SERIES
Seismic Engineering Research Infrastructures for European Synergies
University of Patras • European Commission • Framework Programme 7
8-9 February 2012, Istanbul
İSTANBUL TEKNİK ÜNİVERSİTESİ 1773
International Workshop "Role of research infrastructures in seismic rehabilitation"

SEISMIC VULNERABILITY OF MULTI-LEAF, HERITAGE MASONRY WALLS USING ELASTO-PLASTIC DAMAGE MODEL

By

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OUTLINE

1. Introduction.
2. Subject and Scope
3. Experimental Study at ITU
4. FEM Simulations
5. Conclusions
6. Work in Progress at KFUPM

Introduction

- Masonry structures are also commonly used in **Saudi Arabia** for the construction of low rise buildings especially in small towns and villages due to economy in the cost of construction.

- There exists a **rich heritage** of URM structures in the **Western region** of Saudi Arabia.

- With only a **few incidences** of major earthquakes in the Kingdom in the recent history, research into seismic retrofitting of masonry structures is **rather scant**.

Aim and Scope

In this study

- An experimental study on ‘multi-leaf stone masonry walls’, carried out in ITU Structural and EQ Engineering Laboratory is briefly introduced.

- Finite element analysis results of two experimental studies (Demir et al. (2011) and Nanni et al. (2005) are presented.

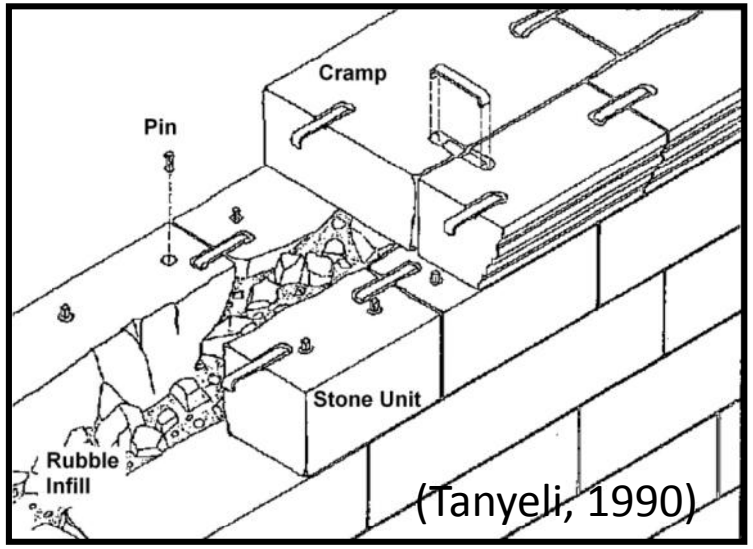
- Axial stress vs. Shear strength curves for both studies are obtained via FEA and compared.

- Ongoing efforts in KFPUM are indicated.

EXPERIMENTAL STUDY CARRIED OUT IN ITU (Demir et al., 2011)

INTRODUCTION TO THE EXPERIMENTAL PROGRAM

- The structure of the walls in monumental buildings constructed in the classical period of the Ottoman Empire usually consist of:
  - The two-layer walls of stone, often cut in the outer wall.
  - Inner layer of rubble filling
  - Iron clamp (and in some cases, shear pins) connected to each other block.
- The reinforcement of stone anchors units is molten lead.

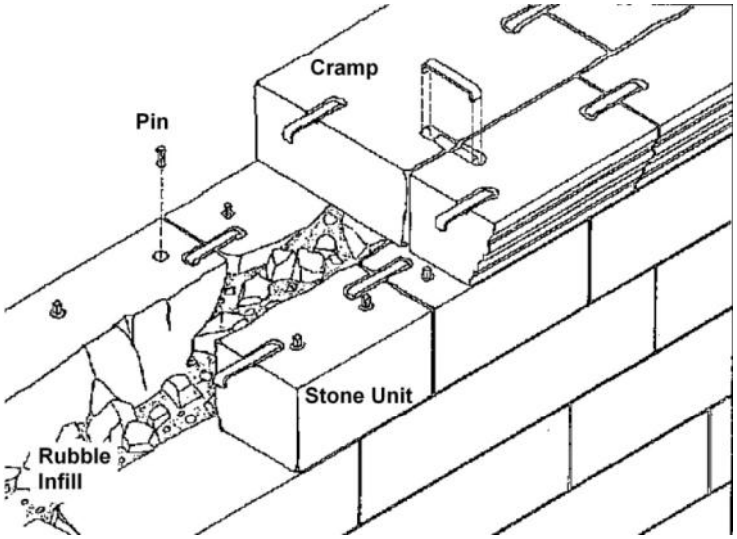


(Tanyeli, 1990)


Sultanhan, 13th century

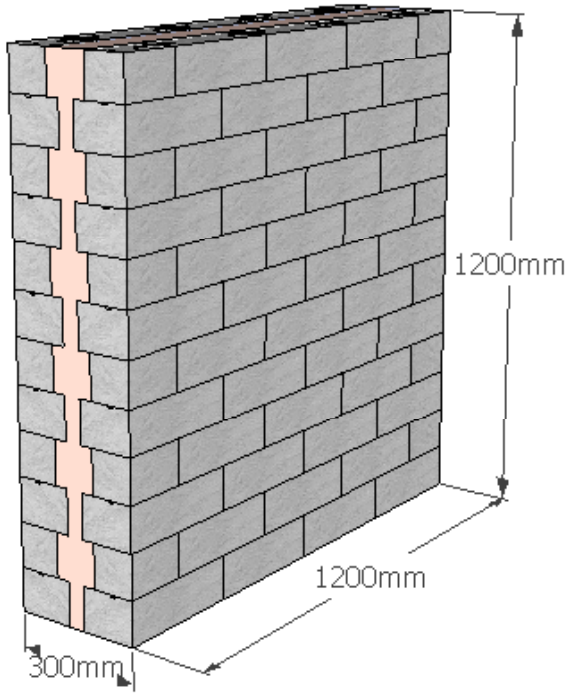
INTRODUCTION TO THE EXPERIMENTAL PROGRAM

Bayezid Mosque-15. century (Cut Stone Wall)

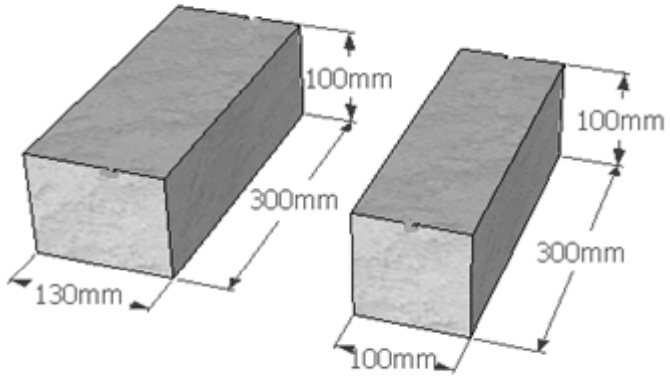


EXPERIMENTAL PROGRAM

1 / 3 scale wall specimens



Wall Model



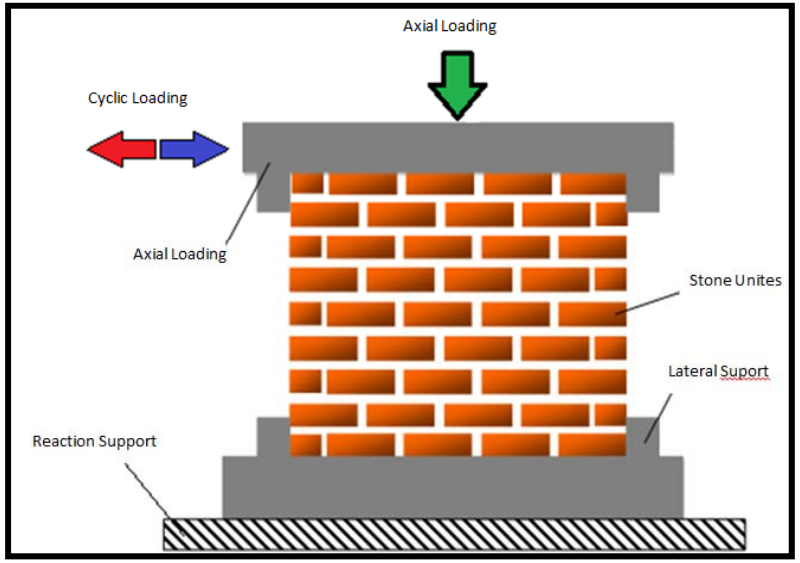
Stone blocks

EXPERIMENTAL PROGRAM

Wall Tests

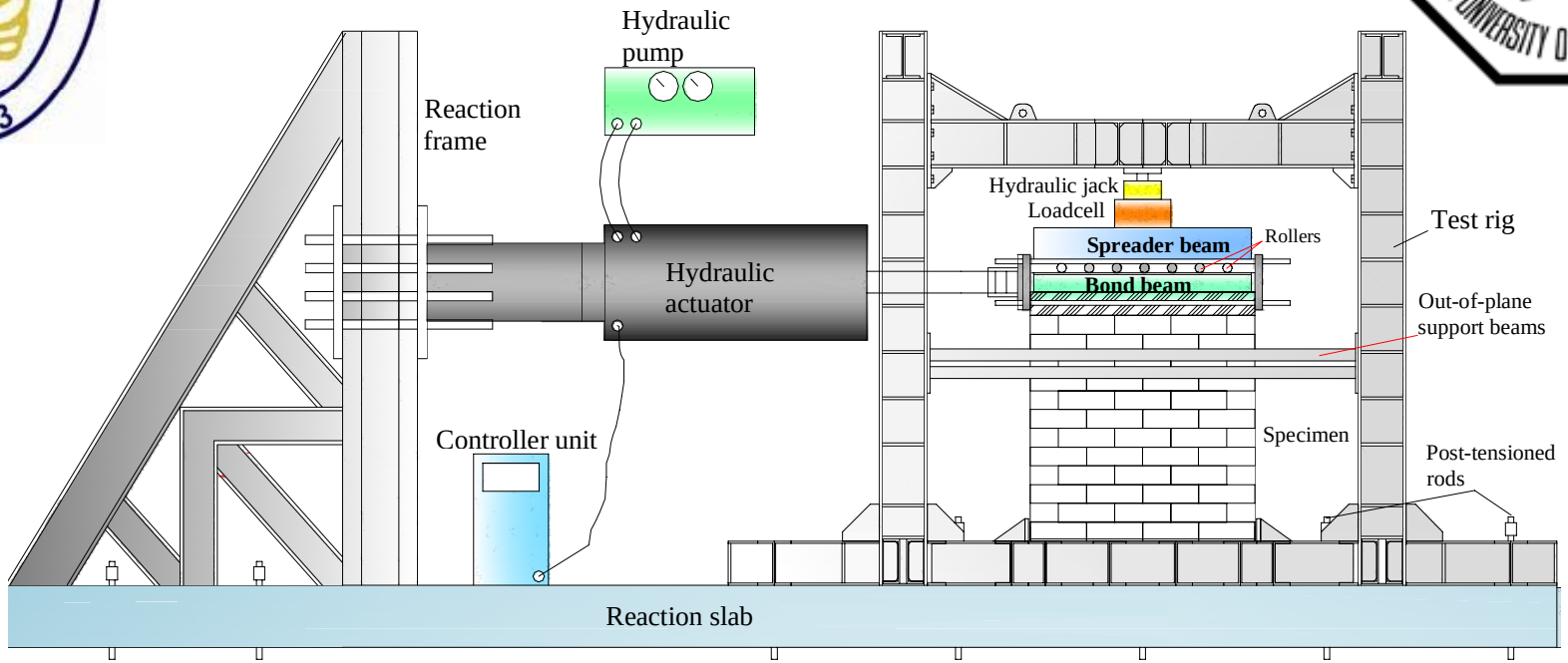
- The tests were done at ITU Structural and EQ Engineering Laboratory.
- The variables are
  - normal stress level,
  - and clamps
- For each axial load, horizontal cyclic force is applied in the in-plane direction

sample	clamp	Axial Load (MPa)	variable
M-25-C	Yes	**0.25**	axial stress
M-50-C	Yes	**0.50**	axial stress
M-75-C	Yes	**0.75**	axial stress
M-100-C	Yes	**1.00**	axial stress
M-50	**No**	**0.50**	**Clamp not used**



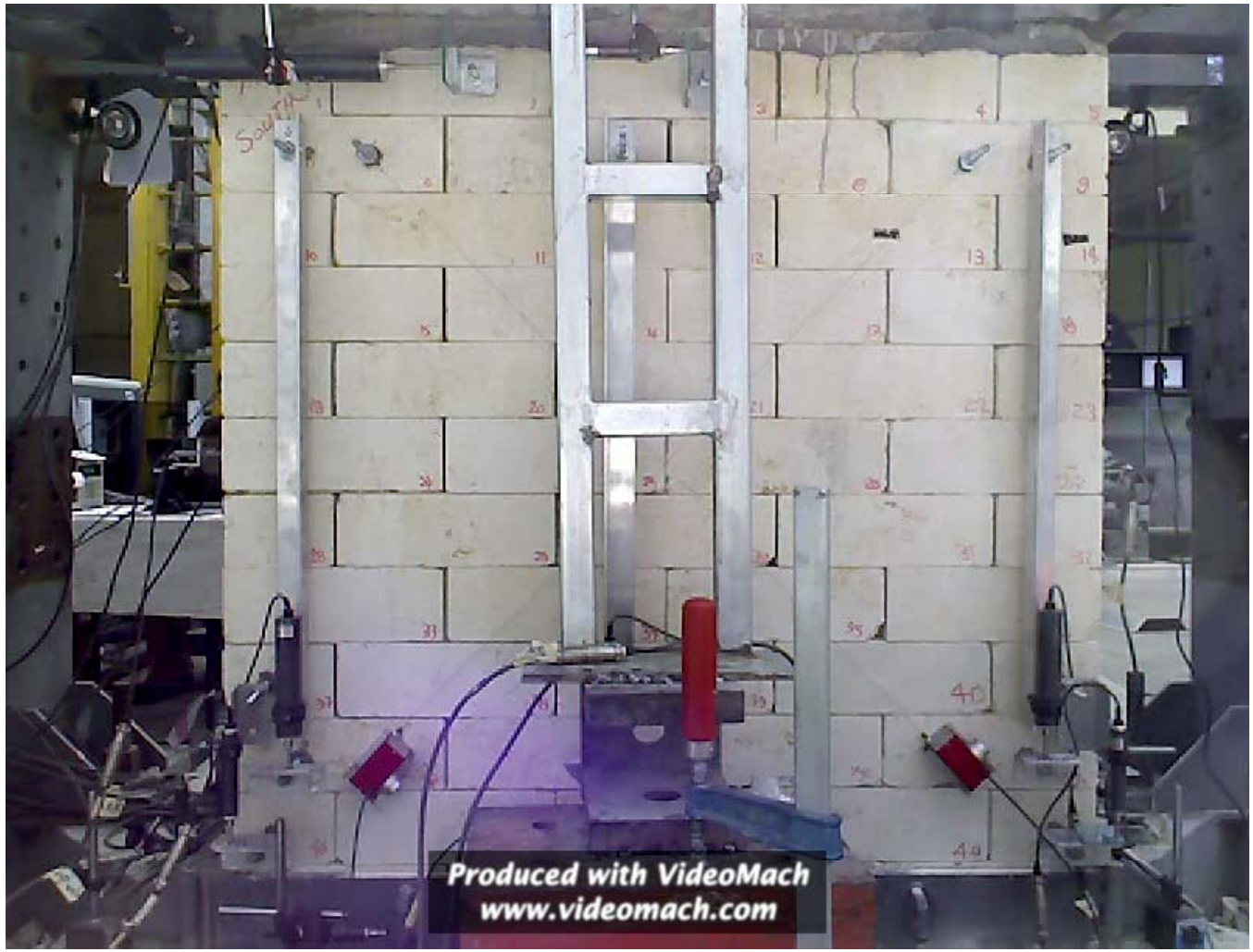
EXPERIMENTAL PROGRAM

Wall Tests



EXPERIMENTAL PROGRAM

Wall Tests



FEM Simulations

FEM Simulations

- FEM analysis has been used to model and simulate the behavior of masonry wall subjected to in-plane loading

- Concrete-damage plasticity (CDP) model available in ABAQUS has been adopted for this purpose. This model provides a good prediction for the behavior of such structures with cyclic loading

- ABAQUS software has been used for the simulation. ABAQUS provides an extraordinary capability to simulate this type of structure under cyclic loading using the desired model.

