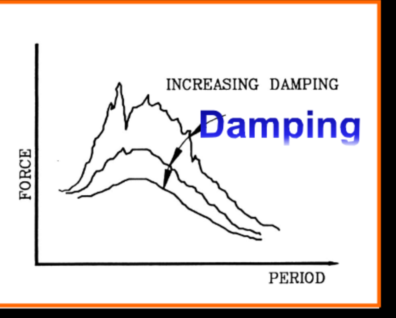
Fundamental principle of base isolation: modify the response of the building so that the ground can move below the buildings without transmitting these motion into the building.

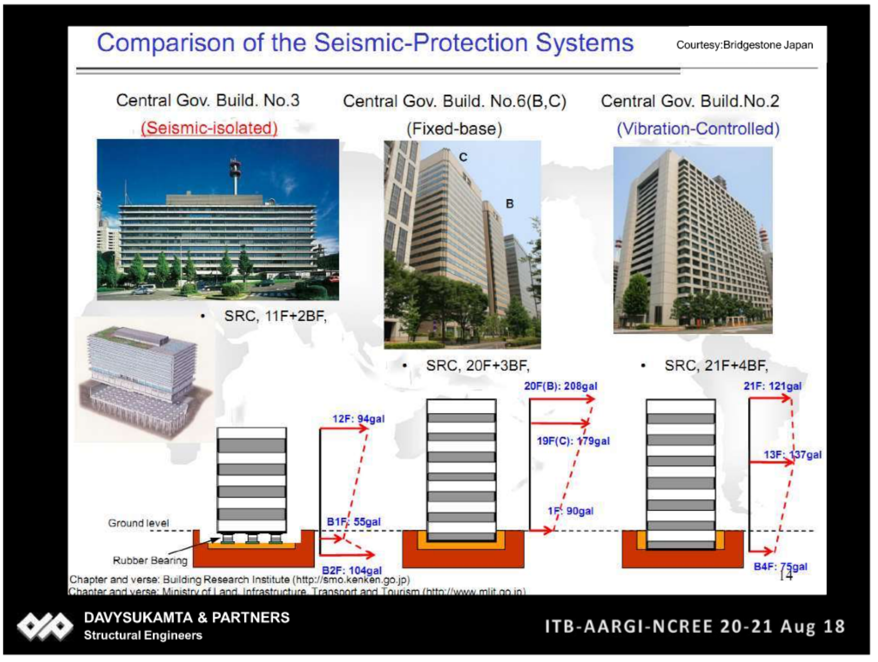




Principle of Base Isolation System

General Philosophy of SNI 1726:2012 Building Code Provision

- No specific isolation systems are described
- All isolation systems must:
  - Remain stable at the required displacement
  - Provide increasing resistance with increasing displacement
  - Have non-degrading properties under repeated cyclic loading
  - Have quantifiable engineering parameters


Comparison of the Seismic-Protection Systems
Courtesy:Bridgestone Japan
Central Gov. Build. No.3
(Seismic-isolated)
Central Gov. Build. No.6(B,C)
(Fixed-base)
Central Gov. Build.No.2
(Vibration-Controlled)
C
B
• SRC, 11F+2BF,
• SRC, 20F+3BF,
• SRC, 21F+4BF,
12F: 94gal
B1F: 55gal
B2F: 104gal
20F(B): 208gal
19F(C): 179gal
1F: 90gal
21F: 121gal
13F: 137gal
B4F: 75gal
Ground level
Rubber Bearing
Chapter and verse: Building Research Institute (http://smo.kenken.go.jp)
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Designed by DSP in 2009
Designed by DSP in 2013
The First Seismically Isolated High-rise Building in S.E.Asia: Gudang Garam Tower 25-story
The Second Seismically Isolated High-rise Building in S.E.Asia: Puri Matahari 27-story
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Design and Permit Process for Gudang Garam Tower
Aug 2010 – Jan 2011

Code: SNI-1726-2002 > UBC-1977 ?

- No provision for seismically isolated structure

Code: SNI-1726:2012 > ASCE 7-10

- On progress

Extensive reviews and interaction between the consultant and the building authorities in Jakarta led to a building permit being issued for this first-of-its-kind project in the city.

ASCE 7-10 Chapter 17

General Design Approach

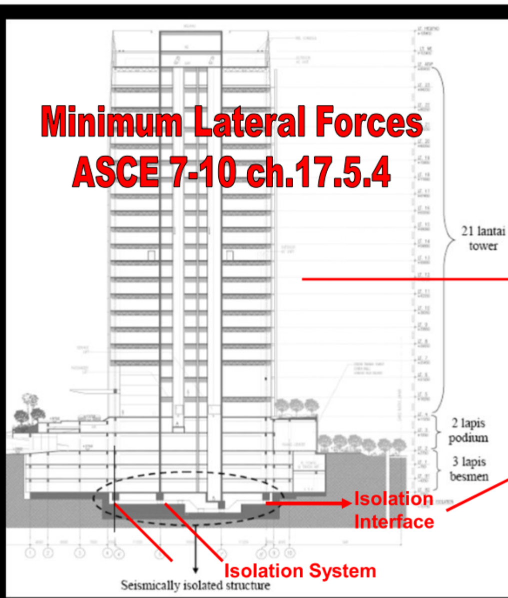
Two-Level Design: DBE & MCE_R

Superstructure Design

DBE = 2/3MCE
Loads may be reduced by seismic reduction factor R
R ≤ 2 allowing limited inelastic response

Isolation System Design (and Testing)

MCE_R
1%/50 yr = 2475-yr return period + fragility factor
No seismic reduction factor



Two-Level Design

Level 1: DBE

$$V_S = \frac{V_b}{R1}$$

Level 2: MCE$_R$

$$V_b = k_{D\max} D_D$$

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17.2 General Design Requirements

17.2.1: Importance Factor I_C= 1.0 (always)

17.2.3 Configuration → regular or irregular structure

17.2.4 Isolation System

17.2.4.1 Environmental Conditions

In addition to the requirements for vertical and lateral loads induced by wind and earthquake, the isolation system shall provide for other environmental conditions including aging effects, creep, fatigue, operating temperature, and exposure to moisture or damaging substances.

→ *Stiffness + 20%*
Mean value stiffness
Stiffness - 20%

17.2.4.2 Wind Forces

Isolated structures shall resist design wind loads at all levels above the isolation interface. At the isolation interface, a wind-restraint system shall be provided to limit lateral displacement in the isolation system to a value equal to that required between floors of the structure above the isolation interface in accordance with Section 17.5.6.

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17.2.4.4 Lateral Restoring Force

The isolation system shall be configured to produce a restoring force such that the lateral force at the total design displacement is at least 0.025*W* greater than the lateral force at 50 percent of the total design displacement.

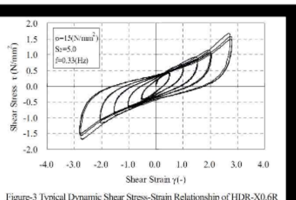

Figure-3 Typical Dynamic Shear Stress-Strain Relationship of HDR-X0.6R

a. $K_{eff,D} \geq 1/3\ K_{eff,0.2D}$

b. $V_{b,D} \geq V_{b,0.5D} + 0.025\ W$

17.2.4.6 Vertical-Load Stability

ASCE 7-10 ch.17.2.4.6 :
Design vertical load shall be computed using load combination
$(1.2 + 0.2S_{MS})\ D + \rho Q_E + L + 0.2S$
$(0.9\ - 0.2S_{MS})\ D + \rho Q_E + 1.6H$

17.2.4.7 Overturning **SF≥1.0**

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ASCE 7-10

Ch.17.4 DESIGN METHODS / Analysis Procedures

Equivalent Lateral Force Procedures

Static Analysis Ch.17.4.1

Dynamic Analysis Ch.17.4.2

Used for Preliminary design

Response Spectrum Analysis

Ch.17.4.2.1

Used for Final design

Time History Analysis

Ch.17.4.2.2

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17.3 Ground Motion for Isolated Systems

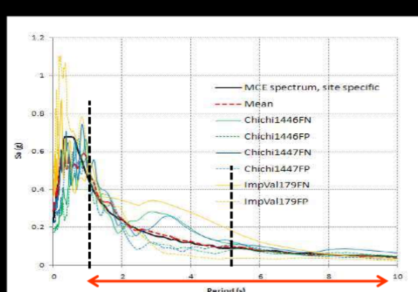
17.3.1 Design Spectra

- Site-specific GM procedures are permitted to be used
- For Site Class F sites, perform according to section 21.1 *Site response Analysis*
- For sites with S1>0.6, perform acording to section 21.2 *MCE_R GM Hazard Analysis*
- If site-specific GM is not used, use established Design Response Spectrum

ASCE 7-10 Chapter 21:
Site-Specific GM Procedures
for Seismic Design

- This procedure was adopted for the GG & Matahari Tower
- DBE & MCE level were developed

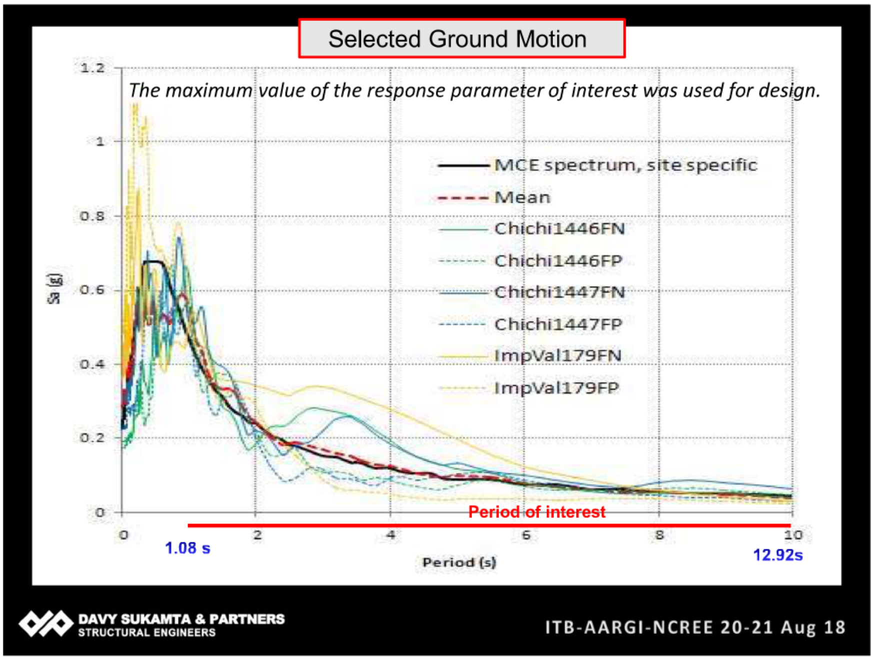
Ground Motion Histories for Gudang Garam Tower



$0.5T_D$ *Period of Interest* $1.25T_M$

Although RSA is permitted to be used for the case of this symmetrical tower, we have adopted the response-history procedure for the final design of GGT

Three pairs of motion were developed to match the target spectra in the period range from 0.5TD to 1.25TM


Selected Ground Motion
The maximum value of the response parameter of interest was used for design.
MCE spectrum, site specific
Mean
Chichi1446FN
Chichi1446FP
Chichi1447FN
Chichi1447FP
ImpVal179FN
ImpVal179FP
Sa (g)
Period (s)
Period of interest
1.08 s
12.92s
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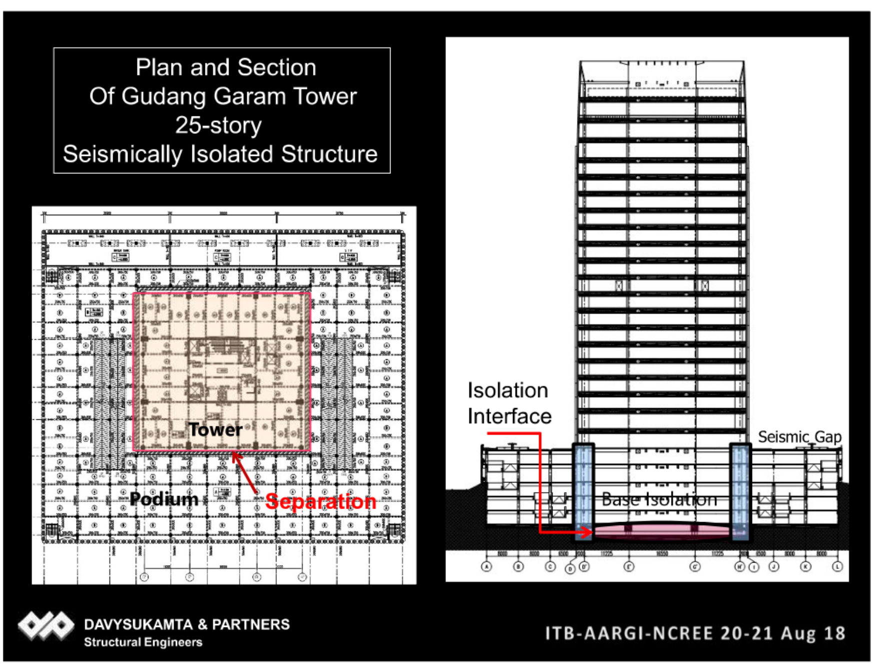
Plan and Section
Of Gudang Garam Tower
25-story
Seismically Isolated Structure
Tower
Podium
Separation
Isolation
Interface
Seismic Gap
Base Isolation
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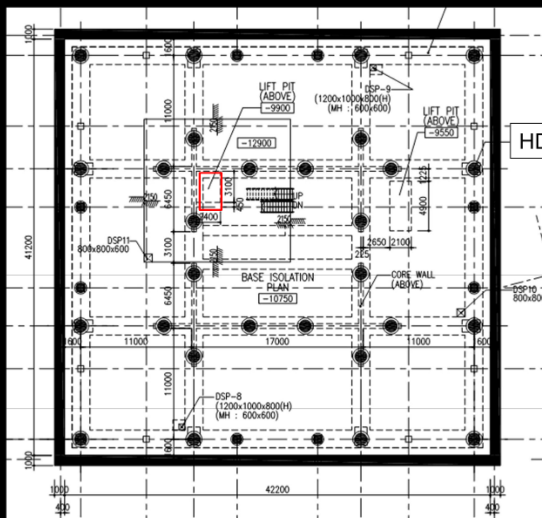
Plan of Base Isolators (High Damping Rubber Bearings)



HDRB

16 HDRB HH130-6R
24 HDRB HH150-6R

Lateral Resistant System: RC Corewall+Outrigger and Seismic Steel Moment Frame, with HDRBs

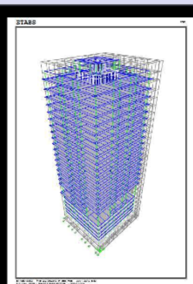
17.6.2.1 Isolation System

ASCE 7-10

17.6.2 Modeling

17.6.2.1 Isolation System. The isolation system shall be modeled using deformational characteristics developed and verified by test in accordance with the requirements of Section 17.5.2. The isolation system shall be modeled with sufficient detail to

a. Account for the spatial distribution of isolator units.
b. Calculate translation, in both horizontal directions, and torsion of the structure above the isolation interface considering the most disadvantageous location of eccentric mass.
c. Assess overturning/uplift forces on individual isolator units.
d. Account for the effects of vertical load, bilateral load, and/or the rate of loading if the force-deflection properties of the isolation system are dependent on one or more of these attributes.



17.6.2.2 Isolated Structure

17.6.2.2 Isolated Structure.

17.6.2.2.1 Forces and Displacements in Key Elements. The maximum displacement of each floor and design forces and displacements in elements of the seismic force–resisting system are permitted to be calculated using a linear elastic model of the isolated structure provided that

1. Stiffness properties assumed for the nonlinear components of the isolation system are based on the maximum effective stiffness of the isolation system.
2. All elements of the seismic force–resisting system of the structure above the isolation system remain elastic for the design earthquake.

Seismic force–resisting systems with elastic elements include, but are not limited to, irregular structural systems designed for a lateral force not less than 100 percent of V_s and regular structural systems designed for a lateral force not less than 80 percent of V_s, where V_s is determined in accordance with Section 17.5.4.2.

