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Palestine Polytechnic University

Faculty Of Graduate Studies

Master Of Civil Engineering

Nonlinear "pushover" Analysis Of Historic Stone Building In  
Palestine.

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Thesis submitted in partial fulfillment of the requirements of the degree of Master of  
Science in Civil Engineering to the Faculty of Graduate Studies at Palestine polytechnic  
University.

January, 2024

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## DECLARATION

I declare that the Master Thesis entitled **Nonlinear "pushover" Analysis Of Historic Stone Building In Palestine**.is my own original work; and hereby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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## DEDICATION

اهدي هذا البحث المتواضع:

الى التي سهرت على راحتى وتحلت بالوفاء والعطاء ..... امى الحنونة

الى من كان لى السند والعون طيلة حياتى..... أبى الغالى

الى رفيق دربى .....زوجى الغالى

الى الشمعة التى انارة حياتى .....ابنى يوسف

الى سندي وقوتى ، ومن اظهروا لى جمال هذه الحياه .....اخوتى

الى من تذوقت معهم اجمل اللحظات وعرفت منهم معنى الحياه ..... عائلتى

الى الذين مهدوا لنا طريق العلم والمعرفة ..... استاذنتنا

الى الأرواح التى سقطت تحت تراب الوطن الغالى .....الى شهدائنا الابرار

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كما أتقدم بجزيل الشكر والتقدير إلى كل من ساهم في إنجاز هذا البحث من أساتذة وزملاء وأصدقاء، وخاصة الدكتور بلال المصري مشرف برنامج ماجستير الهندسة المدنية والدكتور نافذ ناصر الدين عميد الدراسات العليا في جامعة بوليتكنك فلسطين ولكافة اساتذتي في برنامج الماجستير .

ولن أنسى أن أشكر عائلتي الكريمة، والتي كانت دائماً معي في كل خطوة من خطوات حياتي، والتي ساندتني ودعمتني وحثتني على السعي وراء العلم والمعرفة، والتي تحملت معي كل الصعوبات والتحديات التي واجهتني في إنجاز هذا البحث، والتي أسعدتني بكلماتها وأفعالها ودعواتها لي. أهدي هذا البحث إلى والدي العزيزين، إلى زوجي العزيز وإلى إخوتي وأخواتي الأحباء، وإلى كل من يحبني ويتمنى لي الخير.

وأخيراً، أسأل الله تعالى أن يتقبل هذا البحث مني وأن ينفع به من يقرأه أو يستفيد منه، وأن يجعله خالصاً لوجهه الكريم، وأن يزيدني علماً وفهماً وحكمةً، وأن يرزقني العمل الصالح الذي يرضيه عني وأن يجعلني من عباده الصالحين.

والحمد لله رب العالمين.

# **Nonlinear "pushover" Analysis Of Historic Stone Building In Palestine.**

Dana Nidal Naser Al-deen

## **ABSTRACT**

The old historical buildings in Palestine were built thousands years ago, by using large stones and the old traditional methods of construction and materials available at that time.

It is still unknown how these buildings are affected when exposed to the forces of earthquakes. In fact, the effect of these forces varies based on the different establishment of these buildings and the materials used when they were established.

Ancient existing stone structures have been severely affected when subjected to seismic load motions; this may be due to lack the periodic maintenance of these buildings and the presence of weaknesses in these buildings Resistant to earthquake loads. Restoration and retrofitting are two ways to preserve these historic buildings. Therefore, the focus of this research will be on using the Nonlinear Static Analysis Approach and investigating the seismic response of existing historic stone buildings against seismic forces. In addition, it aims at finding ways to develop and strengthen those old buildings against the forces, as well as to assess the seismic bearing strength of historical buildings in Palestine. For this purpose, a typical building structure in the old city of Hebron will be analyzed using 3muri software program, which is a specified finite element software for masonry building assessment. The results of the analysis of this building under the influence of seismic loads will be studied and appropriate recommendations will be presented to strengthen those buildings and support them to resist earthquakes in the future.

## Table of Contents:

DECLARATION .....	II
DEDICATION .....	III
ACKNOWLEDGEMENT .....	IV
ABSTRACT.....	V
CHAPTER ONE: INTRODUCTION.....	1
1. Introduction.....	2
1.1. General.....	2
1.2. Research significance.....	3
1.3. Problem Statement .....	5
1.4. Thesis Objectives .....	5
1.5. Nonlinear "pushover" analysis.....	5
1.6. Research hypotheses : .....	6
1.7. Organization of Thesis .....	7
1.7.1. Chapter 1:.....	7
1.7.2. Chapter 2:.....	7
1.7.3. Chapter 3 .....	7
1.7.4. Chapter 4.....	7
1.7.5. Chapter 5.....	7
1.7.6. Chapter 6.....	8
CHAPTER TWO: LITERATURE REVIEW .....	9
2. Literature Review.....	10
2.1. Historical stone buildings.....	10
2.1.1. Failure Behavior.....	15
2.1.2. Progressive collapse of masonry .....	16
2.1.3. Possible Failure Mechanisms:.....	17
2.1.4. Masonry components and modeling: .....	21
2.2. Analysis of Seismic Behavior:.....	22
2.2.1 Analysis methods .....	23
2.3. Seismic of Palestine .....	28
2.3.1. General.....	28

2.3.2.	Fault of Dead Sea .....	29
2.4.	Seismic hazard and seismic risk.....	30
2.5.	Recent studies .....	34
2.6.	Relevant Codes and Standards .....	43
2.6.1	Euro code .....	43
2.6.2.	American Standards .....	45
CHAPTER THREE: MODELING of CASE STUDY .....		47
3.	Modeling of case study .....	48
3.1.	Introduction.....	48
3.2.	Case study: Zaitoun masonry building (1343-1921):.....	48
3.2.1.	Short description of building.....	48
3.2.2.	Photographs of Building .....	49
3.2.3.	Structural system.....	50
3.2.4.	Layout of building:.....	52
3.2.5.	Seismic of the site .....	53
3.3.	Analysis method and techniques.....	54
3.3.1.	Software's used in the study.....	55
3.3.2.	Mechanical properties for models:.....	56
3.3.3.	Modeling of case study: .....	59
CHAPTER FOUR: ANALYSIS .....		63
4.	Analysis.....	64
4.1.	Pushover analysis.....	64
4.2.	Pushover analysis in x direction: .....	69
4.3.	Pushover analysis in y-direction: .....	82
4.4.	Compare displacement between x and y directions :.....	92
4.5.	Failures analysis.....	95
CHAPTER FIVE: THE GENERAL CONCEPT OF RETROFITTING OF MASONRY BUILDING. .		100
5.	The general concept of Retrofitting of masonry building .....	101
5.1.	Seismic retrofitting strategies.....	101
5.2.	The most important methods used for retrofitting: .....	101
5.3.	study of retrofitting using 3MURI program.....	105
CHAPTER SIX: CONCLUSION AND RECOMMENDATION .....		107
6.	Conclusion .....	108

References:.....	112
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## List of figures

Figure 1.1: Some of Historical Religious Buildings for Muslims in Palestine .....	2
Figure 1.2: Some of Historical Religious Buildings for Christian in Palestine. ....	3
Figure 1.3: some of old towns in Palestinian cities.....	3
Figure 1.4: damage of the old buildings in Nablus. ....	4
Figure 2.1: Collapsed masonry mosques with their dome. ....	11
Figure 2.2: collapsed building corner at Edremit.....	11
Figure 2.3: collapse masonry building .....	12
Figure 2.4: Failure of low-strength stone on a masonry building .....	12
Figure 2.5: Outside view of shear cracking on structural walls in Turkey .....	13
Figure 2.6: Inside view of shear cracking on structural walls in Turkey .....	14
Figure 2.7: Cracks at corners of windows and doors in Turkey .....	14
Figure 2.8: Yield Criterion and a Typical Stress-strain Model for Brick Unit. ....	15
Figure 2.9: In-plane failure mechanisms.....	18
Figure 2.10: Out-of-plane failure mechanisms.. .....	19
Figure 2.11: Out-of-plane failure mechanisms.. .....	19
Figure 2.12: Force-Displacement Curve Corresponding to Out of Plane Failure.....	20
Figure 2.13: Modeling strategies for masonry structures: (a) masonry sample; (b) detailed micro-modeling; (c) simplified micro-modeling; (d) macro-modeling. ....	21
Figure 2.14: Pushover Analysis Procedure. ....	24
Figure 2.15: Capacity curve. [20] Facconi., Plizzari. And Vecchio. ....	25
Figure 2.16: Seismic Hazard Map for Palestine. ....	29
Figure 2.17: Seismic Hazard Map for Palestine. ....	33
Figure 2.18: general view of St. James church. ....	36
Figure 2.19: failure mechanisms in St. James church.....	36
Figure 2.20: Render of Camponeschi Palace- L'Aquila, italy.....	37
Figure 2.21: the Cathedral of Colima (a) before EQ in 1941 and (b) after EQ effects in 1941 .....	38
Figure 2.22: Outside and inside of the Elti Hatun Mosque .....	39
Figure 2.23: FEM model of masonry walls. ....	40
Figure 2.24: masonry wall of senate hall building.....	40
Figure 2.25: General view of Sant' Agostino's Sanctuary. ....	41
Figure 2.26: plane of the masonry palace. ....	42
Figure 3.1: Picture for zaitoun building. ....	49
Figure 3.2: elevations for zaitoon building. ....	50
Figure 3.3: structural system for zaitoun building. ....	51
Figure 3.4: Ground floor plans for zaitoun building. ....	52
Figure 3.5: seismic hazard zone map of the west bank.....	53
Figure 3.6: equivalent frame method use in 3Muri program. ....	55
Figure 3.7 Properties for perimeter walls of zaitoun building. ....	57

Figure 3.8 Properties for vaults of zaitoun building. ....	58
Figure 3.9: a 3D view of the model use in 3Muri program.....	60
Figure 3.10: Elevation of wall in zaitoun building model use in 3Muri program.....	61
Figure 3.11: Example of equivalent frame idealization in a case of irregularly distributed openings.....	61
Figure 3.12: a 3D view of the model use in 3Muri program equivalent frame method.....	62
Figure 4.1: 3D building model.....	65
Figure 4.2: plane deformation shape in x-direction. ....	69
Figure 4.3: Results legend in 3Muri program. ....	70
Figure 4.4: distorted in wall 13 in +x-direction. ....	71
Figure 4.5: pushover analysis in wall 13 in x-direction. ....	71
Figure 4.6: general plane foe walls in zaitoun building. ....	72
Figure 4.7: distorted in wall 1 in x-direction. ....	72
Figure 4.8: pushover analysis in wall 1 in x-direction. ....	73
Figure 4.9: distorted in wall 3 in x-direction. ....	73
Figure 4.10: pushover analysis in wall 3 in x-direction. ....	73
Figure 4.11: distorted in wall 4 in x-direction. ....	74
Figure 4.12: pushover analysis in wall 4 in x-direction. ....	74
Figure 4.13: distorted in wall 5 in x-direction. ....	74
Figure 4.14: pushover analysis in wall 5 in x-direction. ....	75
Figure 4.15: distorted in wall 6 in x-direction. ....	75
Figure 4.16: pushover analysis in wall 6 in x-direction. ....	75
Figure 4.17: distorted in wall 8 in x-direction. ....	76
Figure 4.18: pushover analysis in wall 8 in x-direction. ....	76
Figure 4.19: distorted in wall 9 in x-direction. ....	76
Figure 4.20: pushover analysis in wall 9 in x-direction. ....	77
Figure 4.21: distorted in wall 10 in x-direction. ....	77
Figure 4.22: pushover analysis in wall 10 in x-direction. ....	77
Figure 4.23: plane deformation shape in y-direction. ....	82
Figure 4.24: distorted in wall 9 in y-direction. ....	83
Figure 4.25: pushover analysis in wall 3 in y-direction. ....	83
Figure 4.26: distorted in wall 1 in y-direction. ....	84
Figure 4.27: pushover analysis in wall 1 in y-direction. ....	84
Figure 4.28: distorted in wall 3 in y-direction. ....	84
Figure 4.29: pushover analysis in wall 3 in y-direction. ....	85
Figure 4.30: distorted in wall 4 in y-direction. ....	85
Figure 4.31: pushover analysis in wall 4 in y-direction. ....	85
Figure 4.32: distorted in wall 5 in y-direction. ....	86
Figure 4.33: pushover analysis in wall 5 in y-direction. ....	86
Figure 4.34: distorted in wall 6 in y-direction. ....	86
Figure 4.35: pushover analysis in wall 6 in y-direction. ....	87
Figure 4.36: distorted in wall 8 in y-direction. ....	87
Figure 4.37: pushover analysis in wall 8 in y-direction. ....	87
Figure 4.38: distorted in wall 10 in y-direction. ....	88
Figure 4.39: pushover analysis in wall 10 in y-direction. ....	88

Figure 4.40: distorted in wall 13in y-direction. ....	88
Figure 4.41: pushover analysis in wall 13in y-direction. ....	89
Figure 4.42: Compare between x and y directions.....	94
Figure 4.43: Stages of shear failure in wall no 6 in y-direction. ....	96
Figure 4.44: Stages of bending failure in wall no 6 in x-direction. ....	98
Figure 5.1: Retrofitting strategies for URM structures. [44] .....	101
Figure 5.2: Different configurations of CFRP for retrofitting masonry walls. ....	103
Figure 5.3 different strategies of using FRP retrofitting of masonry .....	104
Figure 5.4: Comparison between numerical damages deriving from pushover analyses and real ones. ...	105
Figure 5.5: Retrofitting intervention (a) with bidirectional strips and (b) comparison among building capacity curves with different reinforcing interventions. ....	106

## List of tables

Table 3.1: Ground types (Euro code 8).....	54
Table 3.2: mechanical properties of masonry typologies.....	57
Table 3.3: the importance classes for building in Euro code. ....	58
Table 3.4: seismic parameters of the selected site. ....	59
Table 3.5: spectral parameters of the selected site.....	59
Table 4.1: all possible cases of seismic analysis for zaitoun building. ....	66
Table 4.2: Result details for seismic analysis for zaitoun building.....	69
Table 4.3: percentage of broken elements presented in case 9 in x-direction.....	78
Table 4.4: relative inter-floor displacement. ....	79
Table 4.5: displacement control. ....	81
Table 4.6: percentage of broken elements presented in case 24 in y-direction.....	89
Table 4.7: relative inter-floor displacement.....	90
Table 4.8: displacement control. ....	92

# CHAPTER ONE: INTRODUCTION

# 1. Introduction

## 1.1.General

We can classify buildings as historical or masonry buildings, depending on two reasons: how long it has been built, and the status of this historical building- whether it was considered as a religious or archaeological building- is of great importance to the history of the city in which they are located. It is well known that these buildings were built in the old traditional ways and with the use of materials that were available at the time of their construction. However, these buildings have a weak response to dynamic force such as earthquakes. The old and recent earthquakes have a strong impact on these buildings- causing damage and loss of heritage, For this reason the old buildings need more repairs, paying attention , as well as evaluating the safety of old buildings in seismic areas. In Palestine, there are many historical buildings, which are considered very special religious monuments for Muslims, such as Al-Aqsa Mosque with the Dome of the Rock in Jerusalem, as shown in the figure a1.1. Also, the cave of the Patriarchs in Hebron, as shown in Figure b 1.1



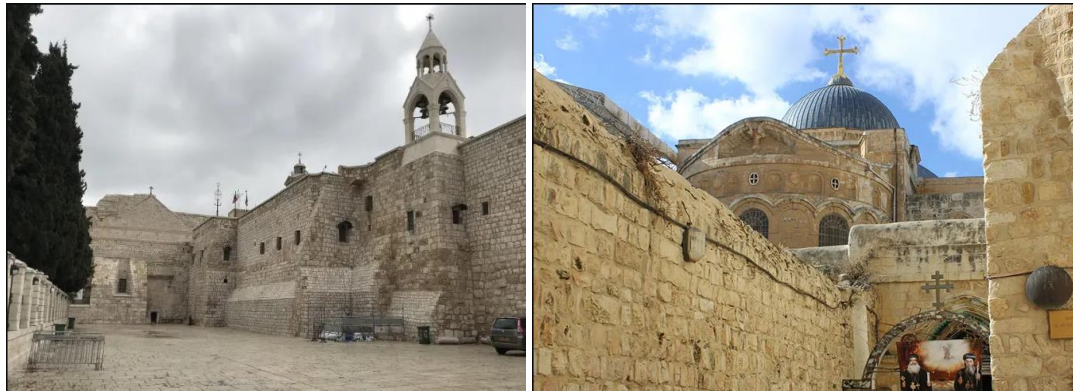
a. Al-Aqsa Mosque with the Dome of the Rock in Jerusalem



b. the cave of the Patriarchs in Hebron

Figure 1.1: Some of Historical Religious Buildings for Muslims in Palestine

There are also Christian landmarks such as the Church of the Nativity in Bethlehem and the Church of the Holy Sepulcher in Jerusalem, as shown in Figure 1.2



a. Church of the Nativity

b. Church of the Holy Sepulcher

Figure 1.2: Some of Historical Religious Buildings for Christian in Palestine.

In addition, there are old towns in most Palestinian cities, for example the old town in Nablus and Hebron, as in Figure 1.3



a. Old town in Nablus.

b. old town in Hebron.

Figure 1.3: some of old towns in Palestinian cities.

## 1.2. Research significance

Throughout history, Palestine has been subjected to several seismic tremors, the most important of which was in 1837, which destroyed the city of Safed, in northern Palestine, killing more than 5,000 people. In 1927, Palestine subjected to an earthquake that caused severe damage to the old buildings and destroyed parts of them in Hebron and Nablus as

shown in fig (1.4). Al-Aqsa Mosque was also, exposed to this earthquake. Recently, in the year 2023, an earthquake strikes Palestine. Its magnitude was 4 degrees on the Richter scale, its epicenter was the north of Nablus. Besides, there were many other earthquakes that differ in their strength and effects.

Specialists indicate that there are several seismic foci in the country. Until now, there has been no seismic code for designing buildings in Palestine, although engineers design their buildings based on international building codes, which they are not subordinate under certain regulation of Palestine. [37]



Figure 1.4: damage of the old buildings in Nablus.

The need for these theses established to preserve the architecture and historical architecture in the ancient historical buildings in Palestine. As most of these buildings were constructed using large stone blocks joined by mortar, as these links cannot be considered as strong ties to resist dynamic loads and prevent losses in these historical buildings.

In this case, it is required to develop the historical buildings to prevent damage to building elements and components, to preserve the safety of life, and to preserve the cultural and historical significance of buildings. This can be done through the study of non-linear seismic analysis and rehabilitation of historical stone buildings.

### 1.3. Problem Statement

Most of the restoration operations in Palestine depend on addressing the weakness in the structural elements and preserving their architectural form in order to preserve the historical and architectural value of the building without considering the seismic loads. Therefore, the most important part of this thesis is to focus on analyzing the behavior of ancient structures in Palestine and describing their seismic behavior through the non-linear analysis of the historical stone buildings in Palestine.

### 1.4. Thesis Objectives

The main objective of this thesis is to evaluate the earthquake performance of an existing historical stone building (unreinforced building) subject to seismic load.

The Zaytoun family building located in the old city of Hebron – Palestine will be studied as a study case for this thesis. In addition to the main objective of this thesis, this thesis aims to study and predict the properties of the old materials used in construction and to know the expected damages on them. Moreover, this work aims to analyze the building against dynamic loads to evaluate the seismic performance and thus conduct a non-linear analysis of the elements in the building and its rehabilitation.

### 1.5. Nonlinear "pushover" analysis

Nonlinear analysis (pushover analysis) are technique used in structural engineering to assess the response of structures under loading conditions that go beyond the linear elastic range. These methods are particularly important for evaluating the behavior of structures under severe loading, such as earthquakes.

Nonlinear analysis is used for masonry buildings because masonry exhibits complex and nonlinear behavior when subjected to loads. Some reasons for using nonlinear analysis for masonry buildings include, Material nonlinearity: Masonry materials such as bricks and mortar exhibit nonlinear behavior under stress, including inelastic deformation, cracking, and crushing. Nonlinear analysis allows for the consideration of these material nonlinearity effects. Geometric nonlinearity: Masonry structures often experience large

deformations and displacements, leading to geometric nonlinearity. Nonlinear analysis accounts for these effects, which can be significant in masonry buildings subjected to seismic or extreme loading. Boundary conditions: Nonlinear analysis allows for the consideration of complex boundary conditions, such as support conditions and interactions with other structural elements, which may exhibit nonlinear behavior. Failure mechanisms: Masonry buildings can fail in various complex and nonlinear modes, such as out-of-plane bending, shear, and combined actions. Nonlinear analysis enables the study of these failure mechanisms and the assessment of structural capacity under different loading scenarios. By considering these nonlinear effects, nonlinear analysis provides a more realistic representation of masonry building behavior, leading to improved design, assessment, and retrofitting of such structures.

This study uses 3Muri finite element software for masonry building assessment to analysis Zaytoun masonry building and to provide the possibility of performing static analysis, and pushover analysis of masonry structures. **3Muri** also offers the possibility of local calculations through local verification of the stability of walls outside the plane. The results will be analyzed to identify locations of failure in the historic building and propose a way to support this failure. This study does not support the retrofitting of old buildings, because the study of consolidation requires other specialized programs.

#### 1.6. Research hypotheses :

This study is concerned with Palestine in general and Hebron city in particular. Zaytoun family building located in the old city of Hebron – Palestine will be studied as a study case for this thesis. An Non-liner (pushover) analysis was made based on the Euro code, The soil profile at the site consist mainly of rook layers, this site has been ground type A . The seismic action corresponds to the design response spectrum, according to the euro seismic code, defined through the spectral parameter  $a$  (GR) (max acceleration value), reported in the euro Code based on the site geographic coordinates of the building site. Taking into account the soil and the topographic category of the site, the soil factor = 1 , the lower limit of the period of the constant spectral acceleration branch (TB) =0.05 , corner period at the upper limit of the constant acceleration region on elastic spectrum

(TC) equal to 0.25 , and the value defining the beginning of the constant displacement response region (TD) equal to 1.2.

## 1.7.Organization of Thesis

This thesis is organized into six chapters, including the present introduction. In addition, the appendices and references are stated in the last. The following subsections summarize each chapter with its content:

### 1.7.1. Chapter 1:

It is an introduction to the research, define the research need, objectives, problem statement, and scope of the work.

### 1.7.2. Chapter 2:

Address the historical development of seismic analysis of masonry structures, discussing the present limitations and inherent uncertainties of the various approaches, with mention of similar researches done over the world.

### 1.7.3. Chapter 3

It is about the used case study, with how the finite element continuum macro-models are prepared to study the response of the structure. This chapter also, discusses the model analyses use of 3Muri software program.

### 1.7.4. Chapter 4

It focuses on the non-linear static analysis for the structure, and shows the results of pushover analysis.

### 1.7.5. Chapter 5

It focuses on the general concept of Retrofitting of masonry building

### 1.7.6. Chapter 6

This final chapter, discusses the results of approaches used, and includes the conclusions, and future research topics to extend the current work

## CHAPTER TWO: LITERATURE REVIEW

## 2. Literature Review

### 2.1. Historical stone buildings

Maintenance of historic buildings has become a relevant scientific issue that has attracted the interest of researchers all over the world as demonstrated by the growing number of researches presented in recent decades.

Historical building is a heterogeneous composite in which stone units held together by mortar. The mortar could be lime or a mixture of cement, lime, sand and water in various proportions. The characteristics of the historical building differ from one building to another according to the type of stone and mortar used. The dimension of stones, how regular building is (bed and vertical joint layout) and the mortar types and width, have factors influencing the behavior of historical building. This building has common constructions all over the world because of low-cost and availability of material as well as convenient and simple construction technology. In particular, historical stone building has limited tensile strength and usually negligible, and the state of stresses in the stone in a historical building prism is compression-tension-tension. In addition, it is characterized by: a) low ductility. b) Low shear and tensile strength. c) Low capacity of bearing reverse loading. d) High rigidity. For these reasons, repeated breakdowns occur in old buildings during earthquakes (Mosalam, Glascoe, & Bernier, 2009)(1). (Taghikhany, Tehranizadeh, & Arabameri, 2008). [2]

Historical building can be classified into three main categories depending on the construction method used. The first one is the confined masonry, which consists of horizontal and vertical RC members. The second, reinforced masonry where steel bars are usually used for the reinforcement. The third, is unreinforced masonry, which refers to stand alone masonry units.

The behavior of historical stone building during earthquakes is poorly understood. Researchers all over the world are conducting analytical studies and many experiments to understand the performance of these buildings. Field investigators observed that the

causes of damage in the historical buildings were concentrated (Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]

1. Poor construction detailing:

This filer causes a heavily damage or collaps for the building as shown in fig (2.1), or collapsed building corner as fig (2.2) because of the lack of connection between floors and walls.



Figure 2.1: Collapsed masonry mosques with their dome.

(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]



Figure 2.2: collapsed building corner at Edremit.

(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]

## 2. Poor historical building material properties:

Many of the old buildings were built using weak materials, or with materials which were severely damaged. That leads to the weakening of these materials. For this reason, many old buildings are completely destroyed when forces are exposed to them (Fig.2.3) One of the main causes of damage is the stones used in walls that have low strength (Fig2.4.). All buildings did not achieve the minimum compressive strength required according to local codes. [3]



Figure 2.3: collapse masonry building.  
(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]



Figure 2.4: Failure of low-strength stone on a masonry building (Images by Alemdar Bayraktar)  
(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]

### 3. Weak structural walls:

The presence of cavities in the structural walls inside the building works to reduce the bearing capacity of these walls against earthquake loads, as through previous studies, if the cavities were less than 10-15%, these walls work like shear walls to resist lateral loads.

Load-bearing masonry walls act as shear walls to resist in-plane lateral loads due to lateral load. Shear cracking in structural walls observed in most of the historical buildings, as shown in (Figs. 2.5 and 2.6). The reasons for shear cracking in structural walls include poor construction detailing, poor material properties, structural weakness, and space for doors and windows. Shear cracking considerably reduces the wall's stiffness. In some cases, the stiffness reduction changes the distribution of shears and moments in complete structures. [3]



Figure 2.5: Outside view of shear cracking on structural walls in Turkey

(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]



Figure 2.6: Inside view of shear cracking on structural walls in Turkey  
 (Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]

4. Cracks at the corners of walls and windows :

Cracks at the corners of windows and doors are observed in most earthquake-damaged masonry buildings (Fig. 2.7)



Figure 2.7: Cracks at corners of windows and doors in Turkey

(Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016.) [3]

### 2.1.1. Failure Behavior

The materials used in old buildings are characterized by the fact that after the material reaches the maximum load it can withstand; the strength gradually decreases to zero. This feature can be described as semi-brittle behavior [6], It can also be defined by the softening procedure, which is defined as the gradual decrease of the resistance of the element under the constant increase of forces, so that these forces cause deformation of the structure of materials and this is a prominent feature of semi-brittle materials such as concrete, clay bricks and rocks, which fail due to the process of gradual growth of internal cracking. The softening phenomenon has been well identified in parallel in cases of tensile and shear failures in construction. Otherwise, in compression, the softening behavior depends on the boundary conditions in experiments and sample sizes, figure (2.8), and introduces the stress-strain relationship of non-reinforced brick masonry and the yield criterion [7].

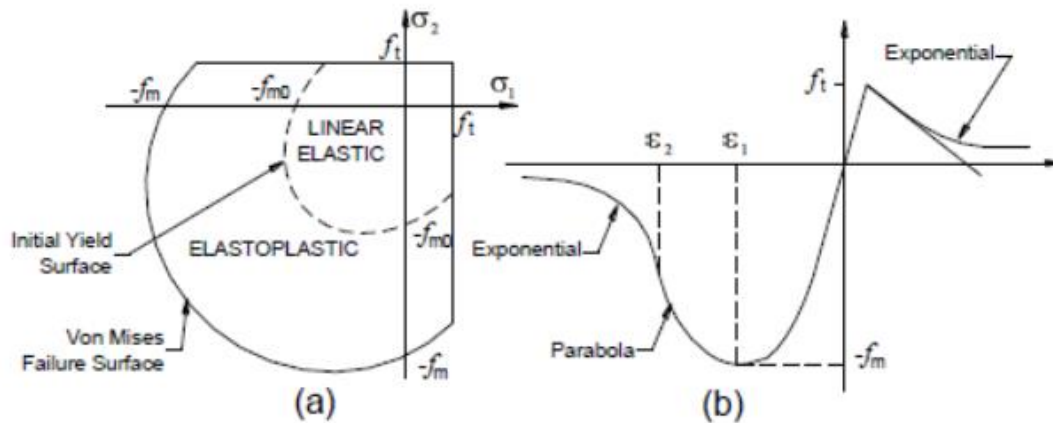


Figure 2.8: Yield Criterion and a Typical Stress-strain Model for Brick Unit [7].

Mechanic behaviors of historical stone building materials depend on many factors:

- 1) Shear strength or compressive of mortars and stones
- 2) stones shape
- 3) volumetric ratio between components and wall texture.

Because of these complex elements and the large number of variables, it is difficult to identify the most expected load of the building except through on-site testing. Semi-destructive methods, which are not always applicable, are being tested on site, and digital estimation of mechanical information is being adopted. Having better technical information regarding the mechanical properties of historical construction will help preserve our construction heritage [11].

