SEISMIC EVALUATION OF BUILDING FRAMES USING HIGH-PERFORMANCE STEEL

Muslinang Moestopo

JSSC Japanese Society of Steel Construction

The Japan Iron and Steel Federation

ISSC INDONESIAN SOCIETY OF STEEL CONSTRUCTION
Masyarakat Konstruksi Baja Indonesia

JOINT RESEARCH PROJECT:

The Japan Iron and Steel Federation

e Japan Iron and Steel Federation

JSSC Japanese Society of Steel Construction

Society of Steel Construction

ISSC INDONESIAN SOCIETY OF STEEL CONSTRUCTION
Masyarakat Konstruksi Baja Indonesia

Indonesian Society of Steel Construction

AGENDA:

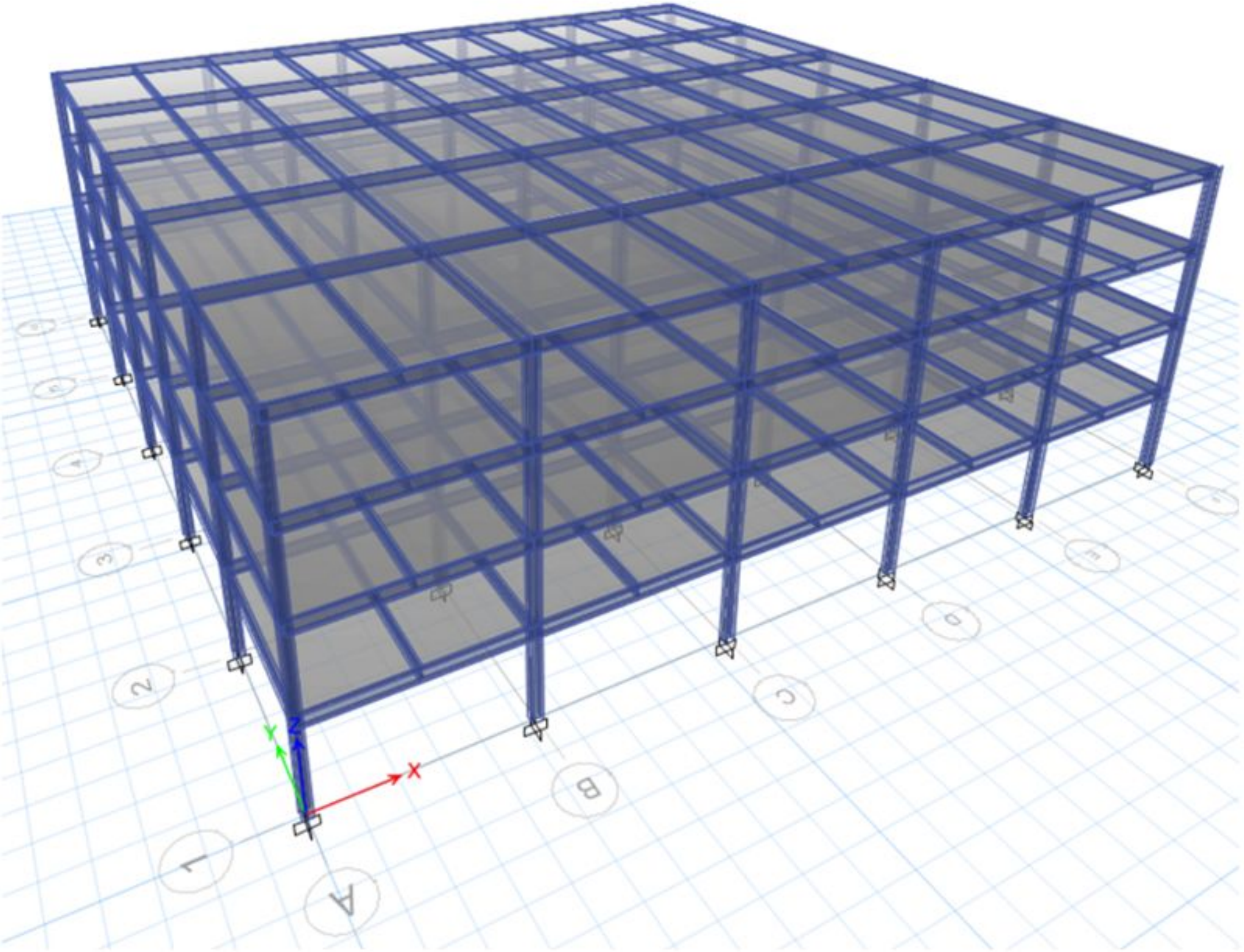
1. **Introduction :**
   Need for reliable seismic resistant structures
2. **Design of Steel Building Frames**
   Using High-performance Steel
3. **Seismic Performance of Steel Building Frames**
4. **Discussion**
5. **Conclusion**

1. INTRODUCTION

- The need for reliable seismic resistant structures is indispensable for earthquake prone area such as Indonesia.
- The need for a higher performance steel material is essential to secure the performance of seismic resistant structure.
- The Indonesian seismic resistant building codes have been updated including the seismic provisions for structural steel buildings.

 To evaluate the seismic performance of structural steel building design using the SN490B steel as compared to the SS400 steel (Push-over analysis)

2. DESIGN OF STEEL BUILDING FRAMES



Four-story Office Building
5 X 8.00 M in each direction

Location : Bandung, Indonesia
Soft-soil

Material : **SS400** and **SN490B**

STEEL MATERIAL

	SS400	SN490B
Yield stress, F_y, MPa	235	325
Tensile stress, F_u, MPa	400	490
R_y	1.5	1.338

FRAMES

Special Moment Frames :

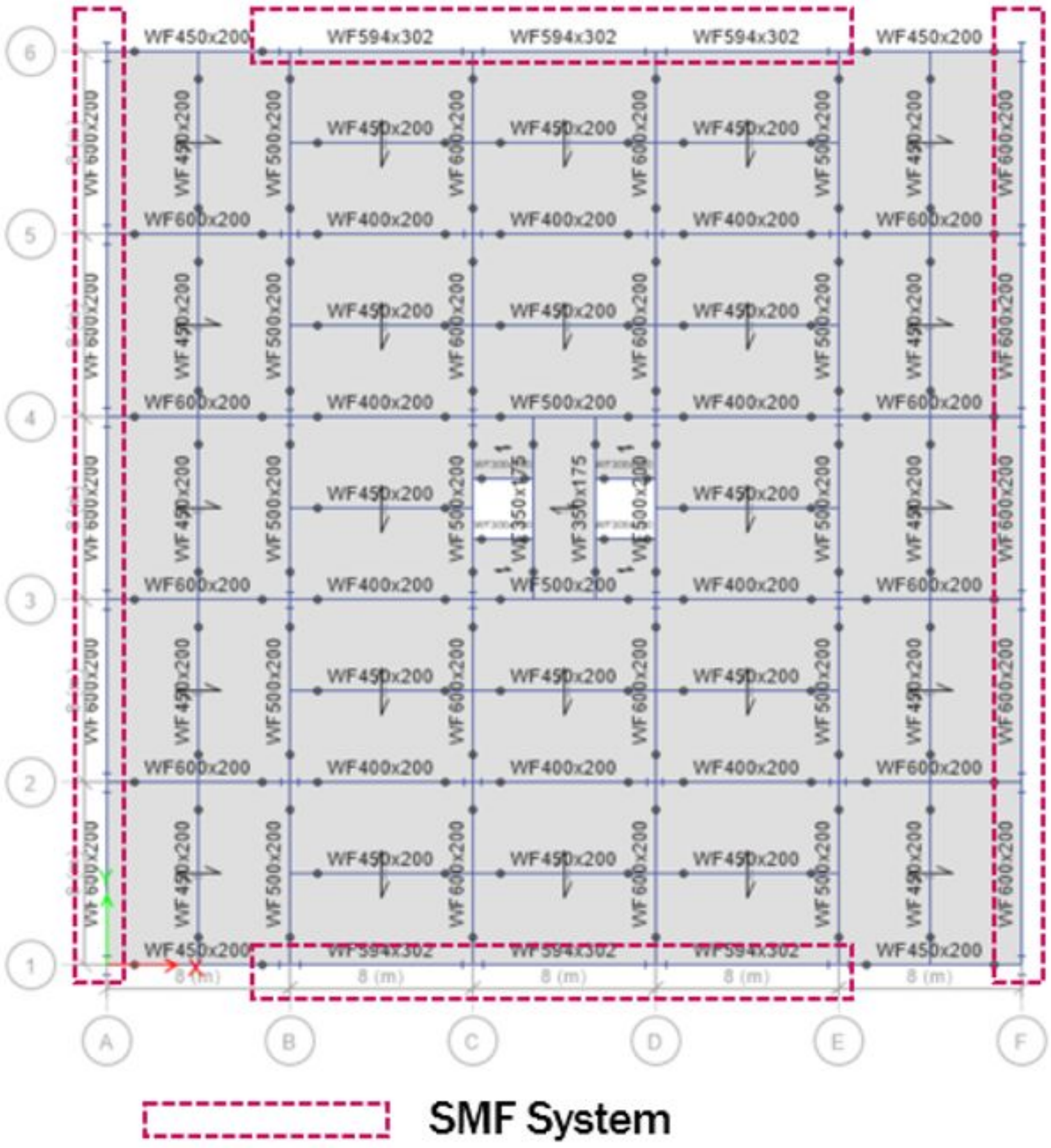
On Building Perimeter

Gravity Frames :

On Building Interior

Building Irregularity :

None (Vertical and Horizontal)



BUILDING STANDARDS

Seismic Loading Other Loadings	SNI 1726 : 2019 SNI 1727 : 2013	ASCE 7-16 ASCE 7-10
Structural Steel Building	SNI 1729 : 2015	AISC 360-2010
Seismic Provision for Structural Steel Building	SNI 7860 : 2015	AISC 341-2010