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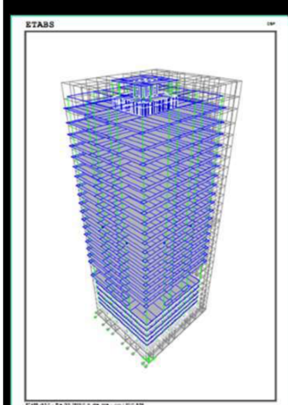
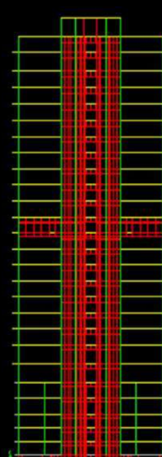
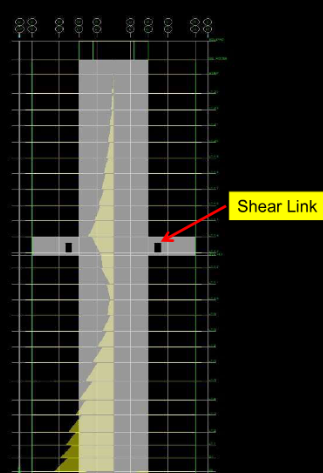
Analysis - Modeling

Gudang Garam Tower

ETABS Model







BM Diagram of Core Wall

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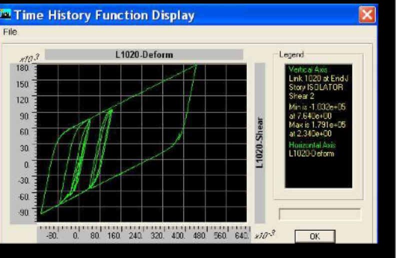
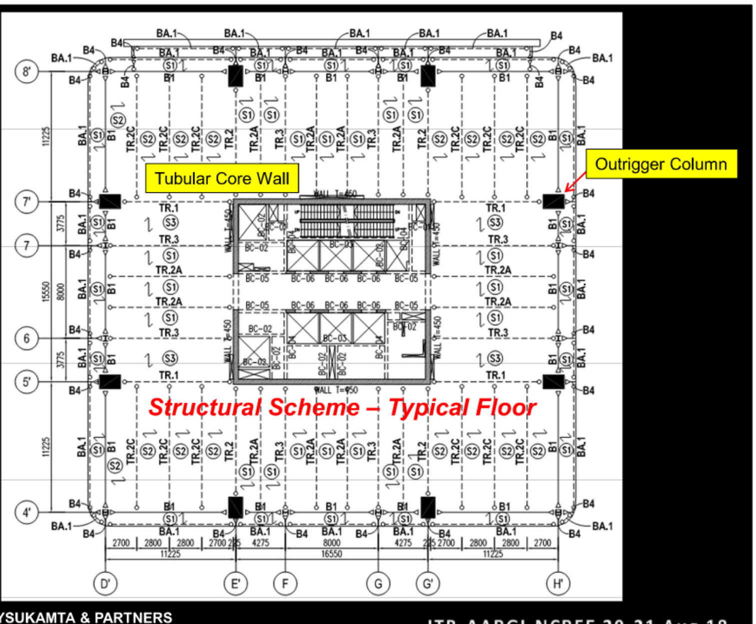
RC Core wall with Outrigger

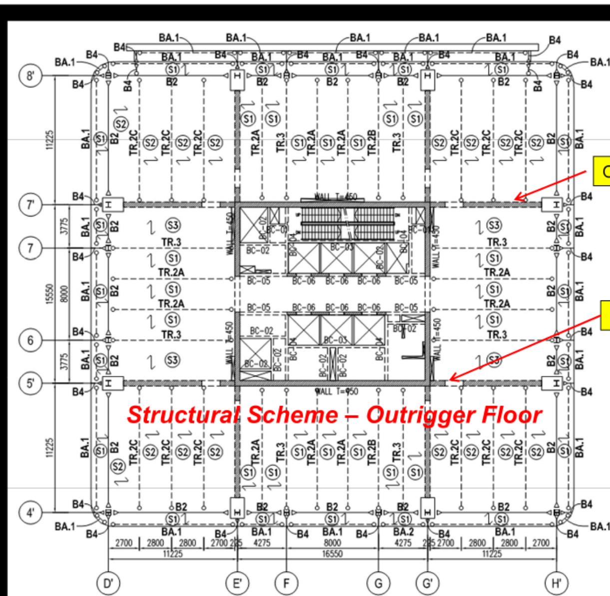
R_1 Factor = 3/8 R

$1.0 \leq R1 \leq 2.0$



The isolation system shall be modeled using non-linear characteristics for the type of isolators being proposed for use, i.e. a bilinear biaxial (shear) hysteretic element with linear axial stiffness for elastomeric isolators.





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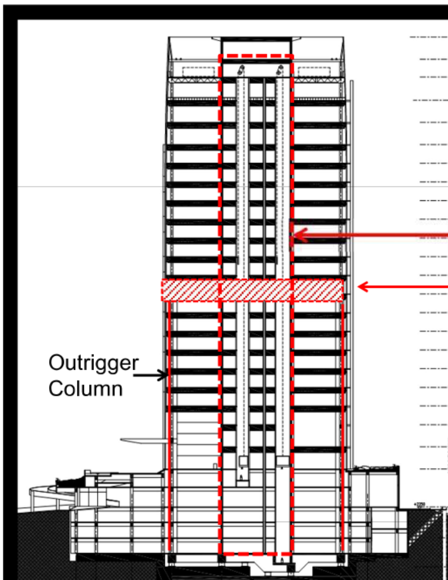

Seismically-isolated Structure

Nomor Ragam	Periode Getar (detik)	Faktor Partisipasi Mass (%) X-trans	Y-trans	Rz-rotn
1	4.233	0.00	99.05	0.00
2	4.160	99.20	0.00	0.18
3	3.454	0.18	0.00	99.81

Fixed-base Structure

Nomor Ragam	Periode Getar (detik)	Nomor Ragam	Periode Getar (detik)	Faktor Partisipasi Mass (%) X-trans	Y-trans	Rz-rotn
1	1.657	1	1.657	0.00	58.08	0.01
2	1.453	2	1.453	54.97	0.00	0.03
3	1.012	3	1.012	0.01	0.00	65.31

Dynamic Characteristic of
Based-Isolated vs Fixed-Base Structure
1.657 sec → 4.233 sec

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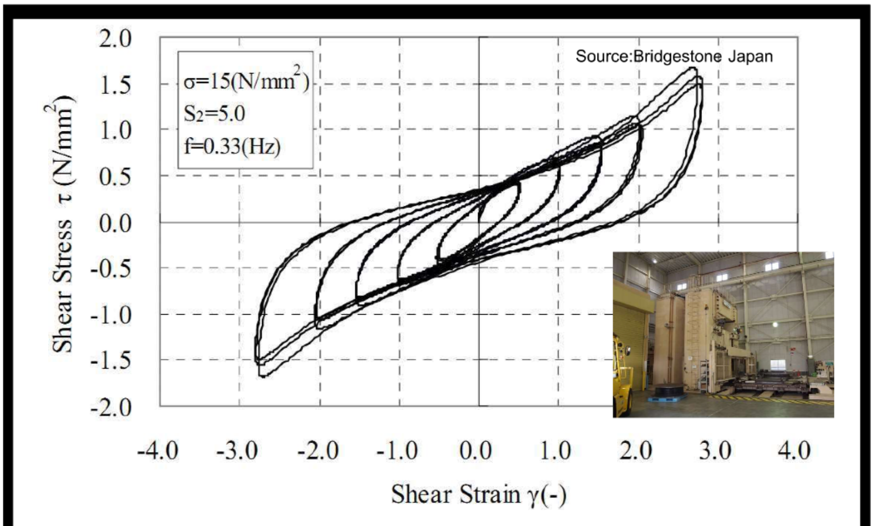


Typical Dynamic Shear Stress-Strain Relationship of HDR-X0.6R

Source: Bridgestone Japan

Properties of the isolators used in the design are related to shear strain

BRIDGESTONE

2. Horizontal Properties (Numerical Model)

□Principle

Shear stiffness 'K_{eq}', equivalent damping ratio 'H_{eq}' and ratio of characteristic strength to maximum shear force of a loop 'u' are given by the following equations (1) to (3).

Shear properties are defined at 3rd cycle of γ_0=1.0γ cyclic sinusoidal loading with frequency of 0.33 Hz. G_{eq}, H_{eq}, u_0 are expressed as functions of shear strain γ (=δ/H) as shown below.

$$K_{eq} = \frac{G_{eq} \cdot A}{n \cdot t_r} \quad (1)$$

$$H_{eq} = \frac{\Delta W}{(2 \cdot \pi \cdot K_{eq} \cdot X^2)} \quad (2)$$

$$u = \frac{Q_d}{(K_{eq} \cdot X)} \quad (3)$$

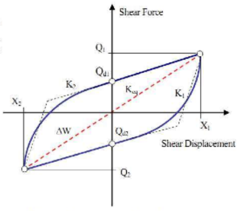
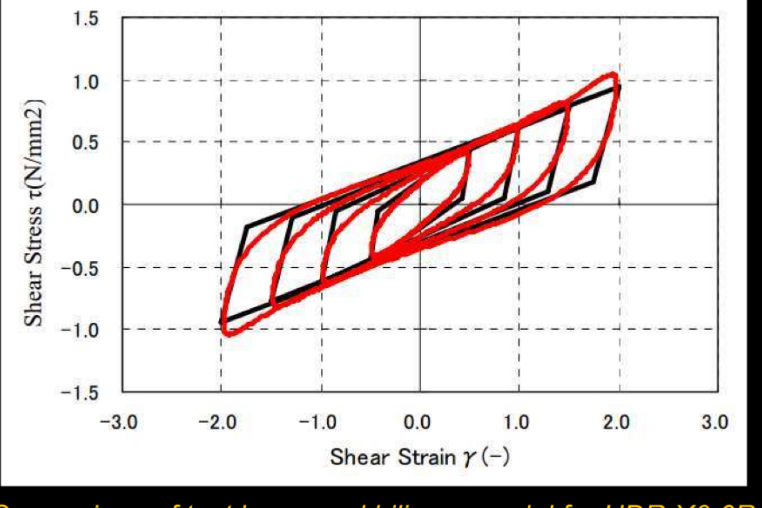


Figure-2 Determination of Shear Properties

Table-7 Design Function of High Damping Rubber Bearing

Compound	Properties at γ=100%	Function
X0.6R	G_{eq}=0.62 (N/mm²) H_{eq}=0.240 u_0=0.408	(10≦γ≦270%) $G_{eq}(\gamma) = G_{eq} \times (2.855 - 3.878\gamma + 2.903\gamma^2 - 1.016\gamma^3 + 0.1364\gamma^4)$ $H_{eq}(\gamma) = H_{eq} \times (0.9150 + 0.2364\gamma - 0.1804\gamma^2 + 0.02902\gamma^3)$ $u_0(\gamma) = u_0 \times (0.9028 + 0.2711\gamma - 0.2083\gamma^2 + 0.03421\gamma^3)$

Each bearing was tested in the manufacturer's lab



Comparison of test loops and bilinear model for HDR-X0.6R

Analysis - Modeling

Gudang Garam Tower

Building - Base Isolated Structure

Static Equivalent Lateral Force

	DBE			MCE	
Load for Isolated Structure	37147	ton	364412.1 kN	37147	ton
Gravity acc.	9.81			9.81	
Seismic Coef. C_v or S_{D1}	0.56			0.84	
Effective Damping	0.21			0.18	
B Factor	1.56			1.48	
Target Period, T_D	4.25	second		4.50	second
Coef. Reduction R_1	2.0			2.0	
the design displacement, D_D	0.38	m		0.63	m

$$D_D = \left(\frac{g}{4\pi^2}\right)\frac{S_D T_D}{B_D}$$

HDRB Properties - Bridgestone HDR DBE

Type	HH150x6R		HH130x6R
Total Rubber Thickness, Tr	250	mm	250
Design Displacement, D	380	mm	380
Diameter of HDR	1500	mm	1300
Area of HDR	1763800	mm^2	1324900
Design Strain	1.520		1.520
Shear Modulus @ design strain , G_{eq}	0.514	N/mm^2	0.514
Equivalen damping ratio, H_{eq}	0.230		0.230
Ratio characteristic strength to max. shear, U	0.389		0.389
Equivalent Shear Stiffness, K_{eq}	3625	N/mm	2723
Characteristic Strength, Q_d	536	kN	403
tan d /4	0.115		0.115
Initial Stiffness, K1	22248	N/mm	16712
Post-Yield Stiffness, K2	2214	N/mm	1663

W/ AXIAL DEPENDENCY

HH150x6R	HH130x6R
250	250
380	380
1500	1300
1763800	1324900
1.52	1.52
0.539	0.539
0.207	0.207
0.350	0.350
3806	2859
506	380
0.104	0.104
21405	16078
2473	1858

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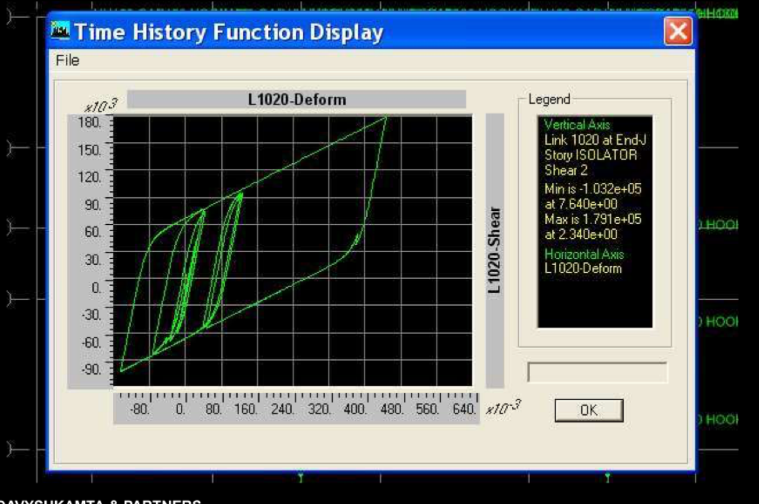
Analysis – Modeling

Gudang Garam Tower



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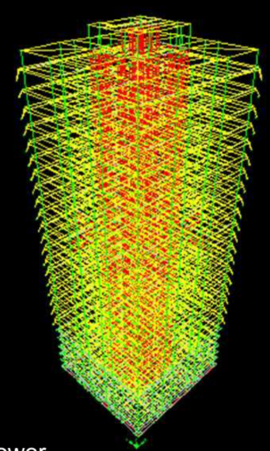
Gudang Garam Tower



RHA for base isolated tower

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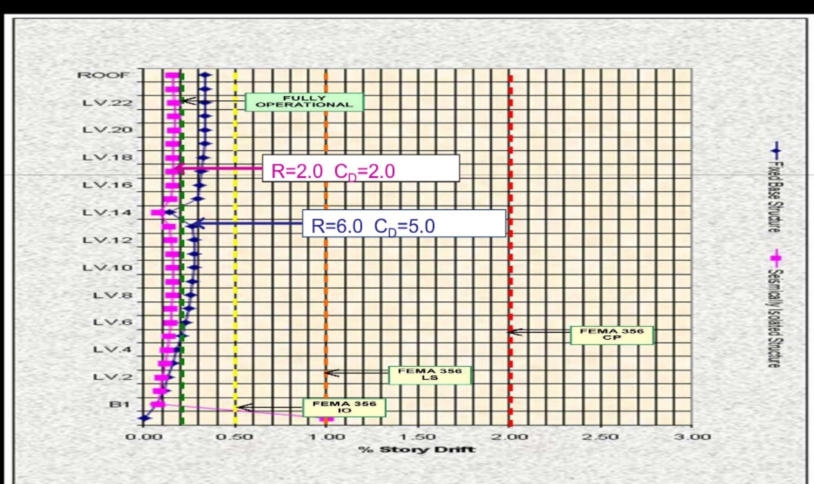
Building Performance



