USER BULLETIN 11

Beam-Column Joint Hinge Generator using an Artificial Neural Network (ANN)

1. INTRODUCTION

This document describes an Excel spreadsheet, *Beam-Column Joint Hinge Generator Using an Artificial Neural Network (ANN)*, which is developed to predict the joint shear strength and derive the shear stress-strain and moment rotation curves of both exterior and interior beam-column joints with or without transverse reinforcement. The spreadsheet uses the feed forward neural network developed by Suwal and Guner (2023b) to predict the joint shear strength. The predicted strength is used to derive the shear stress-strain and moment rotation curves using the approach defined in Suwal and Guner (2023a). The abscissa and ordinate values are based on the experimental testing results and formulations proposed by Anderson et al. (2008), Jeon (2013), and Celik and Ellingwood (2008). The generated values can be copied and pasted into plastic-hinge-based global frame analysis software when defining joint hinges. To facilitate the calculation process, the spreadsheet tool (Suwal and Guner 2023c) is shared as a freeware for the use of practicing engineers. It can be downloaded from the following link:

www.utoledo.edu/engineering/faculty/serhan-guner/docs/8S-ANNJointHingeGenerator.xlsx

This user bulletin presents the application and validation of the spreadsheet for both interior and exterior joints with or without transverse reinforcement. Four application and validation examples are presented in total.

Please use the following text when citing this document:

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This document is prepared by Nirmala Suwal (graduate student at the University of Toledo, OH, USA) as a part of research project supervised by Dr. Serhan Guner

2. APPLICATION AND VALIDATION

Beam-Column Joint Hinge Generator Using an Artificial Neural Network

Validation with an exterior joint with transverse reinforcement (Eshani and Alameddine, 1991)-Specimen LL8

Variables	Range		unit
	Min	Max	
f_c	15.8	101.9	MPa
f_{yjt}	235	1374	MPa
ρ_{jt}	0.0%	2.6%	
f_{yb}	286	1091	MPa
ρ_b	0.4%	4.3%	
h_b	150	750	mm
b_b	100	610	mm
f_{yc}	274	1092	MPa
ρ_c	0.3%	7.7%	
h_c	140	700	mm
b_c	100	900	mm
ALF	0.0	0.7	
JT*	0	1	
τ	1.3	17.4	MPa

** Interior = 0, Exterior = 1*

Definitions	
f_c	Concrete compressive strength
f_{yjt}	Joint transverse reinforcement yield strength
ρ_{jt}	Joint transverse reinforcement ratio
f_{yb}	Beam longitudinal reinforcement yield strength
ρ_b	Beam longitudinal reinforcement ratio
h_b	Beam depth
b_b	Beam width
f_{yc}	Column longitudinal reinforcement yield strength
ρ_c	Column longitudinal reinforcement ratio
h_c	Column depth
b_c	Column width
ALF	Axial load factor ($P/f_c b_c h_c$)
JT	Joint type (=0 for interior, =1 for exterior joint)
τ	Shear strength
M	Equivalent moment
L_b	Span of beam between points of contraflexure
L_c	Span of column between points of contraflexure
P	Axial load applied to column
γ	Shear strain
θ	Rotation
τ_{pred}	Predicted shear strength

Instructions	
Step 1:	Input the variables in the **green** cells
Step 2:	See the output joint shear strength in the **orange** cell
Note:	The inputs **must** be within the variables range. The ANN cannot not be used for extrapolation.