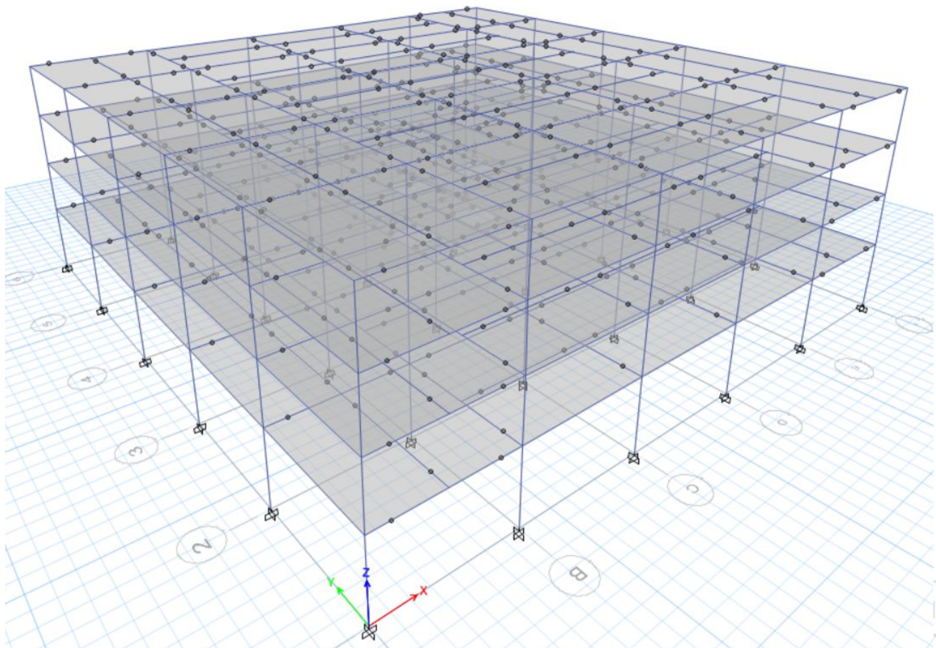
SEISMIC DESIGN PARAMETER

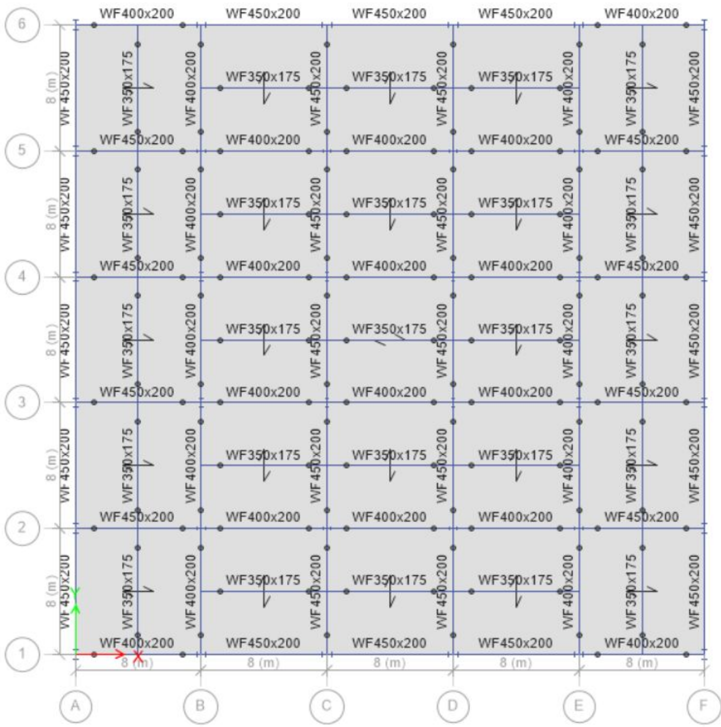
Risk Category	**II**
Importance Factor, **Ie**	**1.0**
SDs **SD_1**	**0.6987 g** **0.6415 g**
Seismic Design Category, **SDC**	**D**
Response Modification Coefficient, **R**	**8**
Overstrength Factor, **Ω_o**	**3**
Deflection Amplification Factor, **C_d**	**5.5**
Redundancy Factor, **ρ**	**1.0**
Drift Limit	**2.5 %**

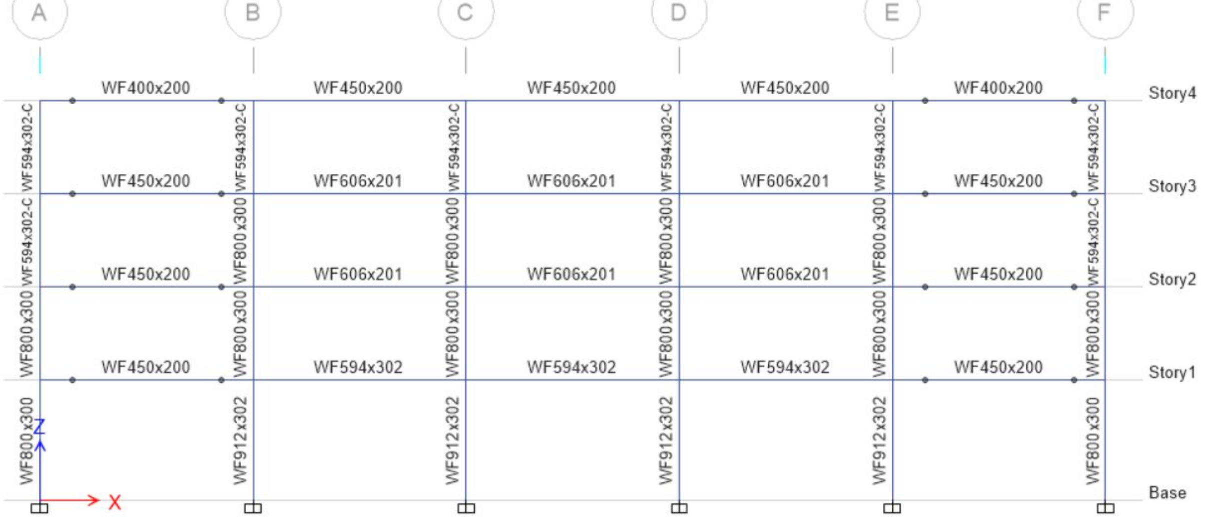
STRUCTURAL DESIGN :

- Frames
- Demand-Capacity Ratio (Beam – Column)
- Interstory Drift
- Structural Weight

SS400 Frame

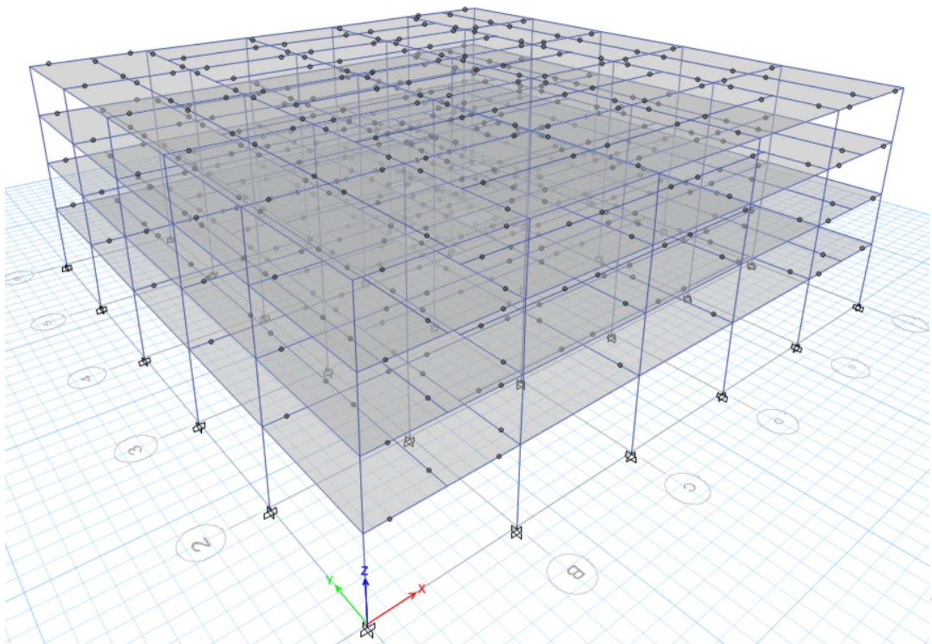

1
2
3
4
5
6
B
C
Z
Y
X

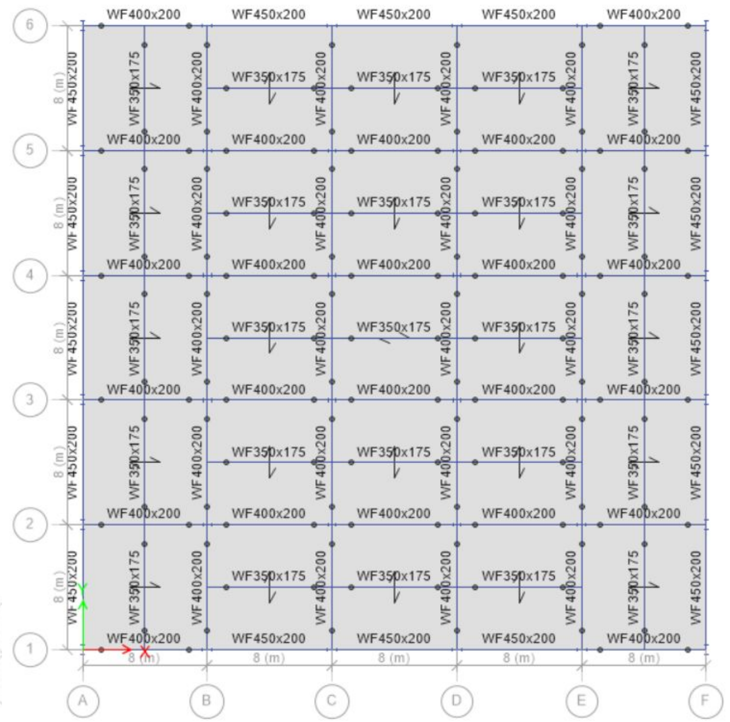

6
5
4
3
2
1
A
B
C
D
E
F
WF400x200
WF450x200
WF450x200
WF450x200
WF400x200
WF450x200
WF400x200
WF400x200
WF400x200
WF450x200
WF400x200
WF450x200
WF450x200
WF450x200
WF400x200
WF450x200
WF350x175
WF400x200
8 (m)
8 (m)
8 (m)
8 (m)
8 (m)
8 (m)