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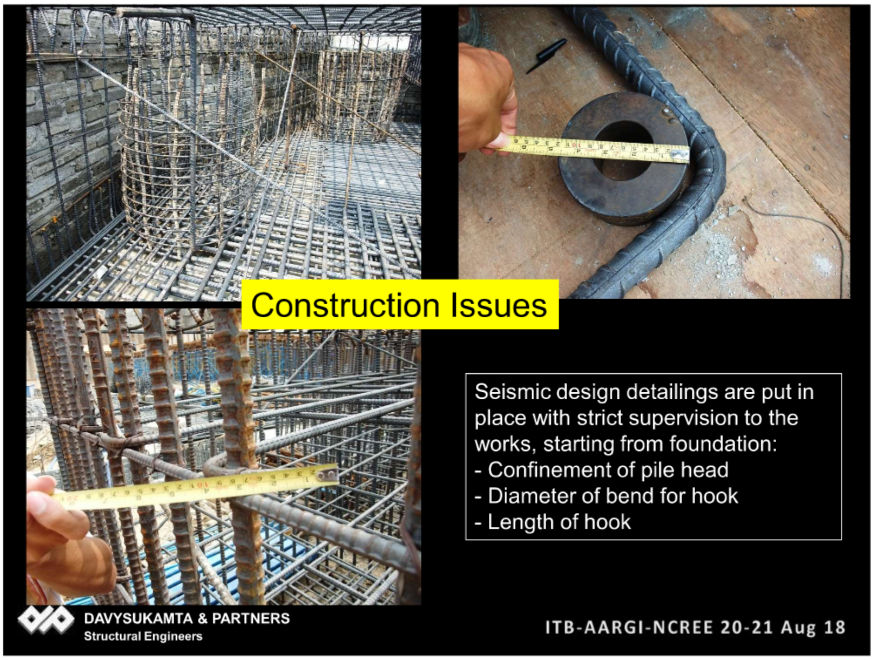
Construction Issues
Seismic design detailings are put in place with strict supervision to the works, starting from foundation:
- Confinement of pile head
- Diameter of bend for hook
- Length of hook
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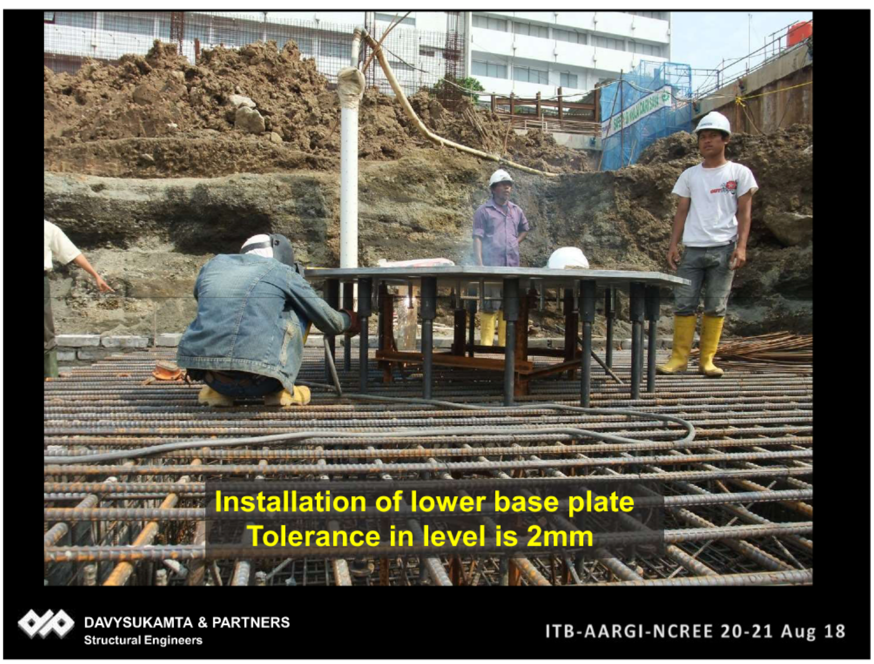
Installation of lower base plate
Tolerance in level is 2mm
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18


Base plates with long bolts and shear connector
DAVYSUKAMTA & PARTNERS
Structural Engineers
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Installation of upper base plate
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Structural Engineers
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Installation of coupling beam
With diagonal reinforcement
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Structural Engineers
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Erection of RC Core Wall
Erection of Steel Structure
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Structural Engineers
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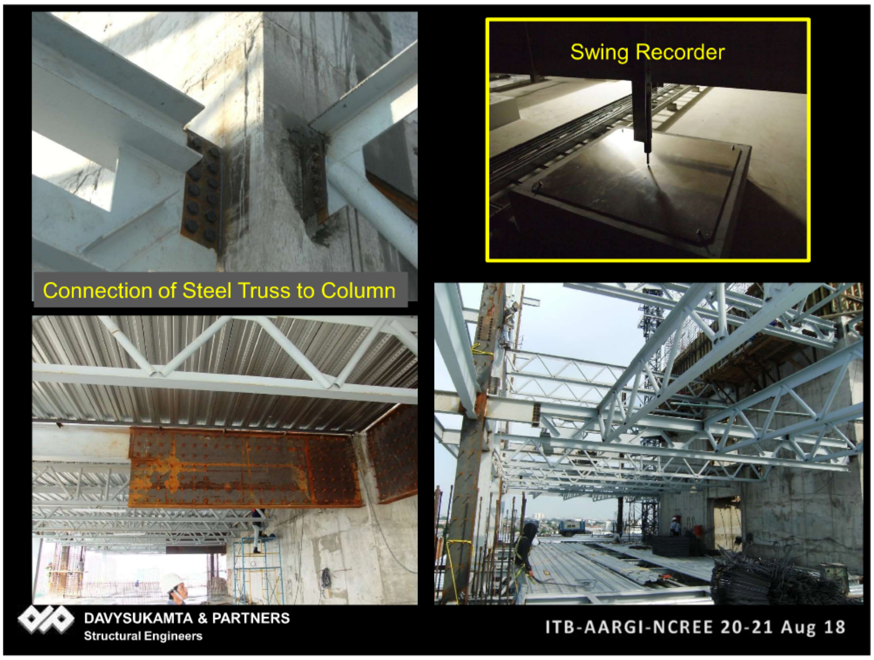
Swing Recorder
Connection of Steel Truss to Column
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Prequalified Moment Connection:
Reduced Beam Section
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Opening to facilitate the transportation of HDRBs
should they be replaced in the future
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Structural Engineers
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During Construction and Completed Project
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Structural Engineers
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4.2 Horizontal Clearance Measurement
Seismic Isolation Interface
Plumbing
P2F
Final Inspection Report
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18


Date
September 18, 2012
Project Name
Gudang Garam Project
Type
Completion Inspection
Object
Seismic Isolation Bearings
Content
Horizontal Displacement Measurement
Bridgestone Corporation
Horizontal Displacement Measurement
During Final Inspection
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18


Date
September 18, 2012
Project Name
Gudang Garam Project
Type
Completion Inspection
Object
Seismic Isolation Bearings
Content
Vertical Displacement Measurement
Bridgestone Corporation
Vertical Displacement Measurement
During Final Inspection
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18


Date
September 18, 2012
Project Name
Gudang Garam Project
Type
Completion Inspection
Object
Seismic Isolation Bearings
Content
Surface Temperature Measurement
Bridgestone Corporation
Surface Temperature Measurement
During Final Inspection
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Gap Measurement
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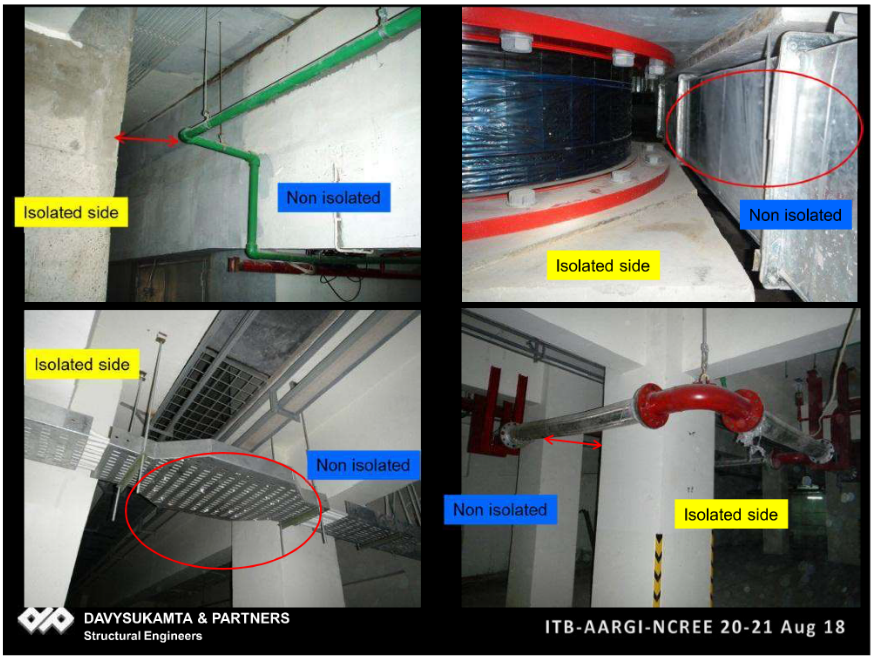
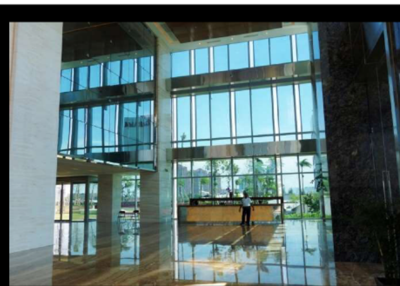
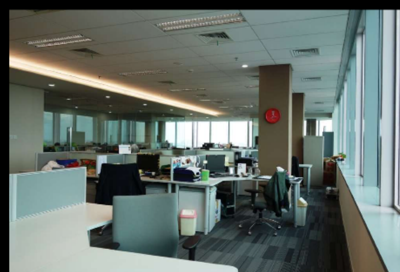

Isolated side
Non isolated
Non isolated
Isolated side
Isolated side
Non isolated
Non isolated
Isolated side
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18





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PURI MATAHARI TOWER JAKARTA

27-story
Base-isolated structure

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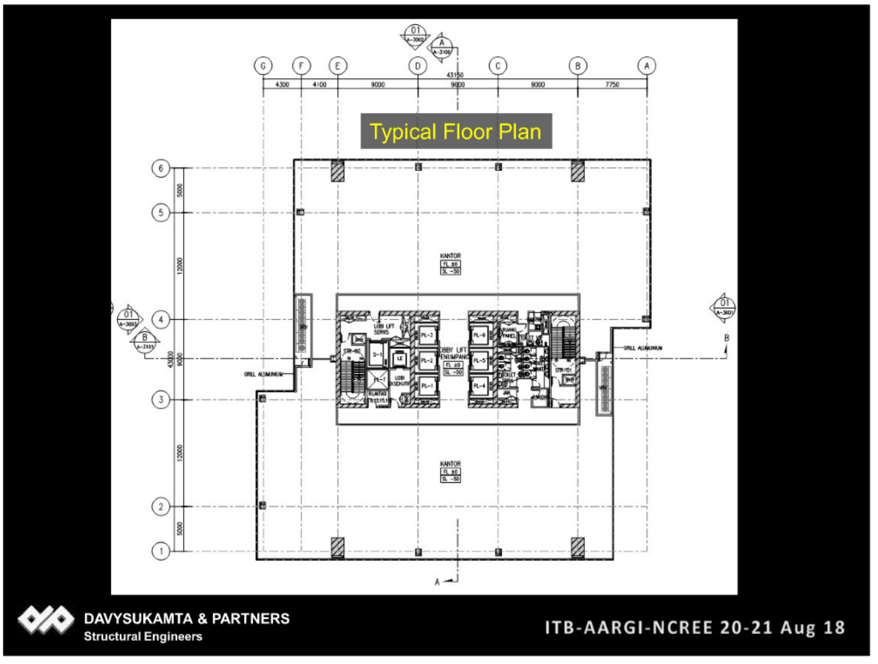
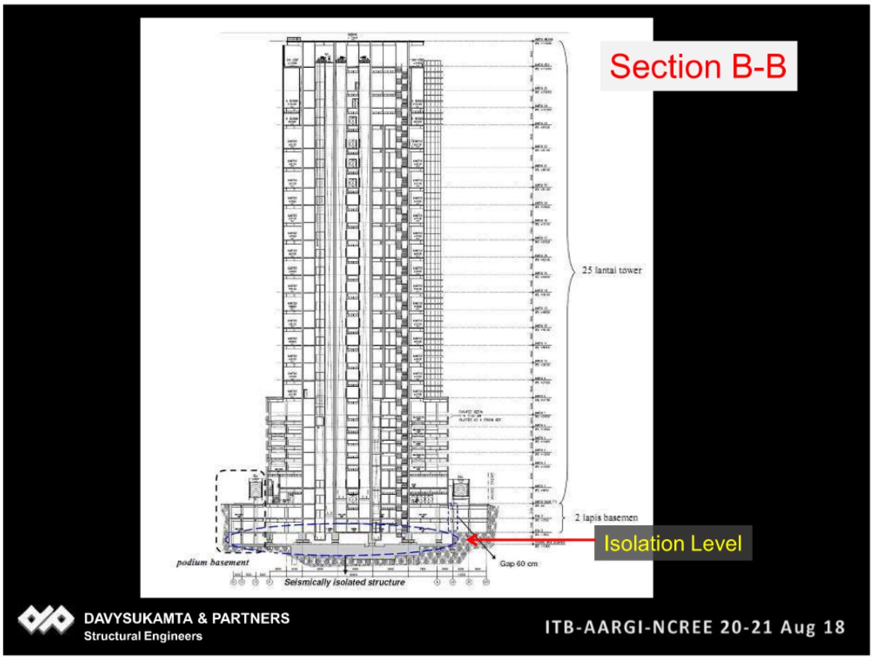
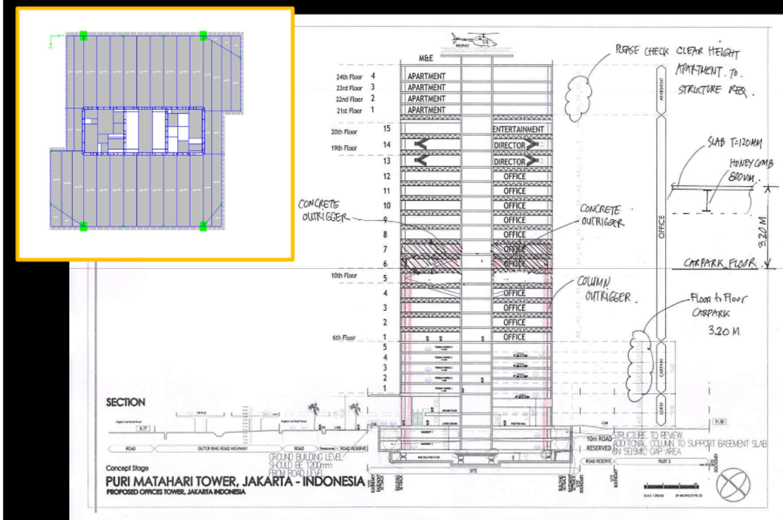
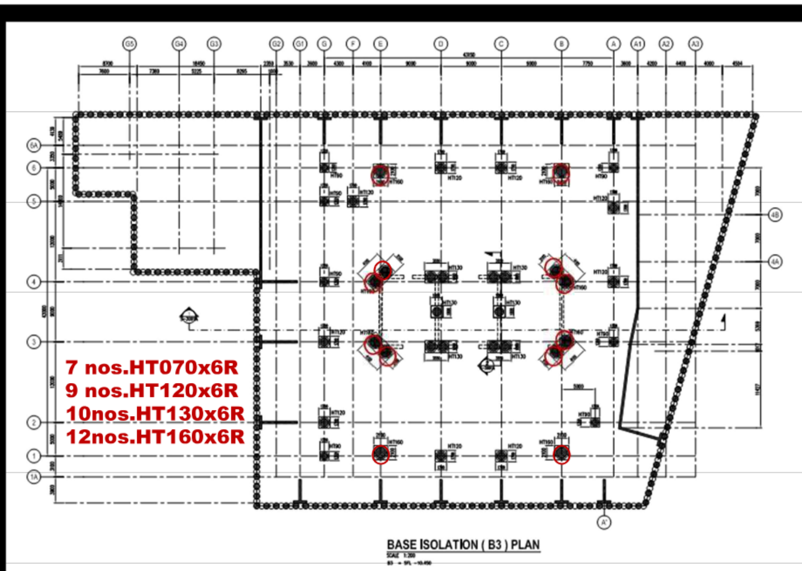

Typical Floor Plan
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18


Section B-B
25 lantai tower
2 lapis basemen
Isolation Level
podium basement
Gap 60 cm
Seismically isolated structure
DAVYSUKAMTA & PARTNERS
Structural Engineers
ITB-AARGI-NCREE 20-21 Aug 18

