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SERIES

Seismic Engineering Research Infrastructures for European Synergies

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International Workshop "Role of research infrastructures in seismic rehabilitation"

Nonlinear Static Pushover Analysis of a Shear Wall Building in Madinah

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Recent Seismic Activities in KSA

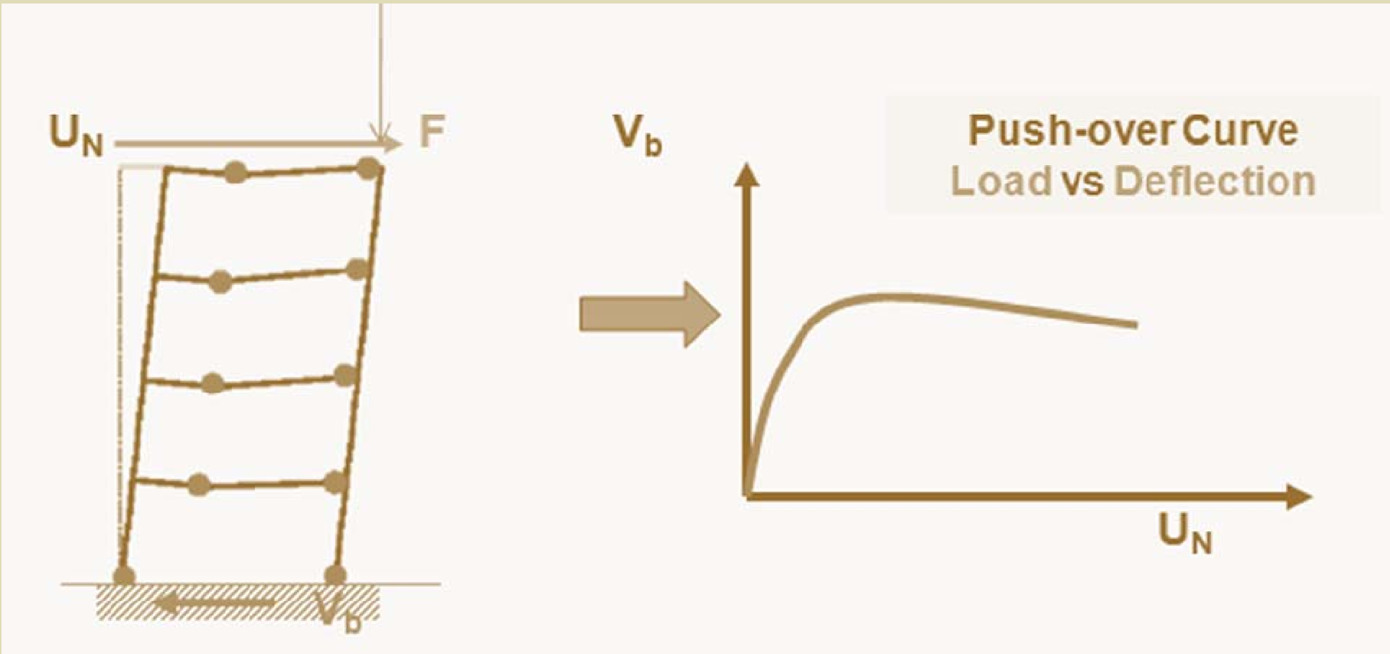
- Recently seismic events that occurred in low to moderate seismicity regions of Saudi Arabia are:
- Otaibah, Makkah (2005)
- Haradh, Eastern Province (2006)
- Al-Hadama, Al-Amid, Al-Qarasa and Yanbu (2009)
- Eastern Province (August, 2010)

Why Research is Needed?

1. Some large cities in the **Eastern and Western Part of Saudi Arabia are located close to fault zones**. *As the population increases and new areas are developed, the seismic risk to human life and infrastructure increases.*
2. Most old structures aredesigned **without considering seismic effect.** i.e. designed for gravity loads.
3. Recent seismic activity in Saudi Arabia have led to concern about the safety of the existing reinforced concrete buildings.
4. **This research is planned as a joint collaboration between King Fahd university of Petroleum and Minerals (KFUPM), Saudi Arabia and Istanbul Technical University (ITU), Turkey.**

NON-LINEAR STATIC PUSH-OVER ANALYSIS

- The pushover analysis, is a static non-linear analysis under permanent gravity loads and gradually increasing lateral loads.



APPLICATION OF PUSHOVER ANALYSIS

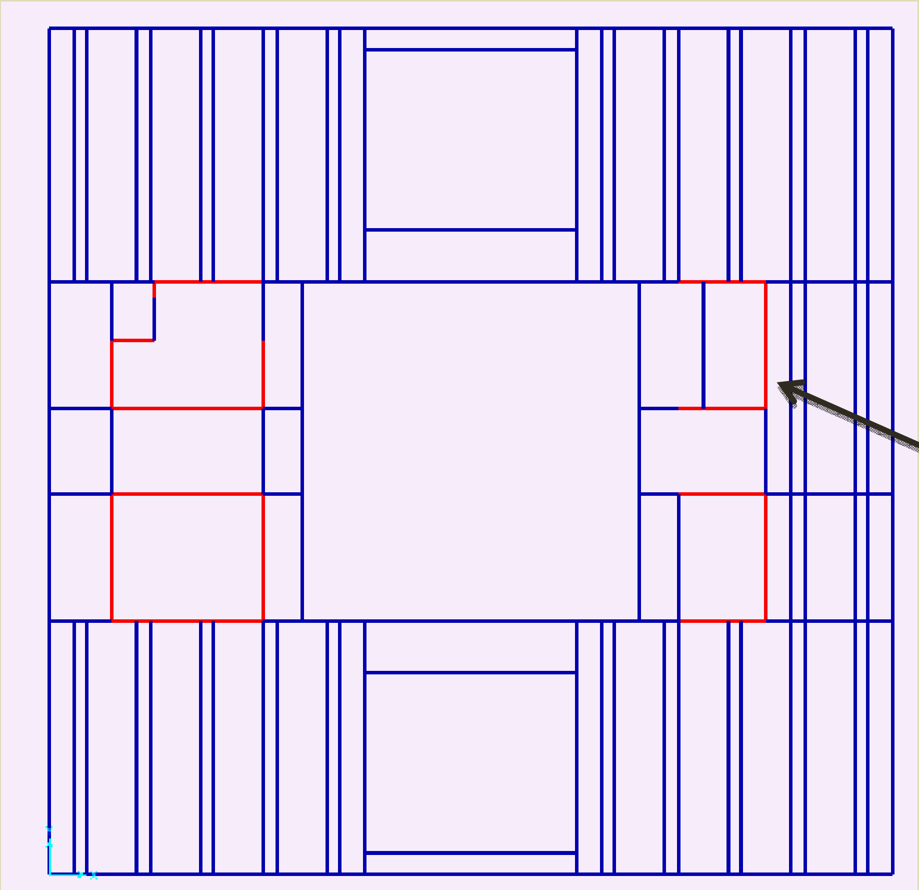
- Pushover analysis may be applied to verify the structural performance of newly designed and the existing buildings for the following purposes:

1. To verify the over strength ratio values.
2. To estimate the expected plastic mechanism and the distribution of damage.
3. To assess the structural performance of existing or retrofitted buildings.
4. As an alternative to the design based on linear analysis.

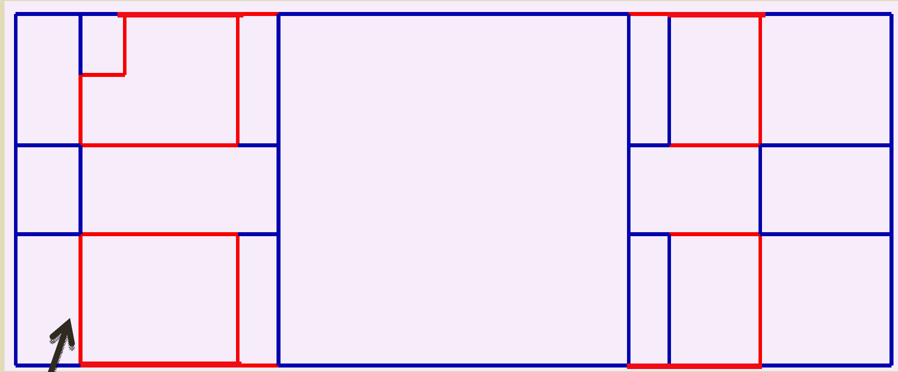
Description of the Building in Madinah

- **Madinah Municipality building is selected.**
- **Constructed in 1996.**
- **Located in western region of Saudi Arabia.**
- **8 storey with dome and elevator shafts**
- **Plan Area = 40m x 40m**
- **Seismic Zone is Z2A according to UBC 1997.**

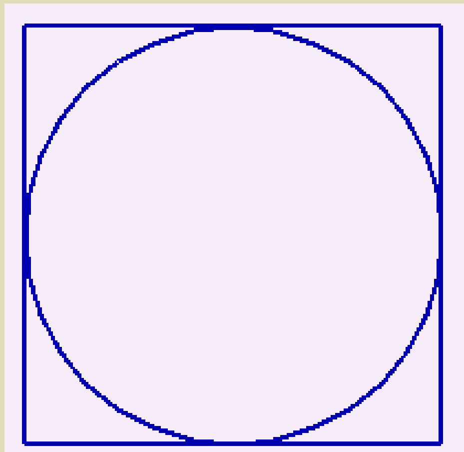
TYPICAL PLAN – MADINAH MUNICIPALITY BUILDING