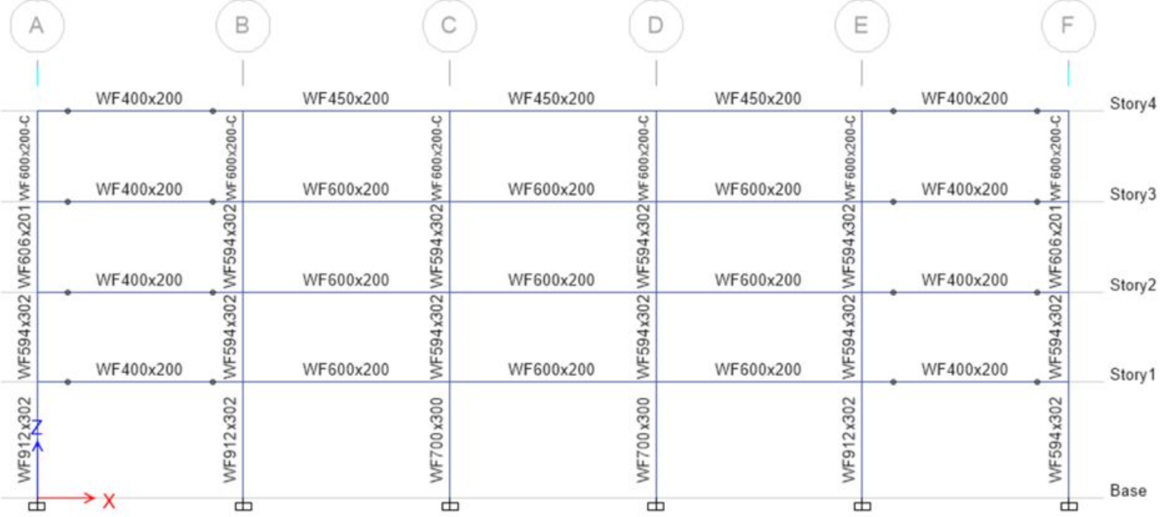

1
A
B
C
D
E
F
WF400x200
WF450x200
WF450x200
WF450x200
WF400x200
Story4
WF450x200
WF606x201
WF606x201
WF606x201
WF450x200
Story3
WF450x200
WF606x201
WF606x201
WF606x201
WF450x200
Story2
WF450x200
WF594x302
WF594x302
WF594x302
WF450x200
Story1
Base
WF594x302-C
WF800x300
WF912x302
WF800x300
Z
X


1
2
6
A
A
A
WF450x200
WF450x200
WF450x200
WF450x200
WF450x200
Story4
WF500x200
WF500x200
WF500x200
WF500x200
WF500x200
Story3
WF600x200
WF600x200
WF600x200
WF600x200
WF600x200
Story2
WF600x200
WF600x200
WF600x200
WF600x200
WF600x200
Story1
Base
WF594x302-C
WF800x300
Z
Y

SN490B Frame







D/C RATIO

SPECIAL MOMENT FRAMES

D/C <<< 1.0

- Ductility demand
- Drift limit

Story	Element	SS400		SN490B	
4F	Column	WF594x302	0.345	WF600x200	0.439
	Beam	WF450x200	0.552	WF450x200	0.426
3F	Column	WF594x302	0.400	WF594x302	0.417
	Column	WF800x300	0.393	WF606x201	0.439
	Beam	WF500x200	0.654	WF500x200	0.527
	Beam	WF606x201	0.695	WF600x200	0.588
2F	Column	WF800x300	0.601	WF594x302	0.531
	Beam	WF600x200	0.655	WF500x200	0.605
	Beam	WF606x201	0.735	WF600x200	0.646
1F	Column	WF800x300	0.712	WF700x300	0.607
	Column	WF912x302	0.722	WF912x302	0.574
	Beam	WF600x200	0.598	WF600x200	0.516
	Beam	WF594x302	0.522		

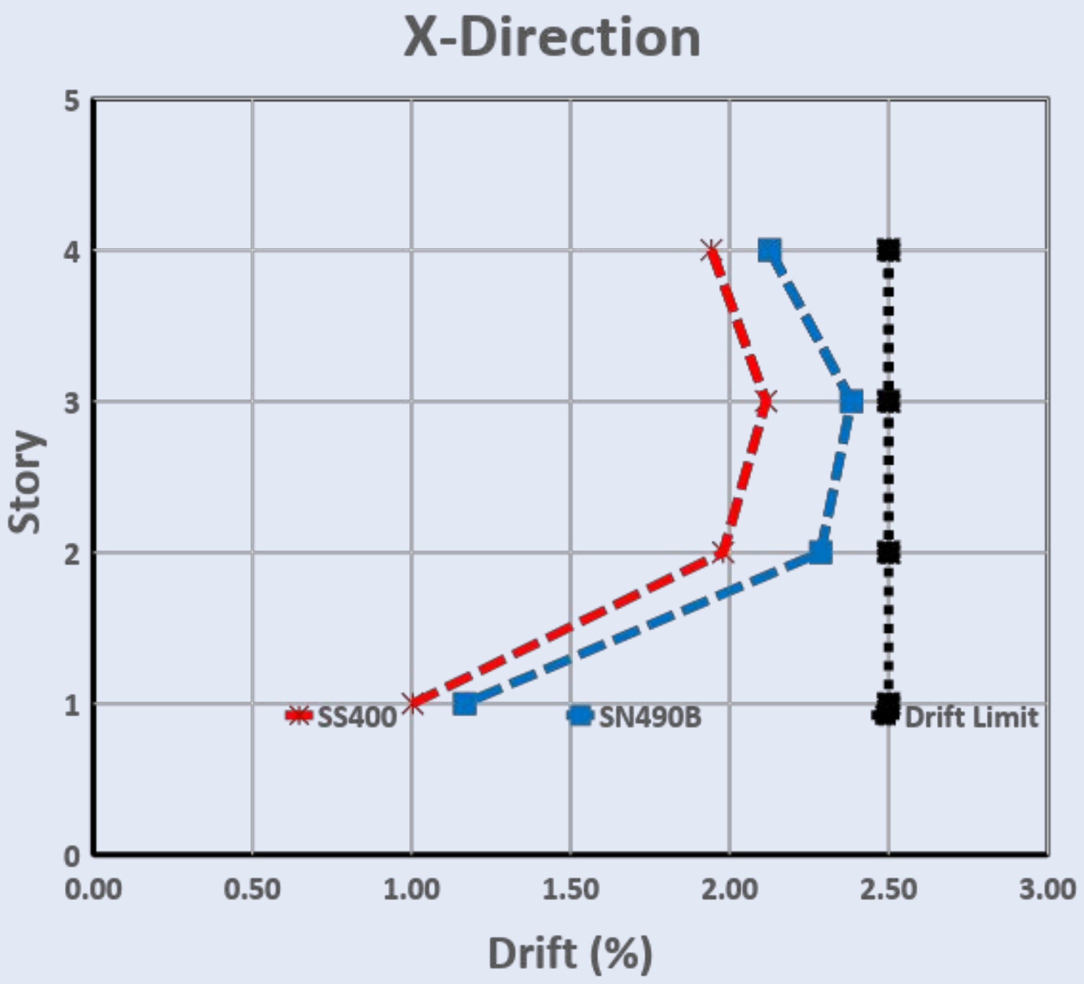
D/C RATIO

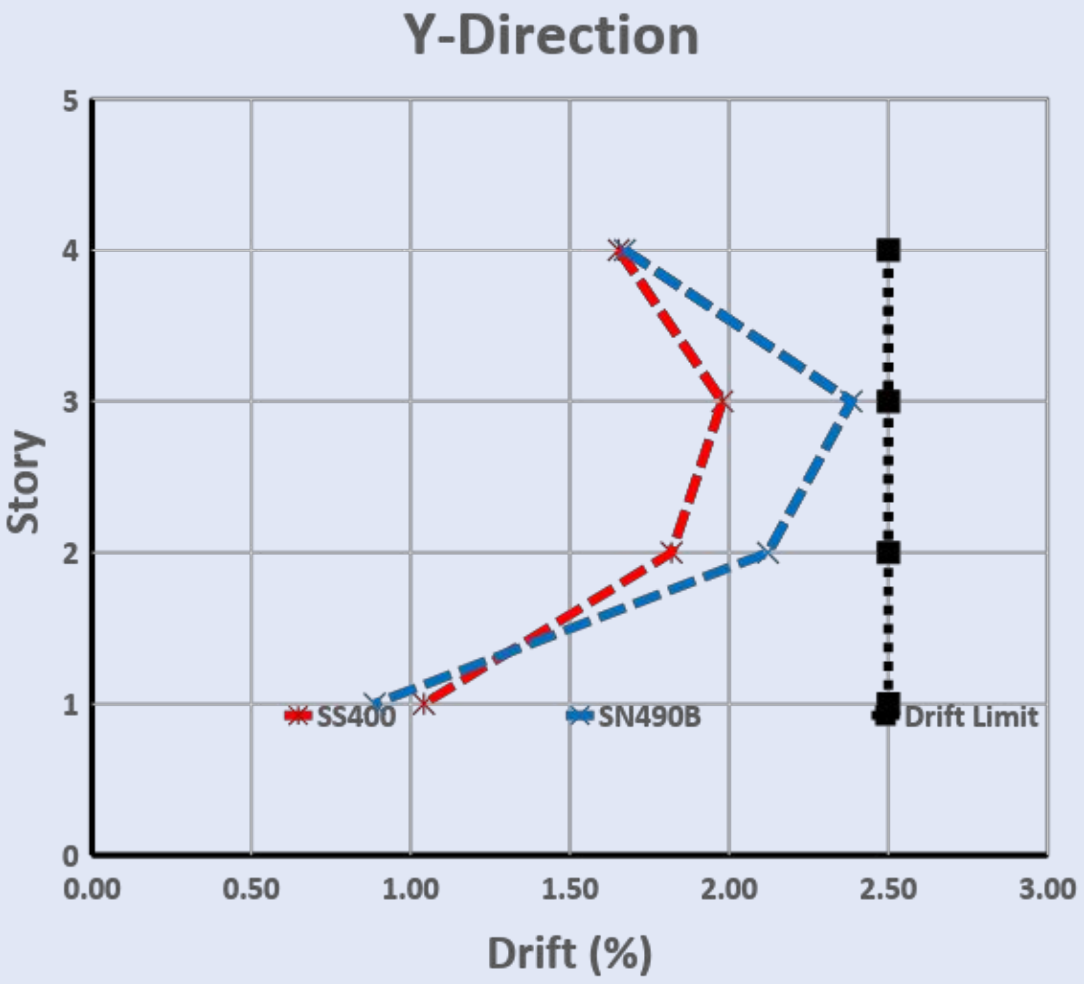
GRAVITY FRAMES

D/C ➡ 1.0

Story	Element	SS400		SN490B	
4F	Column	WF500x200	0.197	WF500x200	0.152
	Beam	WF400x200	0.788	WF350x175	0.878
	Beam	WF450x200	0.843	WF400x200	0.776
3F	Column	WF588x300	0.293	WF600x200	0.394
	Beam	WF400x200	0.954	WF400x200	0.801
	Beam	WF450x200	0.865	WF450x200	0.846
	Beam	WF500x200	0.910	WF500x200	0.888
	Beam	WF600x200	0.902		
2F	Column	WF588x300	0.509	WF588x300	0.399
	Beam	WF400x200	0.954	WF400x200	0.801
	Beam	WF450x200	0.865	WF450x200	0.846
	Beam	WF500x200	0.910	WF500x200	0.888
	Beam	WF600x200	0.902		
1F	Column	WF700x300	0.811	WF588x300	0.686
	Beam	WF400x200	0.954	WF400x200	0.819
	Beam	WF450x200	0.882	WF450x200	0.846
	Beam	WF500x200	0.910	WF500x200	0.888
	Beam	WF600x200	0.902		