Section A-A

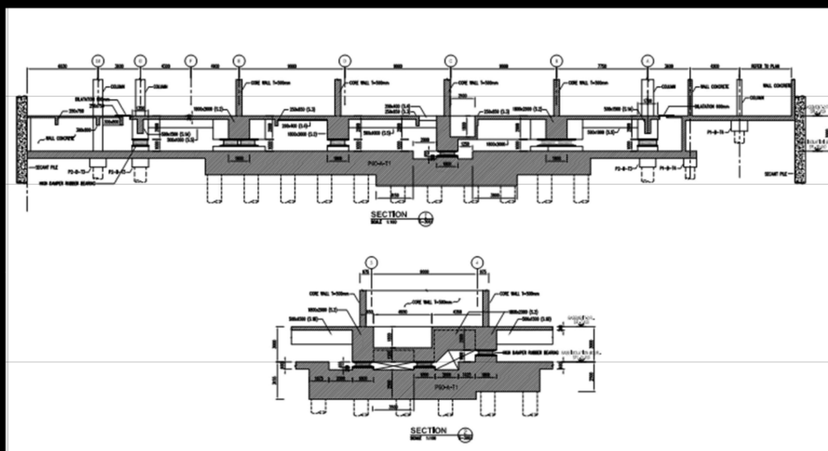


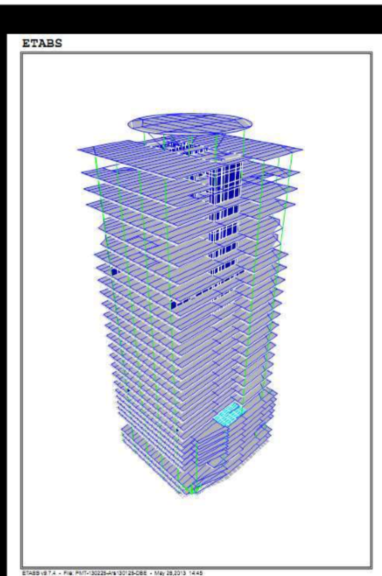
PLEASE CHECK CLEAR HEIGHT APARTMENT TO STRUCTURE REQ.
SLAB T=120MM
HONEYCOMB 600MM
3.20 M
CARPARK FLOOR
CONCRETE OUTRIGGER
CONCRETE OUTRIGGER
COLUMN OUTRIGGER
Floor to Floor CARPARK 3.20 M
M&E
APARTMENT
ENTERTAINMENT
DIRECTOR
OFFICE
24th Floor
23rd Floor
22nd Floor
21st Floor
20th Floor
19th Floor
10th Floor
6th Floor
SECTION
Concept Stage
PURI MATAHARI TOWER, JAKARTA - INDONESIA
PROPOSED OFFICES TOWER, JAKARTA INDONESIA
GROUND BUILDING LEVEL SHOULD BE 1200mm FROM ROAD LEVEL
STRUCTURE TO REVIEW ADDITIONAL COLUMN TO SUPPORT BASEMENT SLAB IN SEISMIC GAP AREA



7 nos.HT070x6R
9 nos.HT120x6R
10nos.HT130x6R
12nos.HT160x6R
BASE ISOLATION (B3) PLAN

Sections at Isolation Level





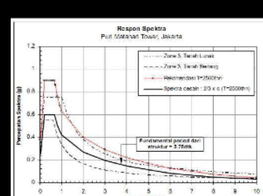
Base-isolated Structure

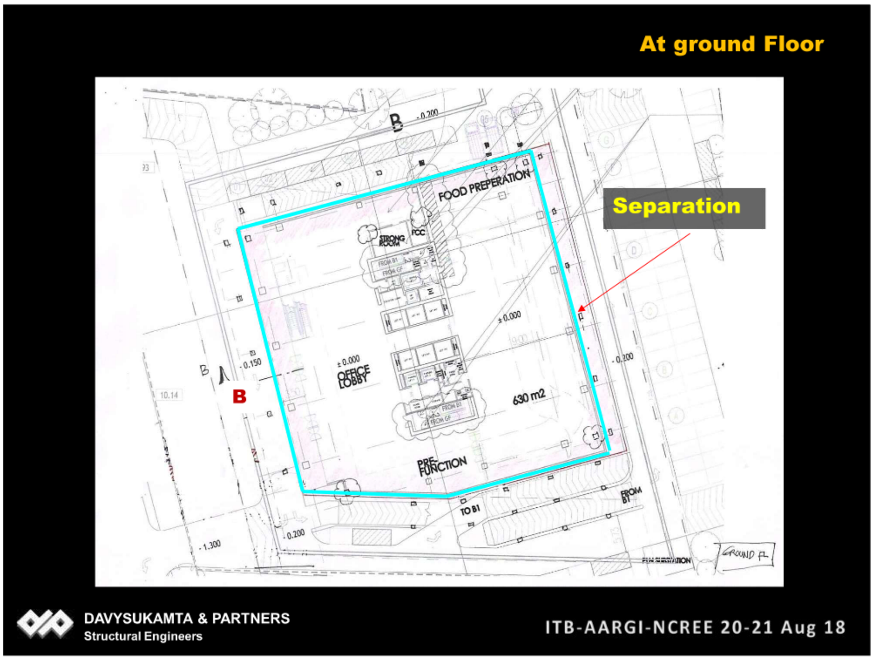
Nomor Ragam	Periode Getar (detik)	Faktor Partisipasi Massa (%)		
		X-trans	Y-trans	Rz-rotn
1	3.755	96.733	0.85	0.434
2	3.704	0.98	96.28	1.240
3	3.256	0.29	1.37	98.319

1.899sec ⟶ 3.755sec

Fixed-based Structure

Area	Mode	Periode (detik)	Modal Participating Mass Ratios (%Mass)		
			Ux-Trans	Uy-Trans	Rt-trans
Tower	1	1.899	57.90	0.07	0.00
	2	1.755	0.06	59.96	1.11
	3	1.308	0.01	0.50	65.13




At ground Floor
Separation
B
FOOD PREPERATION
OFFICE LOBBY
630 m2
PRE-FUNCTION
TO B1
FROM B1
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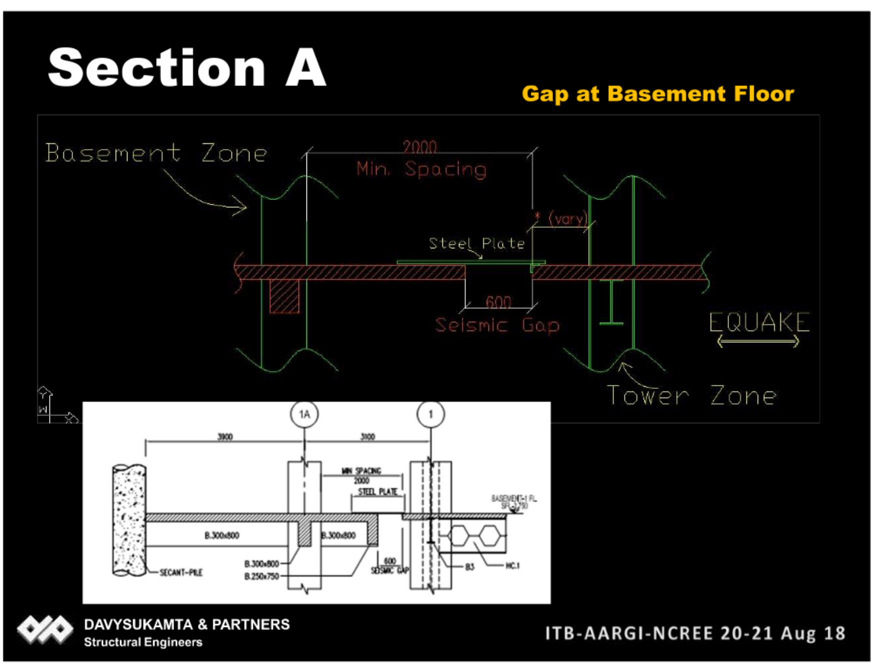
Section A
Gap at Basement Floor
Basement Zone
2000
Min. Spacing
(vary)
Steel Plate
600
Seismic Gap
EQUAKE
Tower Zone
1A
1
3900
3100
B.300x800
SECANT-PILE
B.250x750
HC.1
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Structural Engineers
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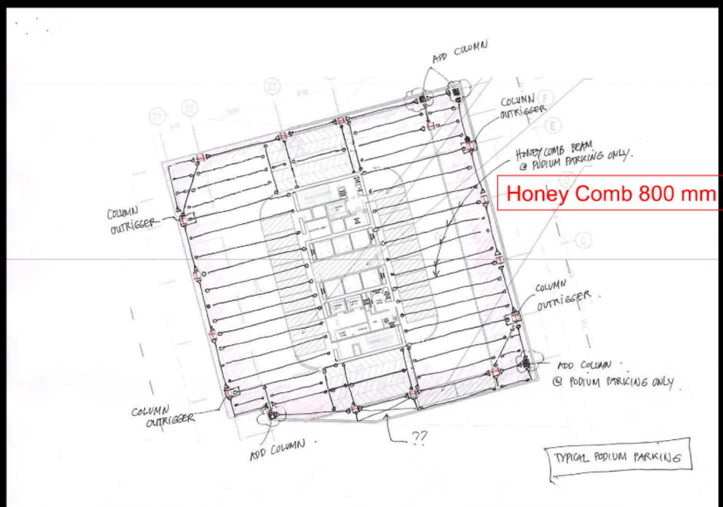
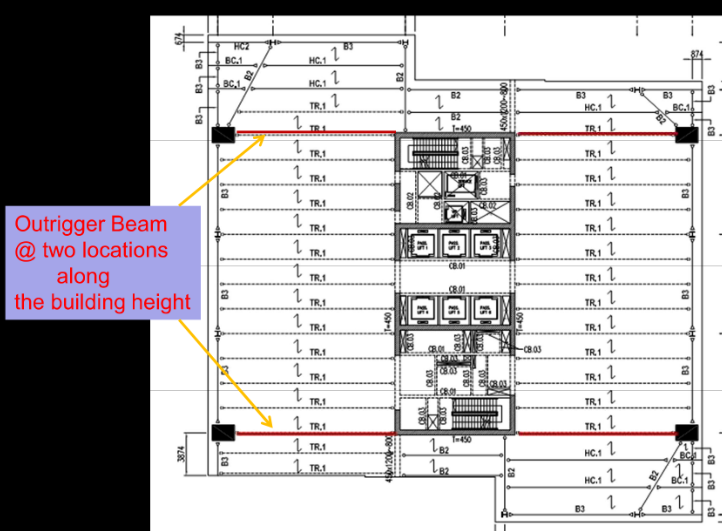
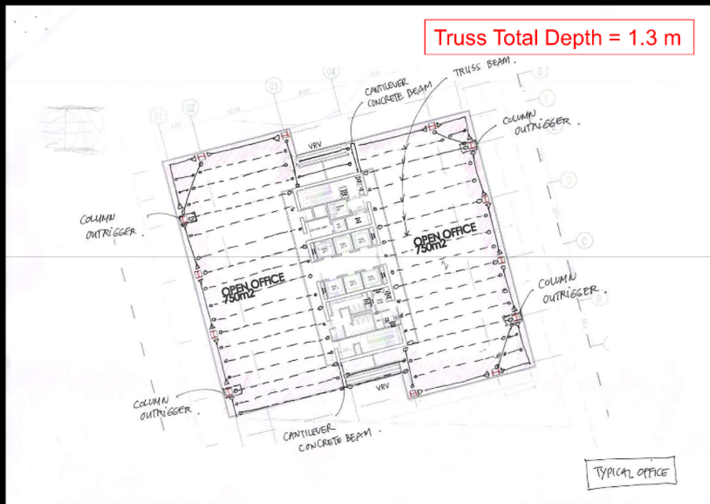
Typical Podium Parking Framing Plan

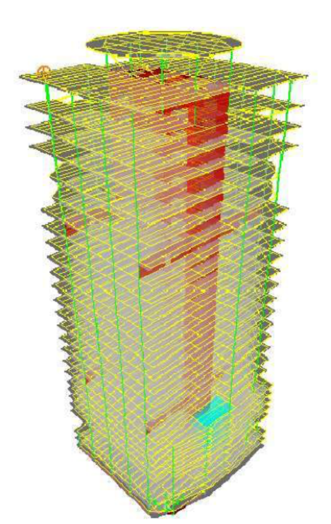


Outrigger Scheme

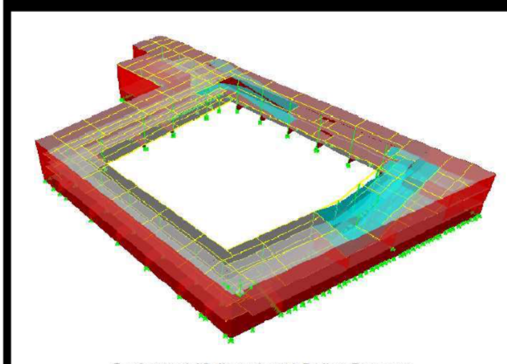


Typical Office Floor Framing Plan





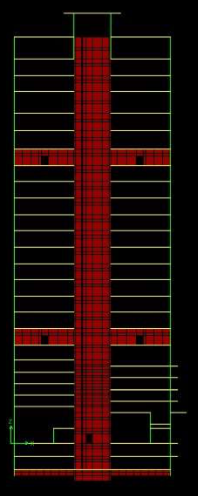
Gambar model 3-dimensi untuk Tower



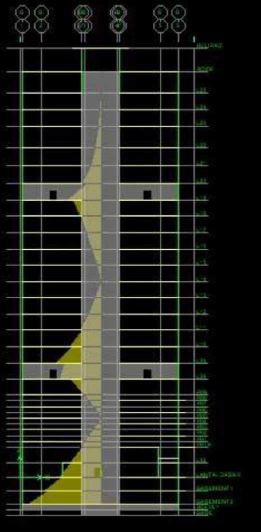
Gambar model 3-dimensi untuk Podium Basement

ETABS models for tower and basement

ETABS Model



BM Diagram of Core Wall



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Study on Location for Base Isolation Floor

