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Structural Static Evaluation of Historic Stone Building (Case Study: Zahdeh Building in Hebron Old City)

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Abstract
The historical buildings are of great importance, as they represent the architectural heritage and the image of history. Accurate structural analysis of stone buildings is a real challenge, as the mechanical properties of stone and mortar units are different and unavailable. The aim of the research is assessment historical stone buildings. An experimental study was conducted to determine the mechanical properties of stone building materials and to modelling validation. A numerical modelling was carried out through a non-linear static analysis based on a macro finite element model, using ANSYS. The result obtained of the model of Zahdeh building is that building can bear its loads in its current condition, and it also has the ability to bear loads equivalent to two floors. The proposed methods, are suitable for structural assessment process and can be applied to similar building models to preserve, both architectural heritage and historic buildings
Keywords: Historical Buildings; Mechanical Properties; Non-linear analysis; Macro modelling; Ansys.

1. Introduction

Palestine witnessed several different periods of its history, so it has a great architectural heritage even though it is a small country (Abuarkub & Al-Zwainy, 2018). Traditional Palestinian architecture used stone on a large scale, especially limestone (Angiolilli & Gregori, 2020), which is the main material in buildings with bonded lime mortar or clay, without using cement and reinforced concrete (Hadid, 2002). The traditional Palestinian construction method for walls is based on the use of thick, of double leave walls of stone, the space between the layers is filled with mud (Hebron Rehabilitation Committee, 2017).

Historical building are a reflection of the culture, history, and science of their builders. As evidence of the innovative spirit of ancient cultures, stonework has been utilized to construct the oldest monuments and is found the most remarkable (Amer, Aita, Mohamed, Torky, & Shawky, 2021). Also, it is a fundamental part of the heritage in many countries (Duran & Chavez, 2022).

Stone structures are the most durable, available and one of the oldest building materials (Smoljanovic, zivaljic, ZeljanaNikolic, & Munjiza, 2018). It is a heterogeneous material mainly composed of units and joints (Betti, Galano, & Vignoli, 2016), which has complex mechanical behavior and brittle behavior in tension is a major reason for the high nonlinearity (Briccola & Bruggi, 2019). The mechanical behaviour of stone structural elements exhibits non homogeneity and directional properties, and generally common features: high specific mass, low tensile and shear strengths and low ductility (brittle behaviour), in addition to cracking due to weakness and brittleness of mortar joints. (Autiero, et al., 2020 ; Hamdy, et al., 2018 ; Kamal, et al., 2014).

The safe and economical operational solution for evaluating heritage structures is based on detecting the beginning of the damage, then performing a structural analysis that requires essentially the knowledge of the mechanical properties of building material, which is beneficial to the efficient and effective restoration (Li,2012; Giaccone,2020). So, the evaluation of historical building structures is a challenging task, mainly due to the inelastic and inhomogeneous mechanical response of the material (Autiero, Martino, Ludovico, & Prota, 2020).

Determining the compressive strength of ancient historical buildings is of fundamental importance for structural evaluation, since building structures are mostly stressed in compression (Marotta, et al., 2016; Lourenço & Pina-Henriques, 2006). A non-destructive testing method can obtain valuable information, but not provide sufficient information about the properties of materials that are needed in advanced modeling. On the other hand, the destructive tests that are performed either on site or by removing large samples from the building, give accurate results, but require high cost, effort, and exposing the building to damage (Oliveira, 2003).

The finite element method is best suited for analyzing building structures, as nonlinear analyzes is the most effective method for its ability to trace the structural response of a building structure from the elastic stage through cracking and crushing to failure, and gives acceptable results (Pegon, et al., 2001; OZEN, 2006; Li, 2012).

Experimental studies and numerical models are an integrative method for conducting a structural analysis of a building, to give a complete and comprehensive description of mechanical behaviors, and an understanding of response structural buildings.

In this research, the structural evaluated process Zahdeh building in Hebron old city is analyzed, based on an integrated approach which includes a set of experimental, simulations, and numerical analysis.

In order to bridge the knowledge gap in this field, the behavior and mechanical properties of traditional stones available in Hebron Old city, mortar, and the prismatic models were studied, under compressive loads, taking into account rubble stone with low strength mortars. Numerical analysis using nonlinear analysis is performed through finite element for an old building in the Hebron Old City, using the ANSYS program, based on Willam-Warnke criteria failure. In addition, A macro-modeling method including units and mortar is followed.
All the experiments were carried out at Building Materials Technology Laboratory of PPU, in cooperation with Stone and Marble Center, Hebron.

1.1 Problem Statement

Historical buildings are importance in documenting an entire civilization and era. As that found of many ancient historical buildings that need a structural evaluation in order to preserve its sustainability, durability, the architectural style, and revive them to be suitable for use. The process of evaluating and modeling historical buildings is difficult challenge for several reasons, the main difficulties in evaluating the performance of historical buildings is summarized in the following points:

- Complex geometry, difference in mechanical properties and the behavior is heterogeneous of structural elements.
- Lack of knowledge about the mechanical properties of the building's components, due to the lack of studies around experiments that carrying old stone and mortar as equivalent materials.
- Modifications, repairs and other interventions during their life, often times, these repairs were carried out with almost different materials.
- The analysis of building structures is usually performed to assume linear isotropic behavior, as this type of analysis reduces the structural capacity, and not giving accurate results or real values. In addition to the non-applicability of concrete laws to old building materials. Therefore, nonlinear analysis, which is capable of describing the behavior of the structure from cracking until complete loss of strength, has been adopted.
- Over the past years and currently, adding loads or floors to existing buildings and changing the uses of buildings occur at different stages of time and without proper planning and urban oversight, and the mixing of uses appears in the same building.

1.2 Research Questions

- Can the old historical buildings have the ability to carry their current load for long and short term, but in this study short term analysis is done?
- Is it possible for old historical buildings to bear additional loads?
- What is the impact of the structural evaluation on preserving the historical buildings?
- Is the structural analysis of old buildings similar to modern buildings?

1.3 Research Goal and Objectives

The main objective of this study is to develop a method for assessment of load carrying capacity of historical stone buildings by using experimental and nonlinear methods. Particularly, the study has the following sub-objectives:

- To determine mechanical properties of constitutive materials which contain stones and mortars materials of ancient building, in addition to describe stress-strain behavior.
- To perform a FE model, which can predict the behavior of the historical stone buildings.
- To check if the historical buildings can sustain an extra load.

1.4 Research Approach

This study includes quantitative and qualitative research methods. The research methodology is mainly based on experimental tests and numerical analysis. A literature review was conducted to describe methods and tools that are needed in experimental tests and numerical simulations, based on published empirical and analytical research.
Structural assessment, is a wide activity, involves several and different types of complementary requirements. These can be summarized and ordered as:
1) On-sight visits to the Old City of Hebron and the case study building took place many times aiming at:

- Preliminary tasks (field surveys, geometrical characterization, historical investigations, etc.)
- Diagnosis of existing and observed damage, looking for respective possible causes.
- Obtaining the structural and architectural plans for the building.
- Measurements of walls thickness, mortars and stones dimensions
- Taking photos for the building from inside and outside.
- On-sight collection of stones of different types and sizes to conduct experimental tests.
- Conducting tests by Schmidt Hammer to obtain compressive srength of mortar and stone in different places inside and outside.