INTERSTORY DRIFT

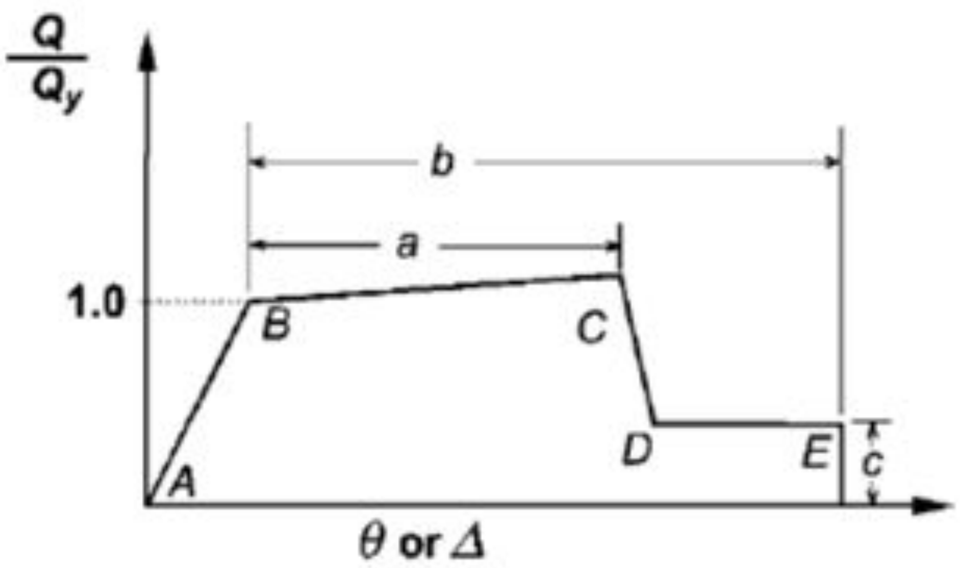




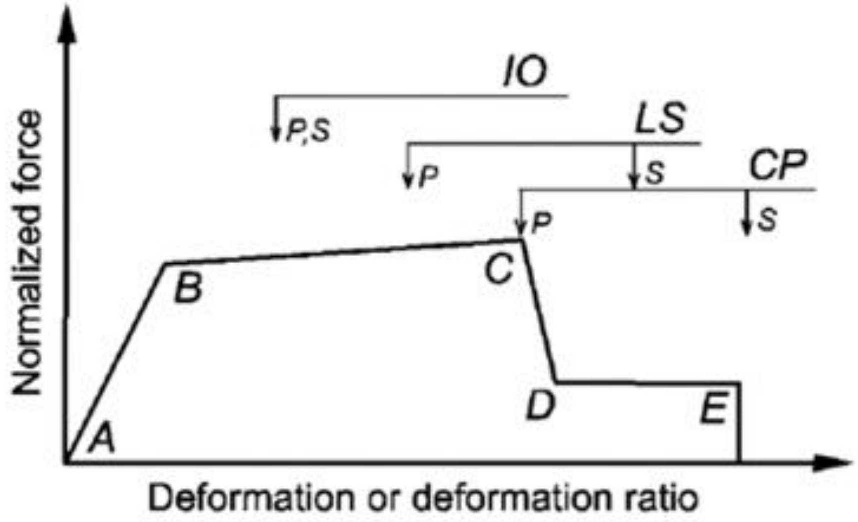
ELEMENT	WEIGHT (KG)	
	SS400	SN490
Column	95,726	82,061
Beam	171,962	149,747
Sub-Beam	57,251	51,491
Total	**324,939**	**283,299**
Difference		**41,639**
Reduction		**12.81 %**

3. SEISMIC PERFORMANCE

ASCE 41-17 : *Seismic Evaluation and Retrofit of Existing Buildings*



Plastic Hinge Model



Acceptance Criteria

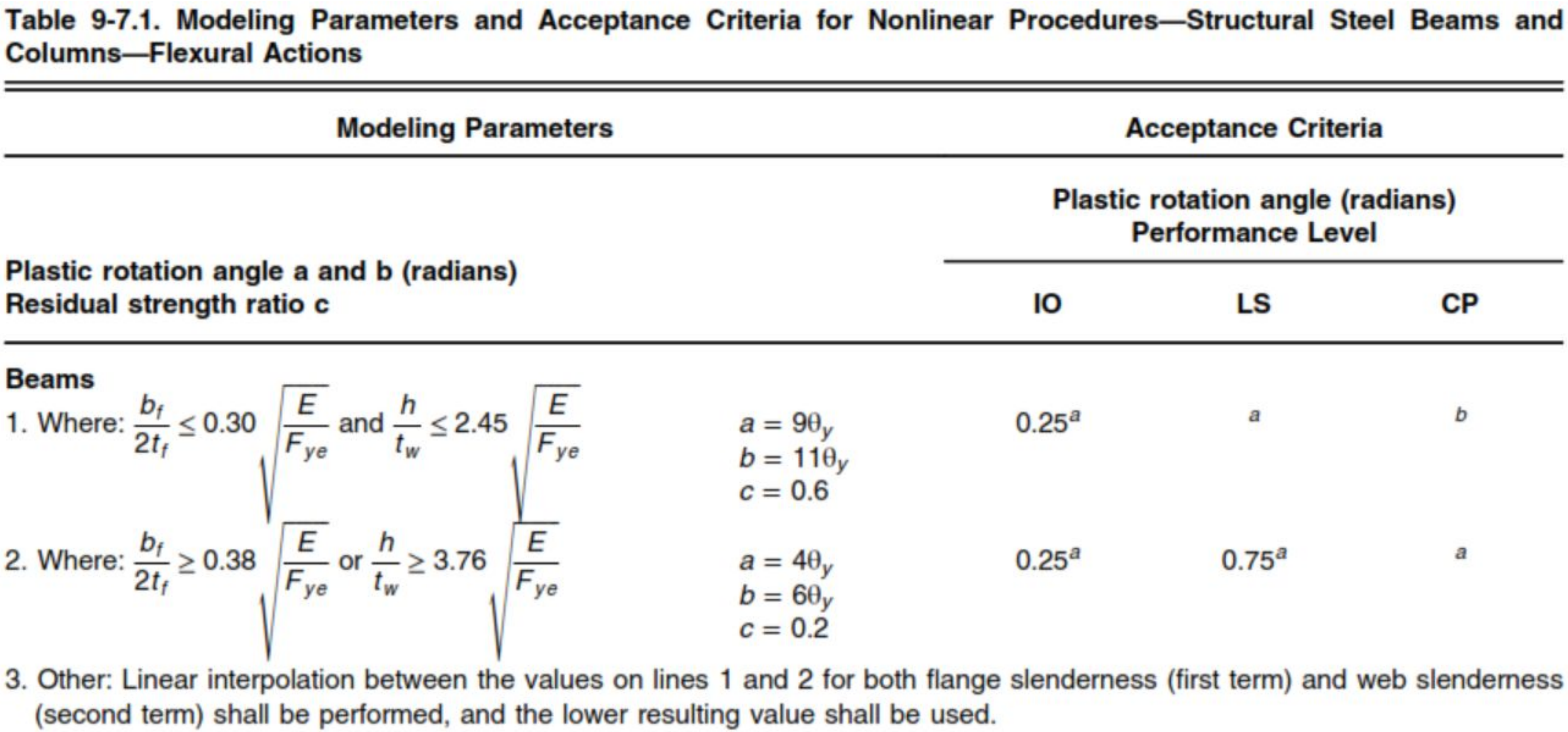
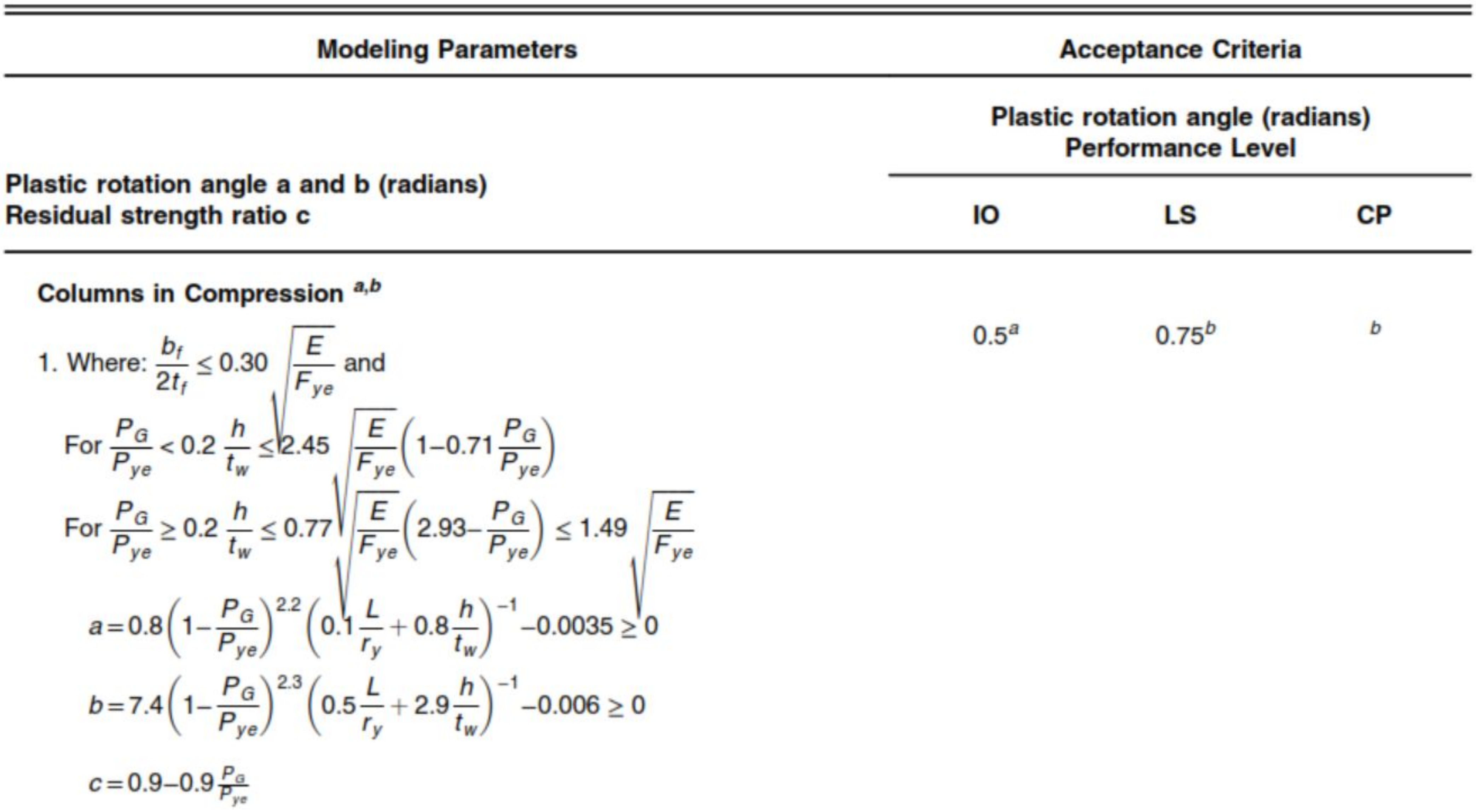