### 2.1.2. Progressive collapse of masonry

Progressive collapse in masonry structures refers to the spread of structural failure from one element to another, eventually leading to the collapse of a significant portion or the entire structure. This phenomenon can occur in buildings made of masonry materials, such as brick or stone, and it is typically characterized by the progressive failure of load-bearing elements. Several factors can contribute to the progressive collapse of masonry structures: [31]. (Eren, Brunesi, and Nascimbene, 2019)

1. **Initial Damage:** A localized failure or damage to one part of the structure, often caused by events like earthquakes, explosions, or overloading, can initiate a chain reaction of failures.
2. **Poor Construction Practices:** If the masonry structure was poorly constructed or lacked proper reinforcement, it may be more susceptible to progressive collapse. Inadequate connections between structural elements can also contribute to the spread of failure.
3. **Foundation Issues:** Problems with the foundation, such as settlement or uneven loading may result in the redistribution of loads and lead to the progressive collapse of masonry elements.
4. **Unexpected Loading Conditions:** Changes in loading conditions, such as additional loads from renovations or the removal of supporting elements, can trigger a chain reaction of failures in a masonry structure.
5. **Seismic Events:** Earthquakes can induce ground shaking that places dynamic forces on masonry structures. In the aftermath of an earthquake, structural elements may be weakened, making them more susceptible to progressive collapse.
6. **Material Deterioration:** Over time, masonry materials may deteriorate due to weathering, chemical reactions, or other environmental factors. This degradation can weaken the structural integrity and contribute to progressive collapse.

Preventing progressive collapse in masonry structures involves careful design, construction, and maintenance practices, Redundancy in Structural Systems Designing structures with redundant load paths can prevent the spread of failure. If one element

fails, others should be able to carry the load. Proper Construction Practices Ensuring that masonry structures are built to code, with appropriate materials and construction techniques, can enhance their resilience. Regular Inspections and Maintenance, Periodic inspections can identify signs of deterioration or damage, allow for timely repairs and maintenance to prevent progressive collapse. Seismic Design Considerations, in earthquake-prone regions, incorporating seismic design principles can help masonry structures withstand ground shaking and reduce the risk of progressive collapse [31]. (Eren, Brunesi, and Nascimbene, 2019)

Understanding the potential triggers and vulnerabilities of masonry structures is crucial for designing and maintaining buildings that can resist progressive collapse and ensure the safety of occupants.

### 2.1.3. Possible Failure Mechanisms:

The structure of old buildings should be examined, with taking into account the horizontal and vertical forces and their impact on all types of old buildings- whether they are reinforced buildings or un-reinforced buildings- because failures can occur in plane or out-off plane. The observed failure of unarmed building structures from previous earthquakes reveals that the two types of failure are independent, so they should be examined in parallel (8). The general patterns of failures related to non-reinforced masonry building structures include:

1. In-plane failure.
2. Out-off plane failure.
3. Lack of anchorage or anchors failure.
4. Diaphragm related failures.

Many researchers have also found that when old buildings, especially the walls of old buildings, are exposed to earthquake loads, the walls behave as shear walls, and that the apparent failure of seismic damage to the walls of old buildings when exposed in plane loading may have the following failure mechanisms: flexural-dominated, shear-dominated or hybrid shear-flexural [9].

1) Flexure failure mechanisms:

It can be associated with the two mechanisms failure as follows: 1) Rocking, when the compressive strength is high of applied compressive load, the tensile flexure cracking at the corner cussed by horizontal load. 2) Toe crushing: it is characterized by a progressive and widespread damage, with sub-vertical cracks directed towards the compressed angle [9].

2) Shear failure:

It can be associated with the two mechanisms failure as follows: 1) sliding: Failure occurs due to horizontal sliding of the links in the building elements .2)diagonal cracking : The cracks which developed through the unit mortar interface and the units itself as a case of biaxial tension compression state. Unfortunately, there are low aspect ratios and lower axial load characterize this failure [9].

Ponte, M., Milosevic, J. and Bento, R., 2019 [9]., can show the types of failure but separated in four main forms, figure (2.9), summarized as flexural failure (rocking and toe crushing), shear failure (sliding and diagonal cracking). These are also defined as global response mechanisms.

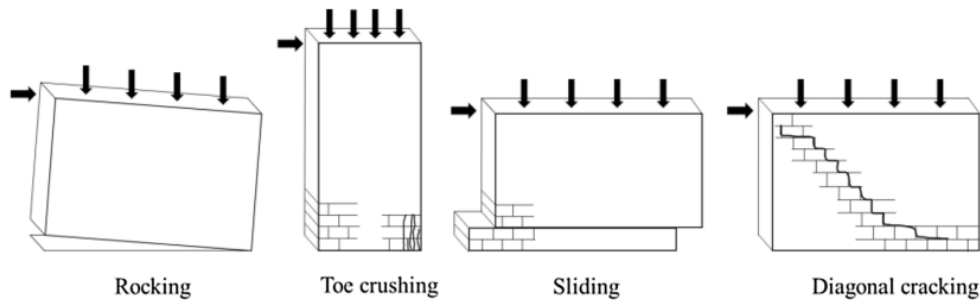


Figure 2.9: In-plane failure mechanisms [9].

On the other hand, the out of plane failure in masonry structures- especially unreinforced masonry- is one of the principal threats for historic building under seismic action. To know the influence of historic building on out of plane seismic behavior we must answer these two question 1) how are stone masonry walls built? 2) how dose masonry arrangement influence out of plane capacity?, after answering these questions, it is approximate to know the out of plane failure, which depends on the method of

construction and the materials used in it, as well as the type and thickness of the bonding materials used for construction [13]( De Felice, G., 2011).

Some types of failures are associated to the spandrels of walls, which are not well restrained by structural elements, that might generate rocking falling when earthquake loads are present, (Calvi, Pinho, Magenes, Bommer, Restrepo-Vélez, and Crowley,2006) [5].

Possible out of plane collapse mechanisms are present in figures (2.10) and (2.11) which is A) vertical overturning. B1) Overturning with 1-side wing. B2) overturning with 2-side wings. C) Corner failure. D) Partial overturning. E) Vertical strip overturning. F) Vertical arch. G) Horizontal arch. H) Relevant to double-leaf walls. (Restrepo, and Magenes, 2004) [10].,(Borri, Corradi, Castori, and Maria, 2015) [12]. (D'ayala,and Speranza, 2002) [14].

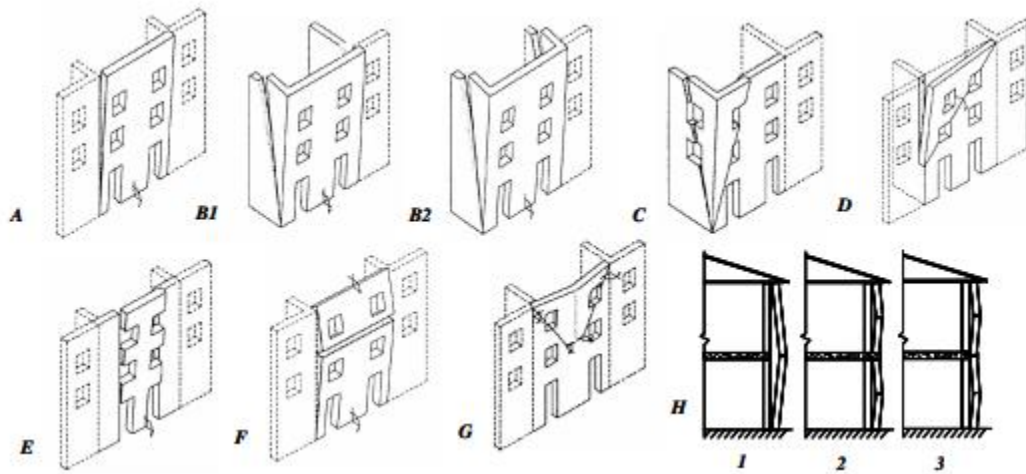


Figure 2.10: Out-of-plane failure mechanisms. (Restrepo, and Magenes, 2004) [10].

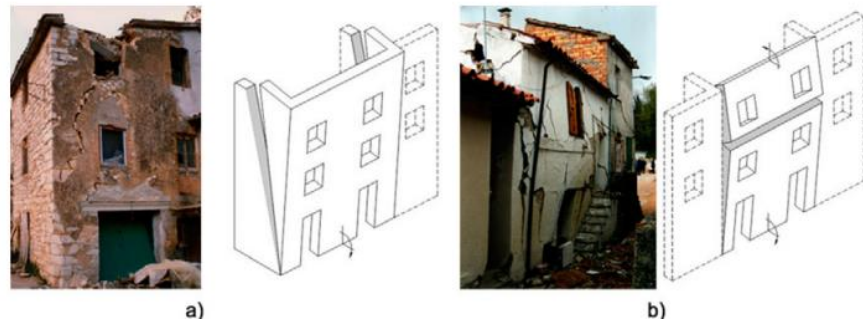


Figure 2.11: Out-of-plane failure mechanisms.(Borri, Corradi, Castori, and Maria, 2015) [12].

Fig (2.12) can show the main line connecting the point of force corresponding to rocking mechanism ( $\lambda W$ ) and the point of displacement where instability happened under static ( $\Delta$ ), load A force-displacement curve corresponding to out-of-plane failure typically represents the behavior of a structure or material when it fails in a direction perpendicular to its intended or designed plane of operation.

The force-displacement curve for out-of-plane failure generally exhibits several characteristic features

- 1) Elastic Deformation: Initially, the structure or material behaves elastically, meaning it deforms reversibly under increasing load without permanent damage. The force increases linearly with displacement during this phase.
- 2) Yielding or Buckling: As the load continues to increase, the structure may reach a point where it starts to yield or buckle out of the plane. This is a critical point in the curve, often referred to as the yield point or buckling point.
- 3) Plastic Deformation: Beyond the yield or buckling point, the curve typically shows a region of plastic deformation. In this phase, the structure deforms plastically, meaning it undergoes permanent and irreversible deformation as the load increases further. The force may increase at a decreasing rate during this phase.
- 4) Ultimate Failure: Eventually, the structure or material may reach a point where it experiences a catastrophic failure, which can be characterized by a sudden drop in the force-displacement curve. This represents the point at which the structure can no longer support the applied load, and it collapses or ruptures out of its intended plane.

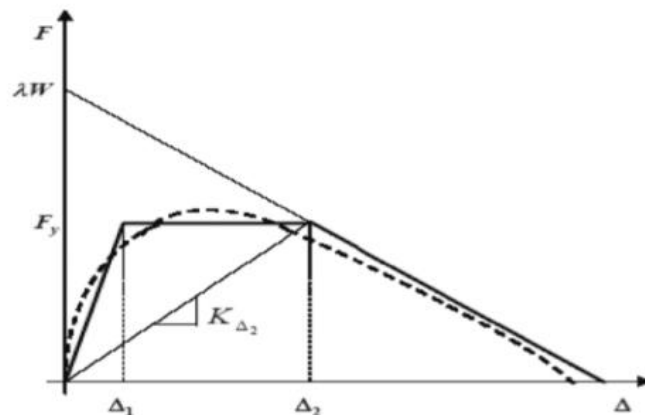


Figure 2.12: Force-Displacement Curve Corresponding to Out of Plane Failure (Restrepo, and Magenes, 2004) [10].

#### 2.1.4. Masonry components and modeling:

Historical building is a composite material that consists of units and mortar. The interface between units and mortar acts as a plane of weakness and is largely responsible for the inelastic behavior, the numerical representation of masonry structures can vary based on the level of accuracy needed. Figure (2.13) shows types of modeling strategies for historical building. (Laurenco, Rots, & Blaauwendraad, 1995) [4]:

- a) Detailed Micro Modeling: is continuum elements represent units and mortar in the joints that must include a representation of units, mortar and the unit/mortar interface, as figure (2.13a&b) show.
- b) Simplified Micro Modeling: expanded units that are represented by continuum elements, while their interface is lumped in discontinuous elements, as figure (2.13c) shows.
- c) Macro Modeling units: where a distinction between individual units and joints is not made , as figure (2.13d) shows :

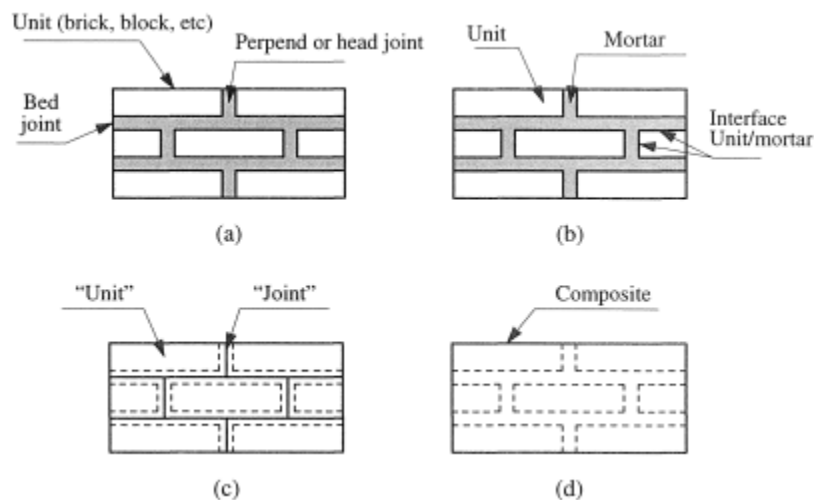


Figure 2.13: Modeling strategies for masonry structures: (a) masonry sample; (b) detailed micro-modeling; (c) simplified micro-modeling; (d) macro-modeling. [4].

The mechanical properties of masonry depend on many parameters such as the material properties of units and mortar, the arrangement of bed and head joints, anisotropy of units, dimensions of units, joint width, quality of workmanship, degree of curing, age of construction and environment.

In the context of masonry building analysis, micro modeling and macro modeling refer to approaches that focus on different levels of detail and abstraction in understanding the behavior of structures. Micro Modeling in Masonry Buildings involves a detailed examination of individual components such as bricks, mortar, stones, and reinforcement elements. It considers the specific behavior and interactions at the level of individual masonry units. It may represent the behavior of individual bricks, joints, and connections. It also considers the mechanical properties and characteristics of each component separately. Typically it may be more complex due to the detailed representation of individual masonry components. Micro models may require extensive material properties and geometric data for accurate simulations. Macro Modeling in Masonry Buildings on the other hand, takes a more holistic approach, considering the masonry structure as a whole. It aims to capture the overall response of the structure without delving into the details of individual components. In macro models, the masonry structure may be represented as a continuum, and the focus is on the overall response of walls, columns, and other structural elements without explicitly modeling individual bricks or joints. Generally speaking, it may be less complex, as it deals with aggregated properties and overall structural response. It may involve simplifications to make the analysis more computationally efficient. [33] (Anecchiarico, M., Portioli, F. and Landolfo, R., 2010)

## 2.2. Analysis of Seismic Behavior:

An earthquake is defined as any sudden shaking of the ground caused by tectonic movements. The main cause is that when tectonic plates collide, one ride over the other, and this creates relative motion between the plates leads to increasing the stresses. it may also , be defined as a wave-like motion generated by forces in constant turmoil under the surface layer of the earth travelling through the earth's crust. [15] (Dowrik, 2009)

Earthquakes are natural disasters that cause great destruction to human live and building. The concept of earthquake, its characteristics and response of the structures to it.

During earthquake the size and severity of the earthquake depend on two important parameters: 1) intensity: the effect in a specific place. 2) Magnitude: it is a measure of the amount of energy produced.

To study the strength of the structures one needs seismic zoning and general principles to observe in the earthquake-resistant design of structures.

### 2.2.1 Analysis methods

The impact of the excitations to the structure can be caught by different methods:

#### a- Lateral force analysis :

Lateral force analysis is a structural engineering technique used to assess the seismic behavior of buildings and other structures. This method is a linear static analysis. The primary purpose of lateral force analysis is to determine the forces and displacements that a structure is likely to experience during an earthquake . It is performed under a set of lateral force applied separately in two orthogonal horizontal direction x and y and applied as a constant force to the center of mass for each floor. This information helps engineers design structures that can withstand seismic forces and protect the safety of occupants.

#### b- Response spectrum analysis:

Is a method commonly used in structural engineering and earthquake engineering to evaluate the dynamic response of a structure subjected to ground motion such as seismic or wind loads. It provides valuable insights into how a structure will behave during an earthquake or other dynamic events by considering the structure's dynamic characteristics, such as natural frequencies and mode shapes, and the characteristics of the ground motion. This method cicatrizes by linear dynamic analysis where the seismic action is given a spectrum.

In linear dynamic analysis the building is modelled as a multi degree of freedom (MDOF) system with linear elastic stiffness matrix and equivalent viscous damping matrix. [16] (Rahul and ravikent).

#### c- Nonlinear pushover analysis:

It's a simple method, used to predict the nonlinear behavior of the structure under seismic load. The pushover analysis represents a static approximation of the effect of the dynamic earthquake load on the structure. It applies vertical distribution of increasing a lateral load which capture the material non-linearities of the structure. The pushover analysis process employs the lateral load with increasing load use to push the structure until the ultimate displacement is reached. This method provides useful data about desired

building performance level, the response spectrum for the design earthquake, floor's displacement (target displacement), base shear, story's drift and other deformation quantities as shown in fig(2.14) [17] ( Martino, Spacone. and Kingsley), .

It can also help demonstrate how progressive failures in structure can really occur, and differentiate the mode of final failure.

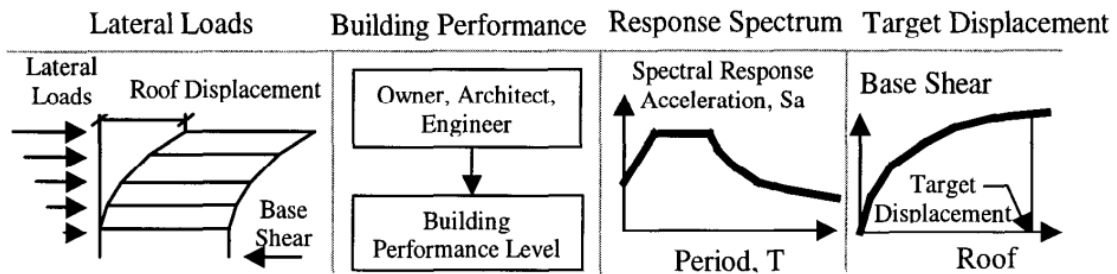


Figure 2.14: Pushover Analysis Procedure.

[17] (Martino, Spacone. and Kingsley),

Capacity curve (also known as a pushover curve) is a graphical representation of the relationship between the lateral (horizontal) loads applied to a structure and the corresponding displacement or drift at a specific point on the structure- typically at the roof level. This curve is a fundamental output of pushover analysis and provides valuable insights into the structural behavior and performance under seismic loads. It shows the deference between experimental and numerical results is emphasized is illustrated in fig (2.15). [20] (Facconi., Plizzari. and Vecchio)

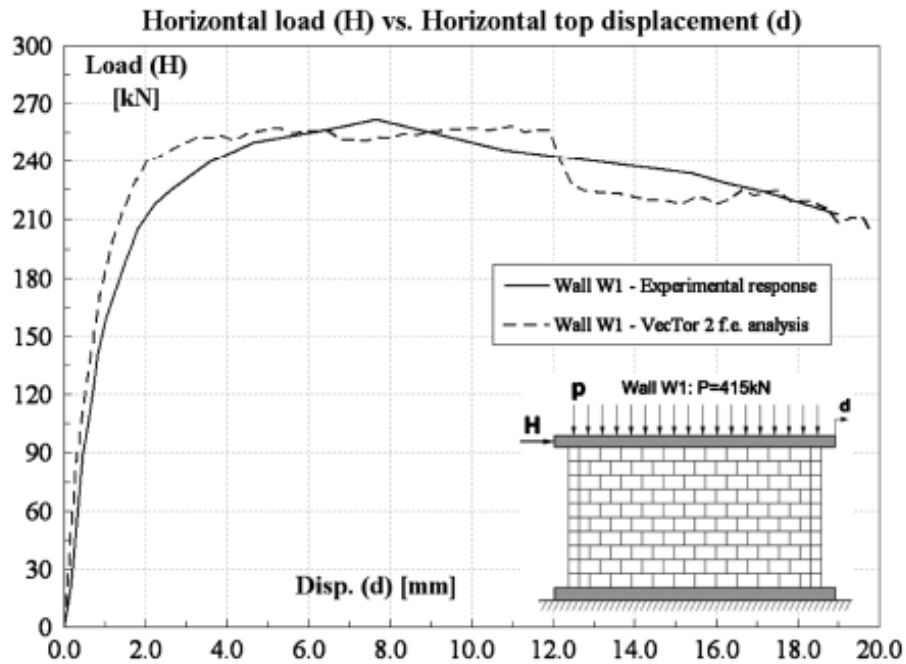


Figure 2.15: Capacity curve. [20] Facconi., Plizzari. And Vecchio.

The capacity curve shows how the structure's strength, represented by the applied lateral load, relates to its displacement or drift. The horizontal load applied to the structure is incrementally increased step by step in the analysis, simulating the progression of lateral forces during an earthquake. At each load step, the displacement or drift at a specified location (often at the roof level) is recorded. As the load increases, the displacement also increases. The shape of the curve depends on the structural response and the sequence of yielding or failure of various components within the structure. The capacity curve may exhibit multiple stages of behavior. Initially, it may show a nearly linear or elastic response until certain structural components or materials begin to yield. As the load continues to increase, the curve may become more nonlinear, indicating inelastic behavior. The point where the curve starts to deviate from linearity is often referred to as the "yield point." The ultimate point on the curve- represents the maximum displacement of the structure- can withstand before reaching a predefined performance limit or failure. Engineers use the capacity curve to assess the structure's seismic performance. They compare the displacement at various load levels to performance criteria, such as inter-

story drift limits, to determine whether the structure meets the desired performance objectives. This analysis helps identify potential weaknesses and informs retrofitting or strengthening measures.

However, pushover analysis can also estimate the ultimate strength of the structure including the point at which significant inelastic behavior occurs, and the inter-story drift. This method helps assess the structure's performance against predefined performance criteria, such as inter-story drift limits, to determine whether it meets desired safety and functionality objectives. It also predicts potential weak area in the structure, by keeping track of the sequence of damages of each and every member in the structure by using of what are the so- called hinges. In addition, Pushover Analysis allows for the comparison of different structural design or retrofitting options to determine which one is the most effective in achieving the desired seismic performance. It also, help Engineers to verify that the structure complies with seismic design codes and standards. [21] (Chopra, and Goel, 2002).

d- Nonlinear time history analysis:

Time history analysis provides for nonlinear evaluation of dynamic structural under seismic forces. It is a sophisticated numerical method that takes into account both geometric and material nonlinearities to accurately predict the behavior of structures under dynamic conditions. [19] (Rathod and Gupta 2020).

Nonlinear time history analysis provides a high level of accuracy in predicting the dynamic response of structures, especially when compared to linear analysis methods. It takes into account geometric and material nonlinearities, which are essential for accurately modeling of the behavior of structures under extreme conditions. This analysis method allows for a realistic simulation of structural response during seismic events or other dynamic loading scenarios. It considers the gradual yielding of materials, large deformations, and the formation of plastic hinges, providing a more realistic representation of how a structure behaves in practice.

Nonlinear time history analysis can capture the post-yield behavior of materials, which is crucial for understanding how structures respond when subjected to forces that exceed their elastic limits. This capability is essential for designing earthquake-resistant structures. The analysis takes into account the complete time history of applied loads, including their magnitude, direction, and duration. This is especially important when analyzing structures subjected to earthquake ground motion, which is characterized by complex time histories. It can help assess the likelihood of structural failure by considering factors like plastic hinge formation and failure criteria. This information is crucial for making design modifications or retrofitting recommendations to enhance structural safety. [19] (Rathod and Gupta 2020).

e- Kinematic analysis:

It is a methods for masonry buildings involve the assessment of the structural behavior and response of masonry structures, such as brick or stone buildings, based on their geometric configuration and the assumed deformations and movements they can undergo. These methods are primarily used to evaluate the stability and safety of masonry buildings, especially in the context of seismic or other dynamic loads. [18] (Mercuri, Pathirage, Gregori. and Cusatis, 2023), the kinematic analysis methods for masonry buildings depend on:

1. Geometric configuration: The analysis starts by considering the geometry and layout of the masonry structure, including the arrangement of walls, columns, arches, and other structural components. This information is crucial for understanding how the building is expected to respond to various loads.
2. Assumed deformations: Kinematic analysis assumes a set of deformations or movements that the masonry structure can undergo without reaching a state of instability or failure. These deformations are typically simplified and often include translation and rotation of structural elements.
3. Limit states: Kinematic analysis aims to determine the limit states of the masonry structure, which are conditions that, if exceeded, could lead to instability or failure. Common limit states include out-of-plane wall deformation, overturning, sliding, and separation of structural elements.

4. Seismic analysis: In seismic-prone regions, kinematic analysis is frequently used to assess how a masonry building will respond to earthquake-induced ground motion. Engineers use kinematic analysis to estimate the displacement demands on the building and assess whether the structure can withstand these demands without collapsing or suffering significant damage.
5. Simplifications: Kinematic analysis often involves simplifications and assumptions to make the analysis manageable. For example, it may neglect material properties and focus solely on the geometric configuration and potential modes of deformation.

### 2.3. Seismic of Palestine

#### 2.3.1. General

Palestine, located in the eastern Mediterranean region, experiences seismic activity due to its location along the boundary of the African and Eurasian tectonic plates. The seismicity in the region is influenced by the Dead Sea Transform fault system, which is a major fault line running from the Red Sea in the south to Turkey in the north, passing through the Jordan Rift Valley. Moreover, Palestine may be affected by earthquakes in the Mediterranean, or in Turkey -as the one which hit it in 2023.

A weak earthquake struck the Palestinian territories, with its epicenter southeast of Nablus, with a magnitude of 3.5 on the Richter scale

The seismicity in Palestine and the surrounding regions can vary in intensity and frequency. Earthquakes can range from small tremors that go unnoticed to larger events that can cause damage to infrastructure and pose a threat to the population.

It's important for the local authorities and residents in Palestine to be prepared for seismic events and to have measures in place to mitigate potential damage and protect lives. This can include earthquake-resistant building designs, public education on earthquake safety, and emergency response planning.

### 2.3.2. Fault of Dead Sea

The Dead Sea Transform fault, often simply referred to as the Dead Sea Fault (DSF), is a significant geological fault system in the Middle East. The Dead Sea Transform fault runs from the northern end of the Red Sea, through the Jordan Rift Valley, and continues into southern Turkey. It is part of the tectonic plate boundary between the African Plate to the west and the Arabian Plate to the east. As shown in fig (2.16) (24) ( Meghraoui, 2015)

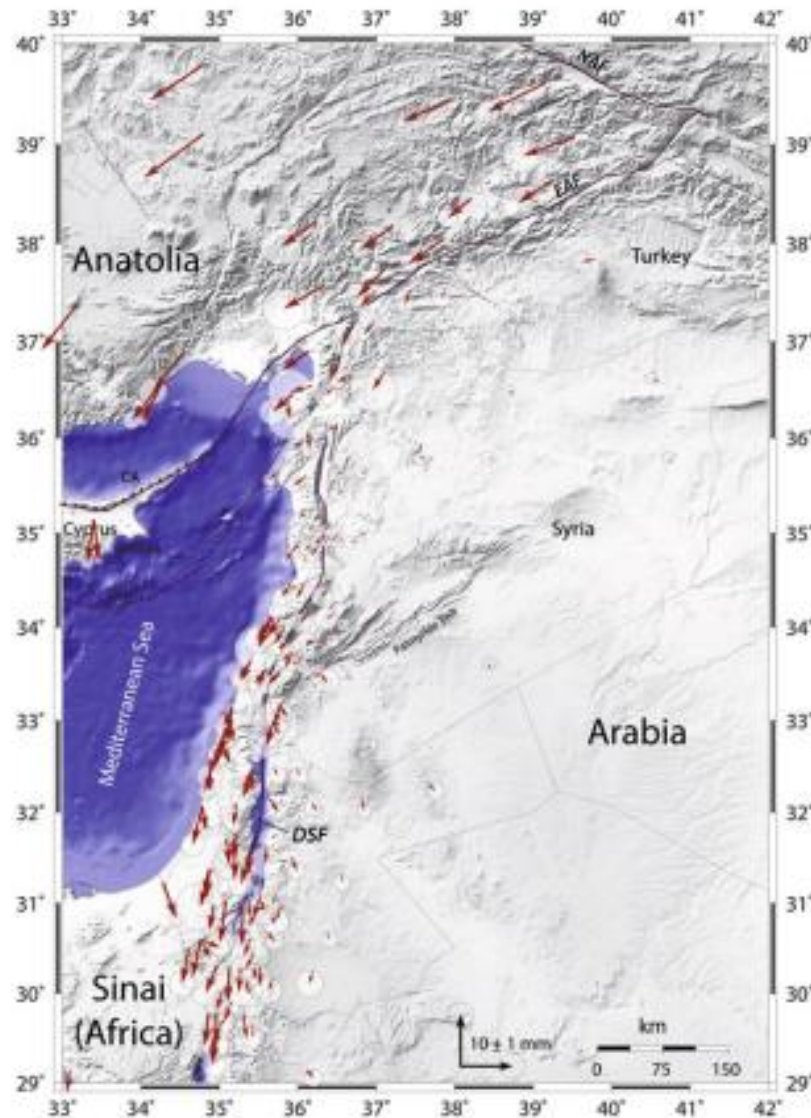


Figure 2.16: Seismic Hazard Map for Palestine. (24)( Meghraoui, 2015)

The Dead Sea Transform is primarily a strike-slip fault, which means that it is a horizontal fault where two tectonic plates slide past each other laterally. Specifically, the African Plate is moving northward relative to the Arabian Plate. The motion along the Dead Sea Fault generates significant seismic activity in the region. Earthquakes are common along this fault and can range in magnitude from small tremors to more powerful events.