2) Experimental tests of stone and mortar using non-destructive methods in the laboratory.

3) Conducting validation between experimental and numerical analyses (models) of flexural beams and wallet samples using ANSYS.
4) The analytical models are compared with experimental models to verify results and validate used analytical parameters.
5) Conducting numerical simulation of the case study building depending on mechanical properties of experimental test and empirical equations according to code.
5) A macro finite element model was used in this study for detailed analysis of the nonlinear behavior of ancient structures.
6) Numerical simulations of the structural response under relevant to mechanical properties of materials and pertinent loading conditions.
7) Determine the condition of the building.

1.5 Research Significance and Relevance

The research is important for preserving of historical buildings, This, in turn, extends the life of buildings to reach future generations. The process of preserving heritage historical buildings is considered an integral part of sustainability that relates to the social cultural pillar. heritage buildings conservation achieves most of the pillars of sustainability. Currently, Palestinian historical buildings are an important asset, due to their cultural and architectural value.

The structural of the paper consists of :

- **Introduction**

contains a brief introduction to the research. A comprehensive background about Problem Statement, research questions, purpose, research significance and the general methodology of this thesis are presented.

- **Material and Methods.**
- **Building Description**

This section describes the architectural and structural of the Zahedh building, the building materials used.

- **Experimental Work**

The experimental work, which is one of the main large parts of the work of this study contain:
details of materials, equations,tables and diagrams, tests results of stone, mortar and model samples of stones and mortar.

- **Numerical Analysis and Modeling**

This is one of the main parts of this study, contain:
Validation of Modelling by comparing the analytical models with experimental models, Numerical simulations of the structural by A macro finite element model based on nonlinear analysis

- **Result &Discusion.**

The results compresive & flexural strengthm of all samples, calculations, comparisons, validations, simulations and analysis.

- **Conclusion.**

gives a summary of the main findings. Conclusions are made on the experimental work and numerical analysis and modeling.

1.7 Sustainability of Historical Buildings in Palestine

Historic buildings and sustainability are closely related, so preservation of historic buildings and sustainability are natural partners (Jelincic & Glivetić, 2020). The process of preserving and renovating historical Palestinian buildings is considered the most sustainable in terms of construction activities (Historic Preservation Office, 2019). (Salameh, Touqan, JihadAwad, & Salameh, 2022) focused on the heritage value of preserving Palestinian historical buildings in a sustainable manner; from an environmental, economic, and social perspective. Added to that (Redden & Crawford, 2020)& (Said & Alsamamra, 2019) emphasized that the traditional Palestinian historic buildings style have an architectural and construction style that meets the requirements of sustainable green building.

1.8 Mechanical properties of materials

The basic mechanical properties of historical materials include compressive and flexural tensile strength, , modulus of elasticity, Poisons ratio, and stress-strain response of constituent materials. It is necessary to understand the strengths and weaknesses of the old building structures, to understand the behavior, and exploitation of their structural potentials, and to be able to evaluate the structure, also understanding deformation properties are required, to compute the settlement of historical structures (Khair & Hossain, 2005). (Gonen & Soyoz, 2021) investigated modules of elasticity of stonework structure in Turkey, ten wallets with approximate dimensions of 320x120x440 mm (length x thickness x height) were formed, using NHL mortar with an average thickness of 10mm, the average results of the values for each of the material compressive strength = 12.34Mpa, and the modulus of elasticity 5490Mpa.

1.9 Numerical modeling and nonlinear analysis

Mostly the numerical analysis of building structures is performed using the finite element method (FEM) (Kamal, Hamdy, & El-Salakawy, 2014) (Ramu, Raja, & Thyla, 2013).

Finite Element Method (FEM) plays a major and important role in better understanding structural behavior where FE models can evaluate capacities beyond maximum load, failure analyzes, locations of stresses and cracks with their various patterns, displacement force relationship etc. (Khair & Hossain, 2005) , in addition that is a technique widely used in structure analysis of heritage building (Giaccone, Fanelli, & Santamaria, 2020).

For the modeling of historical stone structures, the most commonly used failure criteria are Drucker-Prager and Will am-Warnke failure criteria (Khair & Hossain, 2005). (Giordano, Mele, & Luca, 2002).

ANSYS is a nonlinear FE based on a standard crack-stained approach. To predict construction failure, this model is able to determine the failure modes of crushing and cracking (Giordano, Mele, & Luca, 2002).

(Ferrero, Lourenço, & Calderini, 2020) evaluated a school in Italy which built from stone and mortar. A macro modeling approach was chosen, using a 3D finite element (FE) model, to represent building materials, the materials properties of stone masonry were adopted in the numerical model as the following: Specific weight 21KN/m3, Elasticity modulus 1740MPa, Poisson's ratio 0.2, Compressive strength 2.67MPa, Tensile strength 0.108 MPa, The analytical model gave accurate predictions, where the results show the failure mechanisms and cracking pattern.

2. Material and Methods

This section is divided into three parts:

2.1 Building Description

Zahdeh building is located in the center of the old city of Hebron, which can be reached by vehicle or on foot. In addition to the presence of commercial traffic in this place, as a result of the extension of the market near it.

Zahdeh building has medieval-based architecture, which gives great value to it. The building is composed of two main floors, rising above the shops and stores with a total area of about 550 square meters, where the first and second floors are residential,the internal spatial organization shown in Figures 1. The building is roughly rectangular in shape, with an open and covered courtyard on the second floor. The access path between the levels of the floors is through three stairs, the first from the external entrance to the first floor, the second from the first floor to the second, and the last one is open from the second floor to the roof, all of them are made of stone stairs.

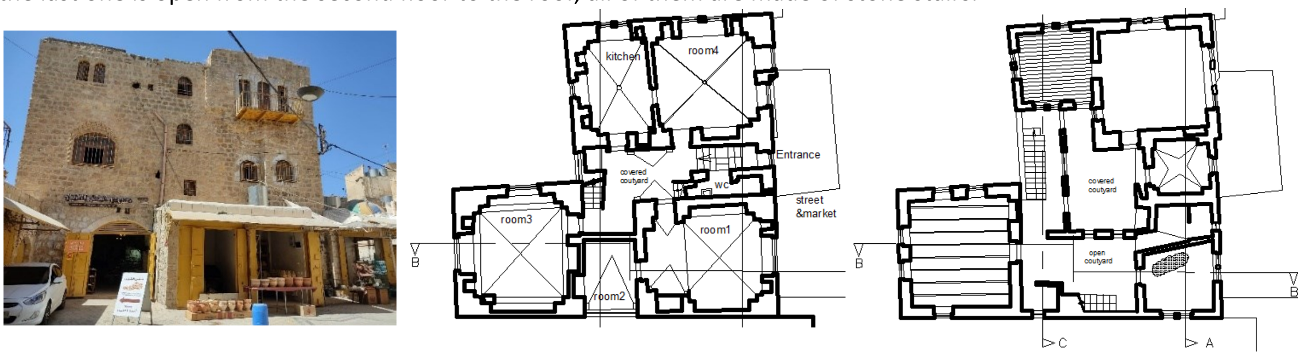


Figure 1:(Left) Front facade of the building, (Middle) First floor,(Right) Second floor.