TYPICAL PLAN FROM 1ST TO 6TH STOREY

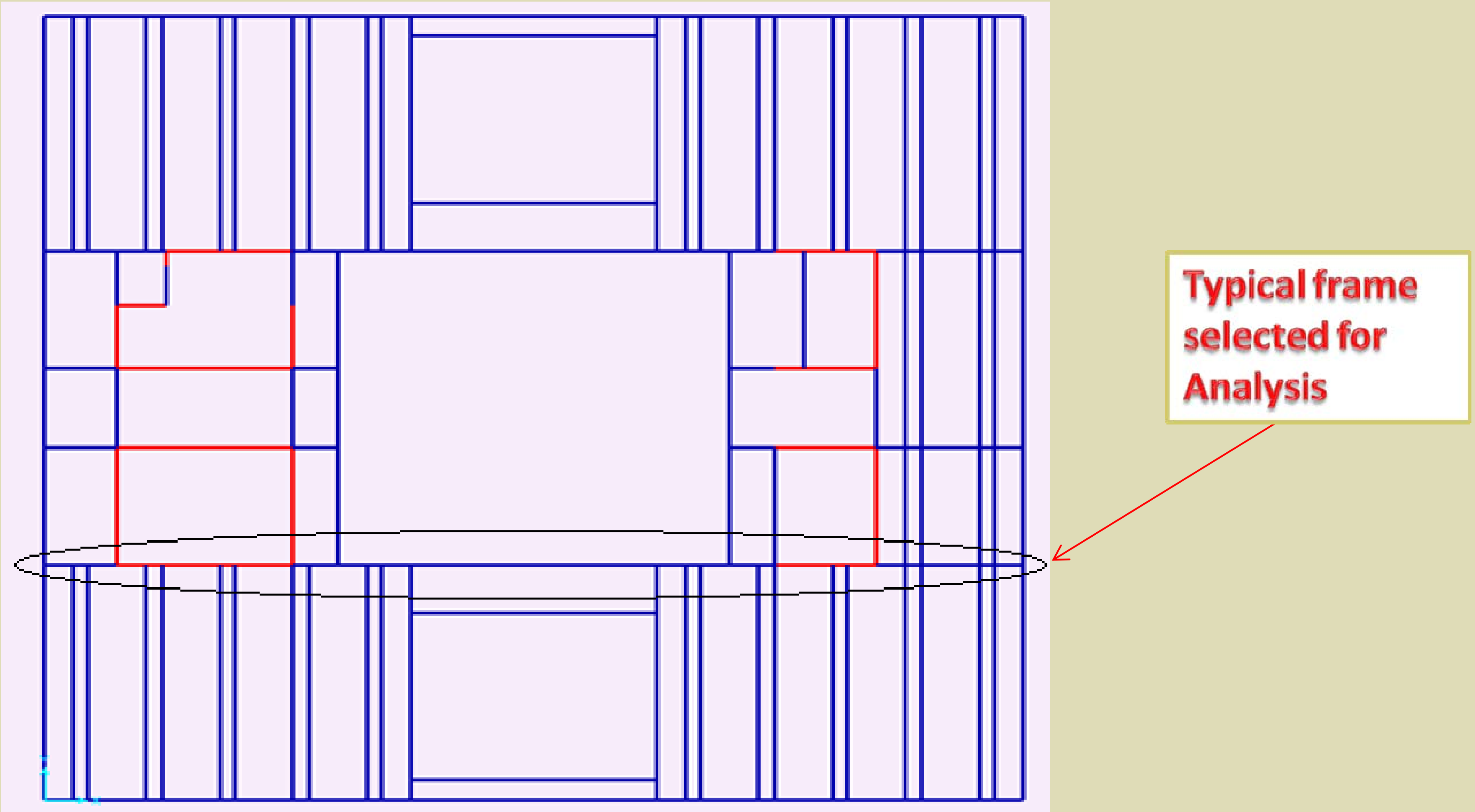


7TH STOREY PLAN

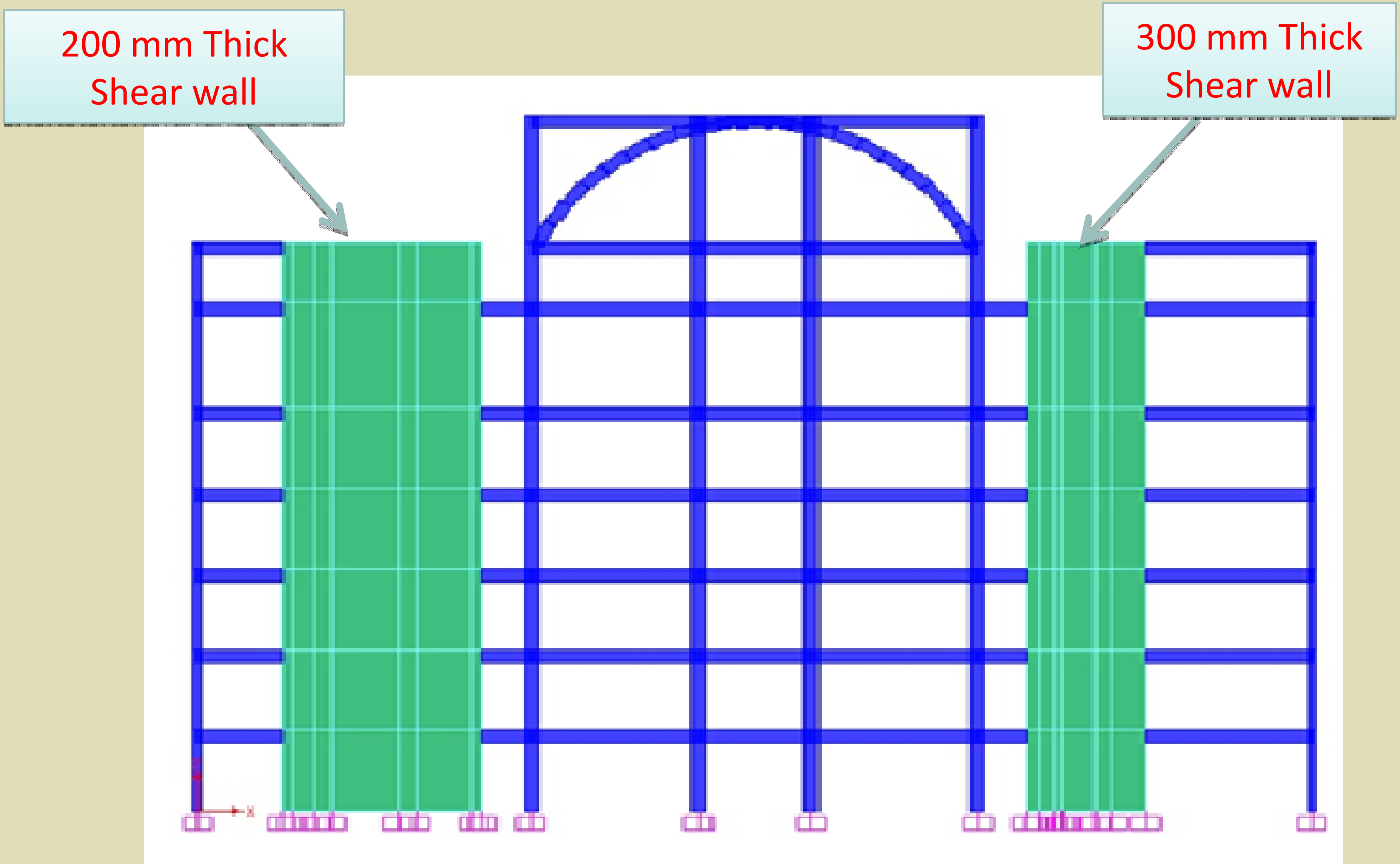


8TH STOREY PLAN

SELECTED 2-D FRAME FOR NONLINEAR PUSHOVER ANALYSIS



ELEVATION OF SELECTED FRAME



Material Properties, Cross-Section and Reinforcement Details

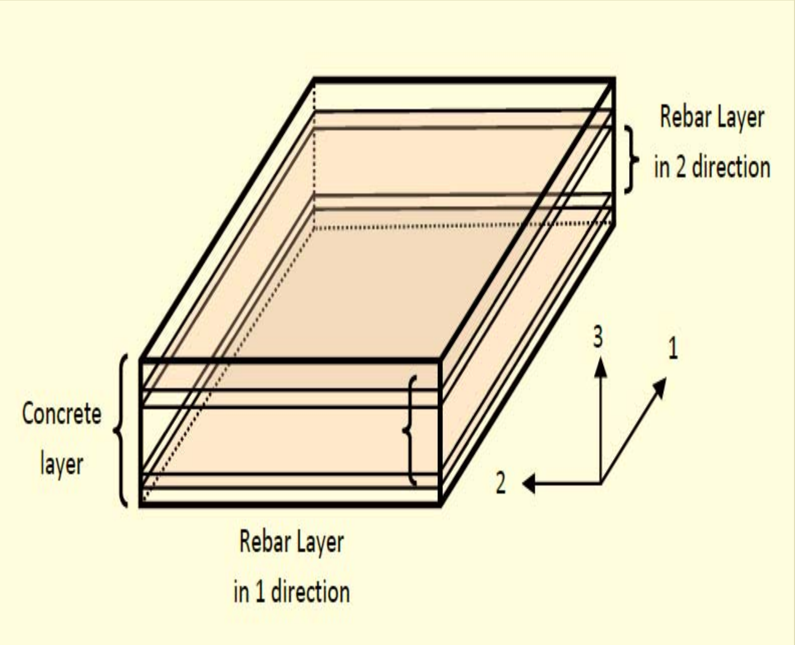
Material Properties	
f_c'	30 MPa
f_y	420 MPa
f_u	620 MPa
E_s	200 MPa

Beam	Dimension(mm)	Reinforcement		
		Top	Bottom	Stirrups
K4	200 x 500	3-ø16	3-ø14	ø8 @ 200 mm
K8	300 x 500	3-ø16	3-ø16	ø8 @ 200 mm
K9	300 x 500	6-ø25	3-ø16	ø10 @ 150 mm
K10 RIGHT	300 x 500	3-ø22	3-ø25	ø10 @ 150 mm
K10 LEFT	300 x 500	6-ø25	3-ø25	ø10 @ 150 mm
K16	500 x 500	4-ø16	8-ø20	ø8 @ 100 mm
K17	500 x 500	6-ø20	11-ø25	ø10 @ 50 mm

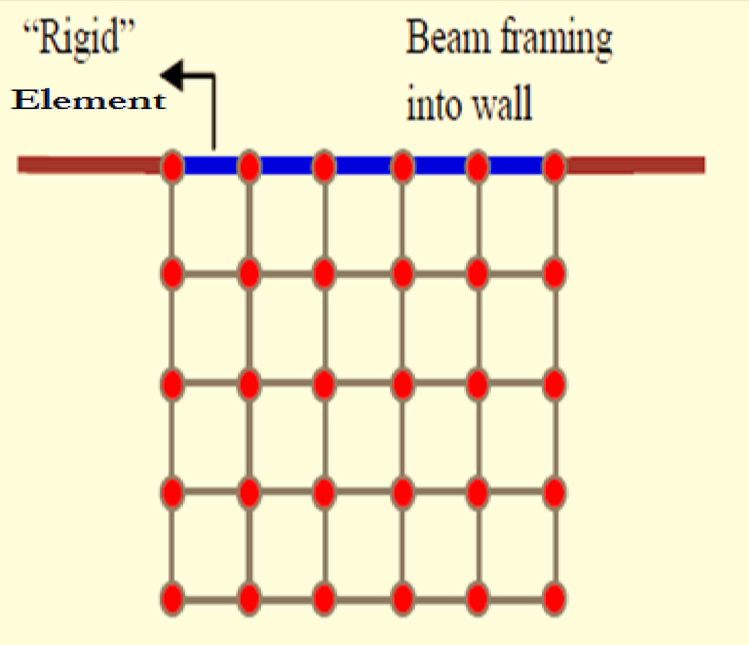
Column	Dimension (mm)	Reinforcement	
		Longitudinal	Ties
A11	300 x 600	14-ø20	2-ø10 @ 168 mm
	300 x 500	12-ø22	3-ø10 @ 142 mm

SHEAR WALL MODELING IN PUSHOVER ANALYSIS

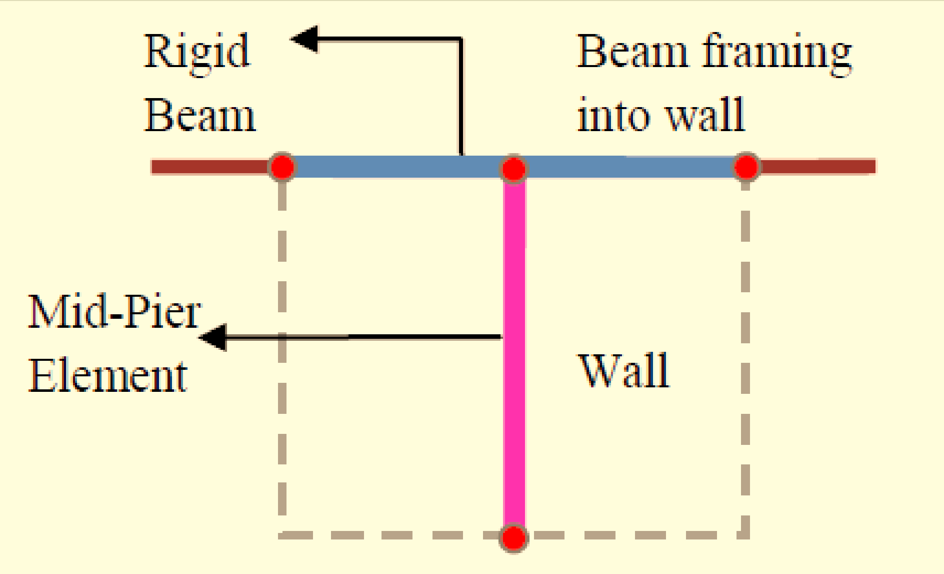
- **Mid-pier model**
  - In mid pier model the is generally based on plastic hinge concept and bilinear moment relationship.
  - The response of this model is governed by the proper selection of stiffness of rigid beam because assumption of infinite rigidity can lead to over estimation of bending moment.
- **Multilayer shell element model**
  - The shell element can be used efficiently for the analysis of building structures with shear walls.
  - The multilayer shell element gives a realistic prediction of stresses and formation of hinges in shear wall.



Smeared Multilayered Shell Element

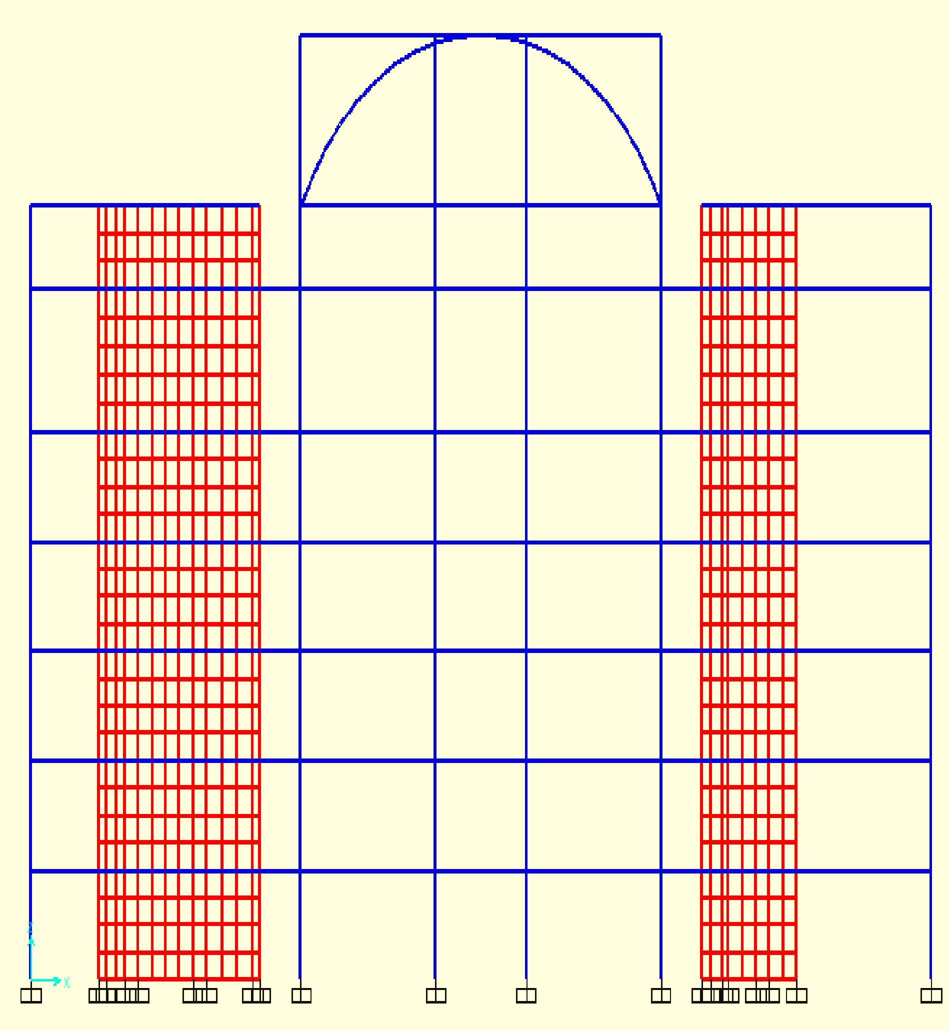


Shell element Model For Shear Wall

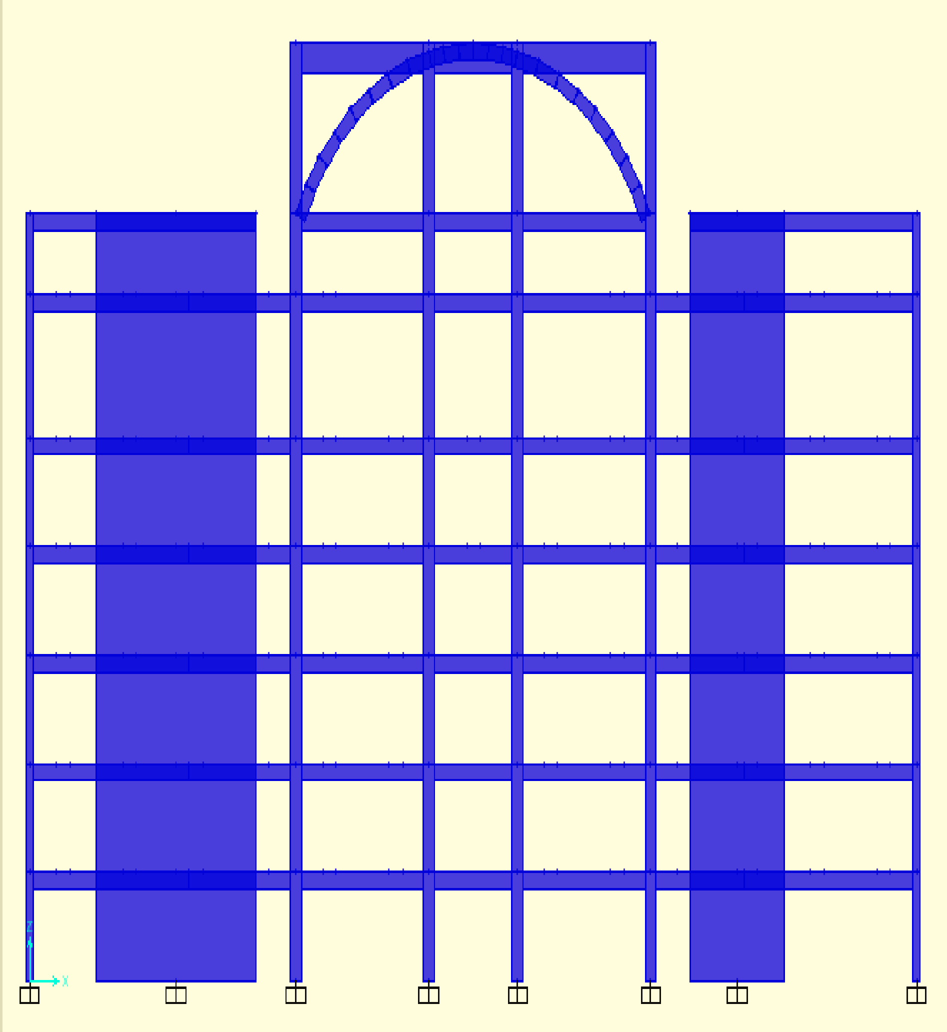


Mid Pier Model for Shear wall

SHEAR WALL MODEL



Multi-layered Shell Element Model



Mid Pier Model

LOADS

- For intermediate storeys
- Dead loads
- Self weight of Slab=4.75 kN/m^2
- Floor finish=2.3 kN/m^2
- Super imposed load =1 kN/m^2
- Live load = 4.8 kN/m^2

- For roof storeys
- Dead loads
- Self weight of slab=4.75 kN/m^2
- Floor finish=3.5 kN/m^2
- Super imposed load =1 kN/m^2
- Live load = 2.4 kN/m^2

SEISMIC WEIGHT OF THE BUILDING

- The Seismic weight of the whole building is the sum of the seismic weights of all the floors.