Table 9-7.1. Modeling Parameters and Acceptance Criteria for Nonlinear Procedures—Structural Steel Beams and Columns—Flexural Actions

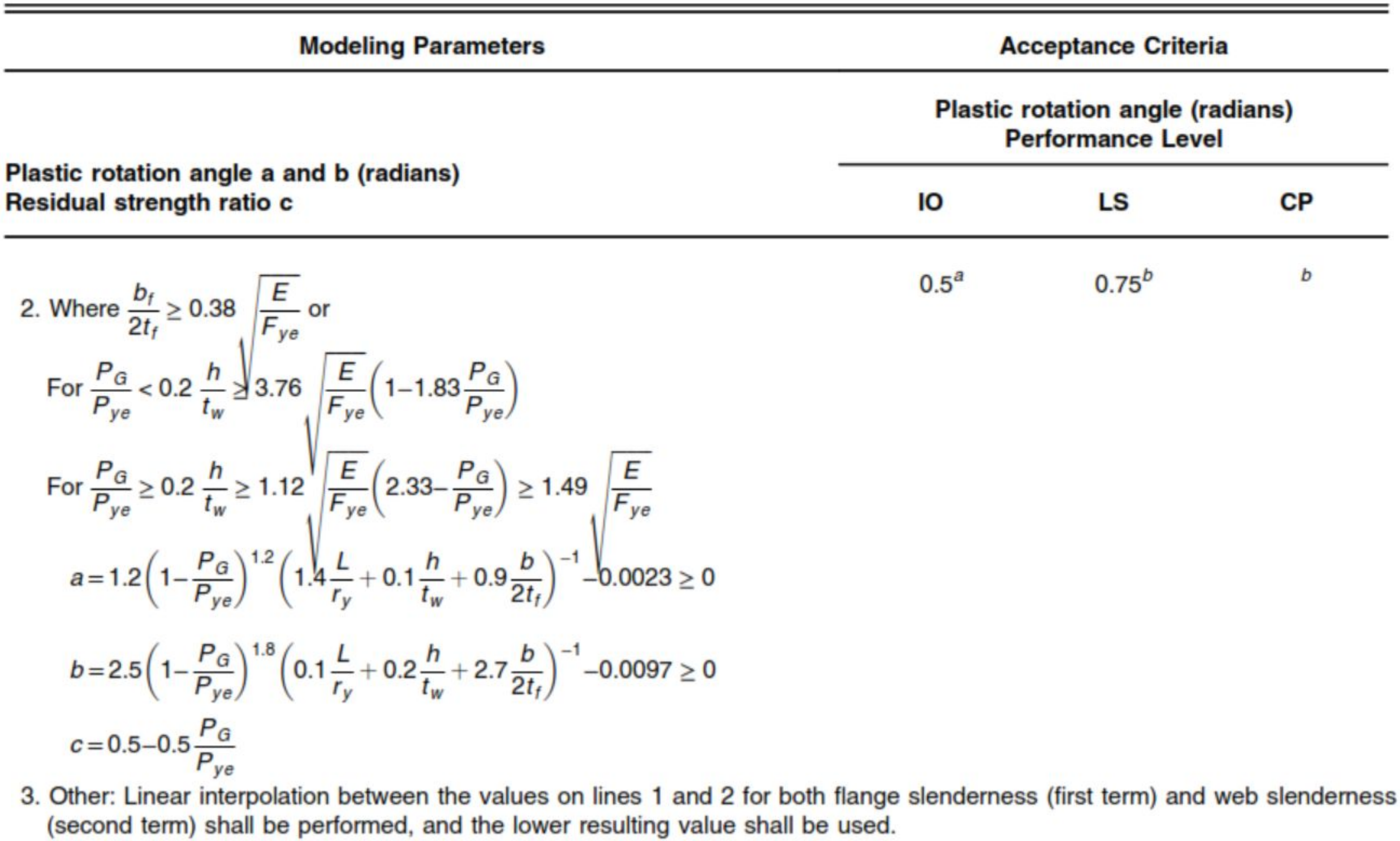
Modeling Parameters		Acceptance Criteria		
		Plastic rotation angle (radians) Performance Level		
Plastic rotation angle a and b (radians) Residual strength ratio c		IO	LS	CP
Beams				
1. Where: $\frac{b_f}{2t_f} \le 0.30\sqrt{\frac{E}{F_{ye}}}$ and $\frac{h}{t_w} \le 2.45\sqrt{\frac{E}{F_{ye}}}$	$a = 9\theta_y$ $b = 11\theta_y$ $c = 0.6$	0.25^a	^{a}	^{b}
2. Where: $\frac{b_f}{2t_f} \ge 0.38\sqrt{\frac{E}{F_{ye}}}$ or $\frac{h}{t_w} \ge 3.76\sqrt{\frac{E}{F_{ye}}}$	$a = 4\theta_y$ $b = 6\theta_y$ $c = 0.2$	0.25^a	0.75^a	^{a}
3. Other: Linear interpolation between the values on lines 1 and 2 for both flange slenderness (first term) and web slenderness (second term) shall be performed, and the lower resulting value shall be used.				

ASCE 41-17 : *Seismic Evaluation and Retrofit of Existing Buildings*



Modeling Parameters	Acceptance Criteria		
	Plastic rotation angle (radians) Performance Level		
Plastic rotation angle a and b (radians) **Residual strength ratio c**	**IO**	**LS**	**CP**
Columns in Compression [a,b]			
1. Where: $\frac{b_f}{2t_f} \le 0.30\sqrt{\frac{E}{F_{ye}}}$ and For $\frac{P_G}{P_{ye}} < 0.2$ $\frac{h}{t_w} \le 2.45\sqrt{\frac{E}{F_{ye}}}\left(1-0.71\frac{P_G}{P_{ye}}\right)$ For $\frac{P_G}{P_{ye}} \ge 0.2$ $\frac{h}{t_w} \le 0.77\sqrt{\frac{E}{F_{ye}}}\left(2.93-\frac{P_G}{P_{ye}}\right) \le 1.49\sqrt{\frac{E}{F_{ye}}}$ $a=0.8\left(1-\frac{P_G}{P_{ye}}\right)^{2.2}\left(0.1\frac{L}{r_y}+0.8\frac{h}{t_w}\right)^{-1}-0.0035 \ge 0$ $b=7.4\left(1-\frac{P_G}{P_{ye}}\right)^{2.3}\left(0.5\frac{L}{r_y}+2.9\frac{h}{t_w}\right)^{-1}-0.006 \ge 0$ $c=0.9-0.9\frac{P_G}{P_{ye}}$	0.5[a]	0.75[b]	[b]

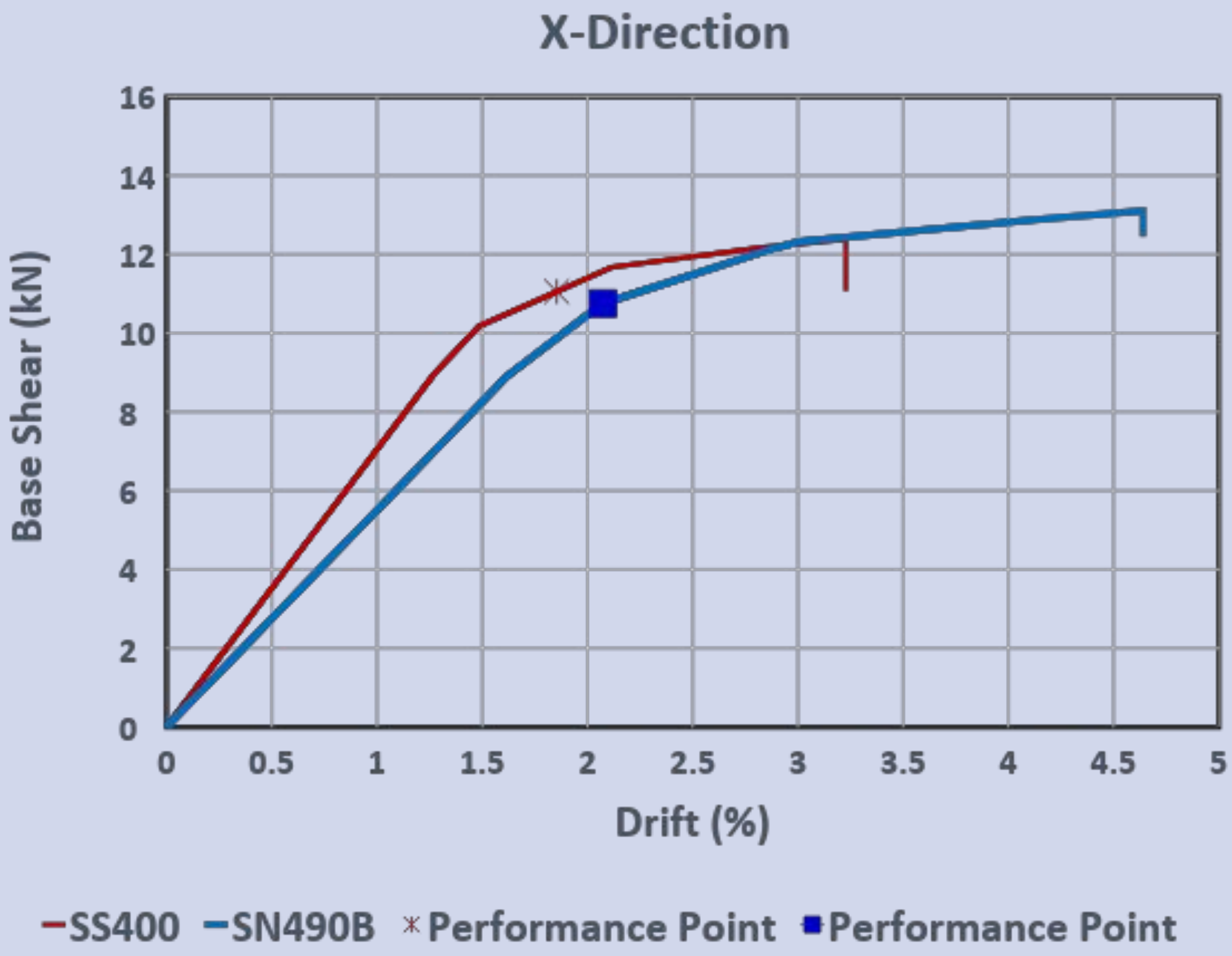
ASCE 41-17 : *Seismic Evaluation and Retrofit of Existing Buildings*