The movement along the Dead Sea Fault has caused the Earth's crust to stretch and get thinner, leading to the creation of a rift valley. This rift valley includes geological features such as the Dead Sea, the Jordan River, and steep escarpments on either side. It is of great geological significance because it provides insights into the processes of plate tectonics and continental rifting. It also, poses challenges for the region in terms of seismic hazard and the potential for earthquakes. The Dead Sea Fault is an essential feature in the region's geology, influencing the landscape and seismic activity, and it plays a vital role in understanding the tectonic processes in the Middle East. (24)( Meghraoui, 2015).

#### 2.4. Seismic hazard and seismic risk

The seismic hazard, defined as the probability of ground shaking at a specific location over a certain period of time. It encompasses the assessment of potential earthquake activity in an area, considering factors such as the frequency, magnitude, and location of earthquakes, as well as the local geological and tectonic conditions that can influence ground shaking, surface rupture, and other seismic-related phenomena that can pose risks to human life, property, and infrastructure. Seismic hazard assessment typically involves studying. [22](Budnitz, Apostolakis, and Boore 1997):

1. **Seismic Activity:** Scientists analyze historical earthquake data to understand the frequency, magnitude, and location of past earthquakes in a region. This information helps them estimate the likelihood of future earthquakes.
2. **Ground Shaking:** Seismic hazard assessments consider the potential ground shaking that can occur during an earthquake. This involves estimating the magnitude of earthquakes that might occur in the area and calculating how the energy from these earthquakes would propagate through the Earth's crust to the surface.

3. **Site-specific Factors:** The local geology and soil conditions can significantly influence the intensity of ground shaking during an earthquake. Soft, unconsolidated soils, for example, can amplify shaking, while bedrock can reduce it.
4. **Building Codes and Vulnerability:** Assessments also take into account the vulnerability of structures and infrastructure in the region. Older buildings and poorly constructed infrastructure are more susceptible to earthquake damage.

Seismic risk, on the other hand, is a comprehensive evaluation that extends beyond seismic hazard. It encompasses the potential consequences of earthquakes by considering the exposure and vulnerability of a region. Exposure involves identifying and quantifying the assets, infrastructure, and population within an area; while vulnerability assesses the susceptibility of structures and communities to seismic-induced damage.

Many seismologists have said that “the earthquakes don't kill people, their structures do”. This is because most deaths from earthquakes are caused by main damage of structures or other human construction falling down during an earthquake. So before any assessments start, a good practice to study two fundamentally different concept of the hazards and risk. In general terms, the deference between seismic hazard and seismic risk is seismic hazards are naturally-occurring phenomena capable of causing loss or damage. Besides, seismic Risk is the potential that exposure to the hazard will lead to a negative consequence such as loss of life or economic loss. For examples, two towns (A and B) are right next to the same earthquake fault. They have the same earthquake hazard. But they don't have the same risk, because Town A has buildings built to withstand earthquake ground shaking while Town B does not. If you are Town B, you have two things you can do to reduce your risk of being hurt or killed in an earthquake. You can build strucures to withstand earthquake ground shaking or you can move. (USGS).

For seismic risk, Vulnerability index method for building can be used as a simplified method allows identifying differences among buildings with the same structural typology by means of a vulnerability index. [23]( Lantada, Irizarry, Barbat, Goula., Roca, Susagna and Pujades,).

It can use simplified formula to calculate the seismic risk:

$$\text{Seismic risk} = \text{seismic hazard} \times \text{vulnerability} \times \text{value}$$

Seismic Hazard (Hazard) is represents the probability and intensity of earthquakes occurring in a specific area. Moreover, the seismic hazard is a measure of the potential shaking that an area may experience due to earthquakes. Vulnerability is a assesses how susceptible the built environment (structures, infrastructure, etc.) and the population are to damage or harm when exposed to seismic hazards. It takes into account factors such as building construction, quality, and retrofitting, as well as social and economic factors that affect a community's resilience. Value is the assets and population at risk in a given area. This includes the monetary value of buildings and infrastructure, as well as the number of people who may be affected by an earthquake. [23](Lantada, Irizarry, Barbat, Goula, Roca, Susagna and Pujades,).

Seismic hazard maps are often created to visually represent the levels of earthquake risk in different areas, helping stakeholders identify high-risk zones and take appropriate measures to reduce vulnerability.

The outputs of the hazard's analysis is either a curve showing the exceedance probabilities for various ground motions, or a graphical map shows the estimated magnitude distribution of ground motion that has a specific exceedance probability over a specified time period at a region. The output maps developed for Palestine is shown in figure (2.17).

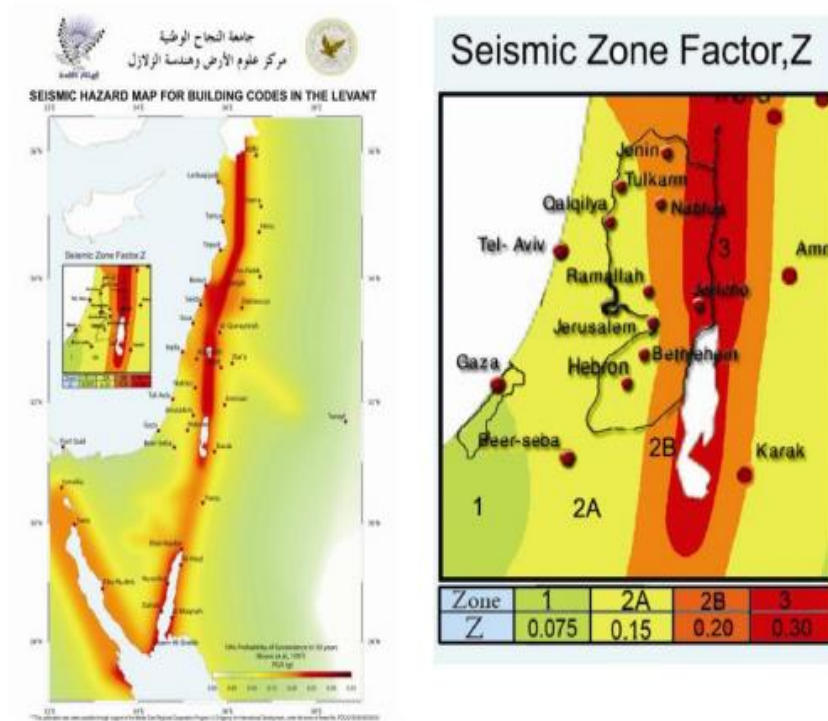


Figure 2.17: Seismic Hazard Map for Palestine.  
[ESSEC, USAID-MERC (M18-057)]

The following steps are used to carried out a new seismic hazard map for any city: [27]  
(Zaslavsky, Rabinovich,, Perelman. and Avirav, 2009.)

1. Selection of equation of ground motion estimation.
2. Update the catalog of earthquakes for the specified city and the neighborhood for last 2000 years.
3. Identification of the seismic zones in the region, according to tectonic, geophysical, geological and seismic data.
4. Determine seismic parameters for selected seismic zones.

## 2.5.Recent studies

The purpose of investigating the seismic behavior of monuments serves several important purposes, primarily related to preserving the cultural and historical heritage of these structures and ensuring public safety in earthquake-prone regions.

The first purpose is to Preservation of Cultural Heritage, Monuments often hold significant cultural, historical, and architectural value. Understanding their seismic behavior helps in assessing their vulnerability to earthquakes and devising strategies to protect and preserve them for future generations. And the second Risk Mitigation, Seismic investigations help identify potential risks and vulnerabilities in historical building when exposed to earthquake forces. This information allows for the development of mitigation strategies to minimize damage and ensure the safety of visitors and nearby communities. The third Structural Assessment, Studying the seismic behavior of monuments involves evaluating the structural integrity of these historic structures. This assessment helps determine if the existing construction methods and materials are capable of withstanding seismic forces, or if reinforcement and retrofitting are necessary. And then it can Retrofitting and Conservation, Seismic investigations often lead to retrofitting or strengthening projects to enhance a monument's seismic resistance while preserving its historical and architectural integrity. Engineers and conservationists can use these findings to make informed decisions about necessary interventions. The fourth one is Risk Reduction Planning: The results of seismic investigations can inform disaster preparedness and risk reduction plans for masonry building. This can include emergency response strategies and evacuation plans to protect both the monuments and the public during an earthquake event. The fifth is Public Safety, beyond preserving the monuments themselves. In fact, understanding their seismic behavior is crucial for public safety. Earthquakes can pose risks to visitors, staff, and neighboring communities, and ensuring the structural integrity of monuments is a vital component of minimizing these risks. Finally, Education and Awareness, Seismic investigations and their findings can serve an educational purpose. They raise awareness about the importance of preserving historic structures and can be used to teach the public about earthquake risks and mitigation measures. [25](Aguilar, Marques, Sovero, Martel, Trujillano and Boroschek, 2015)

Overall, investigating the seismic behavior of monuments is essential for safeguarding our cultural heritage, protecting public safety, and ensuring the long-term sustainability of these iconic structures in regions prone to seismic activity. It involves a multidisciplinary approach that combines engineering, historical preservation, and disaster management expertise.

Investigating and preserving historical masonry structures in earthquake-prone regions is a complex and ongoing process, and have several important challenges when investigating the seismic behavior of historical building. The most important of these challenges is that most of the historical and monumental structures consist of masonry material, as mentioned before, which is considered to be the historically oldest structural material, and they may be located in geographically regions subjected to a higher risk of earthquakes, i.e. around the Mediterranean Sea. Not to mention, the difficulty to find the original designs and architectural plans is also a problem. Over the time, changes may have occurred to the structure, these might be structural modifications due to changes of use or renovations.

Over the years, and especially in last two decades, researchers have studied the seismic assessment and performance of historical buildings, including their details, difficulties, mechanisms, regions, and rehabilitation process. One of the important studies was done by Araújo, Lourenço, Oliveira and Leite, 2012 [26] , for the St James Church, in New Zealand, which was studied and assessed by means of Non-linear pushover analyses (before and after the New Zealand earthquake in 2011) , and presents two numerical models ,damaged and undamaged modeling. It was constructed in order to properly simulate the structural behavior of the building. It incorporates the existing structural damage and considers the intact structure in study a seismic assessment of the St James Church. The structural behavior of the church has been evaluated by using the finite element modeling by using the nonlinear behavior of the structure has been taken into account by proper constitutive assumptions, as shown in figure (2.18)



Figure 2.18: general view of St. James church. [26] (Araújo, Lourenço, Oliveira and Leite, 2012)

Due to the 2011 earthquake that effected the church several failure mechanisms appeared: thin cracks between the window, and the base of the wall and diagonal cracks as in plane failure and horizontal cracks as out of plane failure as shown in figure (2.19)

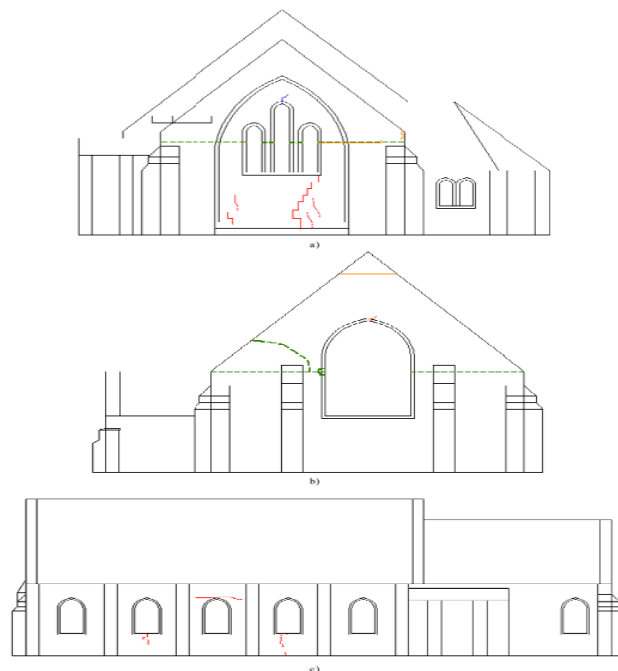


Figure 2.19: failure mechanisms in St. James church.

[26] (Araújo, Lourenço, Oliveira and Leite, 2012)

After the nonlinear pushover analyses are carried out on both principal directions, the Church can no longer be considered safe. The analysis results of the model show moderate agreement with the visual inspection performed in the site, which further validates the model used.

In similar manner, Bucchi with Arangio and Bontempi in 2013, studied different methods for earthquake assessment of existing historic building and then investigates the seismic assessment using the nonlinear static analysis of Camponeschi Palace, located in L'Aquila (Italy), this building was severely damaged by an earthquake on April 2009. As shown in Figure 2.20.

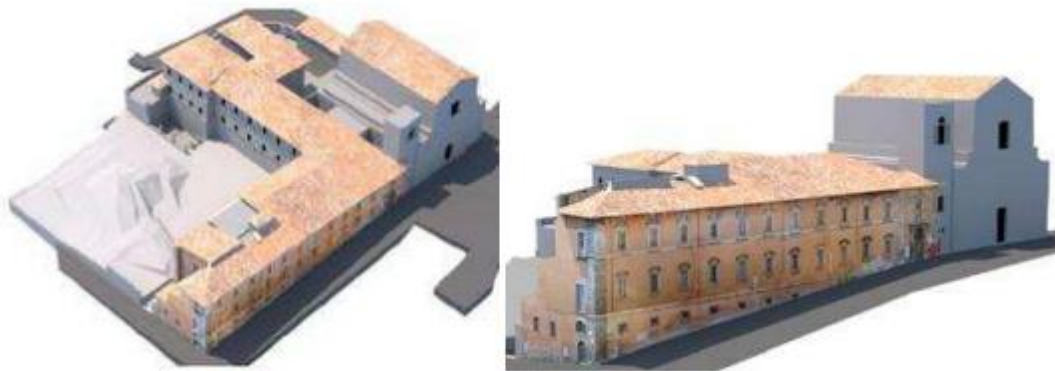


Figure 2.20: Render of Camponeschi Palace- L'Aquila, Italy

[28] (Bucchi with Arangio and Bontempi)

They give the attention for the nonlinear static analysis of equivalent frames models, and under the propose of giving a measure of the response of the structure with simple implement. In particular, its application with SAP2000, with macro element analysis and in Euro Code.

The damage mechanisms obtained are compared with the observed damage and with those obtained from other approaches, the results are in substantial accordance with results reported on the same structures and with the observed damage. [28]

In the same topic, Preciado, A., Orduña, A., Bartoli, G. and Budelmann, H. in 2015, studied the seismic vulnerability of an old masonry cathedral of Colima which is located in Mexico, by mean of two different material models and approaches of limit analysis

and nonlinear finite element analysis, figure (2.21). The attention here is similarly to the failure mechanisms of the St. James church and its interaction with the lateral walls.

Investigations based on results obtained from limit analysis and nonlinear finite element analysis have been conducted on some macro elements and with finite element method software ANSYS, approaches are able to simulate the observed failure mechanisms at the frontal façade and the obtained seismic coefficients are in good agreement, and the results obtained from both approaches are in agreement and can support the selection of possible rehabilitation process and scenarios in order to decrease the vulnerability under seismic loads. [30]

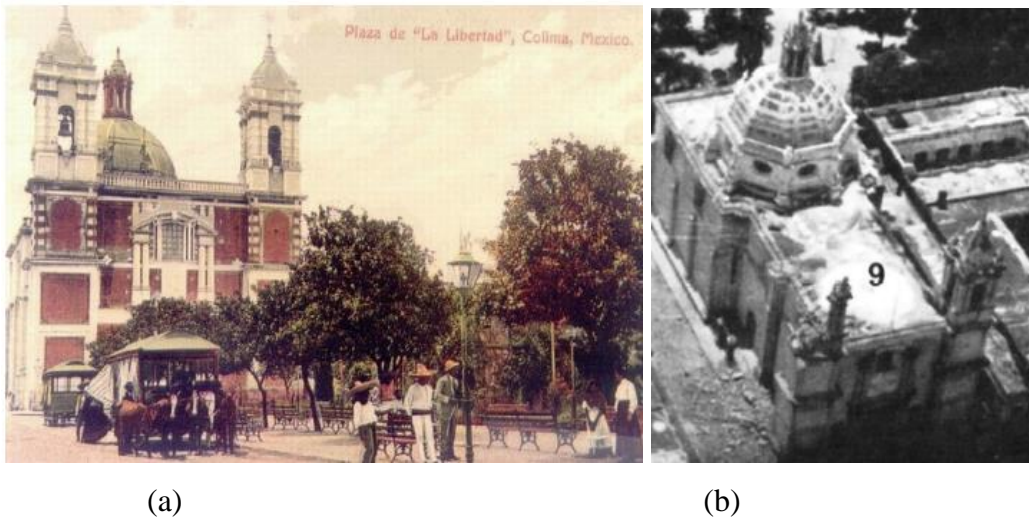


Figure 2.21: the Cathedral of Colima (a) before EQ in 1941 and (b) after EQ effects in 1941 (Preciado, A., Orduña, A., Bartoli, G. and Budelmann, H. in 2015) [30].

For the Turkey historical moments, again Mangia, Ghiassi, Sayın, Onat and Lourenço in 2016. Show the pushover analysis of a historical masonry structure Elti Hatun mosque, located in Tunceli, Turkey, figure (2.22). The modeling and analyzing with **Diana** finite element software based on real dimensions measured by site visiting, and by adapting macro modeling strategy to model masonry elements.

The vertical pushover analysis was done to investigate the safety factor of the mosque under its self-weight, the results is acceptable in all directions. On the other hand, However, The results show that the structure is two times weaker in the transversal

direction than longitudinal direction, for the main reason referred to existence of the main gate of the structure which works as a rigid support system in the longitudinal direction. The presented results are only a prediction of the behavior due to several uncertainties about the material properties. [36]



Figure 2.22: Outside and inside of the Elti Hatun Mosque (Mangia, Ghiassi, Sayın, Onat and Lourenço, 2016) [36].

In Kerala -India masonry building are the most common type used for houses, and recently the frequency of earthquakes in Kerala has increased and damaged this masonry building. Accordingly Bose and Paul in 2014 studied a non-linear seismic analysis of masonry building. In particular, non-linear analysis of brick walls and the effect of openings in these walls, this method used to check whether retrofitting of existing building is required or not, to minimized the loss of life and Building collapse, with finite element method using ANSYS software program, use data of 1940 imperial valley earthquake in Kerala- India .

For the analysis use micro modeling and four models with different dimension were prepared for the non-linear seismic analysis as shown in figure (2.23). For model 1 brick masonry wall without opening the wall collapse in plane case, the stress developed on the bottom and the crack start on the bottom of the wall, can prevent the damage of the wall. For model 2 brick masonry wall with opening at the center of wall and belt concert around the opening; and for model 3 brick masonry wall with wall opening and concert belt at the intel, the wall remains safe at in plane case, and the concert beams around opening make this wall safe against collapse. Only a small magnitude of stress is developed on the brick masonry. For model 4 brick masonry wall with wall opening the

wall collapse in plane, the maximum stress developed in the in plane its greater than the maximum permissible (29).

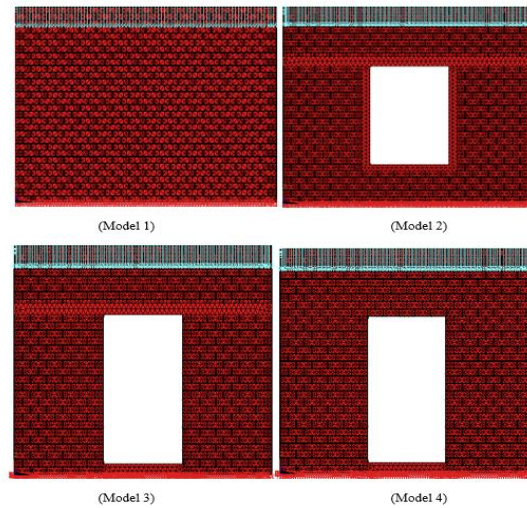


Figure 2.23: FEM model of masonry walls. (Bose and Paul, 2014) [29]

In the same topic, Kumar, A. and Pallav, K., 2018 study a Static and dynamic analysis of unreinforced masonry wall in senate hall building in India, figure (2.24). in survey visit of senate hall building, visible cracks and damaged parts of the building, so this study was carried out to strengthen and retrofitting the weakest element in building. Especial the aim of the study is to comprehensively investigate the behavior of unreinforced masonry wall with openings by identification of crack propagation on the wall during the analysis and investigation, using finite element modeling software ANSYS, and use macro modelling.

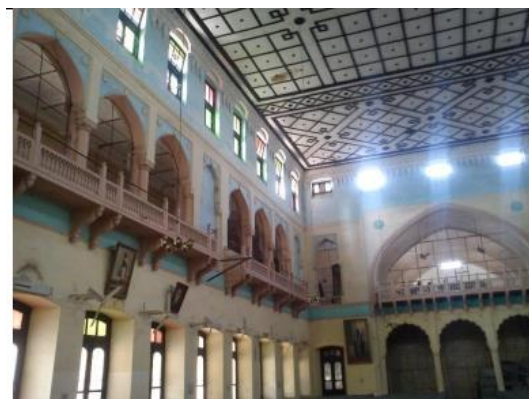


Figure 2.24: masonry wall of senate hall building.

(Kumar, A. and Pallav, K., 2018) [34].

As a result, it is needed to identify much further behavior of unreinforced masonry wall. The static and dynamic analysis in finite element analysis of masonry wall has evaluated the stress and deformation is the similar results were found in situ survey. This confirms the reliability of developed model, it helps protect old buildings from destruction and to know the weakest element in masonry building then retrofitting it. [34]

Turning to Italy, the assessment of the structural damage and stability of Sant'Agostino's Sanctuary in Offida a small town in the center of Italy, was done by Giordano, Clementi, Nespeca and Lenci in 2019, figure (2.25)



Figure 2.25: General view of Sant' Agostino's Sanctuary.

(Giordano, Clementi, Nespeca and Lenci, 2019) [31]

After the seismic events in 2016, the church damaged, and it is currently being made safe of prevent collapses. The analysis present damaged affecting after the seismic sequence of 2016, many cracks appeared inside the church especially on the nave and outside especially on the dome. The octagonal dome has cracks on all corners and the existing cracks have worsted, on the façade of church the vertical and diagonal crucks, and The square of the church has been closed owing to the possibility of façade overturn. Based on the historical survey and site visiting, the macro-modeling technique and a sophisticated finite element model was used for the structural analysis. The 3D non-linear

numerical model investigates the seismic behavior of the complex using sensitivity analysis performed by varying control points and stiffness of the floors, in order to take into consideration, the current deformed state of the structure.

In this analysis, they study the linear dynamic behavior to gain a proper understanding of the seismic demand and compare it with seismic capacity, directly derived by pushover analyses, providing the same result of damaged parts and macro elements of the complex after the seismic sequence in 2016–2017. As a result, this leads to identifying the most vulnerable elements and knowing how to deal with them and retrofitting, and offer an understanding of the safety of a whole complex and not only this church. [31]

Also in Italy in the city of L'Aquila, Capanna, Aloisio, Di Fabio and Fragiaco, in 2021 study a seismic response (non-linear static analyses) of a masonry palace in L'Aquila and discuss the seismic performance exhibited by these buildings during the 2009 earthquake (Figure 2.26), and analyze the damage after it. [35]

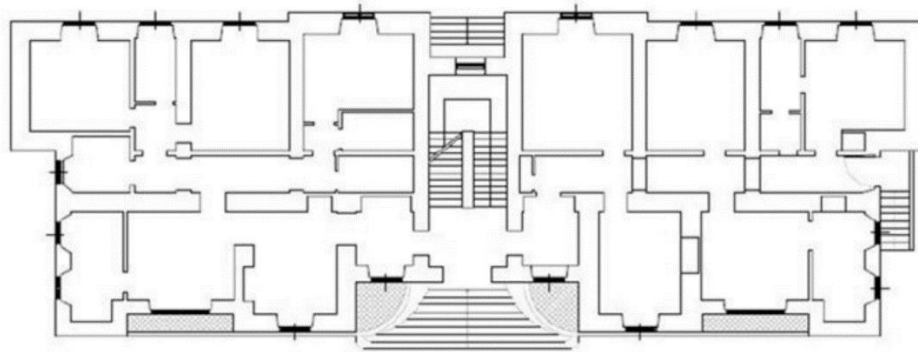


Figure 2.26: plane of the masonry palace.

(Capanna, Aloisio, Di Fabio and Fragiaco, 2021) [35]

They focus on the effect of the structural parameters on the outcomes of non-linear static analyses. The non-linear static analyses' outcomes are then used to derive fragility curves as a function of the spectral demand displacement.

The main result of nonlinear static analysis highlights the three variables influence on the shear resistance, the ultimate displacement, and the behavior factors. These variables help researchers to develop reliable typological approaches for seismic assessment, and it reveals the possibility of collapse of masonry building.

## 2.6.Relevant Codes and Standards

In this section, an in-depth analysis of codes and standards relevant to the resistance of progressive collapse in existing masonry buildings is presented. The researcher has delved into a comprehensive examination, starting with American standards and extending to European codes. The primary aim is to identify potential variations and discrepancies that may exist across different regions.

### 2.6.1 Euro code

Eurocode standards, including Eurocode 6: "Design of Masonry Structures," primarily focus on the linear analysis methods for masonry buildings. However, when dealing with complex or highly nonlinear behavior, such as the behavior of masonry structures under severe seismic loading, engineers often resort to advanced analysis techniques. These may include nonlinear static analysis (also known as pushover analysis) and nonlinear dynamic analysis. Eurocode 6 provides some guidance on these advanced analysis methods within the framework of the Eurocode system.

Here are some key points regarding nonlinear analysis methods for masonry buildings in Eurocode 6:

#### 1. **Nonlinear Static Analysis (Pushover Analysis):**

- Eurocode 6 acknowledges the use of nonlinear static analysis for assessing the seismic performance of masonry buildings. It is particularly useful for evaluating the nonlinear behavior of masonry structures under lateral loads.
- Engineers can use pushover analysis to estimate the ultimate lateral load-carrying capacity, displacement, and ductility of a masonry building under seismic loading conditions.
- The code provides some guidance on selecting appropriate lateral load patterns and load combinations for pushover analysis.

## 2. **Nonlinear Dynamic Analysis:**

- While Eurocode 6 does not provide explicit procedures for nonlinear dynamic analysis, it recognizes its use for complex seismic evaluations.
- Engineers may employ time history analysis or other nonlinear dynamic analysis methods to simulate the dynamic response of masonry structures subjected to ground motion.
- The code emphasizes the importance of considering the nonlinear behavior of masonry materials and connections when performing dynamic analysis.

## 3. **Material and Element Behavior:**

- Eurocode 6 provides information on the mechanical properties and behavior of masonry materials, such as brick and stone, which is essential for modeling the nonlinear response of masonry structures in advanced analyses.
- The code includes guidance on modeling the nonlinear behavior of masonry walls, including cracking and crushing of masonry elements.

## 4. **Capacity Design Principles:**

- The code incorporates capacity design principles, ensuring that the critical elements of a masonry structure deform in a ductile manner before other elements, preventing brittle failures during severe loading.

## 5. **Detailing Requirements:**

- Eurocode 6 specifies detailing requirements for masonry structures to ensure ductility and proper response during severe loading conditions, which are important considerations in nonlinear analysis.

When conducting nonlinear analysis of masonry buildings in accordance with Eurocode 6, engineers often use specialized structural analysis software that can handle nonlinear material properties and complex structural behavior. Additionally, it's essential to have a deep understanding of the code's provisions, nonlinear modeling techniques, and seismic design principles.

For a comprehensive understanding of nonlinear analysis methods for masonry structures, including specific procedures and considerations, it's advisable to consult additional resources, academic literature, and guidelines, especially those developed by national authorities or research institutions that supplement Eurocode standards.

## 2.6.2. American Standards

The research begins with a thorough investigation of American standards, which form a fundamental basis for construction and structural integrity. Key standards such as those developed by the American Society of Civil Engineers (ASCE) and the International Building Code (IBC) are scrutinized for their guidelines on preventing progressive collapse in masonry structures. The emphasis is on understanding the specific requirements, methodologies, and performance criteria outlined in these standards.

### 2.6.2.1. IBC 2012

The International building code (IBC) 2012, establish the foundation for minimum requirements considering buildings and public safety. In particular, for high rise buildings, or high risk regions, IBC, lays out, the requirements to ensure the structural integrity, also for load bearing structures, the vertical ties are required in all walls, in addition to transversal, longitudinal ties at each floor. IBC goes on, to provide design methods and equations in order to meet these design requirements.

### 2.6.2.2. ASCE

The American Society of Civil Engineers (ASCE) plays a crucial role in developing standards and guidelines for various aspects of civil engineering, including masonry structures. Here's an overview of ASCE's involvement in providing standards for masonry:

#### 1. ASCE 7 - Minimum Design Loads for Buildings and Other Structures:

ASCE 7 is a widely recognized standard that provides requirements for general structural design, including the determination of loads and load combinations. It includes provisions

for masonry structures, outlining the minimum design loads applicable to different regions and environmental conditions.

