Development of Risk Based Performance Based Design for Super Tall Building in Indonesia

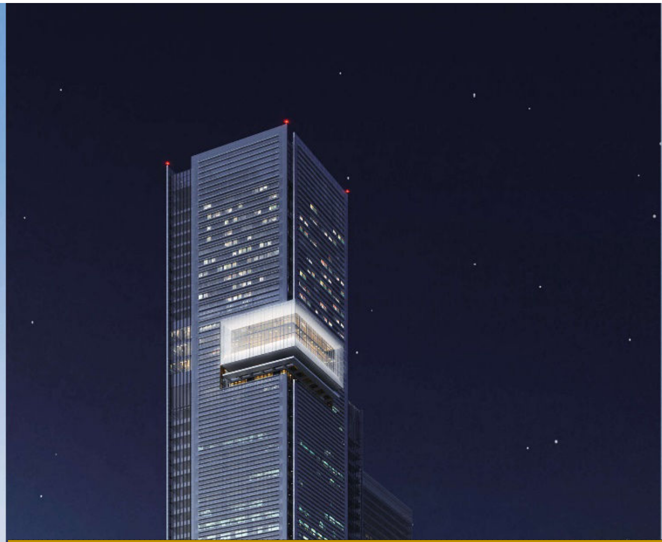
CIBE ITB

Indra Djati Sidi, Bambang Budiono, Eben K. Haezer

ICEEDM - 2019

PADANG, 26 – 27 SEPTEMBER 2019

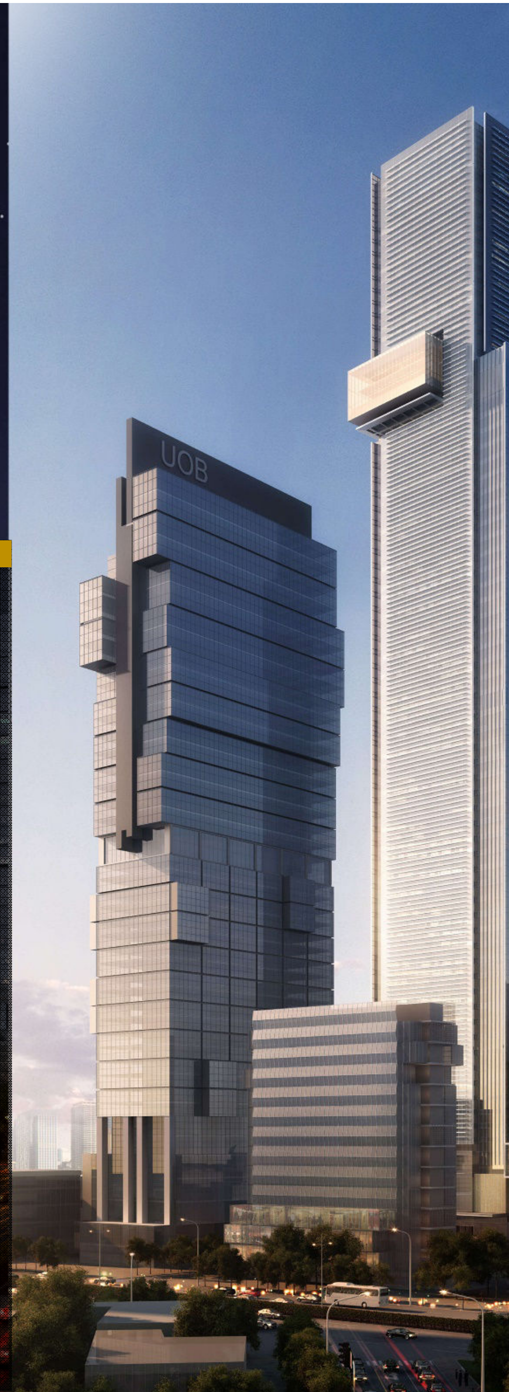
SHARING THE CONSTRUCTION OF TOWER 1 AND TOWER 2 THAMRIN NINE PROJECT JAKARTA



THE THAMRIN 9 PROJECT JL. MH THAMRIN, JAKARTA

72 STORY
6 LEVEL OF BASEMENT
366 METER OF HEIGHT

TOPPING OF MARCH 2020



THE THAMRIN NINE PROJECT, JAKARTA
72 STORY BUILDING
366 METER OF HEIGHT
UNDER CONSTRUCTION
ESTIMATED COMPLETION DATE: MARCH 2020