Floor height from ground level (m)	Seismic weight W_i (kN)
27.6	1900
22.6	865
20.2	2780
16	3408
12.8	3320
9.6	3032
6.4	3032
3.2	3030
	$\sum W_i = 21371$

MODAL ANALYSIS

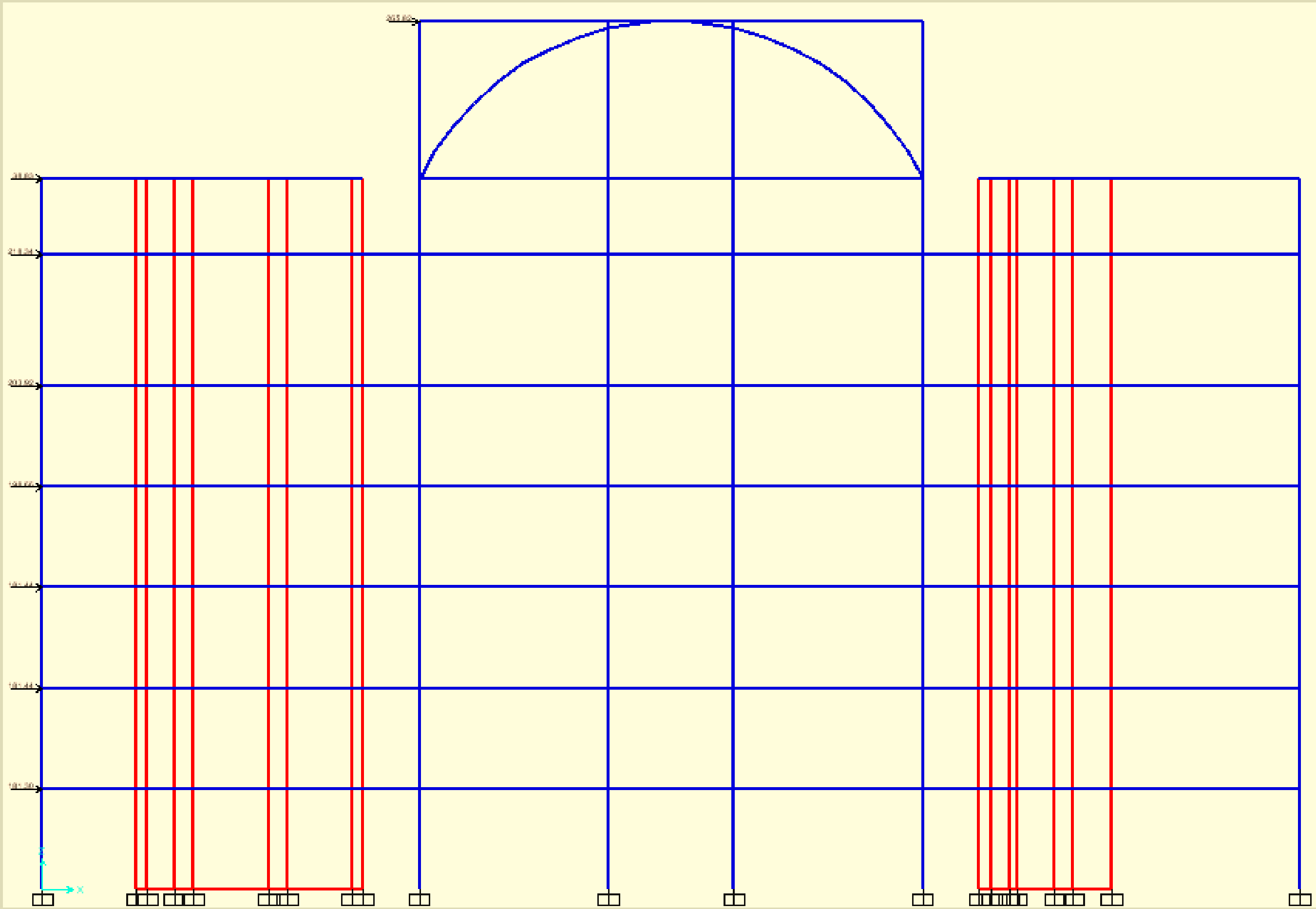
- From the modal analysis time period and frequency for different modes are shown below.

Modal Properties	**Mode**				
	1	**2**	**3**	**4**	**5**
Period (sec)	**0.602**	**0.266**	**0.171**	**0.133**	**0.128**
Frequency (rad/sec)	**1.731**	**3.756**	**5.863**	**7.472**	**7.812**

PARABOLIC LATERAL LOAD FEMA-356

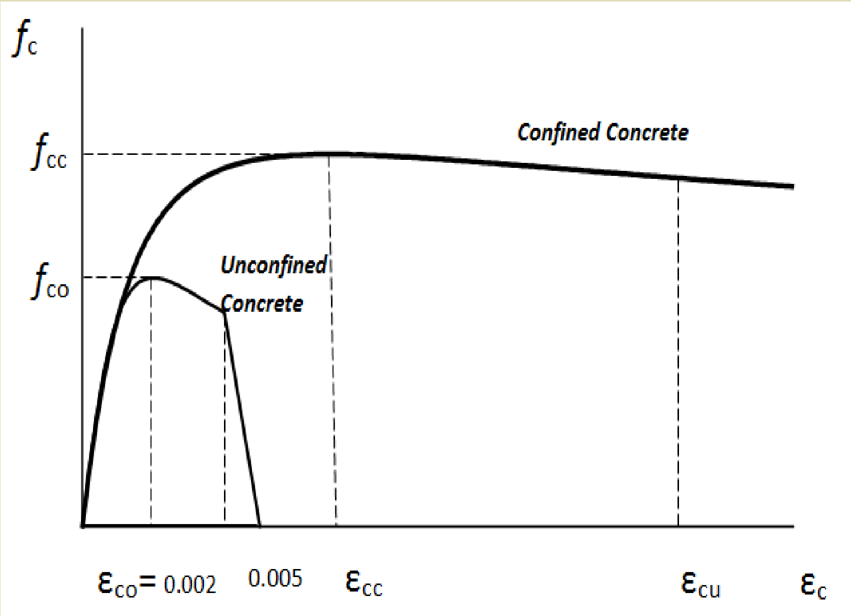
- The lateral force at any story (F_i) is calculated by

$$F_i = V_t \frac{W_i H_i^2}{\sum_{j=1}^{N} W_j H_j^2}$$

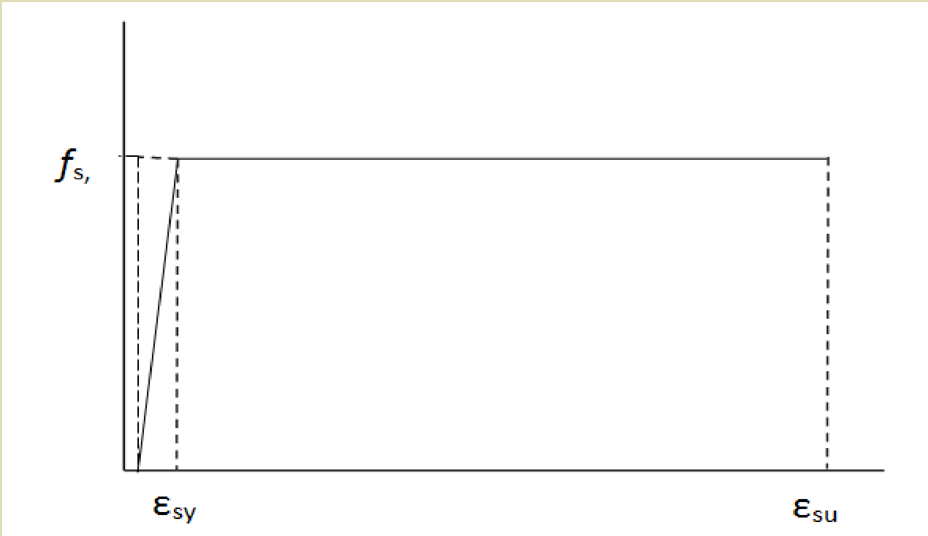


SECTIONAL ANALYSIS USING XTRACT

- **ASSUMPTIONS**
- Mander confined and unconfined concrete model.
- Elasto-plastic steel model without hardening were used.
- Software used for Sectional Analysis is XTRACT.

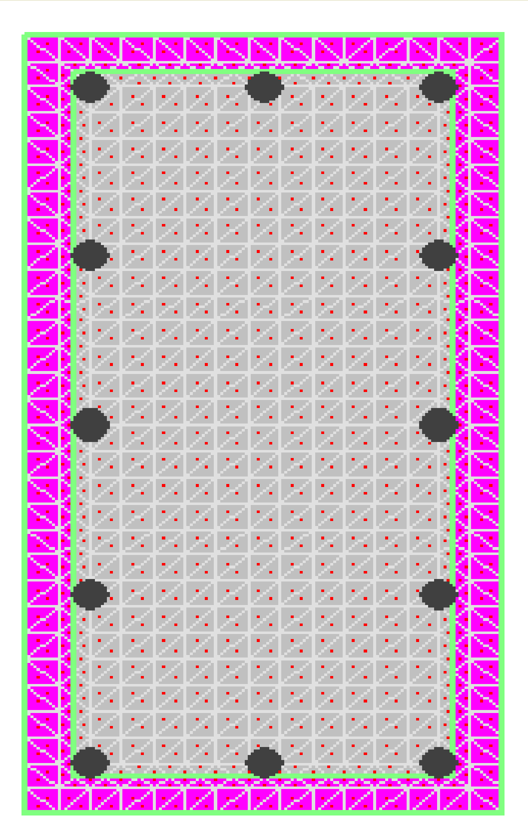


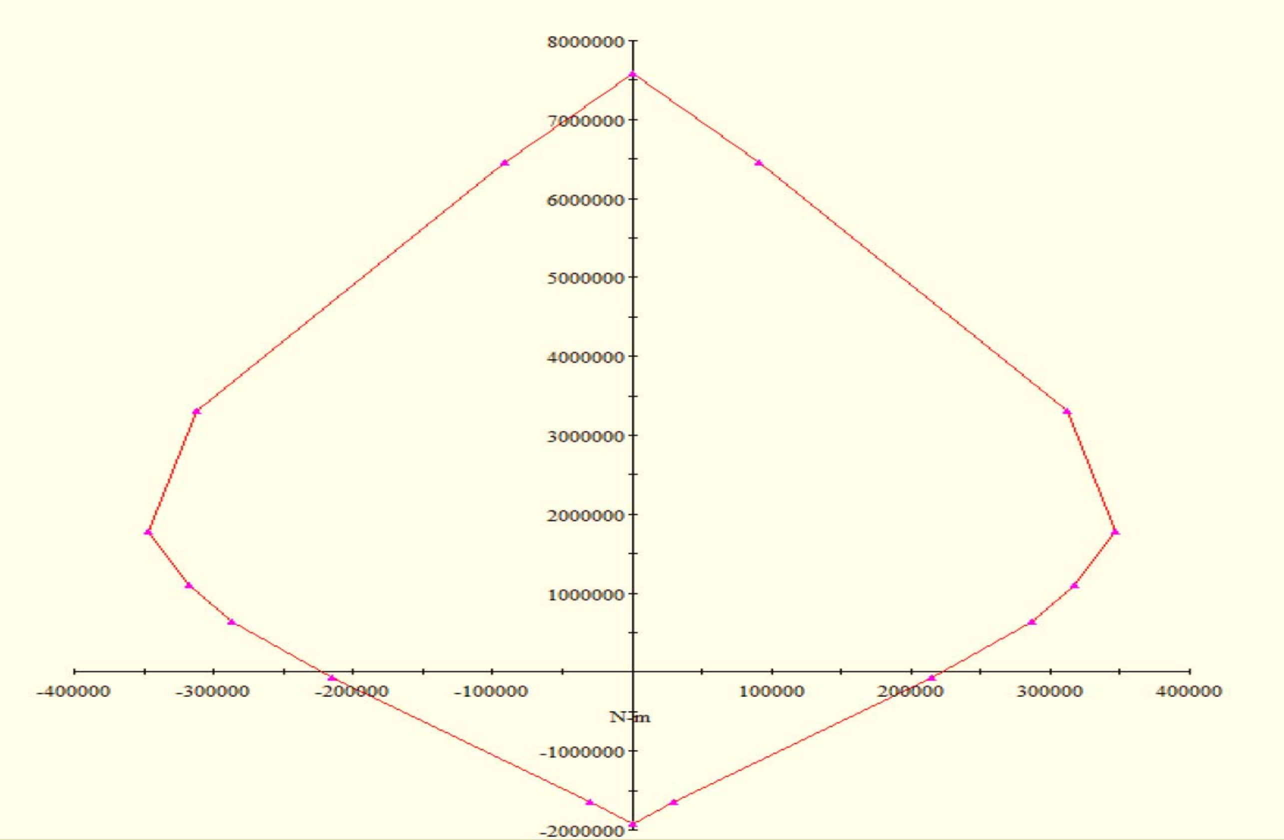
Mander Unconfined, Confined Concrete Model