2. ASCE 37 - Design Loads on Structures During Construction:

This standard focuses on loads and load combinations during the construction phase of structures. For masonry buildings, ASCE 37 provides guidelines on temporary construction loads and considerations to ensure the stability and safety of the structure during the construction process.

3. ASCE/SEI 41 - Seismic Evaluation and Retrofit of Existing Buildings:

ASCE/SEI 41 is specifically relevant when assessing and retrofitting existing masonry buildings for seismic resistance. It outlines procedures for evaluating the seismic performance of structures and provides guidelines for retrofitting to meet current seismic design standards.

## CHAPTER THREE: MODELING of CASE STUDY

### 3. Modeling of case study

#### 3.1. Introduction

The seismic assessment for any structure needs to study fundamental dynamic properties. In this thesis, the needed dynamic properties are obtained by using the finite element method. 3D linear and nonlinear analyses are done for the case study which is Zeitoun masonry building. The model built using 3Muri software, this work was done after the survey of archeological existing building, and making the data acquisition to produce a clear geometrical Image. The study aims to evaluate the building's seismic vulnerabilities and enhance its resilience through continuous structural health monitoring.

#### 3.2. Case study: Zaitoun masonry building (1343-1921):

##### 3.2.1. Short description of building

This house is one of the distinctive historic buildings in the old town - Hebron. It is located just behind the boundaries of the old town, known as the traditional urban fabric in the City of Hebron, on the northern border of the urban fabric of the old town. . This house is owned by rich family called Zaitoun family.

The building was built in late Turkish style: this building, is simple and harmonic, with pure traditional materials, and without exaggeration style.

The building consists of two floors: the first floor of the building was built around 1900 and the Second Floor was built in 1921. Later, the building was exposed to an earthquake in 1927. This earthquake did not have a clear impact, but some cracks appeared in some of the external and internal walls.

### 3.2.2. Photographs of Building



Figure 3.1: Picture for zaitoun building.



a. North West elevation.



b. South east elevation.

Figure 3.2: elevations for zaitoon building.

### 3.2.3. Structural system

The structural system of the building depends on bearing walls with double masonry sand stone with filling (soil, aggregates with big size) inside, the bounding material is lime sand and crashed stone. The ceiling from limestone in a different shape of vaults as shown on figure (3.3) cross vaults, composite sail and sail vaults (with low rigidity and high absorption of water) the loads of the ceiling transfers to stone sandstone columns in the four corners of the rooms.

The I-beam slabs transfer concentrated loads to the bearing masonry walls at the I-beams ends in the second level the bearing masonry stone walls transfer the loads into the bearing walls foundations. (الخطة الشاملة للحفاظ وإحياء البلدة القديمة في الخليل).



Figure 3.3: structural system for zaitoun building.



### 3.2.5. Seismic of the site

Hebron is located between two areas of low to medium seismicity: one to the east and one to the west side. It is situated close to the fault line separating the African and Arabian tectonic plates, and has been affected by several minor and major earthquakes with epicenters in the surrounding areas, such as the 1927 Palestine earthquake.

District of Hebron, where the Zeitoun building is located, is at distance large than 25 Km from the seismically active area of the Dead Sea rift and may not be affected by the tectonic of the rift. Earthquakes of magnitude  $> 6.5$  (modified Richter scale) are rare to occur. The structure is based on the seismic zone 2A criteria as mapped by the seismic hazard zone map of the West Bank area published by earth sciences and seismic Engineering Unit-Al Najah national University, figure (3.5). [Building center materials testing (report no: SI/22103)]

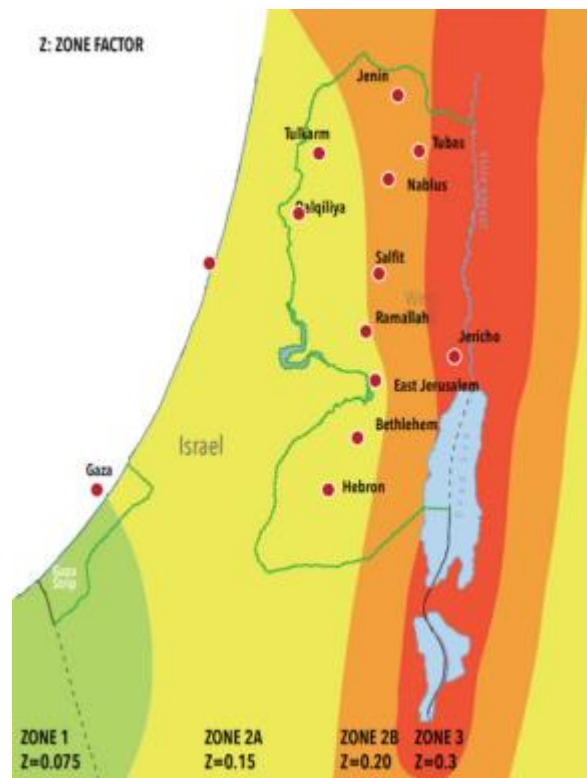


Figure 3.5: seismic hazard zone map of the west bank.

The soil profile at the site consists mainly of rocky layers. As such base on Table 1 from Euro code 8 (table 3.1 Ground types), this site has been as ground type A.

Table 3.1: Ground types (Euro code 8).

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	$N_{SP}$ (blows/30cm)	$c_u$ (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	—	—
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with $v_s$ values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s > 800$ m/s.			
$S_1$	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index ( $PI > 40$ ) and high water content	< 100 (indicative)	—	10 - 20
$S_2$	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or $S_1$			

### 3.3. Analysis method and techniques

In this days finite element method is widely used in structural analysis, It allows to simulate and analyze complex systems without the need for physical prototypes, providing valuable insights into the behavior of structures and materials under different conditions.

The Finite Element Method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is widely used in engineering for solving problems related to structural analysis, heat transfer, fluid

dynamics, and electromagnetism, among others. The method was initially developed in the 1940s and has since become a standard tool in engineering and applied mathematics. FEM has several advantages, including its ability to handle complex geometries, different material properties, and various types of boundary conditions. It provides a versatile and powerful approach for solving a wide range of engineering problems. The method is implemented in various software packages, making it accessible to engineers and scientists in different fields.

For the case study of Zaitoun building, the main approach to model masonry walls studying it as composite material which is summarized as macro level.

### 3.3.1. Software's used in the study.

Through the study of 3Muri software which are used in the analysis, important highlights can be shown, in the first hand; 3Muri Masonry is a finite element package used mainly by civil engineers, it's a complete and comprehensive application for static and dynamic analysis and design of masonry structures according to Eurocode

3Muri software program use equivalent frame modelling approach is followed: the masonry panels, namely, the piers (the vertical elements) and spandrels (the horizontal elements), are modelled as non-linear beams connected to each other by rigid links. The masonry portions confined between piers and spandrels are modelled as rigid nodes. As show in figure 3.6. This method is currently the most suitable tool for seismic evaluation of existing masonry buildings, it has a roots in visual inspections of buildings damaged in earthquakes, where the crack pattern clearly identifies the basic load-bearing elements of masonry structures piers and spandrels.

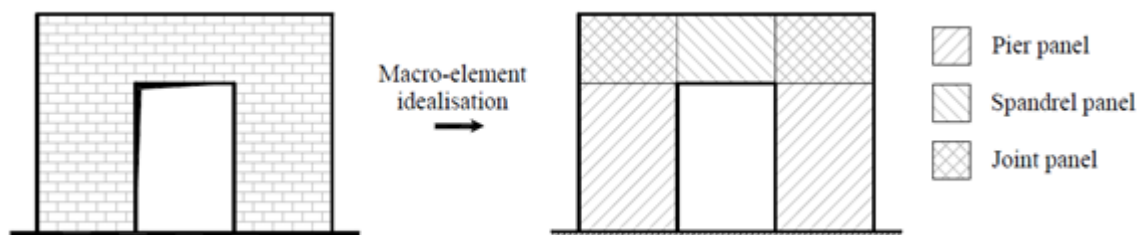


Figure 3.6: equivalent frame method use in 3Muri program.

3muri program it is possible to perform calculations that are satisfactory – and make a difference in deciding whether the object has to be removed, strengthened or the reliability is at a satisfactory level.

### 3.3.2. Mechanical properties for models:

The finite element model of zaitoun building is created by using 3Muri software program, with define the property of the masonry material.

The use of in situ inspection techniques applicable in some cases for obtaining all the desirable information. As a result, and due to lack of laboratory information for materials of zaitoun building, the mechanical properties of the material observed will be used based on a number of onsite tests have been carried out by Hebron Rehabilitation Committee. These tests focusing on the structural components of the masonry building , and generating the material properties of masonry walls like longitudinal elastic modules (E), average compressive strength (FM), shear elastic modules (G), and own weight (w). The constitutive model is a macro model with the given elastic material properties summarized in table (3.2) reports the selected values needed for the definition of the model parameters with respect to some principal elements. Another important points must be discussed, the most predominant characteristic of masonry is that it has a very low tensile strength. So in the analysis work, the tensile strength will be assumed 10% of the compression strength of the macro model elements.

Table 3.2: mechanical properties of masonry typologies.

Properties for perimeter walls of zaitoun building				
longitudinal elastic modules (E) (MPa)	average compressive strength (Fm)(MPa)	shear elastic modules (G) (MPa)	Specific Weight (KN/m <sup>3</sup> )	Material security factor (γm)
1780	2.6	270	23.13	3.5
Properties of vaults				
longitudinal elastic modules (E) (MPa)	average compressive strength (Fm)(MPa)	shear elastic modules (G) (MPa)	Specific Weight (KN/m <sup>3</sup> )	Filling density (g/cm <sup>3</sup> )
1000	1.33	170	19	1.46

Name	masonry walls
E [N/mm <sup>2</sup> ]	1,780.00
G [N/mm <sup>2</sup> ]	270.00
w [kg/m <sup>3</sup> ]	2.31E+03
f <sub>m</sub> [N/mm <sup>2</sup> ]	2.60
f <sub>k</sub> [N/mm <sup>2</sup> ]	0.78
τ [N/mm <sup>2</sup> ]	0.04
f <sub>vlim</sub> [N/mm <sup>2</sup> ]	2.20
FC	1.35
γ <sub>m</sub>	3.50
Shear drift	0.0053
Bending drift	0.0107
φ <sub>∞</sub>	0.0
Damage condition	Existing
Description	
Library	

Figure 3.7 Properties for perimeter walls of zaitoun building.

Name	masonry vaults
E [N/mm <sup>2</sup> ]	1,000.00
G [N/mm <sup>2</sup> ]	170.00
w [kg/m <sup>3</sup> ]	1.90E+03
f <sub>m</sub> [N/mm <sup>2</sup> ]	1.33
f <sub>k</sub> [N/mm <sup>2</sup> ]	0.90
τ [N/mm <sup>2</sup> ]	0.04
f <sub>vlim</sub> [N/mm <sup>2</sup> ]	2.20
FC	1.35
γ <sub>m</sub>	3.50
Shear drift	0.0053
Bending drift	0.0107
φ <sub>∞</sub>	0.0
Damage condition	Existing
Description	
Library	

**Figure 3.8** Properties for vaults of zaitoun building.

Moreover, the importance classes for building in Euro code as shown in table 3.3, which in importance class I, the importance factor = 0.8, and the confidence factor (FC) equal to 1.35, corresponding to a limited knowledge level according to euro standard code.

Table 3.3: the importance classes for building in Euro code.

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

The seismic action corresponds to the design response spectrum, according to the euro seismic code, defined through the spectral parameter  $a$  (GR) (max acceleration value), reported in the euro Code based on the site geographic coordinates of the building site.

Taking into account the soil and the topographic category of the site, the soil factor, the lower limit of the period of the constant spectral acceleration branch (TB), corner period at the upper limit of the constant acceleration region on elastic spectrum (TC), and the value defining the beginning of the constant displacement response region (TD). See Table 3.4 according euro code table 2

Table 3.4: seismic parameters of the selected site.

Ground type	Soil factor	TB	TC	TD
A (rock )	1	0.05	0.25	1.2

The response spectrum is defined for Operational Limit State, NC; 2475 years, for Limit State near collapse, SD; 475 years, limit state of Significant Damage, DL; 225 years, for Limit State of damage limitation, see Table 3.5.

Table 3.5: spectral parameters of the selected site.

a(GR) (m/sec <sup>2</sup> )	NC	SD	DL
0.2 g	0.35	0.2	0.16

### 3.3.3. Modeling of case study:

#### 3.3.3.1. Model geometry

Modelling of the building is done by insertion of walls which are made into discrete macro elements. These represent deformable masonry piers and spandrel beams on the level. Rigid nodes are indicated in the areas of the masonry that are typically less subject to earthquake damage. Generally, the piers and the spandrel beams are contiguous at the openings, and the rigid nodes are an element that connects the piers and spandrel beams. The mathematical concept behind the use of this element allows the damage mechanism to be found. This is shear damage in the central part, or compression-bending at the edges of the element. In this way, the damage dynamic can be understood in the way that it actually occurs in reality.

The nodes of the model are three-dimensional, with five degrees of liberty. (Three displacement components in the overall reference system and the rotation around the X and Y axes) Alternatively, they are two-dimensional nodes with three degrees of liberty.

(Two transfers and the rotation of the level of the wall) The three-dimensional nodes are used to allow transfer of the actions from one wall to a second wall which is located transversally to the first. The two-dimensional nodes only have degrees of liberty on the level where the wall is found, allowing transfer of the force states between the various points of the wall.

The horizontal structures are modelled with the three node floor elements connected to three-dimensional nodes. They can be loaded perpendicularly to their level using accidental or permanent loads. Seismic actions load the floor along the direction of the level. For this reason, the floor finite element is defined with axial rigidity, but without bending rigidity. This is because the main mechanical behavior of interest is that receiving horizontal loads due to the seismic action.

#### 3.3.3.2.Modal shapes:

The modal shape concerning the deformations established using 3muri software program as shown in following figures 3.7

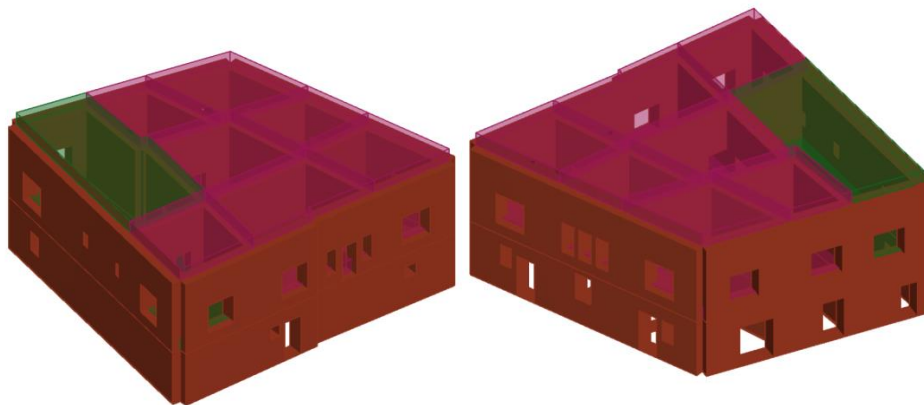


Figure 3.9: a 3D view of the model use in 3Muri program.

In zaitoun building, the openings not perfectly aligned, a possible choice is to conventionally assume a mean value for the height of spandrel elements as a function of the overlapping part between the openings at the two levels. [42](Lagomarsino, Penna, Galasco and Cattari 2013.). (Fig. 3.8); when no overlap is present or the opening lacks at all, it seems more appropriate to assume the portion of masonry as a rigid area .So in this

case we have irregular opening distribution led to have a rigid nodes with complex geometries. As shown in figure 3.9

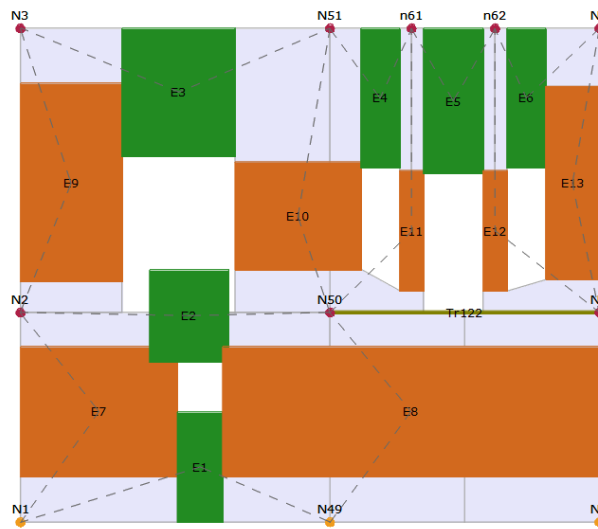


Figure 3.10: Elevation of wall in zaitoun building model use in 3Muri program.

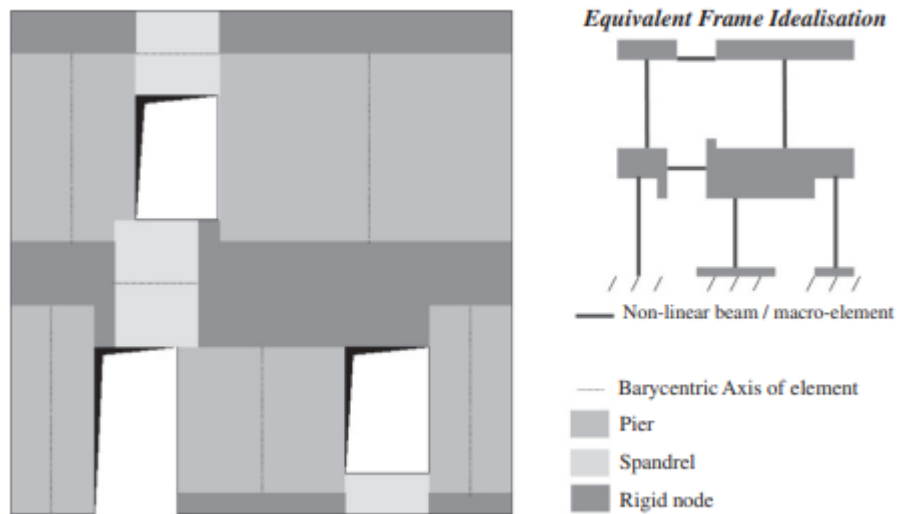


Figure 3.11: Example of equivalent frame idealization in a case of irregularly distributed openings. [42]

The non-linear static analysis along the longitudinal and transversal direction in figure 3.10, by applying the seismic load.

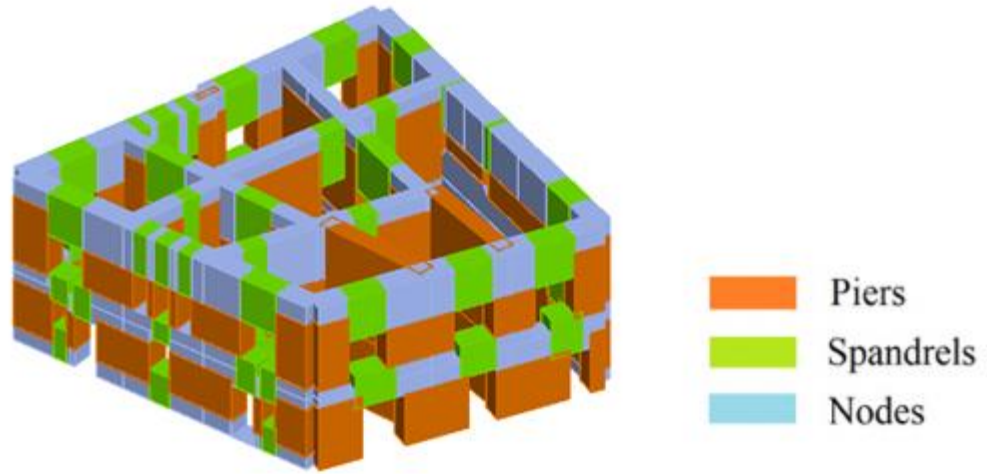


Figure 3.12: a 3D view of the model use in 3Muri program equivalent frame method.

## CHAPTER FOUR: ANALYSIS

## 4. Analysis

In order to perform nonlinear seismic analyses of masonry buildings a set of procedures has been implemented in the 3REMU program: incremental static with force or displacement control; 3D pushover analysis with fixed load pattern; 3D time-history dynamic analysis. In the following, the attention is focused on the numerical algorithm implemented for pushover analyses for zaitoun building, which became more and more popular for seismic structural assessment in the last decades, in particular in conjunction with the spreading of performance-based earthquake engineering concept.

### 4.1. Pushover analysis

The pushover procedure implemented transforms the problem of pushing a structure maintaining constant ratios between the applied forces into an equivalent incremental static analysis with displacement control at only node.

In order to perform the required checks for the building in question, non-linear static analysis was performed [Eurocode 8]. The requested checks involve a comparison between the capacities curves found for the various prescribed conditions with the displacement request required by the code. The capacity curve is identified through a diagram showing maximum displacement-shear at the base. According to the indications in the code [Eurocode 8 ], there are two types of load conditions that must be examined:

- Distribution of forces proportional to the masses:

$$F_i = \frac{m_i}{\sum_i m_i}$$

- Distribution of forces proportional to the product of the masses for the deformation corresponding to the first vibration mode.

In this way, the value for the maximum displacement at the base of the building generated by the distribution of forces is calculated. This displacement value constitutes the ultimate value for the building.

The displacement examined for tracing the capacity curve is the point of the building called the control node. Code requires that tracing of a bi-linear capacity curve for an equivalent system (SDOF).

The determination of the curve relative to the equivalent system allows determination of the period in which the maximum displacement requested by the earthquake to be found, according to the spectrums found in the code.

In order to identify the gravest seismic load condition, individual analyses were performed for load typology, seismic direction, and for possible accidental eccentricity.

in the following, showing the analysis of 3Muri program in describing the seismic response of zaitoun masonry building . Fig. 4.1 shows the front view of the building and the 3D model.

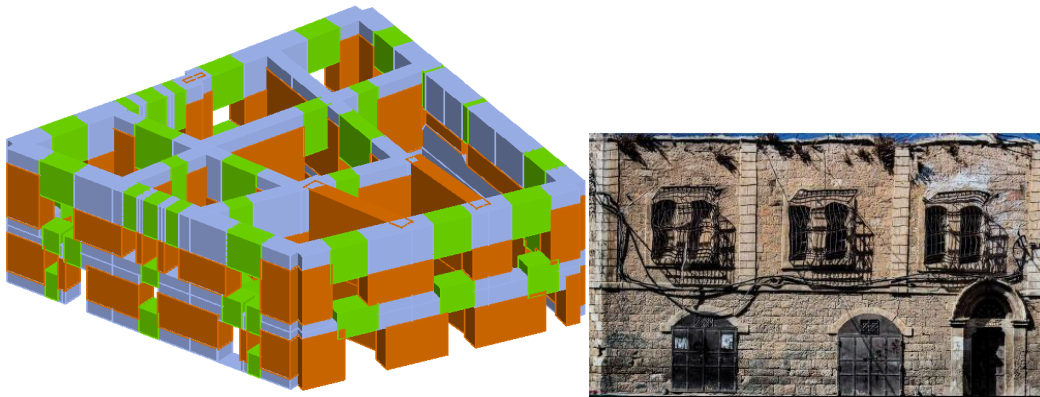


Figure 4.1: 3D building model.

Generally the pushover analysis is performed according to the two main directions X-Y, but in this case study configurations could however give rise to the doubt that these directions are not actually the most significant. Due to the nature of the building's construction, where there is a slope in all the walls without limits of x and y, and accordingly, it is expected that most walls will be affected by earthquakes in all directions. Table 4.1 bellow show all possible cases of seismic analysis for zaitoun building.

No.	Seism dir.	Uniform pattern of lateral load	Eccentricity [m]	Level	Node
1	+X	Uniform	0.00E+00	2	3
2	+X	Static forces	0.00E+00	2	3
3	-X	Uniform	0.00E+00	2	3
4	-X	Static forces	0.00E+00	2	3
5	+Y	Uniform	0.00E+00	2	3
6	+Y	Static forces	0.00E+00	2	3
7	-Y	Uniform	0.00E+00	2	3
8	-Y	Static forces	0.00E+00	2	3
9	+X	Uniform	9.44E-01	2	3
10	+X	Uniform	-9.44E-01	2	3
11	+X	Static forces	9.44E-01	2	3
12	+X	Static forces	-9.44E-01	2	3
13	-X	Uniform	9.44E-01	2	3
14	-X	Uniform	-9.44E-01	2	3
15	-X	Static forces	9.44E-01	2	3
16	-X	Static forces	-9.44E-01	2	3
17	+Y	Uniform	9.81E-01	2	3
18	+Y	Uniform	-9.81E-01	2	3
19	+Y	Static forces	9.81E-01	2	3
20	+Y	Static forces	-9.81E-01	2	3
21	-Y	Uniform	9.81E-01	2	3
22	-Y	Uniform	-9.81E-01	2	3
23	-Y	Static forces	9.81E-01	2	3
24	-Y	Static forces	-9.81E-01	2	3

Table 4.1: all possible cases of seismic analysis for zaitoun building.

The choice of the seismic force distributions is up to the designer, the available options are:

- Uniform: distribution of forces, deduced from a uniform trend of accelerations along the height of the construction
- Static forces: proportional distribution to static forces. [43]

$$F_i = F_h \cdot z_i \cdot W_i / \sum Z_i \cdot W_i$$

Where:

- $F_i$ : load for one story.
- $F_h$ : total load in building.
- $Z$ : represent story height
- $W_k$ : total mass for building.
- $W_i$ : mass of one story.

These values are defined from the seismic load specified in the shape of the spectrum.

No.	Seism dir.	Seismic load	Ecc. [m]	dt NC [mm]	dm NC [mm]	NC Ver.	dt SD [mm]	dm SD [mm]	SD Ver.	Sd DL [mm]	d*y DL [mm]	DL Ver.
1	+X	Uniform	0.00E+00	2.17	33.28	Yes	1.99	24.96	Yes	1.31	10.15	Yes
2	+X	Static forces	0.00E+00	2.36	27.55	Yes	2.15	20.67	Yes	1.42	8.60	Yes
3	-X	Uniform	0.00E+00	2.31	24.19	Yes	2.11	18.14	Yes	1.39	7.82	Yes
4	-X	Static forces	0.00E+00	2.69	30.42	Yes	2.46	22.81	Yes	1.62	9.39	Yes
5	+Y	Uniform	0.00E+00	2.57	26.49	Yes	2.35	19.87	Yes	1.56	11.07	Yes
6	+Y	Static forces	0.00E+00	2.77	20.41	Yes	2.53	15.31	Yes	1.68	8.86	Yes
7	-Y	Uniform	0.00E+00	2.71	23.54	Yes	2.48	17.66	Yes	1.64	6.84	Yes
8	-Y	Static forces	0.00E+00	2.97	22.30	Yes	2.72	16.72	Yes	1.80	6.05	Yes
9	+X	Uniform	9.44E-01	2.13	27.10	Yes	1.92	20.33	Yes	1.26	9.04	Yes
10	+X	Uniform	-9.44E-01	2.41	31.79	Yes	2.21	23.84	Yes	1.45	12.74	Yes
11	+X	Static forces	9.44E-01	2.31	24.87	Yes	2.12	18.65	Yes	1.39	7.66	Yes
12	+X	Static forces	-9.44E-01	2.62	26.60	Yes	2.40	19.95	Yes	1.58	12.70	Yes
13	-X	Uniform	9.44E-01	2.26	23.39	Yes	2.07	17.54	Yes	1.36	8.55	Yes
14	-X	Uniform	-9.44E-01	2.38	24.96	Yes	2.18	18.72	Yes	1.43	7.45	Yes
15	-X	Static forces	9.44E-01	2.58	39.40	Yes	2.36	29.55	Yes	1.55	9.64	Yes
16	-X	Static forces	-9.44E-01	2.82	29.24	Yes	2.58	21.93	Yes	1.70	9.42	Yes

17	+Y	Uniform	9.81E-01	2.59	24.49	Yes	2.37	18.36	Yes	1.57	11.71	Yes
18	+Y	Uniform	-9.81E-01	2.56	25.14	Yes	2.34	18.86	Yes	1.55	10.71	Yes
19	+Y	Static forces	9.81E-01	2.90	24.10	Yes	2.65	18.08	Yes	1.76	10.51	Yes
20	+Y	Static forces	-9.81E-01	2.83	23.41	Yes	2.59	17.56	Yes	1.71	9.29	Yes
21	-Y	Uniform	9.81E-01	2.69	23.99	Yes	2.46	17.99	Yes	1.63	7.13	Yes
22	-Y	Uniform	-9.81E-01	2.72	22.95	Yes	2.49	17.21	Yes	1.65	6.73	Yes
23	-Y	Static forces	9.81E-01	2.99	22.69	Yes	2.73	17.01	Yes	1.81	6.41	Yes
24	-Y	Static forces	-9.81E-01	2.99	21.64	Yes	2.73	16.23	Yes	1.81	5.78	Yes

No.	Seism dir.	Seismic load	Ecc. [m]	$\alpha$ NC	$\alpha$ SD	$\alpha$ DL	dm/dt NC
1	+X	Uniform	0.00E+00	15.316	12.564	7.758	15.336
2	+X	Static forces	0.00E+00	11.696	9.595	6.066	11.674
3	-X	Uniform	0.00E+00	10.479	8.596	5.625	10.472
4	-X	Static forces	0.00E+00	11.321	9.287	5.808	11.309
5	+Y	Uniform	0.00E+00	10.321	8.466	7.114	10.307
6	+Y	Static forces	0.00E+00	7.368	6.044	5.275	7.368
7	-Y	Uniform	0.00E+00	8.682	7.122	4.160	8.686
8	-Y	Static forces	0.00E+00	7.505	6.157	3.359	7.508
9	+X	Uniform	9.44E-01	12.753	10.540	7.168	12.723
10	+X	Uniform	-9.44E-01	13.178	10.810	8.775	13.191
11	+X	Static forces	9.44E-01	10.744	8.813	5.500	10.766
12	+X	Static forces	-9.44E-01	10.146	8.323	8.049	10.153
13	-X	Uniform	9.44E-01	10.339	8.481	6.280	10.350
14	-X	Uniform	-9.44E-01	10.489	8.604	5.203	10.487
15	-X	Static forces	9.44E-01	15.257	12.516	6.204	15.271
16	-X	Static forces	-9.44E-01	10.358	8.497	5.545	10.369
17	+Y	Uniform	9.81E-01	9.456	7.757	7.462	9.456
18	+Y	Uniform	-9.81E-01	9.803	8.042	6.891	9.820
19	+Y	Static forces	9.81E-01	8.320	6.825	5.983	8.310
20	+Y	Static forces	-9.81E-01	8.280	6.792	5.417	8.272
21	-Y	Uniform	9.81E-01	8.915	7.313	4.370	8.918
22	-Y	Uniform	-9.81E-01	8.440	6.924	4.080	8.438

23	-Y	Static forces	9.81E-01	7.591	6.227	3.540	7.589
24	-Y	Static forces	-9.81E-01	7.235	5.935	3.186	7.237

Table 4.2: Result details for seismic analysis for zaitoun building.