THAMRIN 9 PROJECT

IN THE PROCESS OF CONSTRUCTION

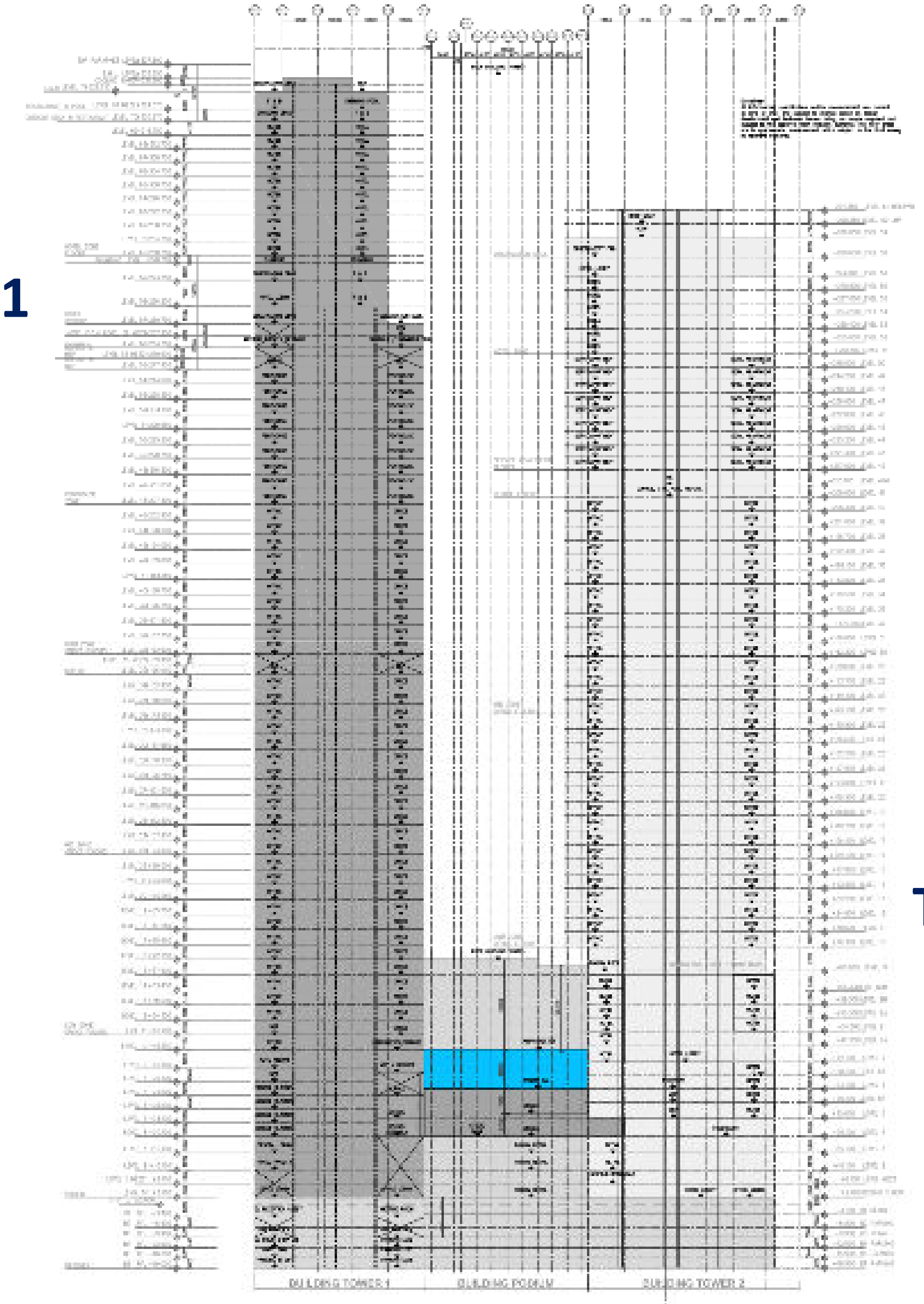
THE THAMRIN 9 PROJECT
JAKARTA – TOWER 1

72 STORY BUILDING
6 LEVEL OF BASEMENT
366 METER OF HEIGHT
UNDER CONSTRUCTION

THE TALLEST BUILDING IN

INDONESIA

WER 1

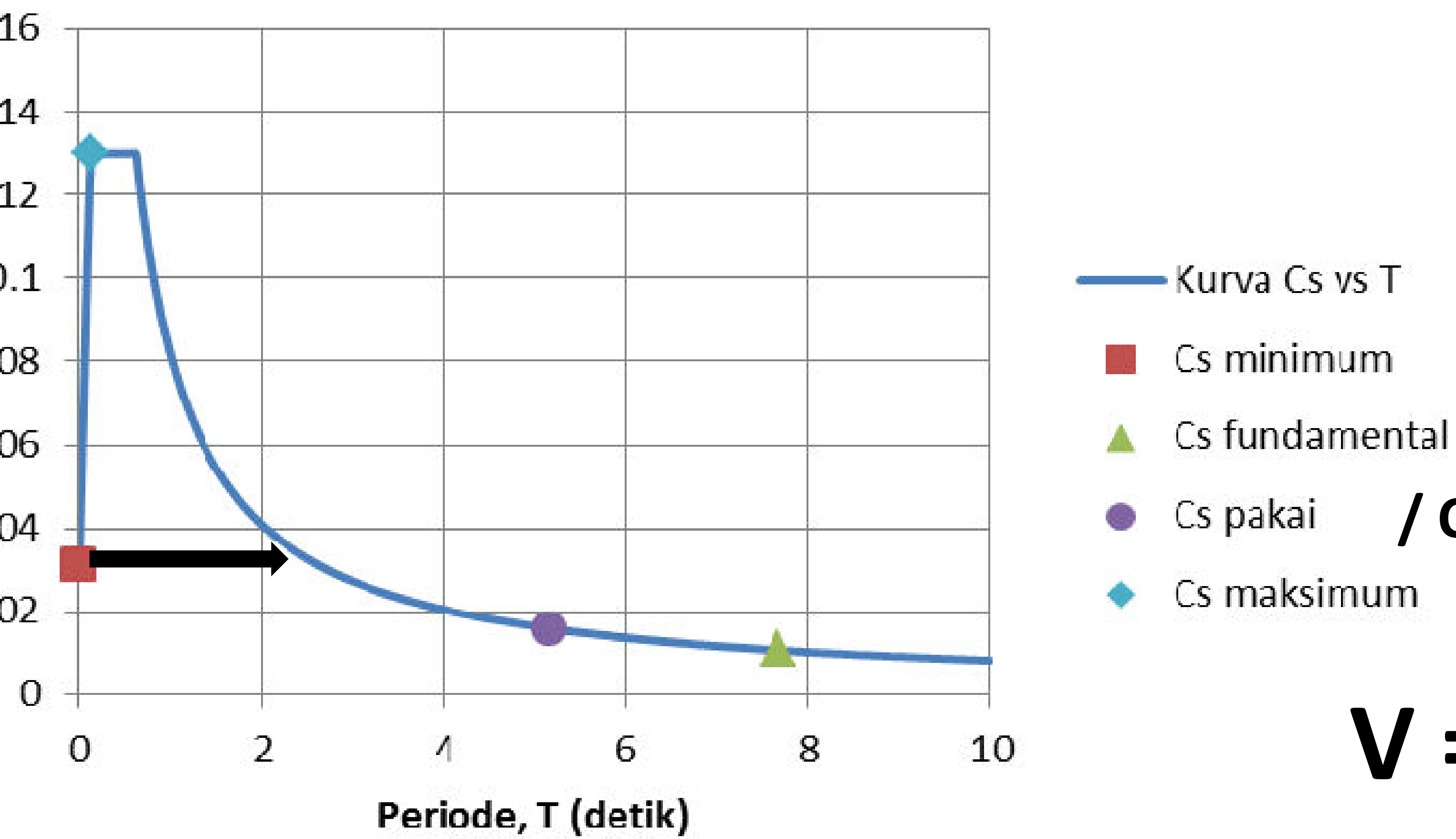


TOWER 2

SECTION OF TOWER 1 AND TOWER 2 THAMRIN NINE PROJECT

The Original Design Concept

- AS A DUAL SYSTEM STRUCTURE AS REGULATED BY ASCE STANDARD (ASCE 7 – 2010) OR INDONESIAN STANDARD OF SNI 1726 - 2012
- MAXIMIZE THE SPACE, MINIMIZE THE COLUMN SIZE, RESULTING A RATHER DENSE REINFORCEMENT FOR CORE WALL AND COLUMN
- THE RESPONSE SPECTRA ANALYSIS



/ Cs design

/ Cs maximum

SEISMIC COEEFICIENT, Cs VS FUNDAMENTAL PERIOD, T (second)

C S MINIMUM

CONTRIBUTE TO THE HEAV REINFORCEMENT

V = Cs x W

V = BASE SHEAR

W = SEISMIC MASS

BASE SHEAR V

$$V = C_S \times W$$

V = base shear

C_S = seismic coeffient ; function of Importance facto

fundamental period, spectral acceleration

W = the weight of the structure

CONDITION OF BARS BEFORE PERFORMANCE BASED DESIGN

COLUMN AND CORE WALL REINFORCEMENT

COLUMN

CORE WALL

DIFFICULTY IN CASTING THE CONCRETE, LONGER CONSTRUCTION PERIOD, DELAY CONSTRUCTION SCHEDULE

FACING FINANCIAL PROBLEM !

MOVE TO PERFORMANCE BASED DESIGN

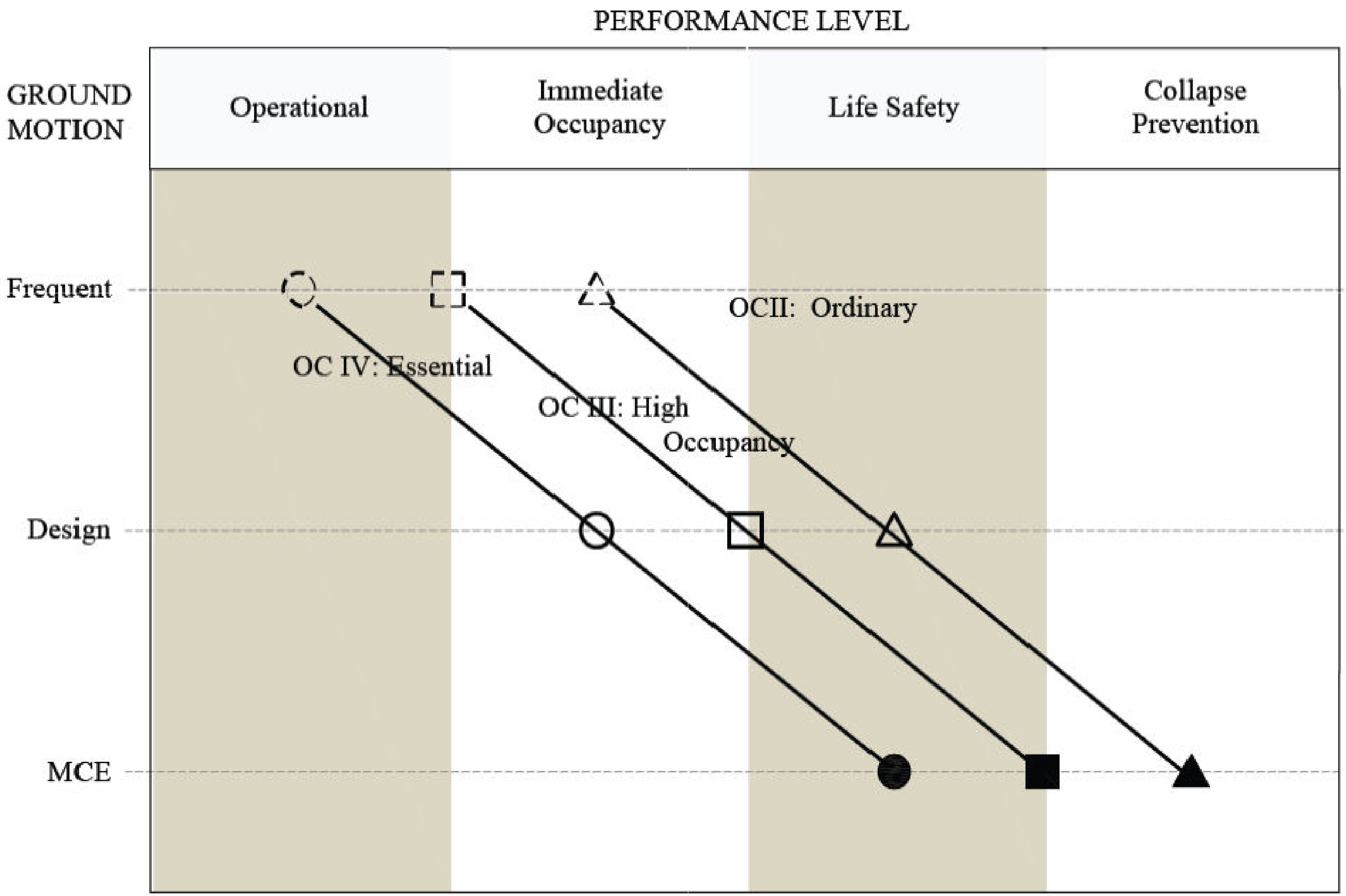
- FOR TOWER 1 WITH THE EXISTING SIZE OF COLUMN, CORE WALL, AND BEAM, **REDESIGN** THE REINFORCEMENT USING SEISMIC COEFFICIENT: $\mathbf{C_{s\ desisgn}}$ SMALLER THAN THE $\mathbf{C_{s\ minimum}}$.
- PREPARE THE INPUT GROUND MOTION IN TERMS OF RESPONSE SPECTRA AND **SEVEN** GROUND ACCERATION FOR **SERVICE LEVEL EARTHQUAKE (SLE)** AND $\mathbf{MCE_R}$

MORE RIGOROUS ANALYSIS

RUN FOR NON LINEAR TIME HISTORY ANALYSIS, 7 RECORDS FROM SITE SPECIFIC RESPONSE ANALYSIS (SSRA), FOR **SLE** AND $\mathbf{MCE_R}$

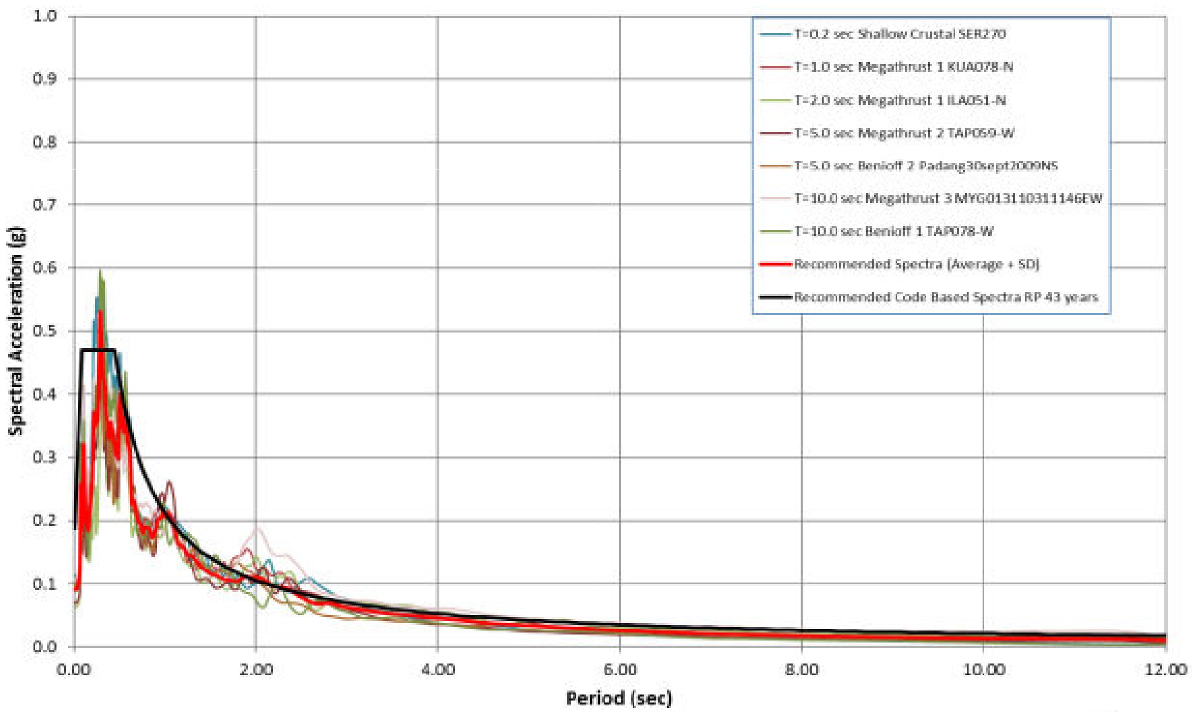
- FOR SLE THE STRUCTURE MEMBER SHOULD BE IN THE ELASTIC CONDITION
- FOR THE $\mathrm{MCE_R}$ THE STRUCTURE MEMBER SHOULD BE IN LIFE SAFE (LS) CONDITION
- THE DRIFT LESS THAN 2%
- ALSO MEET THE RESIDUAL DRIFT REQUIREMENT AFTER THE EARTHQUAKE
- BASE SHEAR GREATER 0.85 BASE SHEAR FROM $\mathbf{C_{s\ minimum}}$