Local traditional building materials have been used, such as:

- Historical natural stone.
- Pottery: It is one of the local building materials and is used in ceilings as a filler for voids.
- Lime: It is used as a bonding material between the stones in the structural elements, and it is used in plastering and to fill the spaces between the courses of the walls. Lime mortar and lime mixture mortar: adopted in this study represents and resembles the old material that is found in a historical stone building. It contains no cement; thus, it has lower strength values compared to modern mortars with Portland cement content. Lime mortar based on NHL 3.5 natural hydraulic lime, which is a powerful mortar alternative selection that offers all the flexibility that comes with natural lime (Stazi, Pierandrei, Perna, & Tittarelli, 2022).
- Natural Fine Aggregate and sand.
- Clay: It was used in filling voids in walls, foundations and ceilings.
- Ash: It has the advantage of reducing cohesion time and has good strength when used.
- Other construction materials were also used, such as zebar, which is the remnants of oils and is devoid of acids. It prevents permeability and works to hold the materials together. It acquires hardness as time passes (Hebron Rehabilitation Committee, 2017).

The structural system of the building is based on the following elements:

- Continuous foundations which loads are transmitted to it from the load-bearing stone walls, with thickness around 1 m (Hebron Rehabilitation Committee, 2017).
- Load-bearing walls with double limestone, total wall thickness between 40-120 cm, with a filler (soil, large aggregates) inside, the surrounding material is lime and sand and crushed pebble. Stone and mortar are used to construct double stone walls, which resist both vertical and horizontal loads in addition to serving as a structural element. It is typical for those walls to be very thick.The ground and first floors of the case-study building have substantial, 0.8 to 1.20 m thick, shale stone walls that are robust. A 0.40 m thick wall may be found on the second story.
- The stone pillars (Patriues) were built of limestone at the four corners of the rooms, through which the roof loads were transmitted to the foundations.
- The cross vaults that form the limestone ceilings, were used in the ground and first floor, in second floor has cross vaults ceiling in addition to the flat ceiling.

2.2 Experimental Work

The materials and construction methods used in this study were selected in method that mimic those found in actual buildings built using the double-leaf stone wall approach. these parameters are used in numerical analysis and to enable the evaluation of historical buildings. Materials and mixtures As mentioned above**.**

Table 1: Mixing ratios for lime mortar (L.M.), Mixing ratios for the lime mixture mortar (L.M.M.)

Materials	Volumetric ratio			
L.M	1	3		
		1.5	1.5	
	NHL 3.5 Lime	Fine Aggregate	Sand	
(L.M.M.)	1	3		
		1.5	1.5	
			0.5	1.0
	NHL 3.5 Lime	Irregular small pieces of aggregate	pottery	Clay

In this study, non-destructive tests were selected in order to preserve the architectural and historical heritage. The experimental program includes a study that examined the mechanical properties of stone structures using conventional mortars, as follows: compression tests on three different types of model samples and flexural tests on double leaf beams, as well as compression and tensile testing of lime mortar and lime mixtures samples, the compressive strength unit's stone, In addition to conducting a Schmidt Hammer test at different locations of building elements on stones and mortar.

2.2.1 Testing of stone units & old mortar

Samples of rubble stones were selected from the old city of Hebron, of different types to mimic the same stones as the historical buildings, stones were collected from collapsed historical building in near location of case study building as shown in figure 2. The compressive strength of stones was obtained from standard cubes (50* 50 *50 mm) and (10 * 10 * 10mm) of different types of stone were tested on Matest hydraulic press machine with a capacity of 1500 KN, and at a speed of the low moving piston about 6 mm / sec, until the samples failed and the crushing load was measured as shown in figure 3.

Figure 2: source location of historical stone & stage of preparing it to cut it into suitable pieces by CNC for experiments.

6 samples of lime mortar and 6 samples of lime mixtures were tested on Matest hydraulic press machine with a capacity of 1500 KN, at a speed of the lower moving piston about 6 mm/s, until the samples were failed and the crushing load was measured. 6 samples of lime mortar and 6 samples of lime mixtures were tested on Tensile machine with a capacity of 8 KN, until the samples were failed and the crushing load was measured.

Figure 3: Compressive strength of (10*10*10) stone, Compressive strength & Tensile strength of lime mortar and lime mixtures.

2.2.2 compressive Strength of model samples

The tested model samples were designed and prepared by reconstructing wall models using stones taken from the demolition of the old buildings of Hebron old city, taking care as much as possible that the walls are similar to those actually found in the historical buildings in the Hebron old city, in terms of stones and mortar mechanical properties, dimensions and arrangements stones. The scale adopted for the samples are 1/6 of the real scale, the 1/6 scale was chosen due to several reason: previous studies showing the conversion coefficients between the prototype scale and the 1/6 scale.

Three different types of model samples that built in the laboratory according to specification ASTM C1314 (ASTM C1314, 2019), Prismatic samples were built in the style of typical ancient building walls, which include double-leafed stone and an inner core of low-strength mortar. The first type double leaf wallets' samples with approximately total dimensions (30 x 15 x 22) cm3 (length, width, height) respectively, with aspect ratio (hs / ts) of 1., which simulates the pattern of the walls of ancient buildings, containing stone in the middle of the model in the direction of width, was chosen to ensure greater strength and cohesion, this type has no similar in previous studies. The second type Included Six prismatic samples with approximately total dimensions (20 x 19 x 23) cm3 (length, width, height) respectively. The third type ncluded double leaf wallets' samples with approximately total 5dimensions (44 x 15 x 22.5) cm3 (length, width, height) respectively, with aspect ratio (hs/ts) of 1.5. All types were built using old mortar and stone pieces with four stone courses and three mortar layers, were built, using old mortar and stone pieces with dimensions ranging from 4-9 cm in length, 4-6 cm in width and 5 cm in height, as shown in Figure 4.

