NONLINEAR RESPONSE HISTORY ANALYSIS OF VISCOELASTIC COUPLING DAMPERS (VCDs) UNDER MAJOR EARTHQUAKE LOADING SUBSTITUTING COUPLING BEAMS OF TALL RC BUILDING IN JAKARTA

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I.

INTRODUCTION

Backgrounds and Objectives

BACKGROUNDS

The increasing of demands for High–rise Buildings

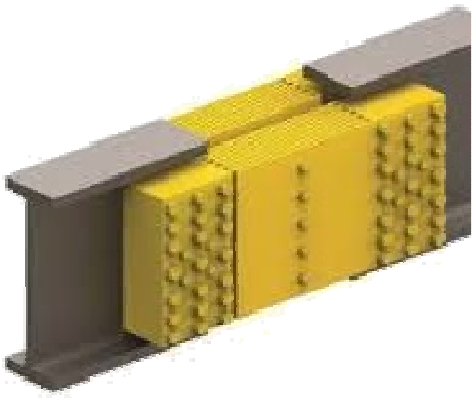
Source: Housing-Estate.com

The difficulty of coupling beams repairment and the economic loss of operation downtime

Source : Buildings.co

Source : https://kumparan.com

The complexity of Seismic Resistance Building design and detailing in seismic vulnerable area



Source : kineticadynamics.com

The potential of as alternative fo more durable en dissipator

OBJECTIVES

"Building retrofitting using VCDs in lieu of Coupling Beams in lower level area of Super Tall Building under major earthquake"

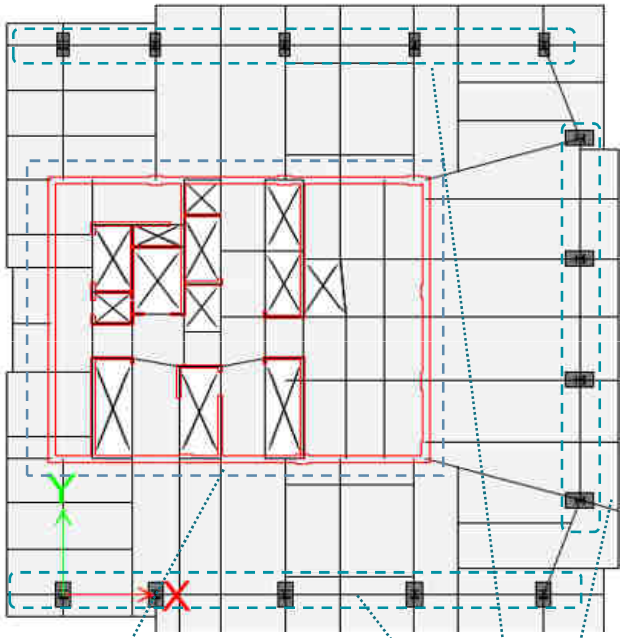
- IS IT WORKING EFFECTIVELY FOR THE BUILDING??
- HOW DOES IT WORK?? (mechanism and hysteretic behaviour)

2.

STRUCTURAL MODELLIN

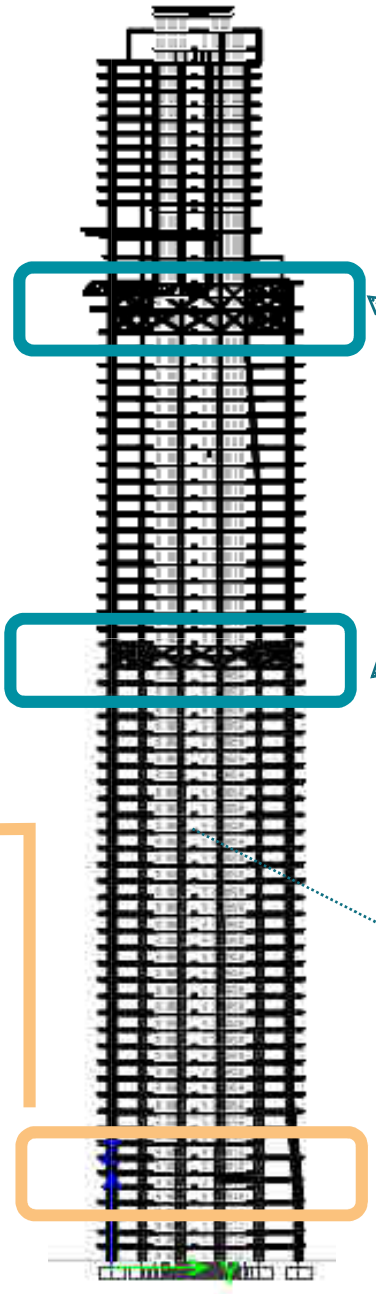
Specifications and Properties (CSI Etabs and Perform3D)

SPECIFICATIONS (I)



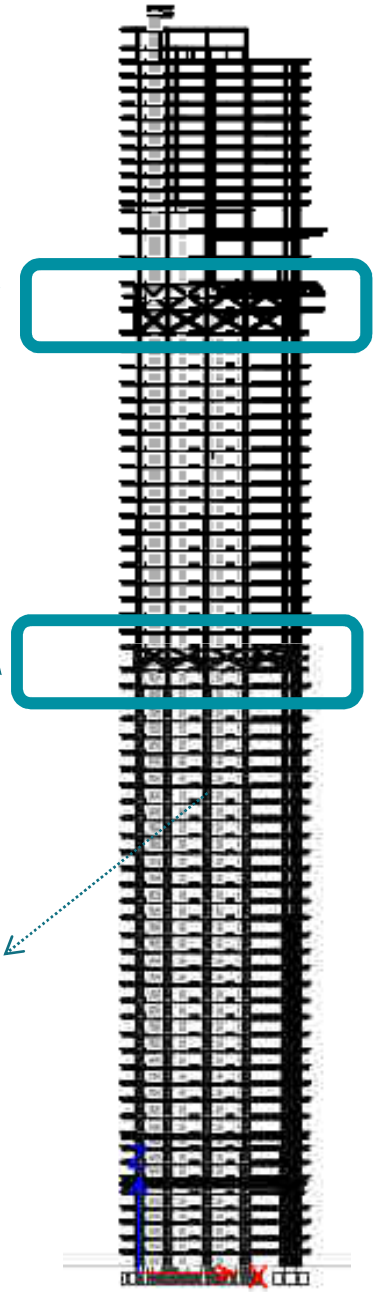
Core-wall

Perimeter Columns



Outriggers Belt-trusses at 57^{th} -59^{th} and 38^{th}-39_{th}

Core-wall + Perimeter Columns at all stories



338,2
80 sto

SPECIFICATIONS (2)

Mix – used building	Risk category III
Importance Factor	I_e = 1,25
Site Class	SE (Jakarta)
Seismic Design Category	D
Design Coefficients and Factors	
R	5
Ωo	2,5
Cd	5,5
Redundance Factor	1,0

MATERIALS

ONCRETE

fc' (MPa)	Story	Element
35	St. 40–Roof	Slabs and Beams
45	GF–St.39	Slabs and Beams
	St.40–Roof	Columns and Shearwalls
55	St.23–St.39	Columns and Shearwalls
60	GF–St.22	Columns and Shearwalls

STEEL

No	Specs.	f_y (MPa)	Element
1	BJTD-40	400	Longitudinal Reinforcements
			Shear Reinforcements
2	BJTD-50	500	Confinements
3	BJ-52	345	Structural Profiles

LOADINGS

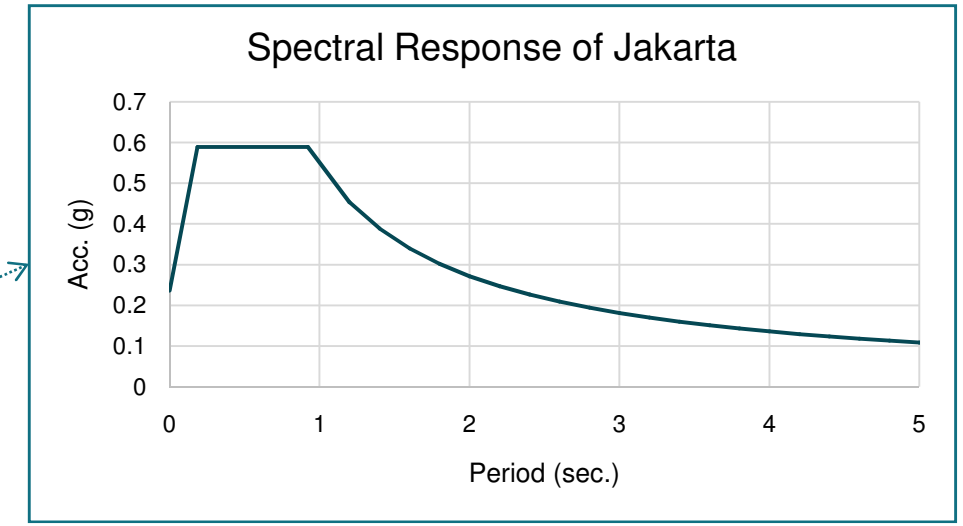
01 DEADLOAD

02 SIDL

03 LIVE LOAD

04 SEISMIC

SNI 1727:2013



Seismic : Jakarta	
MCEr, Site Class SE	
DBE	
SDS (g)	0.5893
SD1 (g)	0.5433
To (sec.)	0.5893
Ts (sec.)	0.5433

SEISMIC RESPONSE COEFFICIENT AND EQ SCALE FACTOR

Period

Mode	Period
	sec
1 (Y)	7.820
2 (X)	7.538

Seismic Response Coefficient

Cs	
Cs X	0,0252
Cs Y	0,0249

$C_{s,min} = 0{,}044 S_{DS} > 0.1$

Static Base Shear

Dir.	V_{static}
	kN
X	$6{,}68 \times 10^4$
Y	$6{,}59 \times 10^4$

Scale Factor

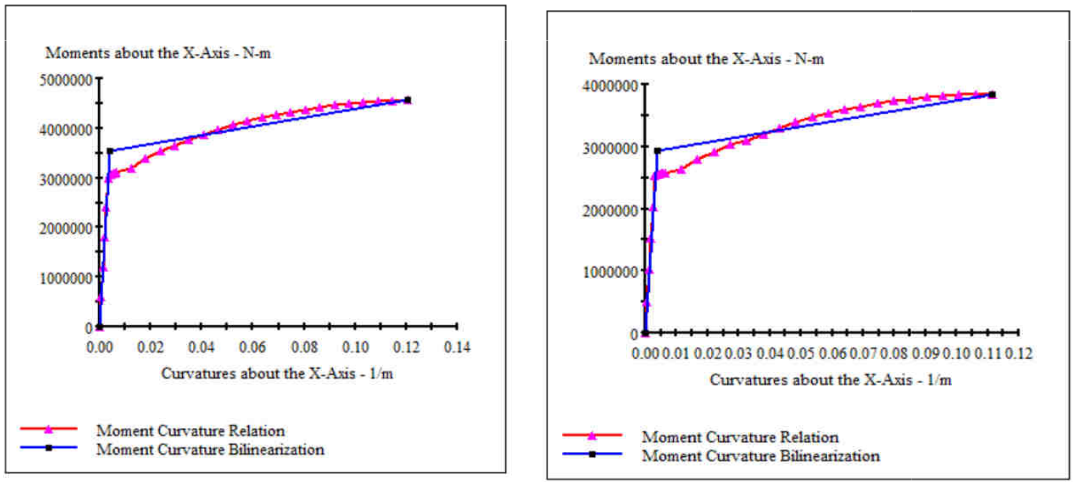
V_b Design

Dir.	$0{,}85V_{static}$	$V_{dynamic.}$	scal
	kN	kN	
X	$5{,}68 \times 10^4$	$5{,}55 \times 10^4$	1,02
Y	$5{,}61 \times 10^4$	$5{,}38 \times 10^4$	1,04

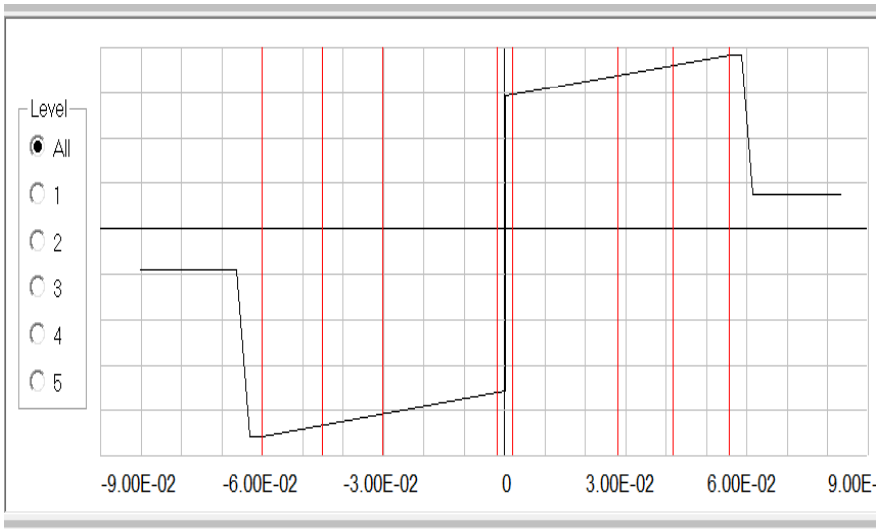
INELASTIC PROPERTIES

Beam Element
Moment Hinge – Rotation Type

Moment-rotation of beam element is calculated using XTRACT program and bilinearized to conform to Perform 3D fo



Example of Moment-Curvature Output by XTRACT

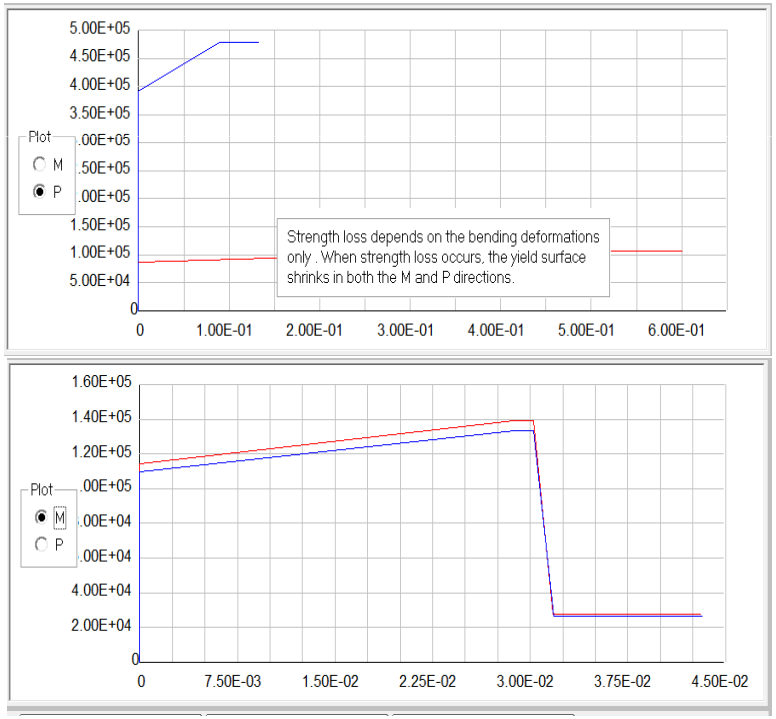


Example of Bilinearized Moment-Rotation with Deformation Capacities for Perform 3D