PERFORMANCE LEVEL - TARGET



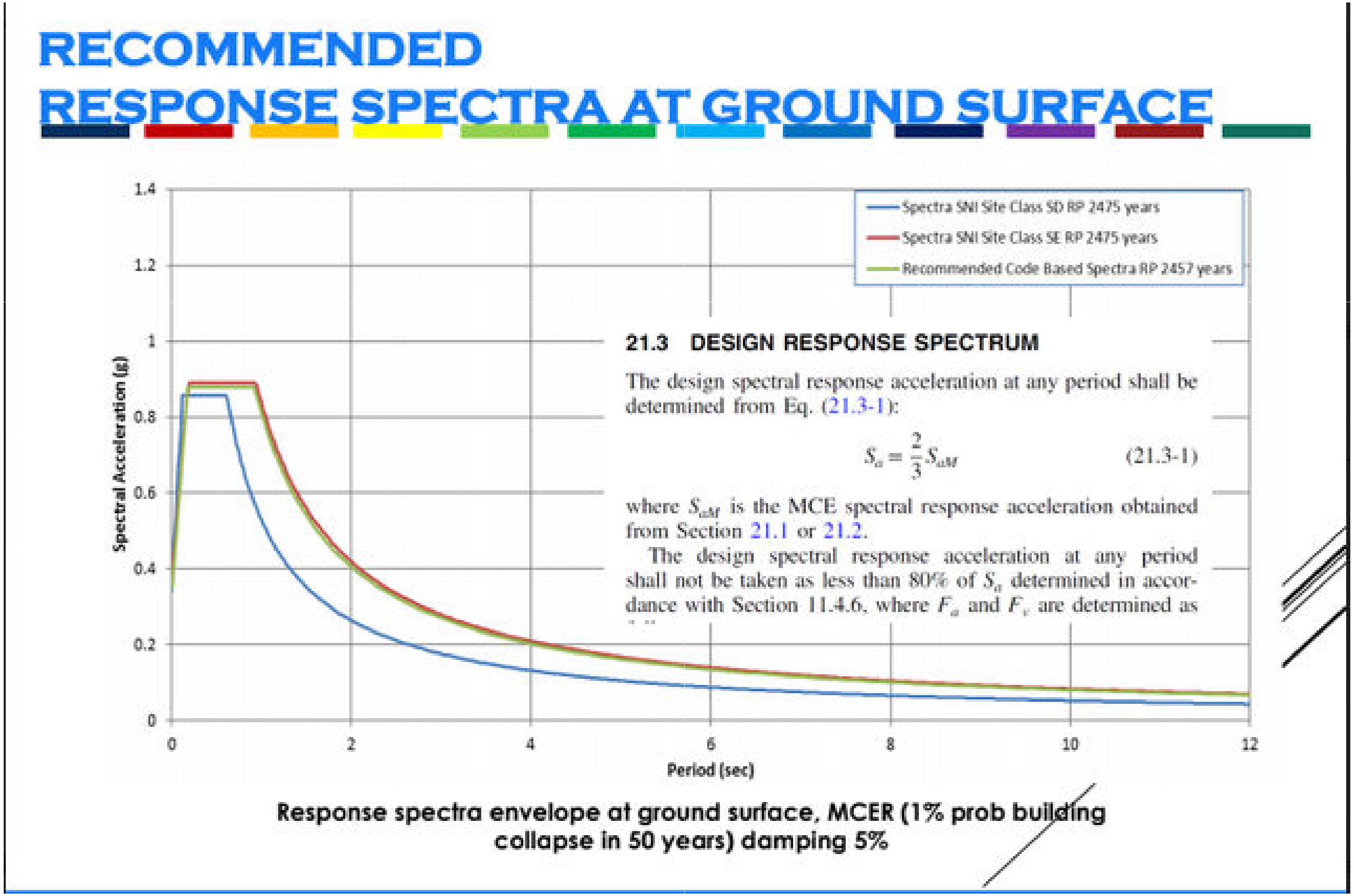
SLE RESPONSE SPECTRA (Wayan Sengara, 2019)

RESPONSE SPECTRA AT GROUND SURFACE



Response spectra envelope at ground surface, SLE (50% PE in 30 years) damping 2.5%

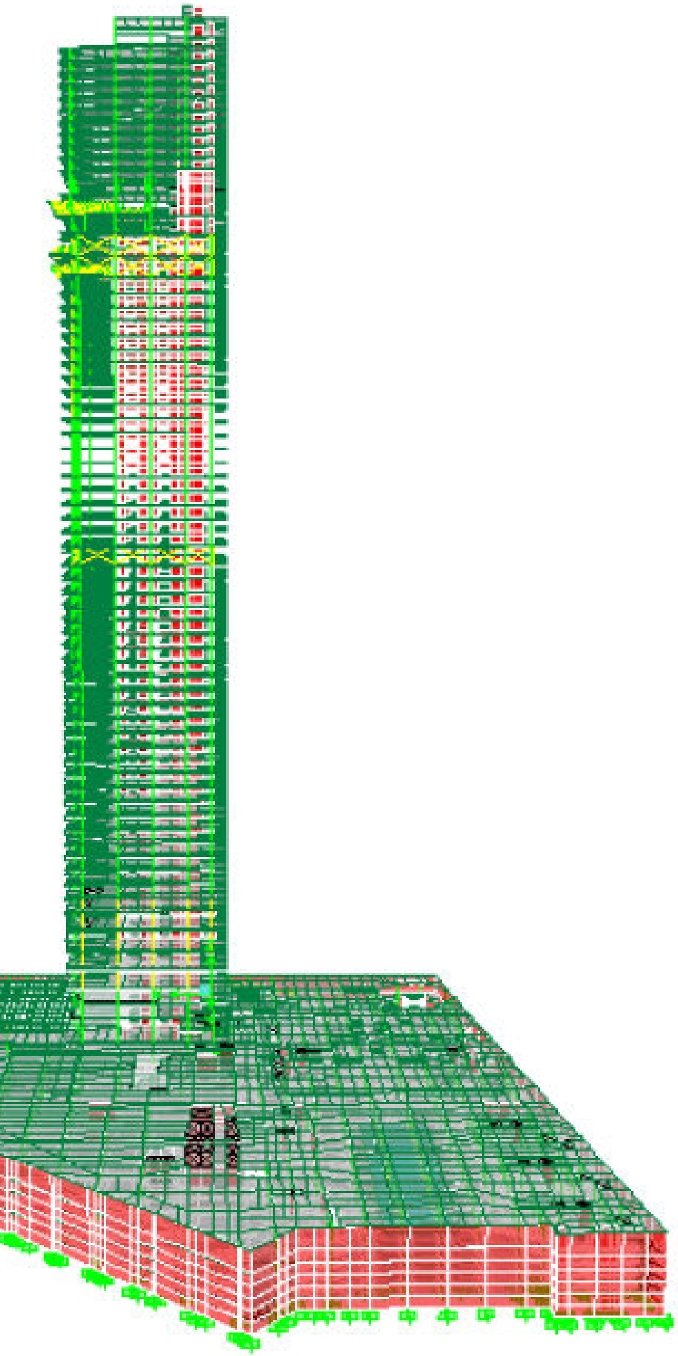
MCEr response spectra (Wayan Sengara, 2019)

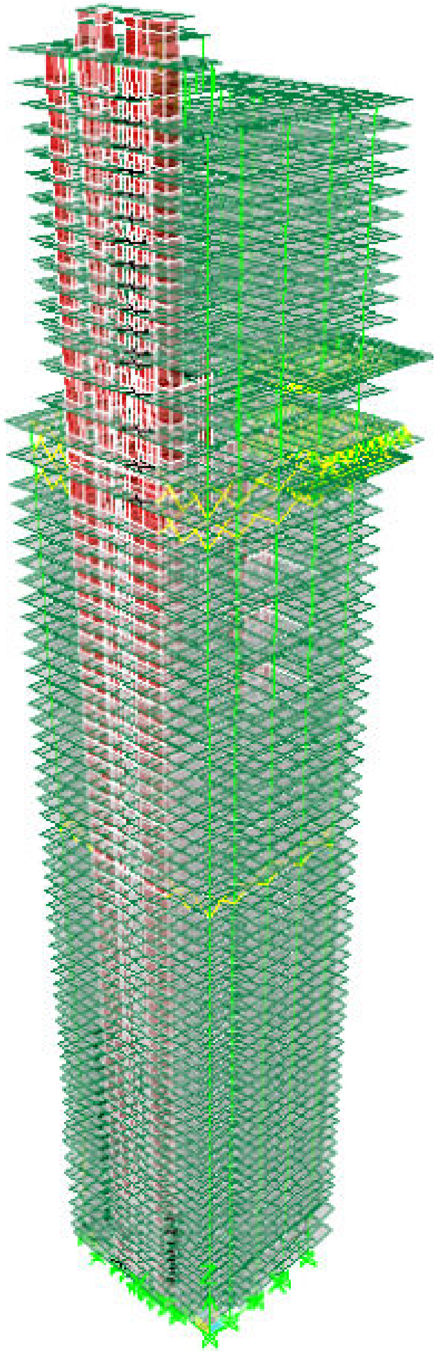


Perform 3D Modelling

tructures Element Modelling:

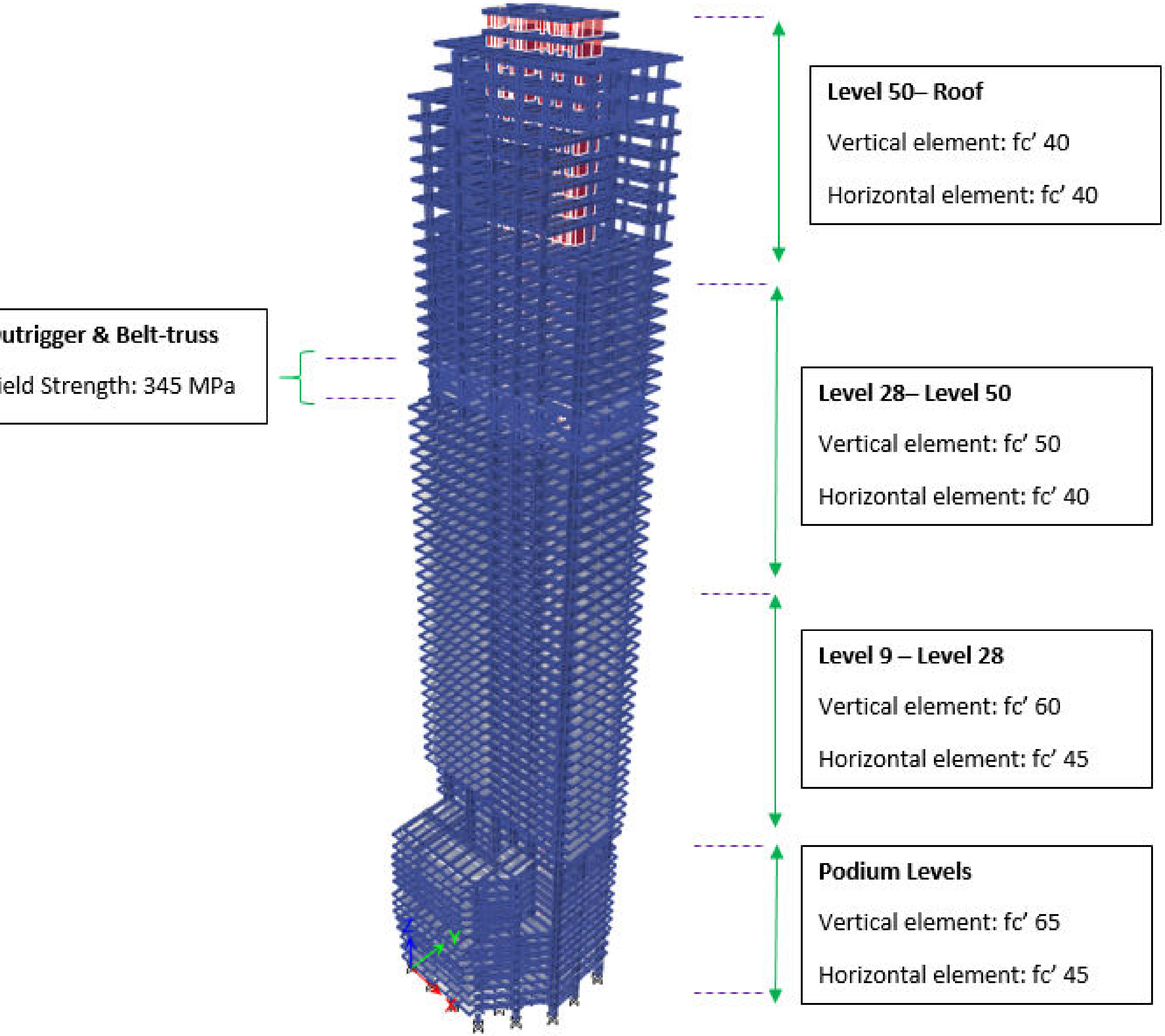
No	Element	Modelling	Non-linear Characteristic
1	**Primary Beam**	Line element	Flexural hinge rotation
2	**Secondary Beam**	Line element	Elastic
3	**Column**	Line element	PMM hinge rotation
4	**Shear Wall**	Fiber Element	a. Stress-Strain of concrete
			b. Stress-strain of steel
			c. Shear stress-Strain of concrete
5	**Link Beam**	a. Fiber Element (Concrete)	a. Stress-Strain of concrete
		b. Bar Element (Diagonal bar)	b. Stress-strain of steel
			c. Shear stress-strain of concrete
6	**Belt-Truss & Outrigger**		
	a. Top & Bottom Chord	a. Line Element	a. Flexural hinge rotation
	b. Diagonal Brace	b. Bar Element	b. Stress-strain of steel





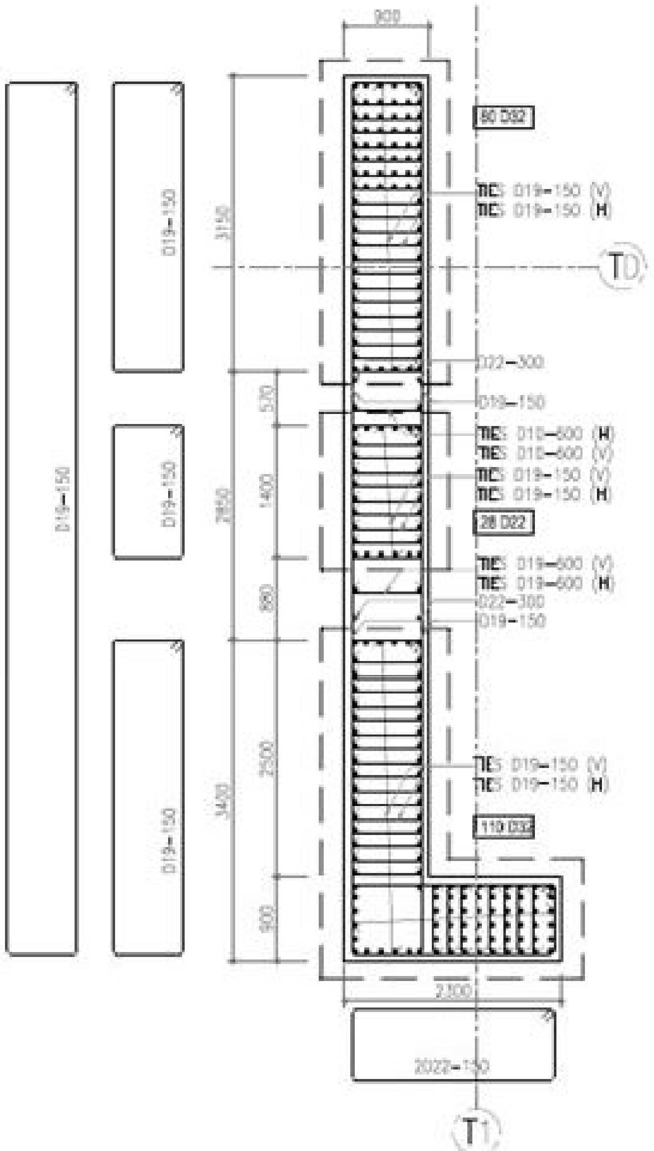
STRUCTURE MODELIN
FOR TOWER 1
THAMRIN NINE PROJE
72 STORIES

TOWER 2 MODEL



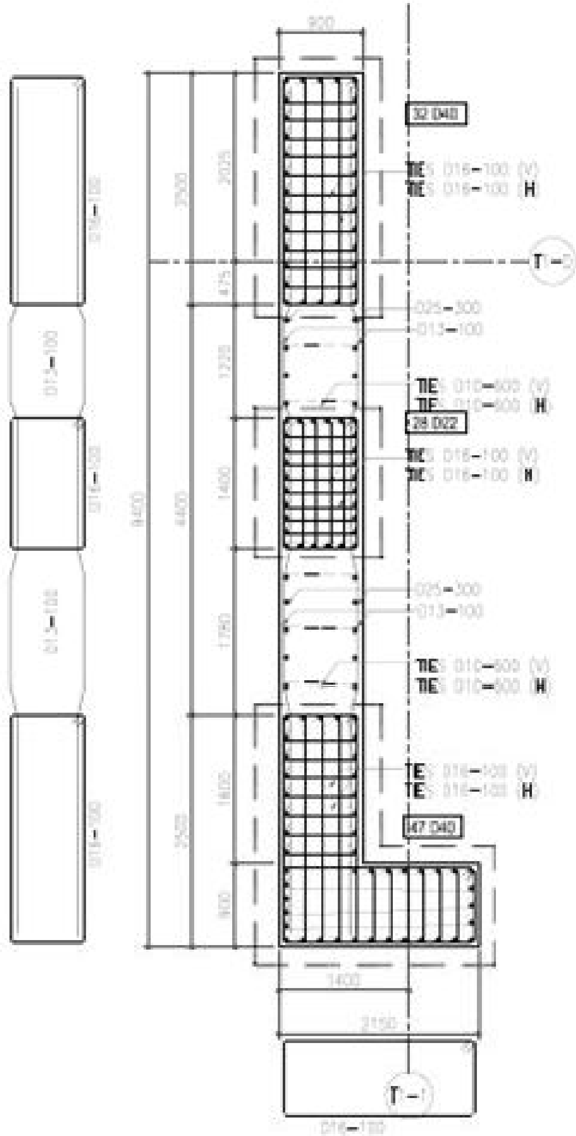
THE RESULTS: OK !

REINFORCING BARS FOR CORE WALL BEFORE AND AFTER PERFORMANCE BASED DESIGN



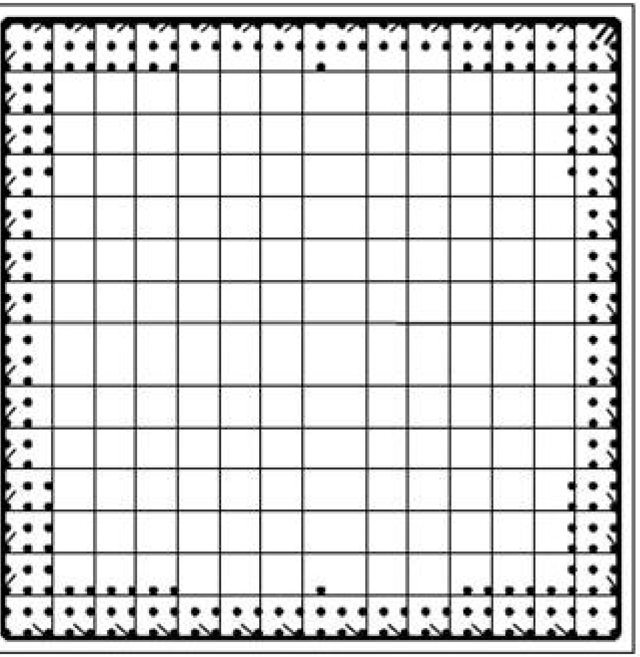
SHEARWALL REINFORCEMENT DETAIL- W1 (LT. 1 ~ LT. 6)
SCALE 1/50

BEFORE PBD

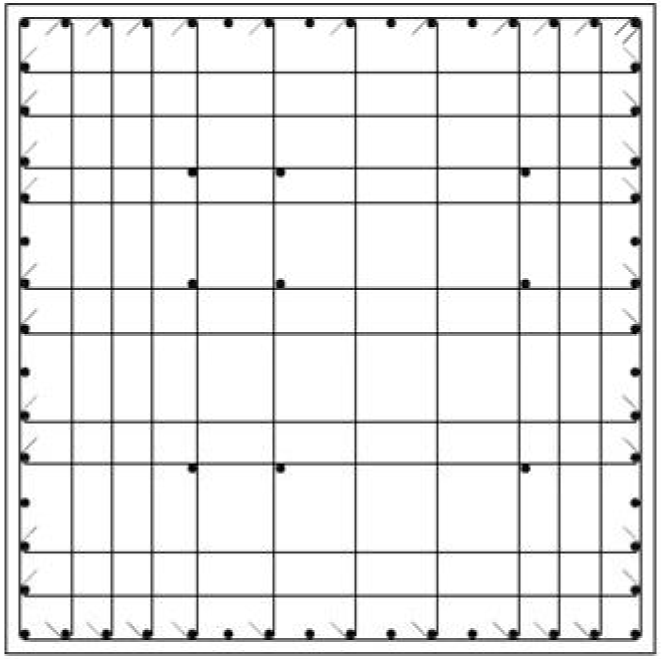


SHEARWALL REINFORCEMENT DETAIL- W1 (LT. GF ~ LT. 6)
SCALE 1/50

AFTER PBD



BEFORE PBD



AFTER PBD

REINFORCING BARS FOR COLUMN BEFORE AND AFTER PERFORMANCE BASED DESIGN

RISK BASED MODELING

INDONESIAN CODE: GUIDE LINE FOR SEISMIC RESISTANT DESIGN FOR BUILDINGS: SNI 1726 – 2012 STATES THE LIFE TIME RISK EQUAL TO 0.01 FOR 50 YEARS DESIGN LIFE TIME

THE QUESTION: WHAT IS THE LEFE TIME RISK ACHIEVED WITH THE CURRENT DETERMINISTIC DESIGN PROCEDURE,

FOR A SUPER TALL BUILDING !