Elasto-Plastic Damage Model

The main purpose of the study is to find the interaction diagram between the normal stress and lateral shear strength of the wall.

For this purpose, a Finite element simulation has been carried out for two walls:

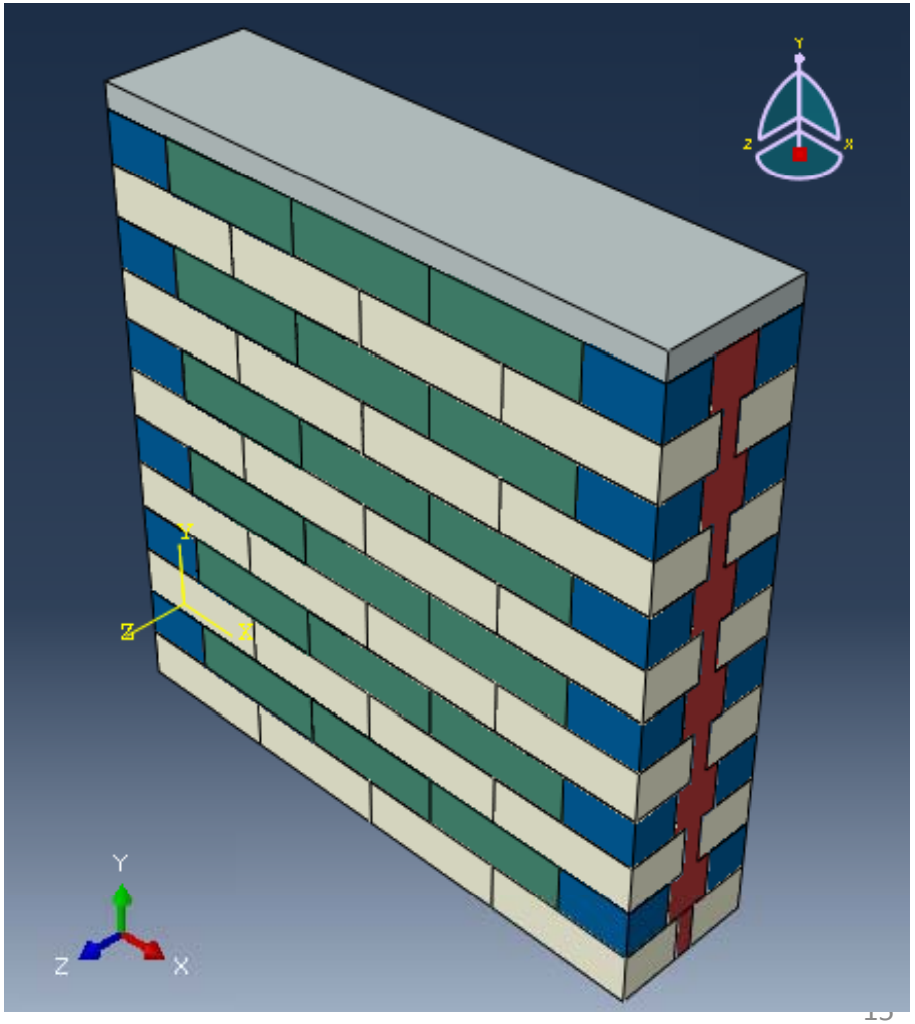
- The wall tested at ITU by Demir et al. (2011)
- A hollow block concrete wall studied by Nanni et al (2005)

Elasto-Plastic Damage Model

Wall tested by Demir et al. (2011)

- The wall is a multilayer, leaf wall (two leaves) with rubble material as filling material between the two leaves.

- The interface between the units is dry connection.



Elasto-Plastic Damage Model

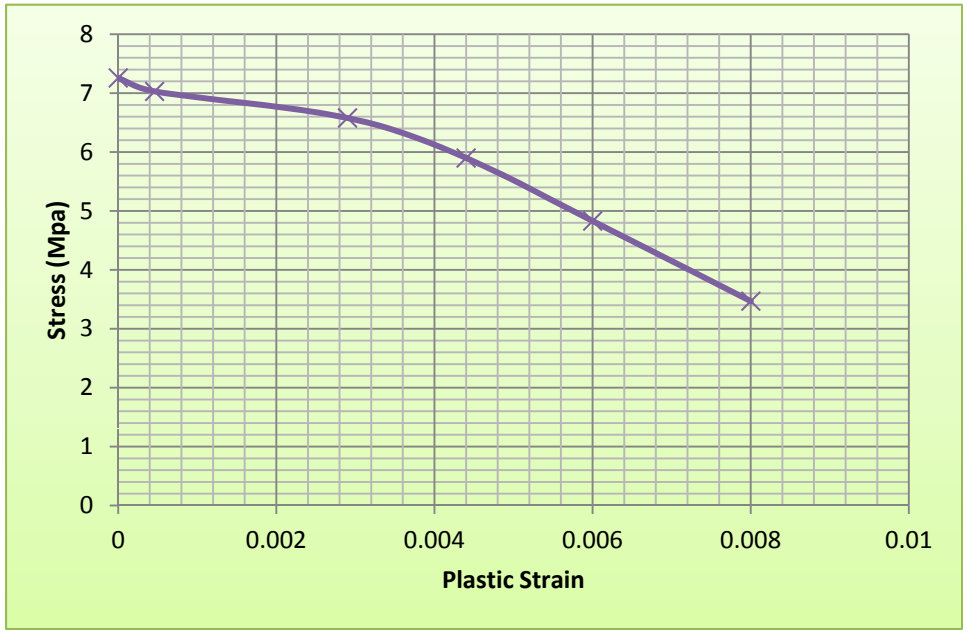
Wall tested by C. Demir et al

Material models used in this wall in ABAQUS

Bricks Compression:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	3200	0.18	36	0.1	1.16	0.67	0

Compression	
Plastic Strain	Stress (Mpa)
0	7.26
0.00046	7.03
0.0029	6.58
0.0044	5.9
0.006	4.83
0.008	3.47



Elasto-Plastic Damage Model

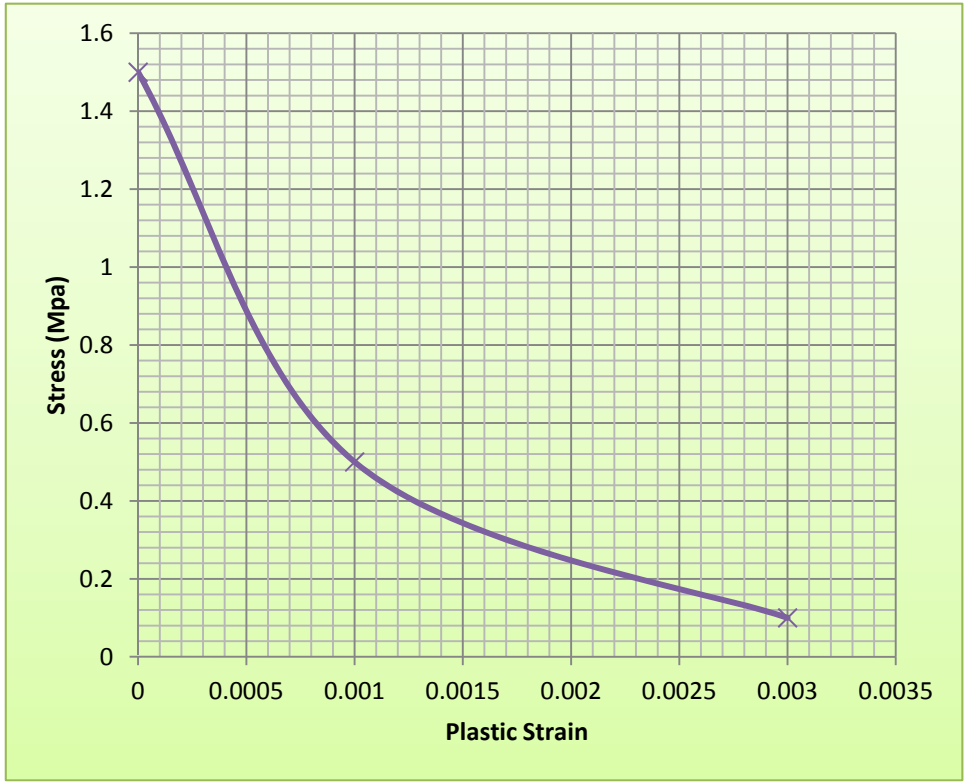
Wall tested by C. Demir et al

Material models used in this wall in ABAQUS

Bricks Tension:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	3200	0.18	36	0.1	1.16	0.67	0

Tension	
Plastic Strain	Stress (Mpa)
0	1.5
0.001	0.5
0.003	0.1



Elastio-Plastic Damage Model

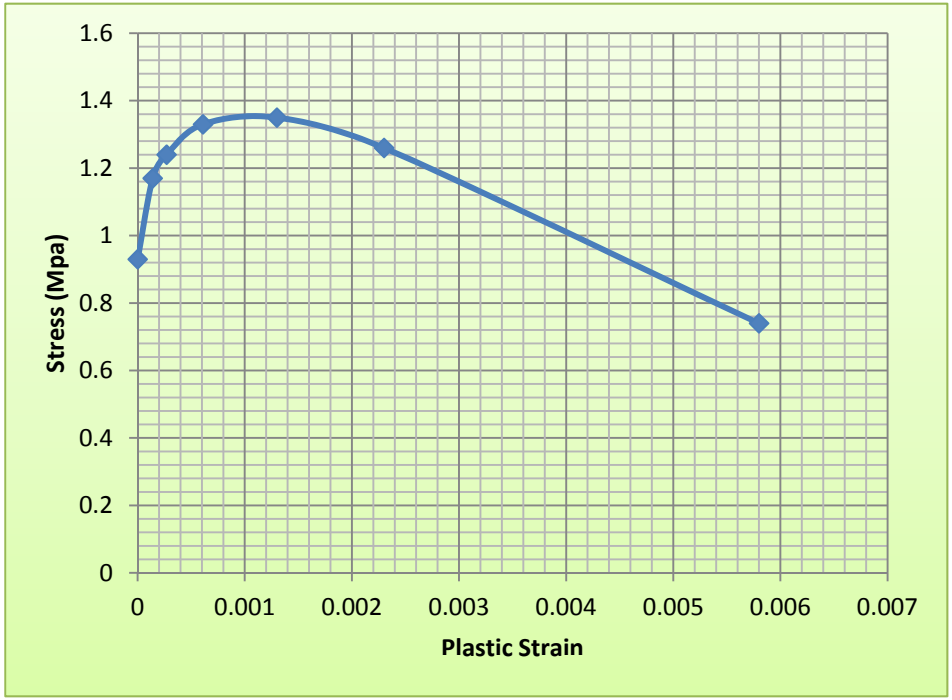
Wall tested by C. Demir et al

Material models used in this wall in ABAQUS

Rubble Compression:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
1E-009	590	0.18	36	0.1	1.16	0.67	0

Compression	
Plastic Strain	Stress (Mpa)
0	0.93
0.00014	1.17
0.00027	1.24
0.00061	1.33
0.0013	1.35
0.0023	1.26
0.0058	0.74



Elasto-Plastic Damage Model

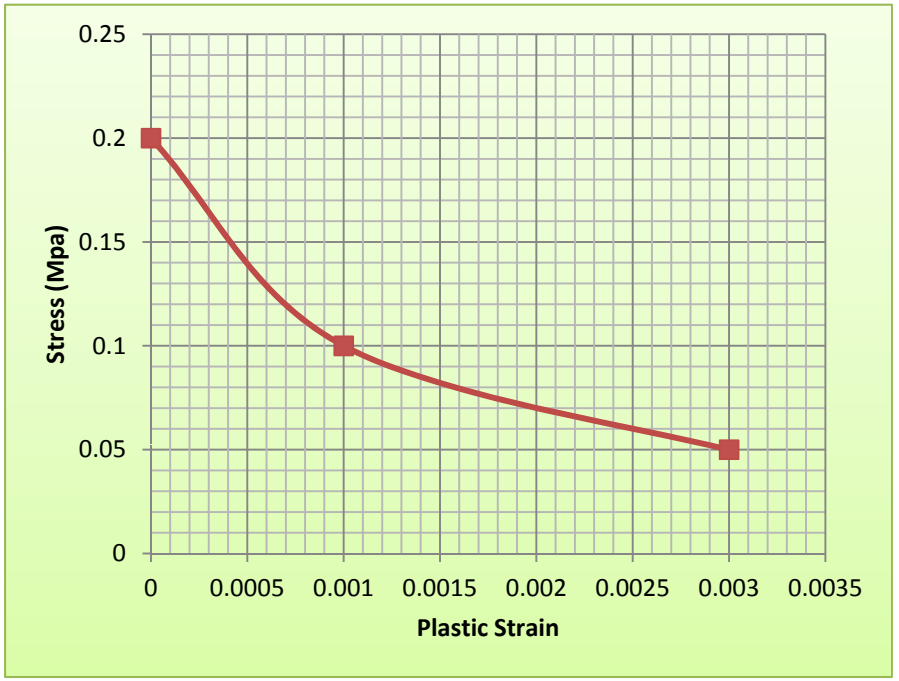
Wall tested by C. Demir et al

Material models used in this wall in ABAQUS

Rubble Tension:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
1E-009	590	0.18	36	0.1	1.16	0.67	0