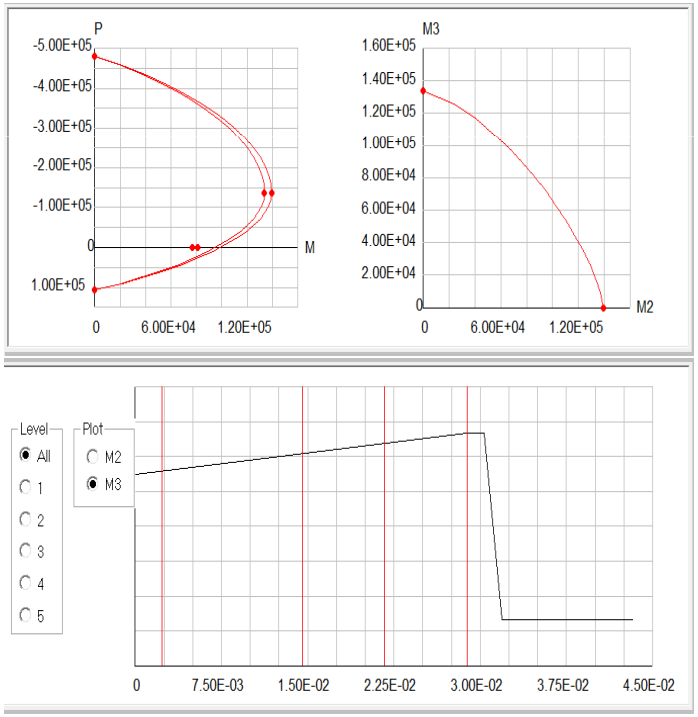
INELASTIC PROPERTIES

Column Element
PMM Hinge – Rotation Type

P-M-M hinge of column element is calculated using XTRACT and spreadsheet programs to conform to Perform 3D fo



Example of Basic F-D Relationship for Perform 3D



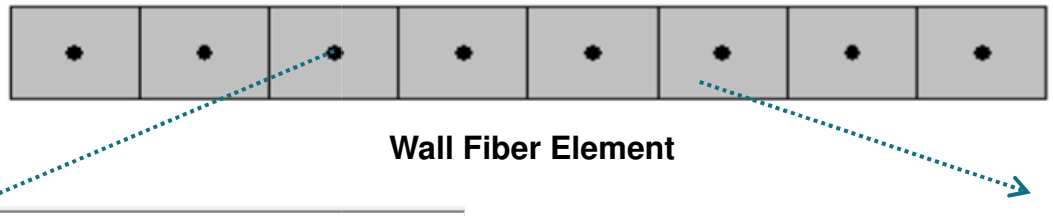
Example of Column Yield Surface for Perform 3D

Example of Column Deformation Capacities for Perform 3D

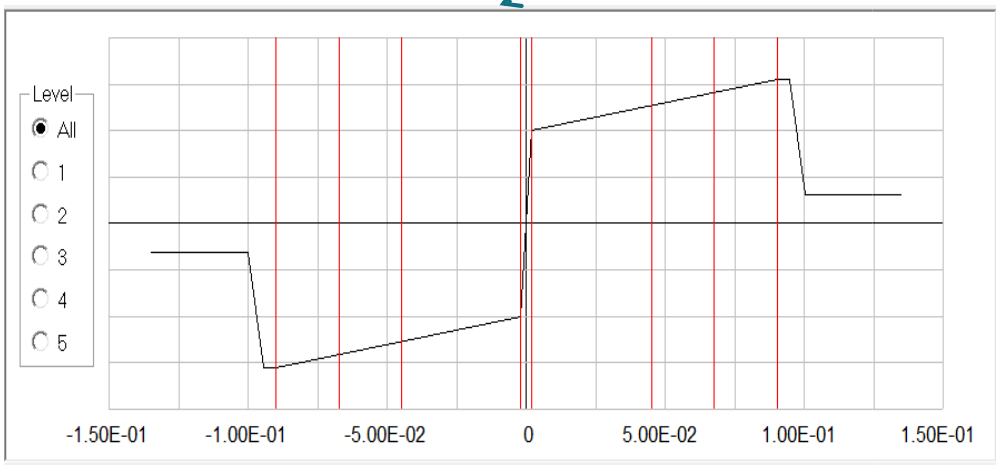
INELASTIC PROPERTIES

Wall Element
Wall, Fiber Type

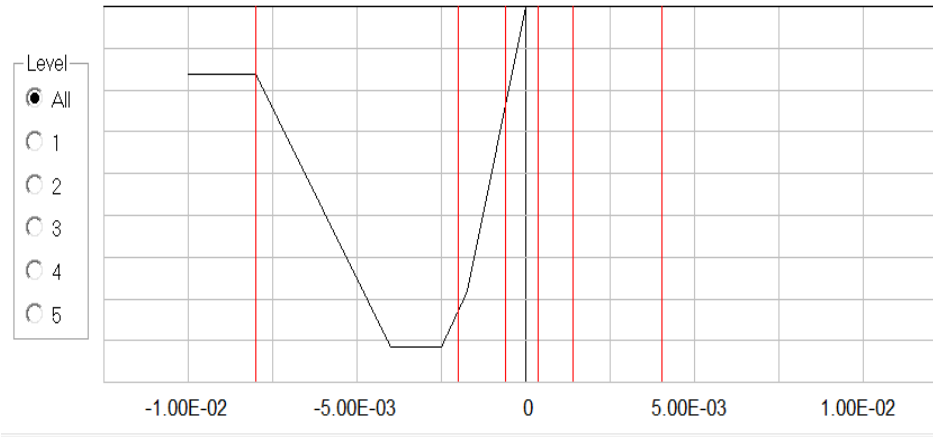
Walls are modelled as fiber elements that require stress-strain relationships for steel and concrete materials as input for Perform 3D.



Wall Fiber Element



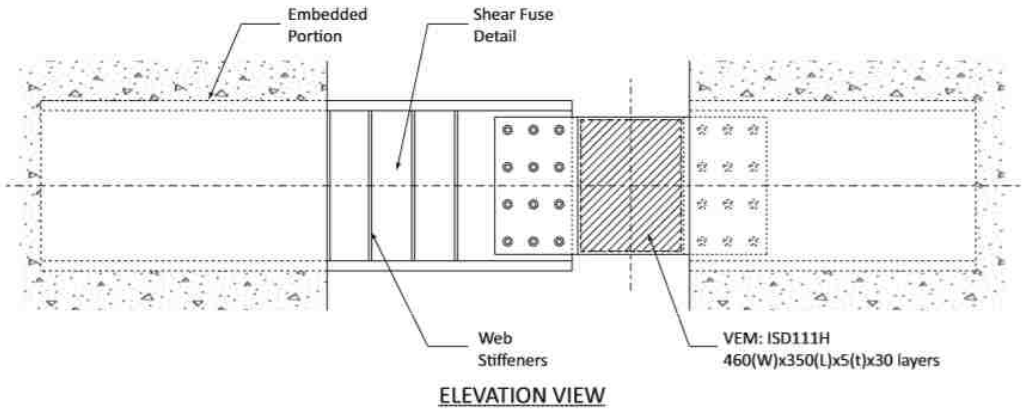
Example of Stress-Strain Relationship for Reinforcement



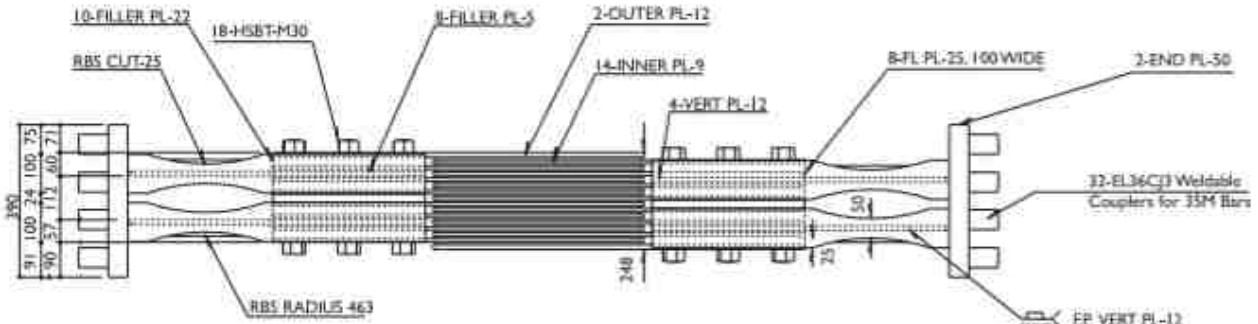
Example of Stress-Strain Relationship for Concrete

VISCOELASTIC COUPLING DAMPERS (VCDs)

Overview

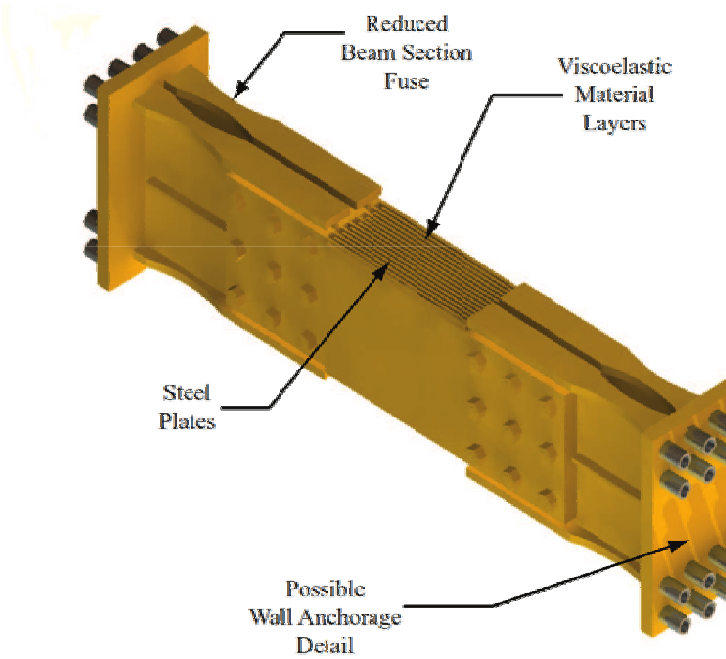


ELEVATION VIEW



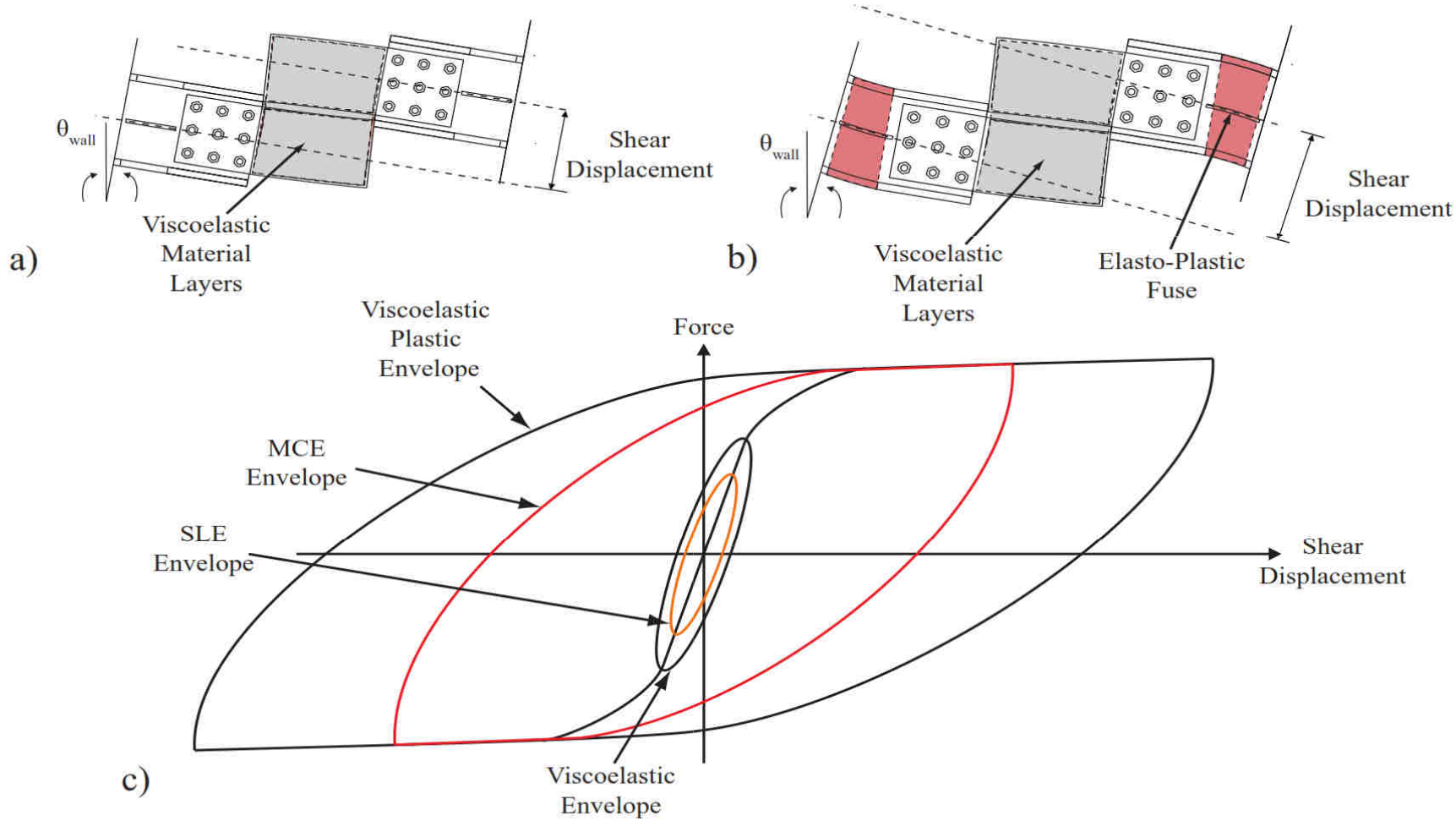
PLAN

NOTE-All Dimensions mm

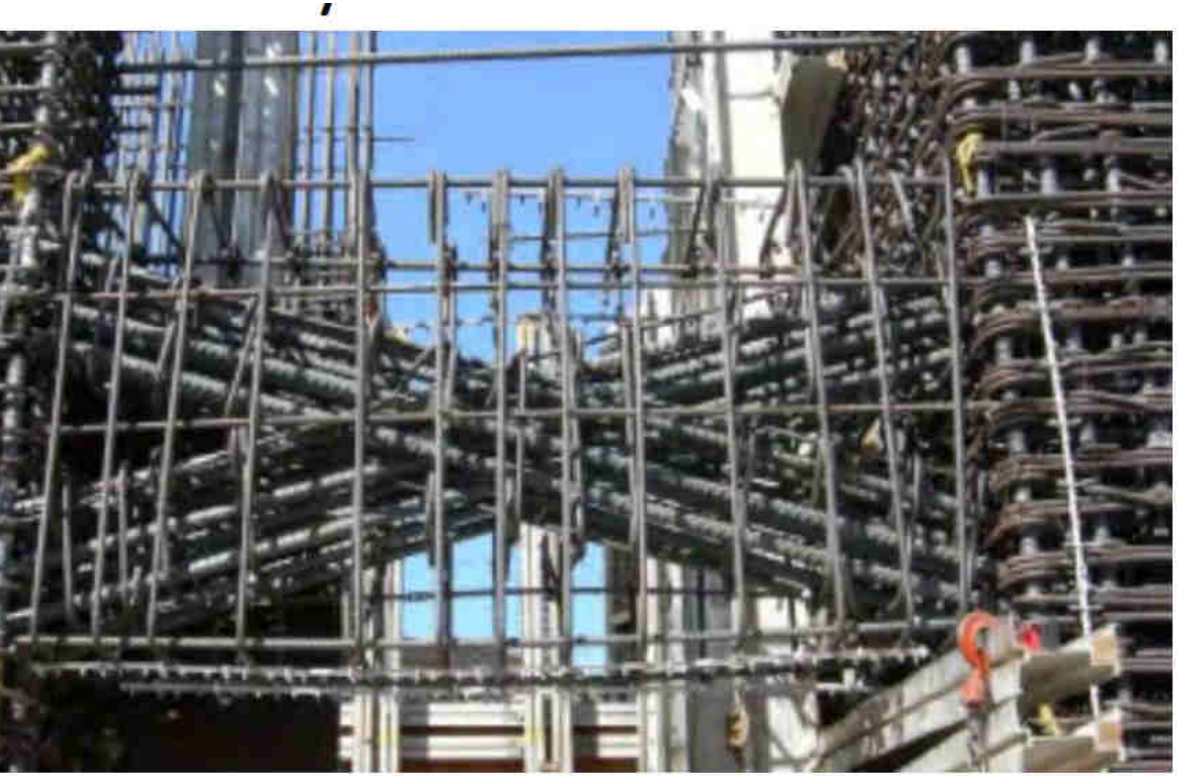


VISCOELASTIC COUPLING DAMPERS (VCDs)