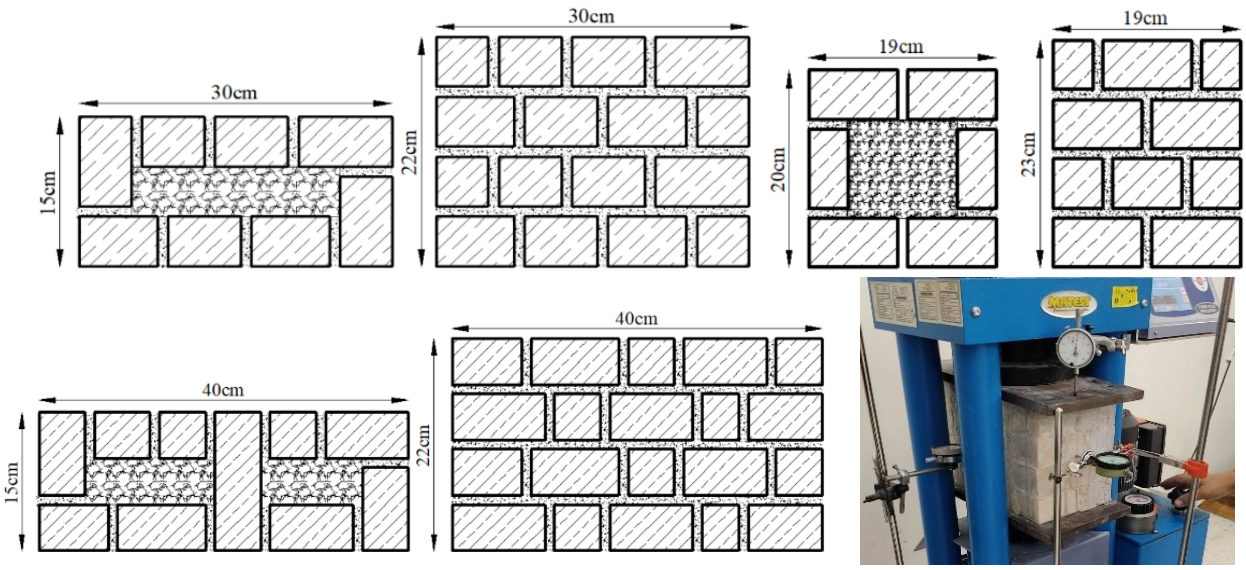


Figure 4: plan and elevation of 30 /20 /40 cm double leaf wallets, Compressive Strength of double leaf wallets.

The compression tests were carried out on 3 types of samples using uniaxial Matest hydraulic press machine with a capacity of 1500 KN 90 days. One ELE with a capacity of 250mm dial gauge was installed on the metal plate in order to capture the vertical displacement, enabling stress-strain diagram to be drawn and calculate the modulus of elasticity, two ELE with a capacity of 250mm dial gauges were installed on the sample faces in order to capture the horizontal displacement, the first one was placed in the longitudinal direction of the samples, the second one was placed in the transverse direction of the samples, then was installed in a central location on the mortar joint, ensuring that it was connected to the surfaces, to calculate the Poisons ratio.

2.2.3 Measurement of flexural Strength

In this paper, two types of samples were adopted when performing the flexural test. The first type includes double leaf beams with approximately total dimensions (55 x 15 x10) cm3 (length, width, height) respectively, three stone courses and two mortar layers, were built, using old mortar and stone pieces with dimensions ranging from 4-9 cm in length, 4-6 cm in width and 2-3 cm in height, in order to determine tensile strength. the second type is the same first but with added two steel bar diameter 6mm, to produce the nonlinear behavior of beam, in order to make validation with FE numerical model.
The flexural test on 6 samples were carried out using Controls Flexural testing machine with a capacity of 50 KN, after 90 days.

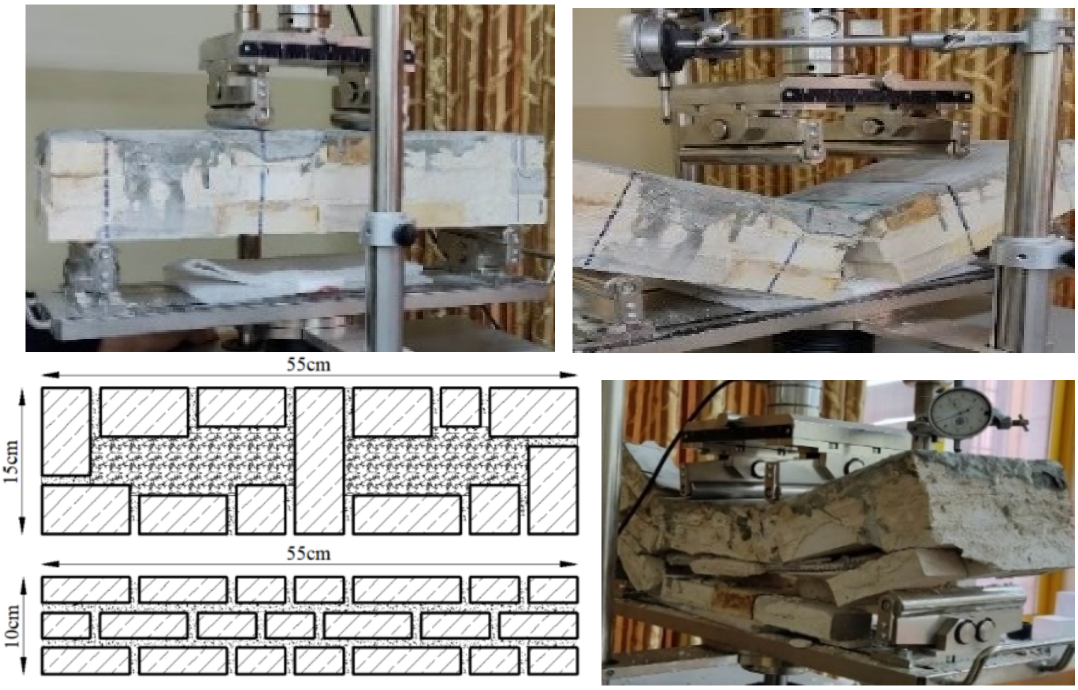


Figure 5: (Top)Flexural Strength sample of 55*15*10 cm double leaf beam without steel/ (Down) Flexural Strength sample of 55*15*10cm double leaf beam with 2 steel barϕ6.

3.3. Numerical Analysis and Modeling

This section is divided into two main parts:

2.3.1 Numerical Analysis and Validation of Modelling

flexural beam (stone with lime mortar) was modeled with SOLID65 element, Steel reinforcement was also modeled using the Link180 element,as for Solid185 is a modeling element used to model the loading and support of steel plates, by nonlinear FE package ANSYS17.2.
Willam and Warnke (1975) failure criteria have been adopted, the Boundary conditions are required added at places of symmetry, due to adopting half of the entire beam was used, to model the symmetry, nodes on this plane must be constrained in the perpendicular direction. These nodes have a degree of freedom constraint UX = 0, as well as the UY, and UZ directions applied as constant values of 0. Material Properties are are used shown in table 2.

Table 2: Material Properties of equivalent materials for ANSYS Flexure Stone Beam.