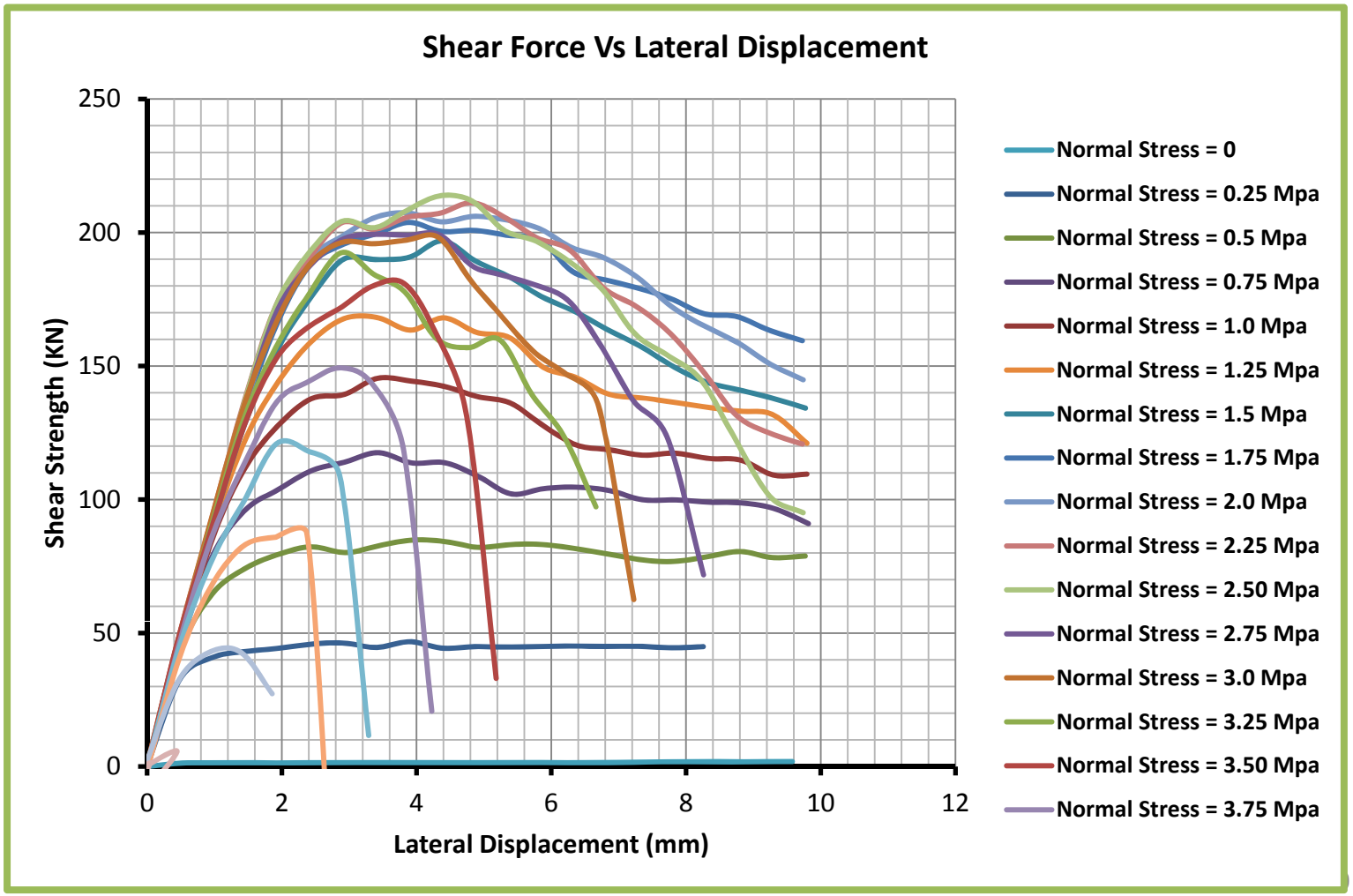
Tention	
Plastic Strain	Stress (Mpa)
0	0.2
0.001	0.1
0.003	0.05



Elasto-Plastic Damage Model

Wall tested by C. Demir et al

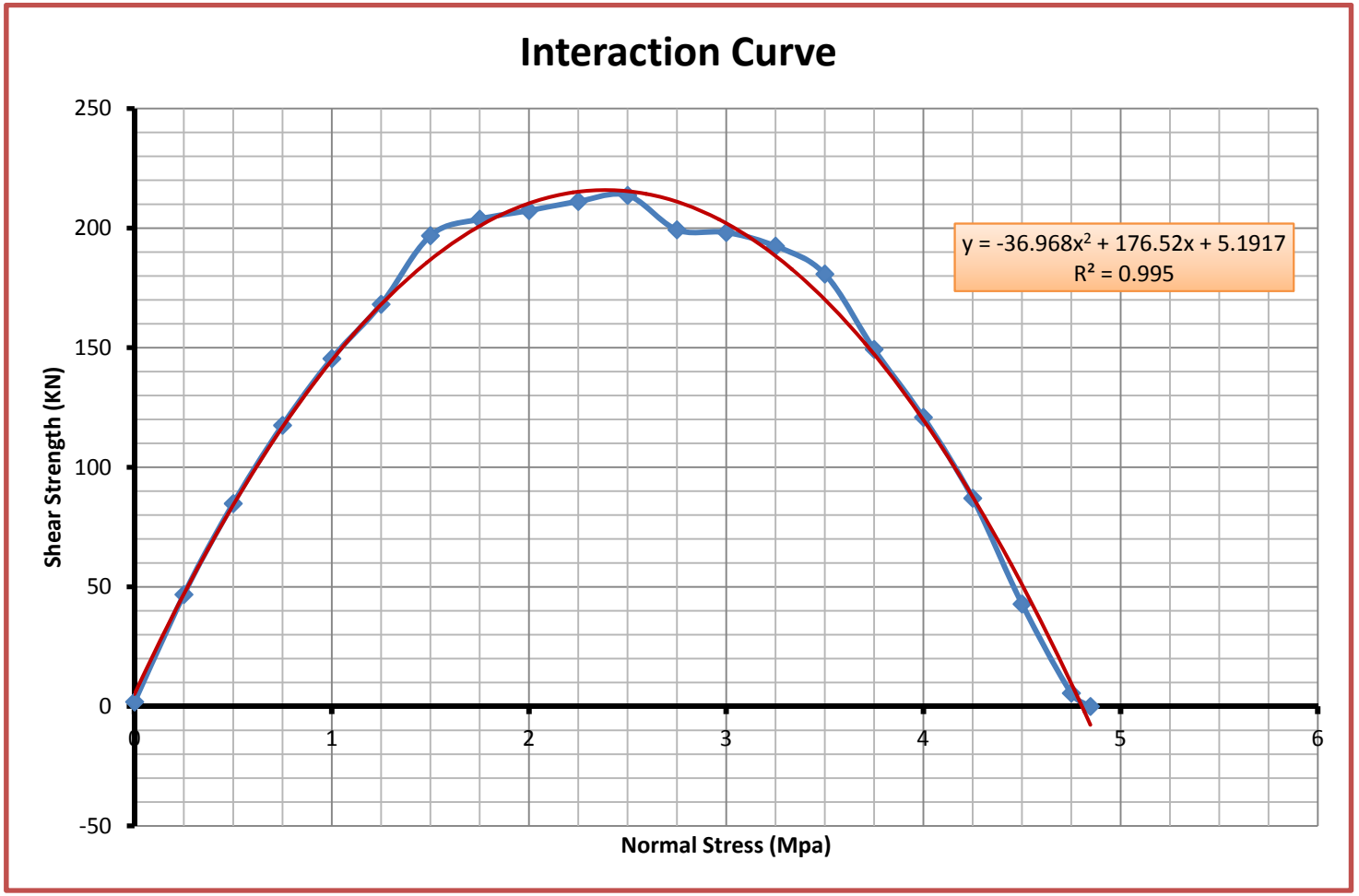
RESULTS: Wall Lateral Strength.



Elasto-Plastic Damage Model

Wall tested by C. Demir et al

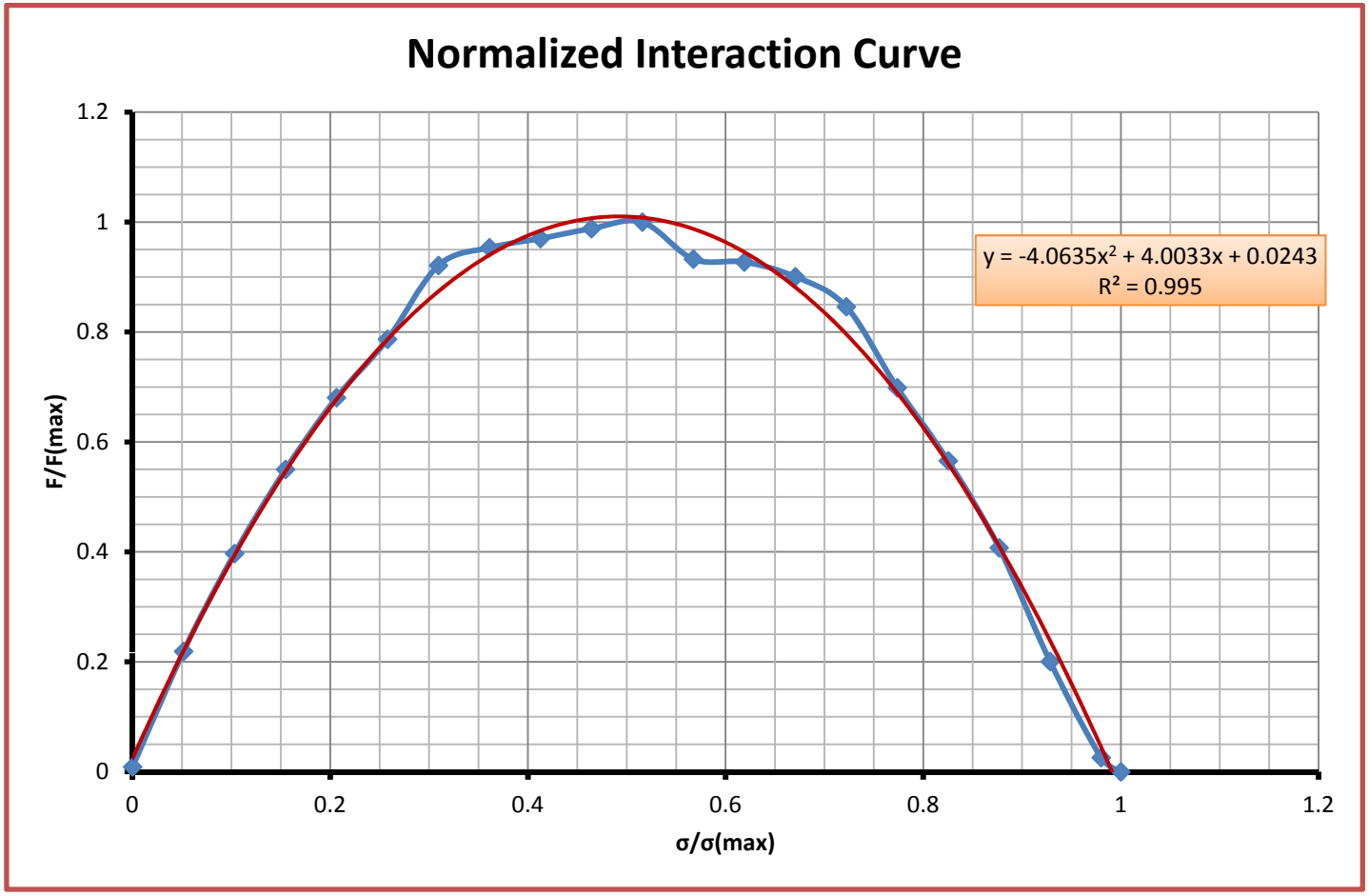
RESULTS: Interaction Curve.



Elasto-Plastic Damage Model

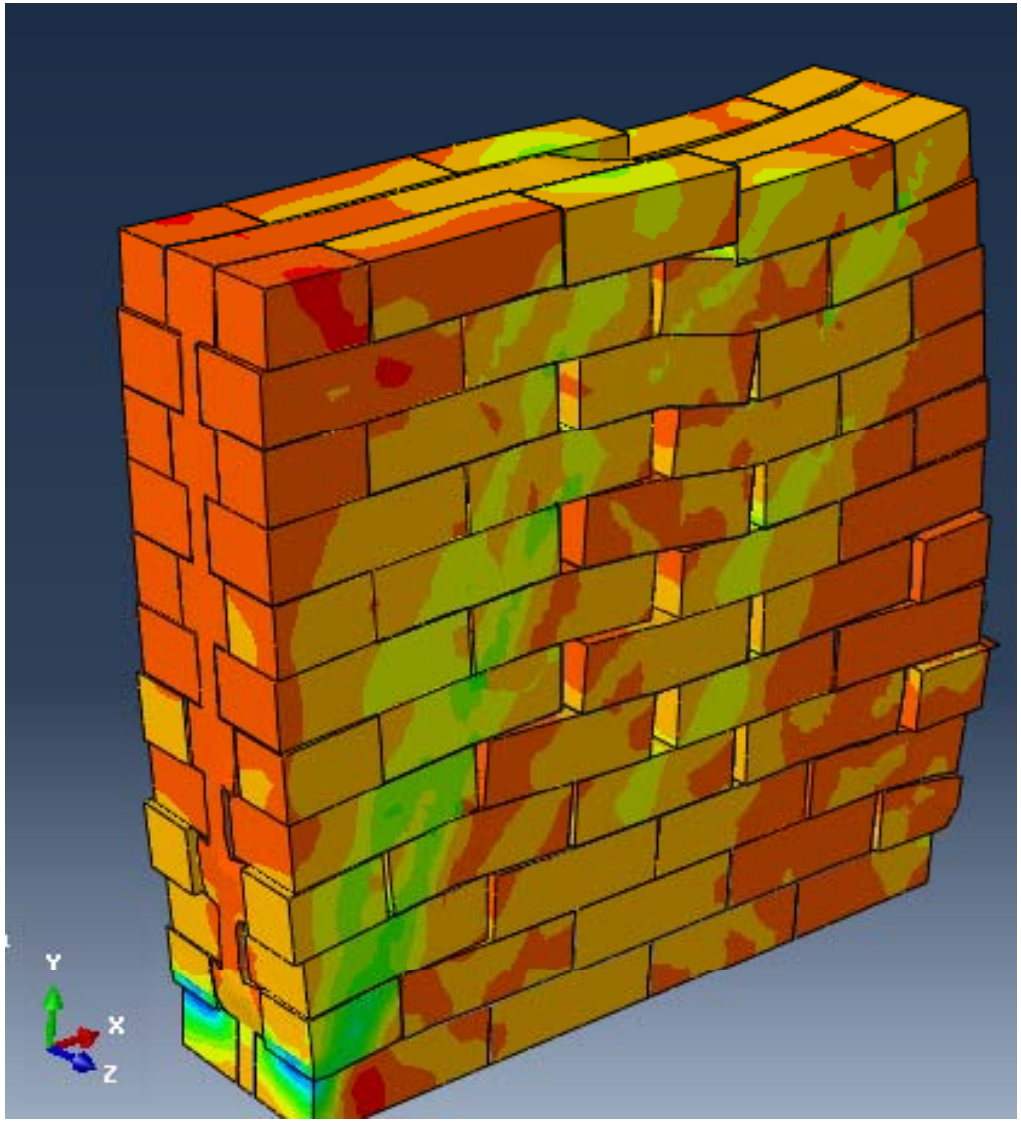
Wall tested by C. Demir et al

RESULTS: Normalized Interaction Curve.