Inelastic Behavior

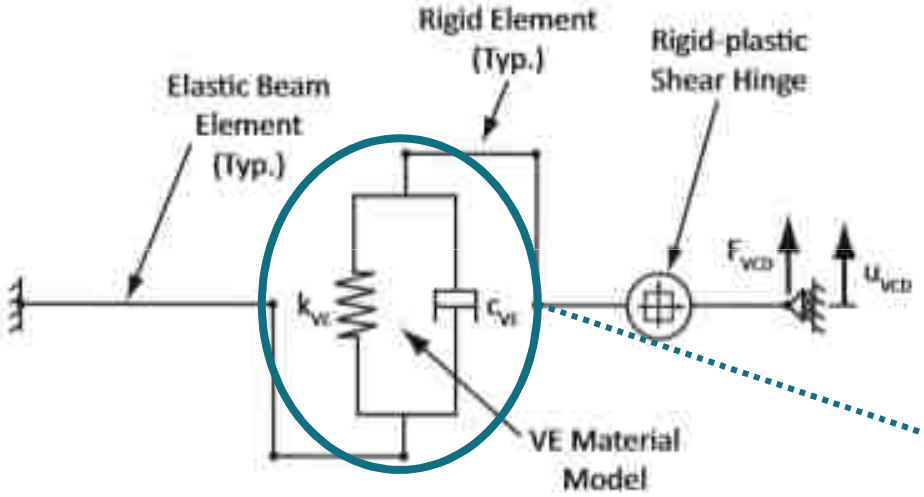


DIAGONAL REBAR vs VCD IN COUPLING BEAM

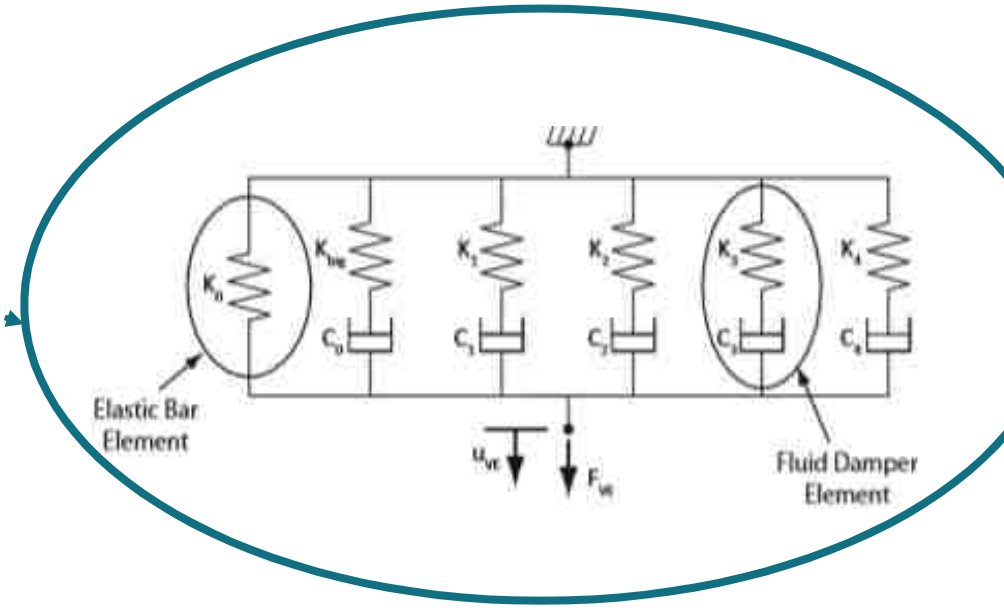


VISCOELASTIC COUPLING DAMPERS (VCDs)

Modelling Scheme



VCD Element Modelling Scheme



Viscoelastic Material Modelling Scheme

VISCOELASTIC COUPLING DAMPERS (VCDs)

Modelling Parameter

$$F(t) = k_{VE}u(t) + c_{VE}\dot{u}\,(t)$$

$$k_{VE} = \frac{G_E A}{h}$$

$$c_{VE} = \frac{G_C A}{h}$$

$$\eta = \frac{G_C}{G_E}$$

Material Properties for ISD:111H (Montgomery, 2011)

G0	0.0623	**β0**	0.000902
G1	0.2605	**Ψ1**	0.0996
G2	0.5493	**Ψ2**	0.0172
G3	8.2335	**Ψ3**	0.0011
G4	0.087	**Ψ4**	1.128

Elastic Bar Element Properties:

Element	K (N/mm)	L (mm)	A (mm^2)	E (N/mm^2)
K0	60.2	100	100	60.2
K1	251.6	50	100	125.8
K2	530.6	50	100	265.3
K3	7954.6	50	100	3977.3
K4	84	50	100	42
K-big	10^6	50	100	5 x 10^5

$$c_o = K_o \times \beta_o$$

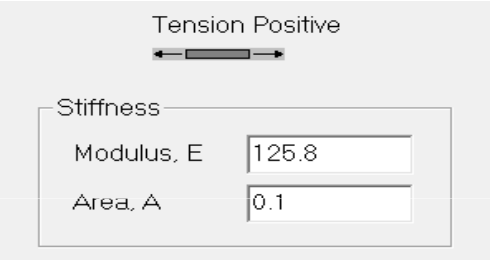
$$c_n = K_n \times \psi_n \; ; n = 1,2,3,4$$

Fluid Damper Element Properties:

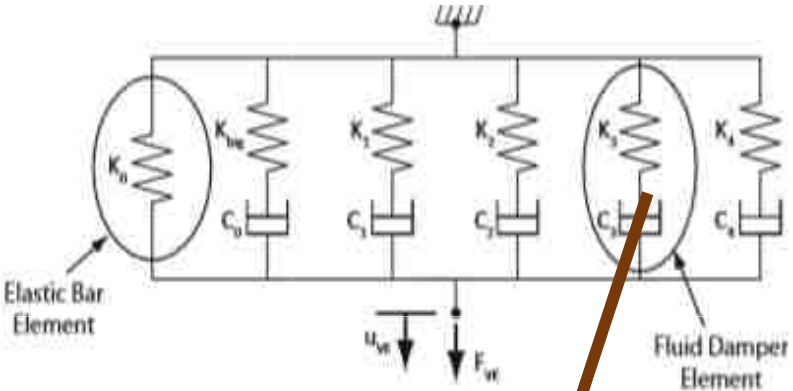
Element	C (Ns/mm)	L (mm)
C0	0.053	50
C1	25.1	50
C2	9.13	50
C3	8.75	50
C4	94.8	50

VISCOELASTIC COUPLING DAMPERS (VCDs)

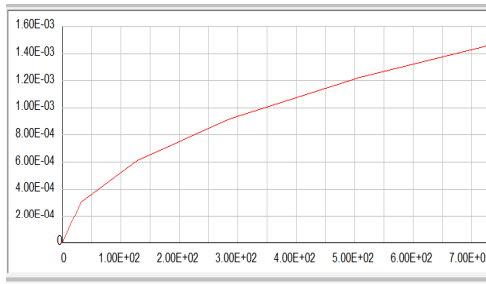
Viscoelastic Material Modelling



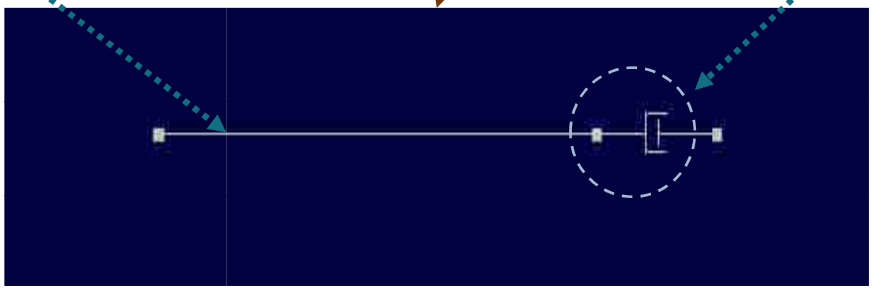
Elastic Bar (Spring Element)



Viscoelastic Material Modelling Scheme



Fluid Damper (Dashpot Element)

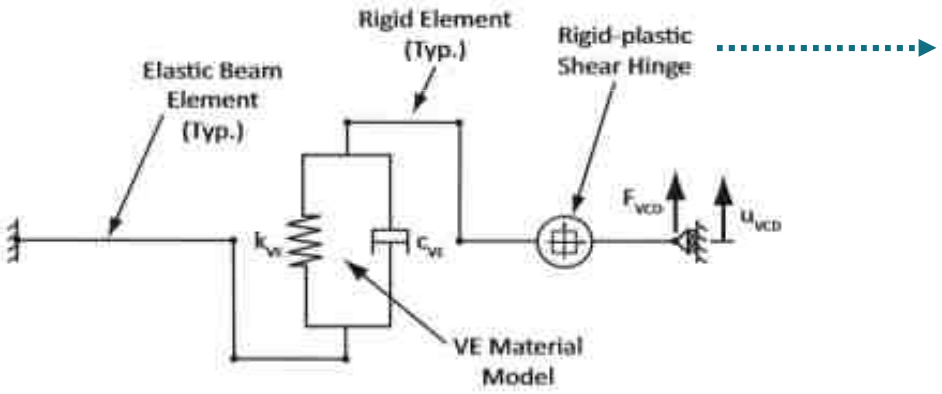


Compound Fluid Damper (Maxwell Element Model)

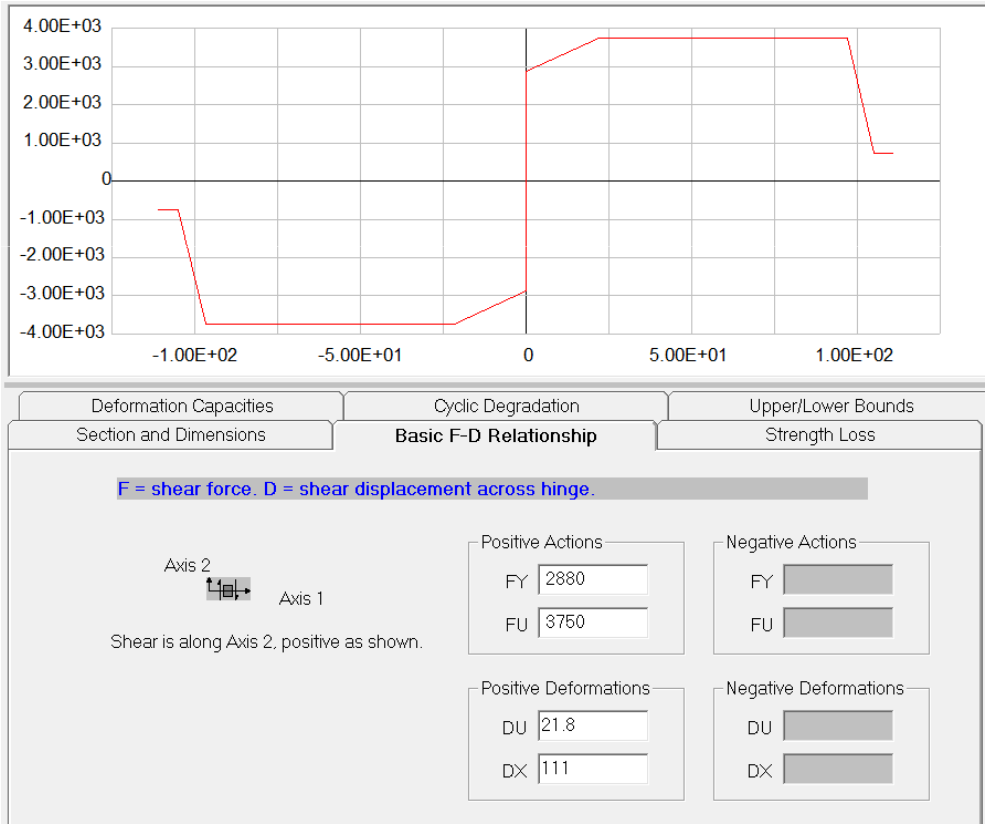
VISCOELASTIC COUPLING DAMPERS (VCDs)

Reduced – Beam Section Modelling

Shear hinge on VCD is designed as fuse mechanism to prevent the VE material to reach the maximum allowable strain of 400% and cause tearing.