Variables	Input	Normalized
f_c	55.8	0.46
f_{yjt}	437	0.18
ρ_{jt}	1.2%	0.46
f_{yb}	437	0.19
ρ_b	3.0%	0.67
h_b	508	0.60
b_b	318	0.43
f_{yc}	437	0.20
ρ_c	2.8%	0.34
h_c	356	0.39
b_c	356	0.32
ALF	0.04	0.06
JT	1	1.00

Hidden Layer

0.16, 0.11, 0.01, 0.36, 0.26, 0.02, 0.01, 0.00, 0.01, 0.80, 0.01, 0.13, 0.02, 0.02, 0.08, 0.06, 0.00, 0.03, 0.03, 0.02, 0.11, 0.03, 0.42, 0.06, 0.08, 0.48, 0.10

Output Layer: 0.39

Output

Ratio (τ_{pred}/τ_{exp})	0.98	
τ_{pred}	7.6 MPa	(Suwal and Guner, 2023b)
τ_{exp}	7.8 MPa	Experimental Value

Compute the equivalient moment (M) (Suwal and Guner, 2023a)

L_b	1778
L_c	3581

M	905.1 kNm	(Celik and Ellingwood, 2008)

Final Output					
Points	τ (MPa)	γ	M (kNm)	θ	
Origin (O)	0.0	0	0.0	0	
Cracking (A)	3.6	0.00043	426.6	0.00043	(Anderson et al., 2008))
Yield (B)	7.2	0.006	859.8	0.006	
Maximum (C)	7.6	0.02	905.1	0.02	(Jeon et al., 2013)
Residual (D)	1.5	0.185	181.0	0.185	

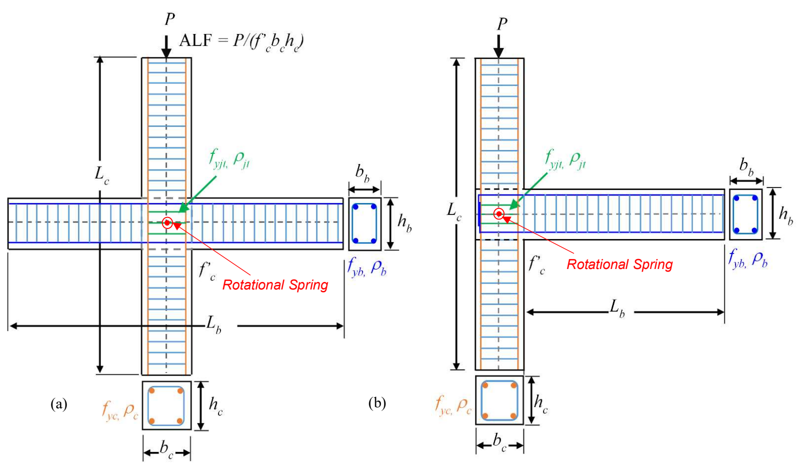
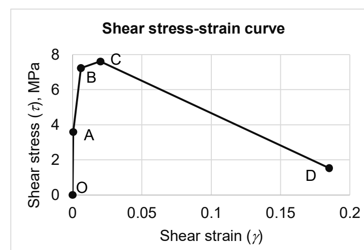
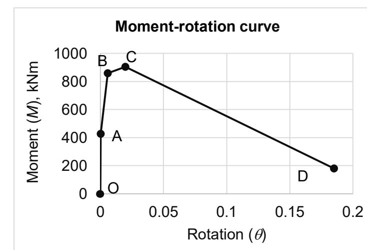


Figure: Sketches of specimens used in the training of the ANN: (a) interior and (b) exterior





Beam-Column Joint Hinge Generator Using an Artificial Neural Network

Validation with an exterior joint without transverse reinforcement (Pantelides et al., 2017) - Specimen Test Unit 2