FEM Simulations

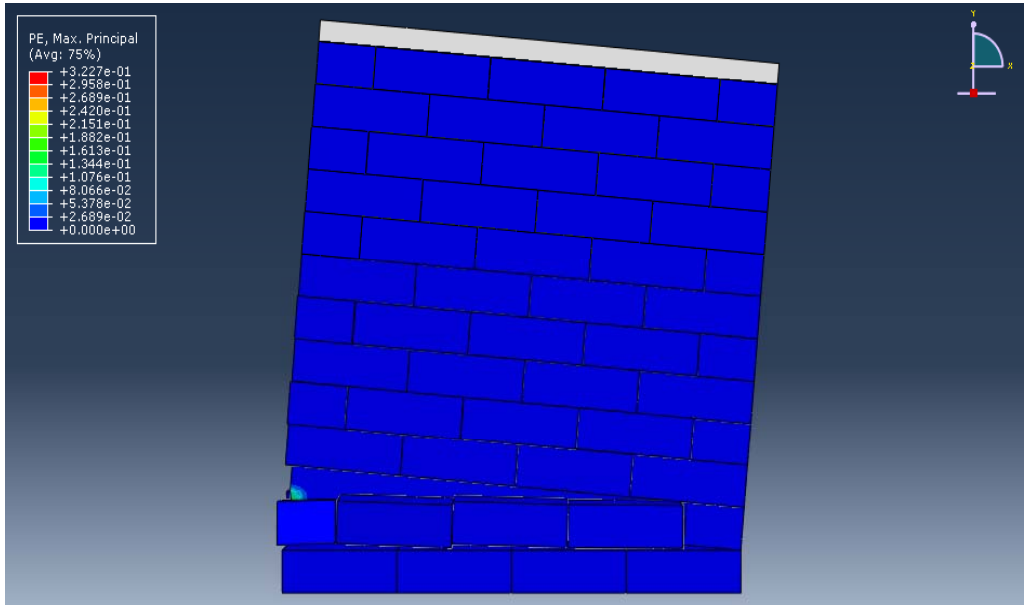
Wall tested by C. Demir et al



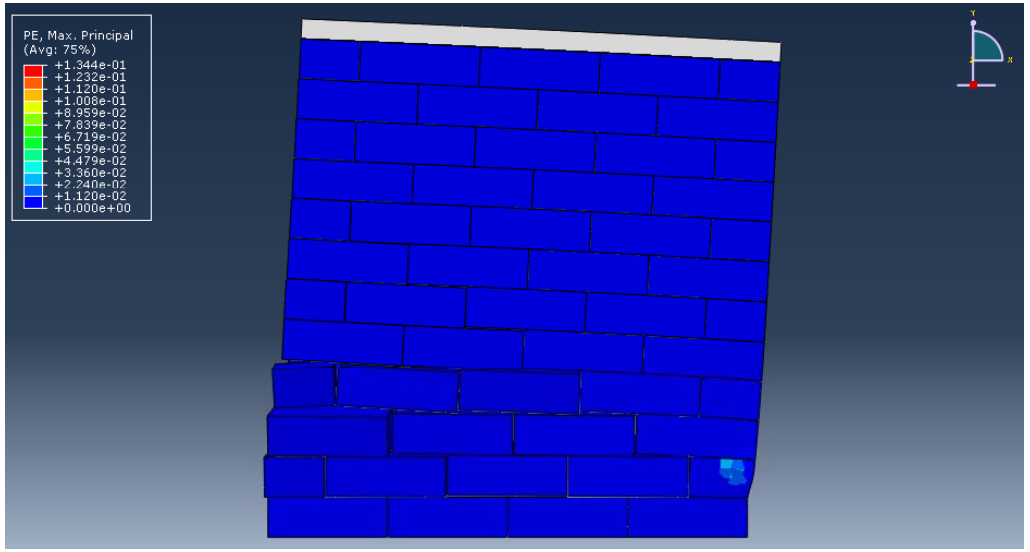
FEM Simulations

Wall tested by C. Demir et al

$\sigma_n = 0\ Mpa$



$\sigma_n = 0.25\ Mpa$

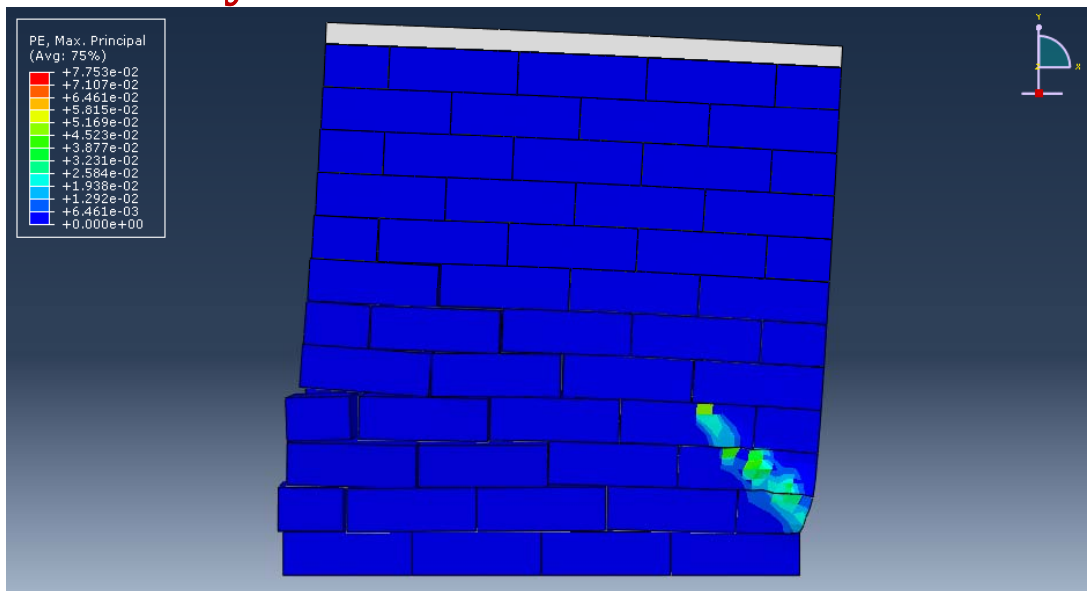


Plastic Strain

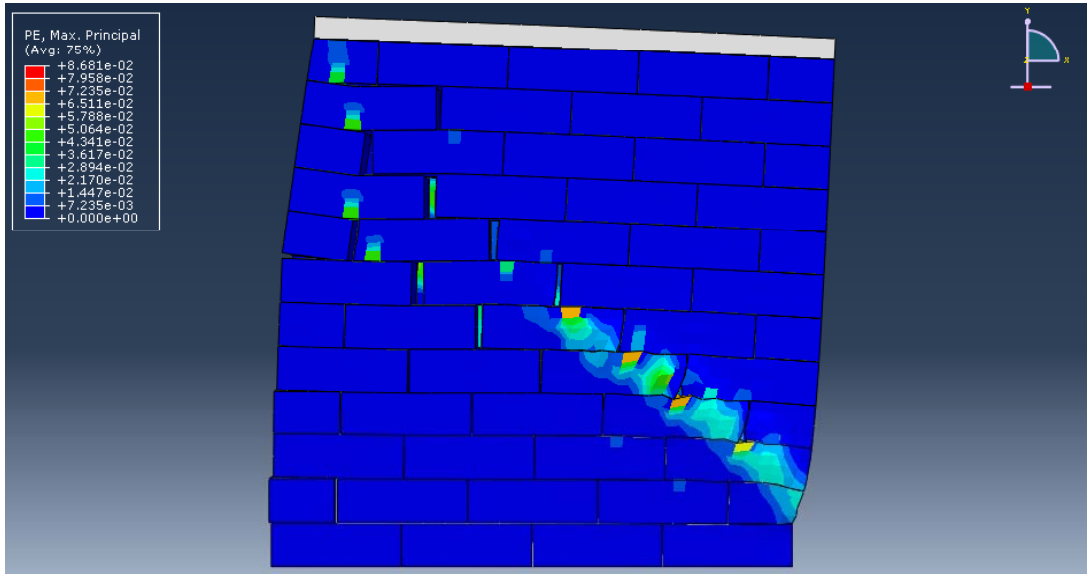
FEM Simulations

Wall tested by C. Demir et al

$\sigma_n = 0.50\ Mpa$



$\sigma_n = 1.0\ Mpa$

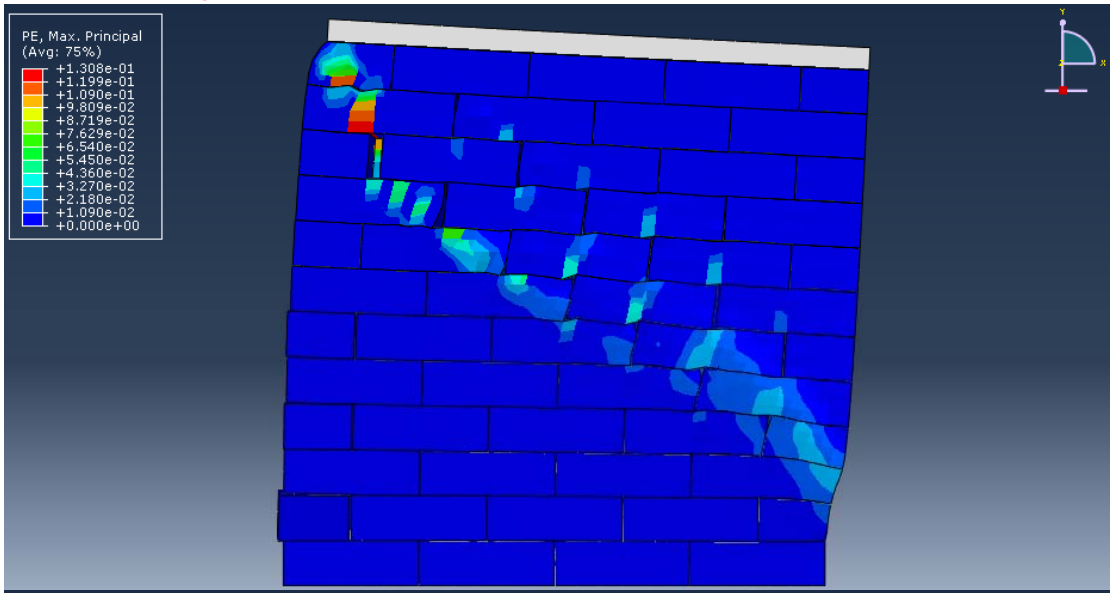


Plastic Strain

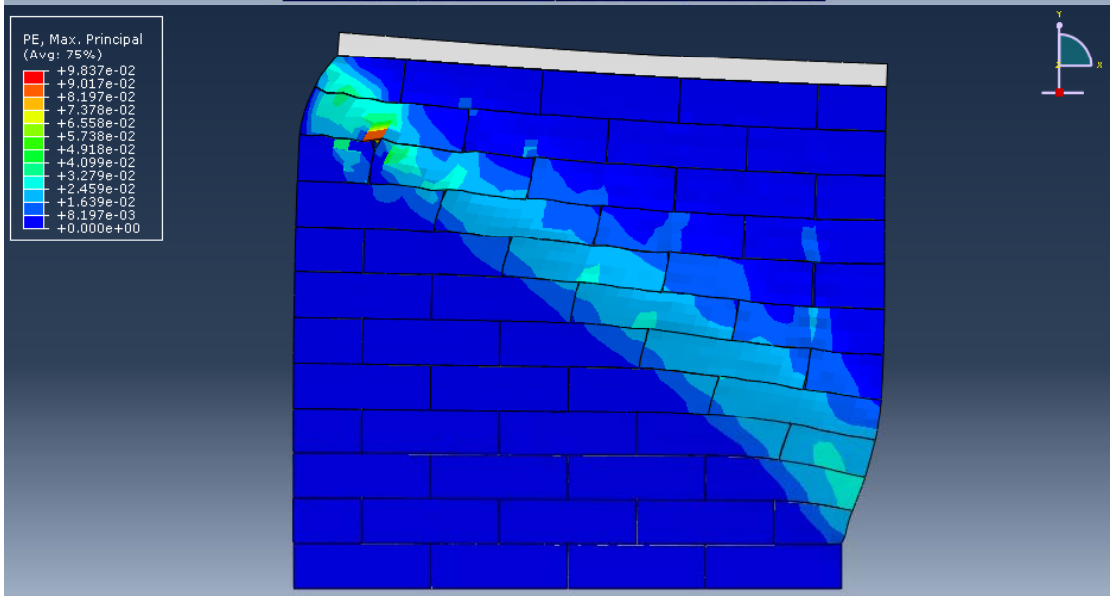
FEM Simulations

Wall tested by C. Demir et al

$\sigma_n = 2.0\ Mpa$



$\sigma_n = 3.0\ Mpa$

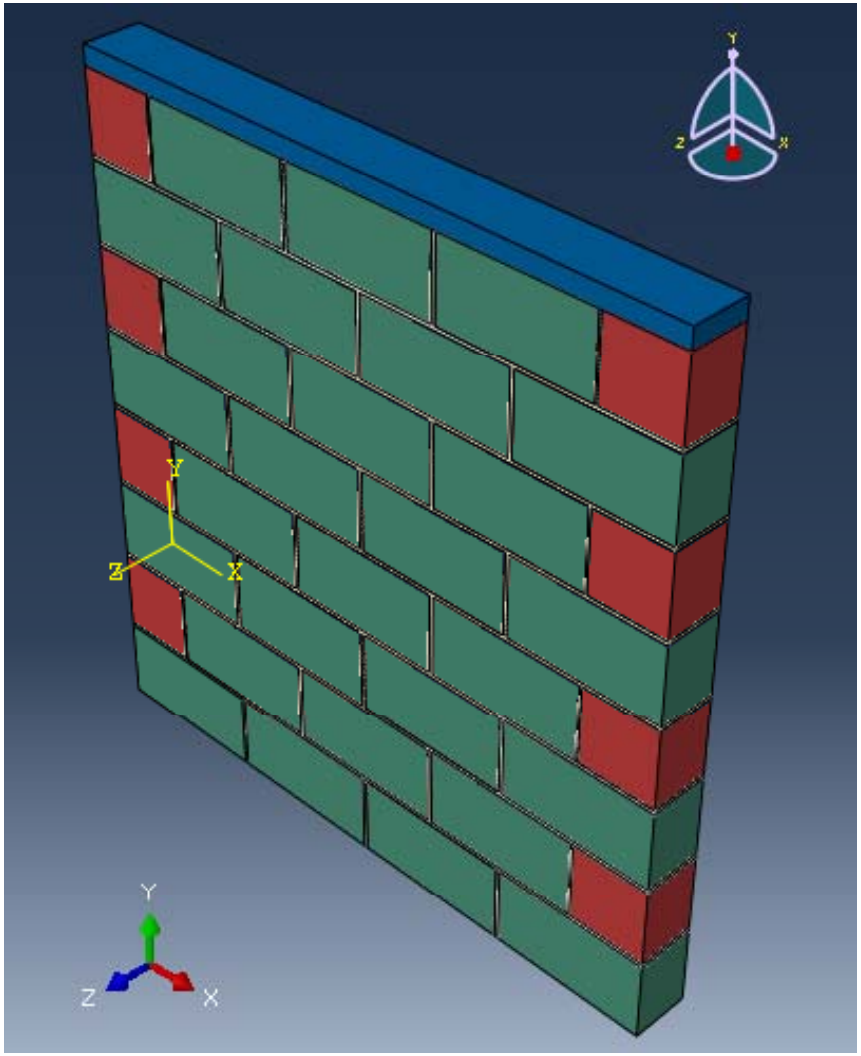


Plastic Strain

Elasto-Plastic Damage Model

Wall studied by Nanni et al. (2005)

- This wall is a single leaf wall of hollow concrete blocks.
- The interface between the bricks is mortar.