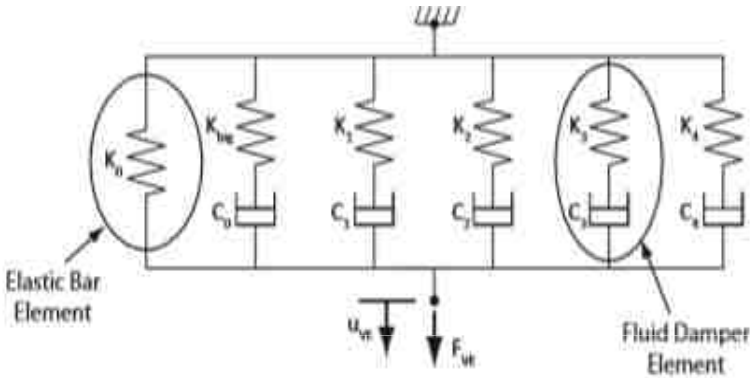
VCD with Rigid – Plastic Shear Hinge Scheme



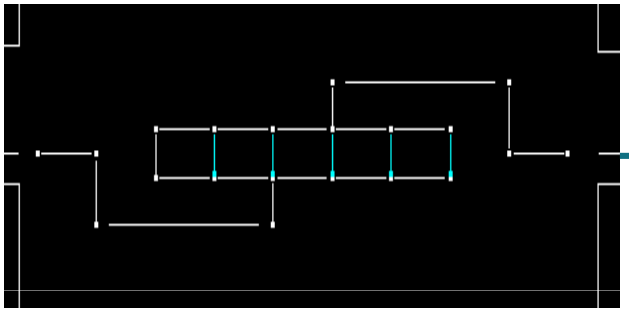
Rigid – Plastic Shear Hinge Scheme Properties (Perform3D)

VISCOELASTIC COUPLING DAMPERS (VCDs)

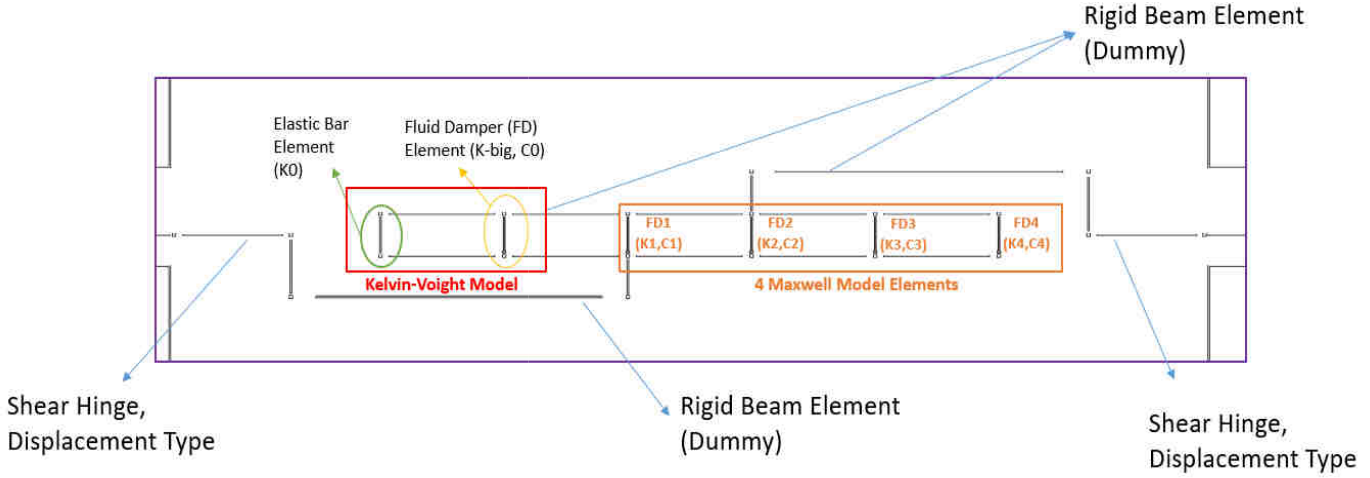
Modelling Using Perform3D (3)



Viscoelastic Material Modelling Scheme



Viscoelastic Material Modelling (Perform3D)



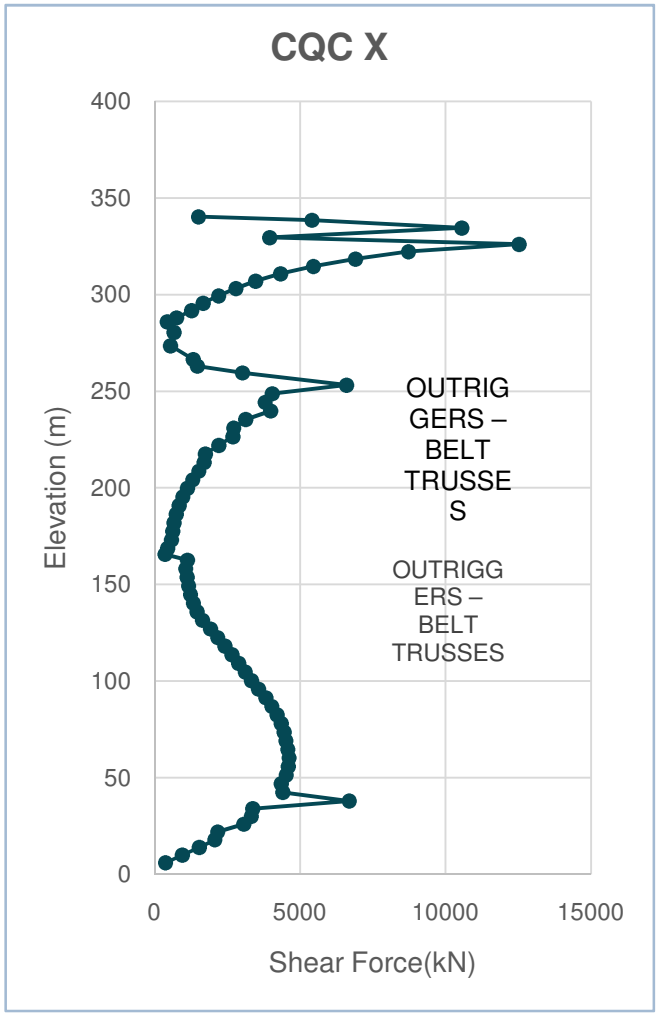
Detail of Viscoelastic Material Modelling (Perform3D)

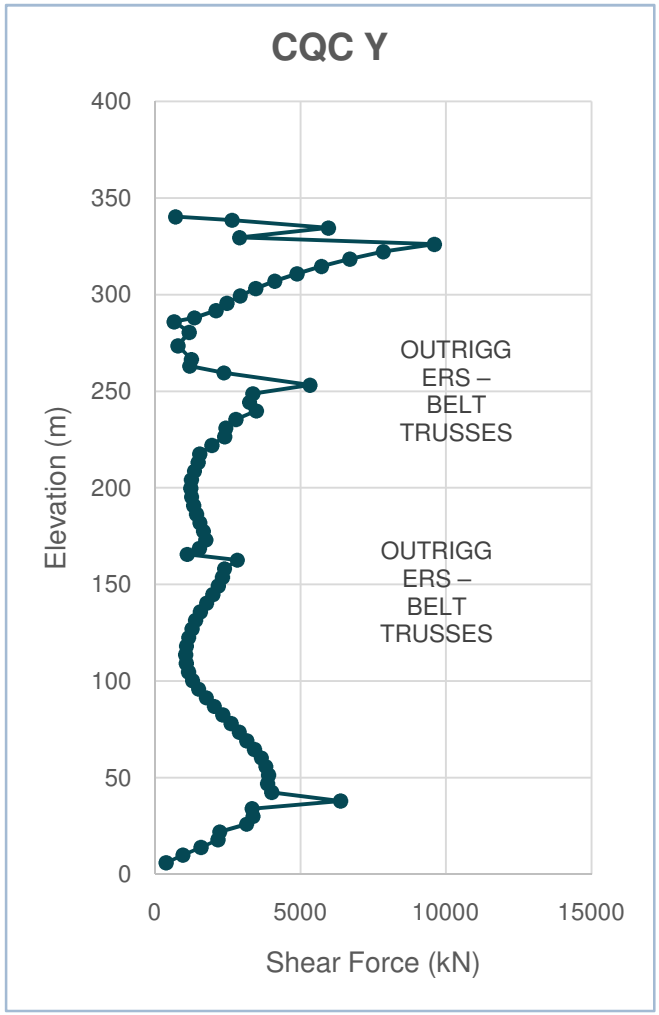
3.

PUSHOVER ANALYSIS

Linear Design Checking (Perform3D)

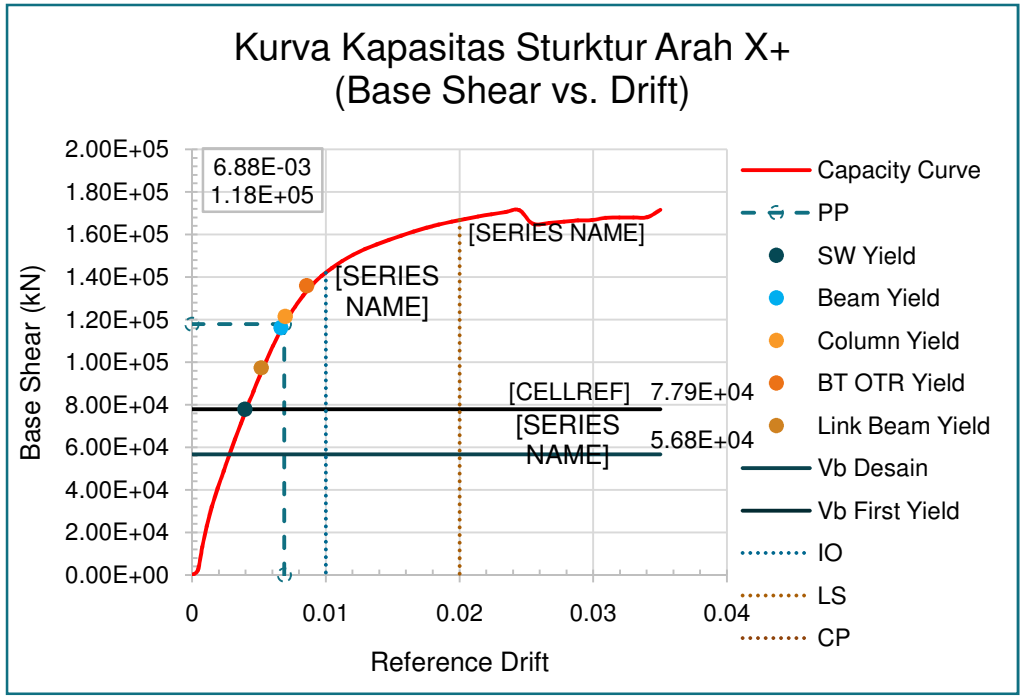
CQC LOADS

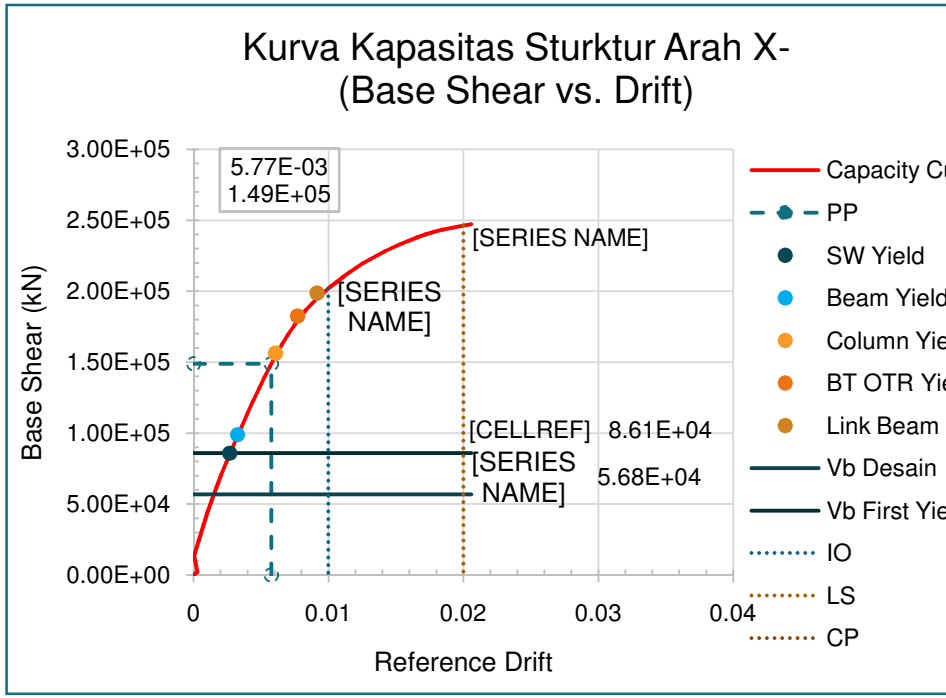

CQC X
400
350
300
250
200
150
100
50
0
Elevation (m)
0
5000
10000
15000
Shear Force(kN)
OUTRIG GERS – BELT TRUSSE S
OUTRIGG ERS – BELT TRUSSES


CQC Y
400
350
300
250
200
150
100
50
0
Elevation (m)
0
5000
10000
15000
Shear Force (kN)
OUTRIGG ERS – BELT TRUSSES
OUTRIGG ERS – BELT TRUSSES

PUSHOVER RESULTS (X DIRECTION)

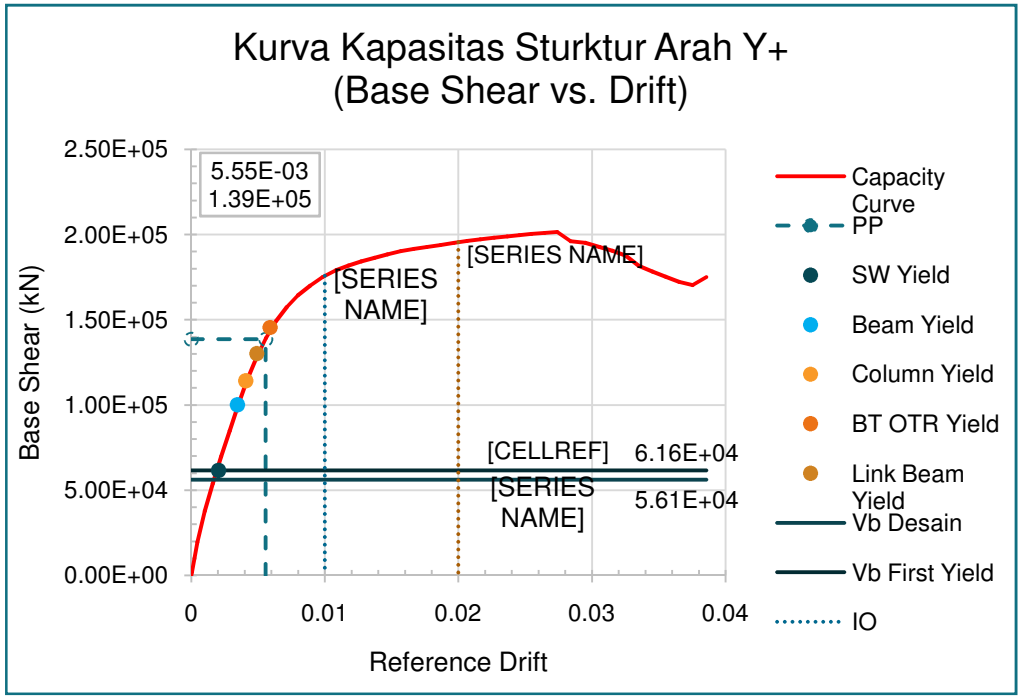
LINEAR DESIGN CHECK : $V_{YIELD} > V_{DESIGN}$

