Structural Assessment and Seismic Performance of Traditional Stone houses in Dropulli region

Key words / Heritage Village, Historic Centers, Stone Masonry, Damage Survey, Structural Assessment, Seismic Vulnerability, Crack Pattern

Nikolla Vesho
PhD researcher / POLIS University

Abstract
The settlement of Derviçan are located next to the important urban center of Gjirokastra, a world heritage of UNESCO. Derviçan is the biggest village in the area and has served as an administrative center for many years. Due to massive emigration and migration trends in the past, there are many abandoned houses which have distinct architectural characteristics and reflect cultural and historical values. The villages that have been abandoned in the recent decades, constitute a serious problem which is all too common in many Balkan countries. As a result, many buildings are in a degraded state, both architectural and structural.
The aim of this paper is to examine the problems in Derviçan's traditional houses and their structures, and to make a technical assessment of the damages prior to a structural repairing strategy in a second phase.
This study will focus on the analysis of old houses and their structures, built with unreinforced traditional masonry, where a lot of problems have been identified as a result of the degradation of material parameters over the years. Initially, there is a need for a detailed analysis of the typology of buildings in this area, and the construction of traditional stone walls and stone tiles without mortar.
After this identification, a matrix will be created with façade and structural damages. The typical damages are cracks in the walls, carvings between the windows, corner damage, wall displacements, and water infiltration and insects. The methodology chosen for this particular context assesses the typical collapse mechanisms. This procedure is also useful to define the seismic vulnerability for other similar regions.

Introduction
Derviçan is one of the historical villages of Dropulli's area. It is unique in terms of its cultural and structural features. Its buildings, however, have deteriorated due to emigration. The potential for restoration, conservation and structural retrofitting is the main motivation in studying the fabric of the village. After the decline of the communist system in 1990, some experts of Albanian's cultural heritage organization did research on the archaeology and history of this village. After 2000, a series of studies were conducted in order to document the cultural heritage and history of this village. The research is documented in handwritten reports and photographs, and it hasn't been published in an integrated and unified manner. There is no study about the potentialities of restoration of Derviçan, especially that of structural retrofitting. This paper aims to briefly represent the existing potential for restoration and to pave the way for future research.

Extended Introduction
The historical and hand-hewn village of Derviçan is located in the northwest part of the Dropull area, located in the south-end of Gjirokastra's province in Albania, near the border with Greece. The Village is 400 meters above sea level, and it is located at the foot of the 'Wide' Mountain. The stones with which the village is built are made of a sedimentary material. This village, which currently has a population of 211 people, has been constructed in stone

with 2-3 story buildings. The population is mainly composed of Greek minorities. This village is located at the edge of two valleys with a length of about 1 km. In fact, its architectural geometry has been developed through establishing a negative environment in the heart of stone with the required elements and according to the culture of its residents. (Bashkia Dropull, et al., 2017)

Derviçan's houses represent a residential unit ends in a small open veranda with a stove that provides more space for routine activities. Inhabitants used to live in these buildings only in the cold seasons of the year, spending most of the year in the plains and valleys doing farming and animal husbandry.

The houses have small doors and windows with characteristic wood material and low height in order to provide a minimal thermal exchange with the outside (Cuberi, 2015). The preservation of the historical houses from potential earthquakes damage presents the need to make their structures stable and safe. Such preservation is essential to encourage the residents return home. The current state of seismicity and functional inefficiency has caused the abandonment of these historical villages of Dropull.

This region, as part of the southern Balkan region, is one of the most problematic seismic areas. Recent earthquakes in the neighboring areas near the border with Greece have shown that village buildings with bricks have suffered maximum damage and are responsible for the loss of life. The age of the buildings and the informal interventions made by people, has rendered these buildings vulnerable to earthquakes (Mitrojorgji, 2015). It is therefore important to evaluate the seismic performance of these buildings. Based on this assessment, techniques must develop to strengthen these buildings in order for them to resist potential earthquake damages and other challenges in the future. The buildings that will be part of this study do not have reinforced concrete (RC) columns and beams.

Their main structure is stone masonry. Therefore, they are more vulnerable to seismic action, that is, shaking and seismic frequency activity. It has been more than 40 years since the design and construction of this typology in Dropulli from their owners. This time undoubtedly has contributed to the degradation of masonry and reduces its load bearing capacity.

This typology can be found across the whole of Dropull region. Consequently, it may be subjected to different climatic conditions and may have suffered various degradations. In our case study shown below, we estimate and evaluate the selected building in terms of the action of seismic elastic spectrum[1] according the Euro Code 8. The methodology uses static nonlinear analysis pushover[2], while the

[1] The period of the communist regime in Albania
[2] Pushover is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern.

masonry of the building is modeled with nonlinear behavior[3].