Elasto-plastic steel model

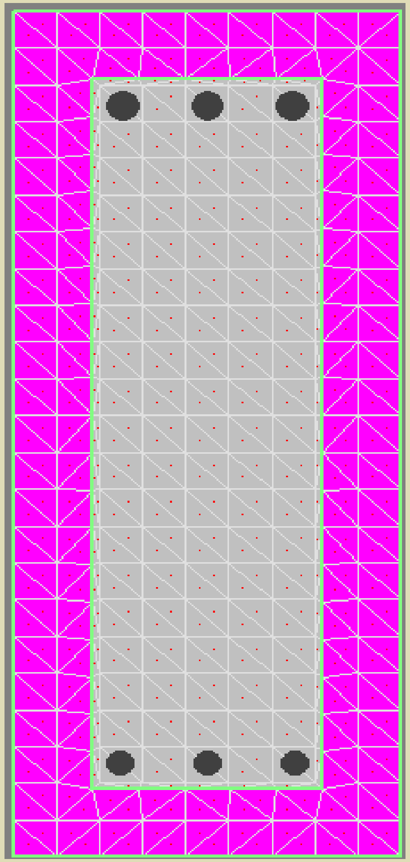
PM-INTERACTION CURVE OBTAINED FROM XTRACT

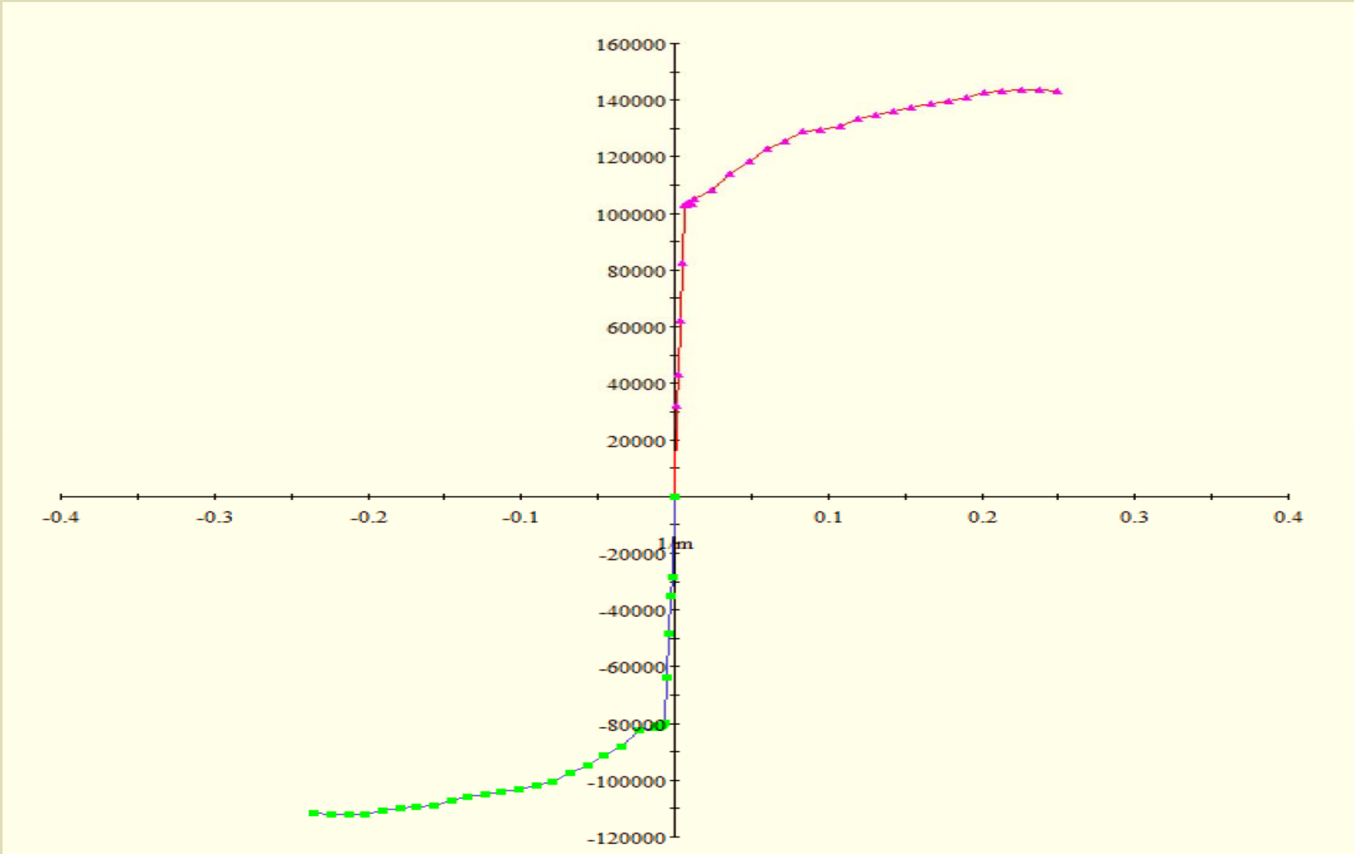




PM-Interaction Diagram For Column A11

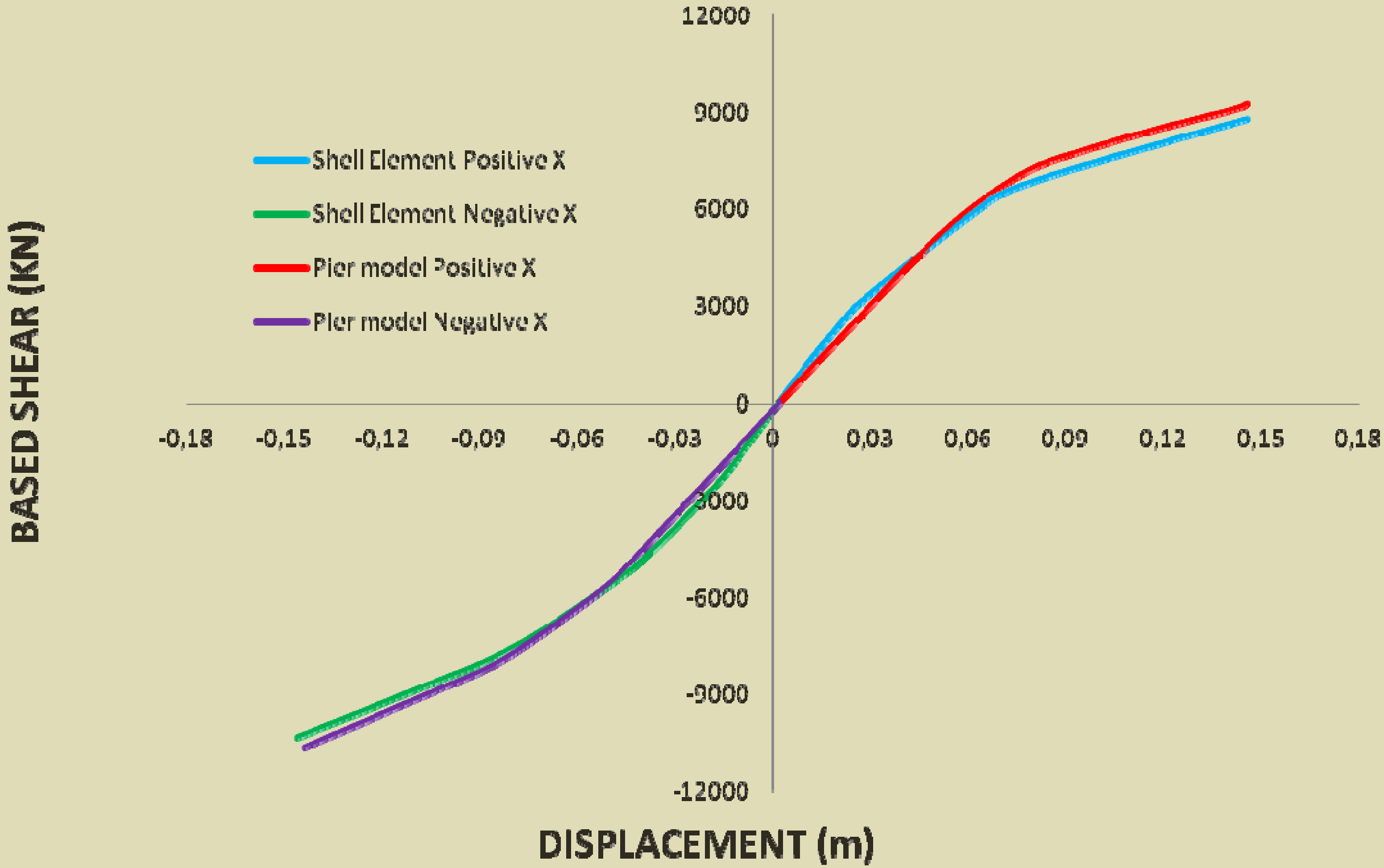
MOMENT CURVATURE OBTAINED FROM XTRACT





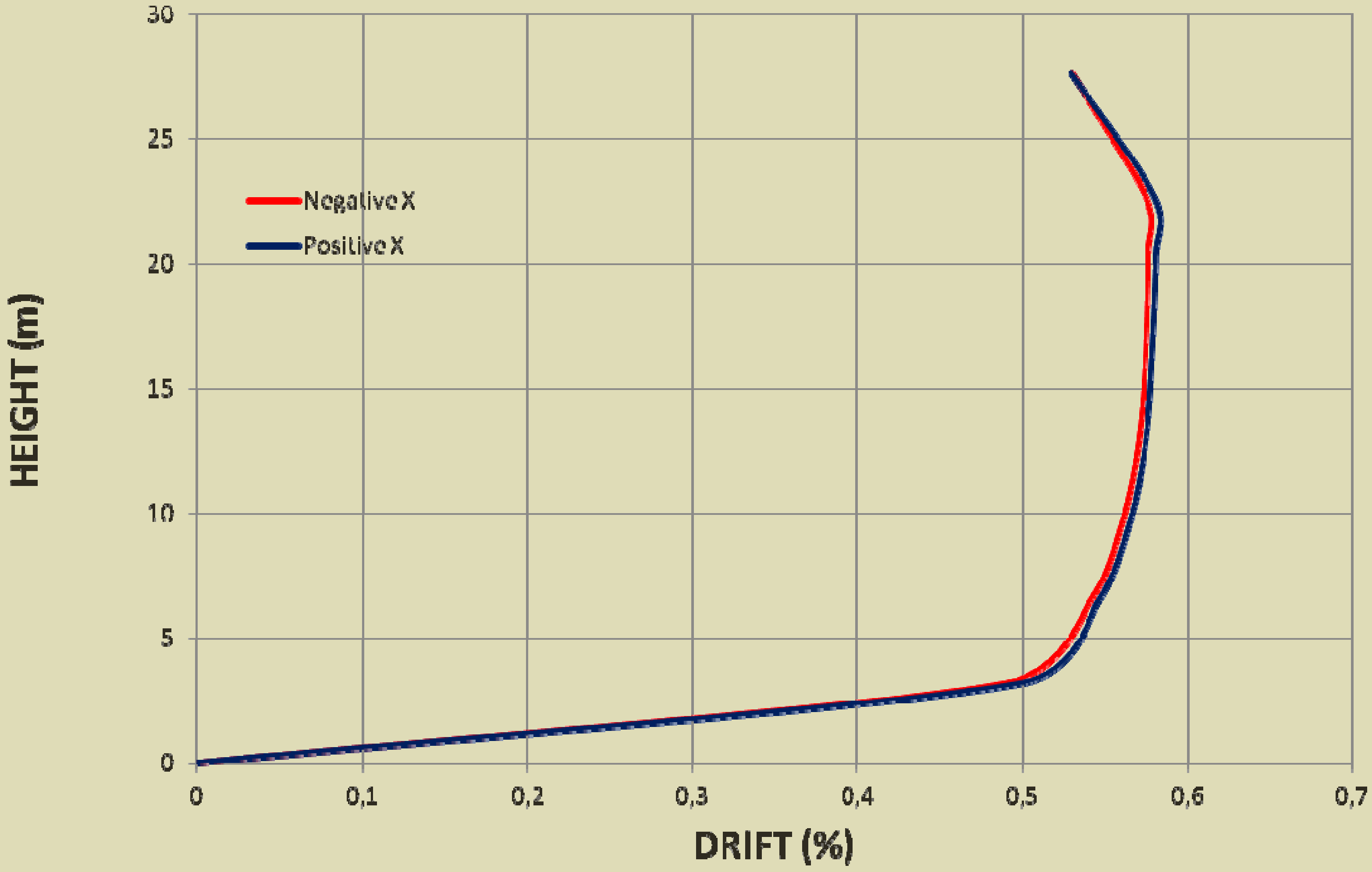
Moment Curvature curve for Beam K4

PUSHOVER ANALYSIS RESULTS