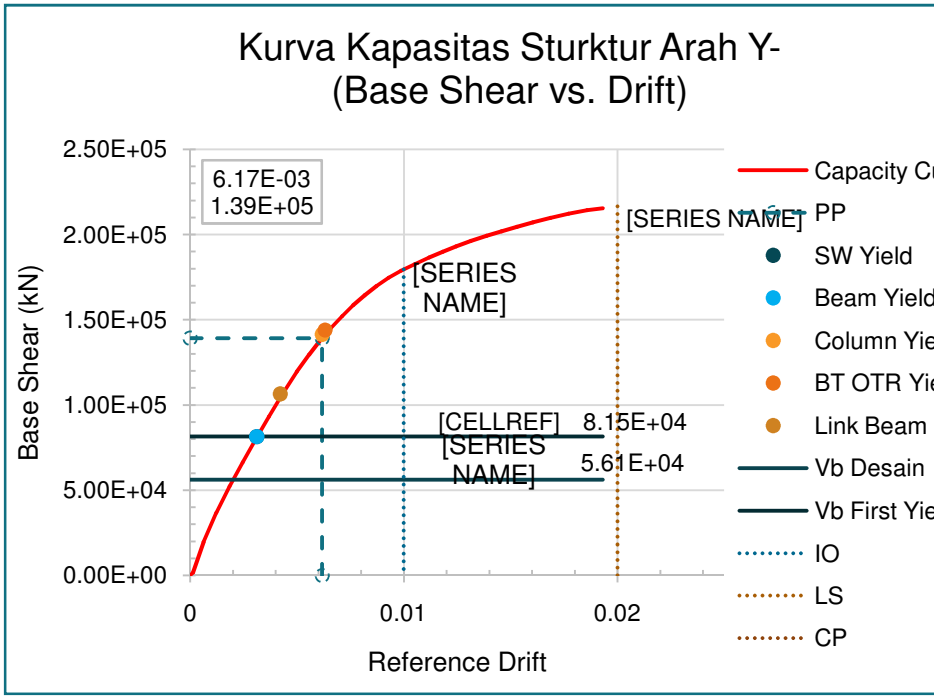




PUSHOVER RESULTS (Y DIRECTION)

LINEAR DESIGN CHECK : $V_{YIELD} > V_{DESIGN}$





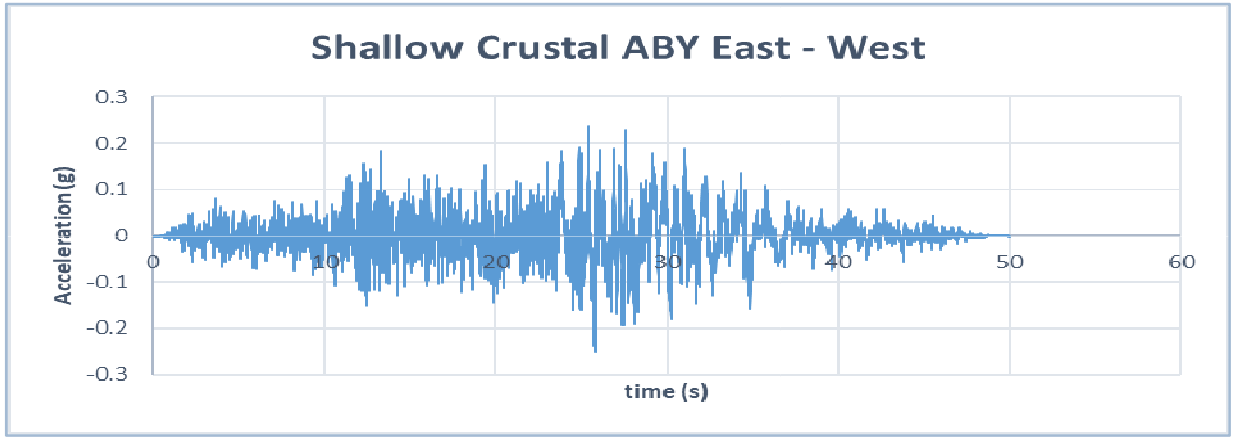
4.

TIME HISTORY ANALYSIS

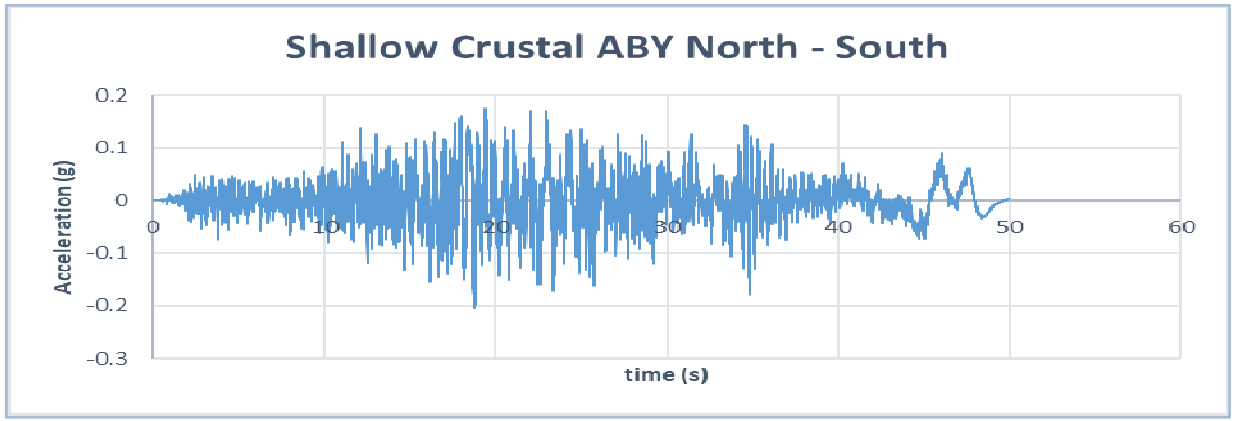
Before and After VCDs Installati

(Perform3D)

GROUND MOTIONS



MAX 0.2504 g

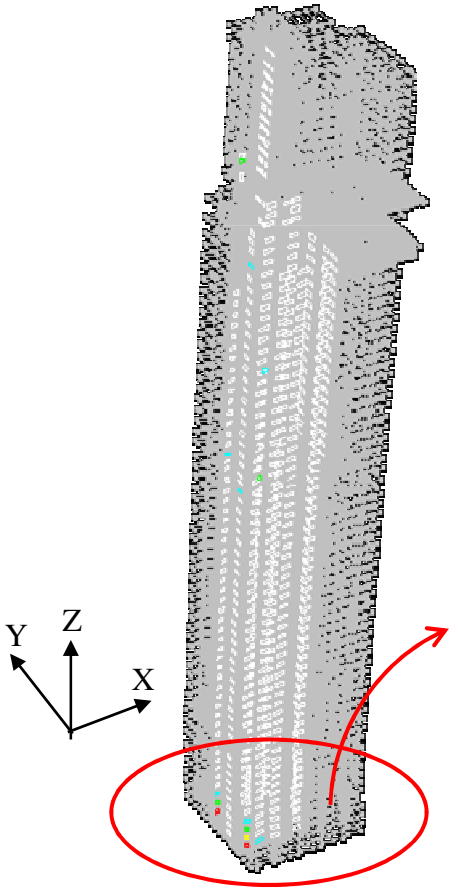


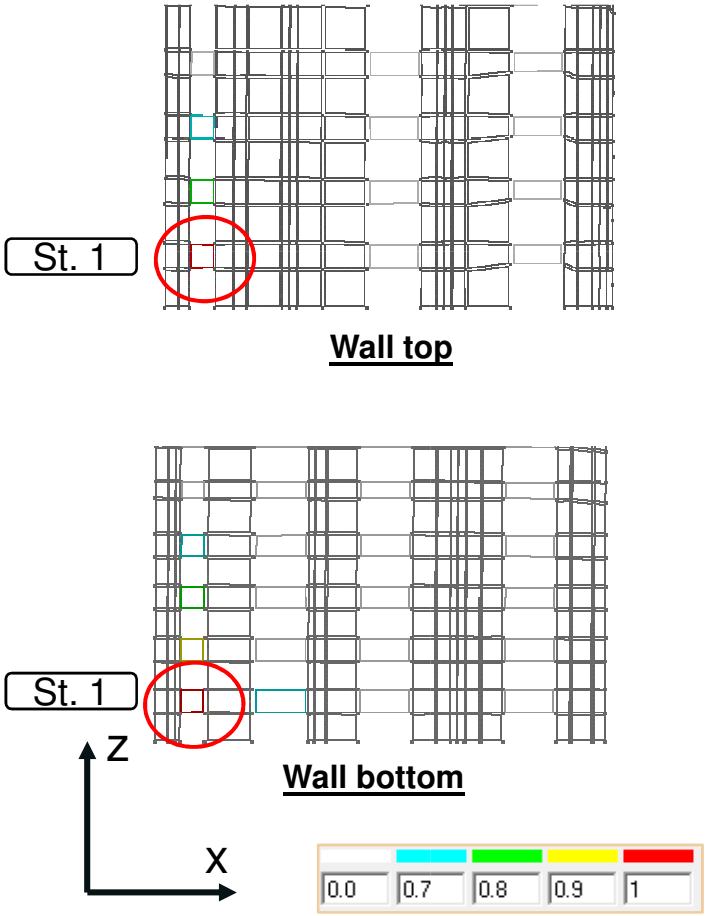
MAKS 0.205 g

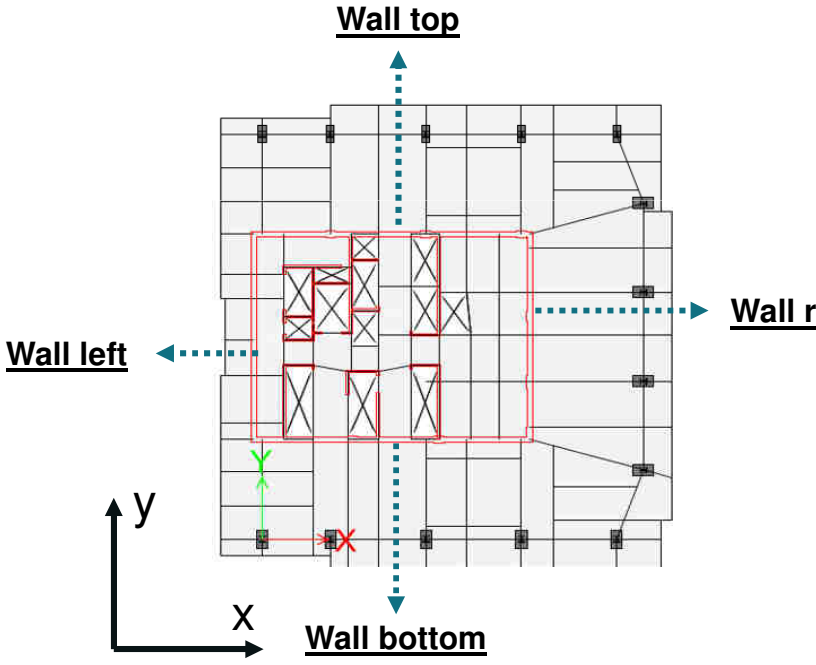
VCDs LOCATION

Lower Level Area

VCDs are installed substituting the damaged link beams indicated from the initial time history analysis.







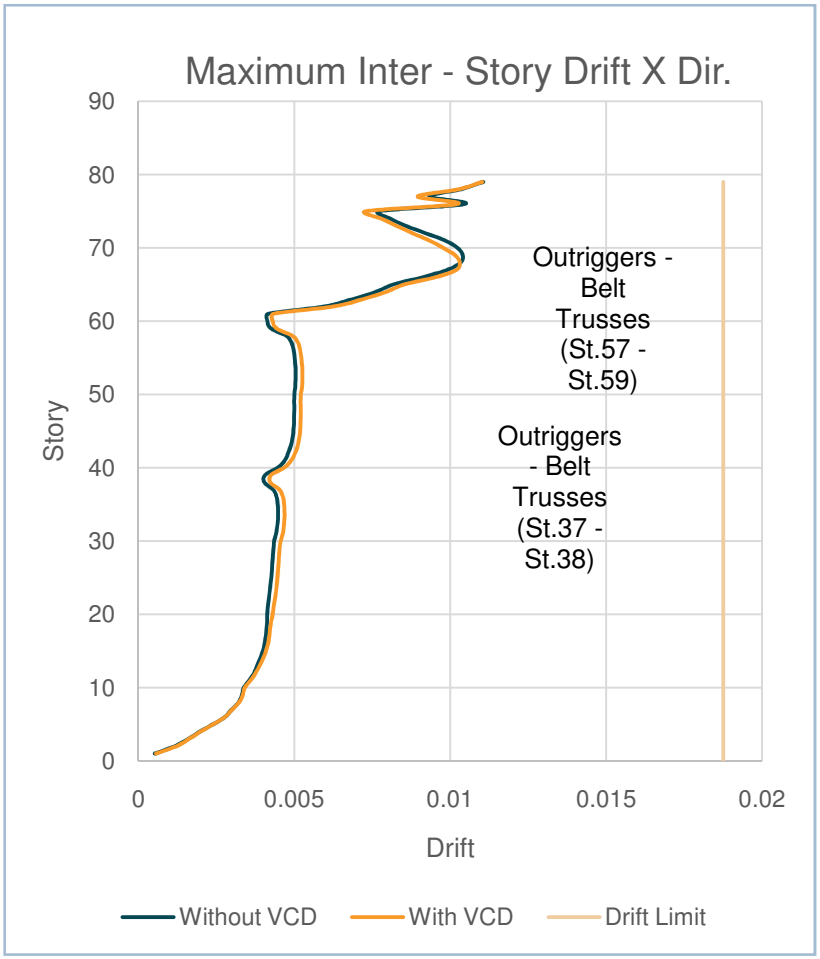
Usage Ratio = 1 indicates that the element has reached deformation capacity limit for yield state