State of the art

Case Studies on four historic centers situated in Umbria, Italy (Binda, et al., 2006)

The authors have proposed an investigation procedure to study the vulnerability of the diffused historic building patrimony in the seismic area previously considered as minor, but with a great wealth of historical and heritage. The research provides a monitoring and investigation program, which supports the designers in their projects and interventions. The research gathered information about the history of the buildings, materials data, structural morphology and typology of the wall section, observed damage and failure mechanisms, and the effectiveness of retrofitting techniques. The methodology, calibrated on these four historic villages located in Umbria region (Italy), allowed to define an abacus of the typical collapse mechanisms. This procedure was useful to define the seismic vulnerability and performance for other similar abandoned villages as well, and to critically evaluate the past and future repair techniques.

Second case-study analyzed is "Seismic Vulnerability assessment of an old Stone Masonry building aggregate in San Pio delle Camere, Italy" (Maio, et al., 2014)

The study approaches the seismic vulnerability assessment of a stone masonry building aggregate located in "San Pio delle Camere", which was slightly affected by the 2009 L'Aquila earthquake. The structure was assessed through static non-linear numerical analysis by using the 3muri-software. Moreover, simplified methodologies based on different vulnerability index formulations were applied to compare all these outputs obtained through distinct procedures. Since the nonlinear analysis procedure exceeds the linear stage of the modal analysis we will perform in our study, it is worth noting that we can focus on this study for general aspects of seismic performance evaluation of similar buildings. Also, the most important aspect of studying and analyzing this case is the modeling of the structure in the software, data entry and material parameters, without forgetting the "static conception" of the way the structural elements work. Referring to the results and "final comments" of this study, we can say that it is a good case and opportunity to make the necessary comparisons among the parameters with our study.

Methodology

At the structural and architectural scale, the study provided a systematic collection of relevant data on the building techniques, stone materials and finish, state of conservation, and seismic restoration. We were was focused on the four main technical elements of these buildings, such as walls, ground floor slabs, roofing, wooden doors and windows. Given the fact that most of the buildings in the historic center are mainly residential, in order to carry out some large-scale seismic improvement interventions, it was necessary for the local administrative unit to encourage people to carry out these types of intervention.

The seismic risk class depends on one parameter: that which takes into account the damage and refers to the cost of reconstruction of the building, taking into account the achievement of the limit state for safeguarding life (life safety level)[4].

Use of ETABS, interpretation of the crack Pattern and their distribution.

The assessment of seismic performance of URM buildings[5] requires the identification of the damage and collapse mechanisms step by step, activated by the synthetic earthquake (elastic demand spectrum)[6].

Referring to the current practice in the Balkan region only a limited number of modes of failure has been taken into account, by studying the capacity curves of certain structural typologies.

The modelling of the structure behavior and its safety assessment by the mesh process (finite-elements) can highly benefit of the ETABS, which enables us to create layered walls, considering the non-linearity of each layer that represent materials data. Then there is a very important step: the transformation and conversion of panels in piers and spandrels labeling[7]. The vertical panels working in

3 / Methodology for modelling the unreinforced masonry with nonlinearity characteristics for each layer of the wall on ETABS, a possibility to create the wall as close as possible to reality.
4 / Second level mostly used for designing civil structures based on seismic performance levels [Eurocode 8]
5 / Unreinforced masonry building typology, without reinforced concrete frames.
6 / Merging a number of strong short-period ground motions and long-period ground motions. From the merging of these accelerograms, an elastic specter is deduced.
7 / pier = column, spandrel = beam. Both piers and spandrels are equivalent panels constructed of shell elements, showing the element way of work according the static concept.

Fig. 1 / Traditional stone house on Dervician, the selected building (February 09, 2019)
Source / the author