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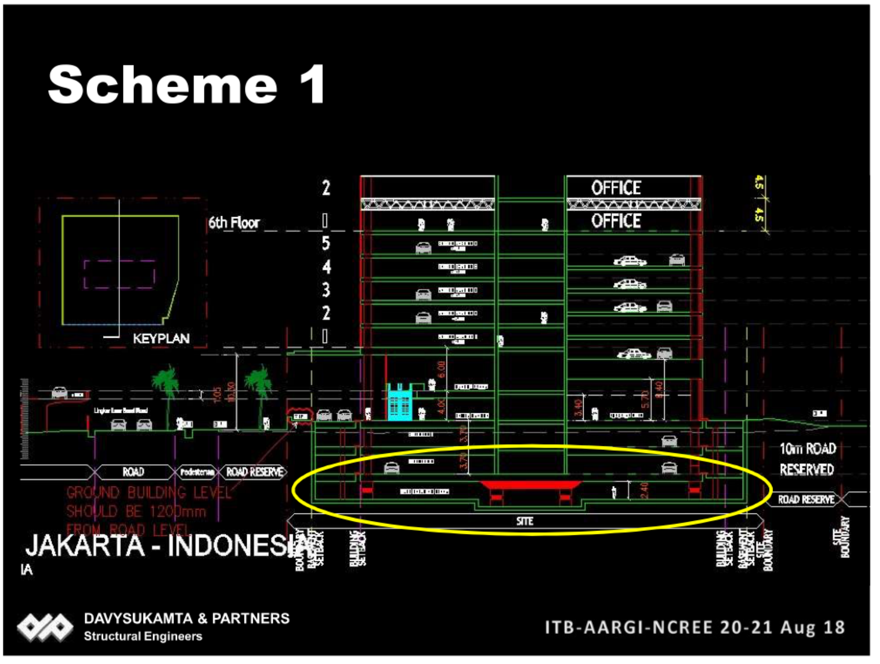
Scheme 1
OFFICE
OFFICE
6th Floor
KEYPLAN
ROAD
ROAD RESERVE
GROUND BUILDING LEVEL
SHOULD BE 1200mm
FROM ROAD LEVEL
10m ROAD
RESERVED
ROAD RESERVE
SITE
JAKARTA - INDONESIA
DAVYSUKAMTA & PARTNERS
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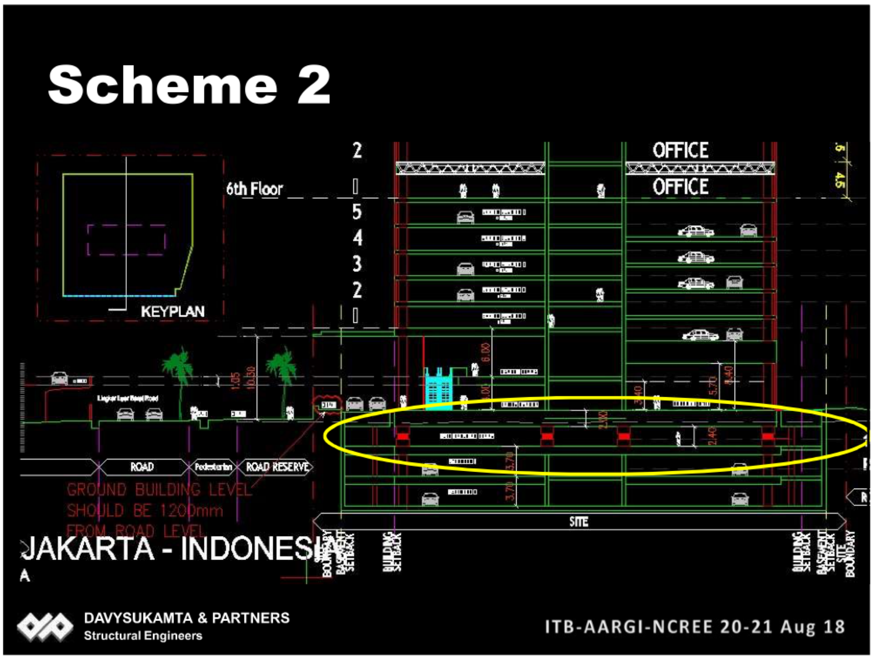
Scheme 2
OFFICE
OFFICE
6th Floor
KEYPLAN
ROAD
ROAD RESERVE
GROUND BUILDING LEVEL
SHOULD BE 1200mm
FROM ROAD LEVEL
SITE
JAKARTA - INDONESIA
DAVYSUKAMTA & PARTNERS
Structural Engineers
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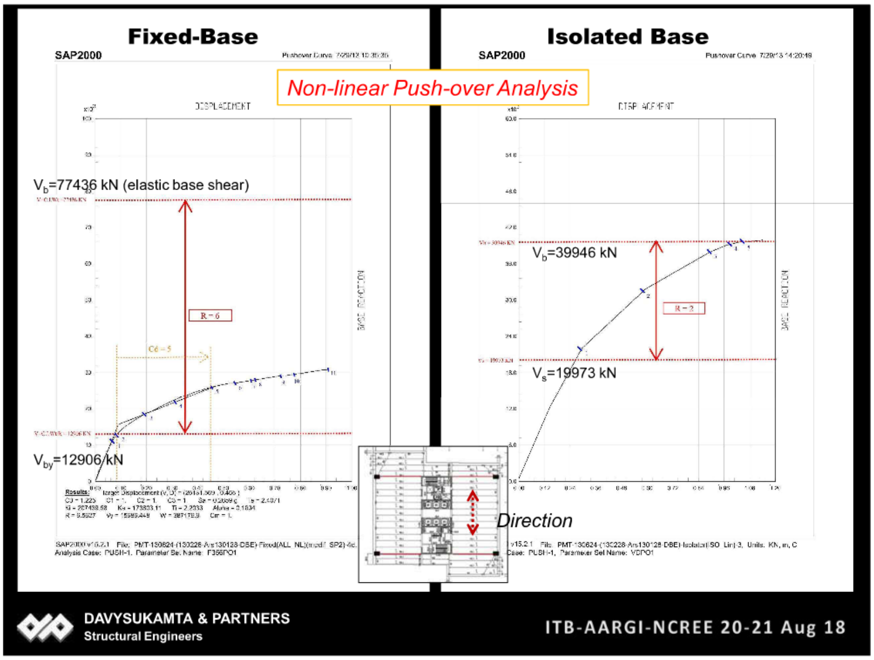
Fixed-Base
Isolated Base
SAP2000
Non-linear Push-over Analysis
V_b=77436 kN (elastic base shear)
V_by=12906 kN
R = 6
Cd = 5
V_b=39946 kN
V_s=19973 kN
R = 2
Direction
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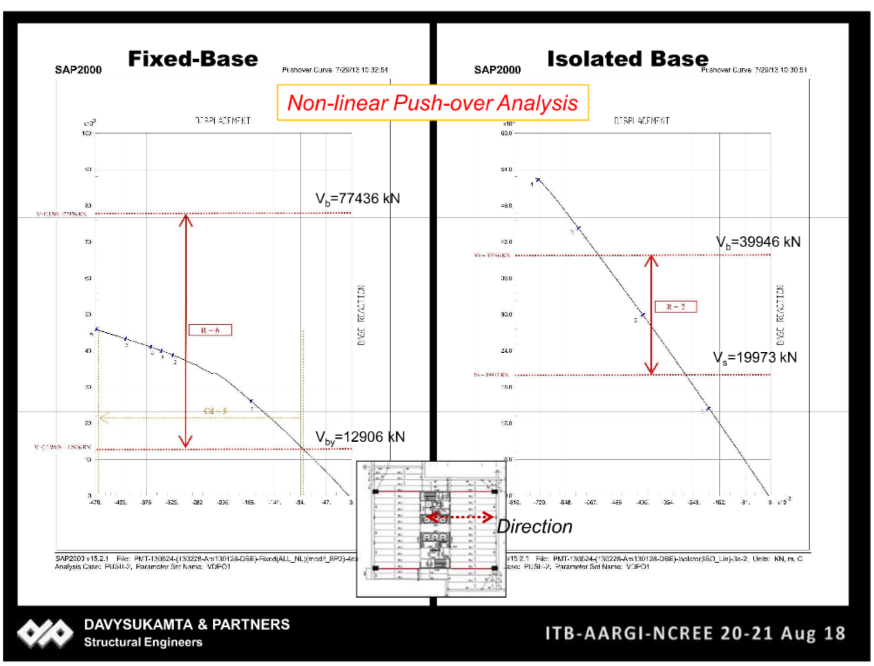
Fixed-Base
Isolated Base
SAP2000
Non-linear Push-over Analysis
V_b=77436 kN
V_by=12906 kN
R = 6
Cd = 5
V_b=39946 kN
V_s=19973 kN
R = 2
Direction
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HT 160 X6 – the biggest HDRB ever produced up to year 2013 by Bridgestone

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Installation of HDRB

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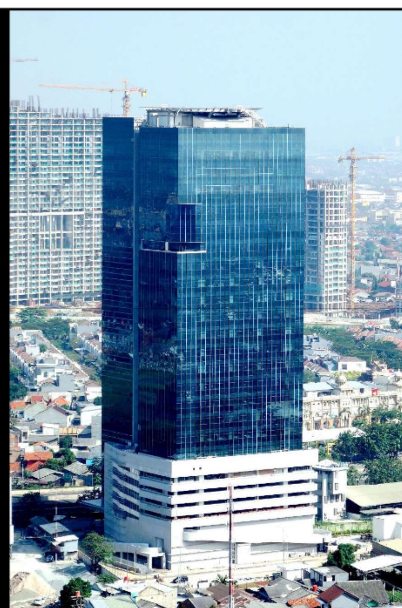
Puri Matahari Tower
27-story



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PURI MATAHARI
Just finished
Coming Soon
DAVYSUKAMTA & PARTNERS
Structural Engineers
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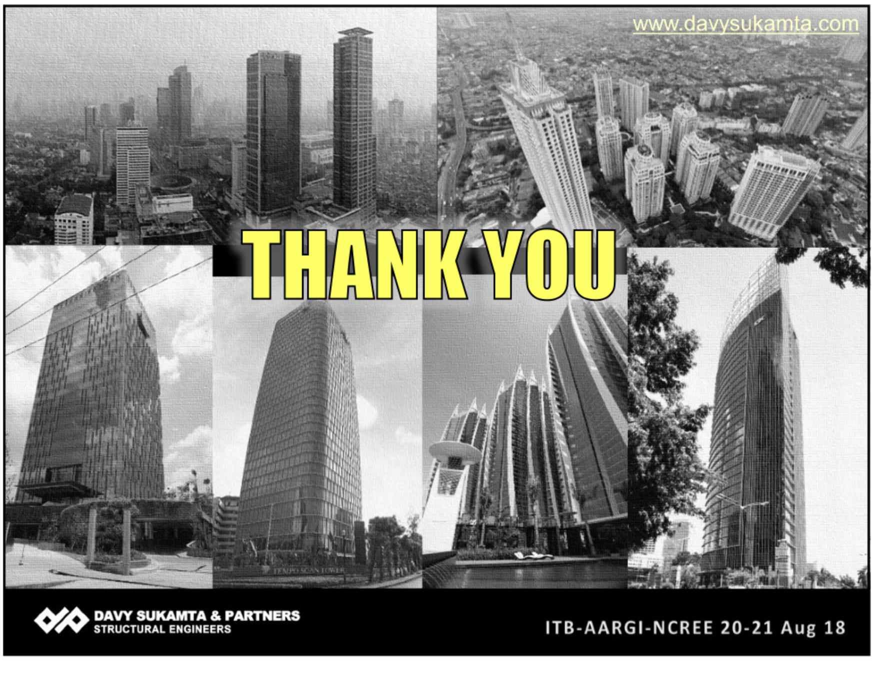
www.davysukamta.com
THANK YOU
DAVY SUKAMTA & PARTNERS
STRUCTURAL ENGINEERS
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Taipei 101 – Structural Design and Application of Wind Damper

Mr. Shaw Shieh

Chairman of Evergreen Consulting Engineering, Inc. and Adjunct Professor at National Taiwan University

Mr. Shieh is a structural engineer focused on the consulting services of tall or challenging buildings. He is the principal-in-charge of the following projects :

1. Taipei 101
2. Taichung Metropolitan Opera House
3. Taipei Performing Arts Center (a structure on "Friction Pendulum System" isolators)
4. C1/D1 MRT Joint Development Project (a project consisting of a 56 story and a 76 story buildings with TMDs and Toggle Brace-Dampers)
5. Building 9 at Jinwan Plaza, a 70 story mixed-use building in Tianjin, China.
6. Farglory The One, a 68 story mixed-use building in Kaohsiung, Taiwan
7. A 61 story residential building in Kaohsiung, Taiwan
8. Fubon Xinyi A25 Commercial Building Complex, a 58 story mixed-use tower in Taipei, Taiwan

Experiences

- Structural Engineer, Brandow & Johnston Assoc., California
- Registered APEC/IPEA Structural Engineer

Taipei 101-- Structural Design and Application of Wind Dampers

Shaw Shieh

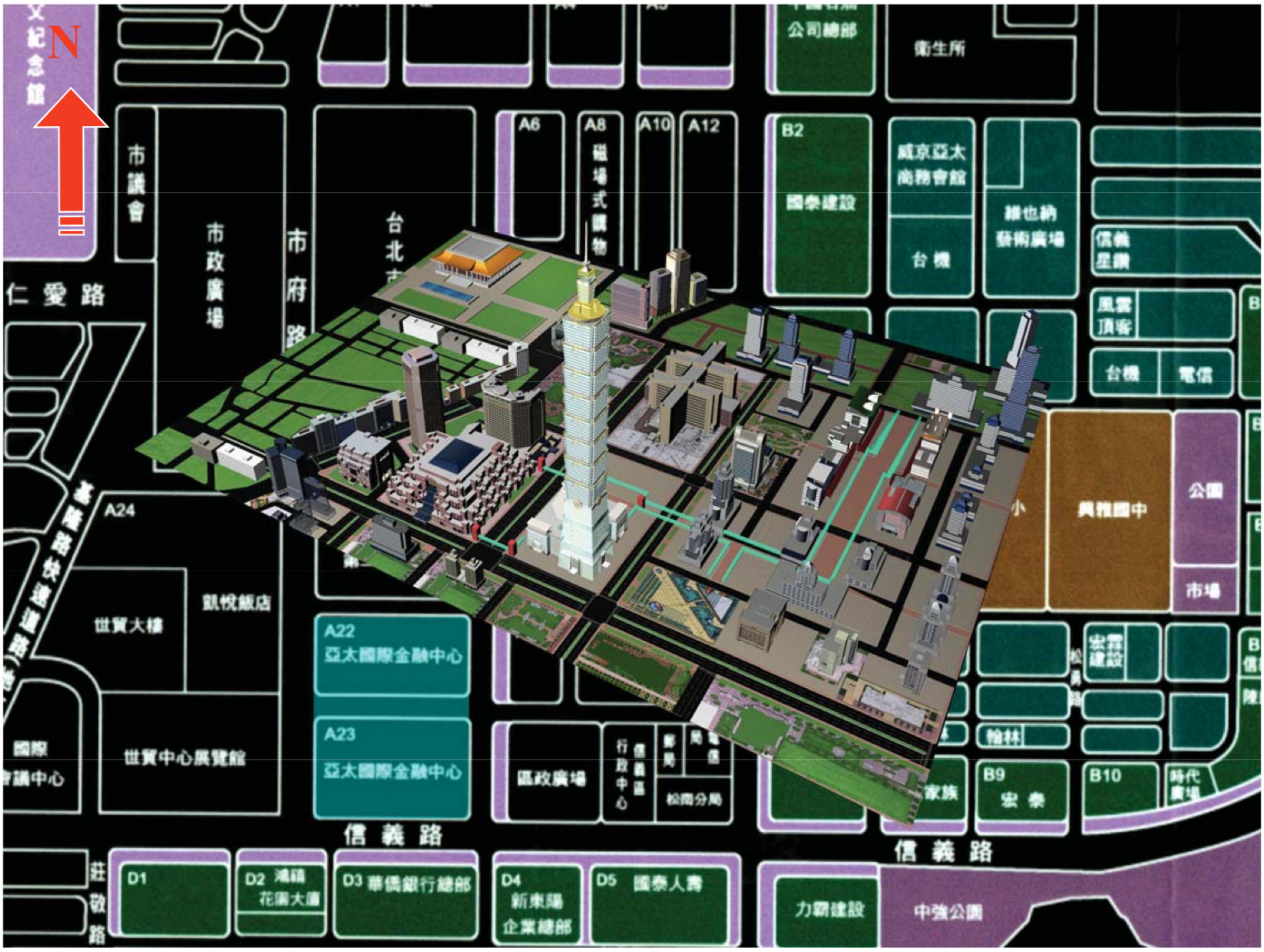
Chairman

Evergreen Consulting Engineering, Inc.

EVERGREEN CONSULTING

Evergreen Consulting Engineering, Inc.

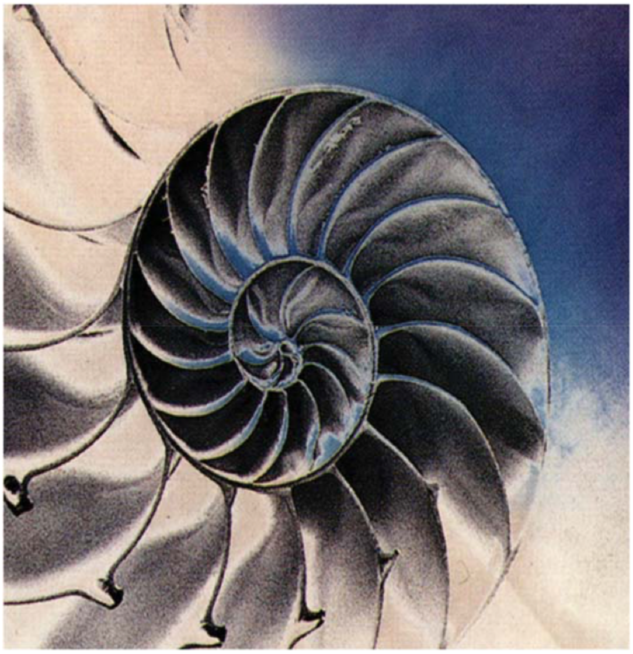
- Structural Design and Site Supervision for Taipei 101
- 40+ Years in Practice, Since 1974
- Specialize in Building Structural Consulting Services



Build-Operate-Transfer

- 1997 City Gov't offers the best land for tender
- Private investors' equity
- 70 years land use right

Shareholders



- Chins Dev't Industrial Bank
- China United Trust & Inv. Co.
- Chie-ho Construction Co.
- Walsin Lihwa Cable & Wire
- Taiwan Stock Exchange
- China Life Insurance
- Cathay Life Insurance
- Shin Kong Life Insurance
- Taishin Bank
- Chinatrust Bank
- Hung Tai Insurance
- United World Chinese Bank
- Chiao Tung Bank
- Chunghwa Telecom