Elasto-Plastic Damage Model

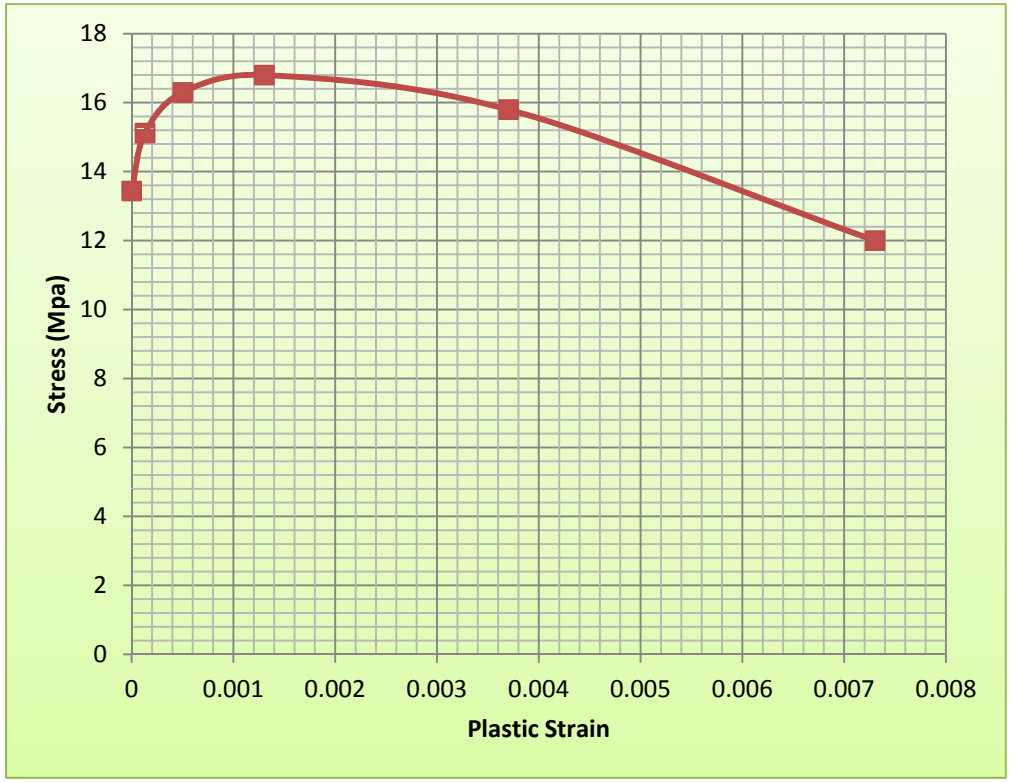
Wall studied by Nanni et al. (2005)

Material models used in this wall in ABAQUS

Hollow concrete blocks:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	19264.26744	0.2	36	0.1	1.16	0.67	0

Compression	
Plastic Strain	Stress (Mpa)
0	13.44
0.000131	15.12
0.000502	16.3
0.001302	16.8
0.003702	15.8
0.007302	12



Elasto-Plastic Damage Model

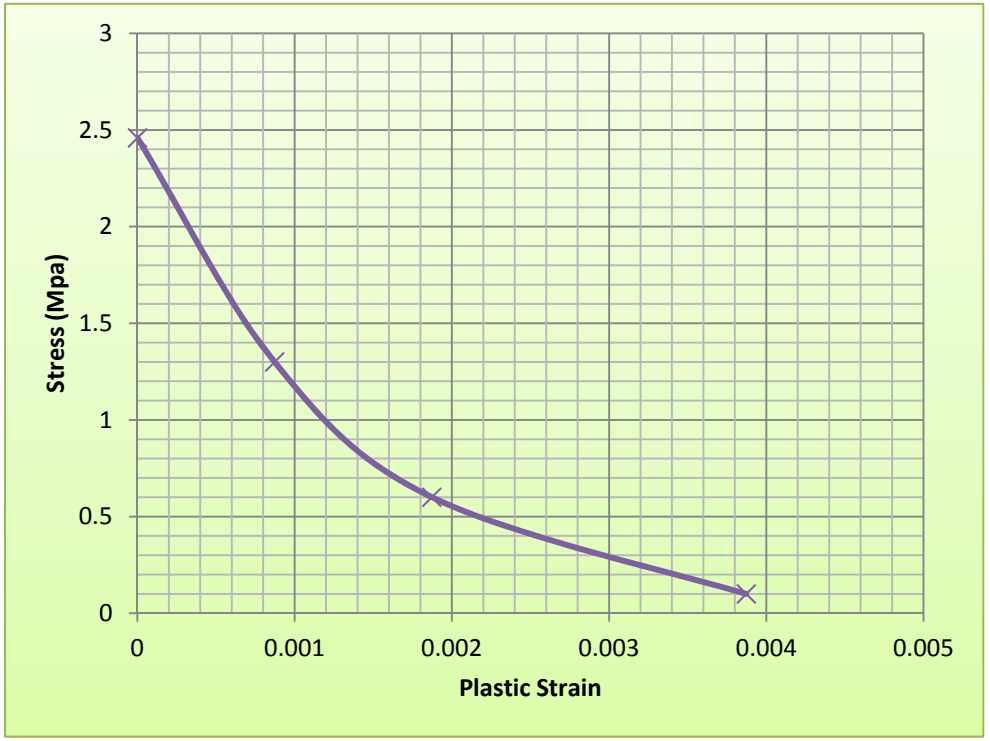
Wall studied by Nanni et al

Material models used in this wall in ABAQUS

Hollow concrete blocks:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	19264.26744	0.2	36	0.1	1.16	0.67	0

Tension	
Plastic Strain	Stress (Mpa)
0	2.459268
0.000872	1.3
0.001872	0.6
0.003872	0.1



Elasto-Plastic Damage Model

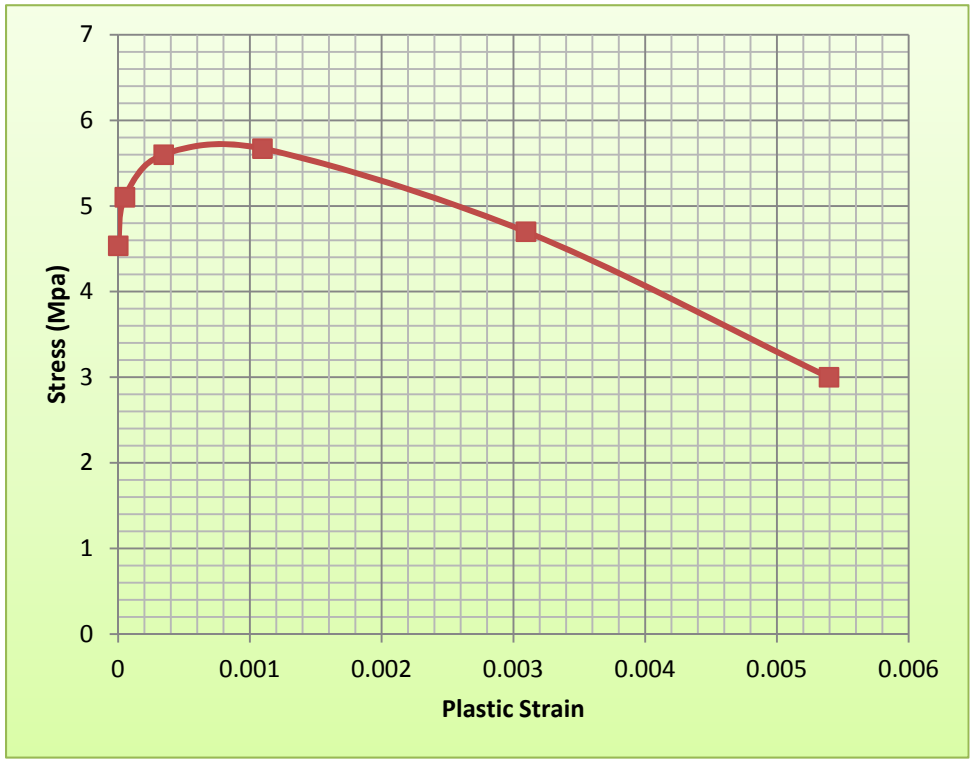
Wall studied by Nanni et al

Material models used in this wall in ABAQUS

Mortar:

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	11191.52805	0.2	36	0.1	1.16	0.67	0

Compression	
Plastic Strain	Stress (Mpa)
0	4.536
5.07E-05	5.103
0.000345	5.6
0.001095	5.67
0.003095	4.7
0.005395	3



Elasto-Plastic Damage Model

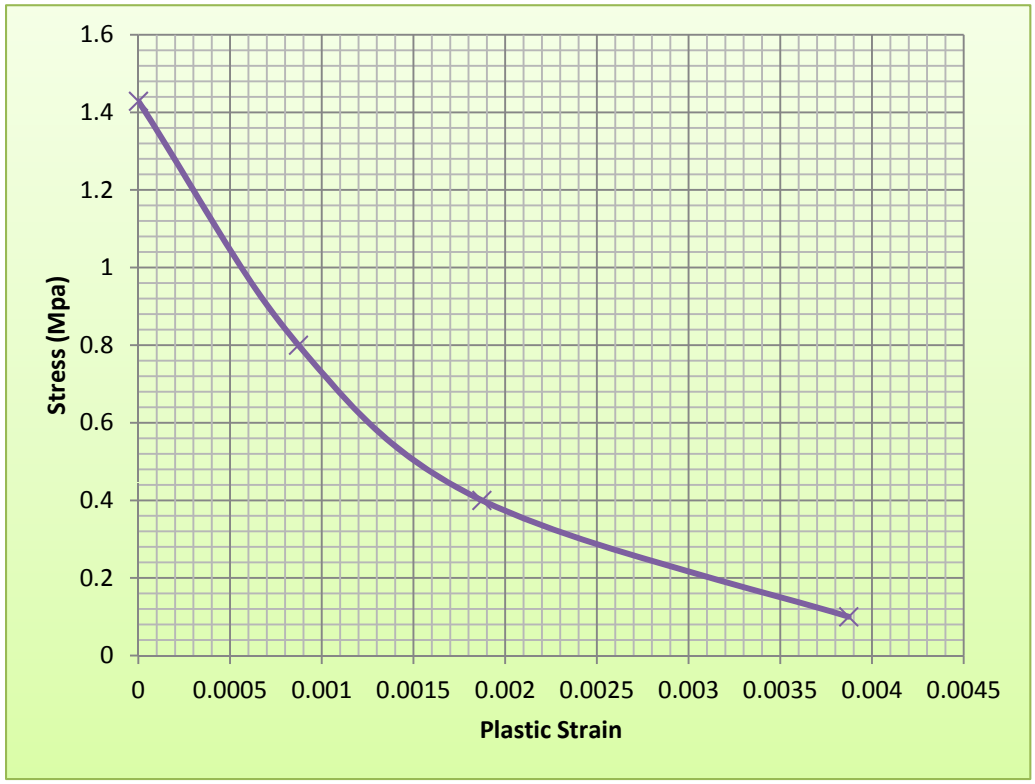
Wall studied by Nanni et al

Material models used in this wall in ABAQUS

Mortar::

Mass Density	Young's Modulus	Poisson's Ratio	Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
2.4E-009	11191.52805	0.2	36	0.1	1.16	0.67	0

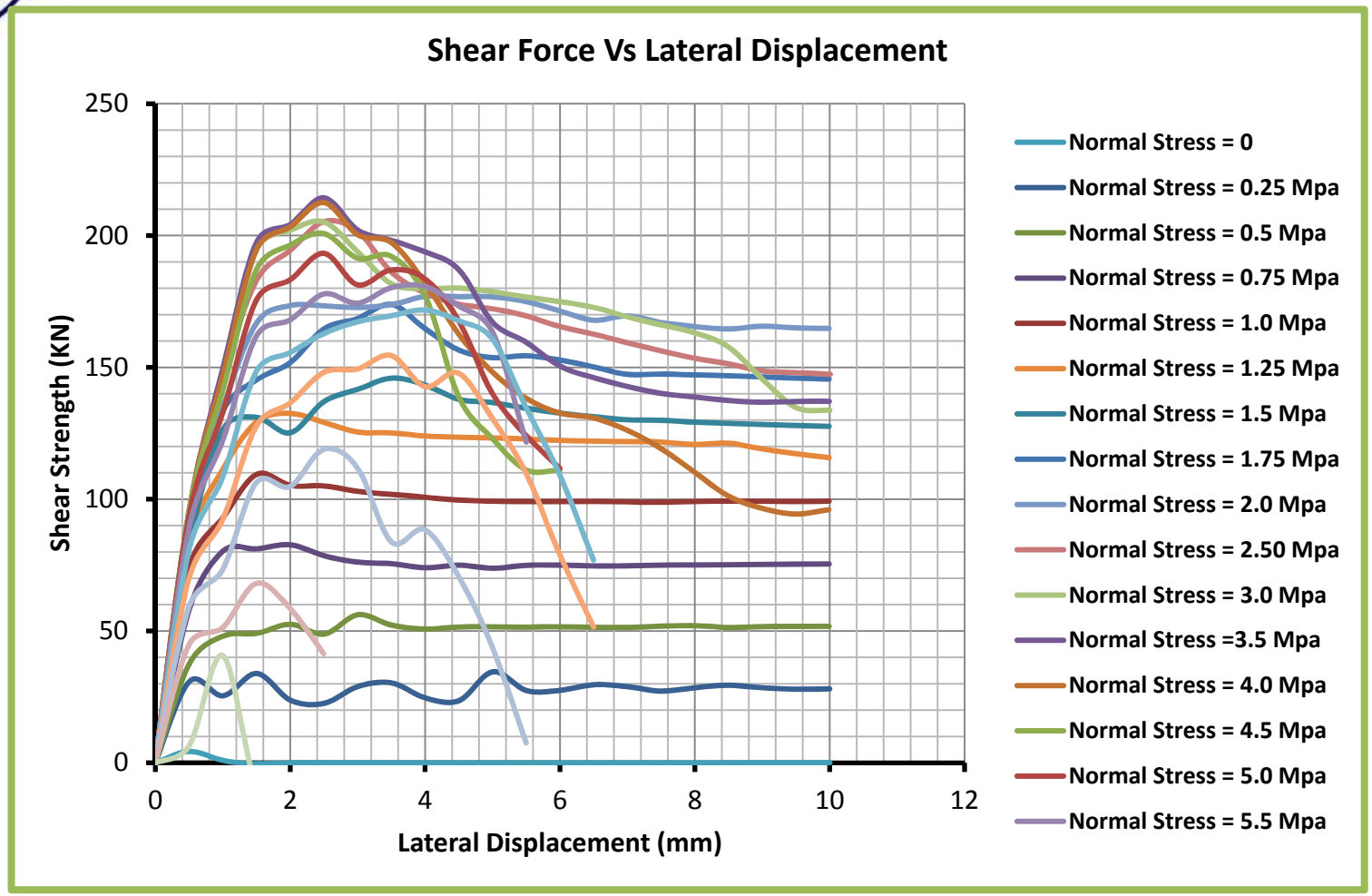
Tension	
Plastic Strain	Stress (Mpa)
0	1.428706
0.000872	0.8
0.001872	0.4
0.003872	0.1