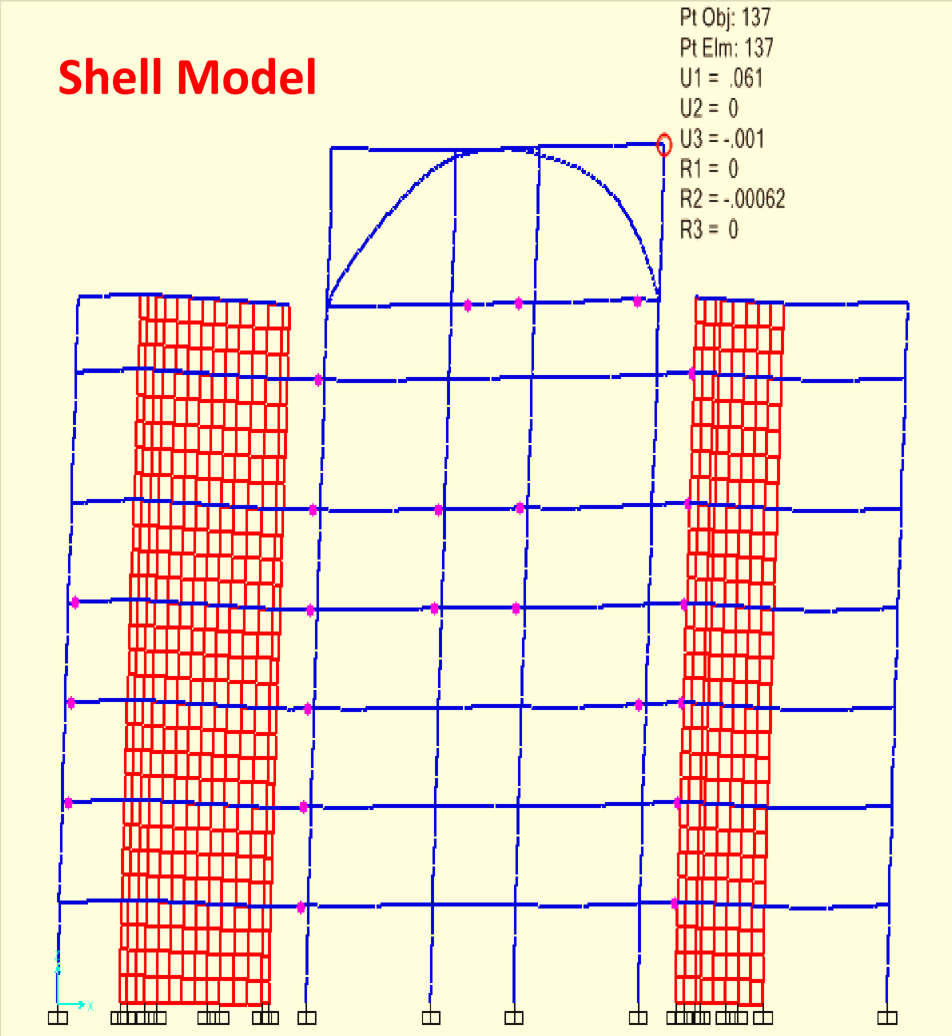


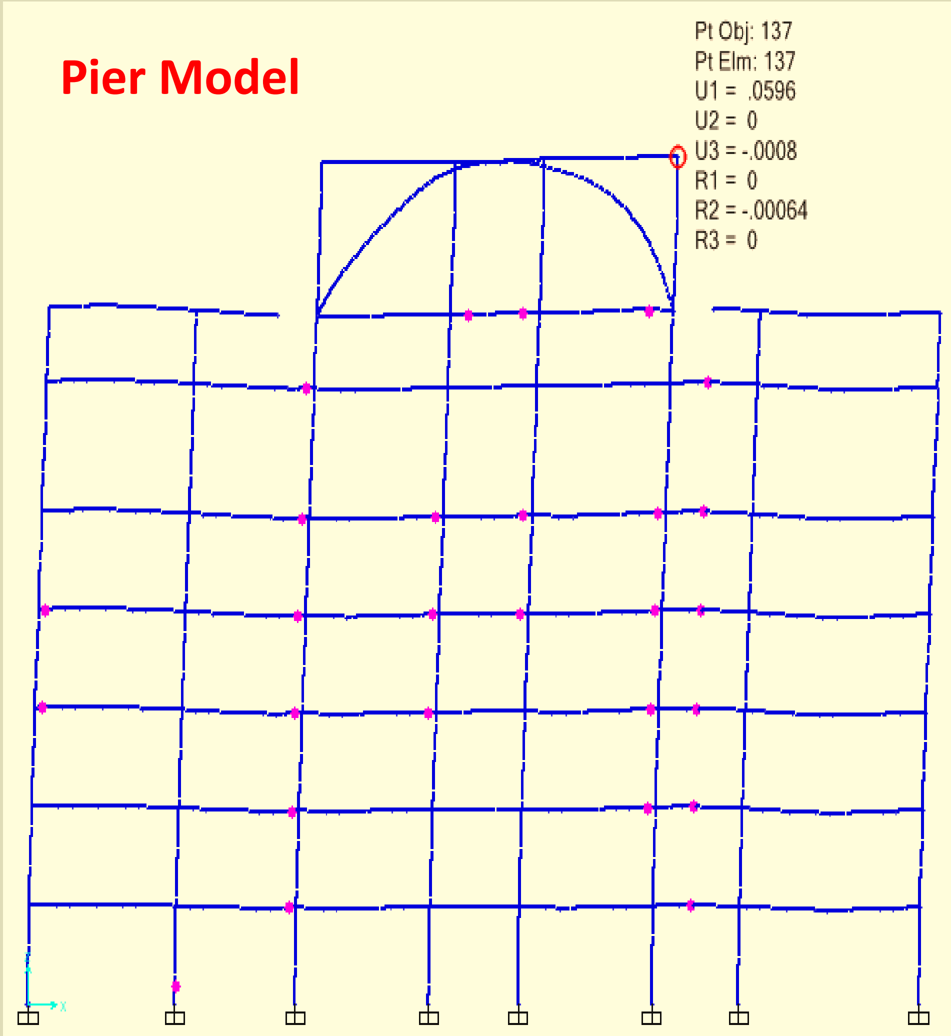
Pushover curve for 2-D Frame Analyzed

STOREY DRIFTS RATIO



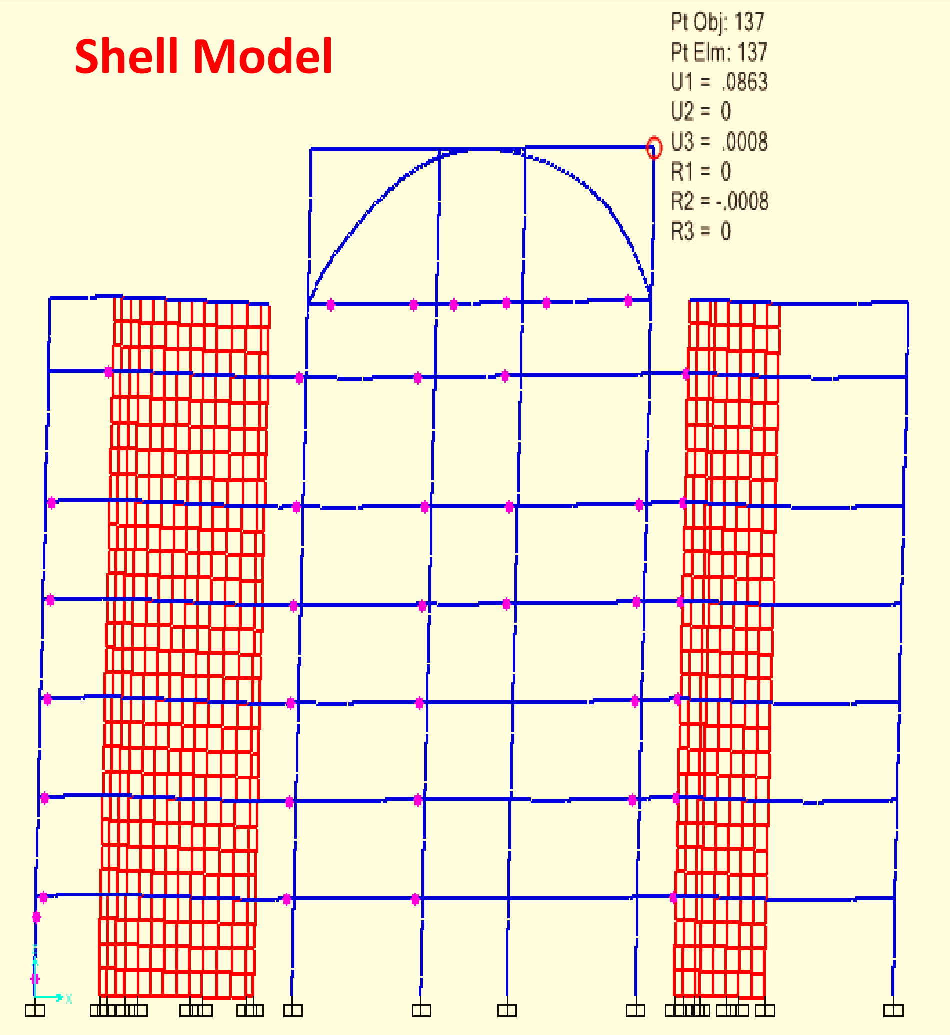
Plastic Hinge Distribution

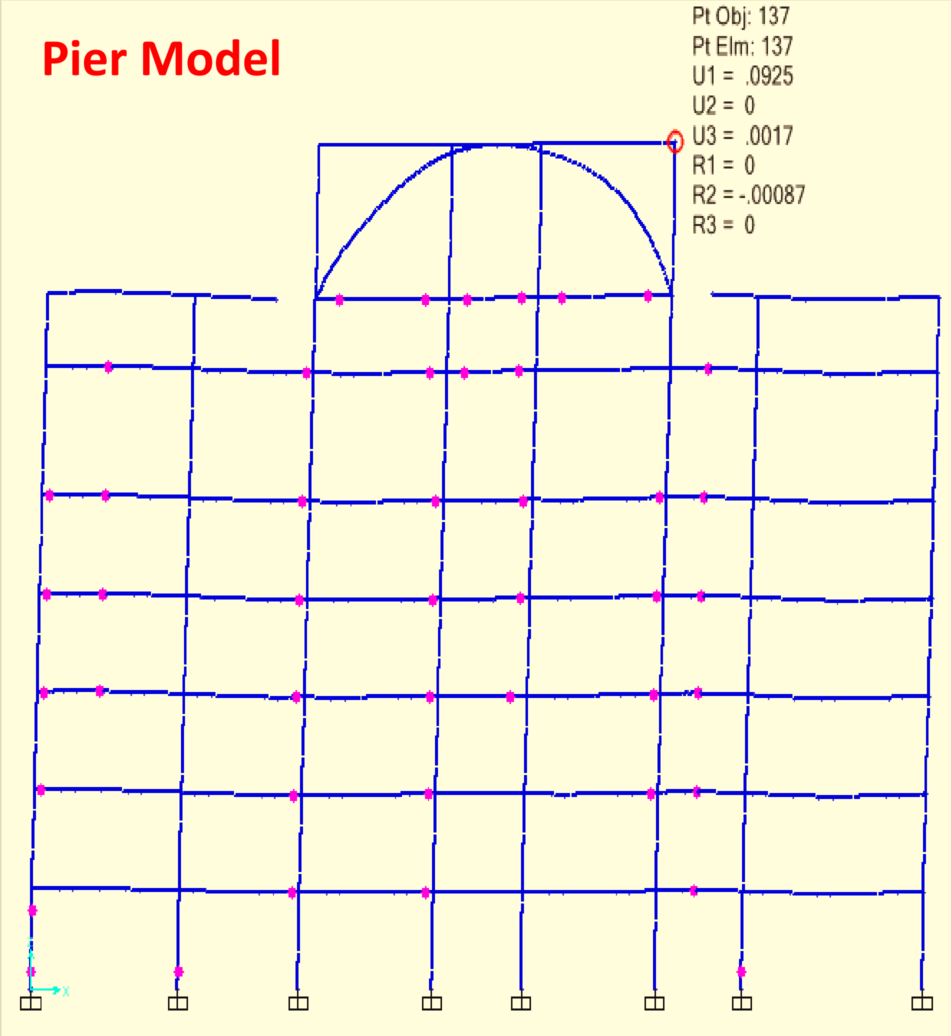




PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN POSITIVE X-DIRECTION AT 6 cm DISPLACEMENT