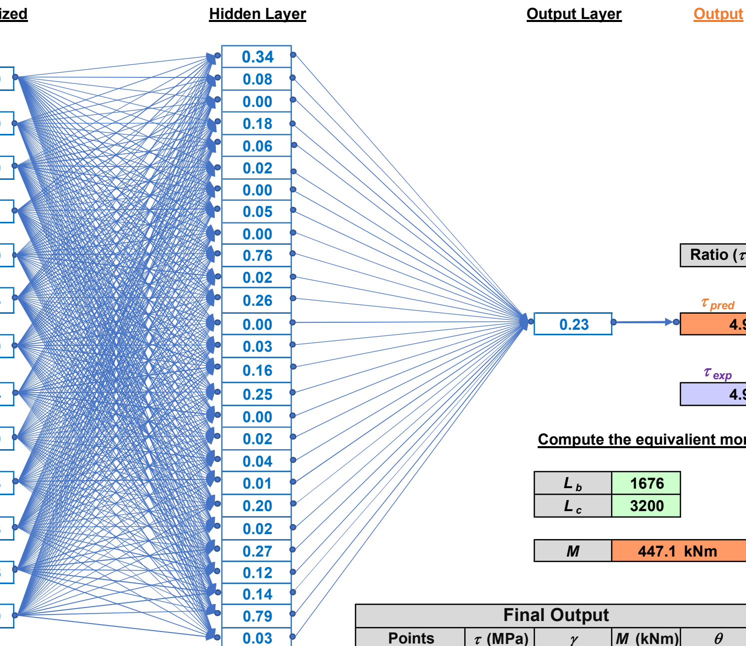
Variables	Range		unit
	Min	Max	
f_c	15.8	101.9	MPa
f_{yjt}	235	1374	MPa
ρ_{jt}	0.0%	2.6%	
f_{yb}	286	1091	MPa
ρ_b	0.4%	4.3%	
h_b	150	750	mm
b_b	100	610	mm
f_{yc}	274	1092	MPa
ρ_c	0.3%	7.7%	
h_c	140	700	mm
b_c	100	900	mm
ALF	0.0	0.7	
JT*	0	1	
τ	1.3	17.4	MPa

** Interior = 0, Exterior = 1*

Instructions		
Step 1:	Input the variables in the **green** cells	
Step 2:	See the output joint shear strength in the **orange** cell	
Note:	The inputs **must** be within the variables range. The ANN cannot not be used for extrapolation.	

Definitions	
f_c	Concrete compressive strength
f_{yjt}	Joint transverse reinforcement yield strength
ρ_{jt}	Joint transverse reinforcement ratio
f_{yb}	Beam longitudinal reinforcement yield strength
ρ_b	Beam longitudinal reinforcement ratio
h_b	Beam depth
b_b	Beam width
f_{yc}	Column longitudinal reinforcement yield strength
ρ_c	Column longitudinal reinforcement ratio
h_c	Column depth
b_c	Column width
ALF	Axial load factor ($P/f_c b_c h_c$)
JT	Joint type (=0 for interior, =1 for exterior joint)
τ	Shear strength
M	Equivalent moment
L_b	Span of beam between points of contraflexure
L_c	Span of column between points of contraflexure
P	Axial load applied to column
γ	Shear strain
θ	Rotation
τ_{pred}	Predicted shear strength

Variables	Input	Normalized
f_c	33.1	0.20
f_{yjt}	0	0.00
ρ_{jt}	0.0%	0.00
f_{yb}	459	0.21
ρ_b	3.5%	0.79
h_b	406	0.43
b_b	406	0.60
f_{yc}	470	0.24
ρ_c	2.5%	0.30
h_c	406	0.48
b_c	406	0.38
ALF	0.25	0.36
JT	1	1.00



Ratio (τ_{pred}/τ_{exp})	1.01

τ_{pred}: **4.9 MPa** (Suwal and Guner, 2023b)

τ_{exp}: **4.9 MPa** Experimental Value

Compute the equivalient moment (M) (Suwal and Guner, 2023a)

L_b	1676
L_c	3200

M	447.1 kNm	(Celik and Ellingwood, 2008)

Final Output					
Points	τ (MPa)	γ	M (kNm)	θ	
Origin (O)	0.0	0	0.0	0	
Cracking (A)	2.8	0.00043	250.0	0.00043	(Anderson et al., 2008))
Yield (B)	4.7	0.006	424.8	0.006	
Maximum (C)	4.9	0.016	447.1	0.016	(Jeon et al., 2013)
Residual (D)	1.0	0.077	89.4	0.077	