Where:

- dt: the targets displacement of the Multi Degree of Freedom (MDOF) system.
- dm: the ultimate displacement of the Multi Degree of Freedom (MDOF) system.

The most significant analysis for zaitoun building is case no.12 in +x direction with uniform seismic load with eccentricity =  $-9.44E-01$  m and no.24 in -y direction uniform seismic load with eccentricity =  $-9.81E-01$  m.

#### 4.2. Pushover analysis in x direction:

The most significant analysis is x direction case no.12 in with uniform seismic load with eccentricity =  $-9.44E-01$  m. figure 4.2 below show the plane deformation shape in this case.

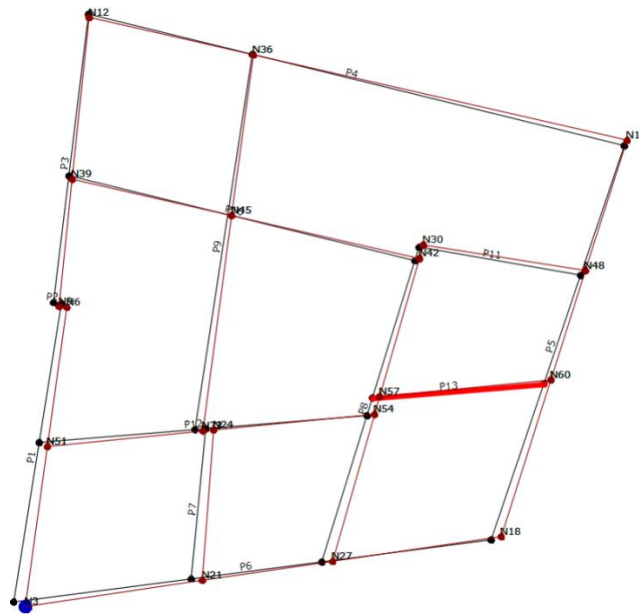


Figure 4.2: plane deformation shape in x-direction.

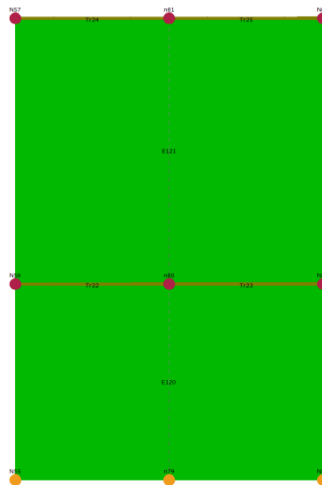
The figure (4.3) bellow show the Results legend for the Locations of failure expected to occur in the building.

### Masonry

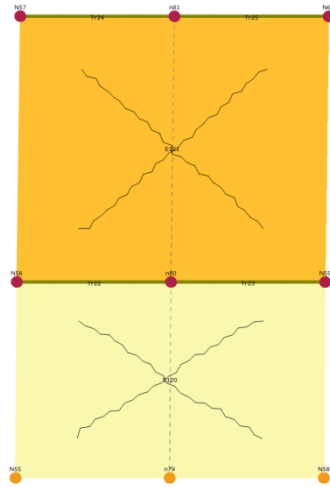
	Undamaged
	Plasticity incipient
	Shear damage
	Incipient shear failure
	Shear failure
	Bending damage
	Incipient bending failure
	Bending failure
	Serious crisis
	Compression failure
	Tension failure
	Failure during elastic phase
	Ineffective element

Figure 4.3: Results legend in 3Muri program.

In this case, the greatest impact was on wall No 13 Sub-step 43. As show in figure (4.4)



a) Step 0 of 115



b) Step 115 of 115.

Figure 4.4: distorted in wall 13 in +x-direction.

The figure below show the pushover analysis in wall 13, with displacement = 26 mm and shear = 4347.41 KN.

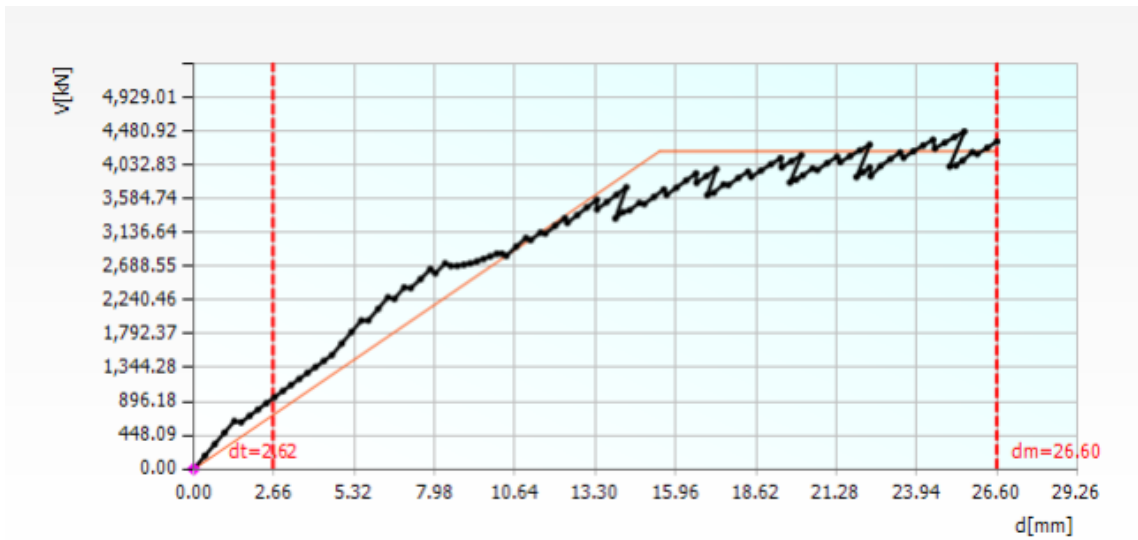


Figure 4.5: pushover analysis in wall 13 in x-direction.

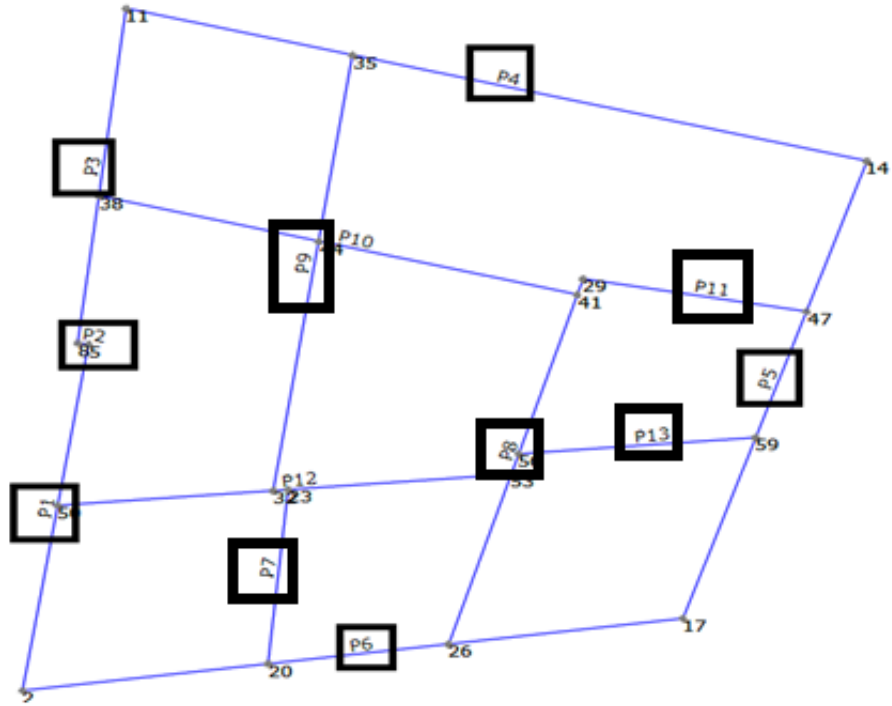


Figure 4.6: general plane foe walls in zaitoun building.

The figures bellow show the impact of case 9 in x-direction in the walls of building and the pushover analysis.

- Wall 1 :

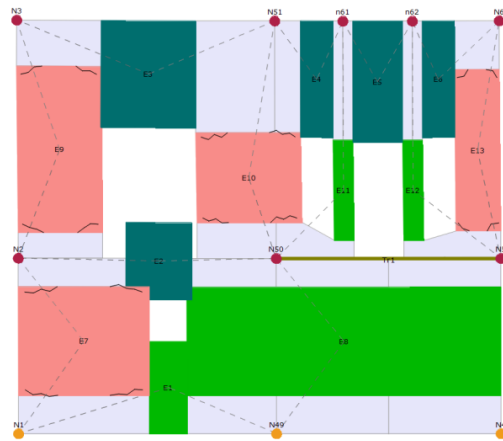


Figure 4.7: distorted in wall 1 in x-direction.

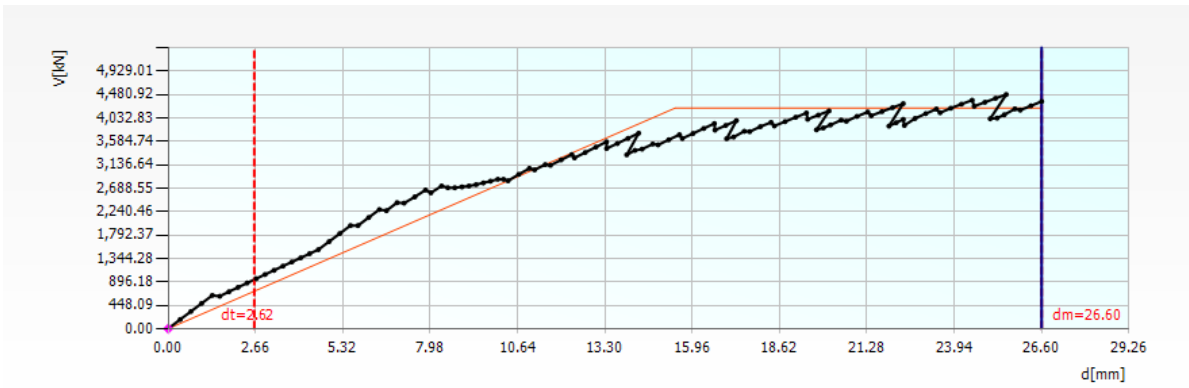


Figure 4.8: pushover analysis in wall 1 in x-direction.

- Wall 3:

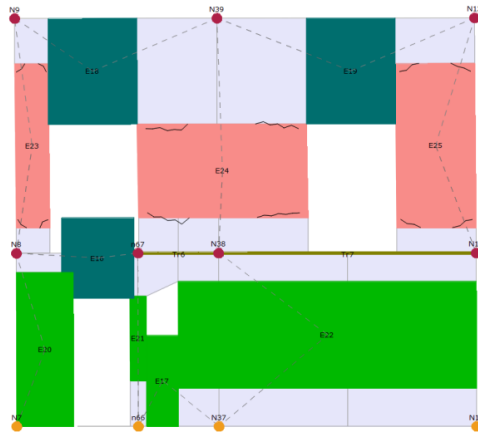


Figure 4.9: distorted in wall 3 in x-direction.

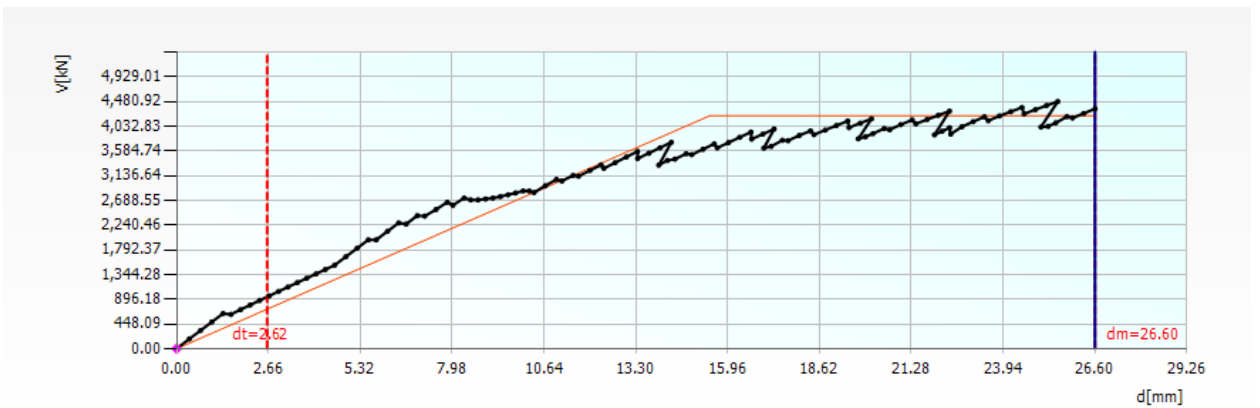


Figure 4.10: pushover analysis in wall 3 in x-direction.

- Wall 4 :

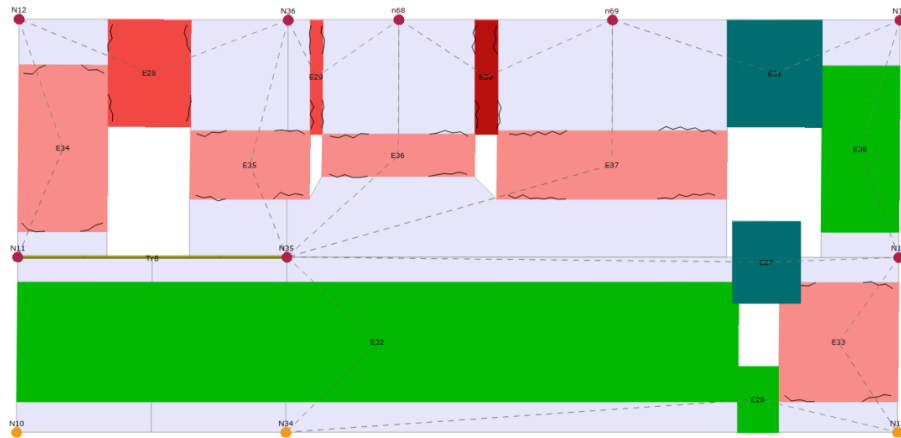


Figure 4.11: distorted in wall 4 in x-direction.

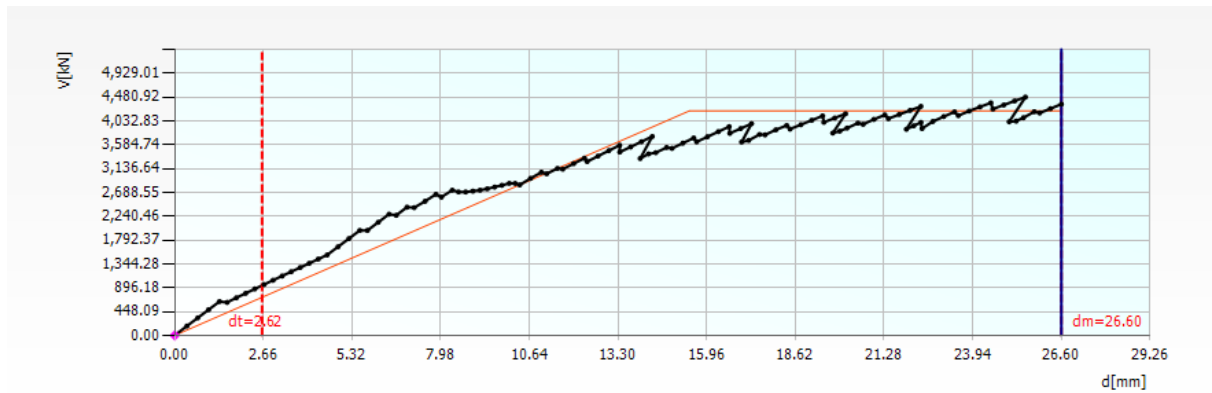


Figure 4.12: pushover analysis in wall 4 in x-direction.

- Wall 5 :

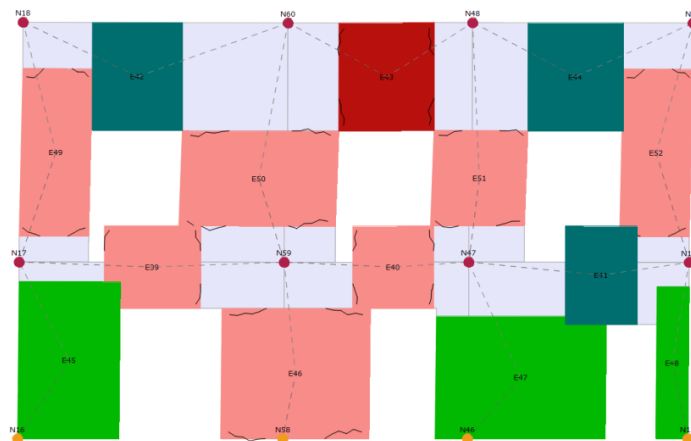


Figure 4.13: distorted in wall 5 in x-direction.

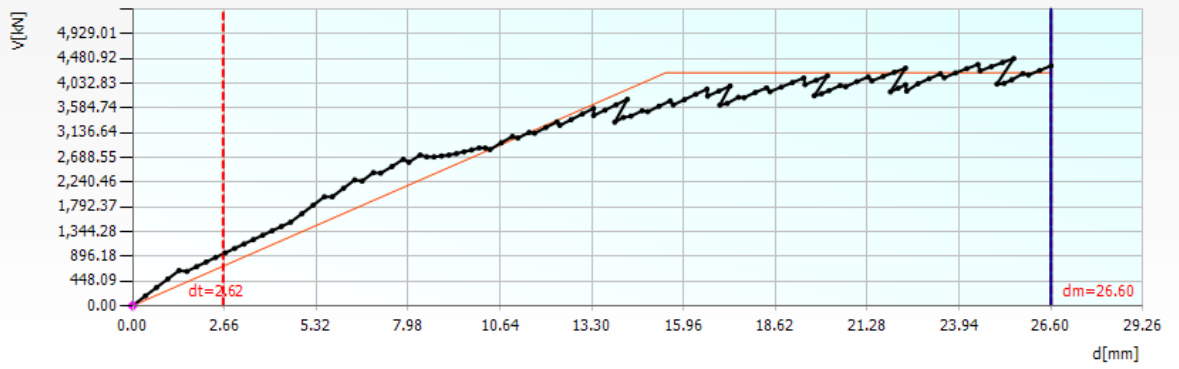


Figure 4.14: pushover analysis in wall 5 in x-direction.

- Wall 6 :

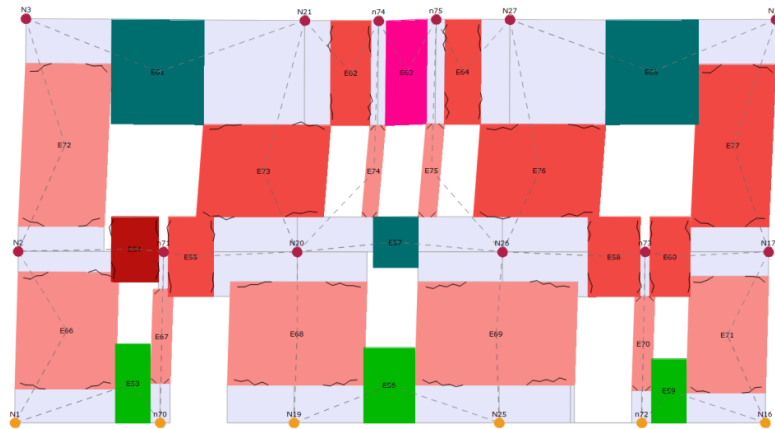


Figure 4.15: distorted in wall 6 in x-direction.

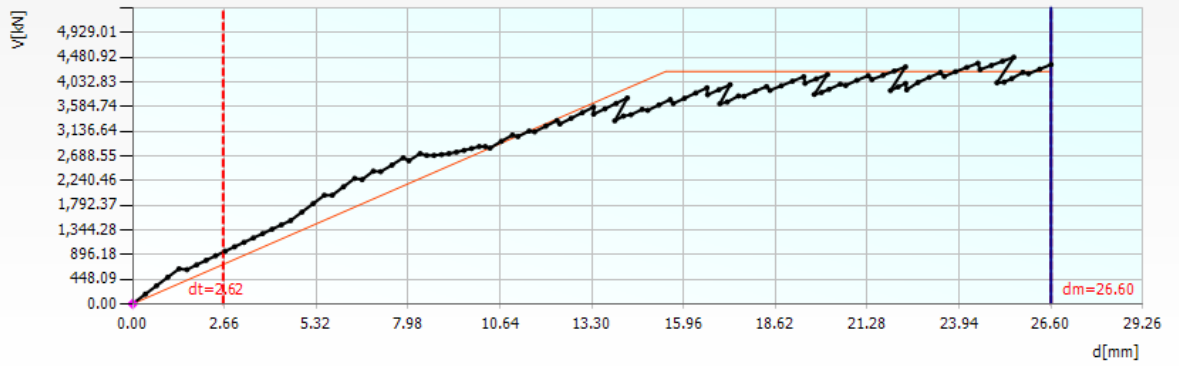


Figure 4.16: pushover analysis in wall 6 in x-direction.

- Wall 8 :

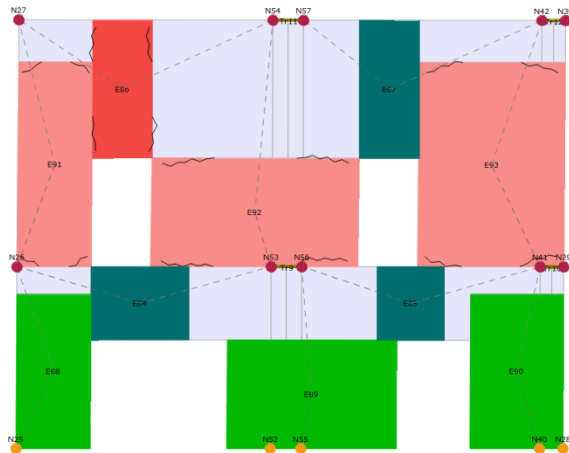


Figure 4.17: distorted in wall 8in x-direction.

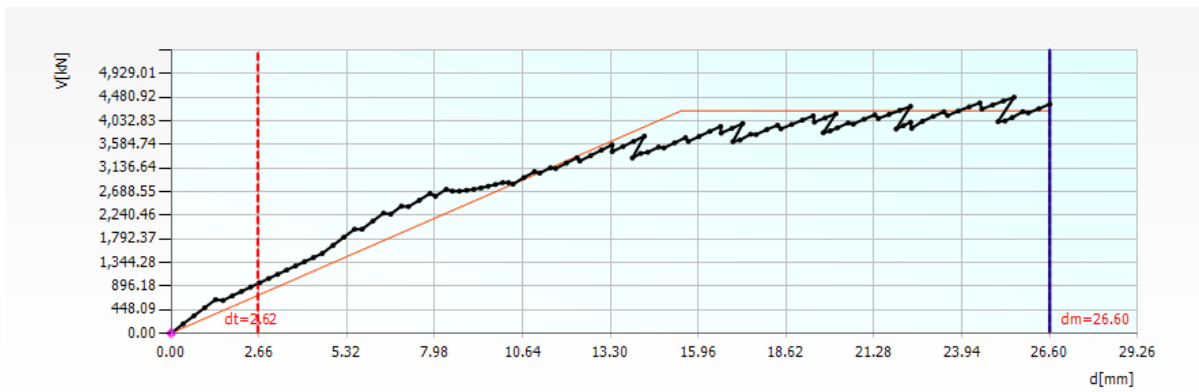


Figure 4.18: pushover analysis in wall 8in x-direction.

- Wall 9 :

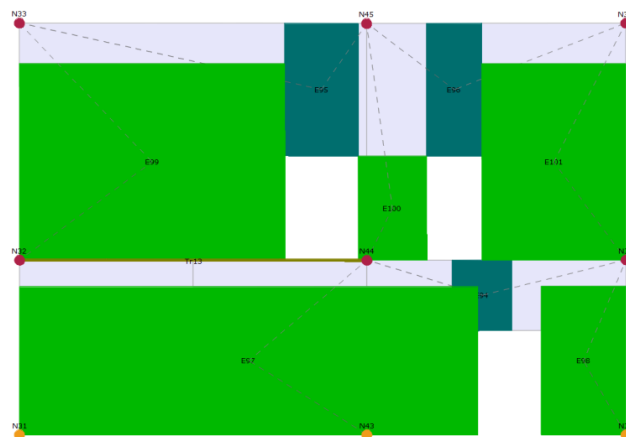


Figure 4.19: distorted in wall 9in x-direction.

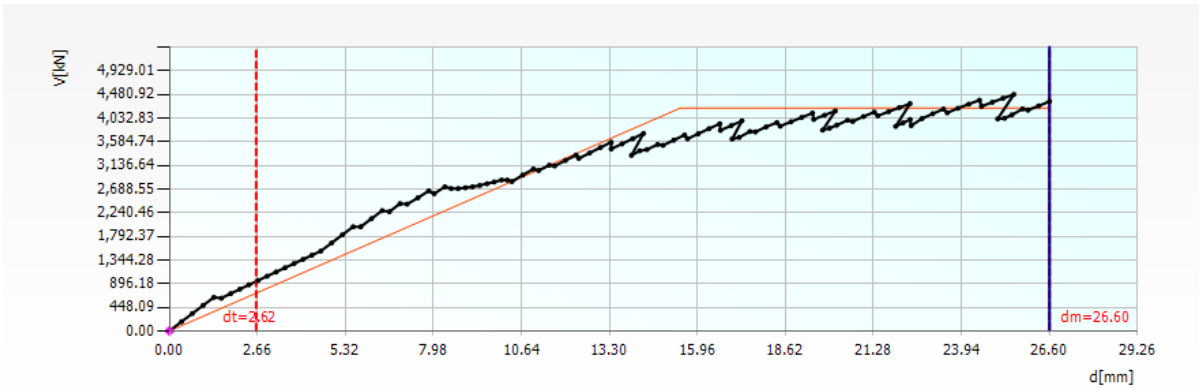


Figure 4.20: pushover analysis in wall 9 in x-direction.

- Wall 10 :

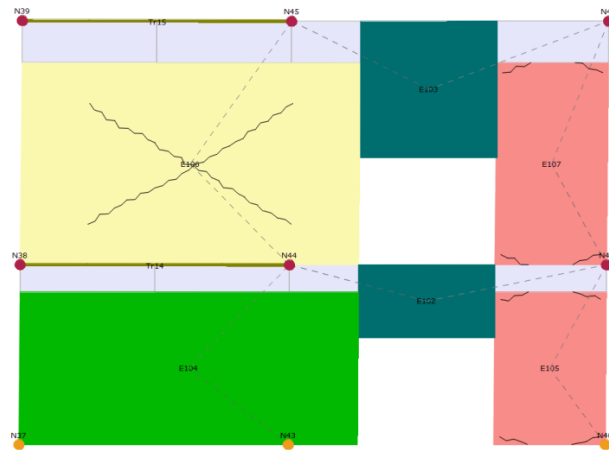


Figure 4.21: distorted in wall 10 in x-direction.

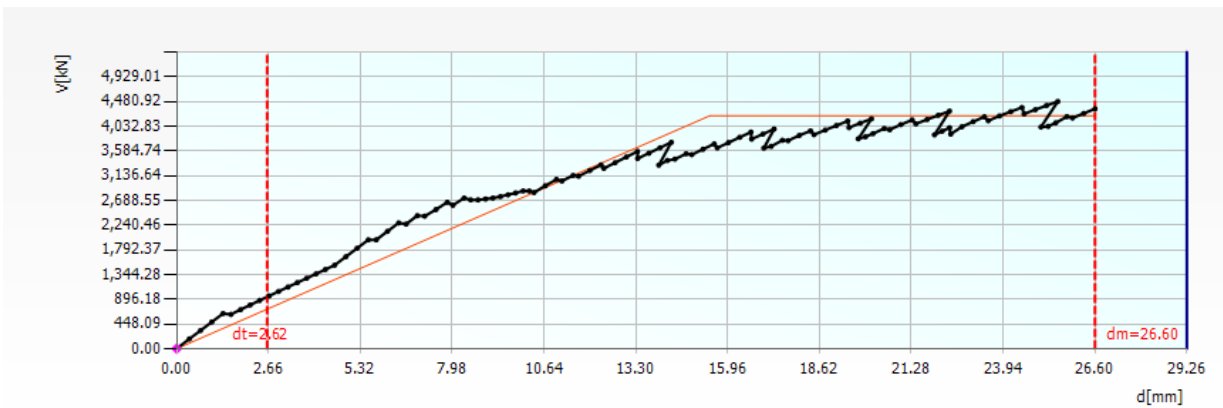


Figure 4.22: pushover analysis in wall 10 in x-direction.