Elasto-Plastic Damage Model

Wall studied by Nanni et al

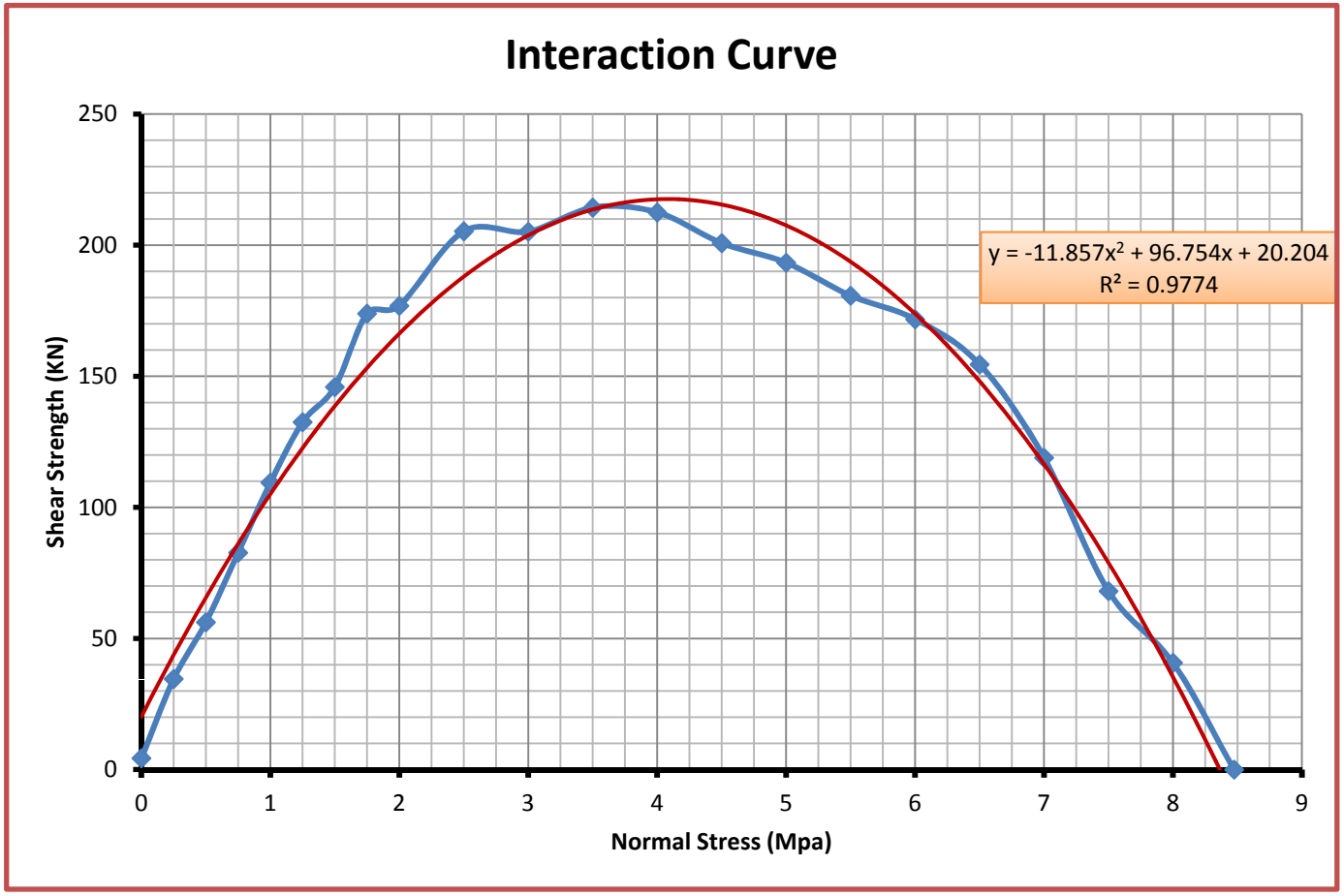
RESULTS - Wall Lateral Strength.



Elasto-Plastic Damage Model

Wall studied by Nanni et al

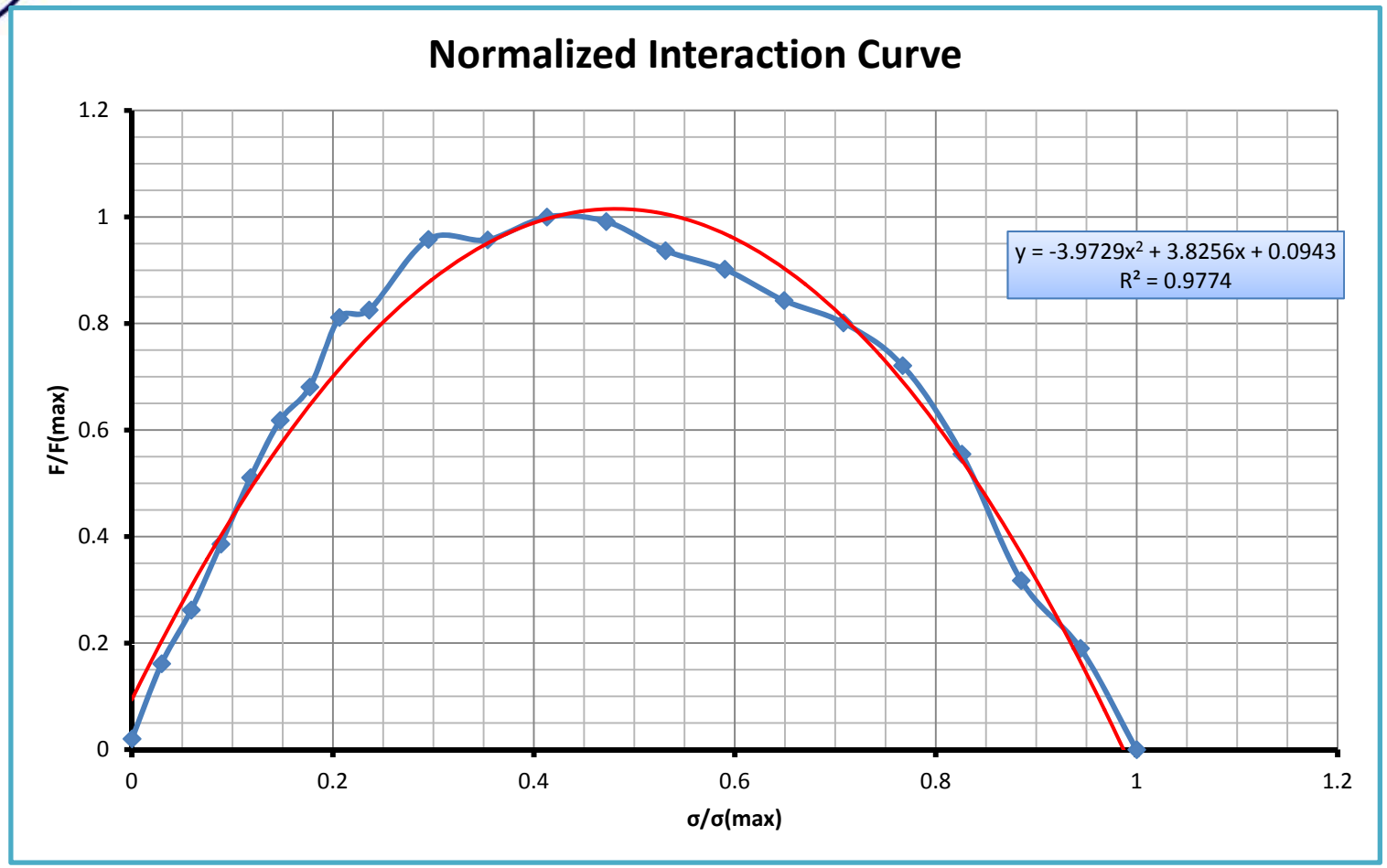
RESULTS- Interaction Curve.



Elasto-Plastic Damage Model

Wall studied by Nanni et al

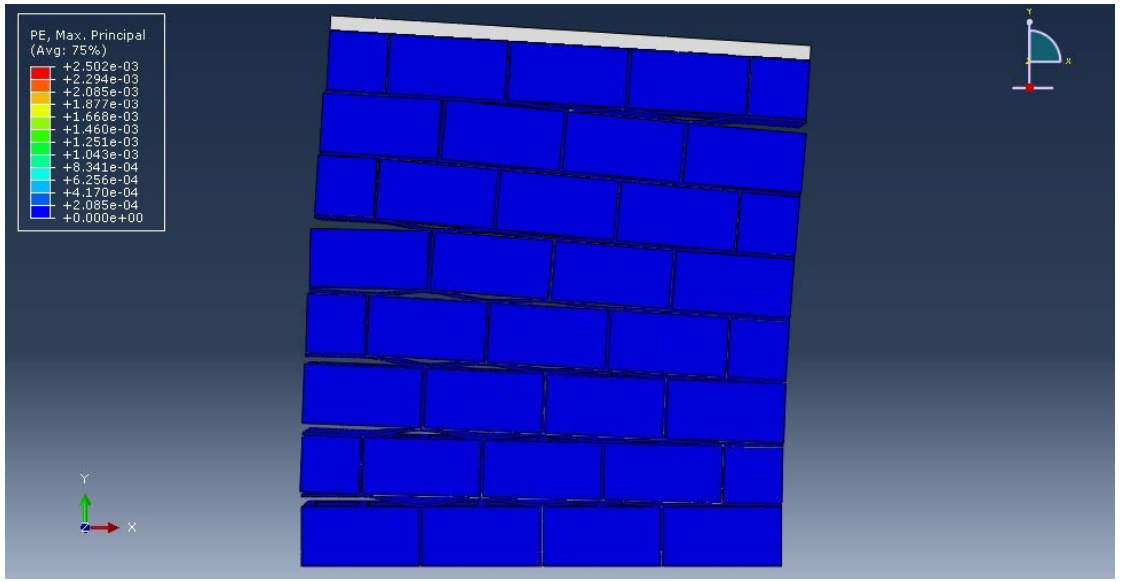
RESULTS-Normalized Interaction Curve.