Material Model	Element Type	Material Properties	
		Linear Isotropic	
		Modulus of elasticity (MPa)	Poisson's ratio
equivalent for stone and lime mortar	Soild65	600-800	0.20
Steel reinforcement	Link 180	200000	0.30
Loading and Supporting Steel Plates	Soild185	200000	0.30

Material Model	Failure Criteria	Open shear transfer coefficients	Closed shear transfer coefficients	Uniaxial tensile cracking stress	Uniaxial crushing stress
equivalent for stone and lime mortar	Willam and Warnke failure criteria	0.2	0.8	0.2 MPa	12 MPa

2.3.2 Numerical Analysis and Modeling of Zahdeh Building

FEM were relied on for structural analysis, thus it became possible to model the complex behavior of the structures of ancient historical buildings.

Description & Geometry of Zahdeh Building Modeling

The Zaheda building was modeled and configured in precise ways, including all the details of the building's architectural and structural elements as it exists based on reality, using the CATIA V5R20 program and then exported to ANSYS. A macro modeling strategy was also adopted.

Table 3: Material Properties and Constants Required of Macro Models for ANSYS Zahdeh Building Model.

Material Model	Element Type	Material Properties		
equivalent for stone and lime mortar	Solid65	Linear Isotropic		
		Modulus of elasticity	Poisson's ratio	weight density
		843MPa	0.20	22 kN/m3

Failure Criteria	Open shear transfer coefficients	Closed shear transfer coefficients	Uniaxial tensile cracking stress	Uniaxial crushing stress
Willam and Warnke failure criteria	0.2	0.8	0.81MPa	8.1MPa

Solid65 is a modeling element used to model (equivalent materials of stone and lime mortar) that represent Zahdeh Building materials . Zahdeh building is modeled as an isotropic material with homogenized properties. Multilinear isotropic hardening material is used to simulate the stone structure. With an isotropic work hardening assumption and a multilinear stress-strain curve as its description. Willam and Warnke (1975) failure criteria have been adopted.

Boundary conditions: The support was modeled in such a way that on the plate was given constraint in the UX, UY, and UZ directions applied as constant values of 0.

Initially, the self-weight and the vertical live loads have been applied to all slab which has different levels in the first load step to the numerical model, where live loads that applied to all slab =2KN/m². This was followed by the application of additional loads that represent floors load that possibly added to the existing building, the additional loads that applied to walls of the existing situation,the loads that have been placed, both in the current situation of the building and in the case of adding loads, in an approximate calculation way, the proposed thickness of the additional slab is 25 cm based on the ACI 9.5.2.1 cod.

Full Newton-Raphson equilibrium iterations and displacement control criteria have been used to facilitate the convergence of these solutions.

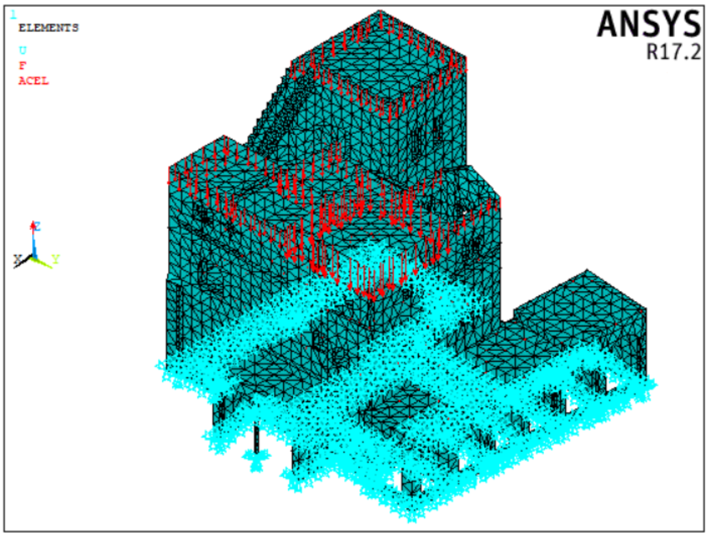


Figure 6: Loading &Support for exist Zadeh Building Model with adding load

3. Results and Discussion

3.1 Results and Discussion of Experimental Work

Tests results of of ancient stones & lime mortar and lime mixture mortar are listed in table 4.

Table 4: Results of mechanical properties of different types of ancient stones & two types of lime mortar.

No. of stone	stone location in the building	loads	Compressive Strength	No. & Type mortar	Vertical loads	Compressive Strength	Tensile load	Tensile Strength
unit	------	KN	MPa	unit	KN	MPa	KN	MPa
A.1	Around windows and doors / soft for engraving	40.3	16.8	L.M. 1	9.7	3.59	1.64	1.18
A.2		43.6	18.28	L.M. 2	9.7	3.74	1.60	1.18
A.3		62.1	25.88	L.M. 3	10.7	4.28	1.60	1.14
B.1	As a structural element in walls, patriues and foundation.	390.0	165.8	L.M. 4	9.5	3.56	1.65	1.18
B.2		219.0	89.9	L.M. 5	10.3	4.00	1.58	1.13
B.3		214.1	91.95	L.M. 6	10.5	4.01	1.63	1.16
C.1		357.7	150.8	L.M.M. 1	12.4	4.96	1.44	1.01
C.2		384.0	161.6	L.M.M. 2	11.4	4.53	1.52	1.06
C.3		207.0	86.2	L.M.M. 3	12.5	4.99	1.36	0.92
H.1		680.7	70.88	L.M.M. 4	12.1	4.80	1.40	1.00
H.2		851.4	92.0	L.M.M. 5	11.6	4.76	1.50	1.07
H.3		1020	104.5	L.M.M. 6	11.9	4.90	1.35	0.96
H.4		677	69.1					
H.5		731.6	78.9					
H.6		632.8	68.8					
H.7		1165	127.4					
Avg			88.7					

Through the results obtained in the tables 4, the stone has high strength, and the Compressive Strength values vary from one sample to another according to the type of stone, where the values range from 68.8 to 165.8Mpa. the stones have high strength and brittle, in contrast to the weak stone such as soft yellow stone, simulated historical mortaras weak and ductile, also is less strong compared to modern mortar.

The compressive strength of stone & mortar models

The models of the samples tested were designed to reproduce the building elements as similar as possible to those found in the historic buildings of Hebron Old City in terms of the mechanical properties of the materials and the arrangement of the stones.

Stone buildings are composite materials consisting of two materials that have completely different properties: stone is more solid and mortar is softer, so that the behavior of these constituent materials differs from that of their basic components. Mortar differs greatly in mechanical properties from stone units. Therefore, the natural of composite and complex geometry result in highly complex structural behavior, and this composite material is characterized as inflexible, inhomogeneous, and anisotropic.

The first model 30 * 15 * 23 gave an average value for compressive strength, modulus of elasticity, and poisons-ratio 15.31MPa, 900-1100 MPa, 0.14-0.25, respectively.