Financial Aspect

- Total project cost USD1.7 bn

a. Land cost USD0.6 bn
b. Construction cost USD0.8 bn
c. Other costs USD0.3 bn

- Investment USD0.7 bn
  Bank loan USD1.0 bn

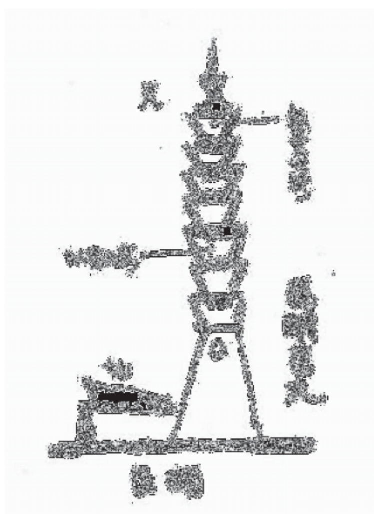
Milestones

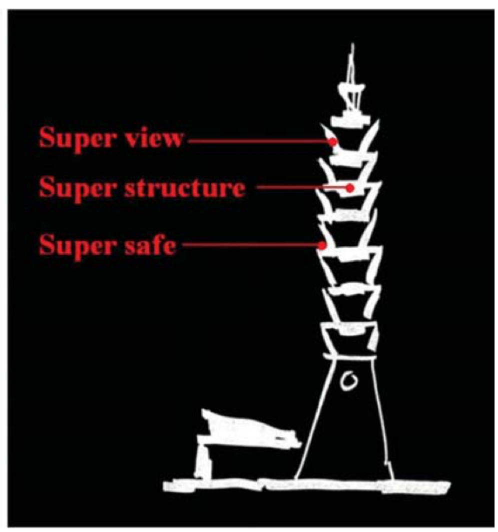
- Jul. 1997 Development right acquired through public tender
- Jan. 1998 Ground Breaking
- Oct. 1998 Building Permit
- Jul. 1999 Construction Started
- Nov. 2003 Shopping Mall Opened
- Dec. 2004 Office Tower Opened

Design Concept

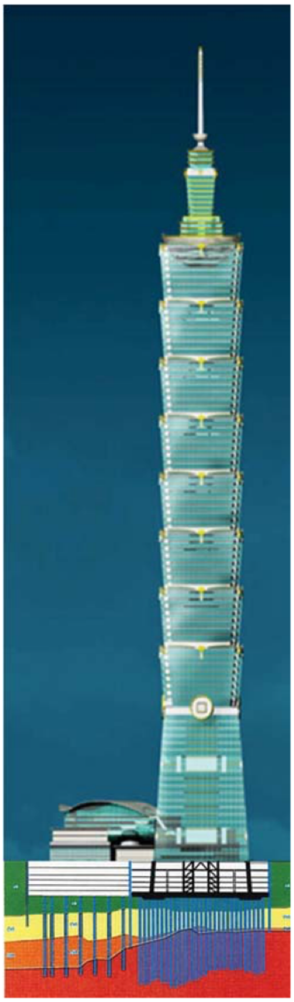
Eastern Image

- **Following Chinese Pagoda Form**
- **Using Number 8 as the Lucky Number x 8 pod**
- **one pod after one pod adding on meaning " Blooming" "Success"**



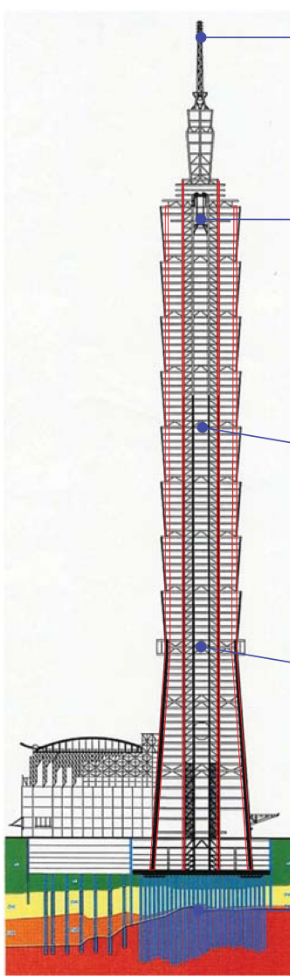


Courtesy of C.Y.LEE & PARTNERS



PROJECT PROFILE

- Site Area — 30,277 m²
- Floor Area — 373,831 m²
- Height — 508 m
- Floors
  - Main Tower — 101
  - Podium — 6
  - Basement — 5
- Main Usage
  - Main Tower — Office (7F – 84F)
    - Mech. Level (Every 8F)
  - Podium — Shopping Mall (B1F – 5F)
  - Basement — Parking (B2F – B5F)



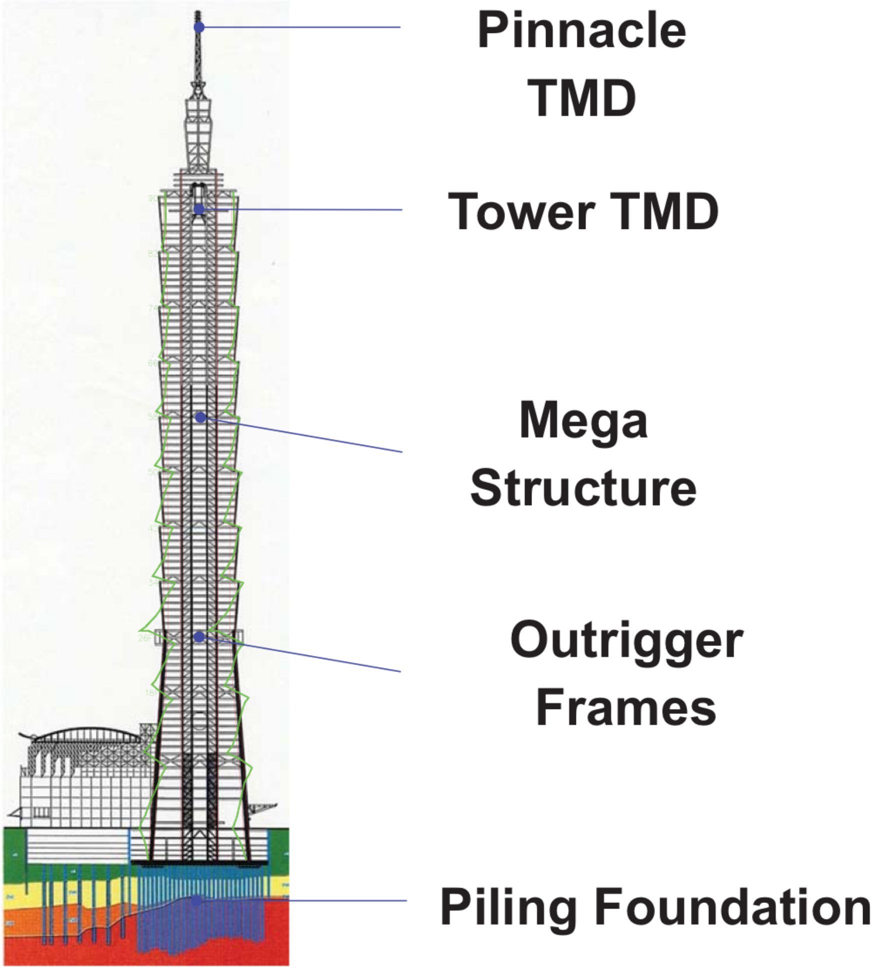
Pinnacle TMD

Tower TMD

Mega Structure

Outrigger Frames

Piling Foundation



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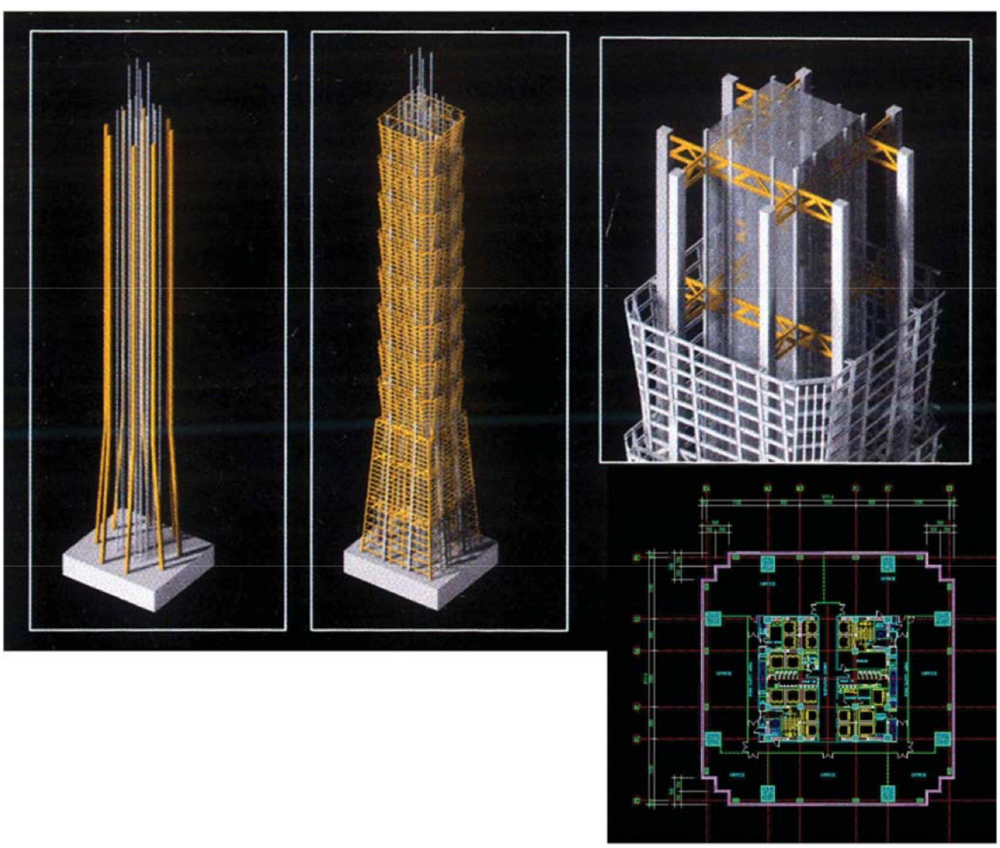

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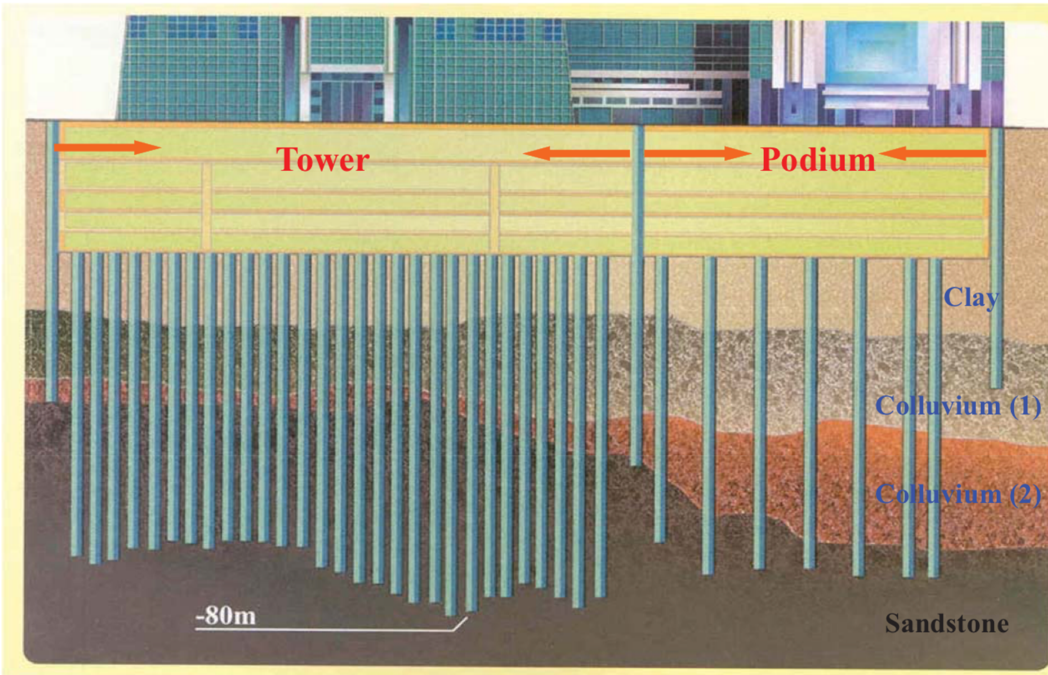

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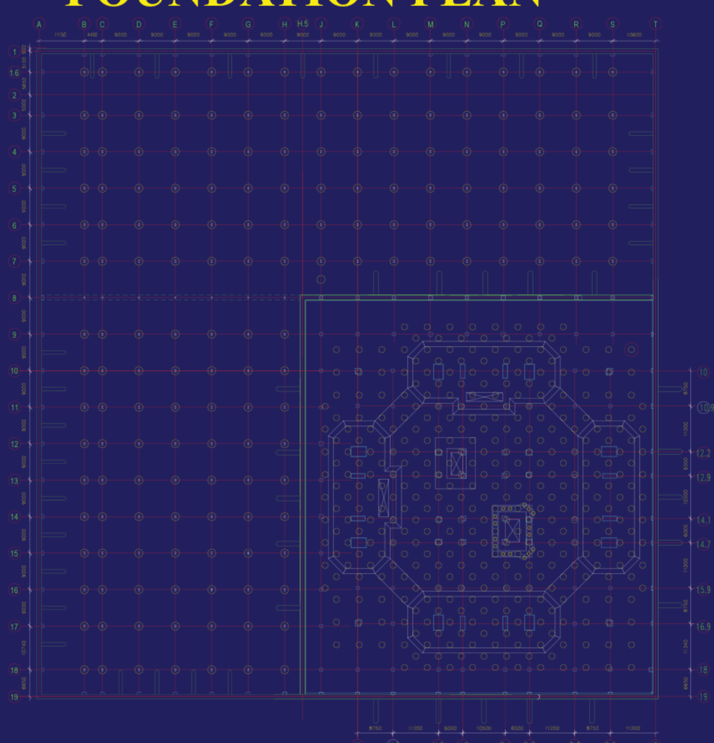
FOUNDATION PLAN



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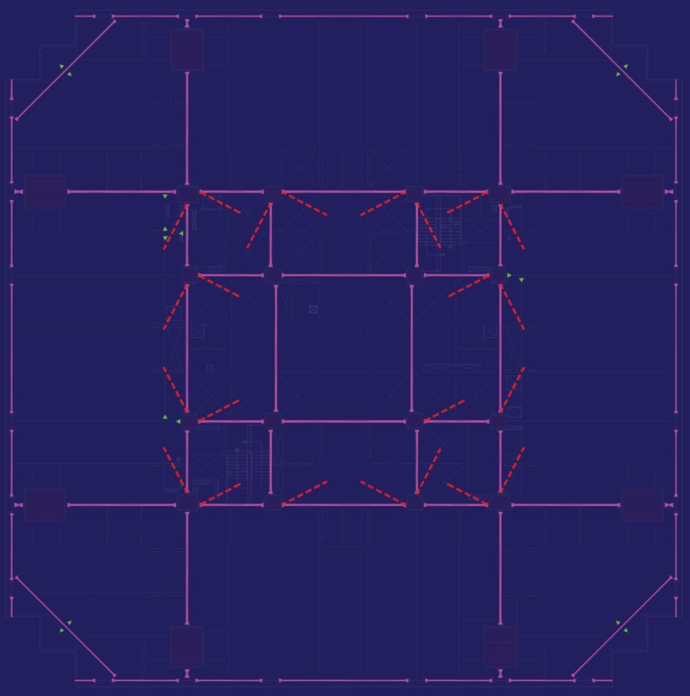
TYPICAL FLOOR FRAMING PLAN