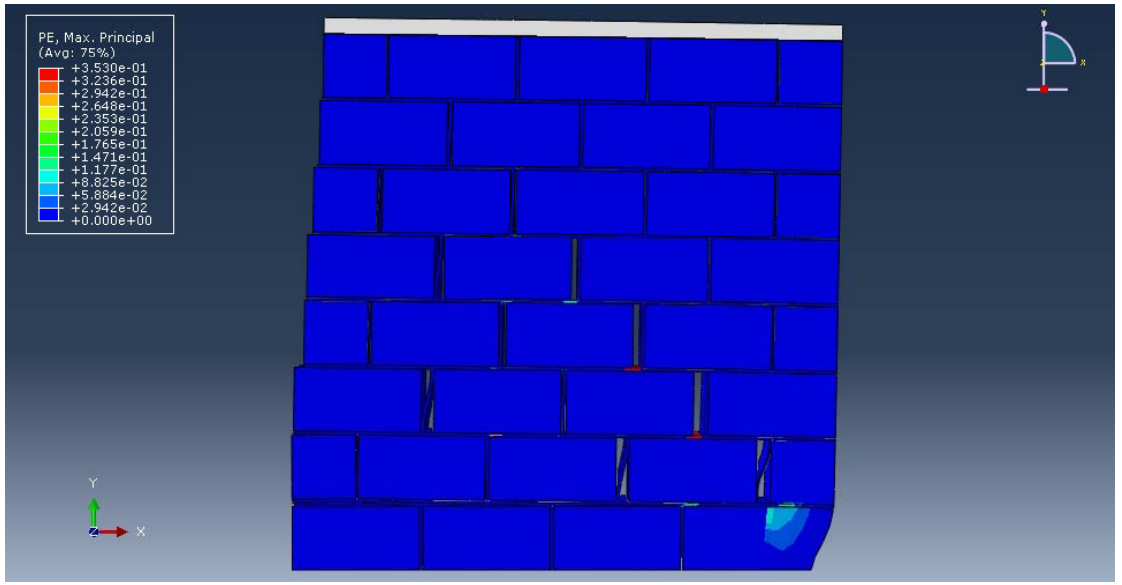
FEM Simulations

Wall studied by Nanni et al

$\sigma_n = 0\ Mpa$



$\sigma_n = 0.25\ Mpa$

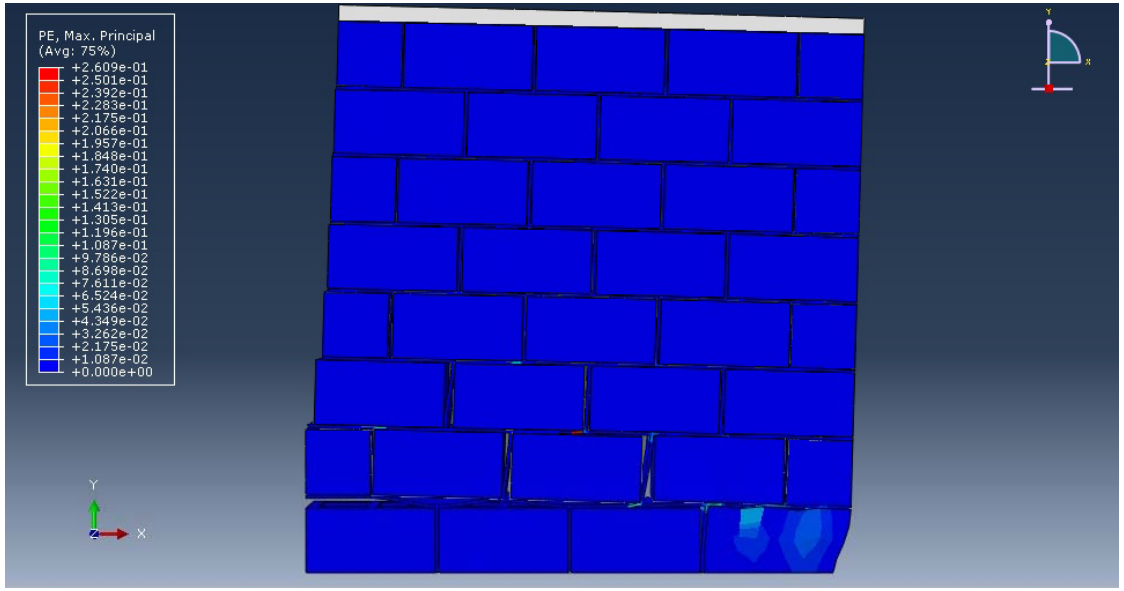


Plastic Strain

FEM Simulations

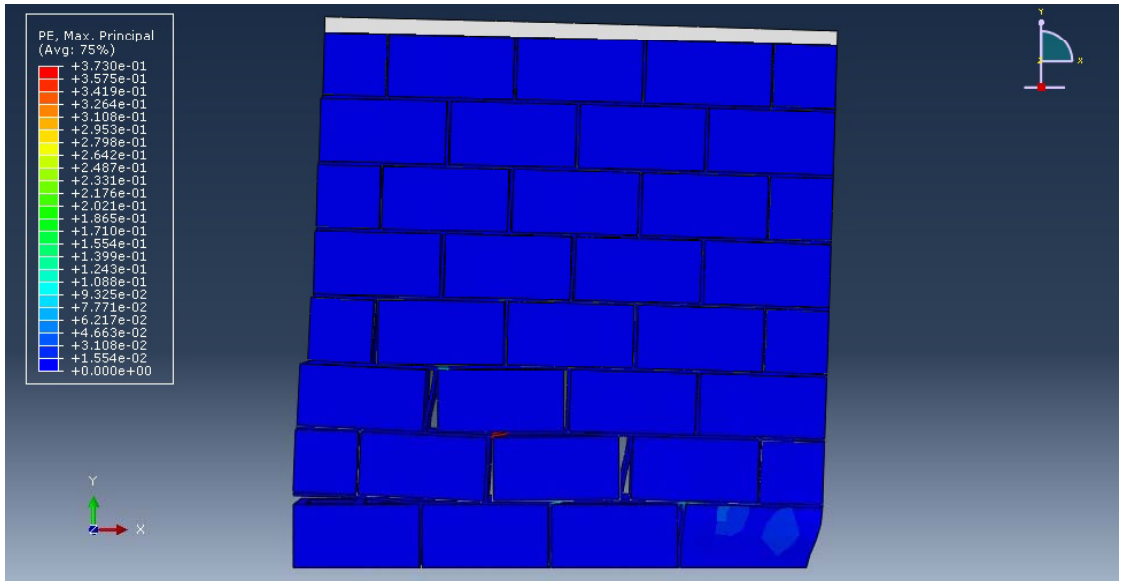
Wall studied by Nanni et al

$\sigma_n = 0.50\ Mpa$



Plastic Strain

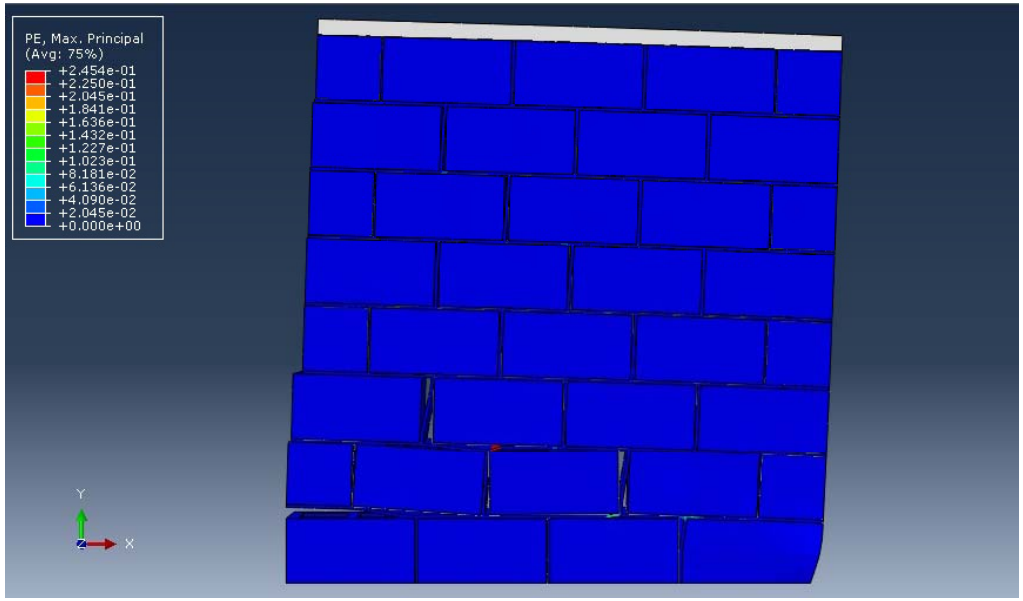
$\sigma_n = 0.75\ Mpa$



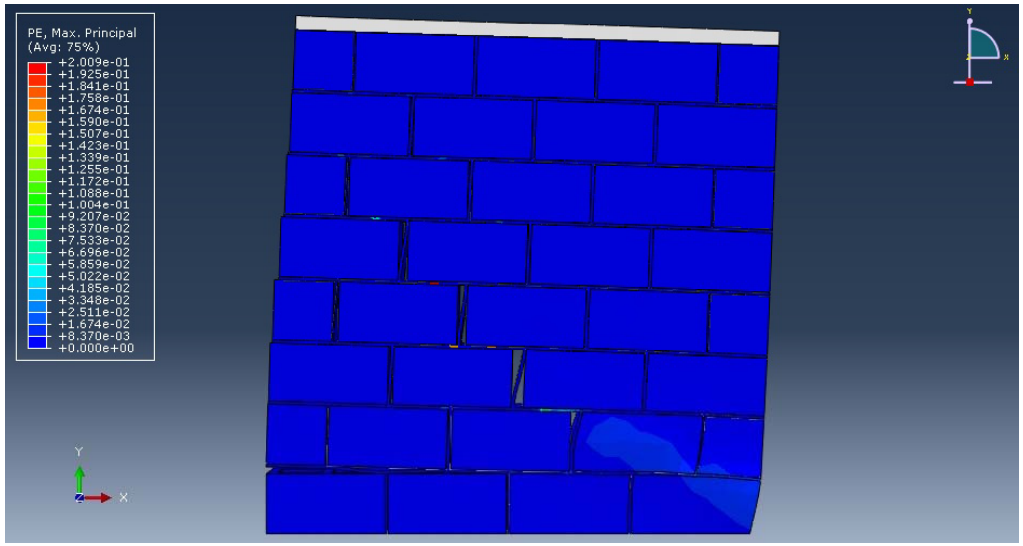
FEM Simulations

Wall studied by Nanni et al

$\sigma_n = 1.0\ Mpa$



$\sigma_n = 2.0\ Mpa$

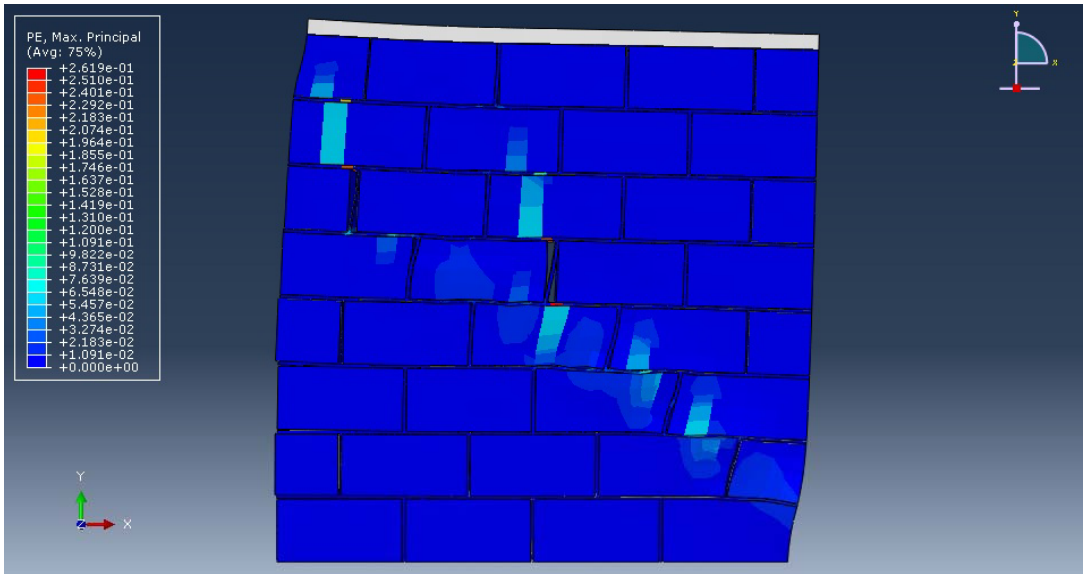


Plastic Strain

FEM Simulations

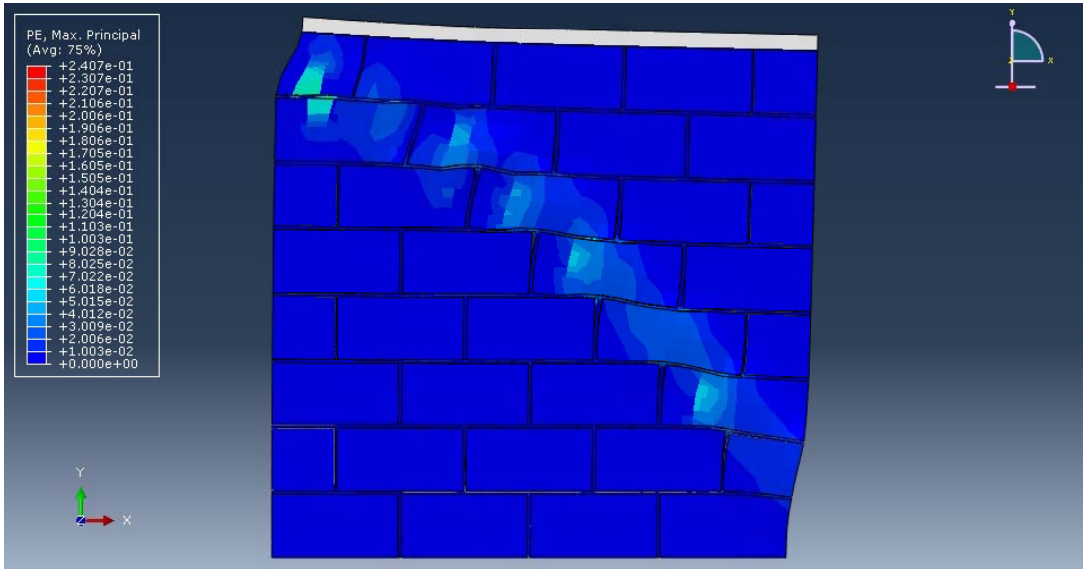
Wall studied by Nanni et al

$\sigma_n = 3.0\ Mpa$



Plastic Strain

$\sigma_n = 4.0\ Mpa$

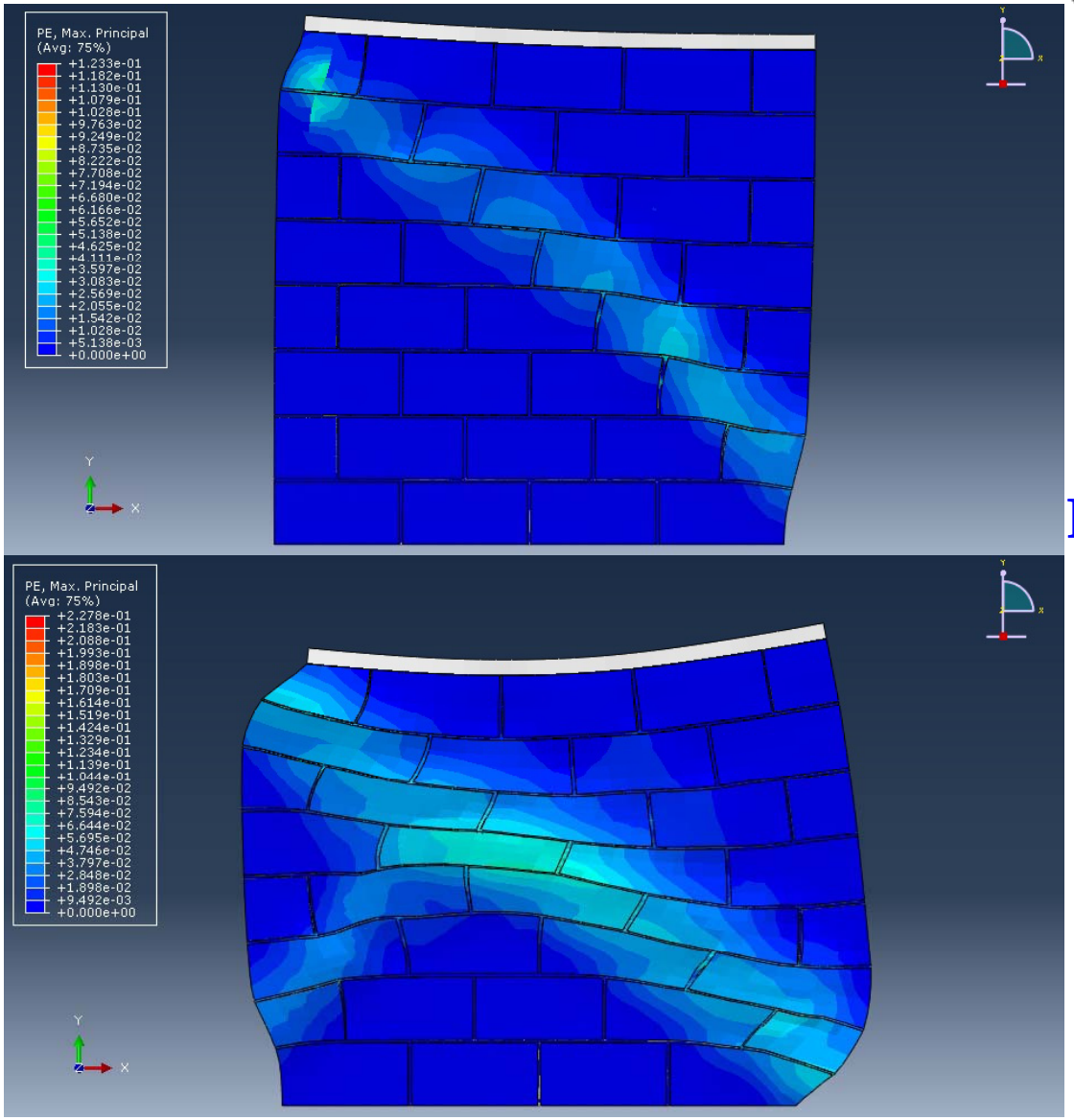


FEM Simulations

Wall studied by Nanni et al

$\sigma_n = 6.0\ Mpa$

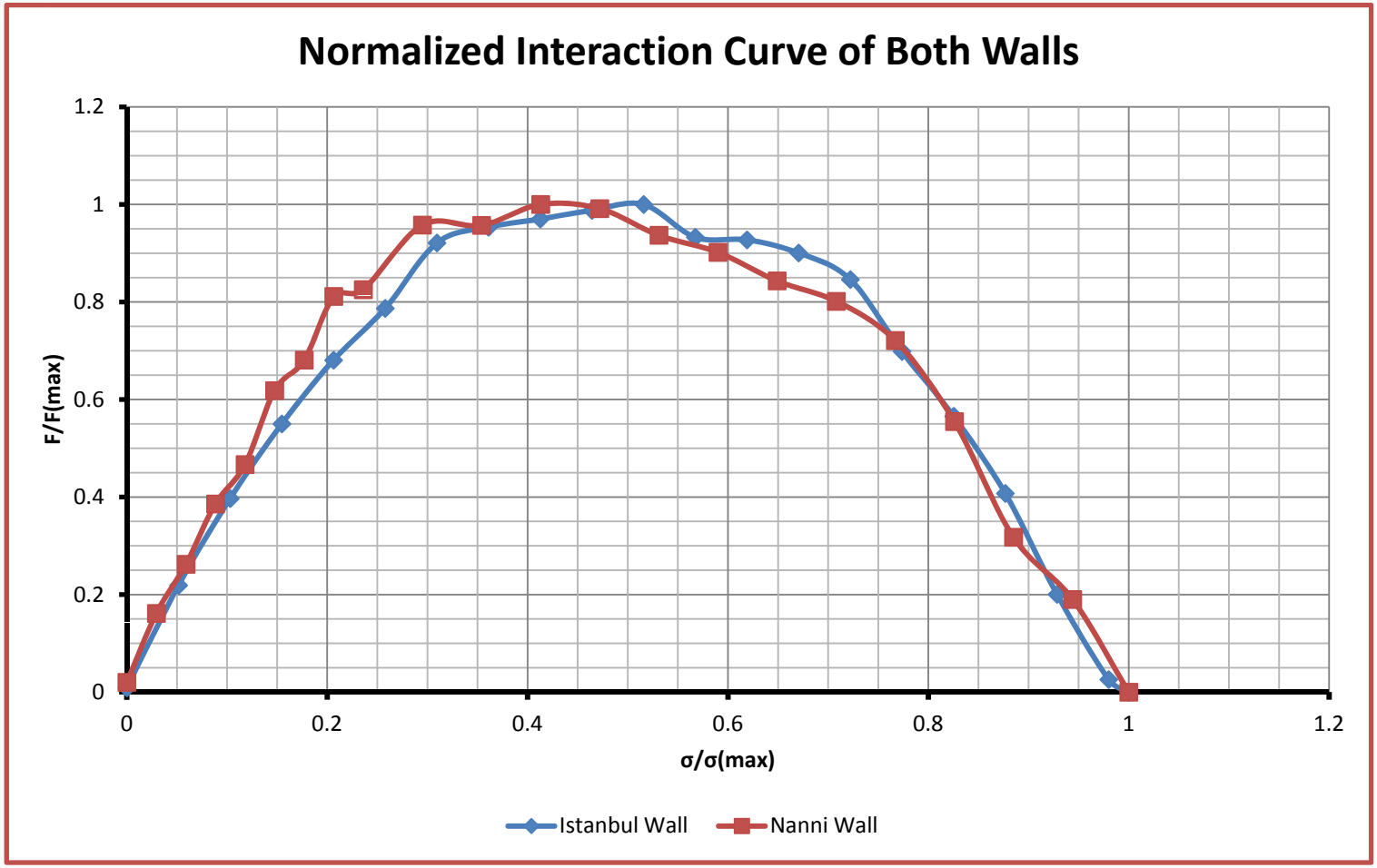
$\sigma_n = 7.0\ Mpa$



Plastic Strain

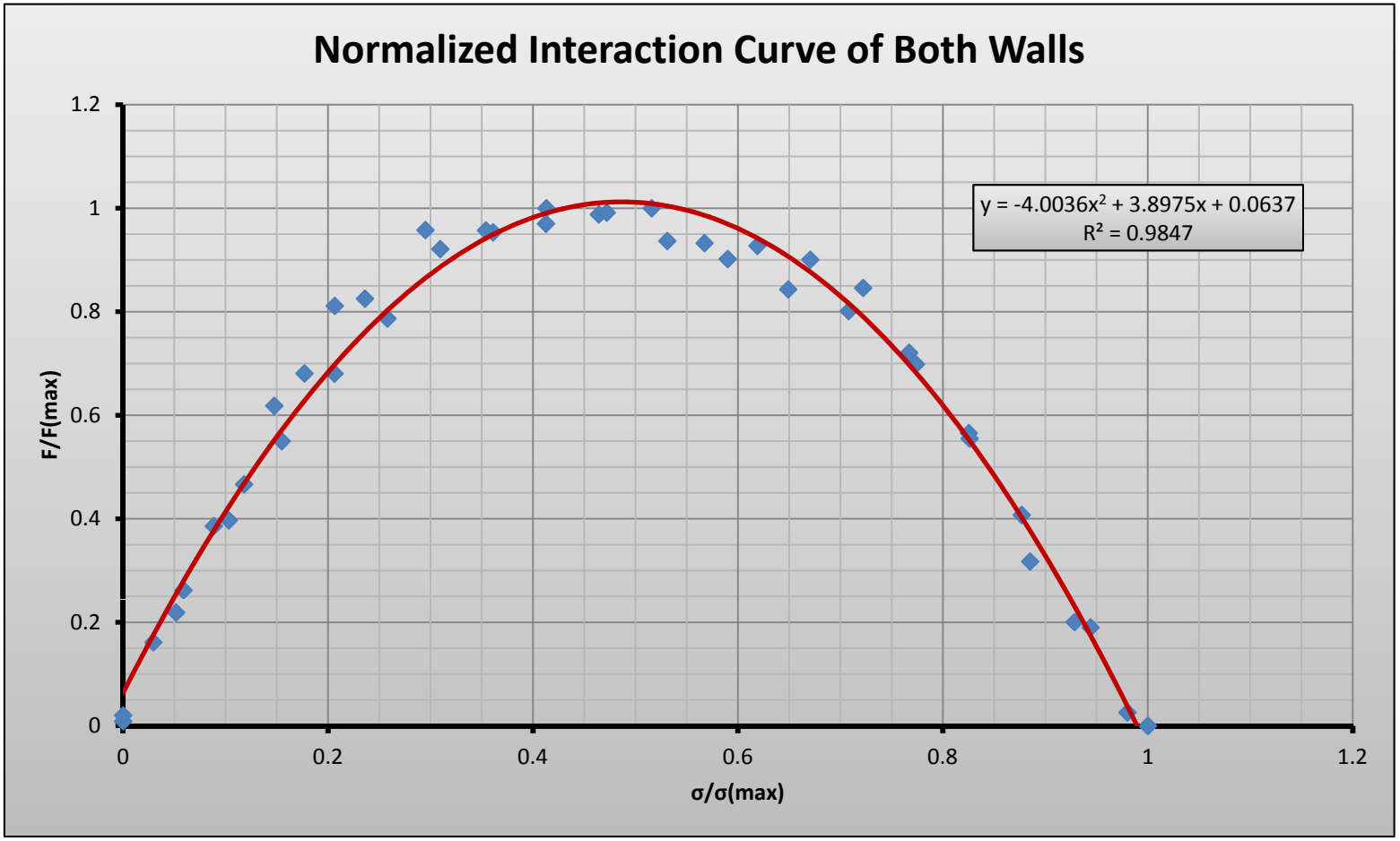
Elasto-Plastic Damage Model

Normalized Interaction Curve of both walls.



Elasto-Plastic Damage Model

Normalized Interaction Curve of both walls.



Conclusion

- Masonry structure mechanics is one of the areas where limited research has been carried out in the Gulf Region.
- There exists a strong need to initiate seismic research as seismic activities could take place at any time in the Region.