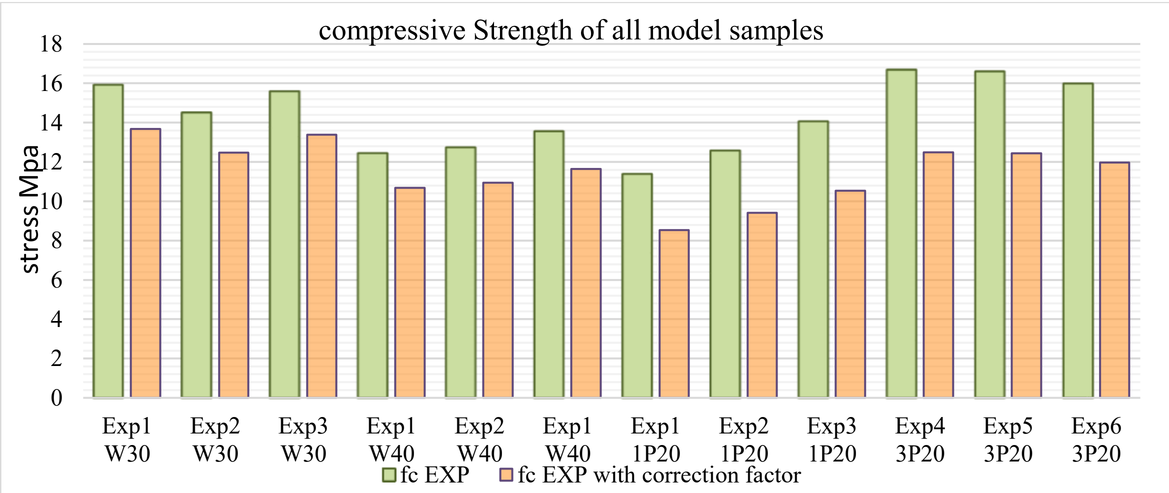
The second model 44 * 15 * 23 gave an average value for compressive strength, modulus of elasticity, and poisons-ratio 12.9MPa, 500-1160 MPa, 0.19-0.27, respectively.

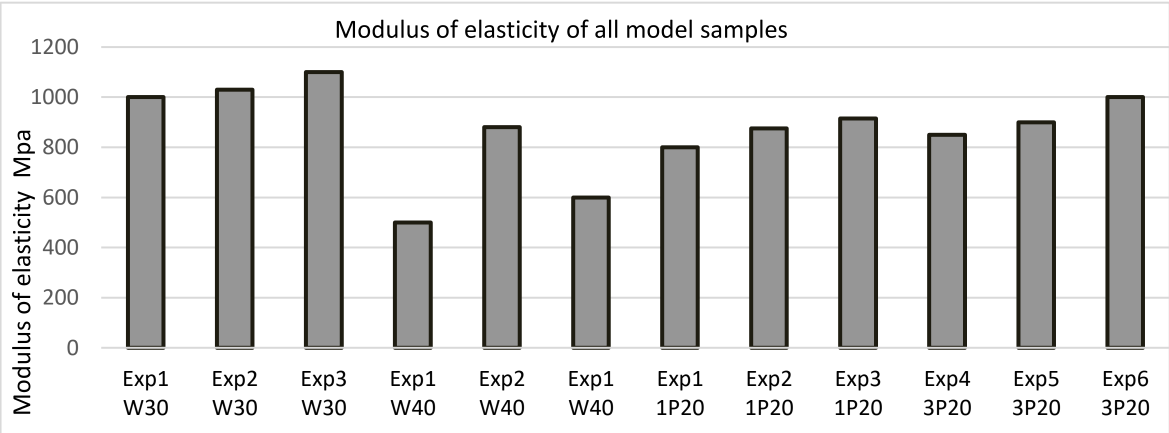
The third model 20 * 20 * 23 gave an average value for compressive strength, modulus of elasticity and poisons-ratio 16.4MPa, 600-1300MPa, 0.20-0.25, respectively.

Figure 7 shows all the results of compressive strength, modulus of elasticity, and stress-strain curves. It was shown that in terms of compressive strength values, the Exp P20 sample gave the highest values. The compressive strength values were multiplied by factor of slenderness,according to the ASTM system, so the values decreased by about 20%.

Through Equation No. 1 It is possible to find the compressive strength of the stone &mortar together, and it gives results close to the experimental results, whether based on laboratory test values or using the Schmidt-Hammer. Through Equation No. 3, the stress at each strain point was calculated, thus the predicted analytical stress-strain curve was obtained, in order to compare it with the experimental results. The stress-strain curve was also drawn based on the analytical prediction equation of Erocode 6, where the modulus of elasticity for each sample was determined based on the initial stiffness obtained from the stress–strain relations at 30-60% fc, in another meaning Ec is calculated as the slope of the linear portion of the stress–strain curve obtained during the compressive strength. The modulus of elasticity was determined using Equation No. 4, and the value of a = 102 was selected based on a study conducted by Costigan, 2015.

The study of the mechanical behavior of all models under compression gave the following results at the age of three months.





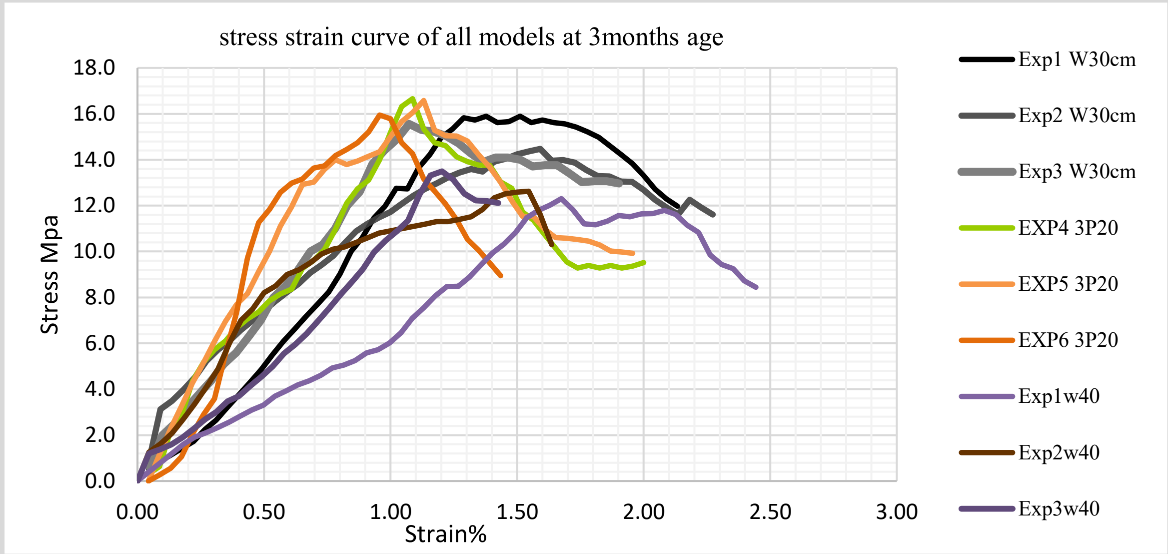


Figure 7: Compressive Strength & fc with correction factor of slenderness, Modulus of elasticity of all model samples, Stress strain curve of all models at 3months age.