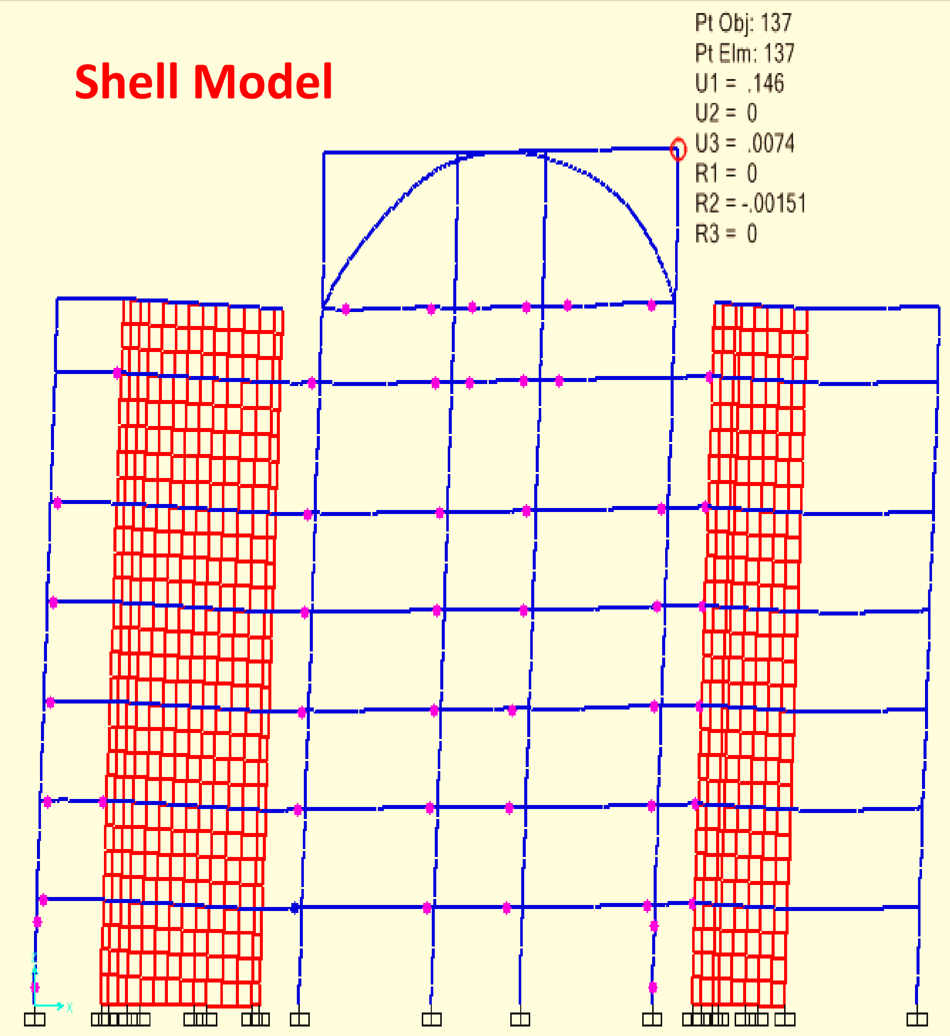
Plastic Hinge Distribution

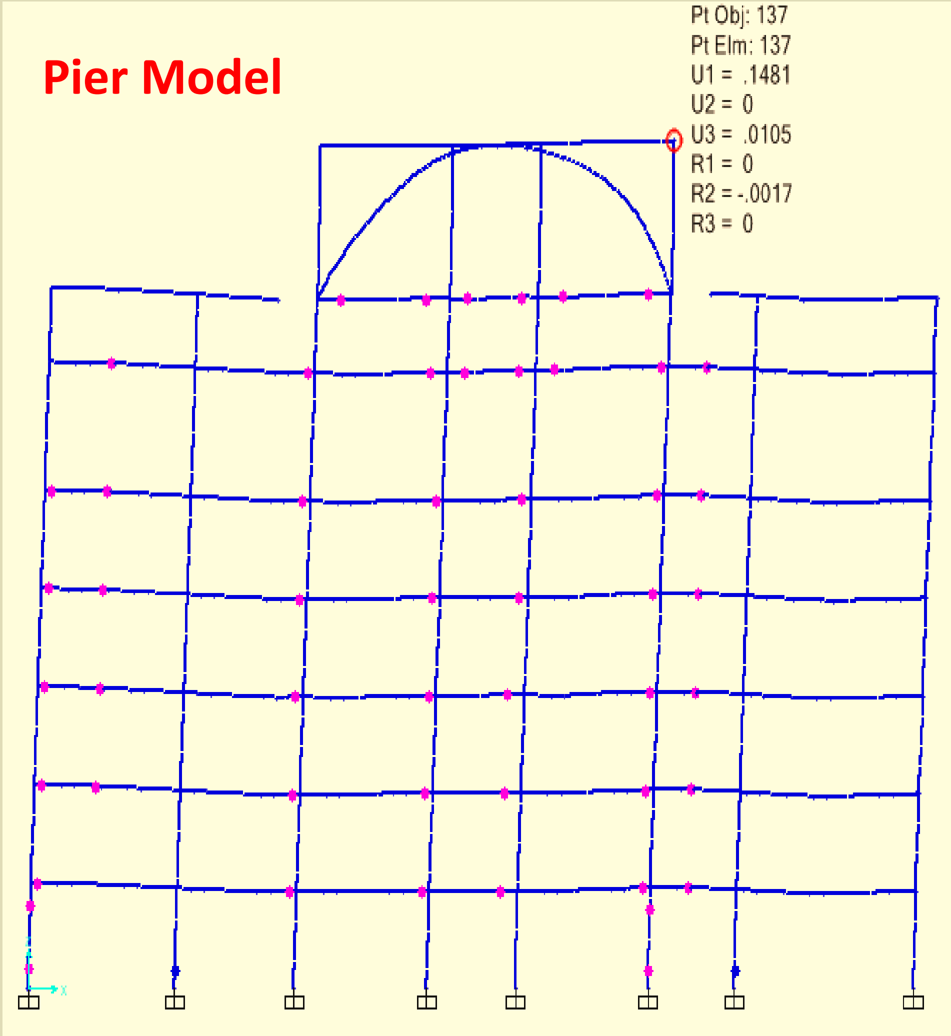




PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN POSITIVE X-DIRECTION AT 9 cm DISPLACEMENT

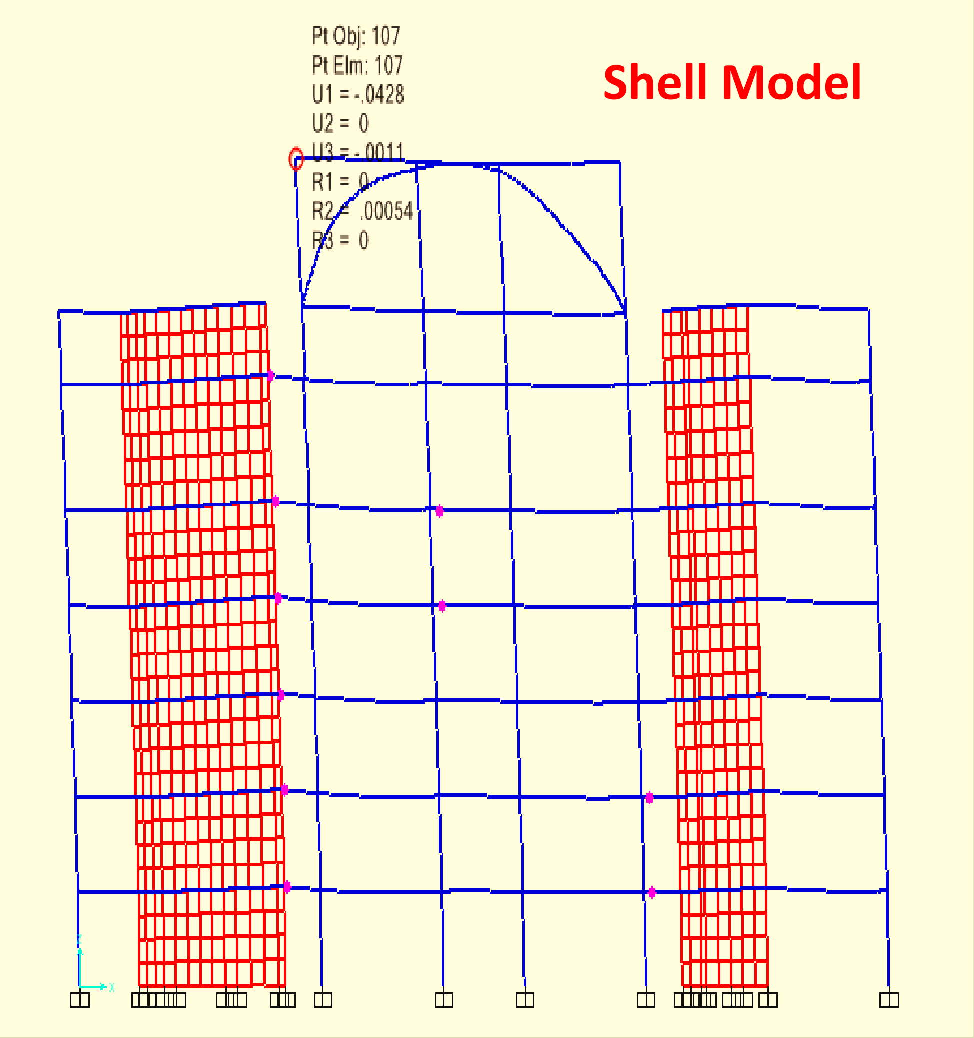
Plastic Hinge Distribution

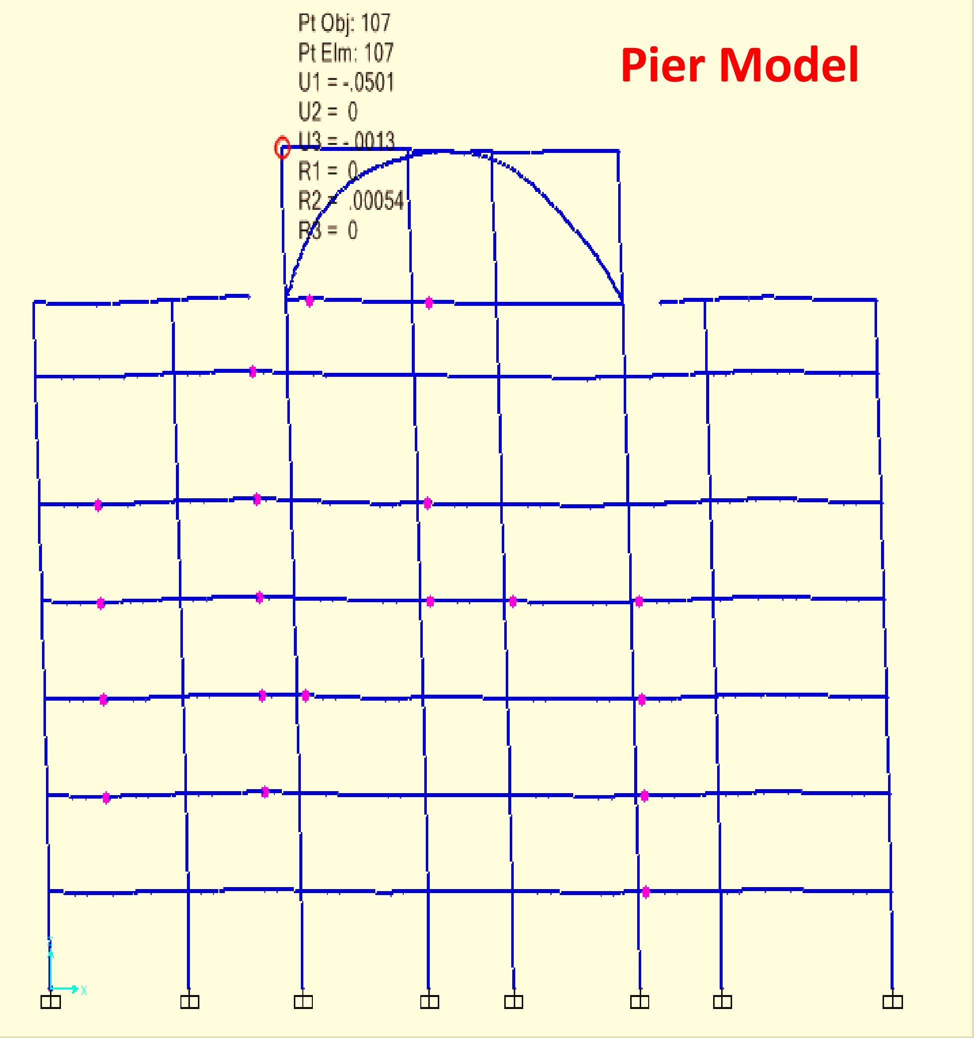




PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN POSITIVE X-DIRECTION
AT 15 cm DISPLACEMENT

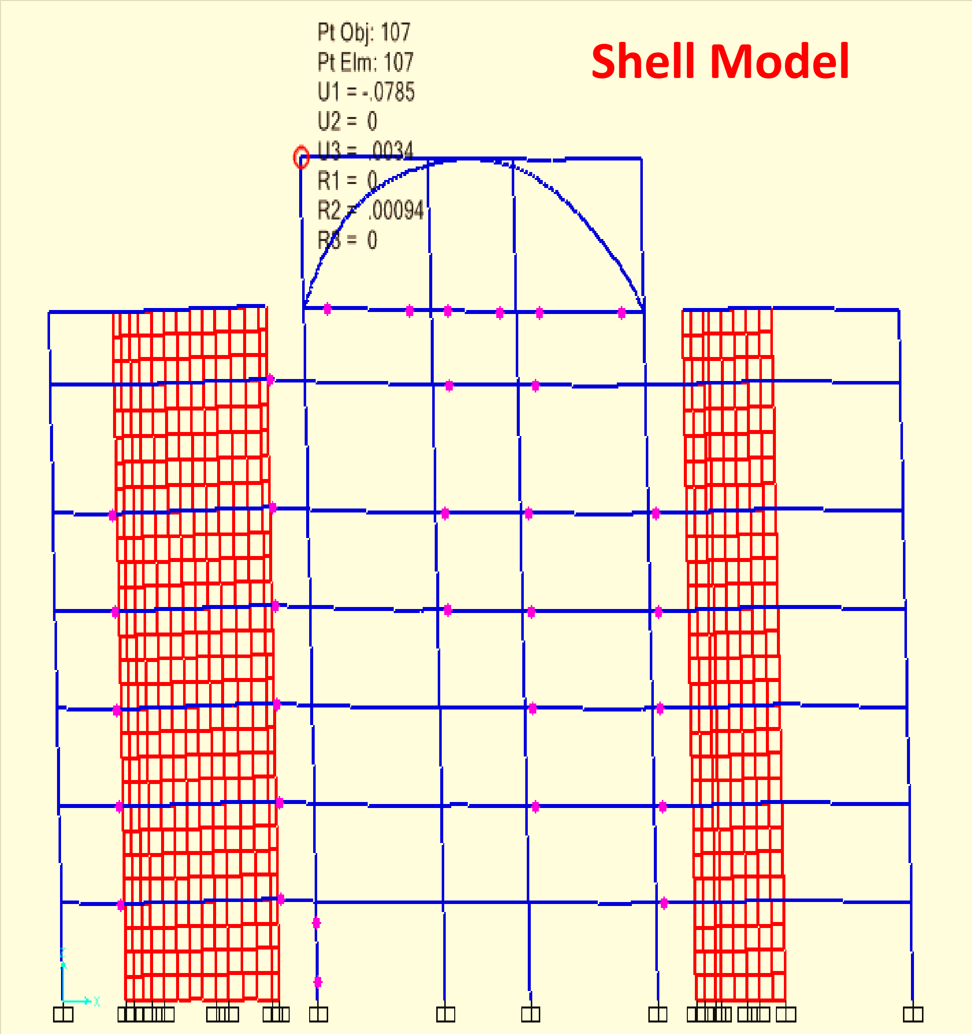
Plastic Hinge Distribution

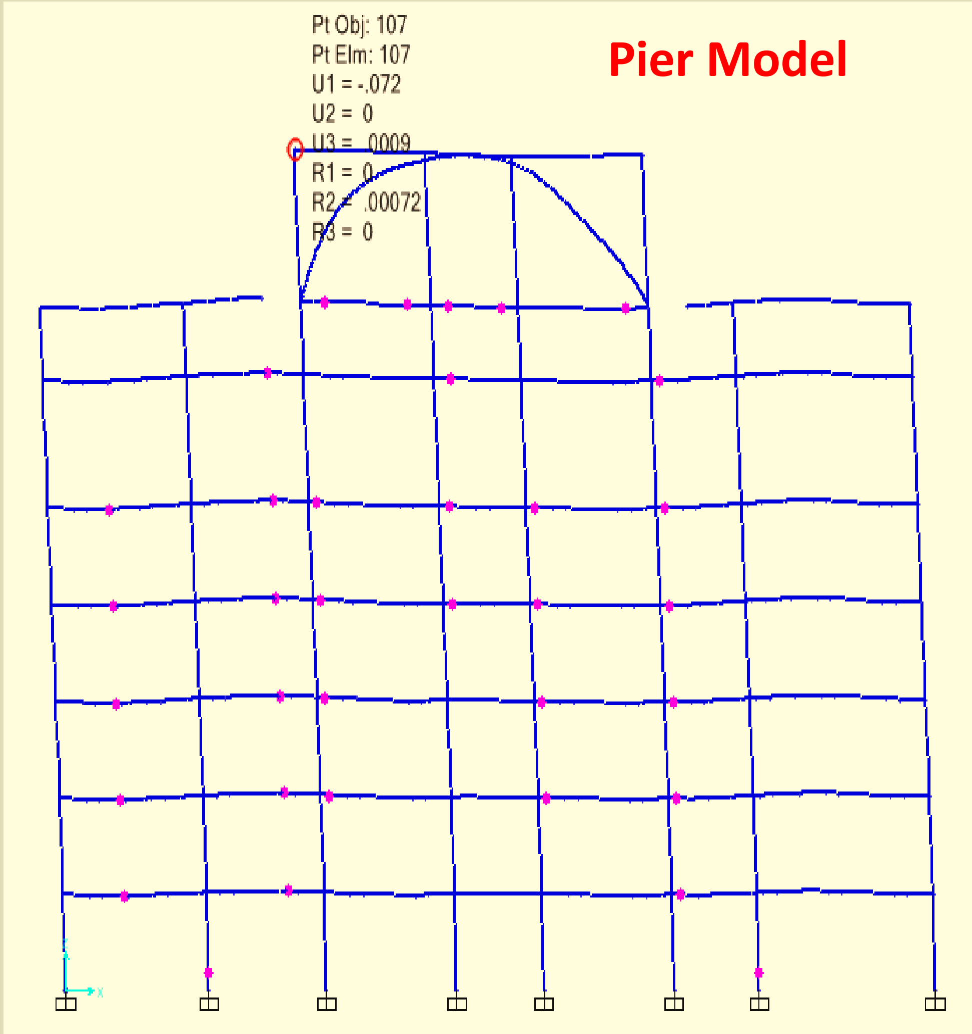




PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN NEGATIVE X-DIRECTION
AT APPROX. 5 cm DISPLACEMENT