ASCE STANDARD

ASCE/SEI

7-16

Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASCE

SEI

TARGET RELIABILITY ASCE 7 - 2016

Table 1.3-2 Target Reliability (Conditional Probability of Failure) for Structural Stability Caused by Earthquake

Risk Category	Conditional Probability of Failure Caused by the MCE_R Shaking Hazard (%)
I & II	10
III	5
IV	2.5

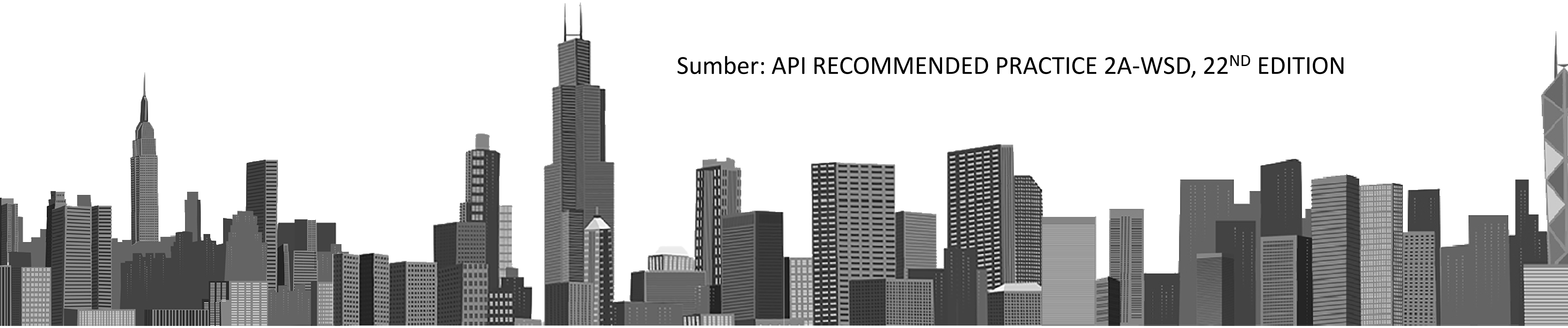
Risk Target American Petroleum Institute (API)

posure Category	P_f
L1	$4 \times 10^{-4} = 1/2500$
L2	$1 \times 10^{-3} = 1/1000$
L3	$2.5 \times 10^{-3} = 1/400$

Life Safety Category	Consequence Category		
	C-1, High Consequence	C-2, Medium Consequence	C-3, Lo Conseque
S-1 manned-nonevacuated	L-1 [a]	L-1 [a]	L-1 [a]
S-2 manned-evacuated	L-1	L-2	L-2
S-3 unmanned	L-1	L-2	L-3

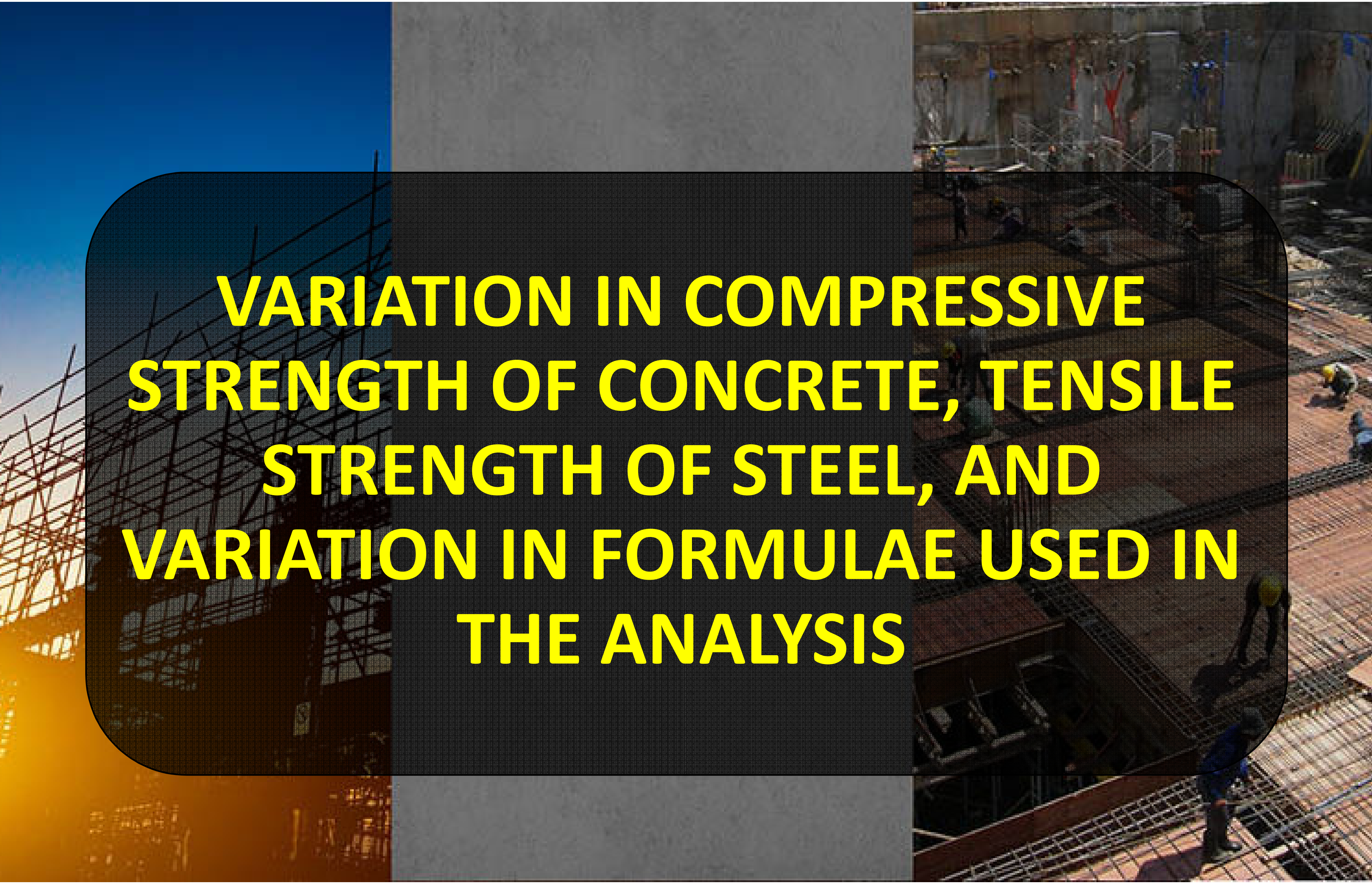
[a] Manned-nonevacuated platforms are presently not applicable to the U.S. GoM waters platforms are normally evacuated ahead of hurricane events. The metocean design crite Section 5 have not been verified as adequate for manned-nonevacuated in the U.S. GoM. How the winter storm, sudden hurricane, and earthquake criteria for the U.S. GoM have been verifi adequate for the manned-nonevacuated situation occurring during those events when platforms U.S. GoM waters are not normally evacuated.

Sumber: API RECOMMENDED PRACTICE 2A-WSD, 22ND EDITION

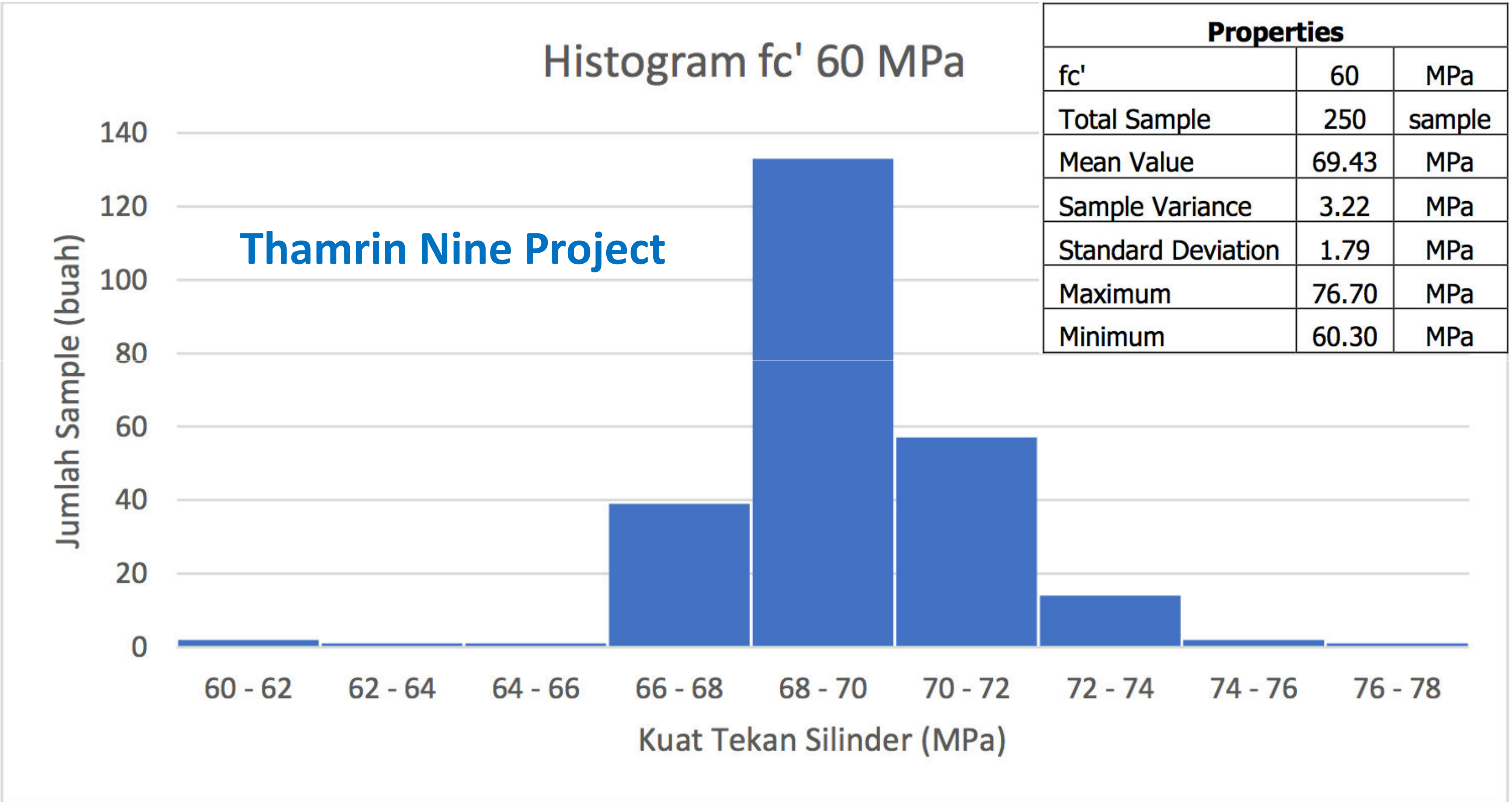


FOR A SUPER TALL BUILDING

- THERE IS A NEED TO EVALUATE THE RELIABILITY OF THE STRUCTURE AGAINST EARTHQUAKE HAZARD, EXPLICITLY.
- THE STRUCTURE DESIGNED USING Cs minimum WILL TEND TO PRODUCE A VERY CONSERVATIVE DENSED REINFORCEMENT, IT IS SUGGESTED TO USE A SMALLER Cs .
- RELIABILITY ANALYSIS WILL SHOW WEATHER THE ASSUMPTION OF USING SMALLER Cs IS CORRECT OR NOT.
- PERFORMANCE BASED DESIGN AND RISK BASED DESIGN