Theories that are followed in finding mechanical properties:

$$fc = \alpha \, . fs^{\beta} . fm^{\gamma} \text{ .... } (1)$$

$$\varepsilon_{o} = \frac{K}{fm^{\alpha}} \left(\frac{fc}{Ec^{\lambda}}\right) \text{ .... } (2)$$

where: K is fixed to 0.27, α to 0.25 and λ=0.7 according to (Kaushik, Rai, & Jain, 2007).

$$\frac{\sigma}{fc'} = 2\frac{\varepsilon}{\varepsilon_{o}} - \left(\frac{\varepsilon}{\varepsilon_{o}}\right)^{2} \text{ .... } (3)$$

$$Ec = a.(fc)^{b} \text{.................. } (4)$$

Table 5: Results of Flexural Strength sample of 55*15*10cm double leaf beam with 2 steel barϕ6 and without steel.

No. of beams	Dimensions of beams	55cm 15cm 10cm	
	Steel bar	loads	Flexural Strength Ϭ t
unit		KN	Mpa
1	without	0.750	0.225
2	without	0.687	0.206
3	without	0.736	0.221
1	with 2 bar ϕ6	3.334	1.24
2	with 2 bar ϕ6	2.866	1.10
3	with 2 bar ϕ6	2.650	0.986

Table 6: Summery comparison of Experimental Results & Analytical Predictions with Literature Review on sample Prisms for mechanical properties**.**

		Compressive Strength MPa		Modulus of elasticity MPa	Poisons ratio
Experimental values	Exp of models W30 avg	f 1/6 Scale	8.2	900-1100	0.14-0.25
	Exp of models W40 avg		6.9	500-1160	0.19-0.27
	Exp of models P20 avg		7.6	700-1300	0.20-0.25
	Schmidt hammer / composite of stone &mortar	9.0		1.87	
Analytical Predictions values	Common models	***fs = 88Mpa, fm=2Mpa***		***102 fc***	
	Eurocode6 2005	14.1		-----	-----
	Hendry and Malek(1986)	3.95		-----	-----
	Dayaratnam 1987	3.65		----	----
	Kaushik 2007	7.1		1.44	
	Adrian Costigan 2015	6.1		0.323	
Literature Review based on Experimental	(Wang, Zhou, Wang, & Wang, 2021). Tibetan rubble stone (SPB)	2.6		72.9	-----
	(Gonen & Soyoz, 2021) Clayey-Limestone/ turkey	12.34		5490	-----
	(Shrestha & Bhandari, 2020) Three-leaf stone	6 -7.34		534 –1570	-----
	(Garcia, San-Jose, Garmendia, & San-Mateos, 2012) Double leaf of stone/ ashlar	8.07		446	-----
	(Magenes, Penna, Galasco, & Rota, 2010) Irregular stones and lime mortar/ Italy	3.28		2550	-----

3.2 Results and Discussion of numerical analysis

The verification section was achieved by comparing the results of the non-linear numerical analysis of the models with the results of the experimental test conducted in the laboratory for flexural experiment.

As in table 7 & Figure 8 the numerical load deflection curves and the experimental curves show good agreement between numerical nonlinear analysis by ANSYS with the experimental results.

In response to the research objectives, this paperaimed to evaluate the performance and load-carrying capability of the Zahdeh building, so nonlinear analysis was performed using the FE computer code ANSYS. The results were based on In contour plot to show the first principal stress 1, principal stress 3, and through Nodal obtained the deflection value, also, the support reaction (nodal load) fined in non-linear analysis.

The three main stresses are commonly identified as $\sigma 1$, $\sigma 2$ and $\sigma 3$. $\sigma 1$ represent the maximum (most tensile/ positive value) principal stress, $\sigma 3$ represent the minimum (most compressive/negative value) principal stress. So principal stress can be used to identify whether a material has failed or not.

Ultimate tensile strength $ft \geq \sigma 1$ …safe.

OR Ultimate compression strength $fc \geq \sigma 3$…. Safe.

Table 7: Comparisons Between Experimental and ANSYS Results – Failure Loads and Deflection

	Failure Load (EXP) N	Failure Load (ANSYS) N	Mid-Span Deflection at Failure (EXP) mm	Mid-Span Deflection at Failure (ANSYS) mm
flexure Stone beam1	3334	3416	10	9.06
flexure Stone beam2	2866	3416	9	9.06
Flexure Stone beam3	2650	3416	7.5	9.06

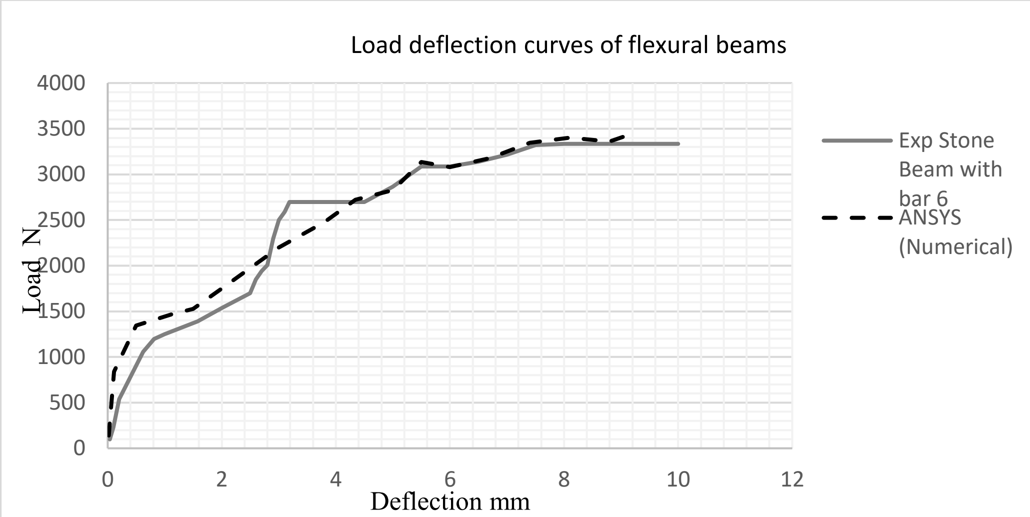


Figure 8: Comparison of Experimental and ANSYS Load Deflection Curves for Flexure Beam