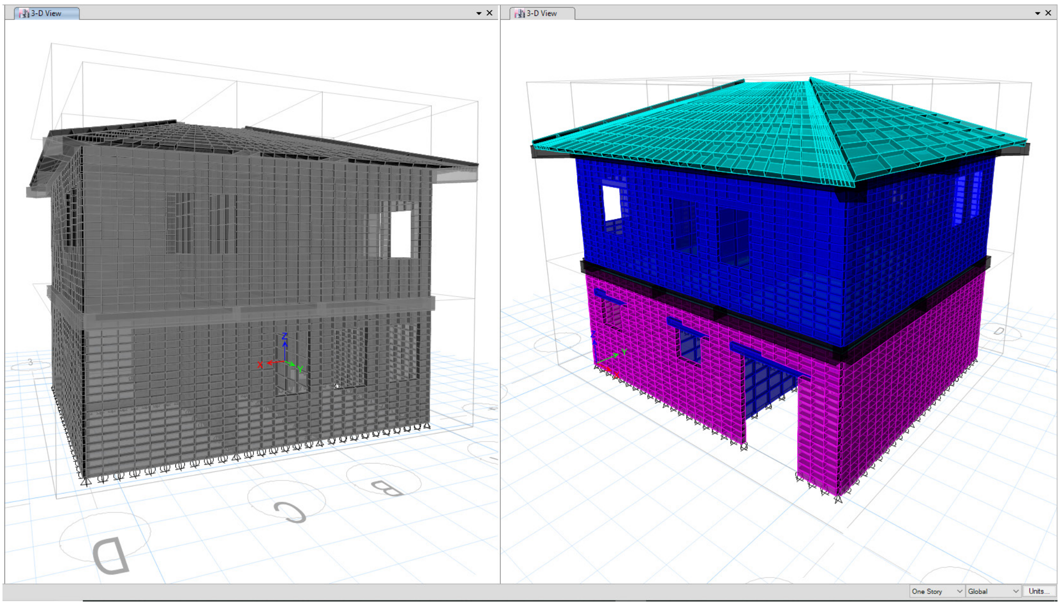

Fig. 2 / The selected house 3D model. Source / the author, ETABSv, 2019

compression are converted in piers (frame elements that work in compression), while the horizontal panels under the openings below are converted in spandrels (frame elements that work in bending) (Pitilakis, et al., 2014).
The methodology for the analytical part was performed on modal analysis (CEN Eurocode 8, 2003).

Case study "Structural evaluation and seismic performance of a traditional house"
Below is two-storey house with stone walls and timber construction under the stone roof. The building has timber-joisted floor and rubble stone masonry foundation.

Stone Masonry structures have large masses due to heavy construction materials. Dead loads consist of the fixed weight of structural members and the weight of any permanent fixtures attached to the structure (superimposed loads).
Dead loads always remain on the structure and affect the structure throughout its lifetime.

General Mechanical Properties of Brick Masonry (Mosalam, et al., October 07, 2009)

Material property data: Stone masonry
Directional symmetry type: Orthotropic
Weight per unit volume:
16 kN/m3

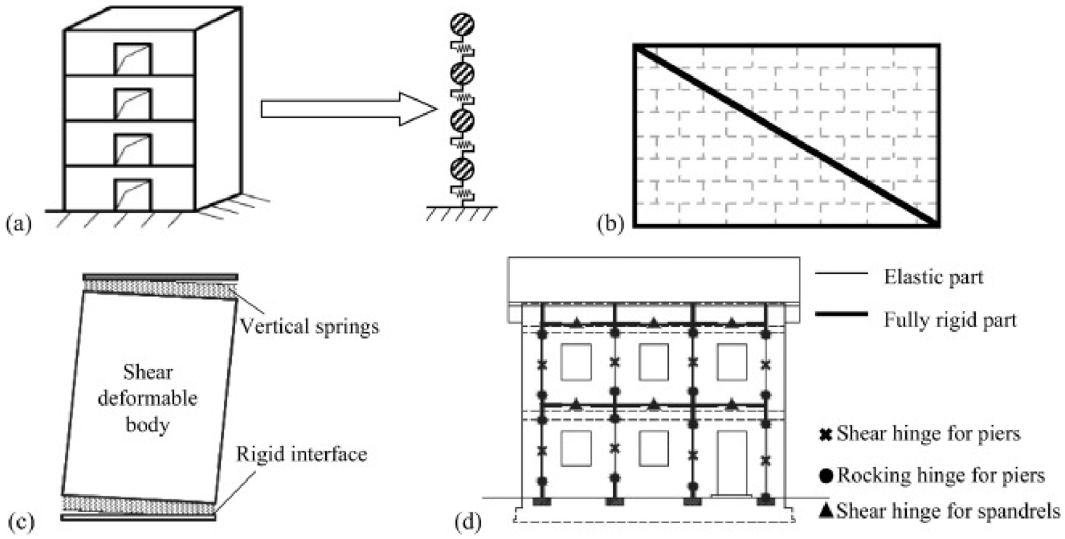

Fig.3 / A unified model for the seismic analysis of brick masonry structures. Source / Xu, et al., 2018