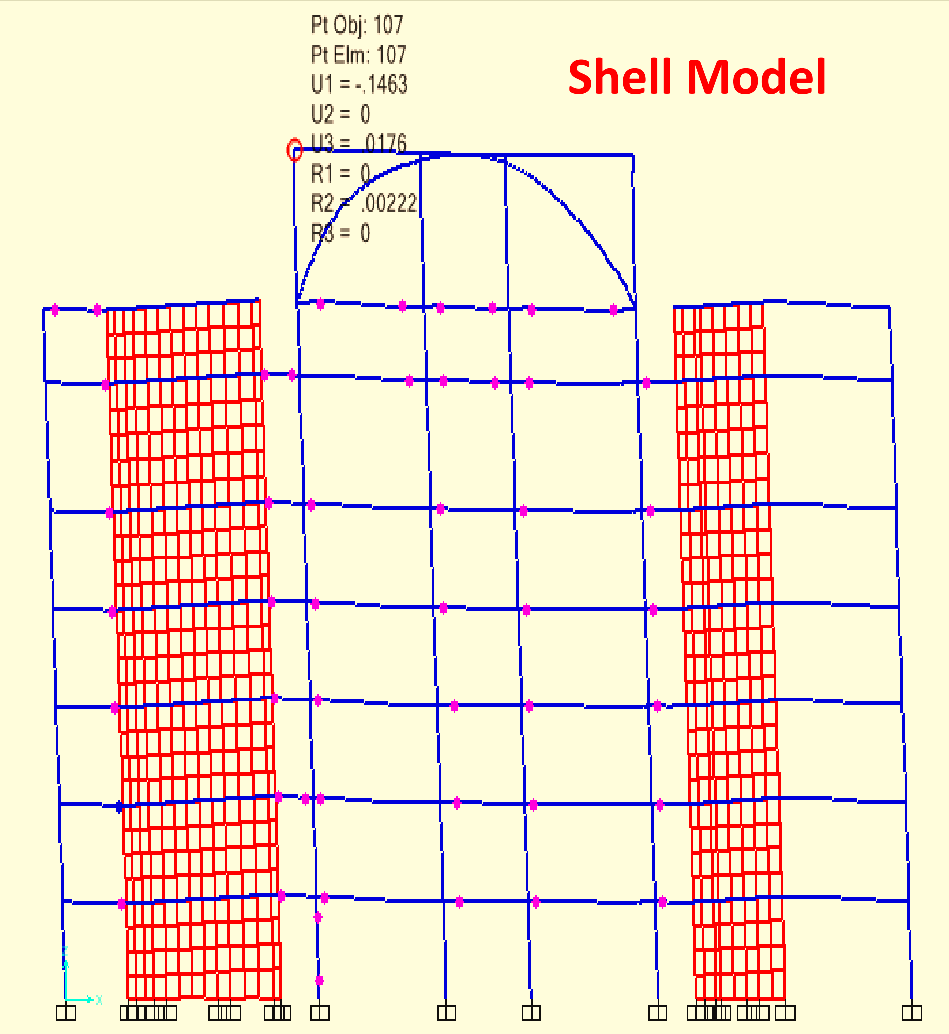
Plastic Hinge Distribution

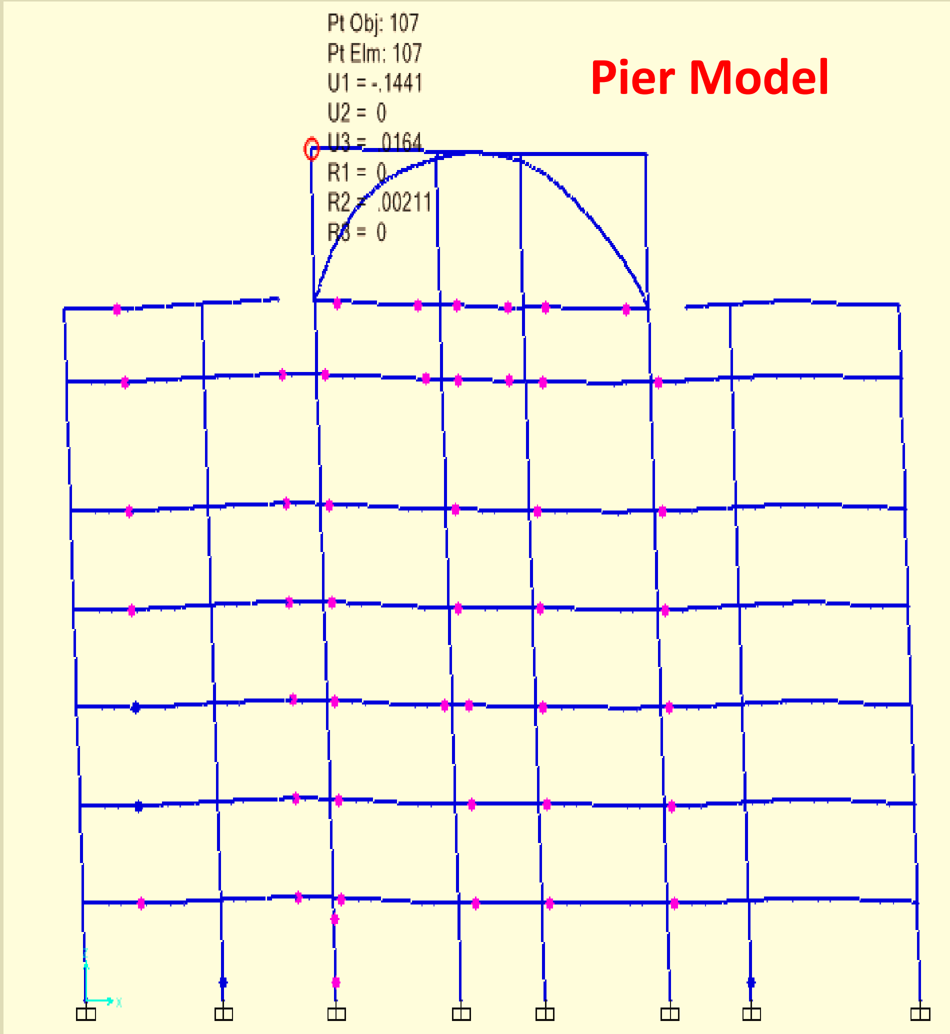




PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN NEGATIVE X-DIRECTION AT APPROX. 7 cm DISPLACEMENT