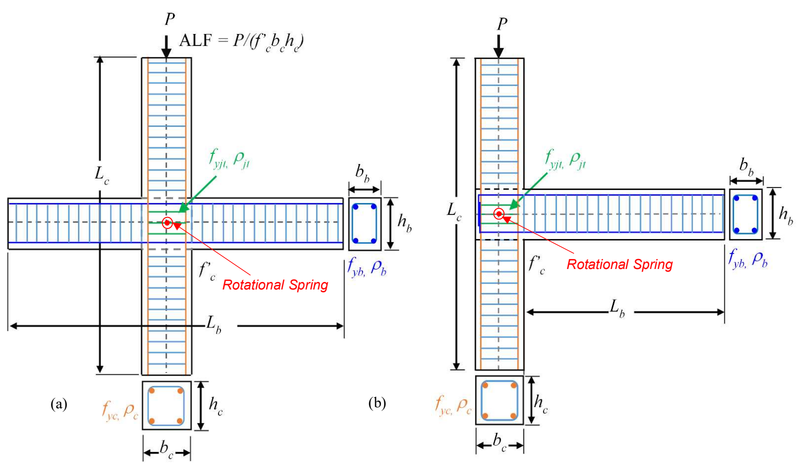
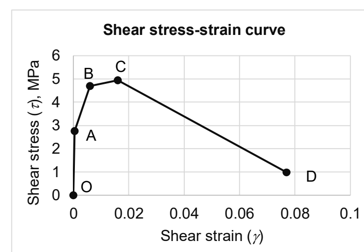
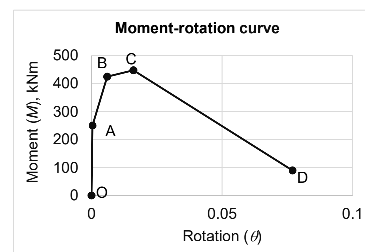


Figure: Sketches of specimens used in the training of the ANN: (a) interior and (b) exterior





Beam-Column Joint Hinge Generator Using an Artificial Neural Network

Validation with an interior joint with transverse reinforcement (Guimaraes et al., 1992) - Specimen J5

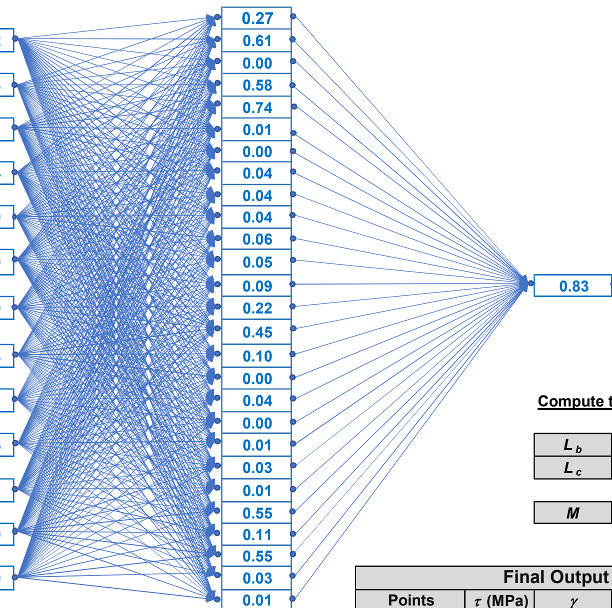
Variables	Range Min	Range Max	unit
f_c	15.8	101.9	MPa
f_{yjt}	235	1374	MPa
ρ_{jt}	0.0%	2.6%	
f_{yb}	286	1091	MPa
ρ_b	0.4%	4.3%	
h_b	150	750	mm
b_b	100	610	mm
f_{yc}	274	1092	MPa
ρ_c	0.3%	7.7%	
h_c	140	700	mm
b_c	100	900	mm
ALF	0.0	0.7	
JT*	0	1	
τ	1.3	17.4	MPa

** Interior = 0, Exterior = 1*

Instructions		
Step 1:	Input the variables in the **green** cells	
Step 2:	See the output joint shear strength in the **orange** cell	
Note:	The inputs **must** be within the variables range. The ANN cannot not be used for extrapolation.	