Modeling Parameters	Acceptance Criteria		
	Plastic rotation angle (radians) Performance Level		
Plastic rotation angle a and b (radians) Residual strength ratio c	IO	LS	CP
2. Where $\frac{b_f}{2t_f} \geq 0.38\sqrt{\frac{E}{F_{ye}}}$ or For $\frac{P_G}{P_{ye}} < 0.2$ $\frac{h}{t_w} \geq 3.76\sqrt{\frac{E}{F_{ye}}}\left(1-1.83\frac{P_G}{P_{ye}}\right)$ For $\frac{P_G}{P_{ye}} \geq 0.2$ $\frac{h}{t_w} \geq 1.12\sqrt{\frac{E}{F_{ye}}}\left(2.33-\frac{P_G}{P_{ye}}\right) \geq 1.49\sqrt{\frac{E}{F_{ye}}}$ $a=1.2\left(1-\frac{P_G}{P_{ye}}\right)^{1.2}\left(1.4\frac{L}{r_y}+0.1\frac{h}{t_w}+0.9\frac{b}{2t_f}\right)^{-1}-0.0023 \geq 0$ $b=2.5\left(1-\frac{P_G}{P_{ye}}\right)^{1.8}\left(0.1\frac{L}{r_y}+0.2\frac{h}{t_w}+2.7\frac{b}{2t_f}\right)^{-1}-0.0097 \geq 0$ $c=0.5-0.5\frac{P_G}{P_{ye}}$	0.5^{a}	0.75^{b}	^{b}
3. Other: Linear interpolation between the values on lines 1 and 2 for both flange slenderness (first term) and web slenderness (second term) shall be performed, and the lower resulting value shall be used.			

ASCE 41-17 : *Seismic Evaluation and Retrofit of Existing Buildings*

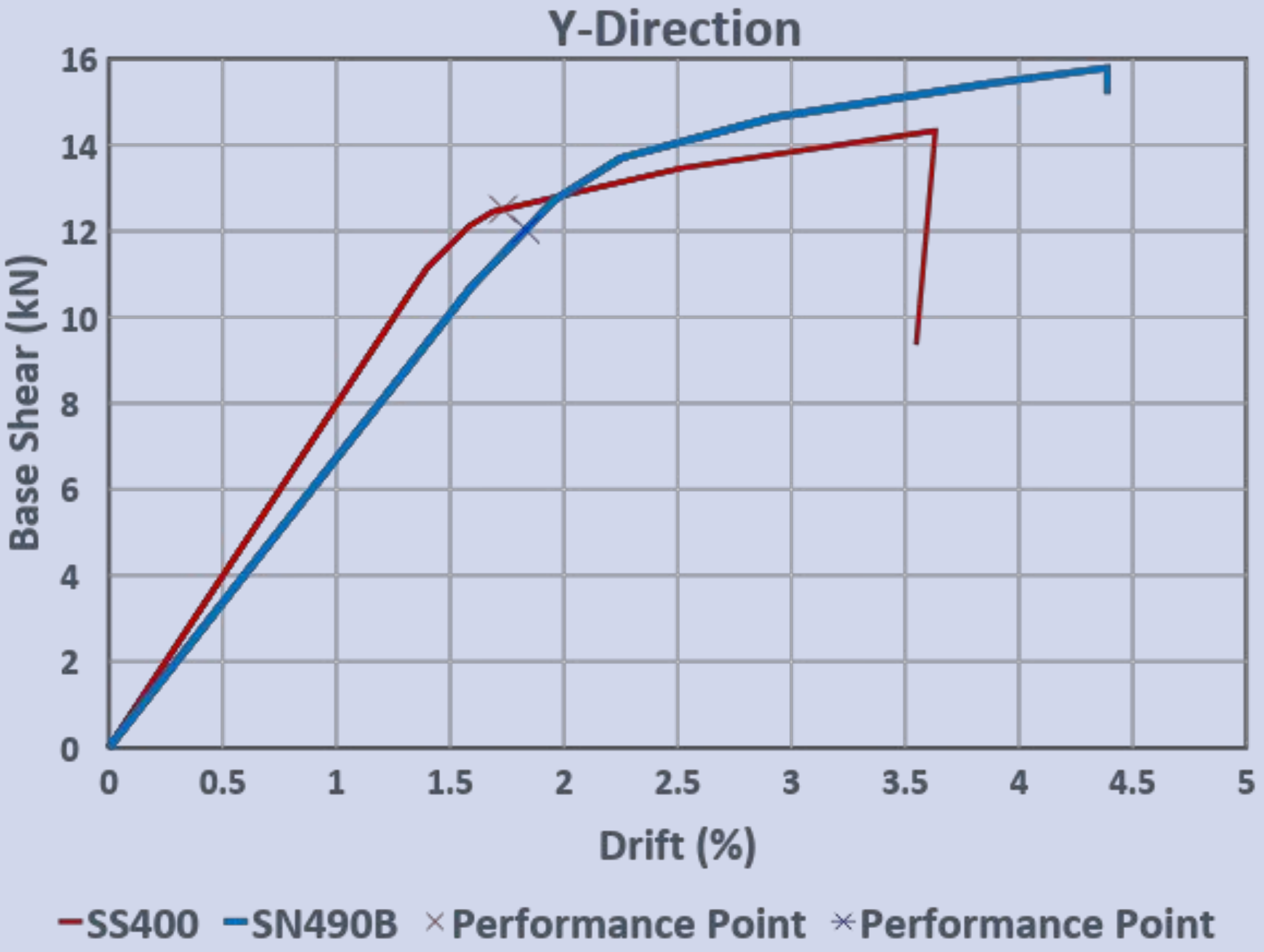
PUSH OVER



SN 490B:

- Less stiffness
- Higher ultimate strength
- More ductile

PUSH OVER



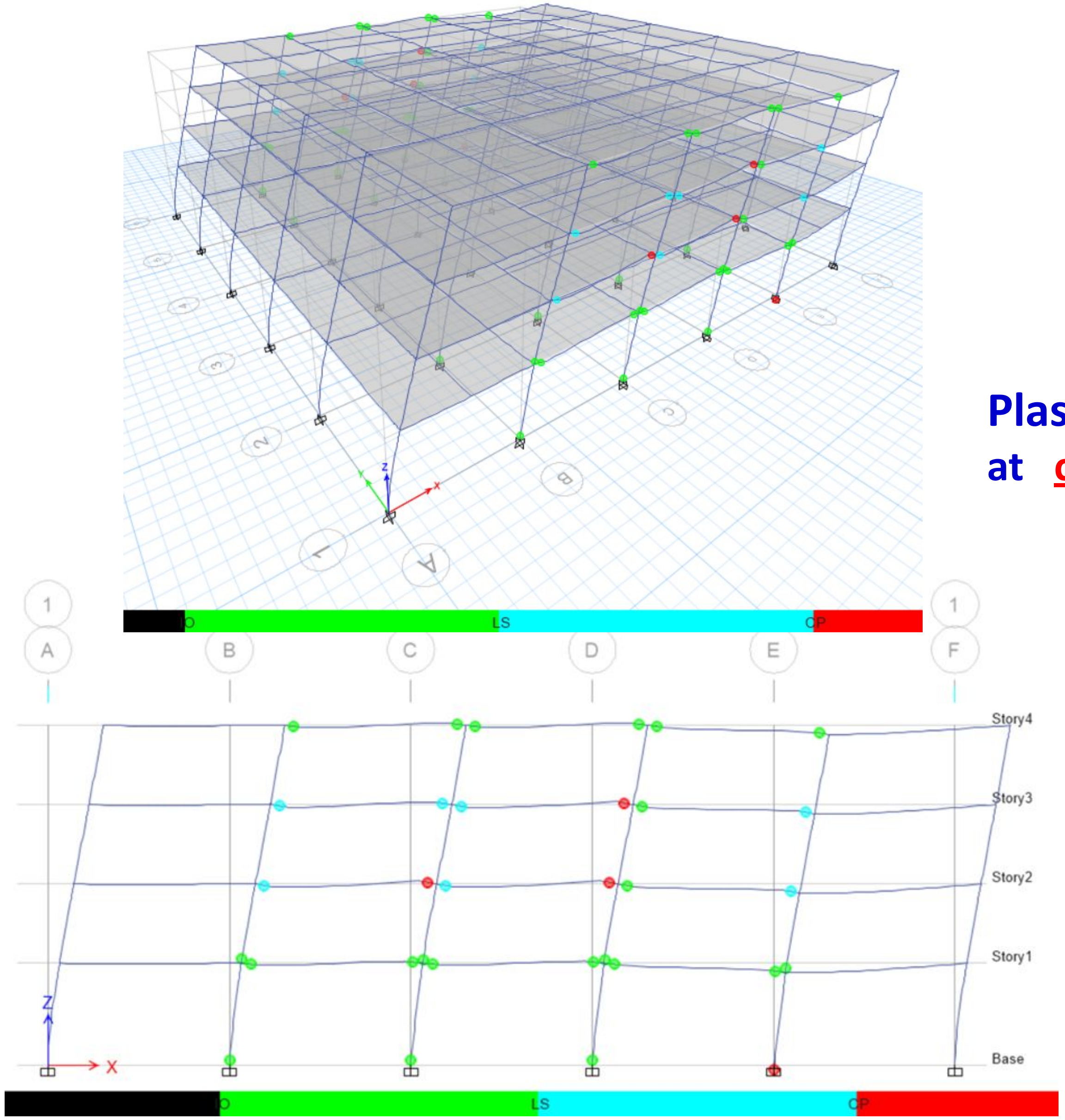
SN 490B:

- Less stiffness
- Higher ultimate strength
- More ductile

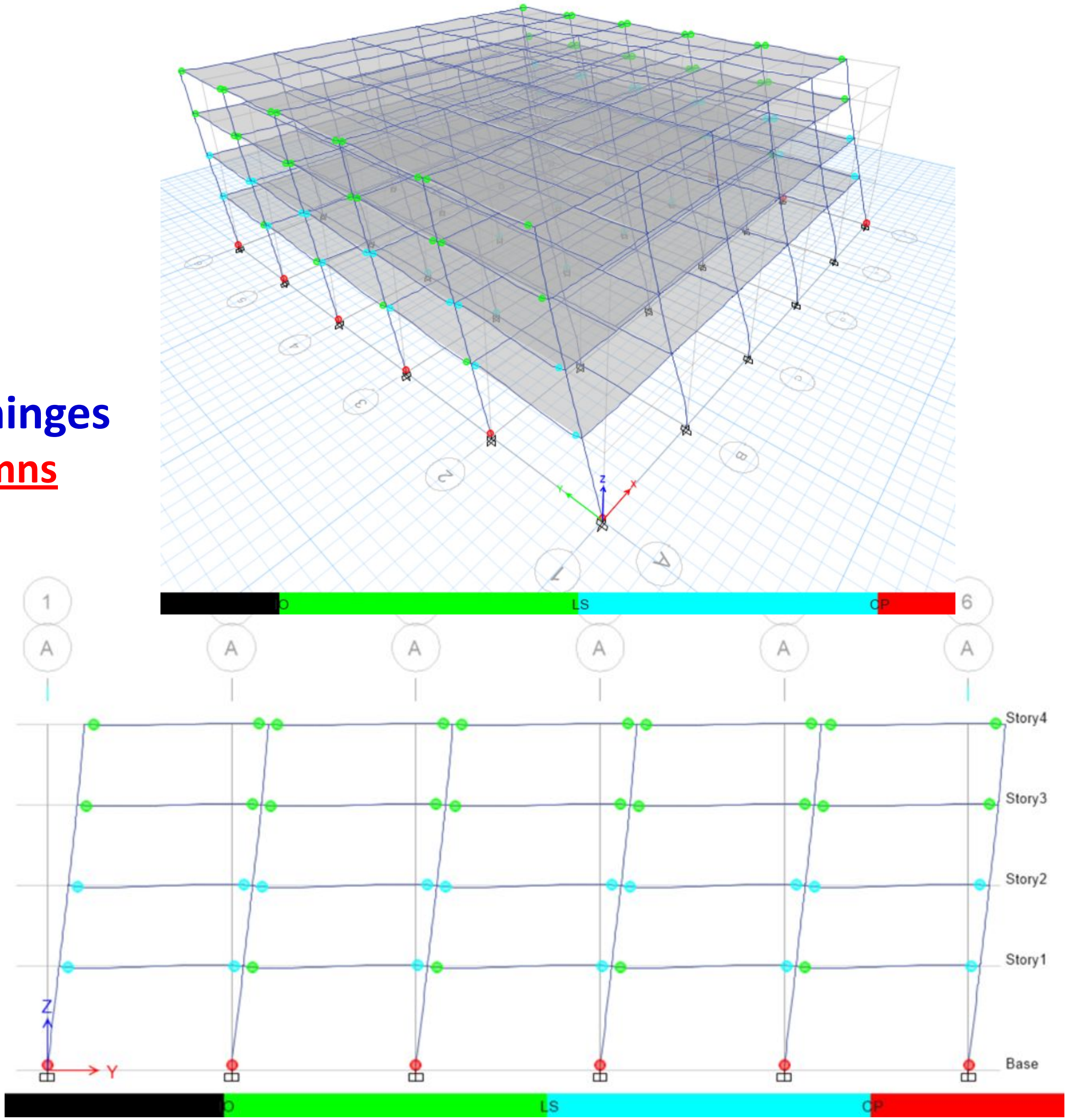
3. DISCUSSION

- Plastic hinge formation
- Energy Dissipation
- Seismic Performance
- Others

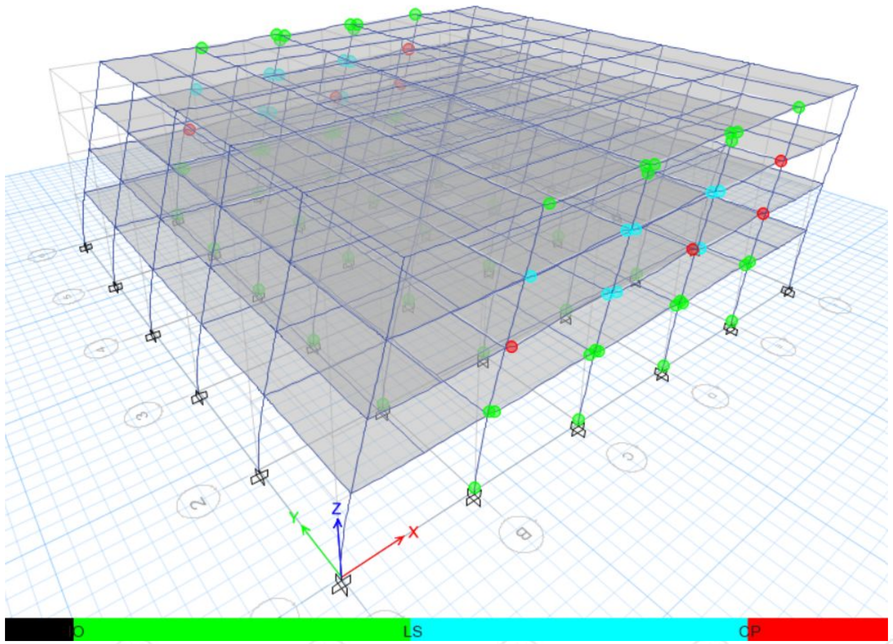
SS400



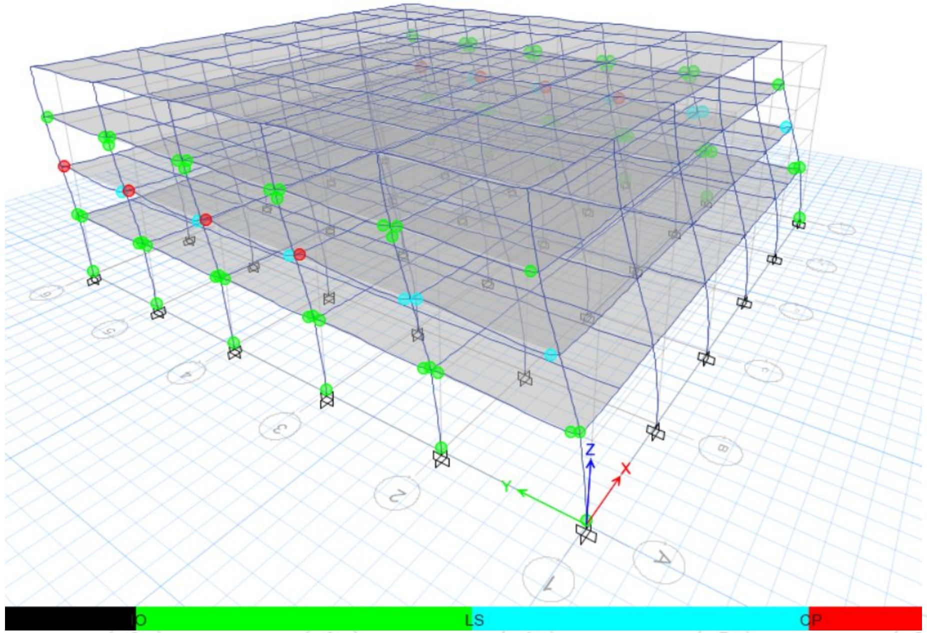
Plastic hinges
at columns

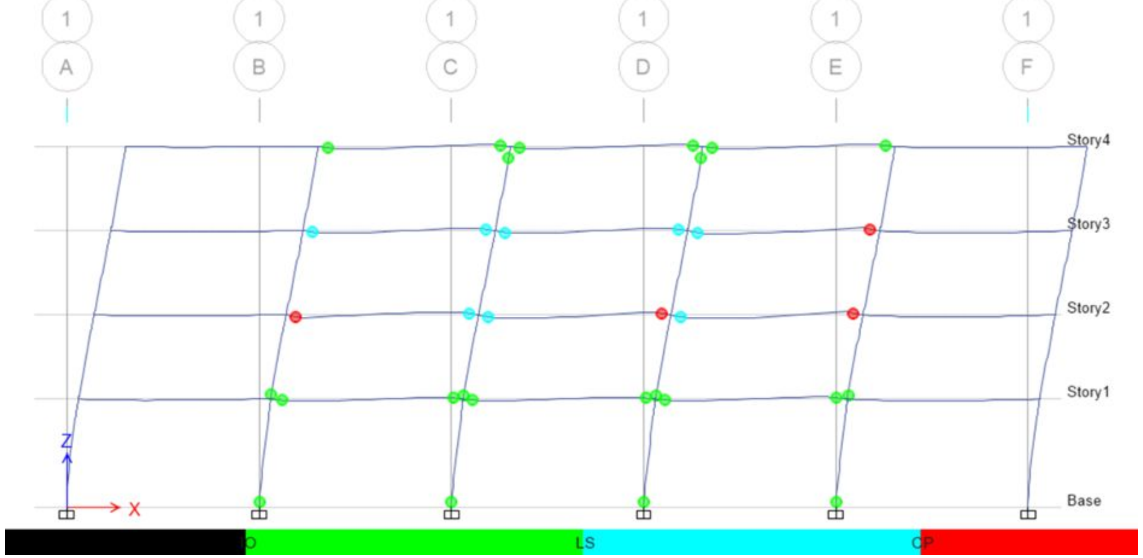


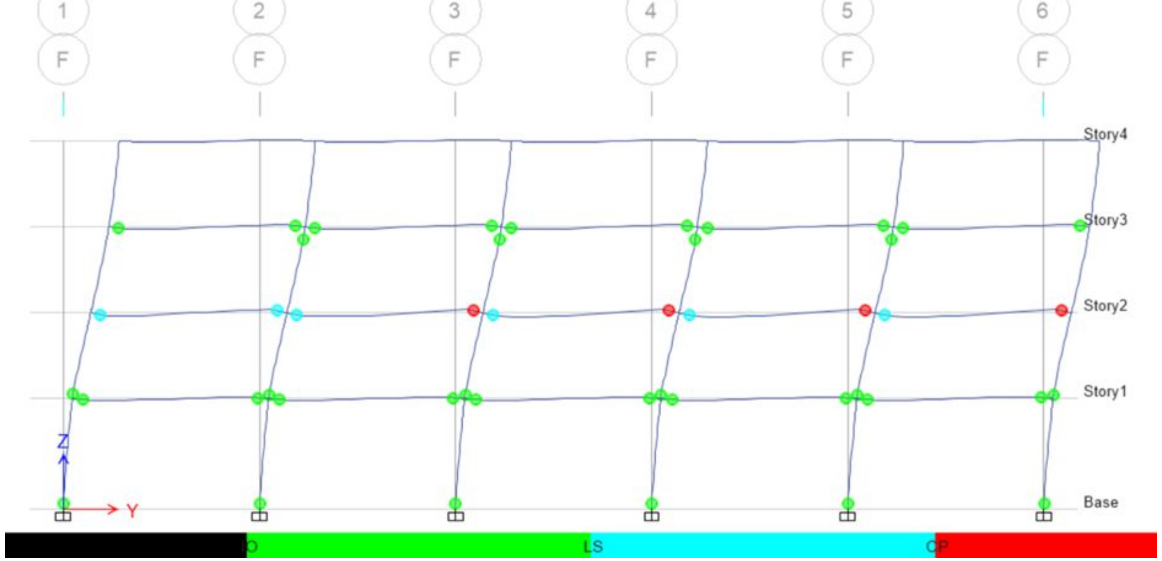
SN490B



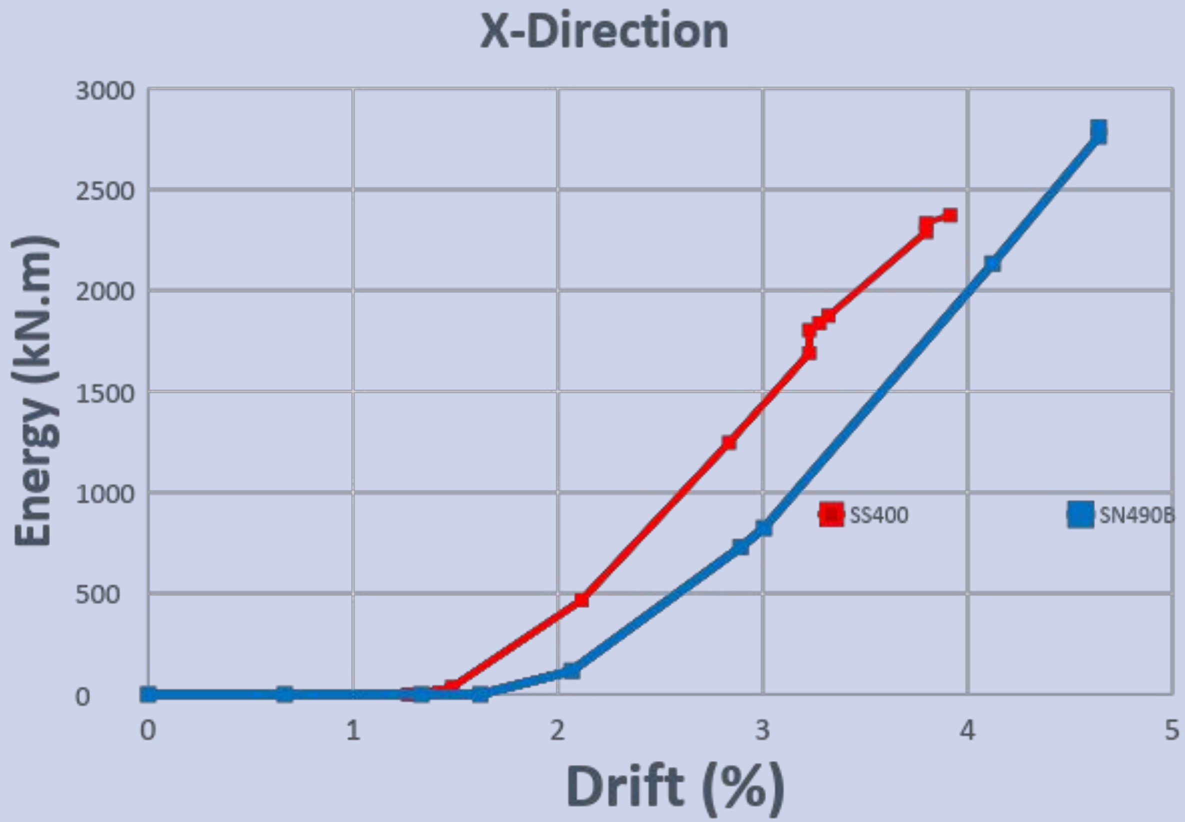
Plastic hinges at <u>beams</u>

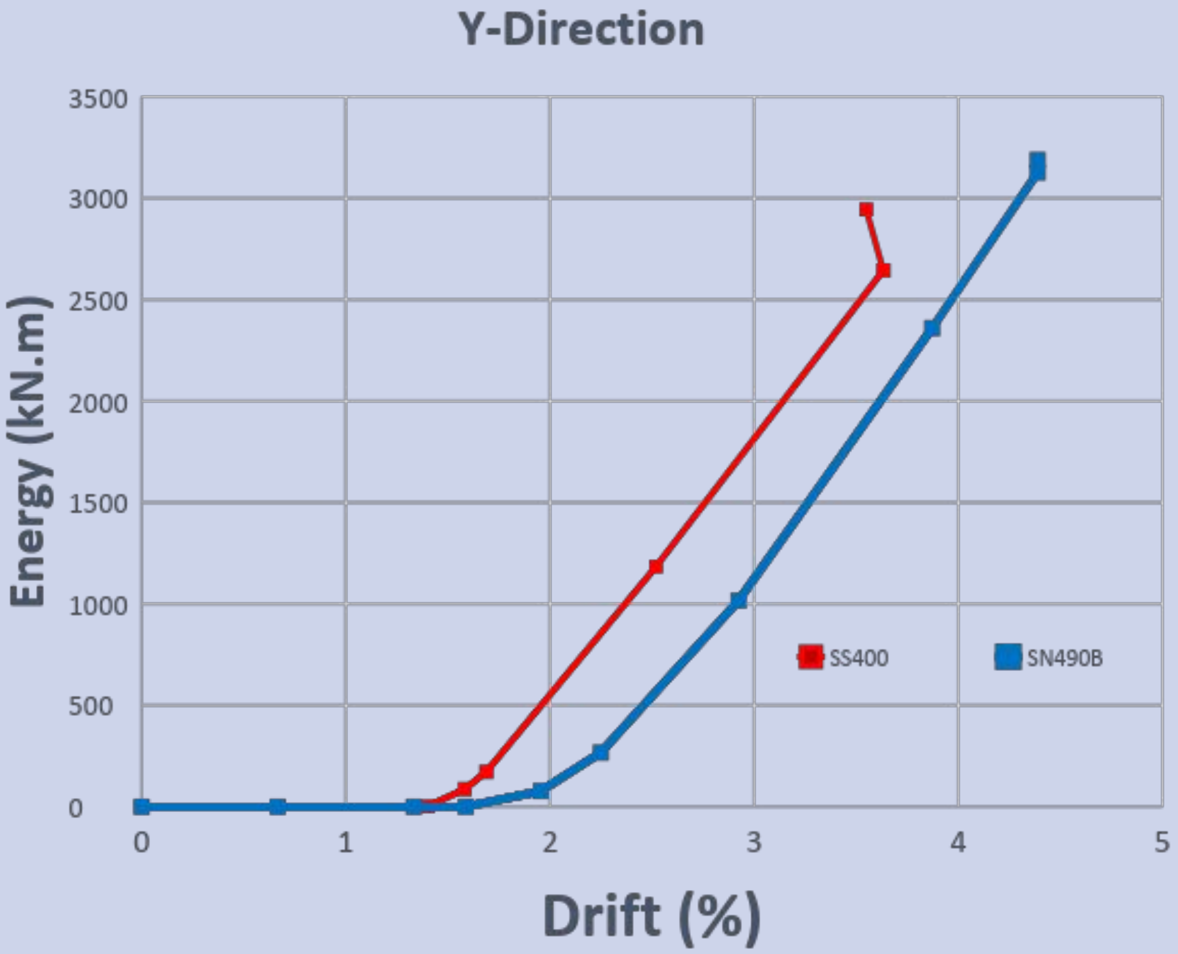






DISSIPATED ENERGY





STRUCTURAL PERFORMANCE

Structure	Pushover Direction	First Yield (kN)	Performance Point		Deformation			Building Performance
			Displacement (mm)	Base Shear (kN)	Immediate Occupancy	Life Safety	Collapse Prevention	
SS400	**X**	8,951	**278.04**	**11,053**	242.07	363.11	484.15	**Life safety**
SN490B		8,916	**311.02**	**10,749**	348.19	522.28	696.37	**Immediate Occupancy**

STRUCTURAL PERFORMANCE

Structure	Pushover Direction	First Yield (kN)	Performance Point		Deformation			Building Performance
			Displacement (mm)	Base Shear (kN)	Immediate Occupancy	Life Safety	Collapse Prevention	
SS400	**X**	8,951	**278.04**	**11,053**	242.07	363.11	484.15	**Life safety**
SN490B		8,916	**311.02**	**10,749**	348.19	522.28	696.37	**Immediate Occupancy**
SS400	**Y**	11,168	**260.04**	**12,507**	272.45	408.68	544.91	**Immediate Occupancy**
SN490B		10,512	**274.90**	**12,032**	330.22	495.34	660.45	**Immediate Occupancy**

More advantages of using SN490B :

(1) limitation of upper yield stress to ensure the final collapse mechanism of frames as it assumed at design stage;