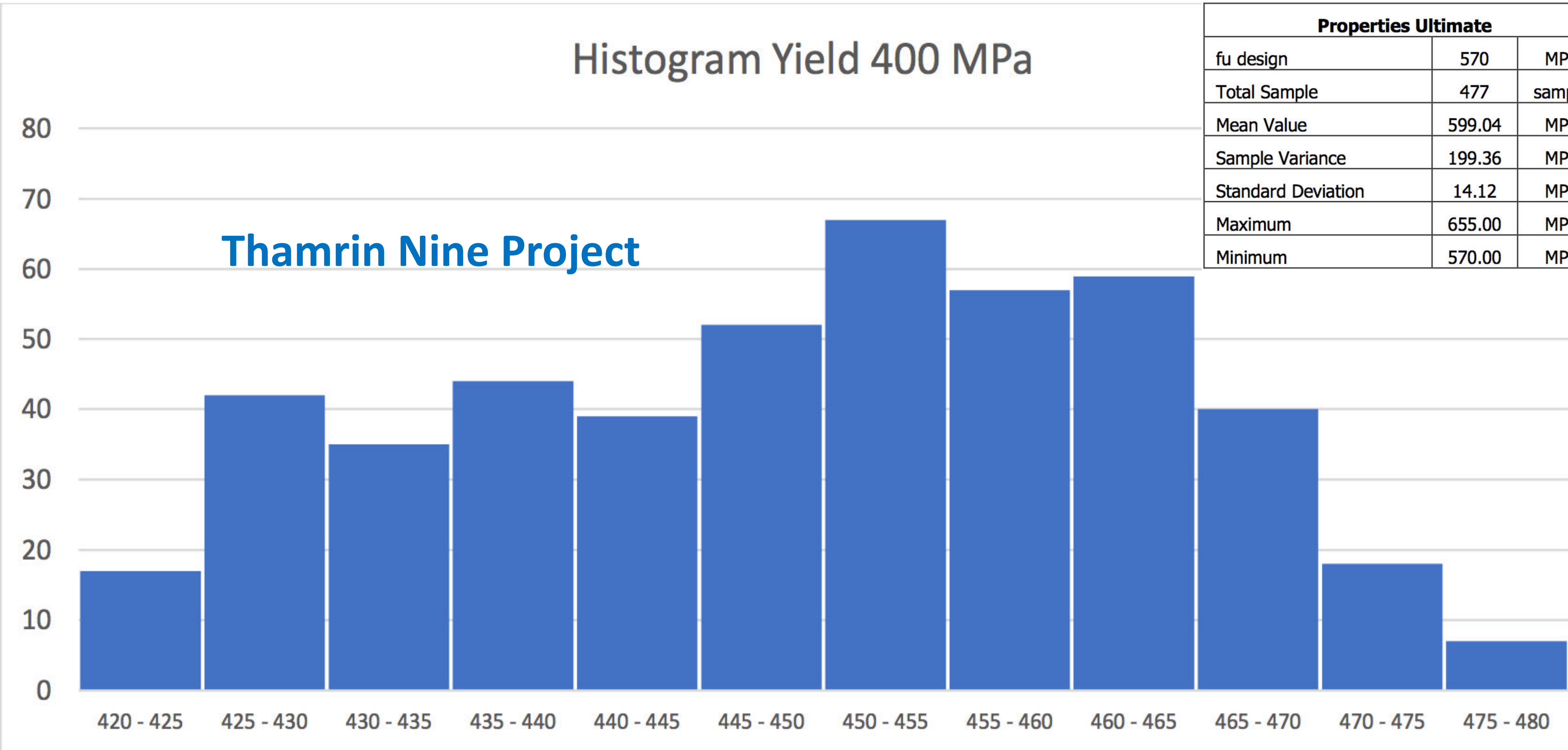

VARIATION IN COMPRESSIVE STRENGTH OF CONCRETE, TENSILE STRENGTH OF STEEL, AND VARIATION IN FORMULAE USED IN THE ANALYSIS

Histogram OF Compressive Strength of Concrete

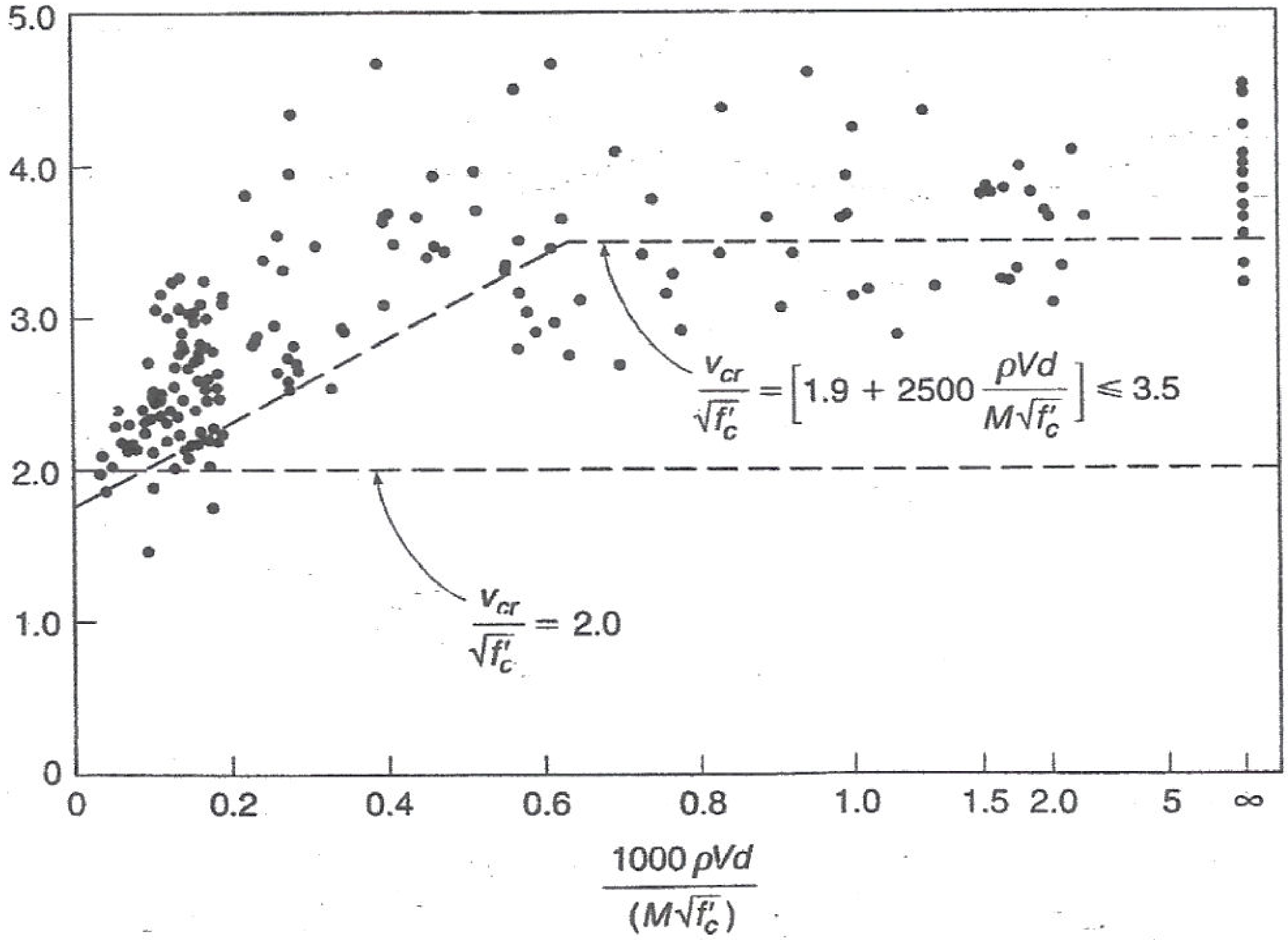


Properties		
fc'	60	MPa
Total Sample	250	sample
Mean Value	69.43	MPa
Sample Variance	3.22	MPa
Standard Deviation	1.79	MPa
Maximum	76.70	MPa
Minimum	60.30	MPa