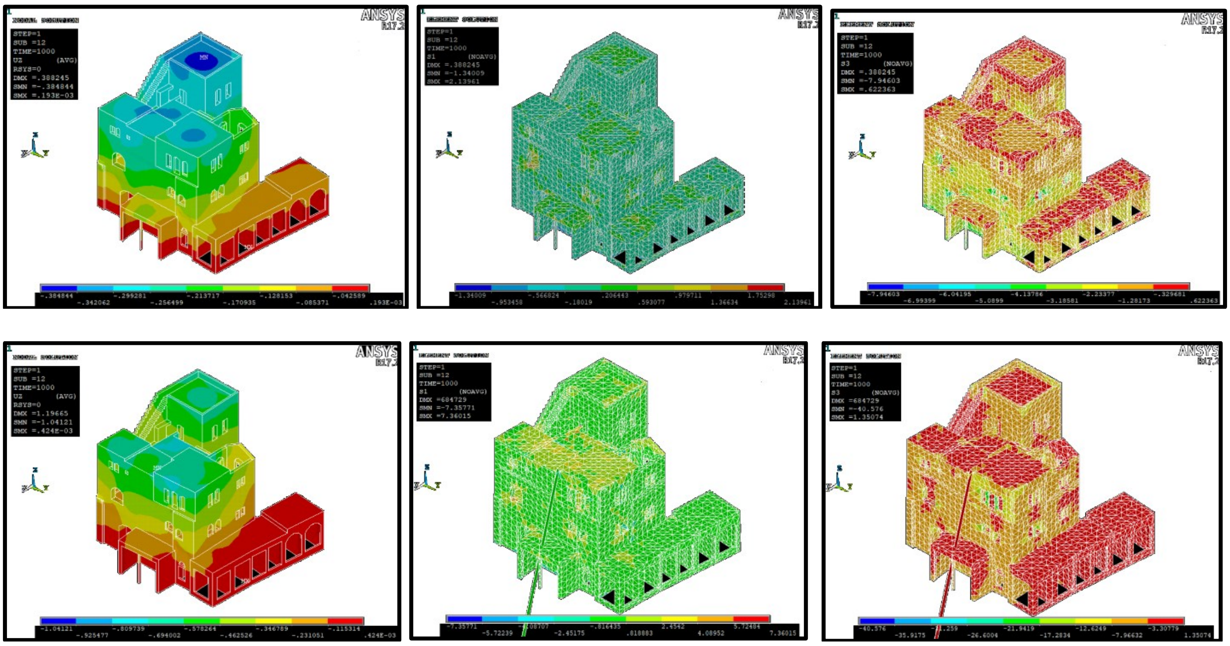


Figure 10: (Top) Deflection, Principal stress σ1, Principal stress σ3 of Zadeh Building Model of the existing situation/solid65.
(Down)bDeflection, Principal stress σ1, Principal stress σ3 of Zadeh Building Model of added three story /solid65.

Table 8: Solution output & Support reaction of solid 65 element for existing situation & additional load.

Case	**existing situation**	**Added one Concrete Story**	**Added two Concrete Story**	**Added three Concrete Story**
Principal stress σ1 (kg/cm²)	< 2.13	< 3.83	< 5.7	failure
Principal stress σ3 (kg/cm²)	< 7.9	< 16.6	< 42	failure
Deflection at Failure (ANSYS) mm	3.9	5.7	11.97	16.9
case	**existing situation**	**Added one Concrete Story**	**Added two Concrete Story**	**Added repeated three Concrete Story**
condition	safe	safe	safe	failure
support reactions (t)	2574.5	2989.3	3440.9	3877.8

Solid 65 element is ideal for modeling the failure of brittle materials like stone buildings. In the case of adding one floor or two floors where one of them is not repeated (design loads), the failure criterion was not satisfied, that is, cracking or crushing did not occur anywhere. the building bears these loads. but when adding three floors with design loads, the failure occurred, where the failure occurred due to divergences in the solution, meaning that the building is unstable, also through comparing ultimate tensile strength with Principal stress σ1.
Where: tensile strength ft= 8.1(kg/cm²), compressive strength fc= 81(kg/cm²),
Another method as used to determine the additional loads that the building can allow to bear, where the support reaction values for all loads, considering that the loads are services, using the general post pro, then list results, reactions solu commands, all the support reactions of the building was found and recorded as follows:

The added load of the building = the Total load on the building when the failure occurred - the original load of the building.

The allowed load to be added = the added load of the building/factor of safety.

The number of floors allowed = thez allowed load to be added / the load of one floor added.

The value of the support reactions was adopted when adding 3 floors, and it was considered the total load =3877.8t, factor of safety is 1.3, the original load of the building =2574.5t, the load for one added floor is 440 tons, through the application of the previous equations, it was found that the value of the permissible load is 1002 t, and the number of floors is 2 floors. To represent the ability of the Al Zahdeh Building to bear additional loads, a method of adding floor loads to it was used, to know at what load failure occurs.

4. Conclusions

The stone building is the oldest that represents an essential part of structural systems, where stone units and mortar join to form stone building systems. Since the historic buildings have heritage significance as they are a living symbol of the rich cultural heritage of Hebron, their preservation is a necessary foundation, and until this is done, there is a need for periodic evaluation of the structural performance. Evaluation of the structural behavior of historical structures is an issue of great interest and a difficult task, mainly due to the inelastic and inhomogeneous mechanical response of the material. Hebron is rich in ancient stone structures. The necessity of preserving this heritage is invaluable in order to pass it on to future generations, as the building system (wall construction) has numerous advantages such as economy, durability, and sustainability. Also, buildings are subjected to natural and human-caused trouble during their lives, which weakens their bearing capacity and causes partial or entire collapse. As a result, the structural assessment method is critical for determining the strength of their bearings and performing periodic maintenance and restoration.
Based on the importance of the study stemming from the need to preserve the historical buildings, and the possibility of adding floors to the old ones, especially since most of these additions are made in random ways without a scientific study, this study gave several results related to safety in these buildings and their ability to bear loads in their current condition and in the case of additional loads.
The results of the experimental section gave that it is possible to obtain the values of mechanical properties of old stones and mortars similar to old mortar, and different models of composite material of mortar and stone in several ways, and the results of the numerical analysis section demonstrated the ability to analyze historical buildings from a structural point of view, and it also gave the buildings bearing capacity for self-loading and additional loads. The study proved that the results of the experiments can be adopted on the same old materials of stone and mortar, in addition to that the numerical analysis can be applied in modeling similar historical building materials.
The following were summarized:

- The stone buildings are strong and durable, but they need regular evaluation and maintenance.
- The process of structural assessment of historical buildings is important, as it is considered the first key to selecting appropriate methods and materials for the restoration process. Through structural analysis, areas of weakness are detected, and accordingly, this leads to the preservation of ancient historical buildings, whose facades reflect centuries of history.
- The structural analysis of old buildings differs from modern buildings, as the materials, construction methods and structural elements are different.
- From the numerical studies, the main conclusion may be presented that the results of the finite element model indicate the good structural state of the current building since no tensile stress exceeded the allowable values, then loads were gradually increased in the numerical model, and the Newton-Raphson iteration method was adopted to verify the convergence in each step. At first, the building was evaluated with its own loads with the live load. Depending on the results, the building is well positioned to withstand the current loads of three floors. In the second stage, loads including dead and live loads were added, where calculations of slab weight self, super dead loads, live loads, and wall weights were made, giving the loads of one floor that were loaded on the walls of the existing building, depending on the results of

adding a floor, it is allowed to add one floor to the existing building, and in the same way, floors were added until the existing building reached additional loads with 3 floors, and the result was that the structure failed when the loads were increased by 3 floors. So, based on the results obtained from the Solid 65 methods, the number of floors allowed is two floors added to the existing building.

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