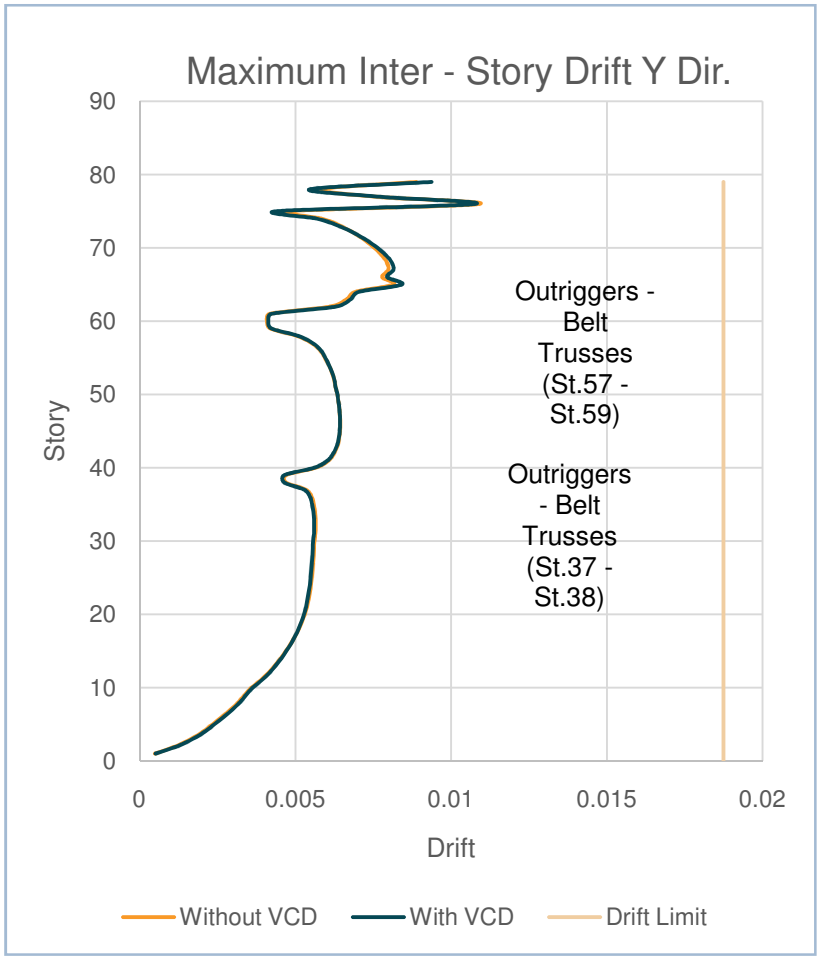
STRUCTURAL LEVEL RESULTS

- Maximum inter-story drift
- Residual drift
- Base shear

MAXIMUM INTER – STORY DRIFT

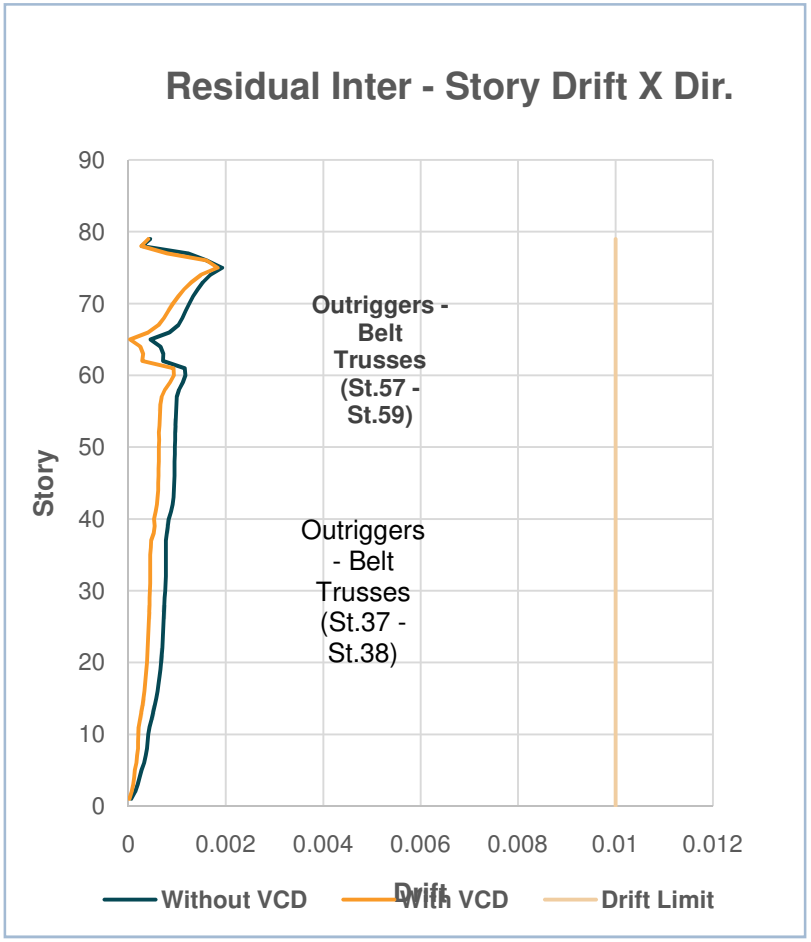
The following graphs reveal maximum drift of building with and without VCD installed. Small differences appear in X direction since VCDs are installed only in this direction.

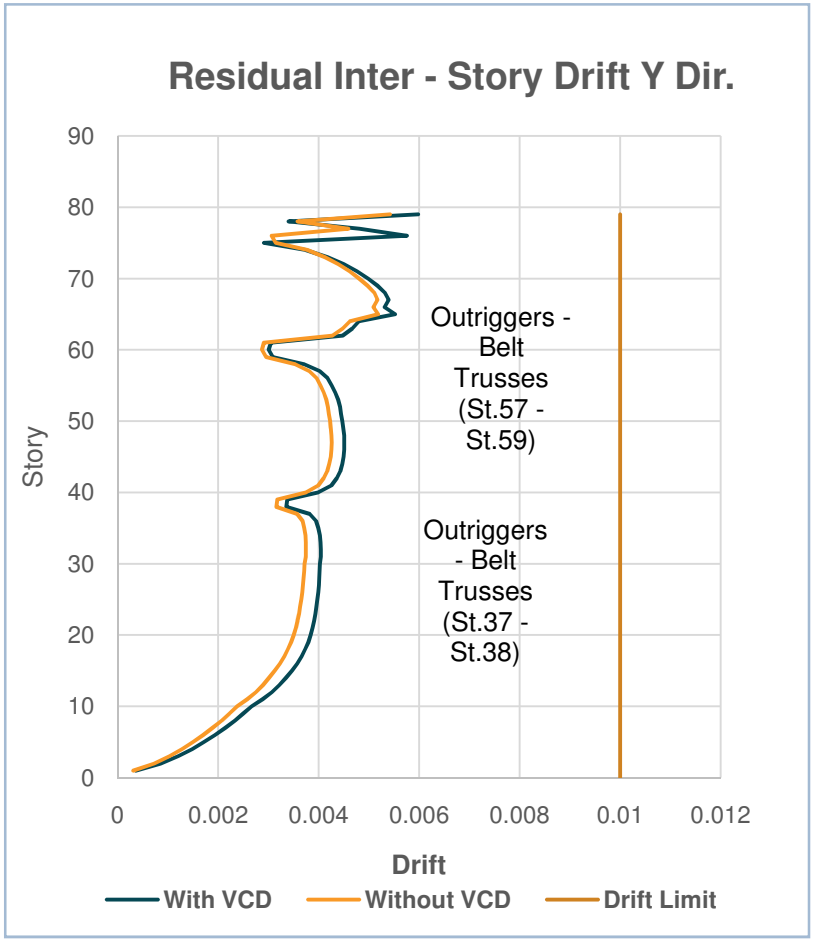




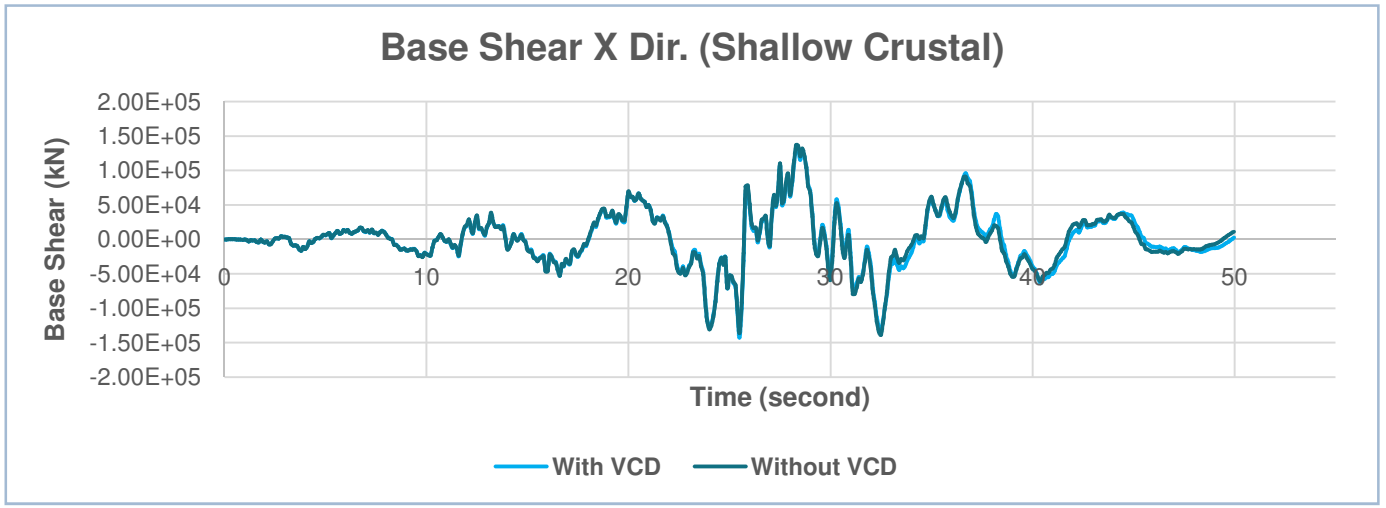
RESIDUAL INTER – STORY DRIFT

Residual drift plots with and without VCD installed coincide due to small difference.

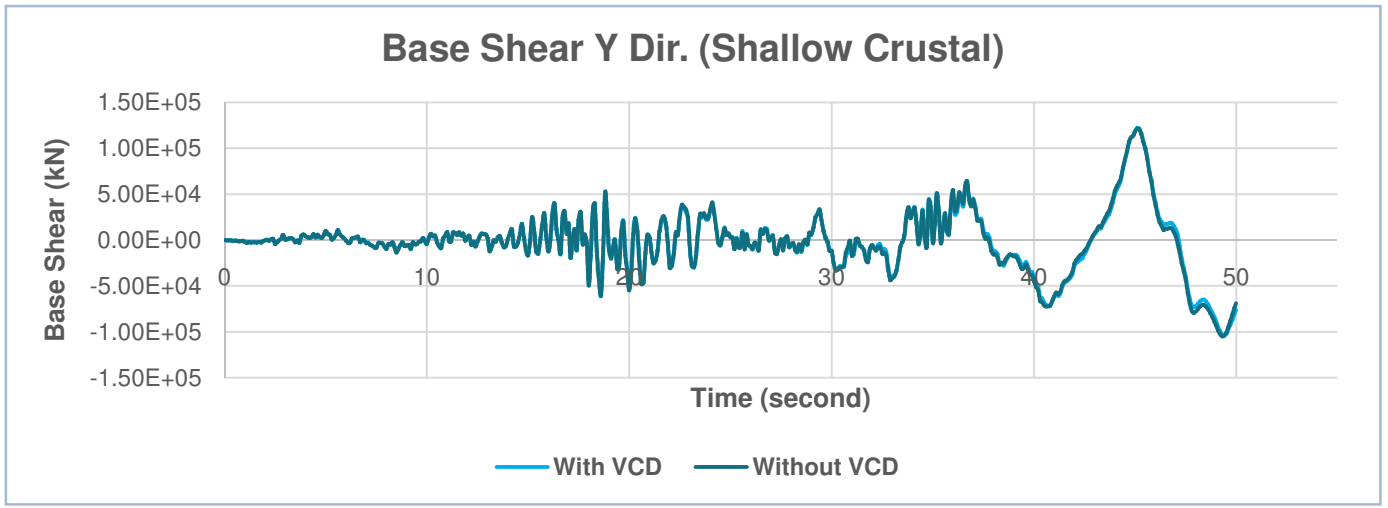




BASE SHEAR



Condition	Shear Forces X Dir.	
	Max.	Mi
Without VCD	$1{,}368 \times 10^5$	−1,387
With VCD	$1{,}323 \times 10^5$	−1,429

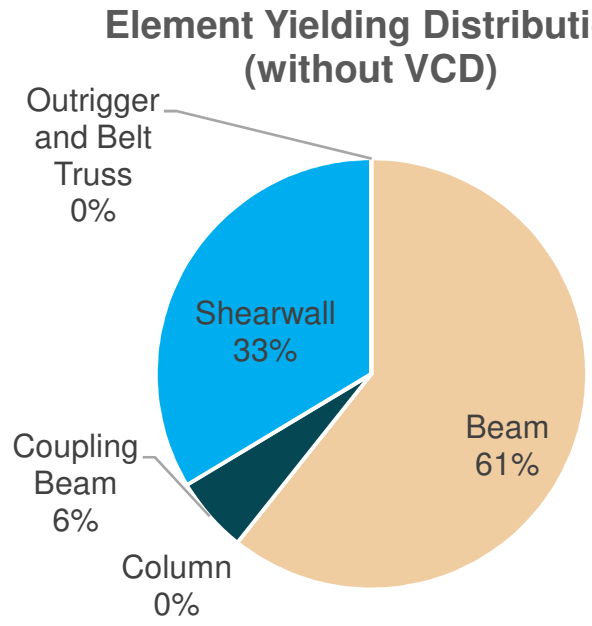


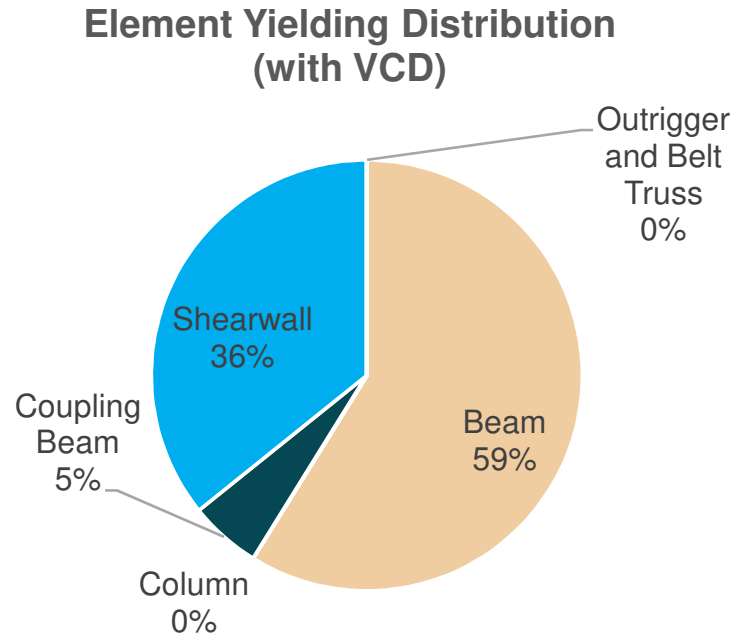
Condition	Shear Forces Y Dir.	
	Max	Mi
Without VCD	$1{,}212 \times 10^5$	−1,050
With VCD	$1{,}219 \times 10^5$	−1,039