Definitions	
f_c	*Concrete compressive strength*
f_{yjt}	*Joint transverse reinforcement yield strength*
ρ_{jt}	*Joint transverse reinforcement ratio*
f_{yb}	*Beam longitudinal reinforcement yield strength*
ρ_b	*Beam longitudinal reinforcement ratio*
h_b	*Beam depth*
b_b	*Beam width*
f_{yc}	*Column longitudinal reinforcement yield strength*
ρ_c	*Column longitudinal reinforcement ratio*
h_c	*Column depth*
b_c	*Column width*
ALF	*Axial load factor ($P/f_c b_c h_c$)*
JT	*Joint type (=0 for interior, =1 for exterior joint)*
τ	*Shear strength*
M	*Equivalent moment*
L_b	*Span of beam between points of contraflexure*
L_c	*Span of column between points of contraflexure*
P	*Axial load applied to column*
γ	*Shear strain*
θ	*Rotation*
τ_{pred}	*Predicted shear strength*

Variables	Input	Normalized
f_c	77.9	0.72
f_{yjt}	550	0.28
ρ_{jt}	0.8%	0.31
f_{yb}	561	0.34
ρ_b	4.3%	1.00
h_b	508	0.60
b_b	406	0.60
f_{yc}	543	0.33
ρ_c	6.3%	0.81
h_c	508	0.66
b_c	508	0.51
ALF	0	0.00
JT	0	0.00



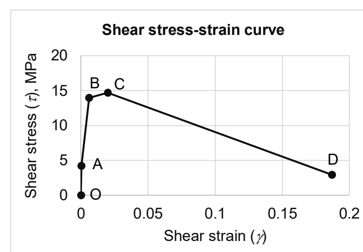
Output	
Ratio (τ_{pred}/τ_{exp})	0.94
τ_{pred}	14.7 MPa *(Suwal and Guner, 2023b)*
τ_{exp}	15.7 MPa *Experimental Value*

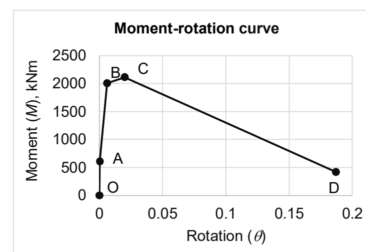
Compute the equivalient moment (*M*) *(Suwal and Guner, 2023a)*

L_b	5181
L_c	4237
M	2112.9 kNm *(Celik and Ellingwood, 2008)*

Final Output

Points	τ (MPa)	γ	M (kNm)	θ	
Origin (O)	0.0	0	0.0	0	
Cracking (A)	4.2	0.00043	609.7	0.00043	*(Anderson et al., 2008))*
Yield (B)	13.9	0.006	2007.3	0.006	
Maximum (C)	14.7	0.02	2112.9	0.02	*(Jeon et al., 2013)*
Residual (D)	2.9	0.187	422.6	0.187	