Tables below show the results of analysis in x-direction:

1. The table (4.3) below show the percentage of broken elements presented in case 9 in x-direction.

<b>Wall</b>	<b>Masonry % Wall</b>	<b>Masonry % Building</b>
1	8.6	0.9
2	0.0	0.0
3	16.3	1.4
4	10.9	1.8
5	18.5	2.1
6	39.0	6.6
7	0.0	0.0
8	23.3	1.5
9	0.0	0.0
10	0.0	0.0
11	0.0	0.0
12	0.0	0.0
13	50.0	1.6

Table 4.3: percentage of broken elements presented in case 9 in x-direction.

2. The table (4.4) below show displacement control orders the walls according to the relative interstate displacement in order to identify where the greater displacement occurs.

<b>Main wall</b>	<b>Bottom node</b>	<b>Top node</b>	<b>Relative displacement [mm]</b>	<b>Level</b>	<b>Walls involved</b>
2	7	8	6.61	1	2-3
2	8	9	15.10	2	2-3
4	10	11	2.45	1	3-4
4	11	12	0.09	2	3-4
6	1	2	9.32	1	1-6
6	2	3	36.61	2	1-6
10	37	38	5.01	1	3-10
10	38	39	7.36	2	3-10
11	28	29	5.81	1	8-11
11	29	30	11.35	2	8-11
12	49	50	8.36	1	1-12
12	50	51	24.24	2	1-12
13	55	56	7.83	1	8-13
13	56	57	20.52	2	8-13

Table 4.4: relative inter-floor displacement.

Displacement control is a technique commonly used in structural engineering and geotechnical engineering to monitor the movement or displacement of structures or the ground. In the context of ordering walls according to relative interstate displacement, it refers to arranging or prioritizing walls based on the extent of displacement between them. This can help identify areas where greater displacement is occurring and may indicate potential issues such as structural instability or ground movement.

The displacement data from different walls are compared to each other to determine the relative interstate displacement. This involves analyzing the magnitude and direction of movement for each wall. Based on the comparison results, the walls are ordered or prioritized according to the magnitude of displacement. Walls experiencing greater displacement are typically ranked higher in the order, indicating areas of potential concern. Engineers experts analyze the ordered list of walls to identify patterns or trends in displacement. They may investigate potential causes such as soil settlement, foundation failure, or structural weaknesses. Depending on the analysis, appropriate actions are taken to address any issues identified. This may include reinforcing

structures, stabilizing the ground, or implementing monitoring and maintenance programs to track displacement over time.

3. Table (4.5) show “displacement control” environment orders the associated nodes and walls according to the chosen limit displacement.

<b>Walls involved</b>	<b>Node</b>	<b>Displacement [mm]</b>	<b>Level</b>
1-6	3	46.09	2
6-7	21	44.15	2
6-8	27	42.55	2
5-6	18	40.23	2
1-12	51	32.82	2
9-12	33	31.68	2
7-12	24	31.62	2
8-12	54	30.17	2
8-13	57	28.75	2
5-13	60	27.87	2
1-2	6	22.01	2
2-3	9	21.94	2
5-11	48	19.26	2
8-10	42	18.38	2
8-11	30	17.43	2
9-10	45	15.07	2
3-10	39	12.40	2
4-5	15	10.86	2
1-6	2	9.52	1
6-7	20	9.33	1
6-8	26	9.31	1
5-6	17	9.26	1
1-12	50	8.49	1
9-12	32	8.37	1
7-12	23	8.36	1
8-12	53	8.15	1
8-13	56	7.94	1
5-13	59	7.81	1

1-2	5	6.69	1
2-3	8	6.67	1
5-11	47	6.09	1
8-10	41	5.99	1
8-11	29	5.83	1
9-10	44	5.41	1
3-10	38	5.00	1
4-9	36	4.63	2
4-5	14	4.30	1
4-9	35	2.76	1
3-4	11	2.32	1
3-4	12	2.19	2
1-6	1	0.00	0
1-2	4	0.00	0
2-3	7	0.00	0
3-4	10	0.00	0
4-5	13	0.00	0
5-6	16	0.00	0
6-7	19	0.00	0
7-12	22	0.00	0
6-8	25	0.00	0
8-11	28	0.00	0
9-12	31	0.00	0
4-9	34	0.00	0
3-10	37	0.00	0
8-10	40	0.00	0
9-10	43	0.00	0
5-11	46	0.00	0
1-12	49	0.00	0
8-12	52	0.00	0
8-13	55	0.00	0
5-13	58	0.00	0

Table 4.5: displacement control.

### 4.3. Pushover analysis in y-direction:

The most significant analysis is -y direction case no.24 in with uniform seismic load with eccentricity =  $-9.81E-01$  m. figure 4.23 below show the plane deformation shape in this case.

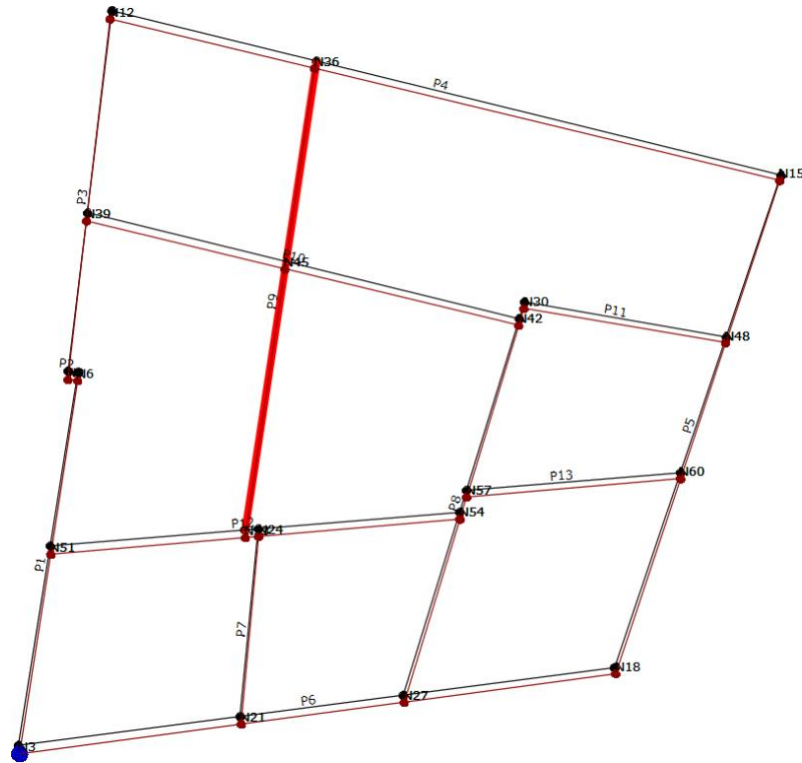
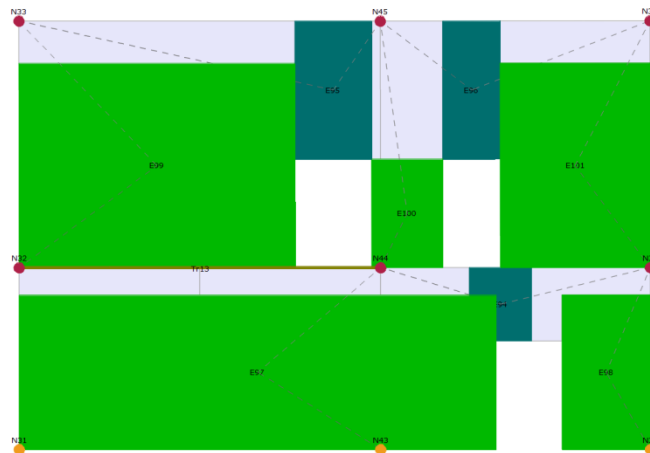
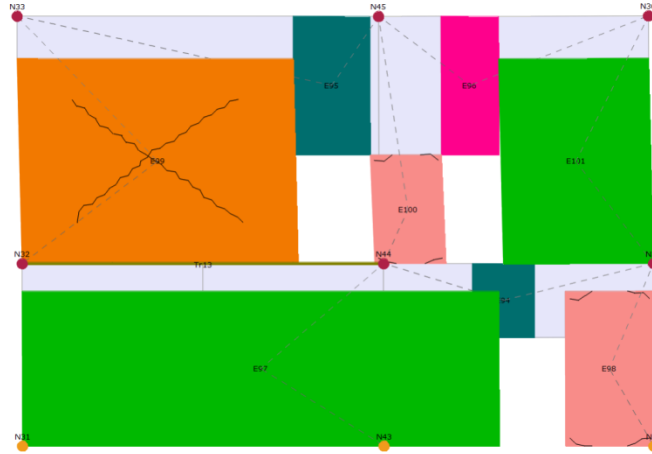


Figure 4.23: plane deformation shape in y-direction.

In this case, the greatest impact was on wall No 9 Sub-step 66. As show in figure (4.24)



a) Step 0 of 66.



b) Step 66 of 66.

Figure 4.24: distorted in wall 9 in y-direction.

The figure below show the pushover analysis in wall 9, with displacement = 21.64 mm and shear = 1463.99 KN.

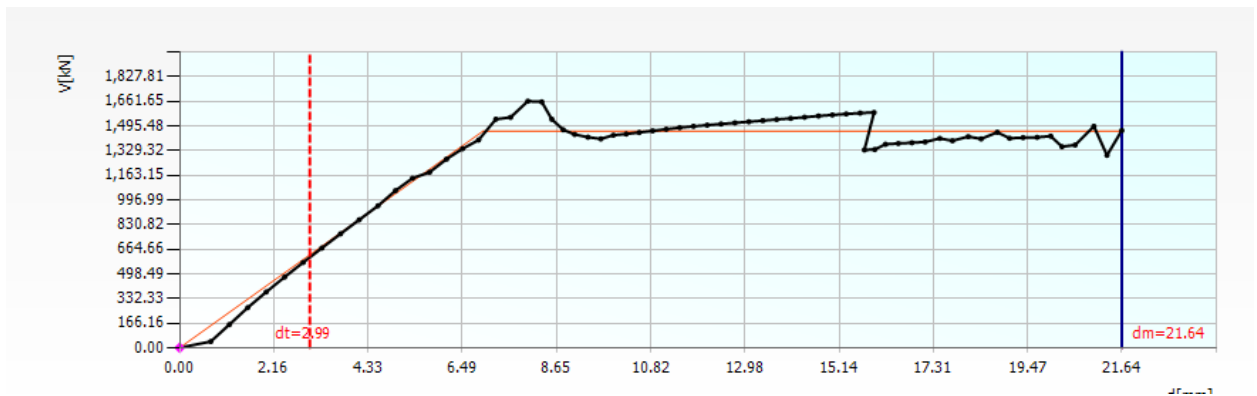


Figure 4.25: pushover analysis in wall 3 in y-direction.

The figures bellow show the impact of case 24 in -y-direction in the walls of building and the pushover analysis.

- Wall 1:

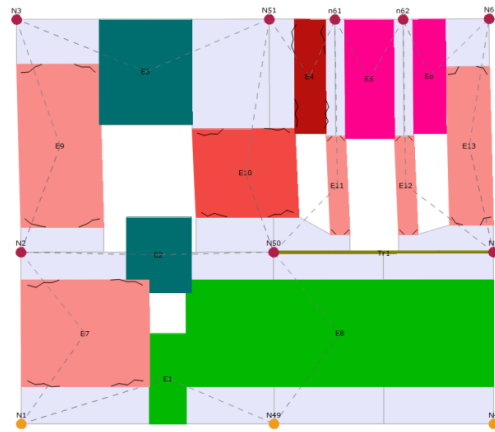


Figure 4.26: distorted in wall 1 in y-direction.

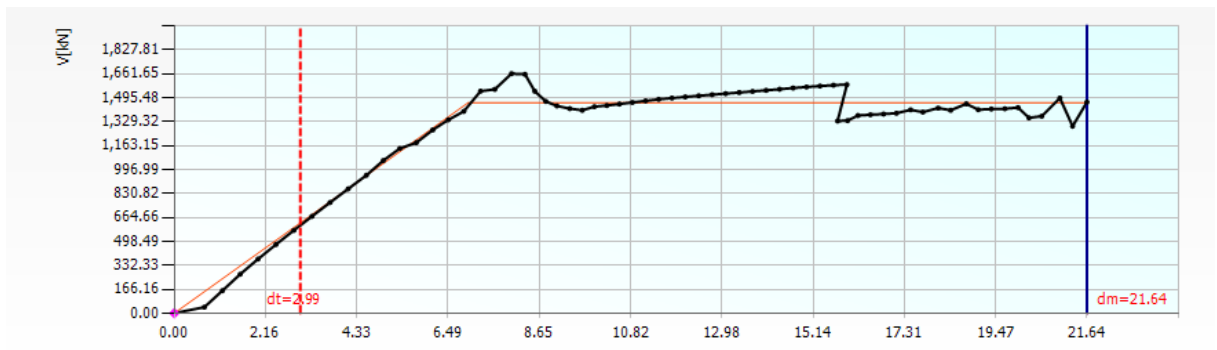


Figure 4.27: pushover analysis in wall 1 in y-direction.

- Wall 3:

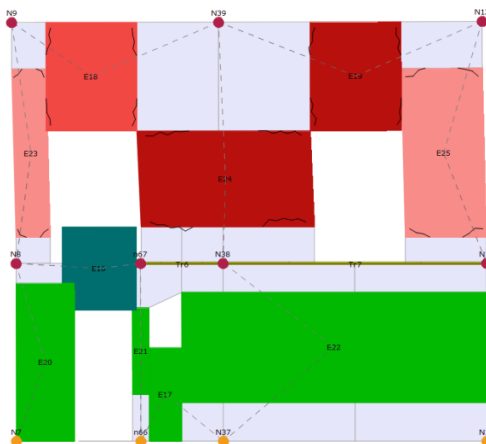


Figure 4.28: distorted in wall 3 in y-direction.

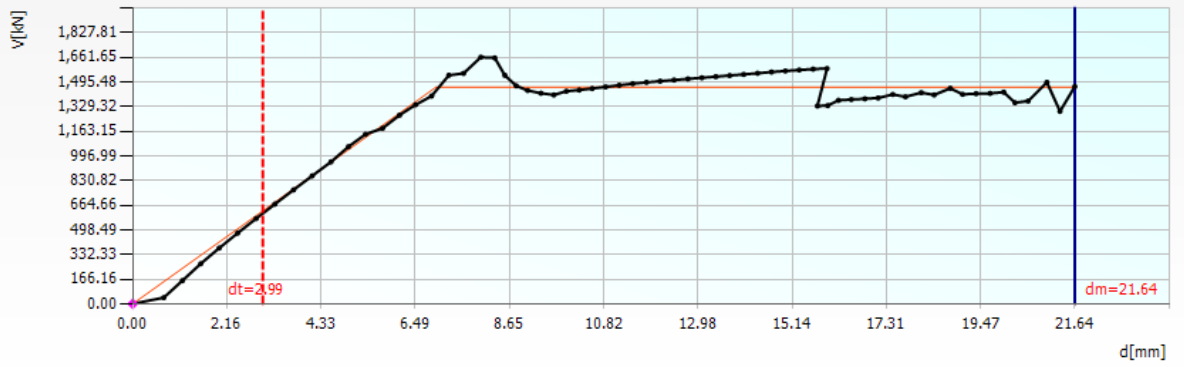


Figure 4.29: pushover analysis in wall 3 in y-direction.

- Wall 4 :

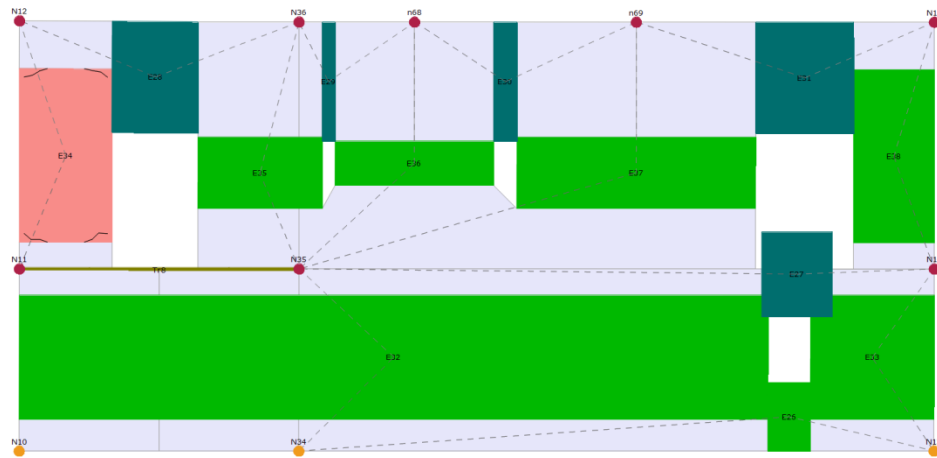


Figure 4.30: distorted in wall 4 in y-direction.

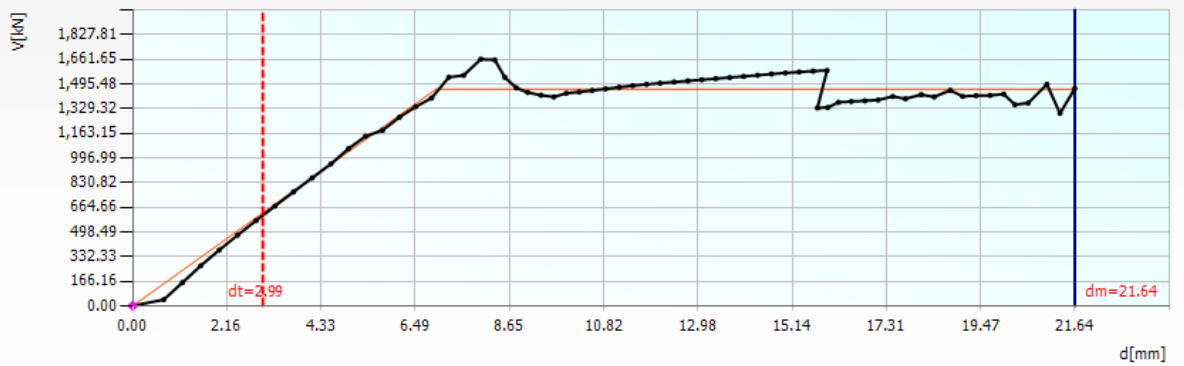


Figure 4.31: pushover analysis in wall 4 in y-direction.

- Wall 5:

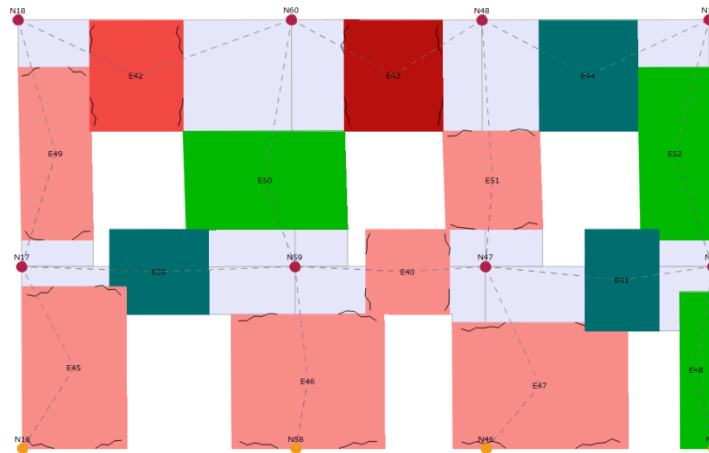


Figure 4.32: distorted in wall 5 in y-direction.

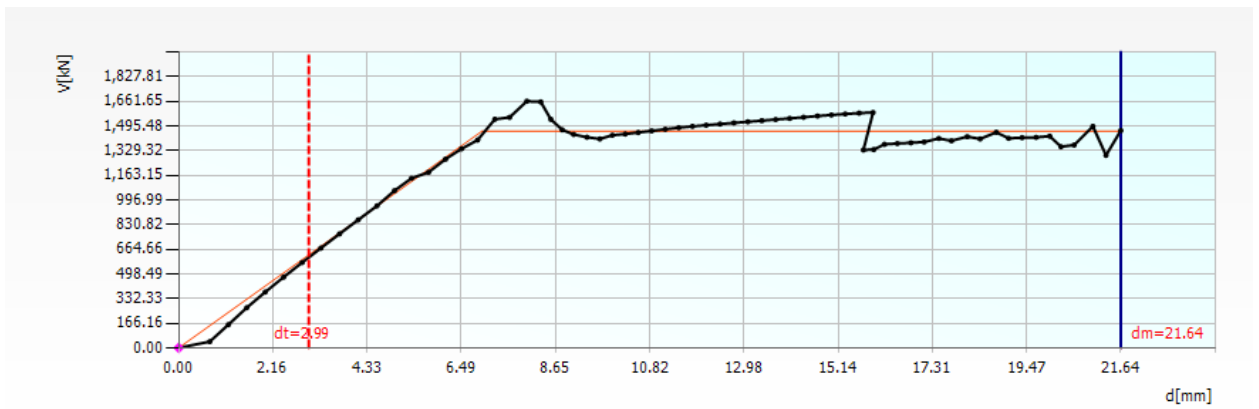


Figure 4.33: pushover analysis in wall 5 in y-direction.

- Wall 6 :

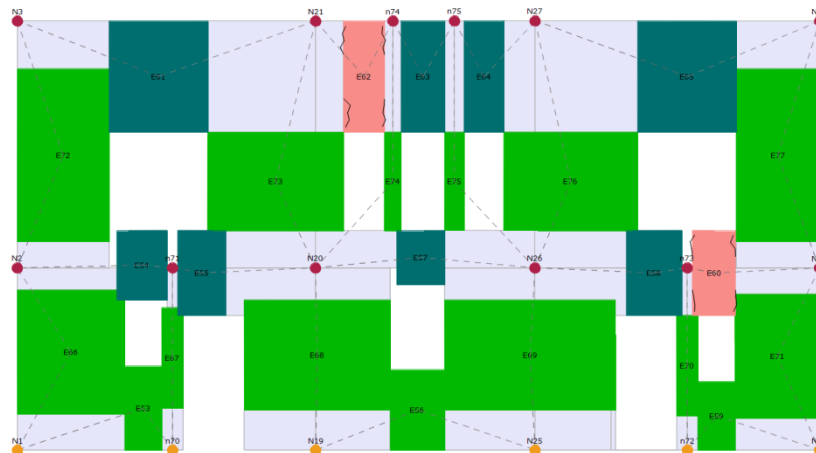


Figure 4.34: distorted in wall 6 in y-direction.

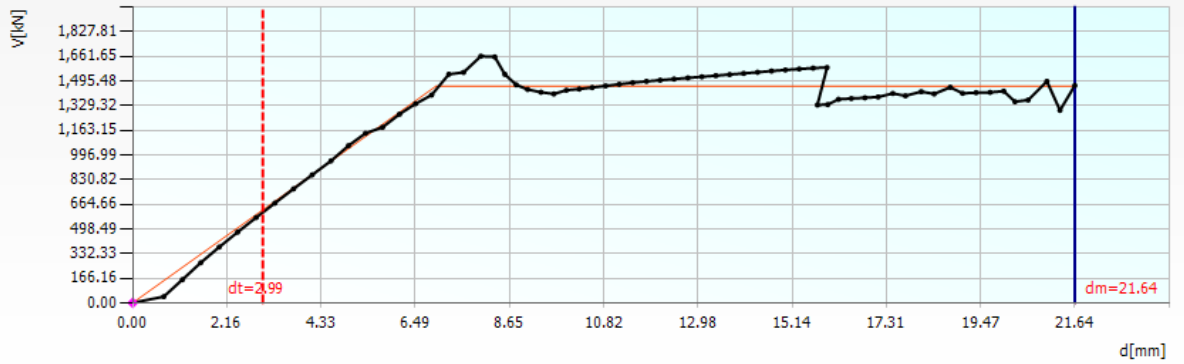


Figure 4.35: pushover analysis in wall 6 in y-direction.

- Wall 8 :

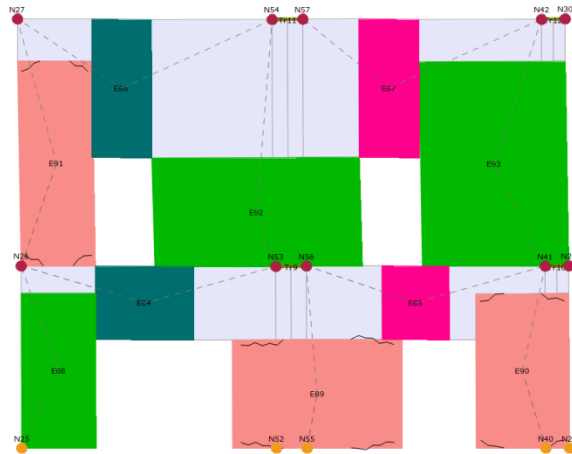


Figure 4.36: distorted in wall 8 in y-direction.

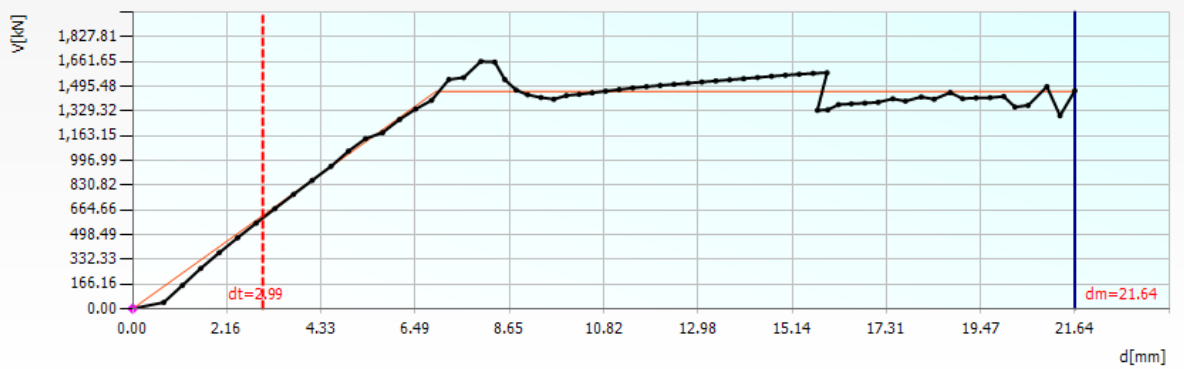


Figure 4.37: pushover analysis in wall 8 in y-direction.

- Wall 10 :

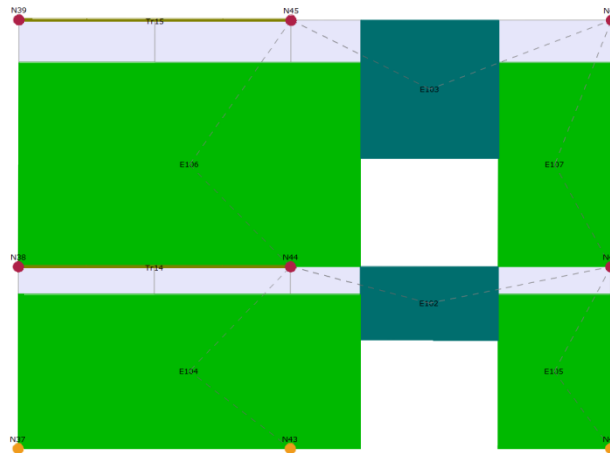


Figure 4.38: distorted in wall 10 in y-direction.

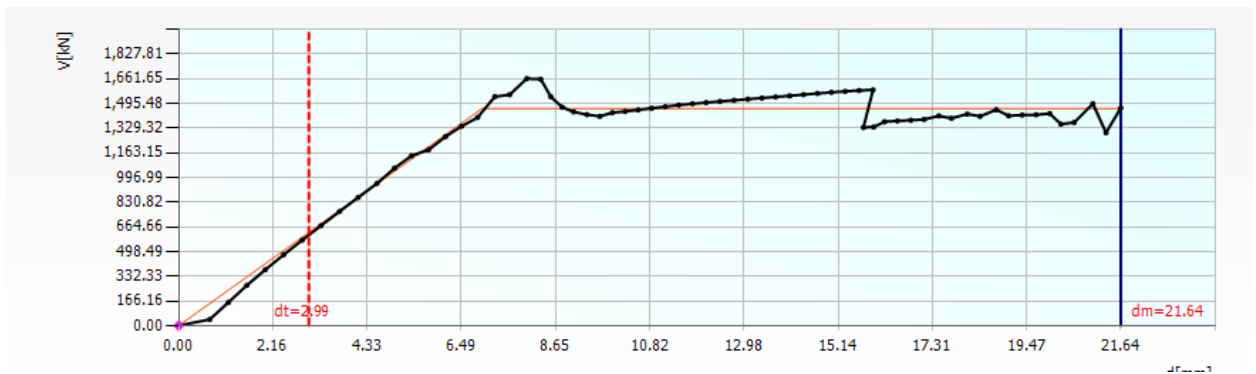


Figure 4.39: pushover analysis in wall 10 in y-direction.