Histogram of Tensile Strength of Steel



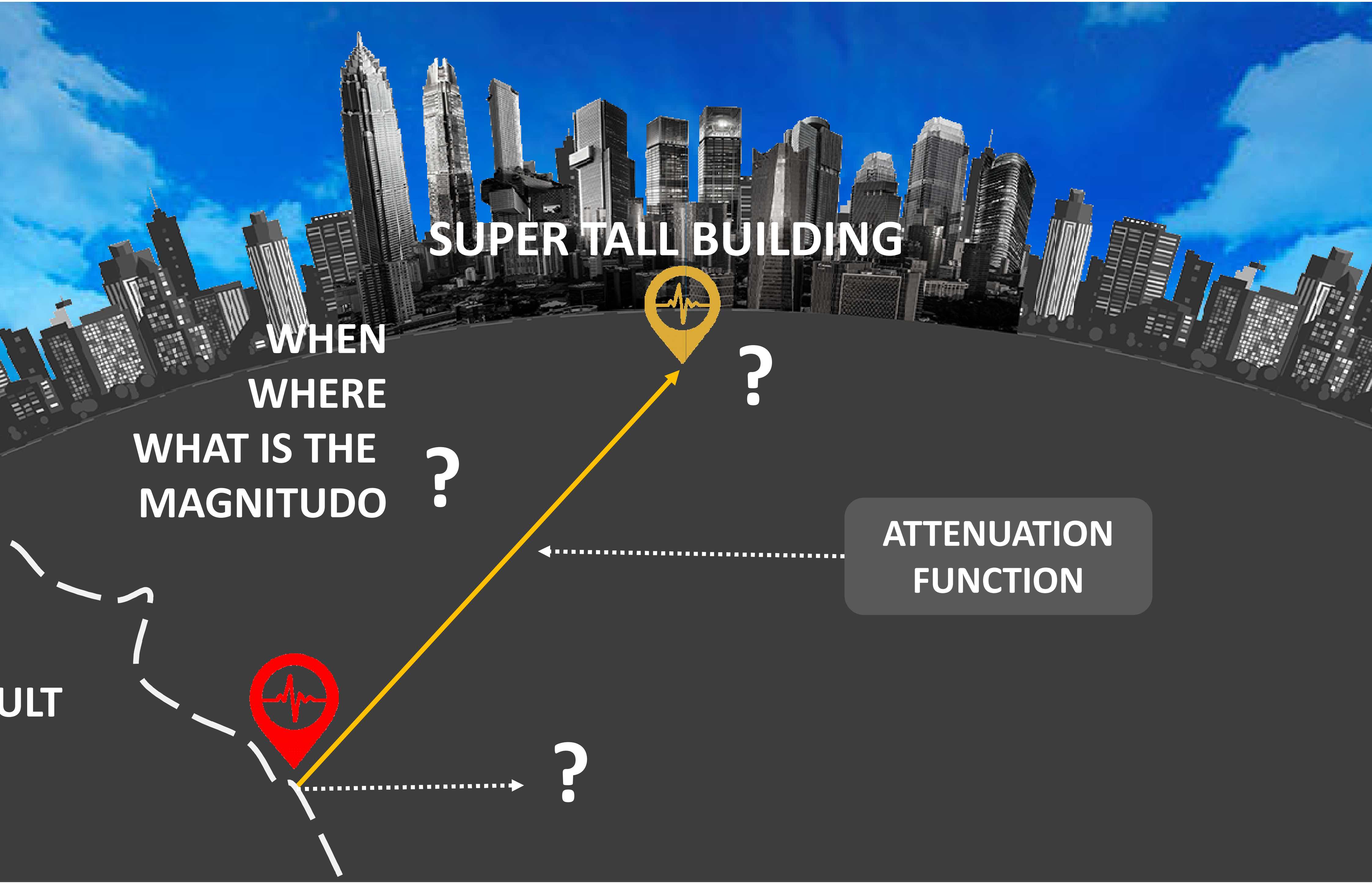
Properties Ultimate		
fu design	570	MPa
Total Sample	477	sample
Mean Value	599.04	MPa
Sample Variance	199.36	MPa
Standard Deviation	14.12	MPa
Maximum	655.00	MPa
Minimum	570.00	MPa



VARIATION IN SHEAR CAPACITY, BETWEEN PREDICTED AND OBSERVED VALUES

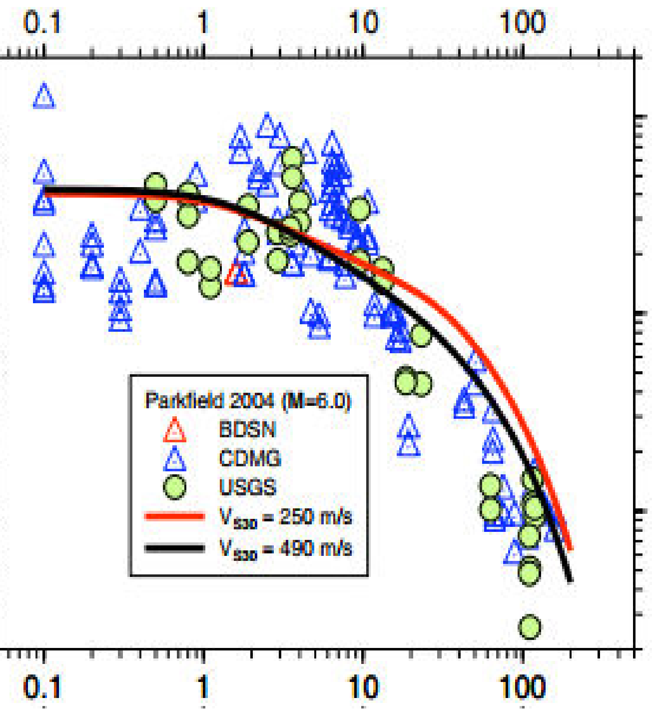
Capacity Variation of Tower 1, Thamrin Nine Project Due to Different Source of Time History (Sesudah Patrisia 2017)

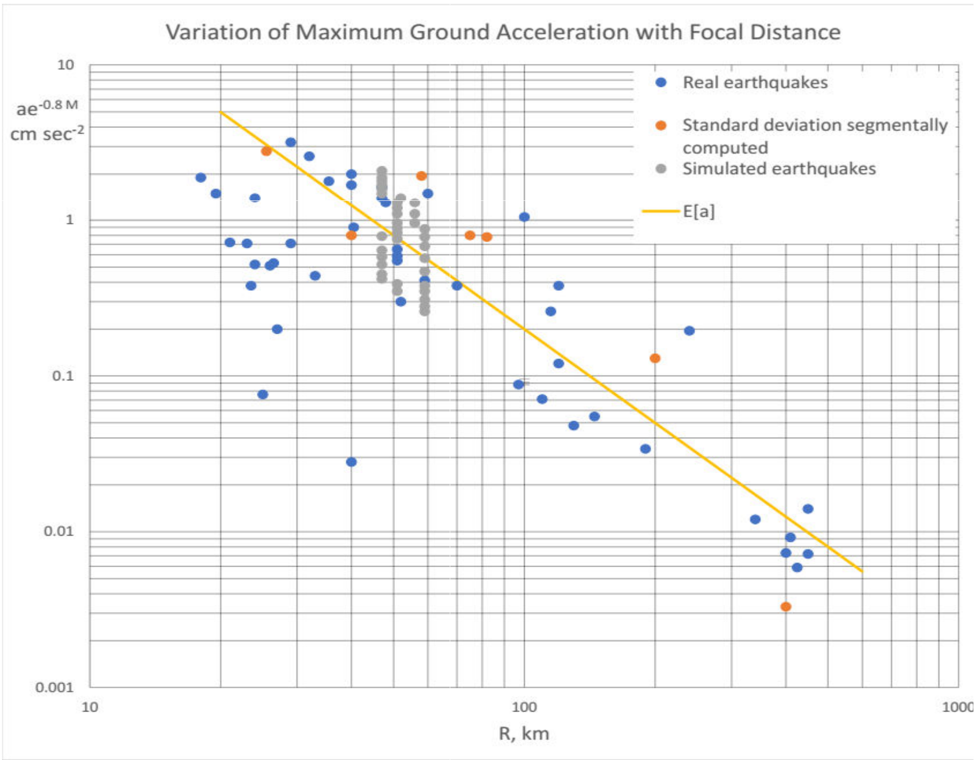
No	Earthquak Record	PGA (g)	Scale	Scaled PGA (g)
1	Loma Prieta	0.4	1.2	0.48
2	Imperial Valley	0.39	1.2	0.468
3	Northridge	0.4	1.05	0.42
4	Chi Chi	0.39	1.31	0.511
5	Kobe	0.43	1.7	0.731
6	Mammoth Lakes	0.42	1.375	0.578
7	Morgan Hill	0.42	2	0.84
8	MYG 013	0.216	5.1	1.104
9	TCU 015	0.187	2.76	0.517
10	TCU 089	0.181	2.75	0.498
11	TCU 120	0.157	1.75	0.275
12	ABY	0.205	3	0.615
13	TAP035	0.241	2.55	0.614
14	Padang	0.272	3	0.816

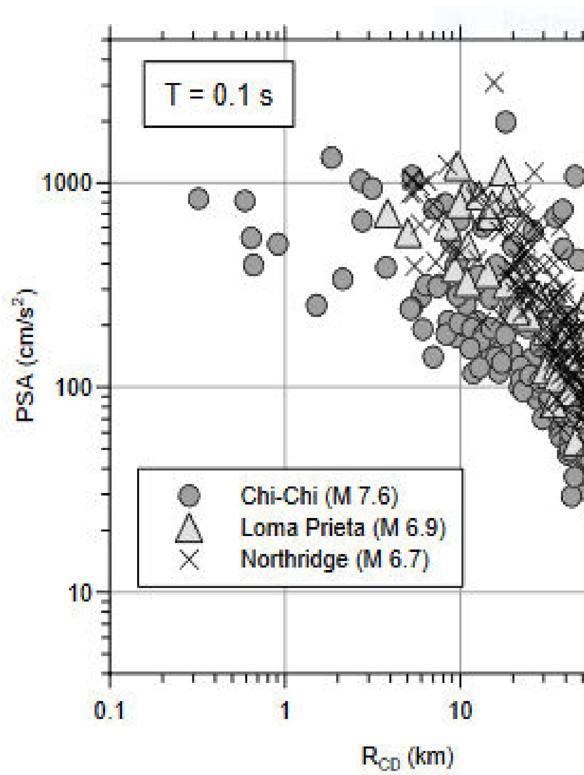

SUPER TALL BUILDING
?
WHEN
WHERE
WHAT IS THE
MAGNITUDO
?
ATTENUATION
FUNCTION
ULT
?

AKURASI FUNGSI ATENUASI TERHADAP DATA PENGUKURAN

FROM 1964 – 2017,
440 ATENUATION FUNCTION WERE INTRODUCED







PROBABILITY OF FAILURE OR RISK

- FAILURE = IF **EARTHQUAKE ACCELERATION** IS GREATER THAN **DESIGN ACCELERATION** (OR CAPACITY ACCELERATION OF A BUILDING), THIS STATEMENT IS GIVEN BY ANNUAL HAZARD FOR A CERTAIN REGION OBTAINED FROM PSHA
- SINCE THE CAPACITY IS RANDOM VARIABLE, WE HAVE TO INTEGRATE FOR ALL THE POSSIBLE CAPACITIES.