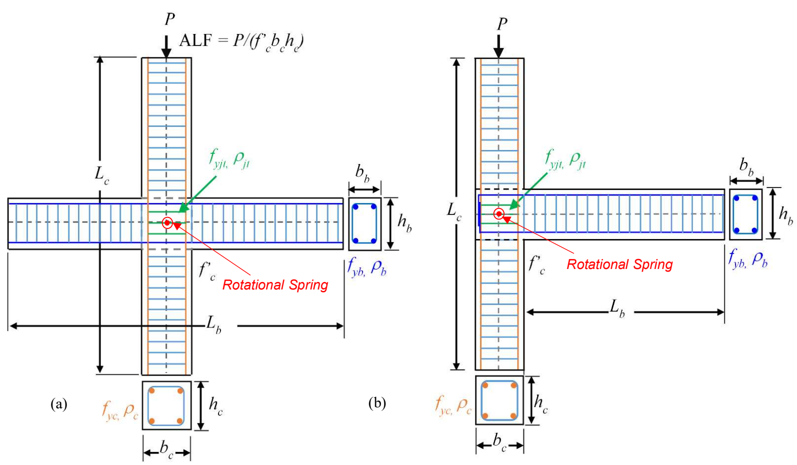


Figure: Sketches of specimens used in the training of the ANN: (a) interior and (b) exterior

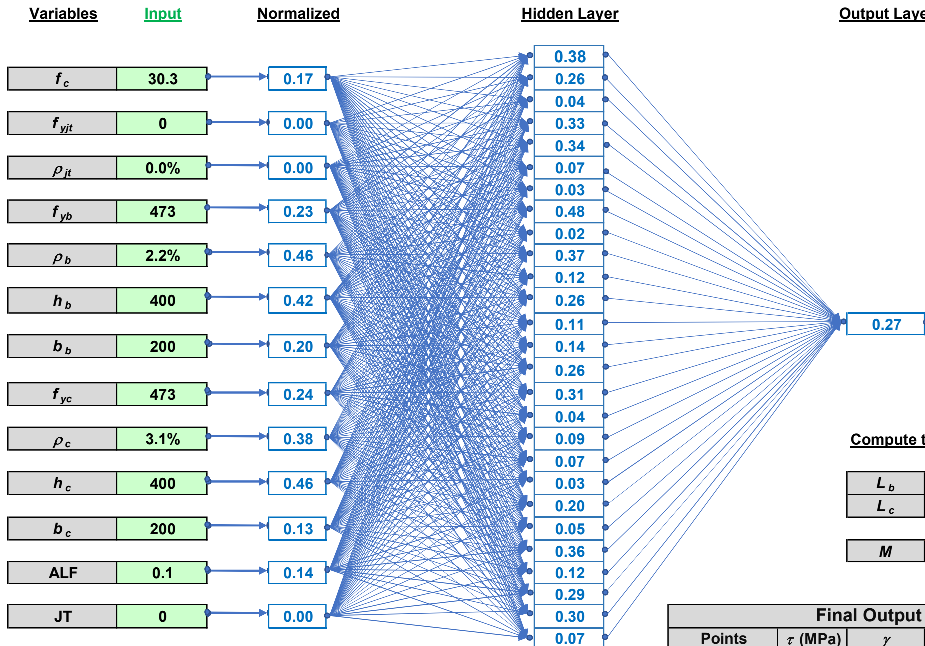
Beam-Column Joint Hinge Generator Using an Artificial Neural Network

Validation with an interior joint without transverse reinforcement (Li et al., 2005) - Specimen AL1

Variables	Range		unit
	Min	Max	
f_c	15.8	101.9	MPa
f_{yjt}	235	1374	MPa
ρ_{jt}	0.0%	2.6%	
f_{yb}	286	1091	MPa
ρ_b	0.4%	4.3%	
h_b	150	750	mm
b_b	100	610	mm
f_{yc}	274	1092	MPa
ρ_c	0.3%	7.7%	
h_c	140	700	mm
b_c	100	900	mm
ALF	0.0	0.7	
JT*	0	1	
τ	1.3	17.4	MPa

** Interior = 0, Exterior = 1*

Instructions		
Step 1:	Input the variables in the **green** cells	
Step 2:	See the output joint shear strength in the **orange** cell	
Note:	The inputs **must** be within the variables range. The ANN cannot not be used for extrapolation.	