- Wall 13 :

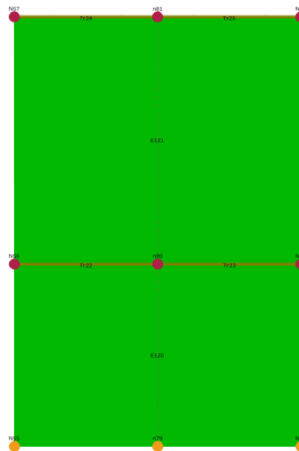


Figure 4.40: distorted in wall 13 in y-direction.

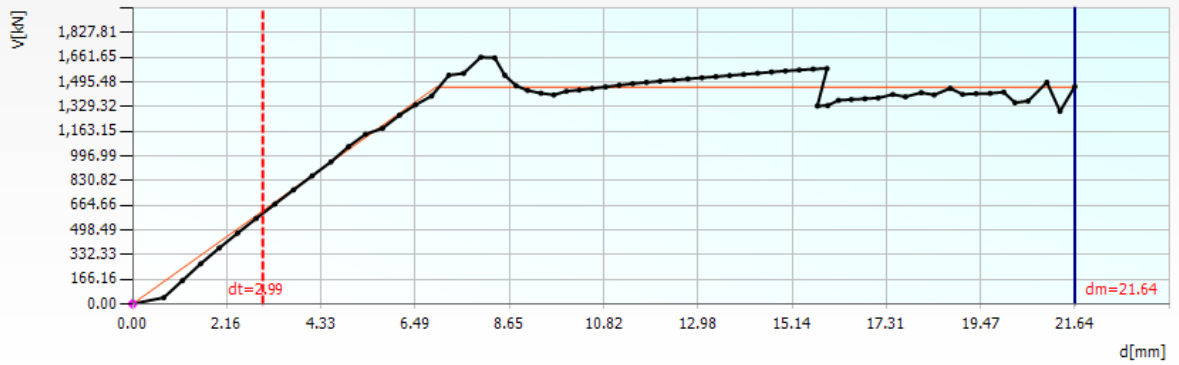


Figure 4.41: pushover analysis in wall 13 in y-direction.

Tables below show the results of analysis in y-direction:

1. The table (4.6) below show the percentage of broken elements presented in case 24 in y-direction.

Wall	Masonry % Wall	Masonry % Building
1	25.4	2.8
2	0.0	0.0
3	26.6	2.2
4	0.0	0.0
5	15.1	1.7
6	0.0	0.0
7	25.2	0.7
8	17.8	1.1
9	29.3	2.2
10	0.0	0.0
11	0.0	0.0
12	0.0	0.0
13	0.0	0.0

Table 4.6: percentage of broken elements presented in case 24 in y-direction.

2. The table (4.7) below show displacement control orders the walls according to the relative interstate displacement in order to identify where the greater displacement occurs.

Main wall	Bottom node	Top node	Relative displacement [mm]	Level	Walls involved
1	2	3	25.24	2	1-6
3	8	9	24.88	2	2-3
9	32	33	22.33	2	9-12
7	20	21	22.28	2	6-7
8	26	27	19.87	2	6-8
5	17	18	16.52	2	5-6
5	16	17	2.49	1	5-6
8	25	26	2.08	1	6-8
7	19	20	1.74	1	6-7
9	31	32	1.72	1	9-12
3	7	8	1.42	1	2-3
1	1	2	1.39	1	1-6

Table 4.7: relative inter-floor displacement.

3. Table (4.8) show “displacement control” environment orders the associated nodes and walls according to the chosen limit displacement.

Walls involved	Node	Displacement [mm]	Level
1-6	1	0.00	0
1-2	4	0.00	0
2-3	7	0.00	0
3-4	10	0.00	0
4-5	13	0.00	0
5-6	16	0.00	0
6-7	19	0.00	0
7-12	22	0.00	0
6-8	25	0.00	0
8-11	28	0.00	0

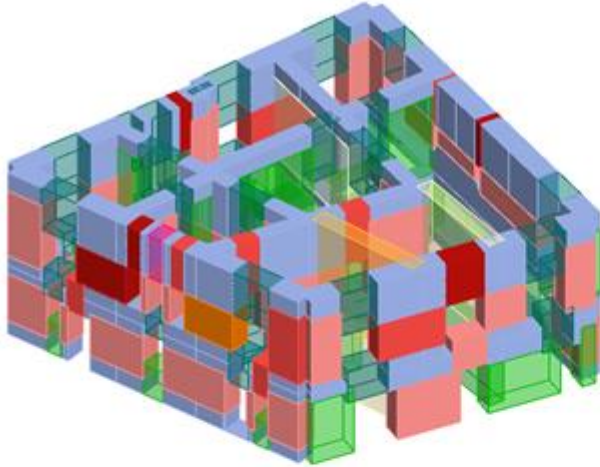
9-12	31	0.00	0
4-9	34	0.00	0
3-10	37	0.00	0
8-10	40	0.00	0
9-10	43	0.00	0
5-11	46	0.00	0
1-12	49	0.00	0
8-12	52	0.00	0
8-13	55	0.00	0
5-13	58	0.00	0
3-4	11	-1.20	1
3-10	38	-1.20	1
1-12	50	-1.22	1
1-6	2	-1.22	1
1-2	5	-1.23	1
2-3	8	-1.24	1
9-12	32	-1.47	1
7-12	23	-1.50	1
9-10	44	-1.50	1
6-7	20	-1.50	1
4-9	35	-1.54	1
6-8	26	-1.72	1
8-13	56	-1.77	1
8-12	53	-1.78	1
8-10	41	-1.80	1
8-11	29	-1.81	1
5-6	17	-1.97	1
5-11	47	-2.02	1
4-5	14	-2.06	1
5-13	59	-2.09	1
4-5	15	-14.91	2
5-11	48	-15.71	2
5-13	60	-16.43	2

5-6	18	-17.53	2
8-11	30	-18.86	2
8-10	42	-18.94	2
8-13	57	-19.78	2
8-12	54	-19.89	2
6-8	27	-20.96	2
4-9	36	-22.08	2
9-10	45	-22.53	2
7-12	24	-23.10	2
9-12	33	-23.33	2
6-7	21	-23.55	2
3-4	12	-25.00	2
3-10	39	-25.47	2
1-2	6	-25.65	2
2-3	9	-25.81	2
1-12	51	-25.92	2
1-6	3	-26.29	2

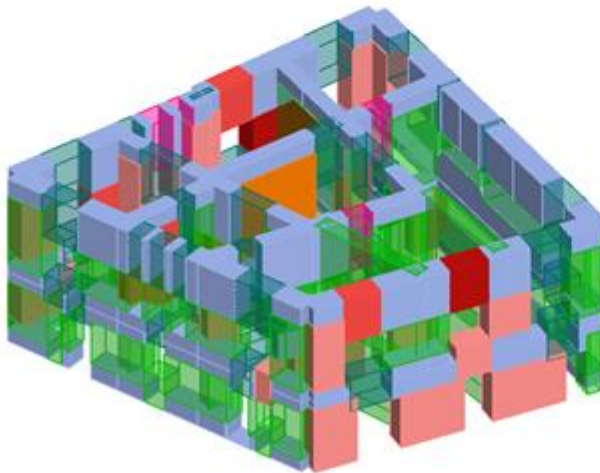
Table 4.8: displacement control.

#### 4.4. Compare displacement between x and y directions :

Comparing displacement between the x, y directions involves analyzing the movement of structure. The displacement data are analyzed to determine their magnitudes (how much movement occurred) and directions (whether the movement was along the positive or negative coordinates of each axis). the figure (4.42) below show the possible Failures for zaitoun building in x and y direction, and notes that the Some walls were affected in both directions due to the irregularity of the building.



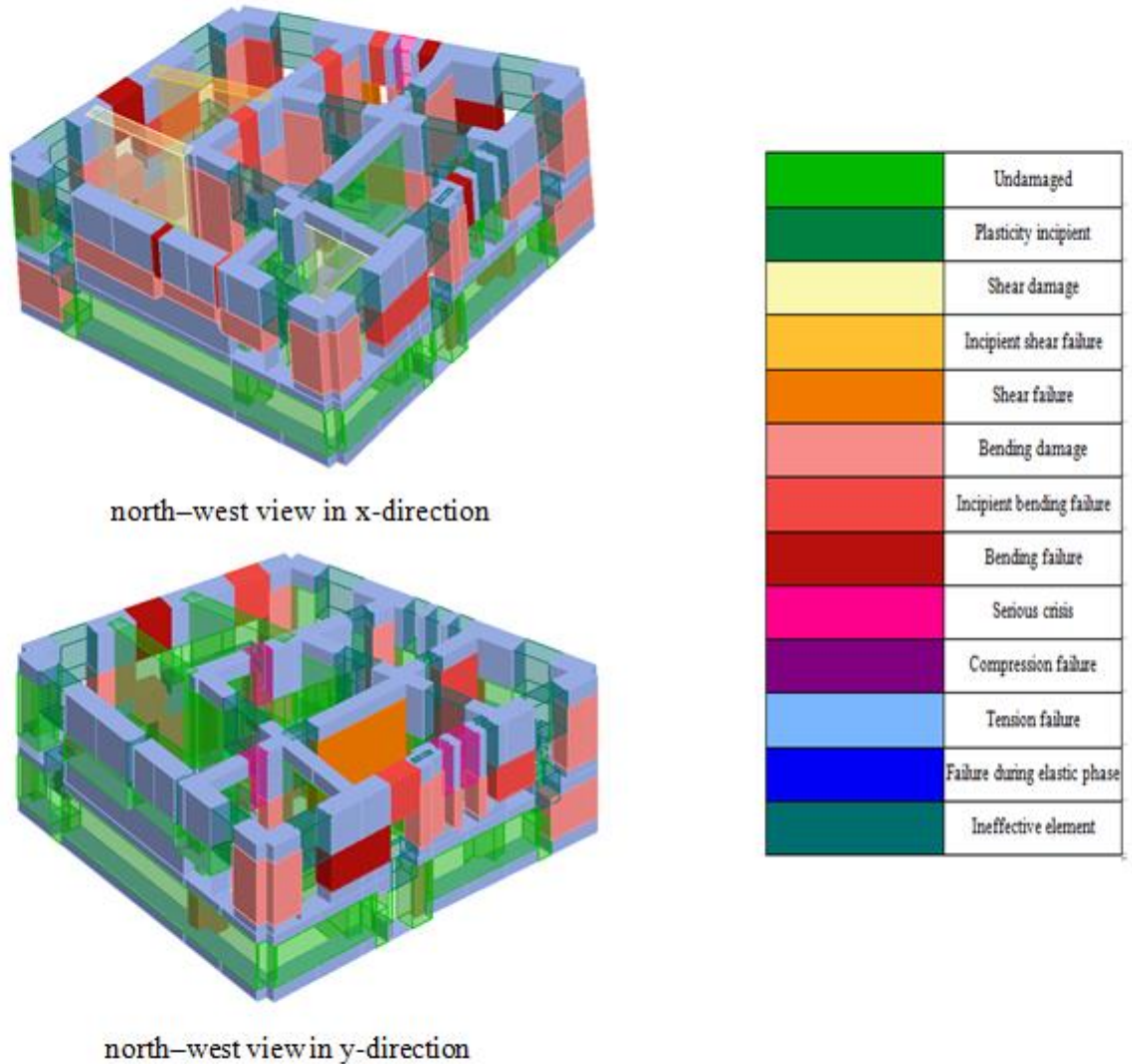
South –east view in x-direction



South –east view in y-direction

a) south –east view

	Undamaged
	Plasticity incipient
	Shear damage
	Incipient shear failure
	Shear failure
	Bending damage
	Incipient bending failure
	Bending failure
	Serious crisis
	Compression failure
	Tension failure
	Failure during elastic phase
	Ineffective element



b) north –west view.

Figure 4.42: Compare between x and y directions.

in general, if walls are affected by earthquakes in both direction X and Y directions due to the irregularity of the building, it indicates a significant structural vulnerability. the irregularities can impact walls in both directions in: [45] (Abd-El-Rahim and Farghaly, 2010)

1. Lateral Shaking: walls can experience lateral forces caused by earthquake. Irregularities in the building's structure, such as asymmetrical distribution of mass or inadequate bracing, can lead to uneven stress on walls.
2. Shear Forces: Walls perpendicular to the direction of shaking may experience shear forces, causing them to crack or fail. Irregularities in the building's layout or

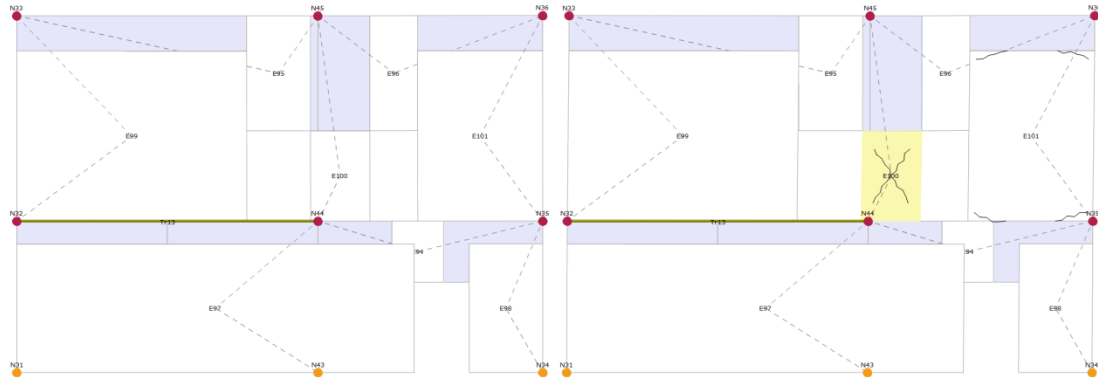
design can exacerbate these effects, as some walls may be more heavily loaded or supported than others, but it is known that the masonry buildings were not designed against lateral load .

3. Toppling: If the building lacks proper reinforcement or anchoring, walls can be prone to toppling over due to the lateral forces exerted by the earthquake.

Irregularities in wall height or placement can further increase the risk of toppling.

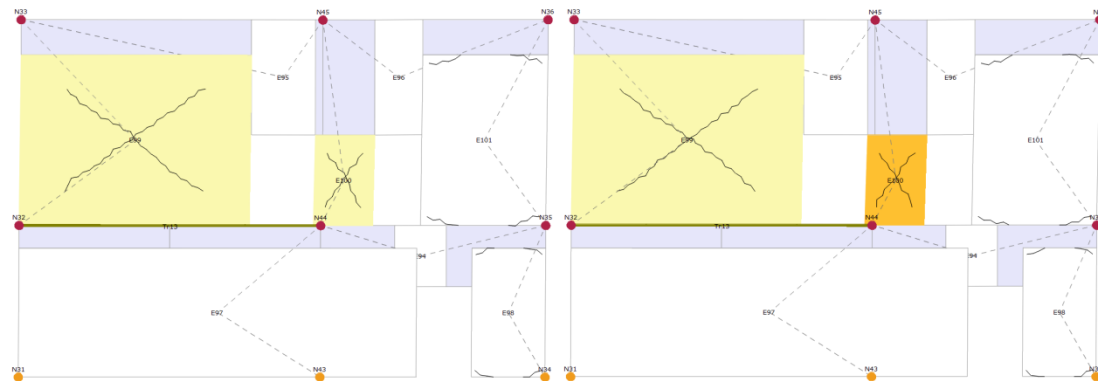
#### 4.5. Failures analysis

After analysis the building in x and y direction we have many failures, shear and bending. In shear failure divide to Shear damage, incipient shear failure, and shear failure represent different stages of the response of a structure to shear forces. Shear damage is a broad term that encompasses any form of structural deterioration or impairment resulting from shear forces. It can include a range of issues, such as cracking, deformation, or sliding within the structural elements. Shear damage is a general description and doesn't specify the severity or stage of the damage. Incipient shear failure refers to the initial or early stages of shear damage within a structure. It is characterized by the onset of deformation, cracking, or other signs of structural distress due to applied shear forces. At this stage, the damage may be localized and not yet progressed to a level where it significantly compromises the integrity of the structure. It signals the early warning signs that intervention may be necessary to prevent further deterioration. And shear failure occurs when the structure can no longer resist the applied shear forces, leading to a loss of structural integrity. This is a more advanced and critical stage compared to incipient shear failure. Shear failure can manifest as the collapse of structural elements, severe deformation, or a complete breach of load-carrying capacity. In shear failure, the structure may no longer be able to support the applied loads, posing a risk to safety and necessitating immediate attention. As show below (figure 4.43) show the Stages of shear failure in wall no 9 in y-direction case no.6 with static force before effect the seismic load and, after 36 steps, after 42 steps and in 56 steps.



a. Before effect the seismic load.

b. after 36 steps .



c. After 42 steps.

d. after 56 steps .

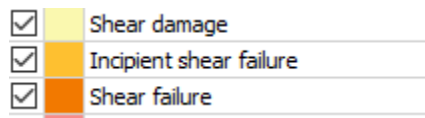
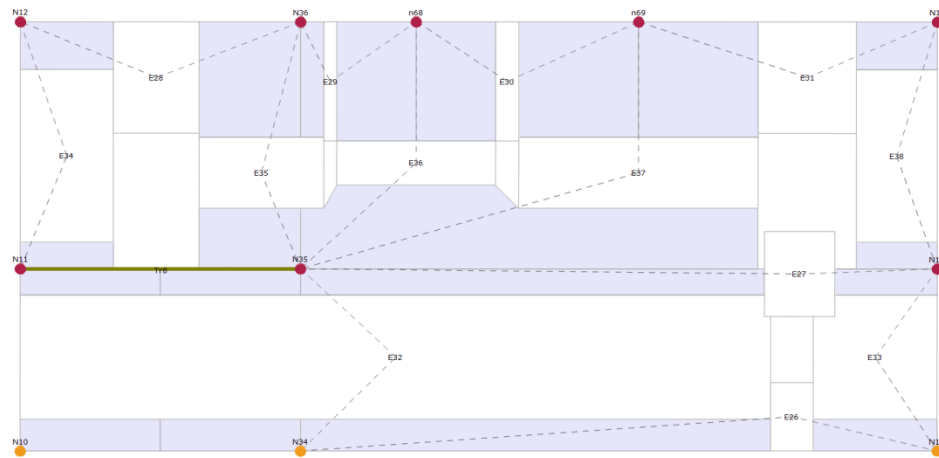


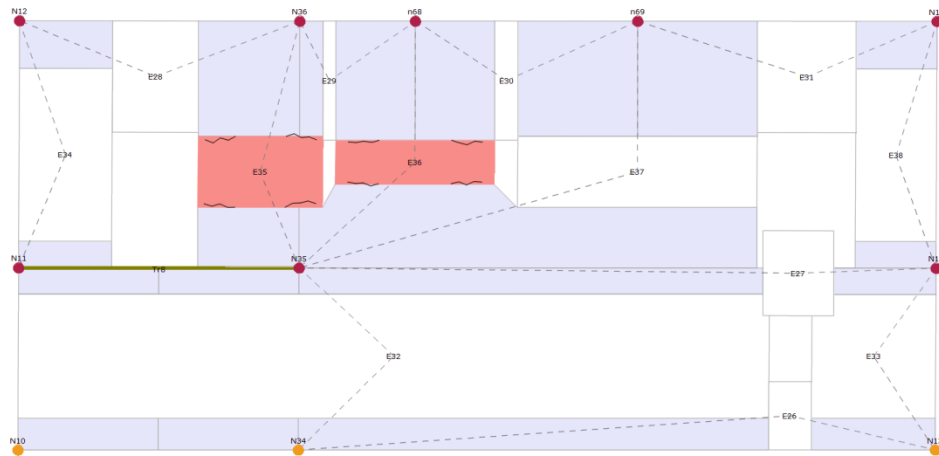
Figure 4.43: Stages of shear failure in wall no 6 in y-direction.

In bending failure divide to Bending damage Incipient bending failure and bending failure are terms that describe different stages of masonry walls refer to different stages of structural response to bending forces. Bending damage in masonry walls refers to any form of structural deterioration or impairment resulting from bending forces. This can include cracking, deformation, or failure of the masonry units or the mortar joints due to the application of bending moments. Incipient bending failure in masonry walls indicates the early stages of damage caused by bending forces. This may involve the initiation of cracks in the masonry units or mortar joints due to the development of bending stresses. At this stage, the damage may be localized, and intervention may be required to prevent further deterioration. And bending failure in masonry walls occurs when the structure can no longer resist the applied bending forces, resulting in a loss of structural integrity. This

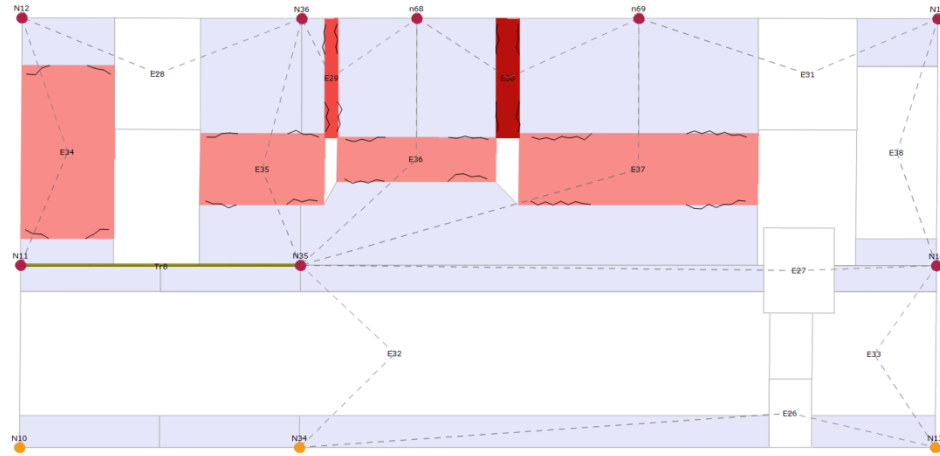
is a more advanced and critical stage compared to incipient bending failure. Bending failure in masonry walls can manifest as severe cracking, deformations, or even collapse of sections of the wall due to excessive bending moments. As show below (figure 4.44) show the Stages of bending failure in wall no 4 in x-direction case no.12 with uniform seismic load before effect the seismic load and, after 35 steps, after 77 steps and in 115 steps.



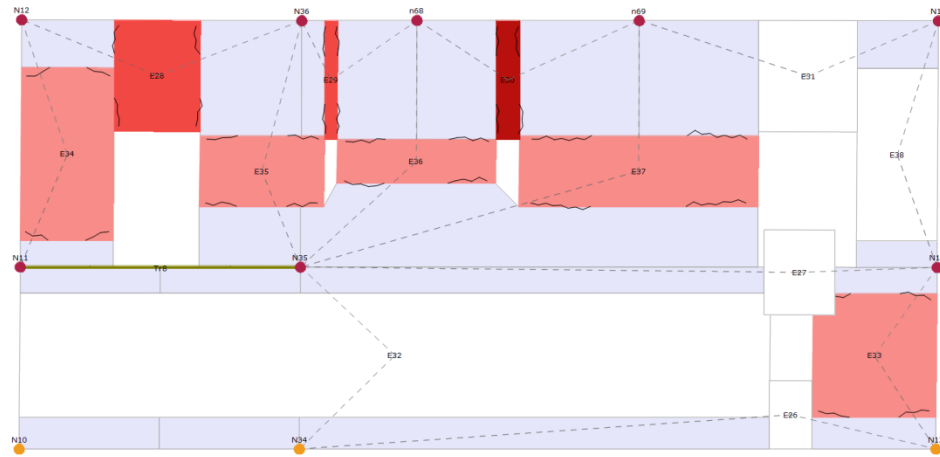
a. Before effect the seismic load.



b. after 35 steps.



c . after 77 steps.



d. after 115 steps.

- Bending damage
- Incipient bending failure
- Bending failure

Figure 4.44: Stages of bending failure in wall no 6 in x-direction.

While analyzing buildings against seismic loads and observing failure areas in relation to shear depending on its types shear damage, incipient shear failure, and shear failure, and in bending failure divide to Bending damage Incipient bending failure and Bending failure, It was noted that most of the failure areas located in Corners, and Areas around doors and windows, Lintel areas (piers). Because they experience both horizontal and vertical forces. The intersection of walls is subjected to different stress patterns, making it prone to cracking and shearing.

In general, after analyzing Zaitoun building against seismic loads, and depending on the findings and the specific requirements of the structure, and after assessment of Structural Integrity, from Evaluate the structural integrity of the building based on the analysis results from 3muri program. We identify a vulnerabilities or deficiencies in the existing structure. And the next step is Reinforcement or Retrofitting, the analysis reveals weaknesses in the building's ability to withstand lateral loads. Reinforcement may involve adding bracing elements, strengthening existing components, or introducing new materials to enhance structural performance.

**CHAPTER FIVE: THE GENERAL CONCEPT OF  
RETROFITTING OF MASONRY BUILDING.**

## 5. The general concept of Retrofitting of masonry building

### 5.1. Seismic retrofitting strategies.

Seismic retrofitting involves making modifications to existing structures to enhance their resistance to seismic activity. The specific retrofitting strategies depend on the type of structure, its current condition, and the seismic risk in the region. As show in figure (5.1) The techniques is based on the principle of providing some additional tensile reinforcement in order to capture the formation of cracks and prevent them from excessive opening and propagation. [44] (Gkournelos, Triantafillou. and Bournas. 2022.)

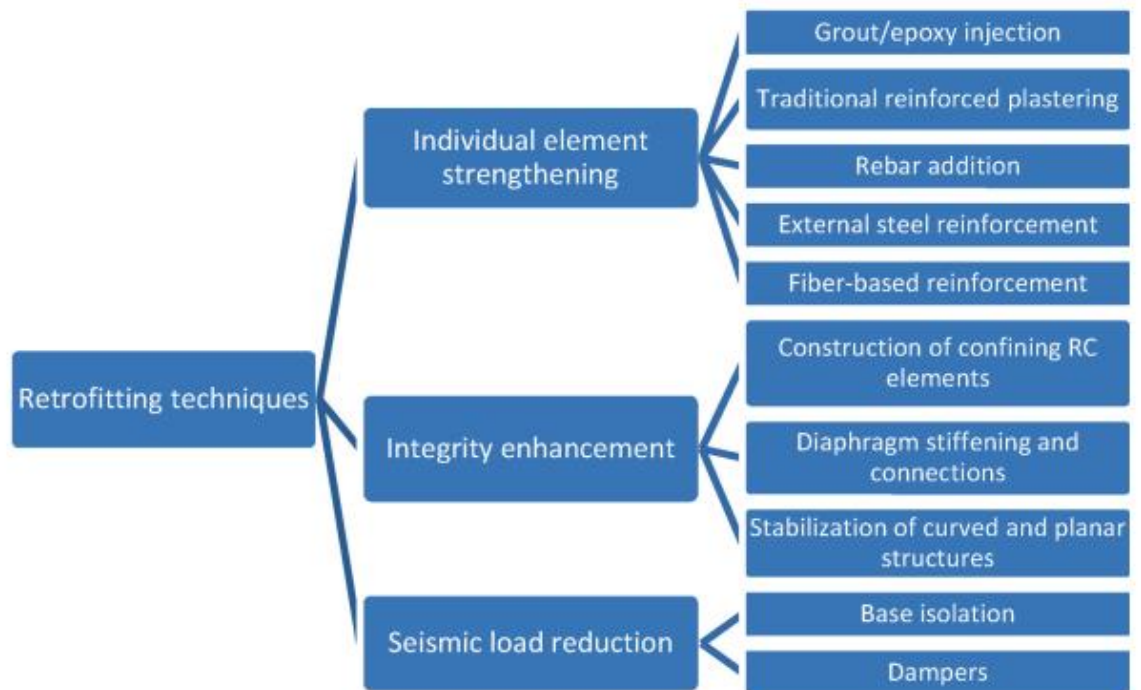


Figure 5.1: Retrofitting strategies for URM structures. [44]

### 5.2. The most important methods used for retrofitting:

Retrofitting of masonry buildings involves the modification or enhancement of existing masonry structures to improve their structural integrity, safety, and performance.

Masonry buildings, constructed with materials like brick, stone, or concrete blocks, may require retrofitting for various reasons, such as changes in building codes, deterioration over time, or the need to strengthen the structure against seismic events. The steps associated with seismic retrofitting of masonry buildings is at first to analysis of the seismic hazard in the region to understand the potential ground shaking and other seismic forces that a building may experience. This assessment helps engineers determine the level of retrofitting required, then Structural Analysis of the masonry building to identify weaknesses and vulnerabilities. This involves examining the load-carrying capacity of walls, columns, and other structural elements.[38] (Sassu, M., Stochino, F. and Mistretta, F., 2017). As a result, retrofitting can be done in several ways, the most important of which is:

1. Base Isolation:

Introducing base isolators between the building's foundation and superstructure. Technique that involves introducing a flexible or sliding interface between a building's superstructure (above ground) and its substructure (foundation or base). Base isolators allow the building to move independently of the ground motion, reducing the transfer of seismic forces to the structure and minimizing potential damage. [39] (Petrovčić, S. and Kilar, V., 2017.)