RISK FORMULATION

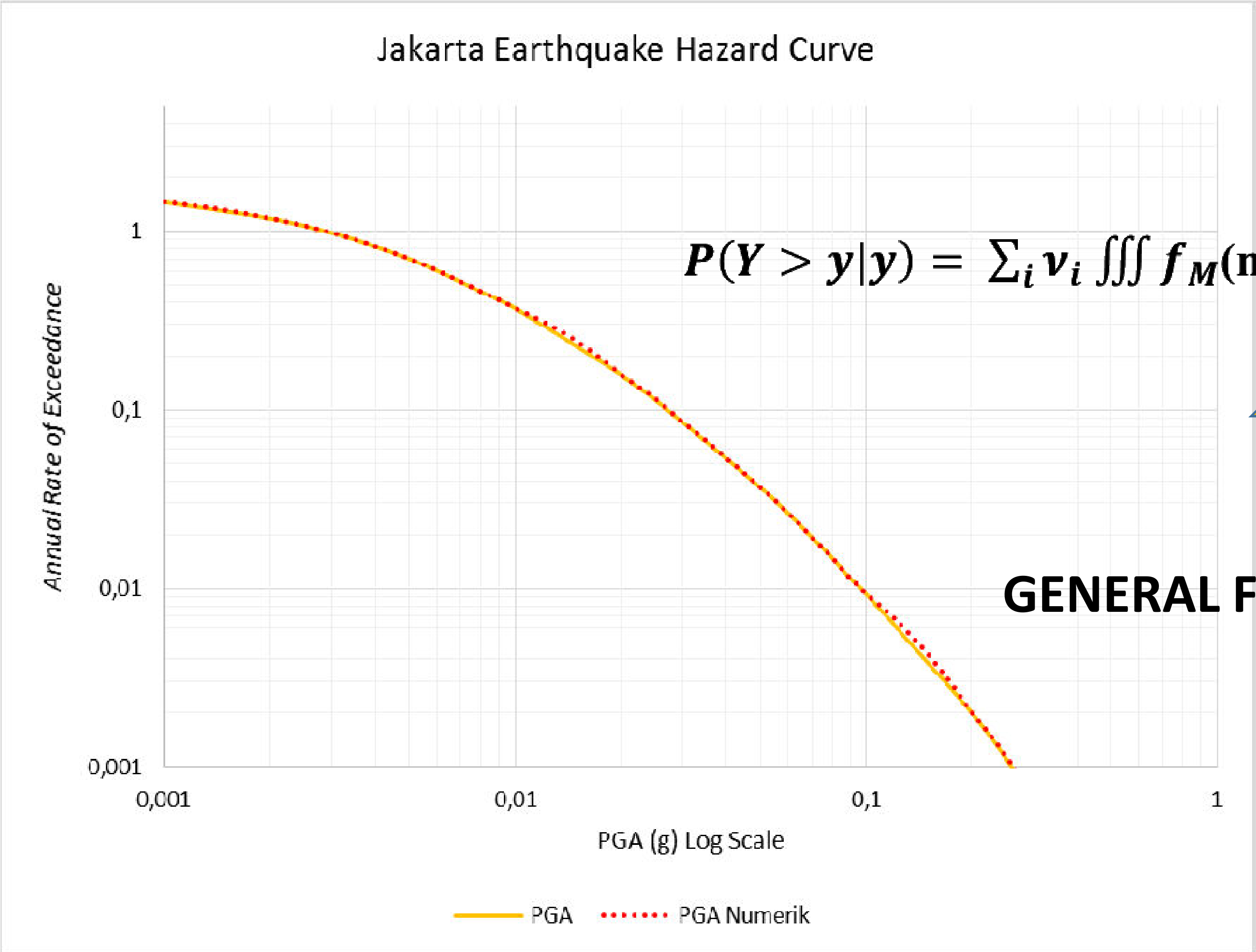
$$P_F = T \times \int P(Y > y \mid r) \; \frac{1}{\sqrt{2\pi}\beta r} \exp\left\{ -\frac{1}{2} \left[\frac{\ln r - \ln \mu + 0.5 \ln(1 + \Omega_p^2)}{\beta} \right]^2 \right\}$$

ANNUAL HAZARD CURVE FROM PSHA FOR A CERTAIN LOCATION

CAPACITY OF A BUILDING OR FRAGILITY FUNTION

$$P(Y > y|y) = \sum_i \nu_i \iiint f_M(\mathrm{m}) f_R(\mathrm{r}) f_\varepsilon(\varepsilon)\ \mathrm{P}(\mathrm{Y}>\mathrm{y}|\mathrm{m},\mathrm{r},\varepsilon)\ \mathrm{dm\ d}$$

GENERAL FORMULATION OF PSHA



HAZARD CURVE OF JAKARTA RESULT OF PSHA

UNCERTAINTY IN STRUCTURE CAPACITY

ESISTANT $$\Omega_R^2 = \Omega_p^2 + \Omega_D^2 + \Omega_S^2 + \Omega_M^2$$

ECORD TO RECORD VARIATION

LIMITED DATA CORRECTION

STRUCTURE IDEALIZATION

MATERIAL VARIABILIT

$$\beta = \sqrt{\ln(1 + \Omega_R^2)}$$: combined variability

Non-Linear Time History Analysis

There are 2 sets of time history load which will be used :

1. 7 time history load from outside Indonesia
2. 7 time history load that are generated in Jakarta

i. Imperial Valley-1940 El Centro

ii.Loma Prieta-1989

iii.Chi-Chi-1999

iv.Kobe-1995

v.Northridge-1994

vi.Mammoth Lakes

vii.Morgan Hill

i. Benioff-TCU120

ii.Benioff-TCU136

iii.Megathrust-212V5

iv.Megathrust-TCU089

v.Megathrust-MYG013

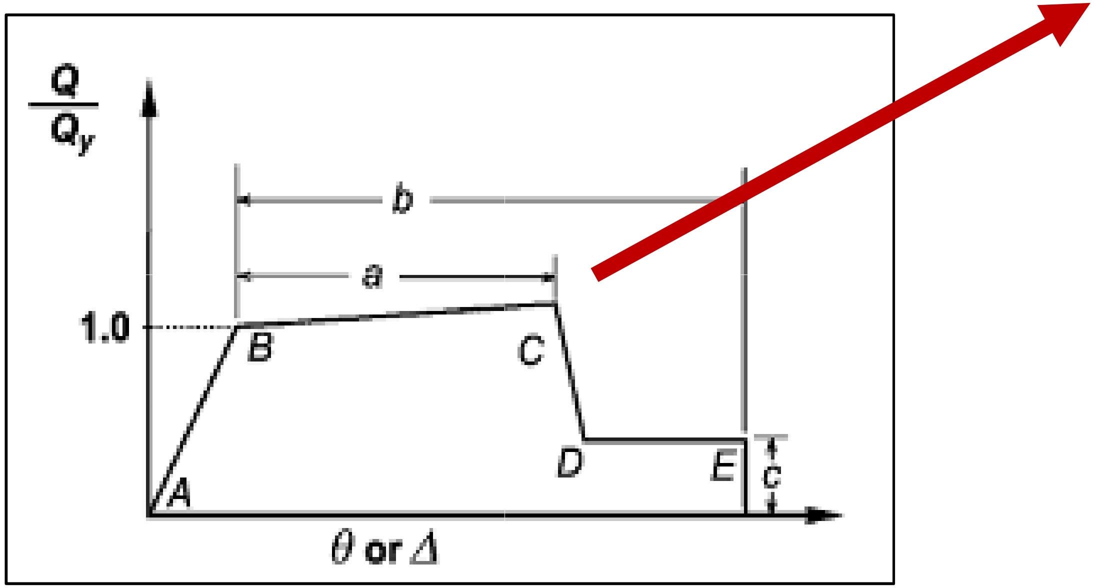
vi.Shallow Background ABY

vii.Shallow Crustal MEL

Nonlinear Parameter of Elements

- **BEAMS & COLUMNS**

REACHING COLLAPSE PREVENTION STATE



- Moment-rotation is integrated of moment-curvature along the plastic zone length (Lp) (assumed Lp = 0.5 x Element Depth)
- Moment-rotation of columns depends on the axial force subjected to column
- Acceptance criteria refer to ASCE 41-13

Table 1. Life Time Risk of Several Building with Outrigger and Belt Truss Designed with C_s Smaller than $C_{s\ minimum}$ Required by Indonesian Code

No.	A	B	T (sec)	$C_{s\ min}$ Indonesian Code	$C_{s\ design}$	$C_{s\ design}$ / $C_{s\ minimum}$	Life Time Risk	Reference
1	60	2	5.6	0.0252	0.0172	0.68	5.5×10^{-4}	1
2	80	2	7.8	0.0332	0.0183	0.55	1.1×10^{-2}	4
3	60	2	6.4	0.0252	0.0169	0.67	4.2×10^{-4}	3
4	90	2	8.04	0.0315	0.0155	0.50	2.7×10^{-2}	5

A = number of story

B = number of outrigger and belt truss

T = fundamental period of the structure

RISK OF TOWER 1 TH, T = 50 YEARS:

$$\mathbf{0.9 \times 10^{-2}}$$

OR THE ANNUAL RISK:

$$\mathbf{1.8 \times 10^{-4} = 2 \times 10^{-4}}$$

OR EQUIVALENT TO HAVE A PROBABILITY OF GETTING A RED BALL FROM A BOX CONTAINING **2 RED BALLS** DAN **9998 WHITE BALLS**,

TOTAL = 10000 BALLS

AND THE STRUCTURE PERFORMANCE = **LIFE SAFE**

T = 50 YEARS:

0.37×10^{-2}

OR ANNUAL RISK = 0.74×10^{-4}

CONCLUSION (1)

- THE PERFORMANCE BASED DESIGN HAS BEEN APPLIED TO TOWER 1 AND TOWER 2 TO IMPROVE CONSTRUCTABILITY OF THE STRUCTURE
- THE USE OF $\mathbf{C_{s\ design}}$ SMALLER THAN THE $\mathbf{C_{s\ minimum}}$ MEET THE REQUIREMENT OF ASCE OR SNI CODE. THE POTENTIAL OF THIS ASSUMPTION MAY BE STUDIED FUTHER MORE.
- PBD GIVES MORE REASONABLE REINFORCEMENTS WITHOUT SACRIFICING SAFETY AND RELIABILITY, AND FINALLY SAFE MONEY

CONCLUSION (2)

- A SIMPLE RELIABILITY MODEL HAS BEEN DERIVED BASED ON TOTAL PROBABLITY THEOREM, e.g., BY COMBINING ANNUAL HAZARD FROM **PSHA** AND THE FRAGILITY FUNCTION **R** THROUGH RISK INTEGRAL PROSEDURE
- STATISTICS OF CAPACITY **R** ARE OBTAINED BY PUSHING THE STRUCRURE UNTIL REACHING COLLAPSE STATE FOR A CERTAIN HISTORICAL RECORD, e.g., BY PERFORMING NON LINEAR INCEREMENTAL TIME HISTORY ANALYSIS.
- COEFFICIENT OF VARIATION OF **R** VARIES FROM 0. 12 – 0.65

CONCLUSION (3)

- THE CAPACITY OF A SUPER TALL BUILDING AGAINST EARTQUAKE HAZARD DEPEND ON THE LINK BEAM IN THE CORE WALL AS A DISSIPATOR ELEMENTS.
- LIFE TIME RISK OF THE BUILDING IS LESS THEN 10^{-2}, THE RELIABILITY IS DOMINATED BY THE VARIABILITY OF RECORD TO RECORD VARIATION.
- TARGET RELIABILITY EQUAL TO $\mathbf{10^{-2}}$
- THE OUTRIGGER AND BELT TRUSS ARE DESIGNED TO REMAIN IN ELASTIC STATE, THE COMPONEMT PROBABILITY OF FAILURE IS VERY SMALL.

THAMRIN 9 PROJECT

IN THE PROCESS OF CONSTRUCTION

THE BELT TRUSS AT 35th floor

THE CONSTRUCTION TEAM

THANK YOU