Ratio (τ_{pred}/τ_{exp})	0.91

τ_{pred} **5.7 MPa** *(Suwal and Guner, 2023b)*

τ_{exp} **6.3 MPa** *Experimental Value*

Compute the equivalient moment (*M*) *(Suwal and Guner, 2023a)*

L_b	5181
L_c	4237

M	381.4 kNm	*(Celik and Ellingwood, 2008)*

Final Output					
Points	τ (MPa)	γ	*M* (kNm)	θ	
Origin (O)	0.0	0	0.0	0	
Cracking (A)	2.6	0.00043	176.1	0.00043	*(Anderson et al., 2008))*
Yield (B)	5.4	0.006	362.3	0.006	
Maximum (C)	5.7	0.019	381.4	0.019	*(Jeon et al., 2013)*
Residual (D)	1.1	0.117	76.3	0.117	

Definitions	
f_c	Concrete compressive strength
f_{yjt}	Joint transverse reinforcement yield strength
ρ_{jt}	Joint transverse reinforcement ratio
f_{yb}	Beam longitudinal reinforcement yield strength
ρ_b	Beam longitudinal reinforcement ratio
h_b	Beam depth
b_b	Beam width
f_{yc}	Column longitudinal reinforcement yield strength
ρ_c	Column longitudinal reinforcement ratio
h_c	Column depth
b_c	Column width
ALF	Axial load factor ($P/f_c b_c h_c$)
JT	Joint type (=0 for interior, =1 for exterior joint)
τ	Shear strength
M	Equivalent moment
L_b	Span of beam between points of contraflexure
L_c	Span of column between points of contraflexure
P	Axial load applied to column
γ	Shear strain
θ	Rotation
τ_{pred}	Predicted shear strength

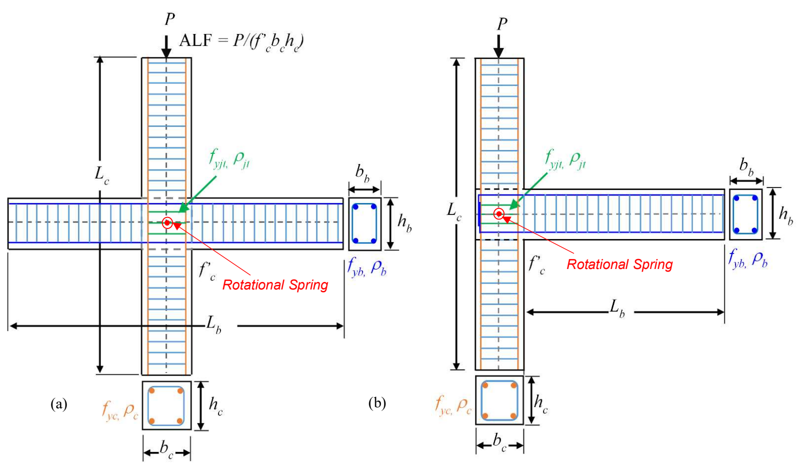
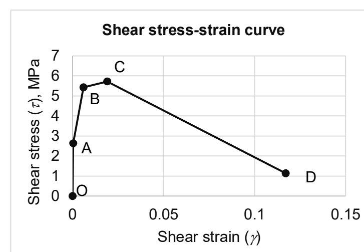
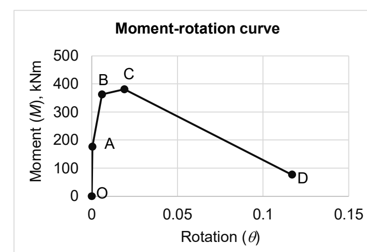


Figure: Sketches of specimens used in the training of the ANN: (a) interior and (b) exterior





3. REFERENCES

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Suwal N. and Guner S. (2023c) "Beam-column joint hinge generator using an artificial neural network," Excel Spreadsheet, Department of Civil and Environmental Engineering, University of Toledo, OH, USA. https://www.utoledo.edu/engineering/faculty/serhan-guner/docs/8S-ANNJointHingeGenerator.xlsx