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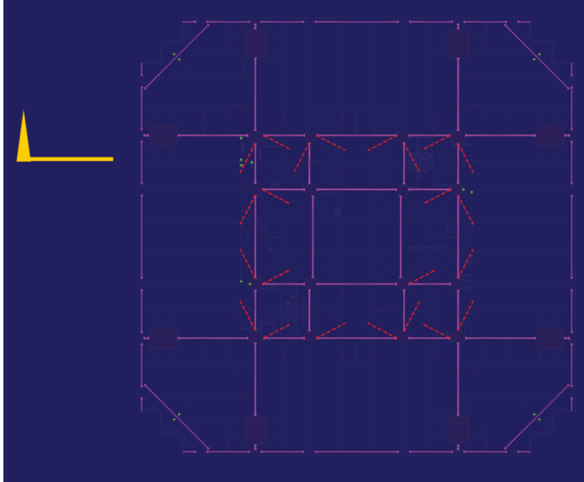
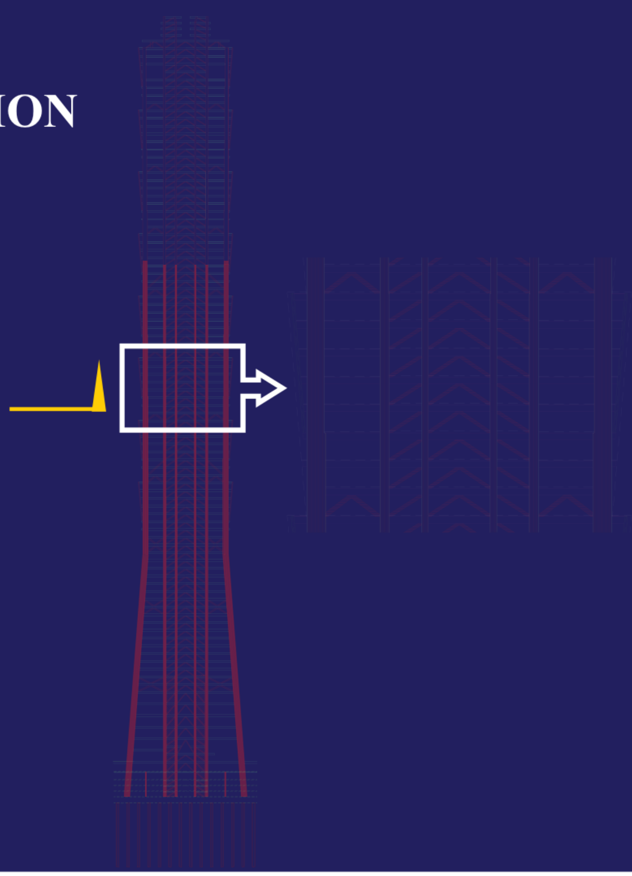
MEGAFRAME ELEVATION





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DESIGN CRITERIA

WIND

- ½ YEAR - HUMAN COMFORT
- 50 YEAR - DRIFT RATIO
- 100 YEAR - STRESS

SEISMIC

- 100 YEAR - REMAIN ELASTIC
- 950 YEAR - RETAIN STABILITY

EVERGREEN CONSULTING

SPECIAL MEASURES TO RESIST WIND AND SEISMIC FORCES

- High Strength and High Ductility Steel Plates
  - SM570M
- High Strength and High Performance Concrete

  Infilling Columns - 10,000 psi
- High Ductility Beam-Column Connection
  - Reduced Beam Sections
- Tuned Mass Damper - Tower
- Smaller Tuned Mass Dampers - Pinnacle

EVERGREEN CONSULTING

HIGH PERFORMANCE STEEL PLATES - SM570M

- Used for tower columns, girders & braces
- High strength : 60 ksi≦Fy≦74 ksi
- High ductility :

  Yield ratio≦80% For girders & braces (t ＞40 mm)

  ≦85% For girders & braces (t ≦40 mm), columns
- High weldability : Ceq ≦ 0.44 % (t ＜40 mm)

  ≦ 0.47 % (t ≧40 mm)
- Through-thickness ductility
- Impact absorption energy

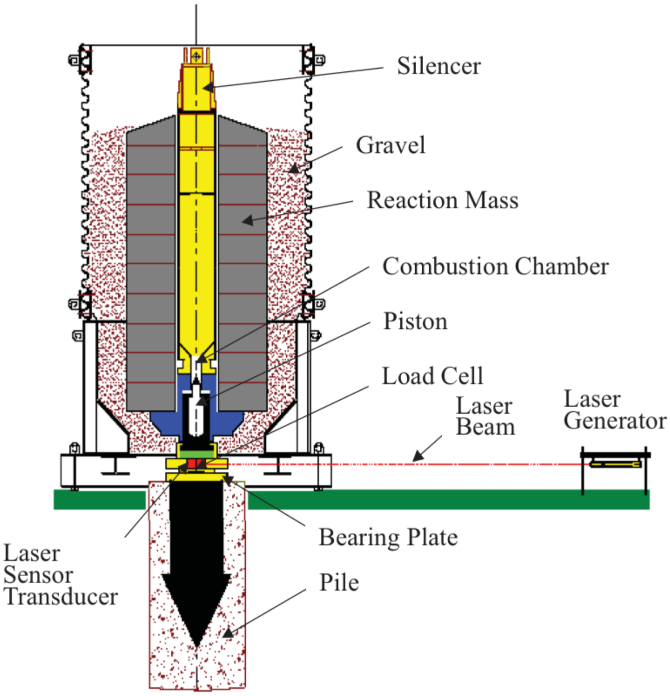
EVERGREEN CONSULTING

REVERSE CIRCULATION PILE

STATIC TESTING OF PILES

COMPRESSION: 4000 TONNES
TENSION: 2200 TONNES

DYNAMIC TESTING OF PILES



COMPRESSION:
2000 TONNES MAX.

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SLURRY WALL

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SUPER-COLUMN FABRICATION

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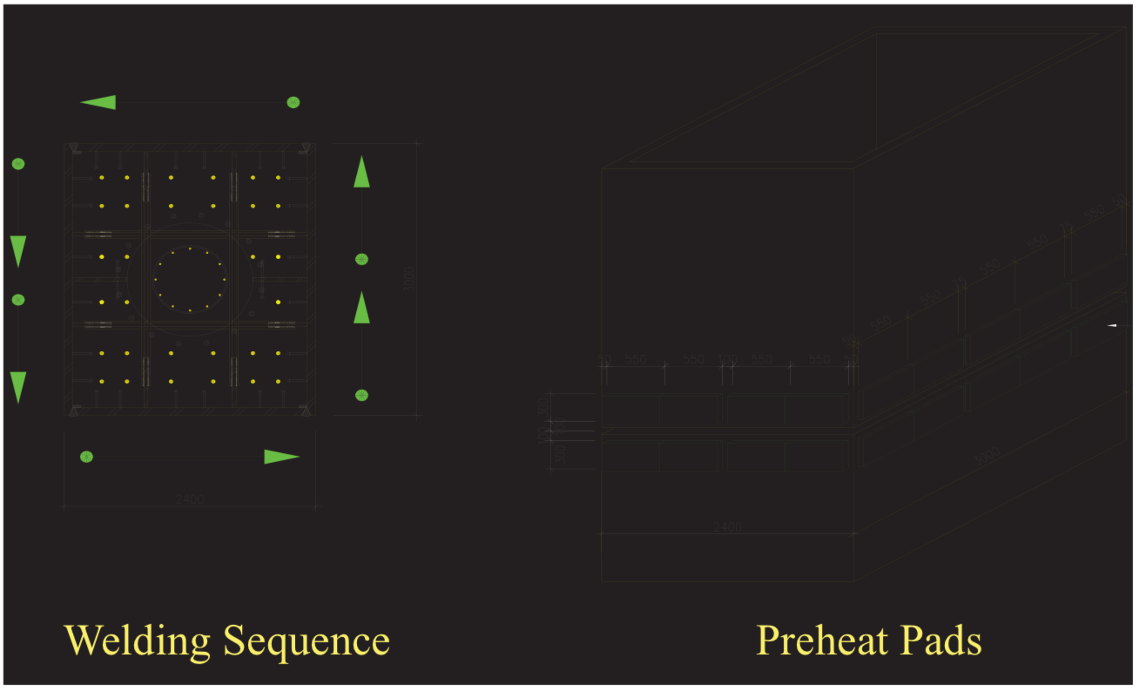
WELDING OF SUPER-COLUMN



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WELDING OF SUPER-COLUMN

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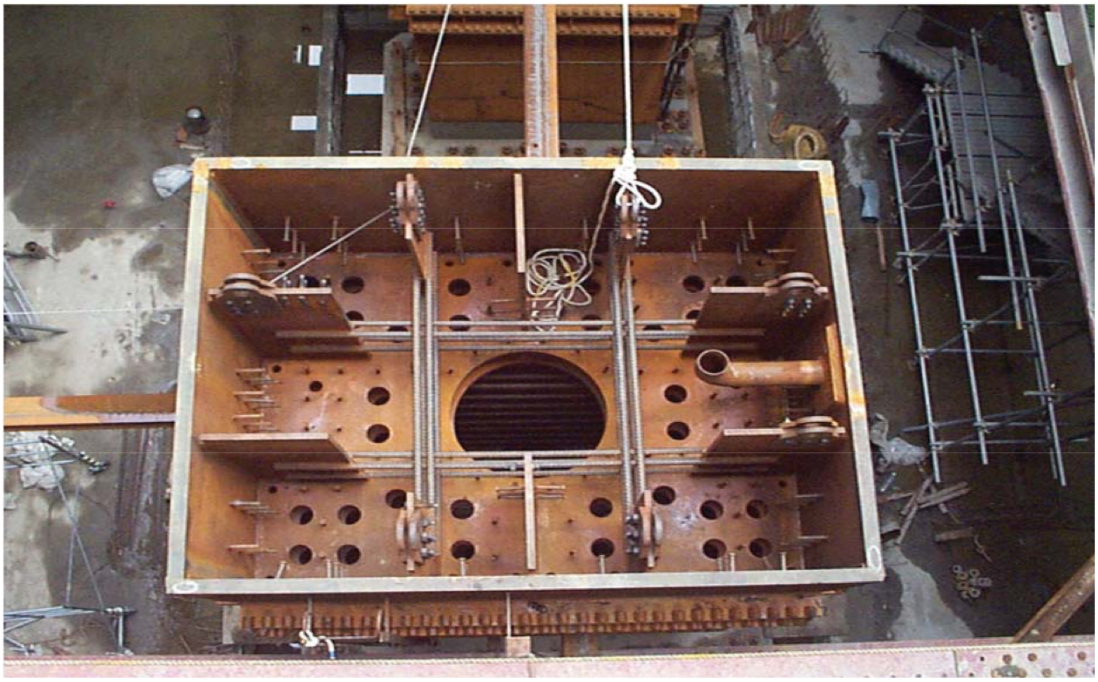
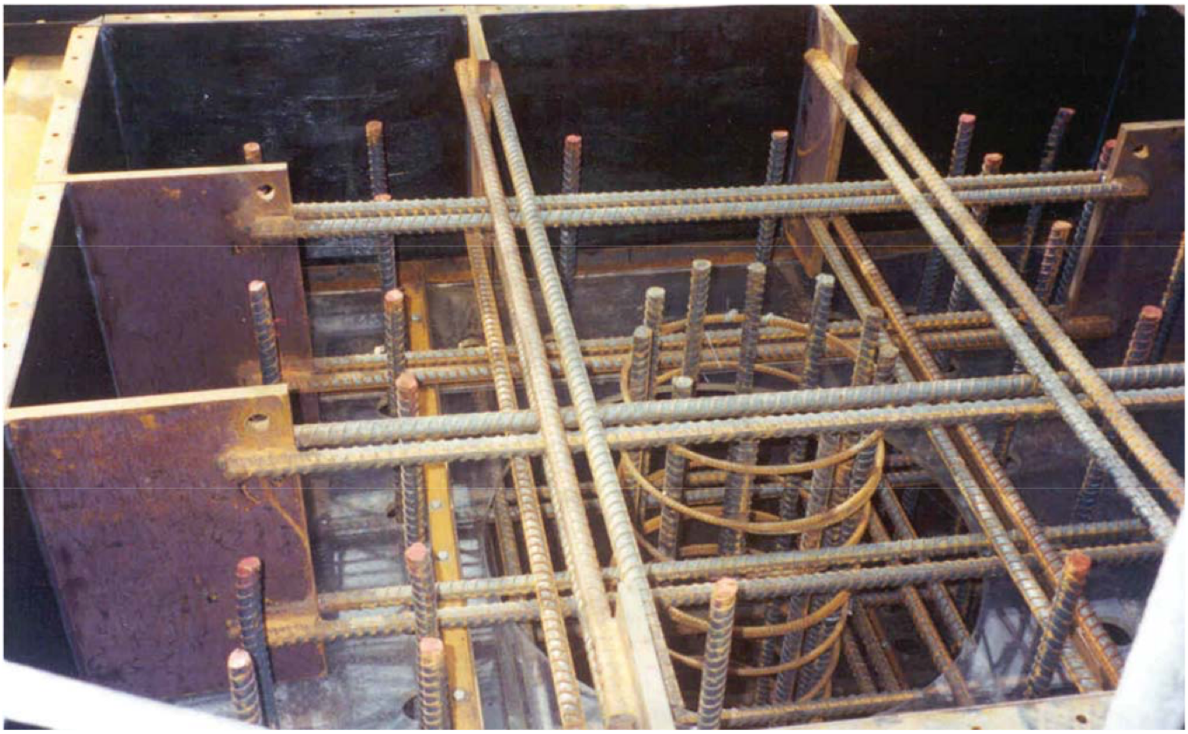
CROSS-SECTION OF SUPER-COLUMN



EVERGREEN CONSULTING



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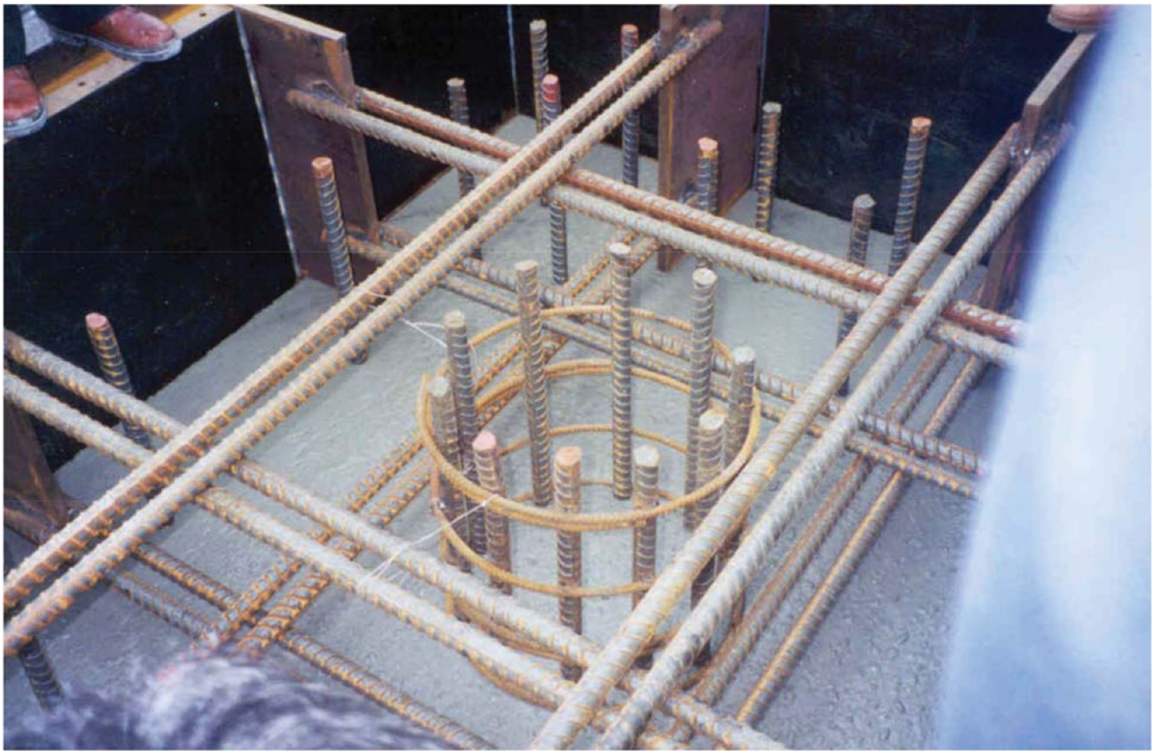

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10000 psi HIGH PERFORMANCE CONCRETE

- **Design strength : 10000psi @ 90 days**
- **High flowability: slump - 250±20mm**
  slump flow - 600±20mm
- **5% maximum air bubble underneath diaphragm plate**
- **Autogenous shrinkage ≦ 300×10^{-6} m/m @ 90 days**