ELEMENT LEVEL RESULTS

- Element yielding
- Usage ratio
- F – D Relationship

ELEMENT YIELDING DISTRIBUTION

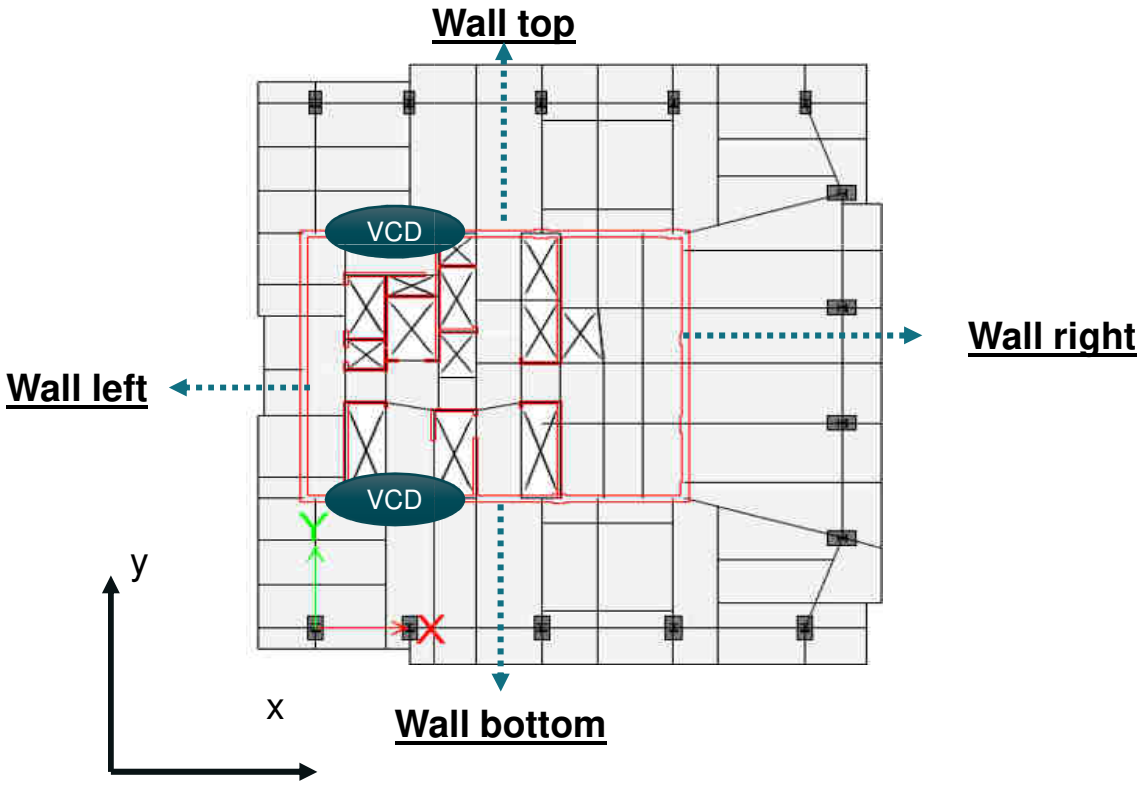




RETROFITTED ELEMENTS

Substituting Coupling Beams with VCDs

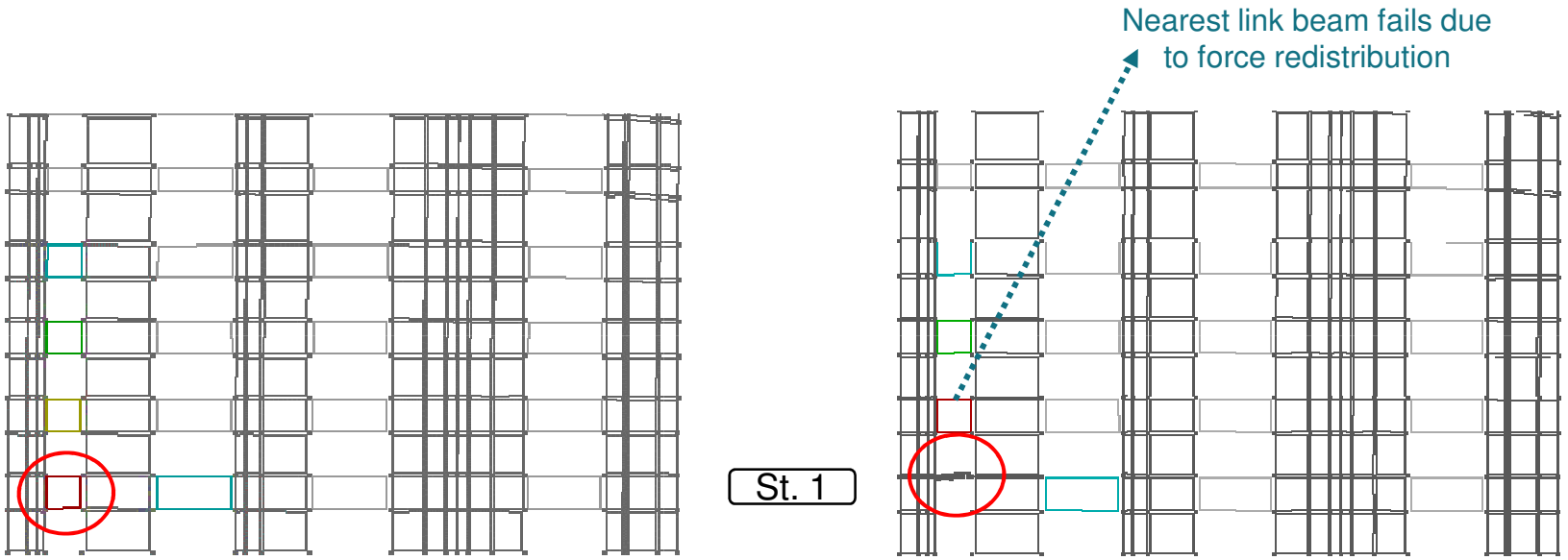
Link Beams / VCDs on the 1st story



Plan View of 1st Story

RETROFITTED ELEMENTS

Wall Top Side

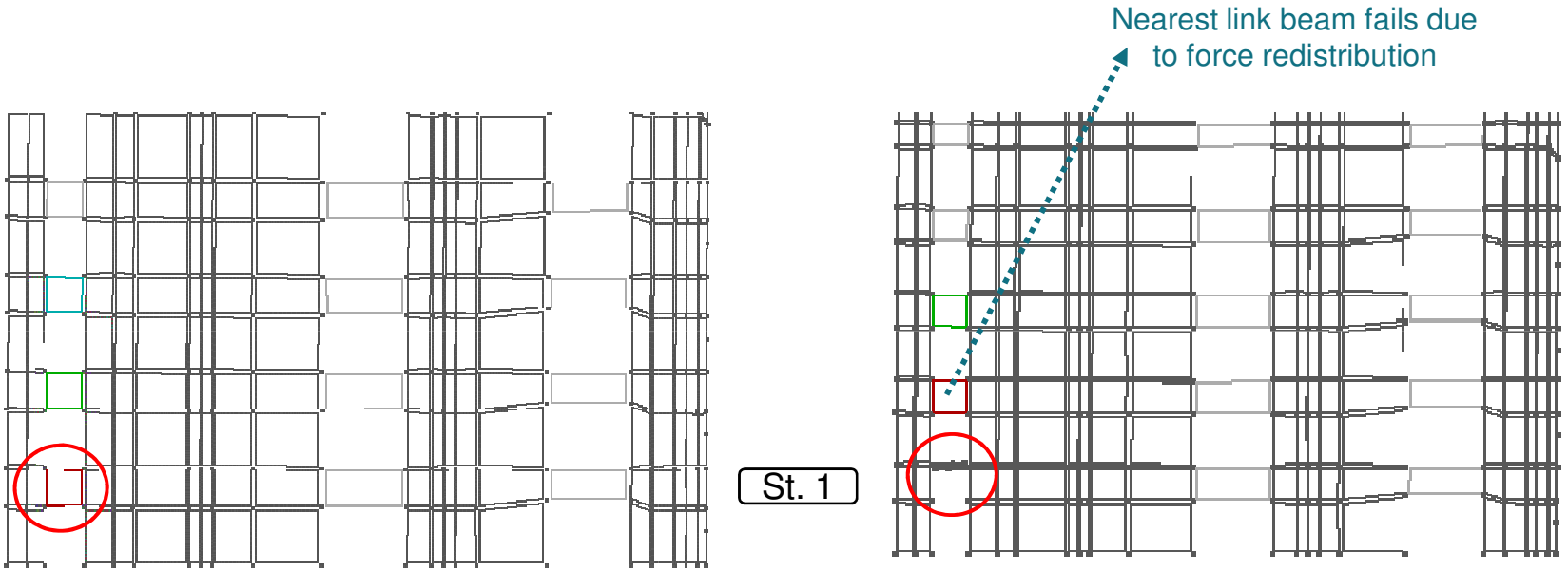


Without VCD **With VCD**

Usage Ratio = 1 indicates that the element has reached deformation capacity limit for yield state

RETROFITTED ELEMENTS

Wall Bottom Side

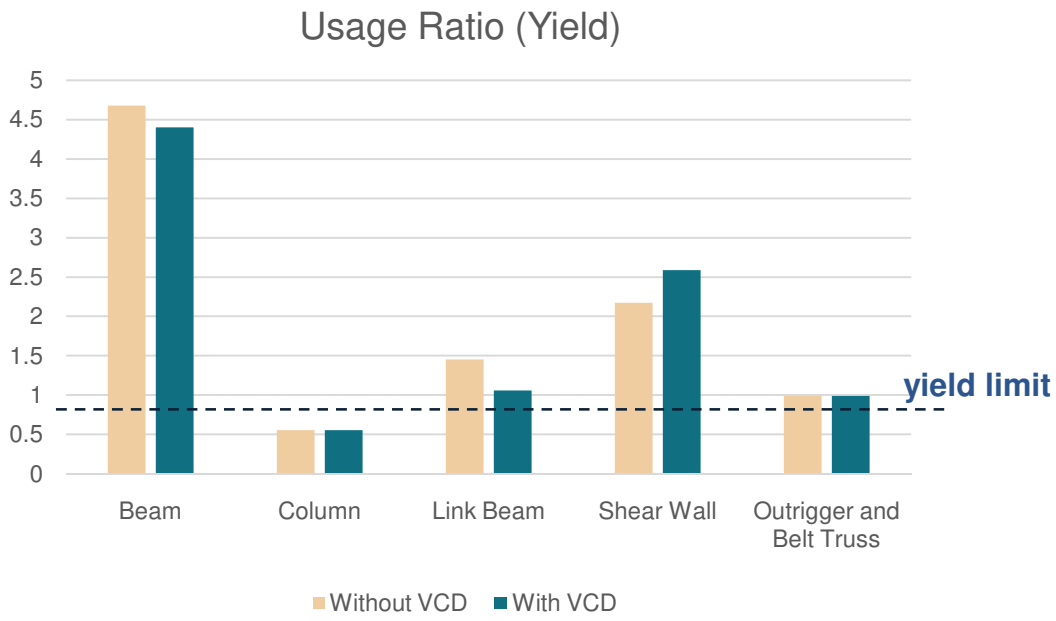


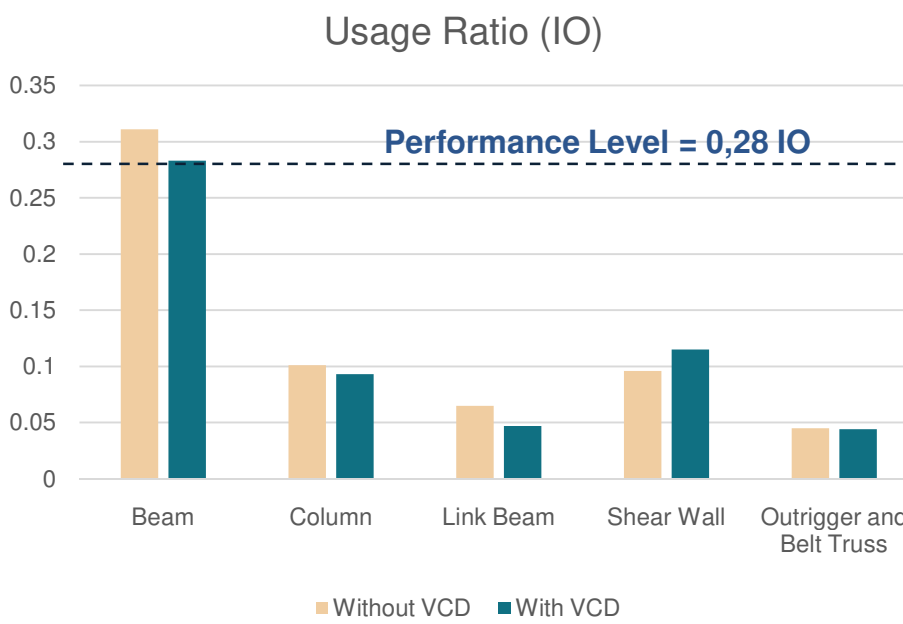
Usage Ratio = 1 indicates that the element has reached deformation capacity limit for yield state

FINAL USAGE RATIO AND PERFORMANCE LEVEL

Comparing element condition with and without VCDs

Performance level improved to 0,28 IO from 0,31 IO by installing VCDs as link beams substitute.

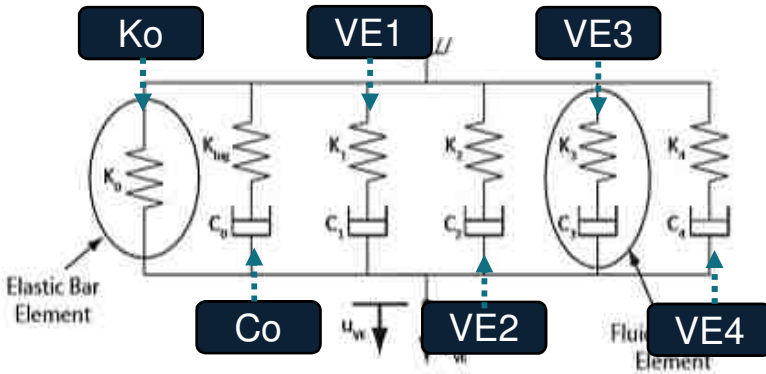


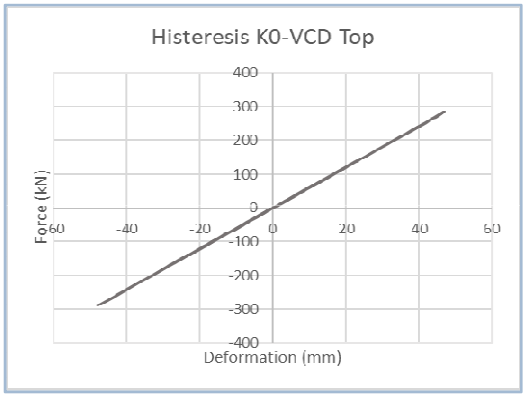


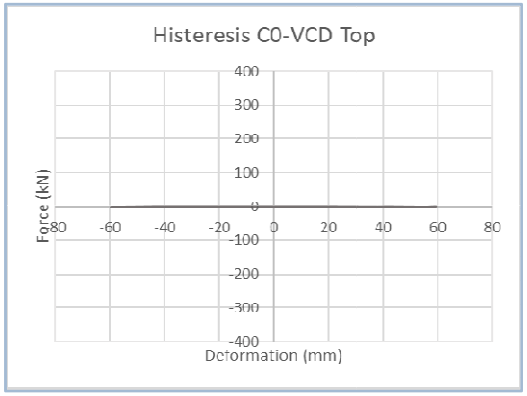
Usage Ratio : demand-capacity ratio measured according to deformation capacities of inelastic elements.