(2) restrict yield ratio (yield stress to tensile strength) to 0.80 or lower, to provide better over-strength capacity;
(3) limitation of fracture toughness index higher than 27 Joule at 0^oC to provide better weldability for better performance of connection;
(4) limits the carbon, phosphorus, sulphur, and specified weld cracking sensitivity composition, to secure the weldability, workability and resistance to through-thickness cracking.

5. CONCLUSION

1. The design of two identical buildings of Special Moment Frames according to the recent Indonesia Seismic Building Codes (using SS400 steel and SN490B steel) shows the advantage of the SN frame in steel weight due to its **higher yield stress** and **lower Ry.**

   This advantage could be **more apparent** when the design of building structure is governed **by the strength limit, not by the drift limit**.

2. The result of the non-linear static push over analysis of both design frames shows that the SN frame exhibits:
   (1) **less structural stiffness**;
   (2) **higher structural strength;**
   (3) **more ductile structure;**
   (4) **better structural performance;**
   (5) **higher energy dissipation capacity;**
   (6) **better plastic hinge formation**

   that prevents a sudden collapse due to column failure.

3. From the viewpoint of risk assessment for building due to earthquake occurrence, the use of SN490B steel with a smaller variation of Yield Point ensures **the structure will perform much closer to the design performance** that was determined for the building. This indeed will **increase the performance of the building** in protecting the human live and social assets. -

Thank You

For your kind attention