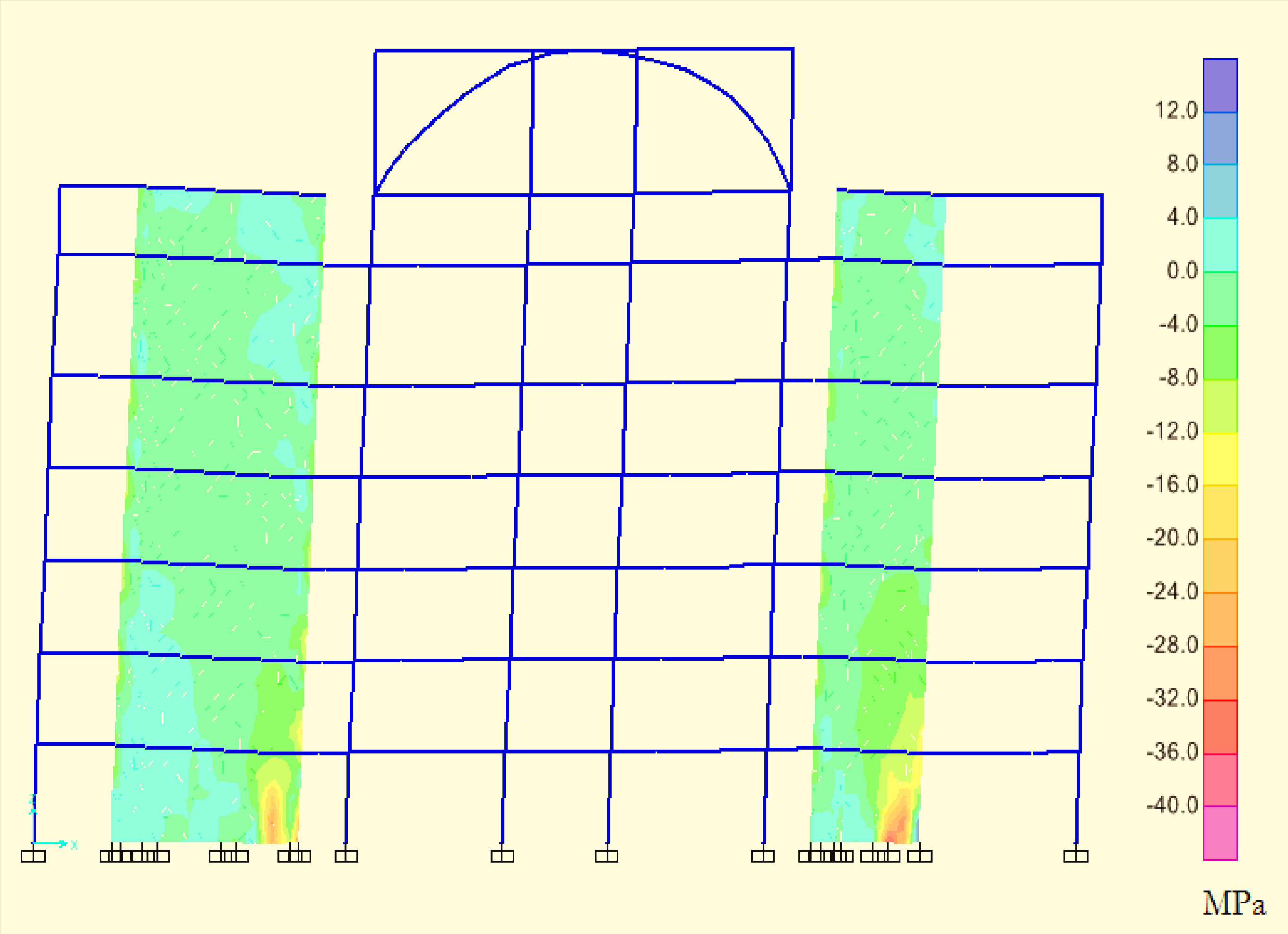
Plastic Hinge Distribution





PLASTIC HINGES DISTRIBUTION WHEN PUSHED IN NEGATIVE X-DIRECTION AT APPROX. 14 cm DISPLACEMENT

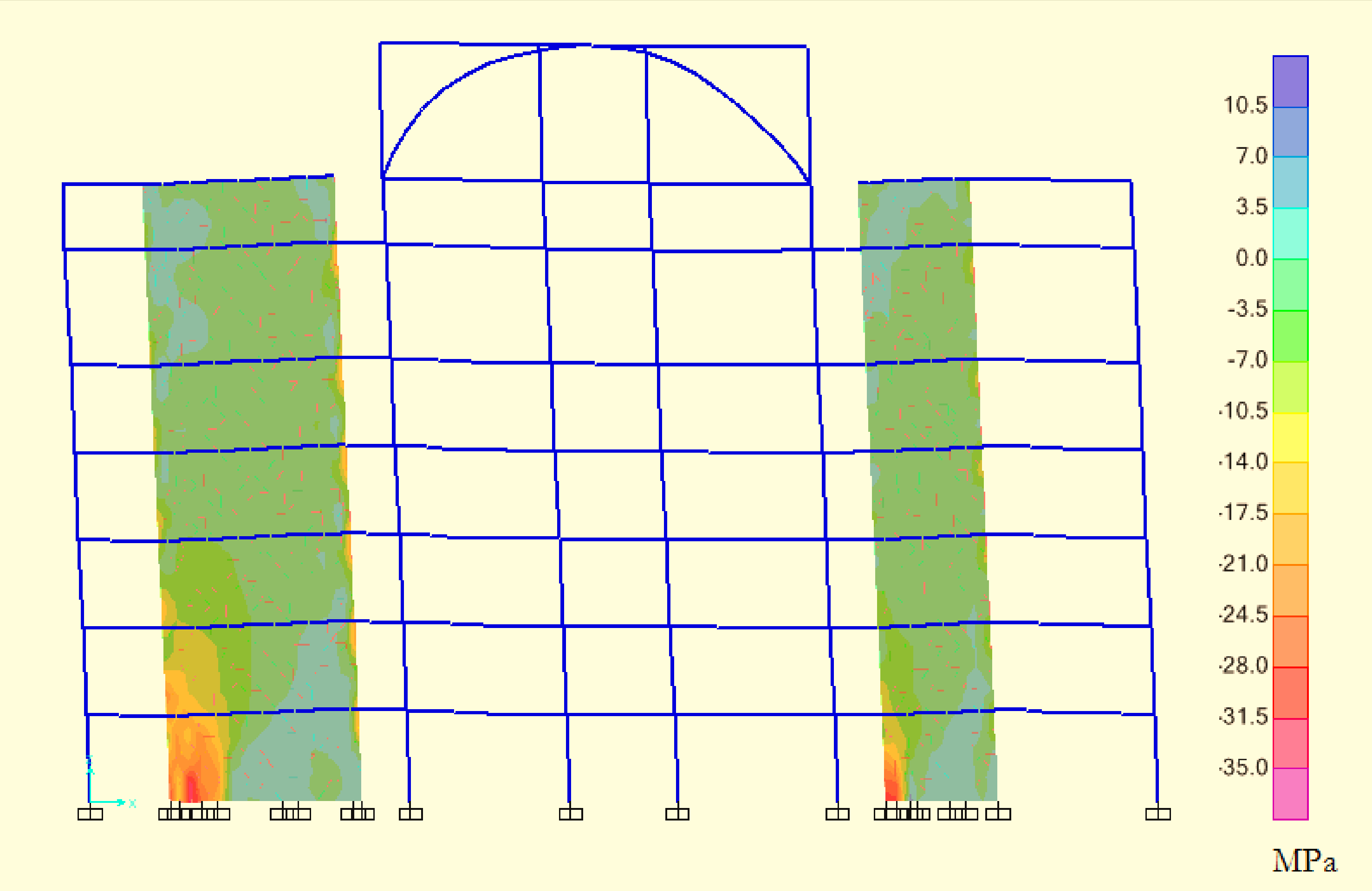
CONCRETE STRESSES IN SHEAR WALL



Crushing of concrete as maximum stress in concrete reaches ultimate stresses

CONCRETE STRESS WHEN PUSHED IN POSITIVE X-DIRECTION

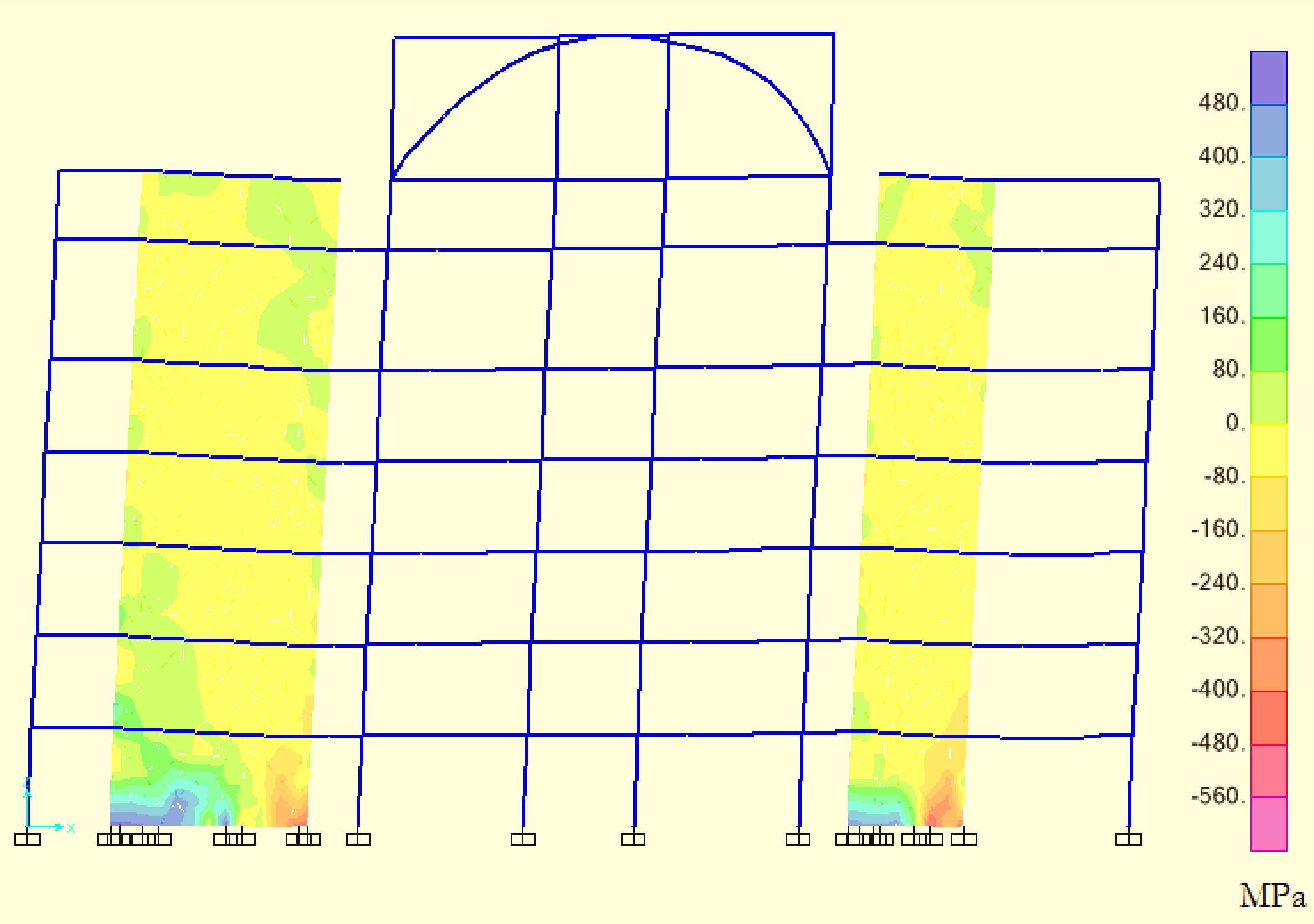
CONCRETE STRESSES IN SHEAR WALL



Crushing of concrete as maximum stress in concrete reaches ultimate stresses

CONCRETE STRESS WHEN PUSHED IN NEGATIVE X-DIRECTION

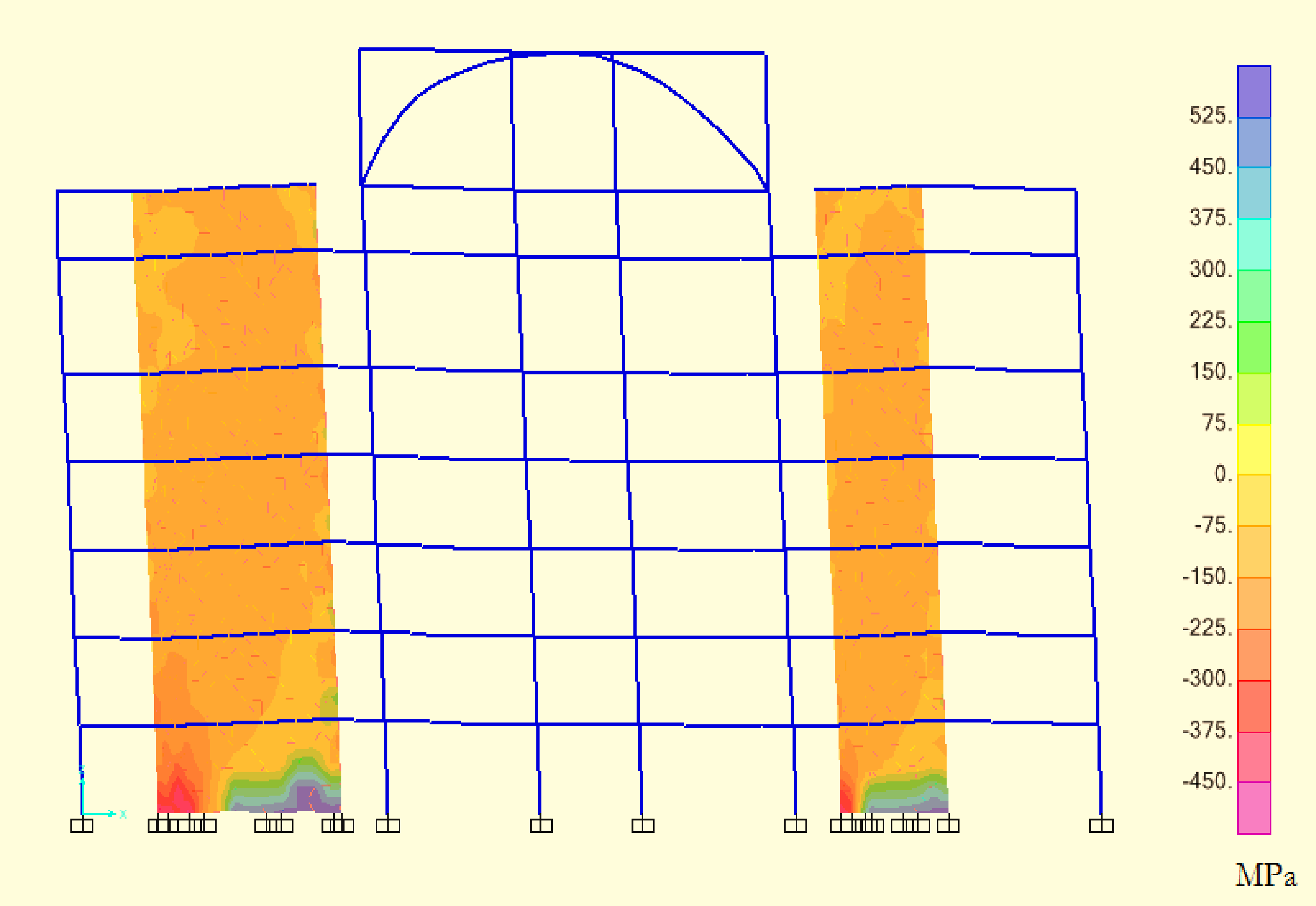
STEEL STRESSES IN SHEAR WALL



Hinged formed at the bottom of shear wall as maximum stress in steel reaches yield stress

STEEL STRESS WHEN PUSHED IN POSTIVE X-DIRECTION

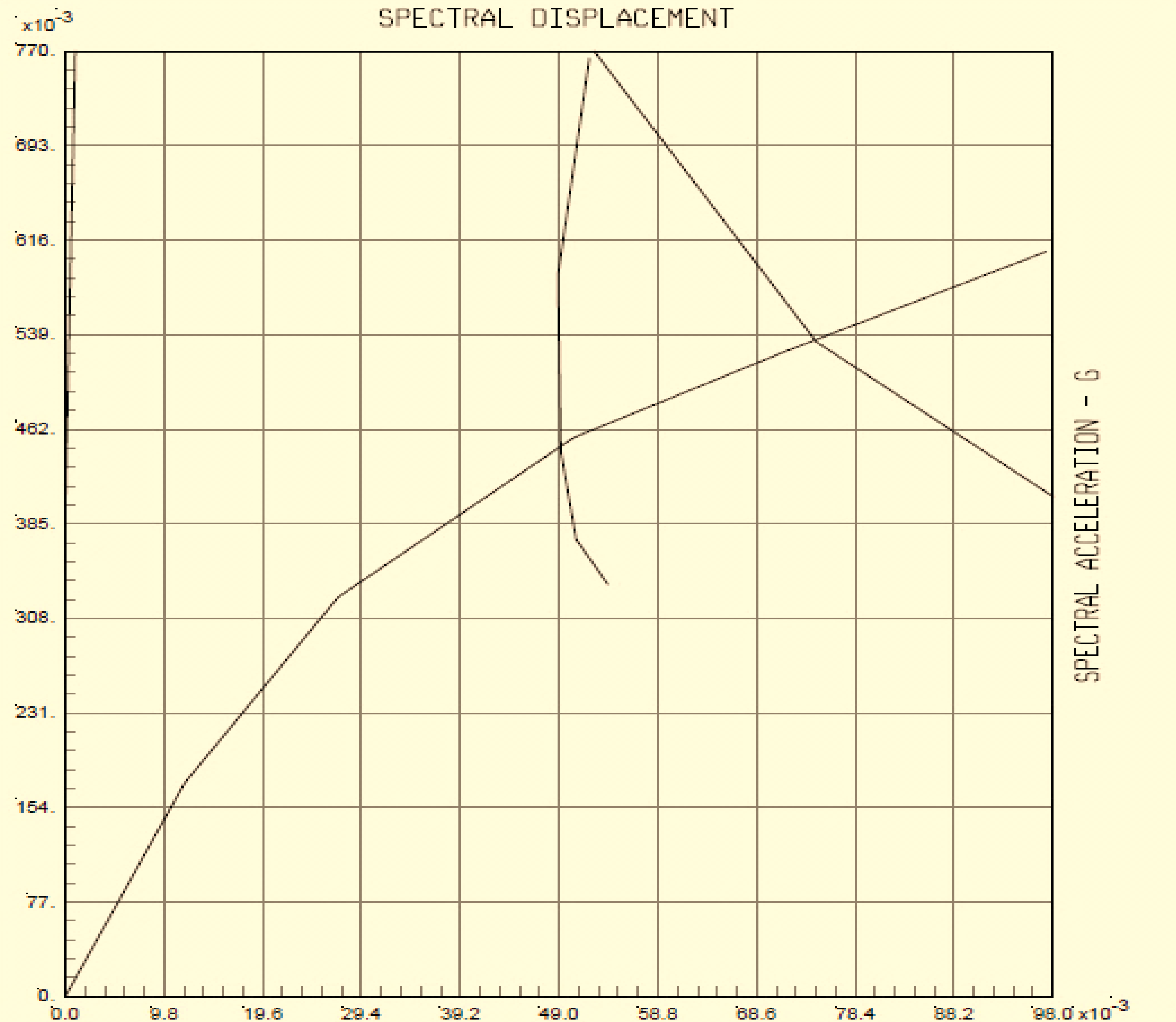
STEEL STRESSES IN SHEAR WALL



Hinged formed at the bottom of shear wall as maximum stress in steel reaches yield stress

STEEL STRESS WHEN PUSHED IN NEGATIVE X-DIRECTION

PERFORMANCE ASSESSMENT USING ATC-40



PERFORMANCE POINT	
BASE SHEAR	7349 KN
DISPLACEMENT	0.07 m

CONCLUSIONS

- The hinge status of Shell Element and Mid Pier method at maximum displacement provide almost the same pattern.
- Mid Pier method overestimate base shear because of rigid beam rigidity, so appropriate rigidity must be selected.

ONGOING RESEARCH

- Time history analysis of selected 2D frames of the building is in progress.
- Research will be carried out on 3-D model of Madinah Municipality Building by the application of Pushover and time history analysis.
- Pushover analysis will be subsequently carried out for building retrofitted with CFRP.

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