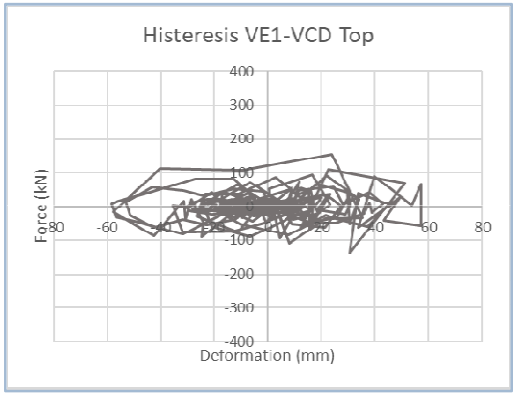
HYSTERESIS CURVE OF VISCOELASTIC COMPONENTS

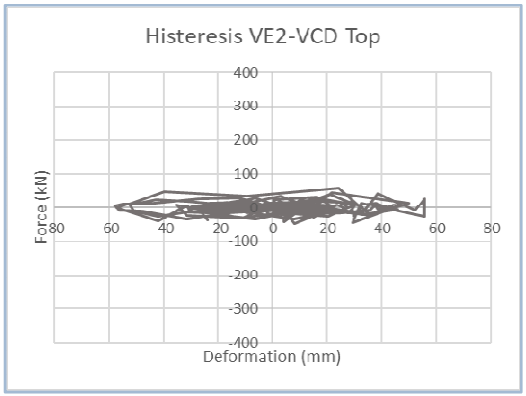
F – D RELATIONSHIP OF VCD ON WALL TOP SIDE OF 1ST STORY

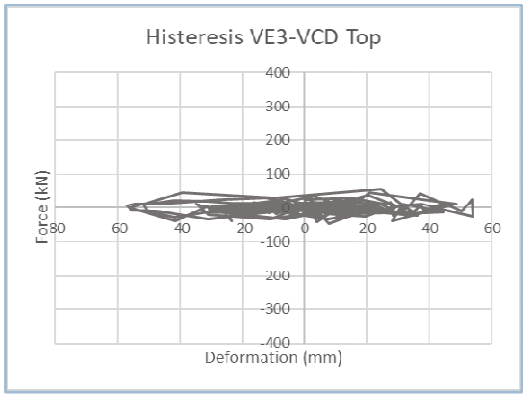


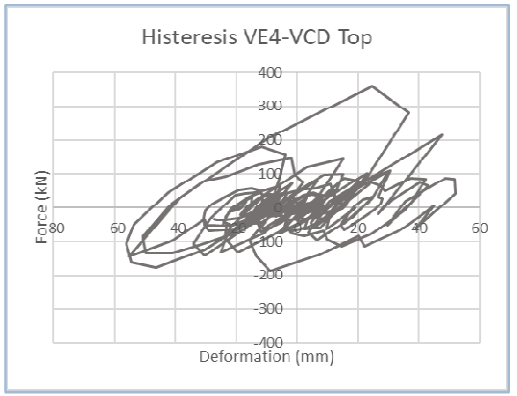






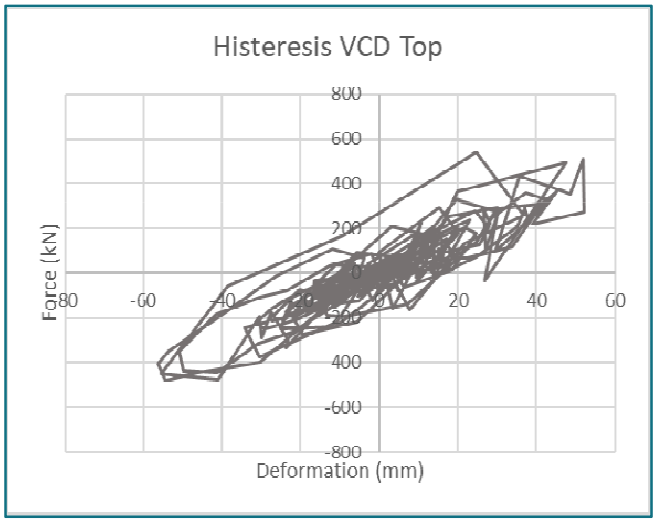


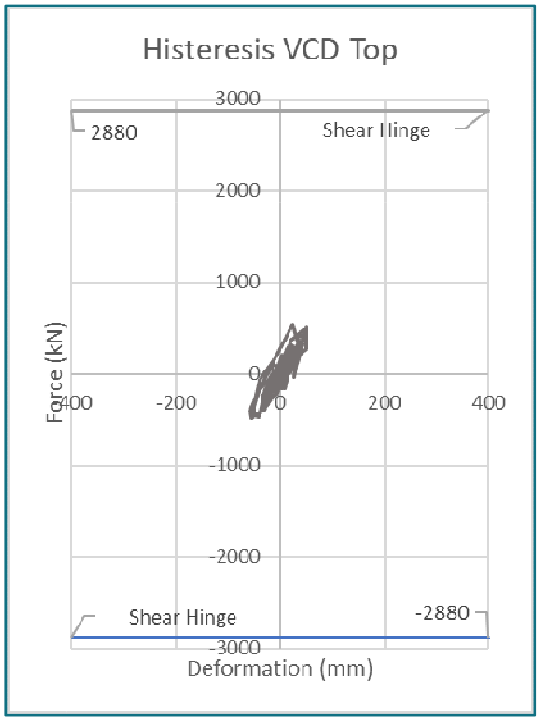




HYSTERESIS CURVE OF VCD

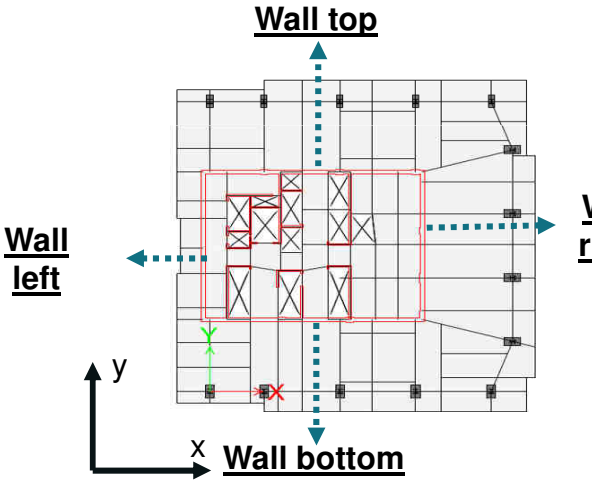
F – D RELATIONSHIP OF VCD ON WALL TOP SIDE OF 1ST STORY





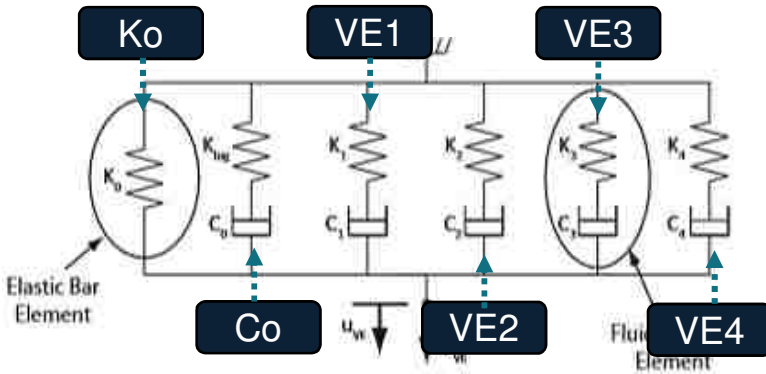
Shear Strain VCD Top = 40%

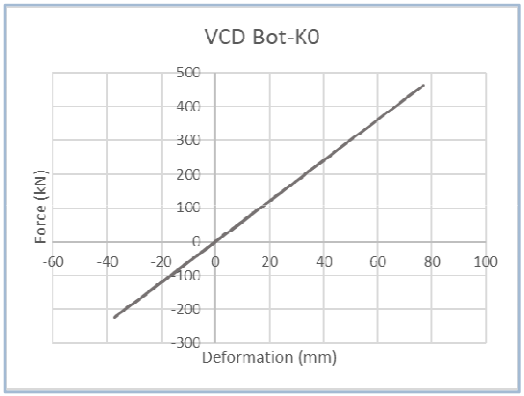
Shear Strain Max. = 400%

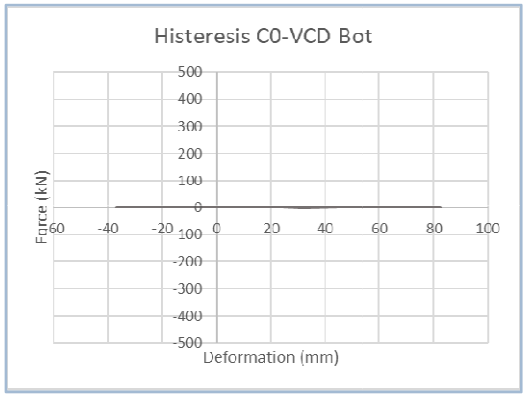


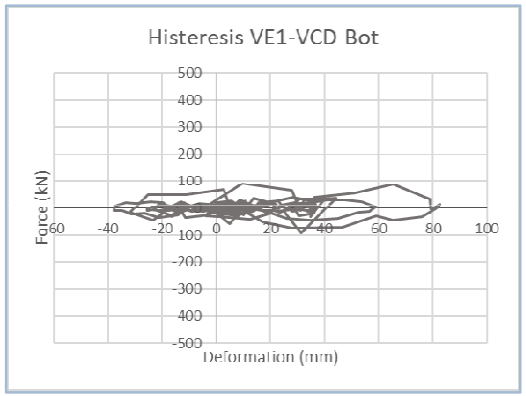
HYSTERESIS CURVE OF VISCOELASTIC COMPONENTS

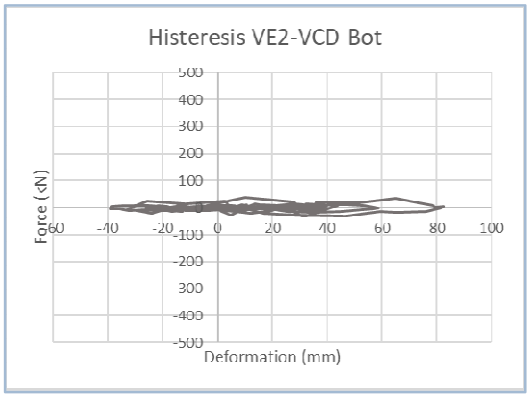
F – D RELATIONSHIP OF VCD ON WALL BOTTOM SIDE OF 1ST STORY

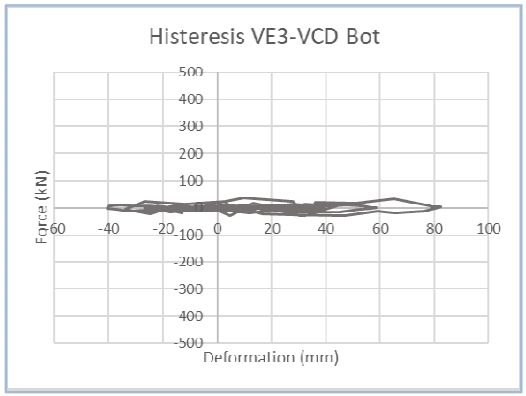


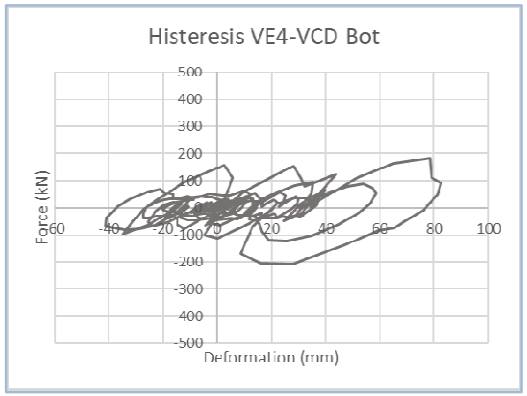






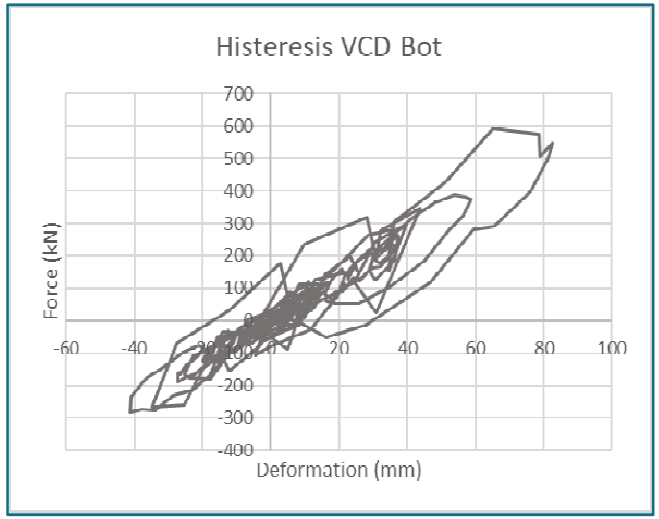


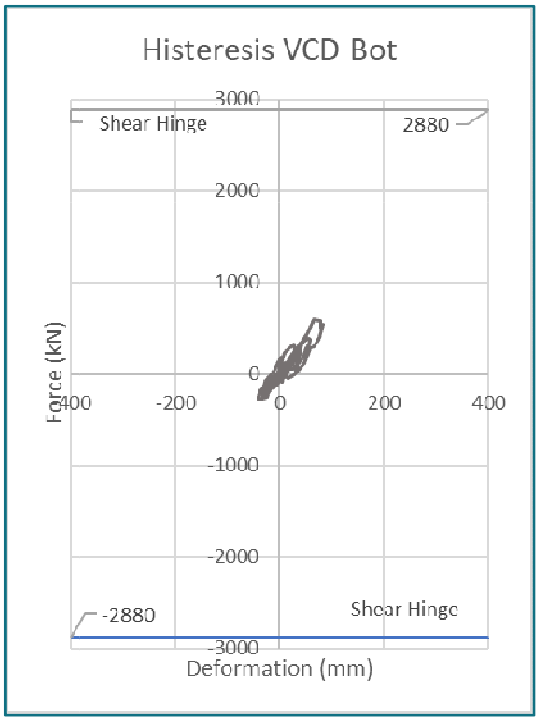




HYSTERESIS CURVE OF VCD

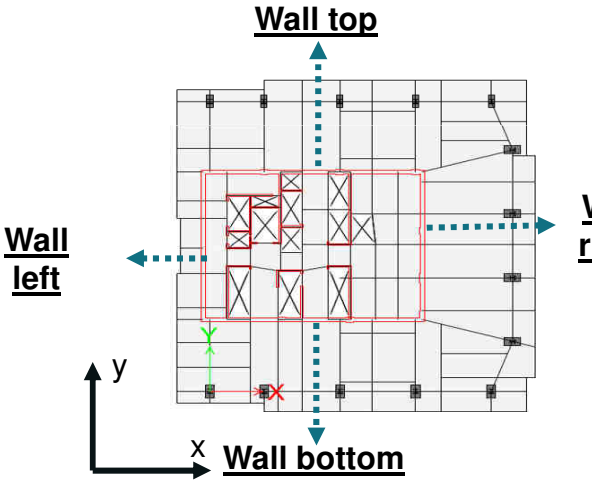
F – D RELATIONSHIP OF VCD ON WALL BOTTOM SIDE OF 1ST STORY





Shear Strain VCD Top = 52,8%

Shear Strain Max. = 400%



5.

CONCLUSIONS

Effectiveness and Behavior of VC

CONCLUSIONS

1. VCDs configuration used in this research results in the failure shifting of 2 link beams in the upper level, in other words the use of VCDs in this research are less effective. This is because of the redistribution effect occurring in the structural elements
2. The hysteresis curves of VCD reveal that the use of VCDs substituting the link beams as energy dissipator are justified. Based on the analysis results, the maximum actual strain of VCD is 53% - below the maximum allowable strain of 400% - while the shear hinge elements show no hinge formation.

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Mackay-Lyons, R., Montgomery, M., Christopoulos, C. 2012. *Enhancing The Seismic Performance of RC Coupled Wall High-Rise Buildings with Viscoelastic Coupling Dampers*. Lisboa: 15th World Conference on Earthquake Engineering (15WCEE).

Pant, DR., Montgomery, M., Christopoulos, C., Xu, B., Poon, D. 2017. *Viscoelastic Coupling Dampers for The Enhanced Seismic Resilience of a Megatall Building*. Santiago: 16th World Conference on Earthquake Engineering (15WCEE).

Diah Puspita Rahmi., 2018., Master Thesis, Nonlinear Response History Analysis of Viscoelastic Coupling Dampers (VCDs) Under Major Earthquake Loading in Lieu of Coupling Dampers at Lower Level Area of Super Tall Building, Faculty of Civil and Environmental Engineering, Institute Technology Bandung, Indonesia.


THANK YOU !