2. Adding Shear Walls:

Installing reinforced shear walls to improve the lateral stability of the building and reduces the maximum drift of the building considerably. Shear walls are strategically placed to absorb and dissipate seismic forces, preventing excessive swaying or deformation and The shear and moment demand of shear walls are also reduced by including the lateral resistance of masonry walls [40] ( Sartaji, P., Moghadam, A.S. and Ashtiany, M.G., 2018.)

3. External Reinforcement:

Adding external reinforcements, such as steel braces, fiber-reinforced polymers (FRP) or carbon fiber-reinforced polymers (CFRP) to strengthen masonry walls and enhance their ability to withstand lateral forces.

Carbon fiber-reinforced polymers (CFRP) use to increase the horizontal load capacity and deformation capacity, when applied vertically to increase the bending strength and

applied diagonally to strangle the shear capacity. As shown in the fig (5.2)[41] (Bischof, P., Suter, R., Chatzi, E. and Lestuzzi, P., 2014)

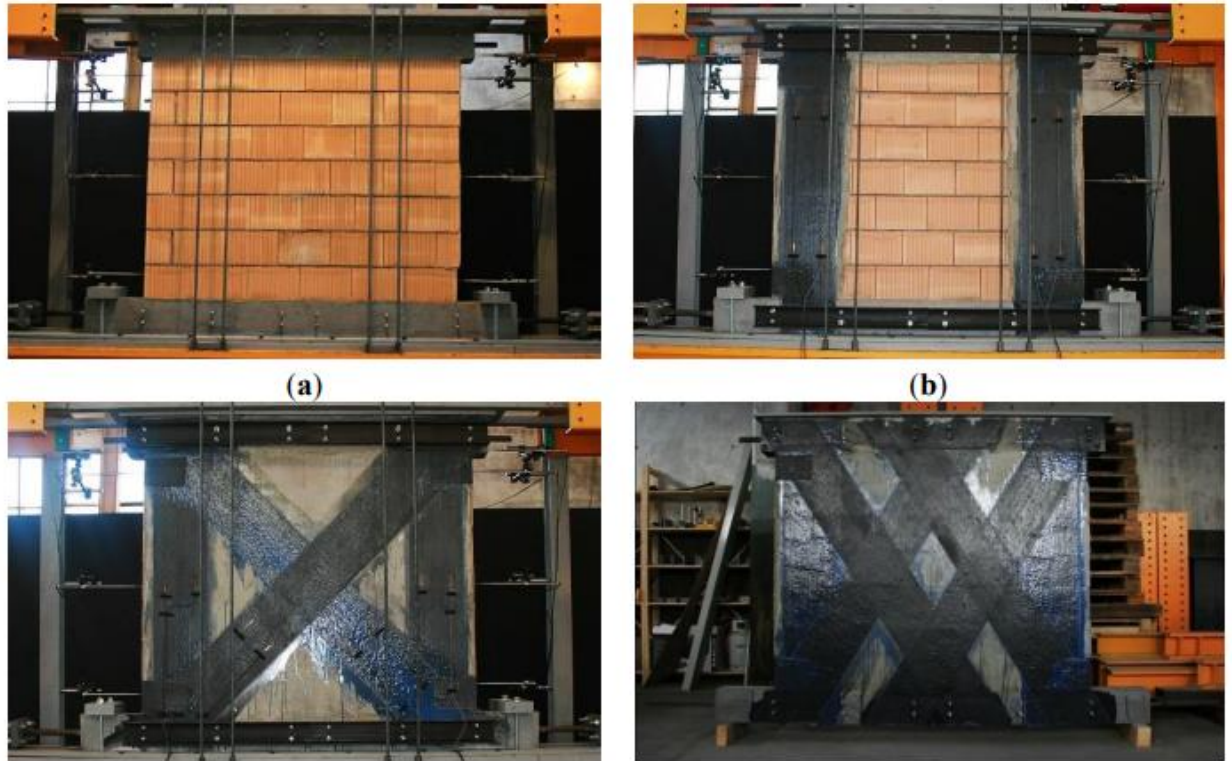


Figure 5.2: Different configurations of CFRP for retrofitting masonry walls.

in figure 5.3 below show the different strategies of using Fiber-Reinforced Polymer (FRP) retrofitting of masonry: (a) and (b) In-plane shear strengthening with diagonal and possibly vertical/horizontal strips and it is a technique used to enhance the seismic resilience and structural integrity of walls and other structural elements susceptible to shear forces during earthquake (c) near-surface mounted FRP strips; are used in structural strengthening to improve the load-carrying capacity and ductility of concrete members,. (d) confinement of masonry columns it use to enhance the seismic performance and load-carrying capacity of masonry structures. [44] (Gkournelos, Triantafillou. and Bournas. 2022.)

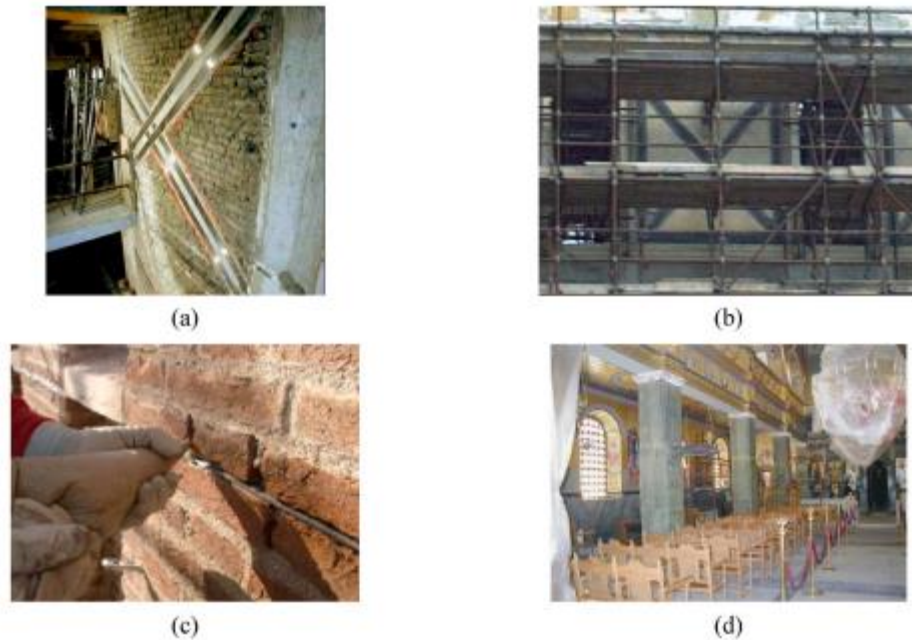


Figure 5.3 different strategies of using FRP retrofitting of masonry

In general, these strengthening materials are used to Strengthening Masonry Walls, it can be used to externally reinforce masonry walls. The application of CFRP sheets or wraps to the surface of masonry elements enhances their flexural and shear strength, addressing weaknesses in the existing masonry. And flexural and Shear Strengthening CFRP laminates or strips can be applied to masonry elements, such as beams or lintels, to increase their flexural and shear capacities. This helps improve the load-carrying capacity of these structural elements.

#### 4. Grouting and Repointing:

Repairing and reinforcing masonry joints through processes like repointing and grouting. This helps improve the overall integrity of the masonry structure.

#### 5. Foundation Upgrades:

Strengthening the building's foundation to better resist seismic forces. This may involve underpinning, adding piles, or enhancing existing foundation elements.

Seismic retrofitting is essential for preserving masonry buildings, especially in regions with a high seismic risk. It not only improves the resilience of the structure but also contributes to the safety of occupants during seismic events. The specific retrofitting

measures depend on factors such as the building's design, condition, and local seismic conditions.

### 5.3. study of retrofitting using 3MURI program

In 2014, Formisano, Iaquinandi and Mazzolani, [46] Study the Seismic retrofitting by FRP of a school building located in Bomporto (Modena, Italy) and hit by the Emilia Romagna Italian earthquake in 2012 and damaged from it , use 3MURI program.

The achieved results have shown that the used software is able to foresee well the damages occurred under earthquake. As shown in figure 5.4

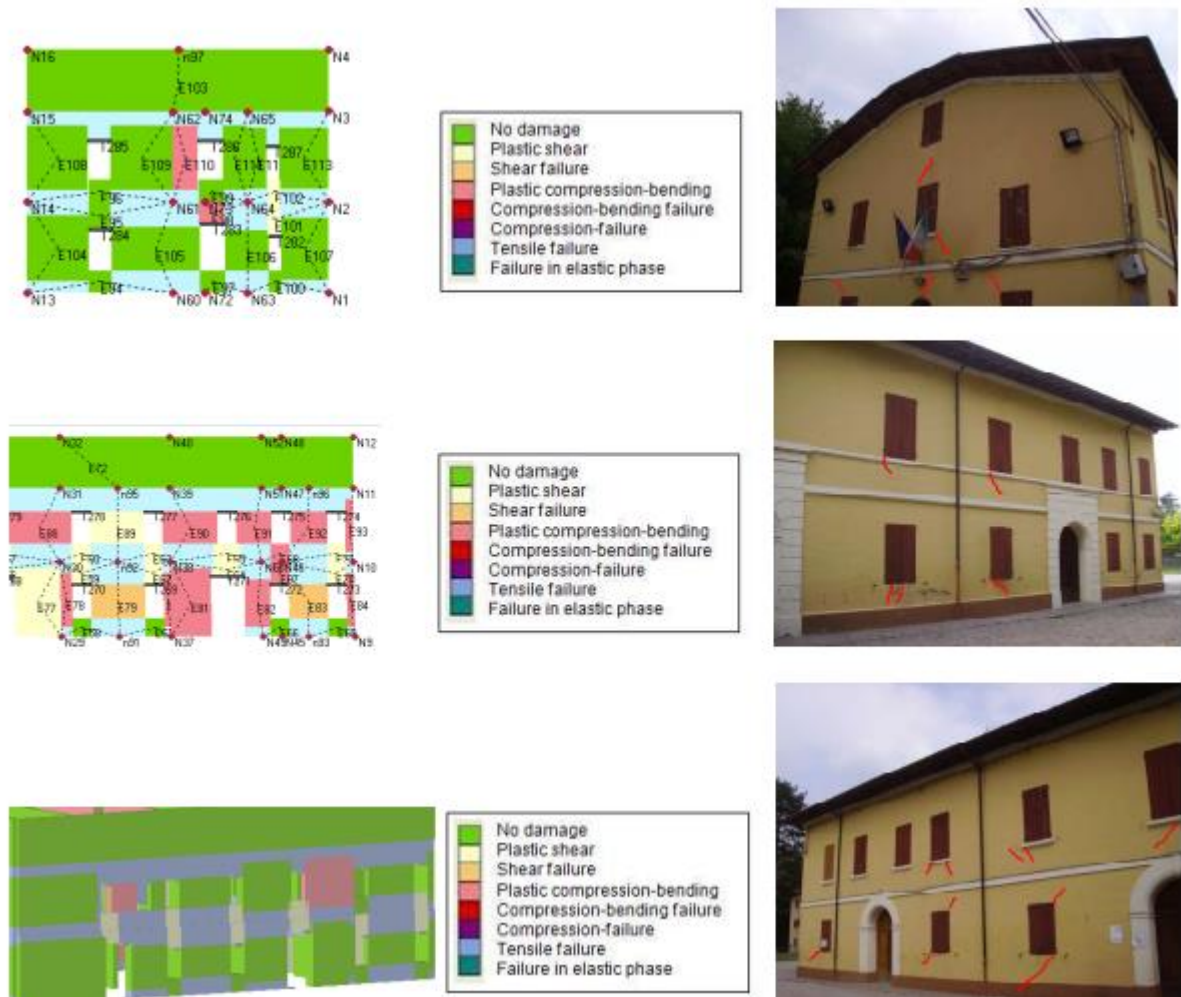


Figure 5.4: Comparison between numerical damages deriving from pushover analyses and real ones. [46]

the analysis of the seismic deficiencies on the school has led to design and apply two different retrofitting solutions for masonry walls, namely jacketing with fiber composite materials and reinforcement with two-direction steel strips. The comparison between the retrofitting building capacity curves has demonstrated that steel strips allows to attain the same ductility and a strength level greater than that offered by composite fiber strips. Moreover, a sensitivity analysis conducted on steel strips with different thicknesses has provided, as the best solution, the one characterized by 7 mm thick elements.

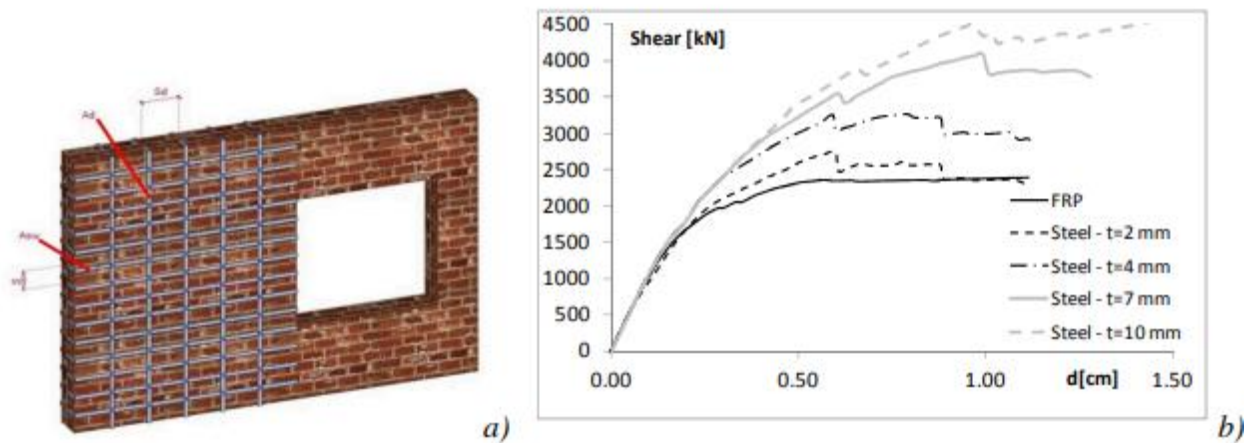


Figure 5.5: Retrofitting intervention (a) with bidirectional strips and (b) comparison among building capacity curves with different reinforcing interventions. [46]

Accordingly, it is possible to retrofitting of zaitoun building using the 3MURI program.

## CHAPTER SIX: CONCLUSION AND RECOMMENDATION

## 6. Conclusion:

This work aimed established to preserve the architecture and historical architecture in the ancient historical buildings in Palestine. As most of these buildings were constructed using large stone blocks joined by mortar, as these links cannot be considered as strong ties to resist dynamic loads and prevent losses in these historical buildings.

In this case, it is required to develop the historical buildings to prevent damage to building elements and components, to preserve the safety of life, and to preserve the cultural and historical significance of buildings. This can be done through the study of non-linear seismic analysis and rehabilitation of historical stone buildings.

The main objective of this thesis is to evaluate the earthquake performance of an existing historical stone building (unreinforced building) subject to seismic load.

The Zaytoun family building located in the old city of Hebron – Palestine will be studied as a study case for this thesis.

The nature of a masonry building can significantly affect its strength and durability. Several factors contribute to this, including the materials used, construction techniques, environmental conditions, and maintenance over time. Here are some key aspects to consider:

### 1. Materials:

- **Type of Material:** The type of material used in construction is crucial. Ancient buildings were often constructed using materials such as stones. The quality and durability of these material can vary significantly, impacting the overall strength of the structure.
- **Quality of Materials:** The quality of the materials used can influence the building's strength. For instance, natural stone with good load-bearing capabilities may contribute to a more robust structure compared to inferior quality stones.
- The materials used and the strength of this materials have a major impact on the analysis of masonry buildings, the shape of stones used in masonry building construction can have several impacts on the structure:

- **Strength and Stability:** Irregularly shaped stones might not fit together as tightly as uniformly shaped ones, potentially compromising the stability of the structure. Uniformly shaped stones allow for tighter fits, leading to stronger and more stable walls.
- **Durability:** Well-fitted, uniform stones can create a more durable structure with fewer gaps for moisture to penetrate, potentially increasing the lifespan of the building. Irregularly shaped stones may result in more gaps and weak points, leading to potential structural issues over time.

but the most impact is the strength of stones differs based on their shapes and how they are cut, can refer to the Italian Building Code, which explains the difference in strength of stones based on the classification of stones. There is also an effect of the type of mortar used. Therefore, accurate and detailed laboratory tests must be carried out on materials in old buildings to obtain good results in analyzing old buildings and to reach failure areas.

2. **Masonry Techniques:** The methods used to join stones or bricks, such as mortar composition and bonding techniques, can impact the building's structural integrity.
3. **Environmental Conditions:**
  - **Climate:** The climate of the region can affect a building's strength over time. For instance, exposure to extreme weather conditions, such as frequent freeze-thaw cycles or high humidity, can lead to deterioration of certain materials.
  - **Natural Disasters:** Buildings in regions prone to earthquakes, floods, or other natural disasters may have been designed and constructed to withstand these specific challenges.
4. **Age and Wear:**
  - **Weathering and Erosion:** Over time, exposure to the elements can cause erosion and weathering of building materials. This can weaken the structure and compromise its strength.

- Foundation Settling: Changes in the soil composition or gradual settling of the foundation over the years can affect the stability of the building.

#### 5. Maintenance and Restoration:

- Maintenance Practices: Regular maintenance, such as repairing damaged areas and addressing structural issues, can contribute to the longevity of a building.
- Restoration Techniques: If a building has undergone restoration or preservation efforts, the techniques used can impact its strength. Modern interventions should ideally complement the original construction without causing harm.

Understanding these factors is crucial for the conservation and preservation of ancient buildings. Conservation efforts often involve a balance between maintaining the historical authenticity of the structure and implementing measures to ensure its continued stability and safety.

- A masonry building constructed without a proper design poses significant risks to its structural integrity, safety, and long-term stability. The absence of a well-thought-out architectural and engineering design can lead to various issues that may compromise the building's strength. Without a well-designed structural system, the building may lack proper load distribution and support. This can result in uneven stress on different parts of the structure, leading to instability and potential collapse.
- Nonlinear seismic analysis and rehabilitation of historic stone structures yield several important results that are crucial for preserving these heritage buildings while ensuring their safety under seismic events. And the most important results reached in the analysis of a building zaitoun building
  - Seismic Performance Assessment: Nonlinear seismic analysis evaluates the structural response of zaitoun buildings under seismic loading conditions. It provides insights into zaitoun building vulnerability to earthquake-induced damage, including potential failure mechanisms in bending or shear failure .

- Identification of Vulnerabilities: Nonlinear analysis identifying vulnerable areas within the zaitoun building, such as weak mortar joints, inadequate connections, or deteriorated stone elements. By pinpointing these vulnerabilities, can develop targeted rehabilitation strategies to improve the zaitoun building seismic performance.
- Evaluation of Retrofitting Options: Nonlinear analysis enables engineers to assess the effectiveness of various retrofitting options for historic stone buildings. This may include techniques such as adding steel reinforcement, installing damping devices, or strengthening vulnerable elements to enhance the structure's seismic resistance while preserving its historical integrity.

Overall, the results of nonlinear seismic analysis and rehabilitation play a critical role in safeguarding historic stone structures against seismic hazards while preserving their architectural and cultural significance for future generations.

- In zaitoun building, the openings not perfectly aligned, a possible choice is to conventionally assume a mean value for the height of spandrel elements as a function of the overlapping part between the openings at the two levels. when no overlap is present or the opening lacks at all, it seems more appropriate to assume the portion of masonry as a rigid area .So in this case we have irregular opening distribution led to have a rigid nodes with complex geometries.

And due to the irregularity of the building the walls are affected by earthquakes in both direction X and Y directions. the irregularities can impact walls in both directions in Lateral Shaking, Shear Forces and Toppling.

## References:

1. Mosalam, K., Glascoe, L. and Bernier, J., 2009. Mechanical Properties of Unreinforced Brick Masonry, Section1 (No. LLNL-TR-417646). Lawrence Livermore National Lab.(LLNL), Livermore, CA (United States).
2. Taghikhany, T., Tehranizadeh, M. and Arabameri, M., 2008, October. Vulnerability of Hybrid Masonry Building under Seismic Action. In The 14th World Conference on Earthquake Engineering. Beijing: Tsinghua University Press.
3. Bayraktar, A., Altunışık, A.C. and Muvafık, M., 2016. Field investigation of the performance of masonry buildings during the October 23 and November 9, 2011, Van Earthquakes in Turkey. *Journal of Performance of Constructed Facilities*, 30(2), p.04014209.
4. Laurenc0, P.B., Rots, J.G. and Blaauwendraad, J., 1995. Two approaches for the analysis of masonry structures: micro and macro-modeling. *HERON*, 40 (4), 1995.
5. Calvi, G.M., Pinho, R., Magenes, G., Bommer, J.J., Restrepo-Vélez, L.F. and Crowley, H., 2006. Development of seismic vulnerability assessment methodologies over the past 30 years. *ISET journal of Earthquake Technology*, 43(3), pp.75-104.
6. Pelissou, C. and Lebon, F., 2009. Asymptotic modeling of quasi-brittle interfaces. *Computers & Structures*, 87(19-20), pp.1216-1223.
7. Parisi, F. and Augenti, N., 2013. Assessment of unreinforced masonry cross sections under eccentric compression accounting for strain softening. *Construction and Building materials*, 41, pp.654-664.
8. Magenes, G. and Calvi, G.M., 1997. In-plane seismic response of brick masonry walls. *Earthquake engineering & structural dynamics*, 26(11), pp.1091-1112.
9. Ponte, M., Milosevic, J. and Bento, R., 2019. Parametrical study of rubble stone masonry panels through numerical modelling of the in-plane behaviour. *Bulletin of Earthquake Engineering*, 17, pp.1553-1574.
10. Restrepo-Velez, L.F. and Magenes, G., 2004, August. Simplified procedure for the seismic risk assessment of unreinforced masonry buildings. In *Proceedings of the 13th world conference on earthquake engineering*.
11. Borri, A., Corradi, M., Castori, G. and De Maria, A., 2015. A method for the analysis and classification of historic masonry. *Bulletin of Earthquake Engineering*, 13, pp.2647-2665.

12. Sorrentino, L., D'Ayala, D., de Felice, G., Griffith, M.C., Lagomarsino, S. and Magenes, G., 2017. Review of out-of-plane seismic assessment techniques applied to existing masonry buildings. *International Journal of Architectural Heritage*, 11(1), pp.2-21.
13. De Felice, G., 2011. Out-of-plane seismic capacity of masonry depending on wall section morphology. *International Journal of Architectural Heritage*, 5(4-5), pp.466-482.
14. D'ayala, D. and Speranza, E., 2002. An integrated procedure for the assessment of seismic vulnerability of historic buildings. In *12th European conference on earthquake engineering* (p. 3).
15. Dowrick, D.J., 2009. *Earthquake resistant design and risk reduction*. John Wiley & Sons.
16. Rahul, M. and Ravikant, P., 2018. Approaches for analysis of seismic behavior of structures: A review.
17. Martino, R., Spacone, E. and Kingsley, G., 2000. Nonlinear pushover analysis of RC structures. In *Advanced technology in structural engineering* (pp. 1-8).
18. Mercuri, M., Pathirage, M., Gregori, A. and Cusatis, G., 2023. Analysis of the behavior of the masonry Medici tower resorting on a hybrid discrete-kinematic methodology. *Procedia Structural Integrity*, 44, pp.1640-1647.
19. Rathod, K.V. and Gupta, S., 2020. A nonlinear time history analysis of ten storey RCC building. *International Research Journal of Engineering and Technology*, 7, pp.7153-7160.
20. Facconi, L., Plizzari, G. and Vecchio, F., 2014. Disturbed stress field model for unreinforced masonry. *Journal of Structural Engineering*, 140(4), p.04013085.
21. Chopra, A.K. and Goel, R.K., 2002. A modal pushover analysis procedure for estimating seismic demands for buildings. *Earthquake engineering & structural dynamics*, 31(3), pp.561-582.
22. Budnitz, R.J., Apostolakis, G. and Boore, D.M., 1997. *Recommendations for probabilistic seismic hazard analysis: guidance on uncertainty and use of experts* (No. NUREG/CR-6372-Vol. 1; UCRL-ID-122160). US Nuclear Regulatory Commission (NRC), Washington, DC (United States). Div. of Engineering Technology; Lawrence Livermore National Lab.(LLNL), Livermore, CA (United States); Electric Power Research Inst.(EPRI), Palo Alto, CA (United States); US Department of Energy (USDOE), Washington DC (United States).

23. Lantada, N., Irizarry, J., Barbat, A.H., Goula, X., Roca, A., Susagna, T. and Pujades, L.G., 2010. Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE vulnerability index method. *Bulletin of earthquake engineering*, 8, pp.201-229.
24. Meghraoui, M., 2015. Paleoseismic history of the Dead Sea fault zone.
25. Aguilar, R., Marques, R., Sovero, K., Martel, C., Trujillano, F. and Boroschek, R., 2015. Investigations on the structural behaviour of archaeological heritage in Peru: From survey to seismic assessment. *Engineering Structures*, 95, pp.94-111.
26. Araújo, A.S., Lourenço, P.B., Oliveira, D.V. and Leite, J.C., 2012. Seismic assessment of st. james church by means of pushover analysis: before and after the new zealand earthquake.
27. Zaslavsky, Y., Rabinovich, M., Perelman, N. and Avirav, V., 2009. Seismic hazard maps in terms of spectral acceleration at period of 0.2 sec and 1 sec for design response spectrum (tow-point method) in the new version of the Israel building code (SI 413). *The National Steering Committee for Earthquake Preparedness, Report No. 522/474*, 9, p.36.
28. Bucchi, F., Arangio, S. and Bontempi, F., 2013, September. Seismic assessment of an historical masonry building using nonlinear static analysis. In *Proceedings of the 14th International Conference on Civil, Structural and Environmental Engineering Computing, Sardinia, Italy* (Vol. 36).
29. Bose, D.C. and Paul, M.M., 2014. Non-linear seismic analysis of masonry structures. *International Journal of Engineering and Technology*, 3, pp.1367-1378.
30. Preciado, A., Orduña, A., Bartoli, G. and Budelmann, H., 2015. Façade seismic failure simulation of an old Cathedral in Colima, Mexico by 3D Limit Analysis and nonlinear Finite Element Method. *Engineering Failure Analysis*, 49, pp.20-30.
31. Giordano, E., Clementi, F., Nespeca, A. and Lenci, S., 2019. Damage assessment by numerical modeling of sant'agostino's sanctuary in offida during the central italy 2016–2017 Seismic Sequence. *Frontiers in Built Environment*, 4, p.87.
32. Eren, N., Brunesi, E. and Nascimbene, R., 2019. Influence of masonry infills on the progressive collapse resistance of reinforced concrete framed buildings. *Engineering Structures*, 178, pp.375-394.

33. Anecchiarico, M., Portioli, F. and Landolfo, R., 2010, August. Micro and macro finite element modeling of brick masonry panels subject to lateral loadings. In *Proc., COST C26 Action Final Conf* (pp. 315-320).
34. Kumar, A. and Pallav, K., 2018. Static and dynamic analysis of unreinforced masonry wall using finite element modeling in senate hall building. IASEM Conferences.
35. Capanna, I., Aloisio, A., Di Fabio, F. and Fragiaco, M., 2021. Sensitivity assessment of the seismic response of a masonry palace via non-linear static analysis: A case study in l'aquila (italy). *Infrastructures*, 6(1), p.8.
36. Mangia, L., Ghiassi, B., Sayın, E., Onat, O. and Lourenço, P.B., 2016. Pushover analysis of historical Elti Hatun mosque.
37. <https://www.birzeit.edu/ar/about/life-at-bzu/earthquakes/history>
38. Sassu, M., Stochino, F. and Mistretta, F., 2017. Assessment method for combined structural and energy retrofitting in masonry buildings. *Buildings*, 7(3), p.71.
39. Petrovčić, S. and Kilar, V., 2017. Seismic retrofitting of historic masonry structures with the use of base isolation—modeling and analysis aspects. *International Journal of Architectural Heritage*, 11(2), pp.229-246.
40. Sartaji, P., Moghadam, A.S. and Ashtiany, M.G., 2018. Interaction of masonry walls and shear walls in masonry buildings. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, 171(3), pp.226-240.
41. Bischof, P., Suter, R., Chatzi, E. and Lestuzzi, P., 2014. On the use of CFRP sheets for the seismic retrofitting of masonry walls and the influence of mechanical anchorage. *Polymers*, 6(7), pp.1972-1998.
42. Lagomarsino, S., Penna, A., Galasco, A. and Cattari, S., 2013. TREMURI program: an equivalent frame model for the nonlinear seismic analysis of masonry buildings. *Engineering structures*, 56, pp.1787-1799.
43. Elghazouli, A. ed., 2016. *Seismic design of buildings to Eurocode 8*. CRC Press.
44. Gkournelos, P.D., Triantafyllou, T.C. and Bournas, D.A., 2022. Seismic upgrading of existing masonry structures: A state-of-the-art review. *Soil Dynamics and Earthquake Engineering*, 161, p.107428.

45. Abd-El-Rahim, H.H. and Farghaly, A.A., 2010. Influence of structural irregularity in plan floor shape on seismic response of buildings. *JES. Journal of Engineering Sciences*, 38(4), pp.911-928.
46. Formisano, A., Iaquinandi, A. and Mazzolani, F.M., 2014. Seismic retrofitting by FRP of a school building damaged by Emilia-Romagna earthquake. *Key Engineering Materials*, 624, pp.106-113.