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COLUMN INFILL MOCKUP TEST

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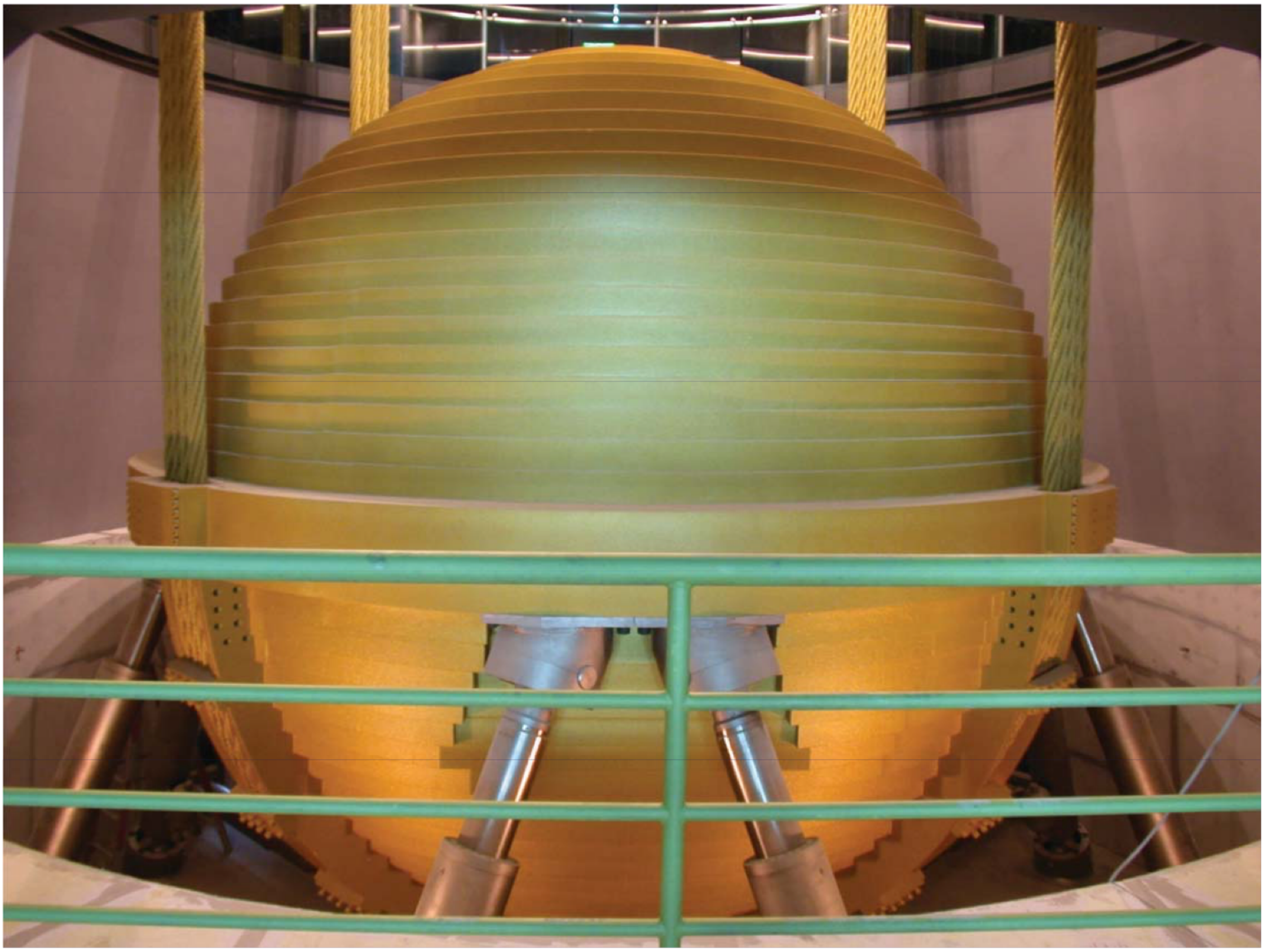
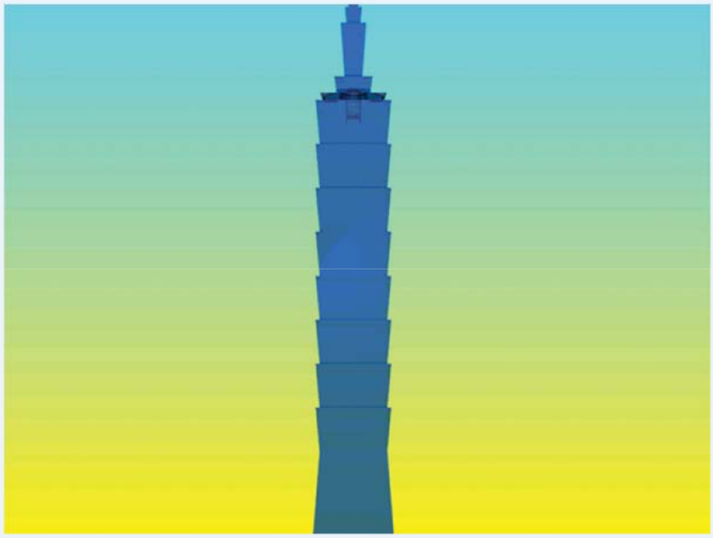
REDUCED BEAM SECTION



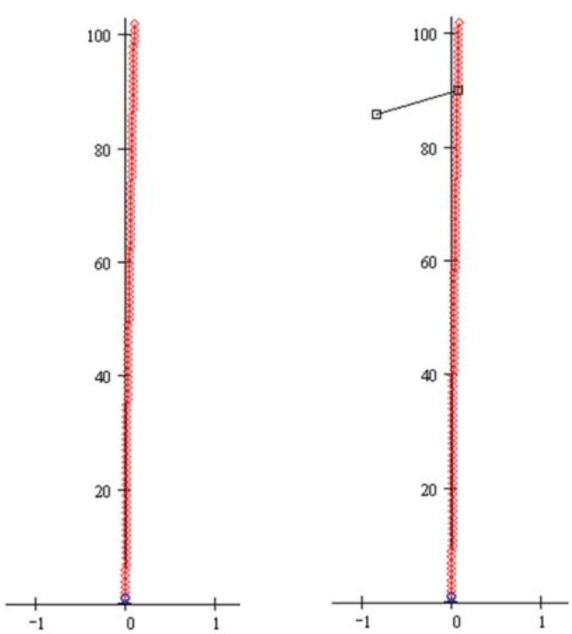
TMD Facts

- Tower motions reduced by about 40%
- TMD System is earthquake-resilient
- Computer-monitored at all times
- Largest TMD in the world for Tallest Building in the World
- First TMD Architecturally-exposed
- 660 tonne Tuned Mass Damper



Taipei 101 – Taiwan (Height 508m)

Why A TMD ?



Components from all over the world.....

International Effort
Fabrication and Installation

- **RWDI** (Canada)
- **Motioneering** (Canada)
- Taipei 101 (TFCC) Taipei Financial Center Corporation
- Turner International
- KTRT (Japan)
- CY Lee (Taiwan)
- Evergreen Consulting Engineers (Taiwan)
- Thornton Tomasetti (USA)
- TH Tsai & Associates (Taiwan)

Jarret Snubbers – from France

RWDI
motioneering
Experts in engineering motion...
because nothing stands still

FIP Viscous Dampers – from Italy

Cables – Wire Rope Industries from Montreal

Steel Components – from A&H Custom Machine – Burlington, ON

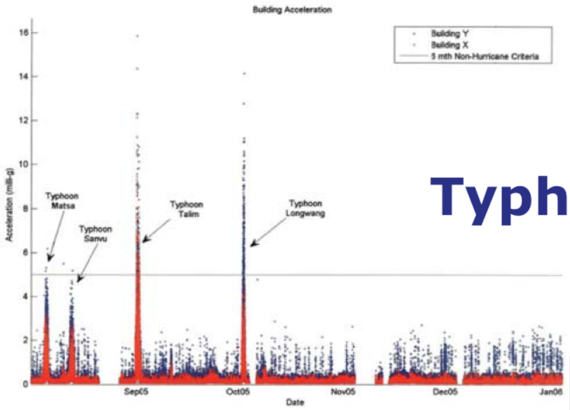
RWDI

motioneering
Experts in engineering motion...
because nothing stands still

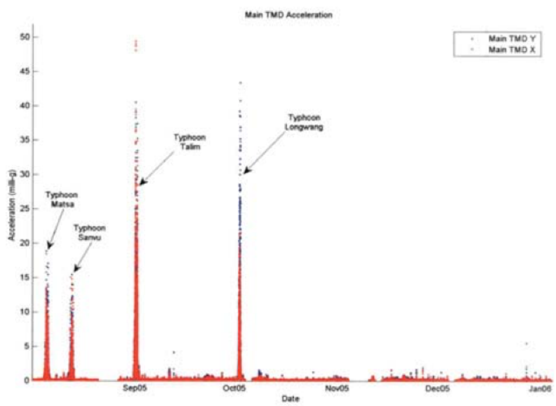
Mass Plates – China Steel Structure Co., LTD – from Kaohsiung, Taiwan

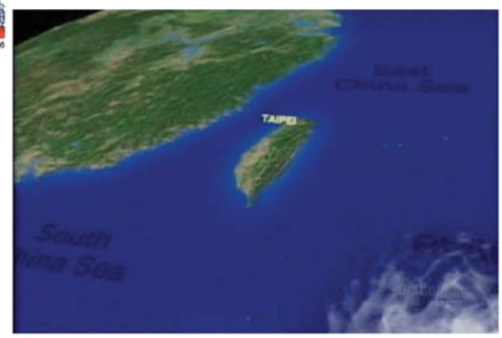
Typhoon season 2005

Building Accelerations

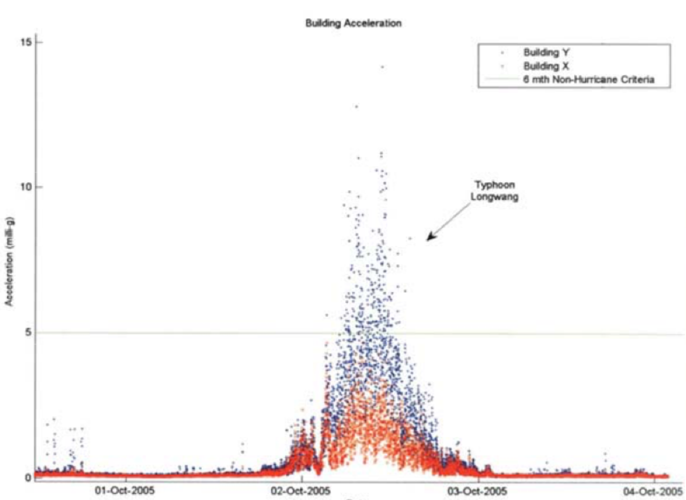


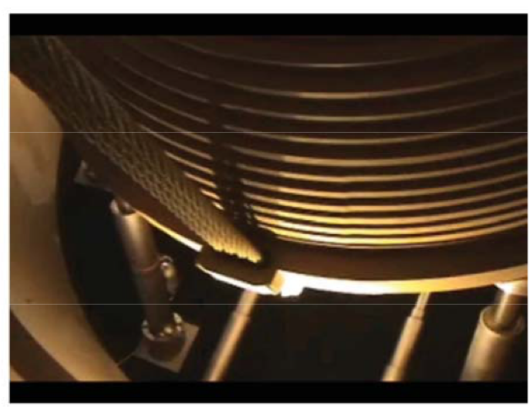
Main **TMD** Accelerations





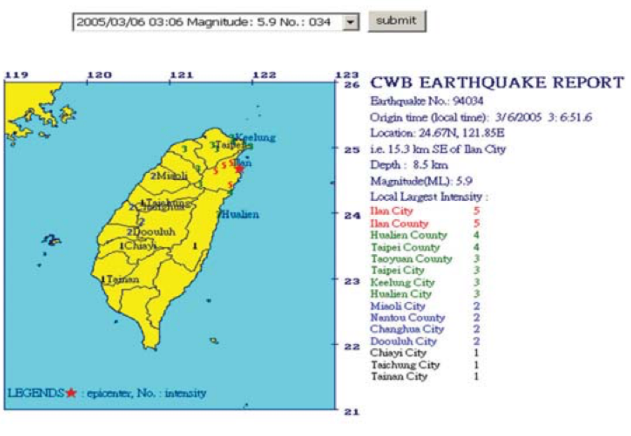
TMD in operation….during Typhoon Longwang- October 2005

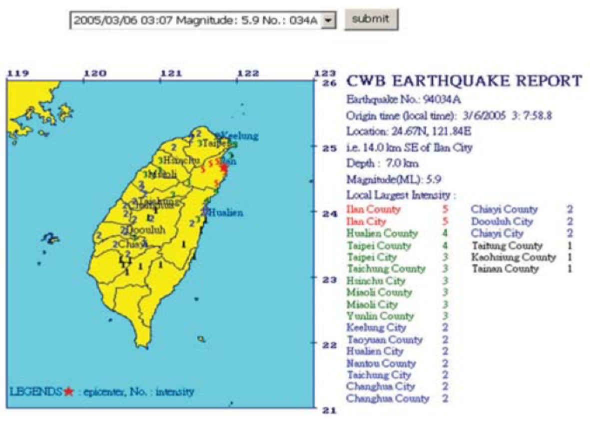




TMD in operation….during a double earthquake in March 2005

Taiwan CWB Earthquake Report





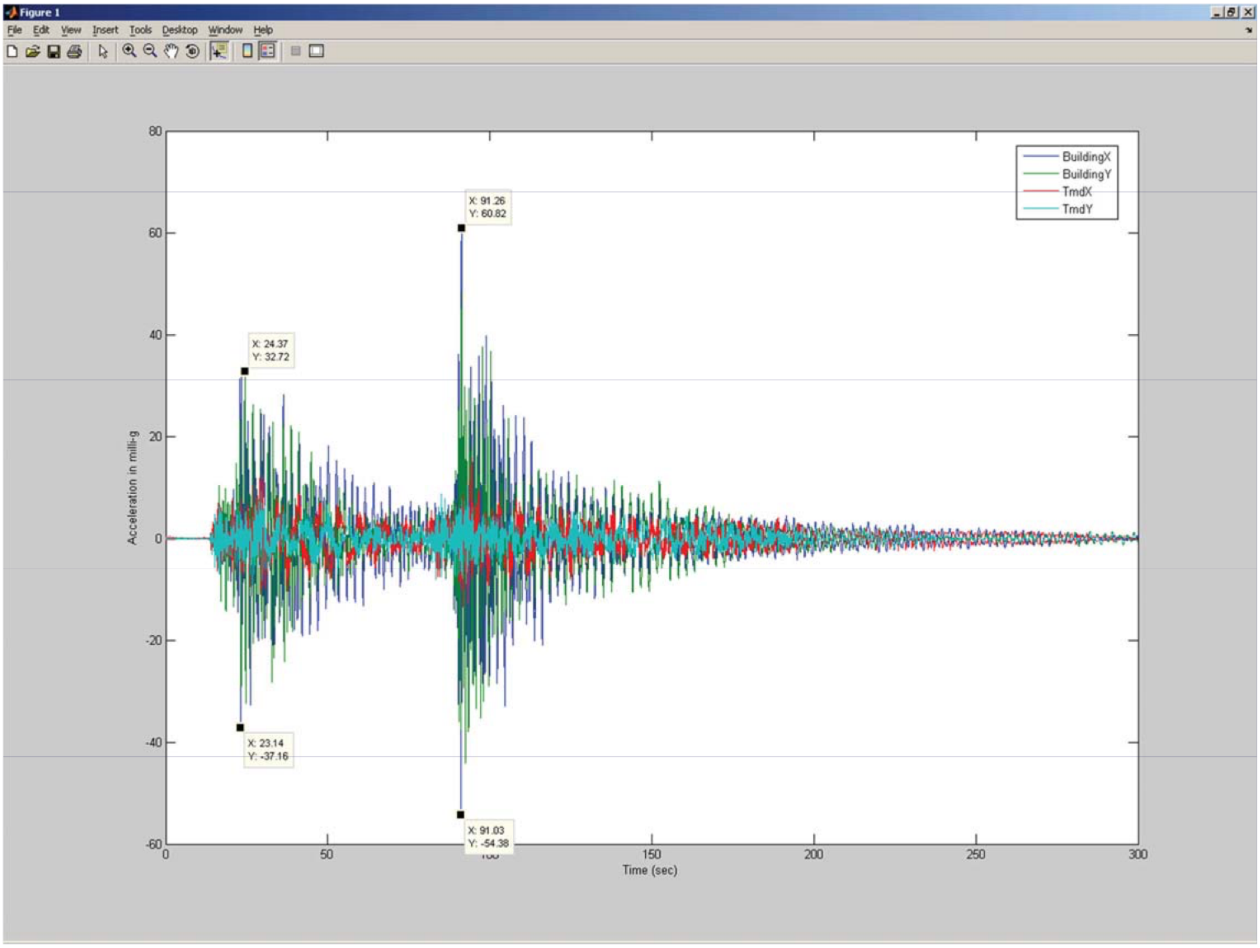


Figure 1
File Edit View Insert Tools Desktop Window Help
BuildingX
BuildingY
TmdX
TmdY
X: 91.26
Y: 60.82
X: 24.37
Y: 32.72
X: 23.14
Y: -37.16
X: 91.03
Y: -54.38
Acceleration in milli-g
Time (sec)


Thank You!