- ABAQUS shows promising features in handling analysis of complex structures and loads.

Conclusion

- The effect of axial loading on the capacity of the lateral wall is independent of the wall pattern and material used.
- Walls with aspect ratios =1.0 exhibited maximum lateral resistance when the axial loading was almost 50% of the wall axial capacity.

WORK IN PROGRESS KFUPM

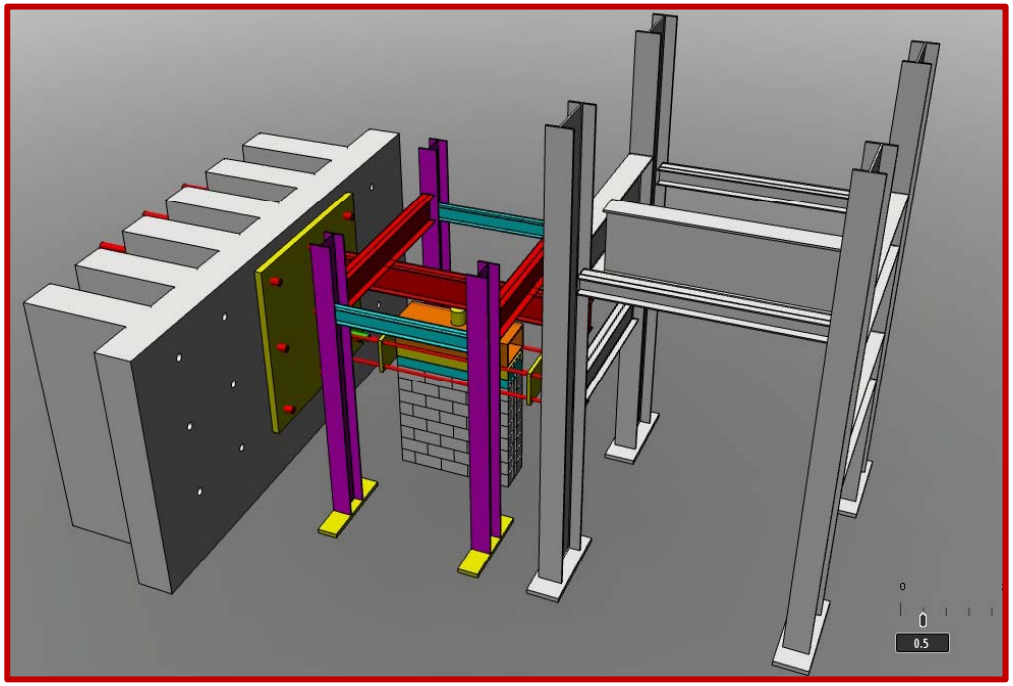
- As mentioned before, there is a cooperation between KFUPM and ITU.

- Recently, the lab facilities are being constructed in KFUPM for cyclic load testing of masonry walls.

- In Numerical Modeling work on Nonlinear FEA of CFRP Retrofitted masonry walls is in progress

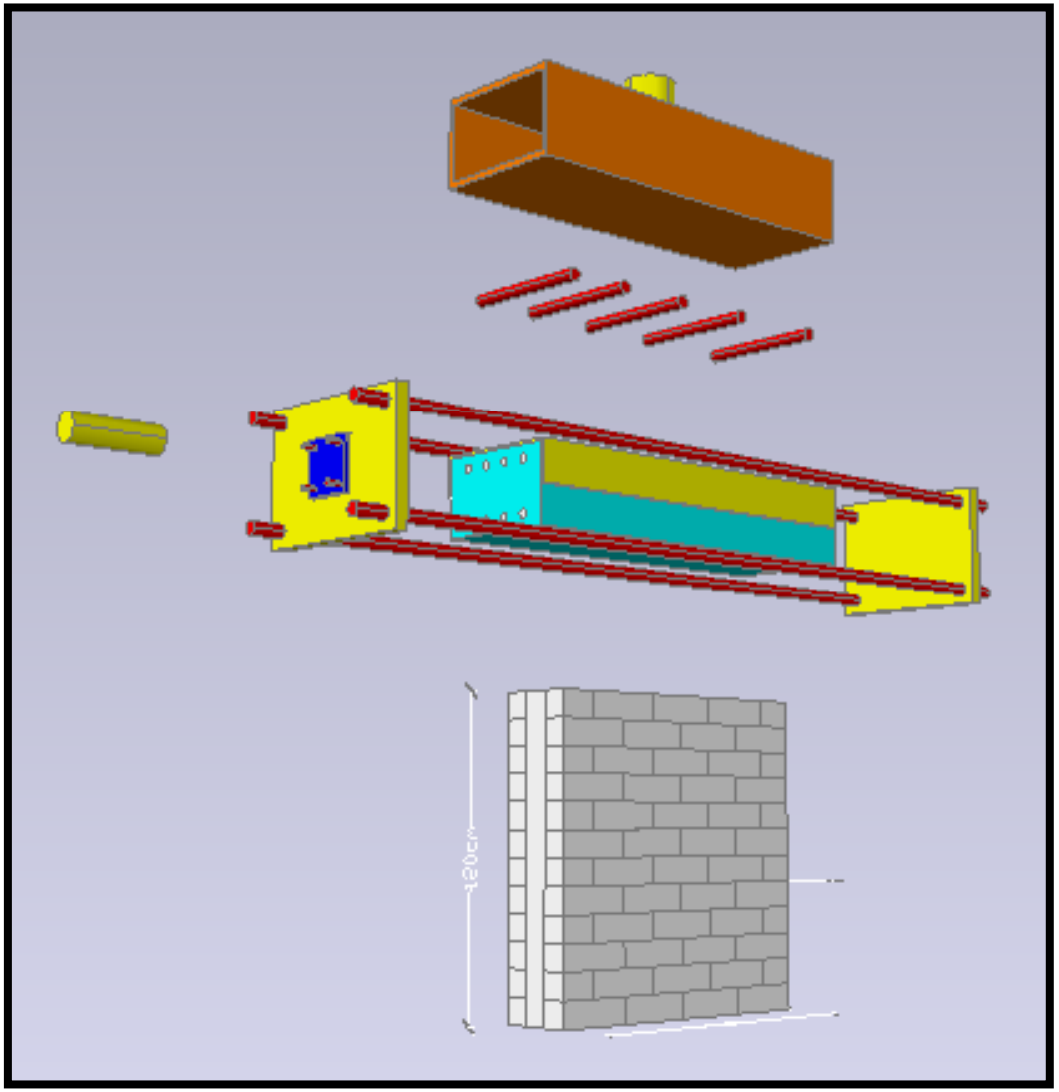
WORKS IN KFUPM

Reaction wall and loading frame.



WORKS IN KFUPM

Wall testing set up



Acknowledgments

- Experimental study was funded by ITU Research Fund.
- The study being carried out in KFPUM is funded by King Fahd University of Petroleum & Minerals under project number IN101016 “ Seismic Retrofit of Typical Wall Systems in Traditional Structures in the Kingdom” which is gratefully acknowledged.
- The authors acknowledge the mentoring provided by ITU to the KFUPM graduate students involved in this project

Thank you for your attention