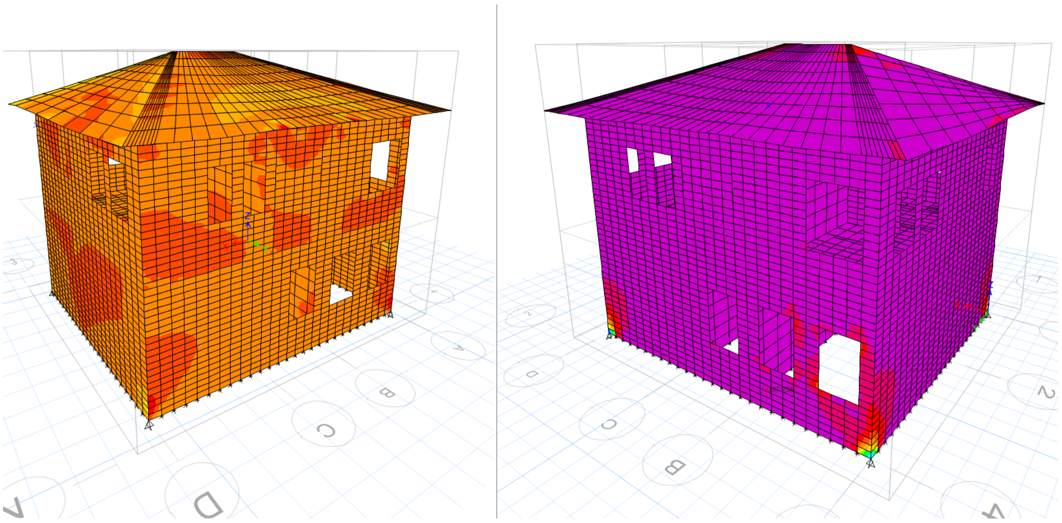

Fig.4 / Deformed shape of the building and displacements. Source / the author, ETABSv, 2019

Mass per unit volume:
1631.546 kg/m3

Material mechanical property data:
(Jurina & Peano, 2009)

Modulus of Elasticity:
E1=4167 MPa,
E2=4167 MPa,
E3=4167MPa

Shear Modulus:
G12=1811MPa,
G13=1811MPa,
G23=1811MPa

Poisson's ratio:
U12=0.15, U13=0.15, U23=0.15

Coefficient of thermal expansion:
A=0.0000081 1/C

Timber mechanical property data:
(Halicioglu, et al., 2014)

Modulus of Elasticity:
E=10.5*10-6 kN/m2

Mass density:
5 kN/m3

Material parameters on ETABS are set to the current state, with a lower percentage of parameters considering degradation over the years.

The masonry behavior is modeled by two different layers accompanied by stress and strain characteristics (Tomazevic, 2007). The layers represent the vertical stresses S11, S22 horizontal stresses and shear stresses S12. It is very important to predict the best possible stress - strain graph for each direction (Baballeku, 2014).

The nonlinear analysis Pushover methodology is able to define capacity curves with performance point, the shear resistance and collapse mechanisms. It is able to combine different mechanisms for global seismic performance analyses of buildings with sufficient regularity and limited height, and take into account the type of connection among the structural elements.

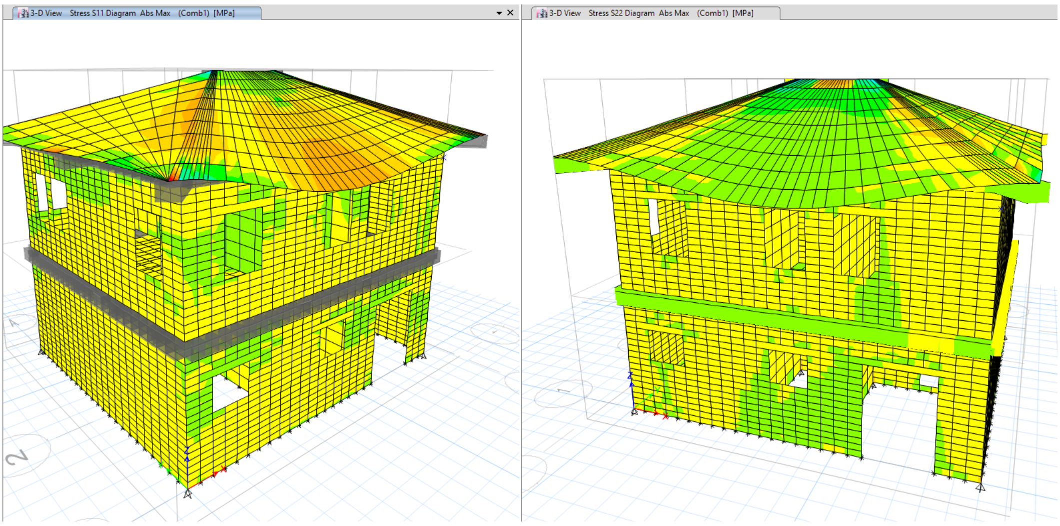

Fig. 5 / The selected house 3D model (ETABS, 2019)
Source / the author, ETABSv, 2019

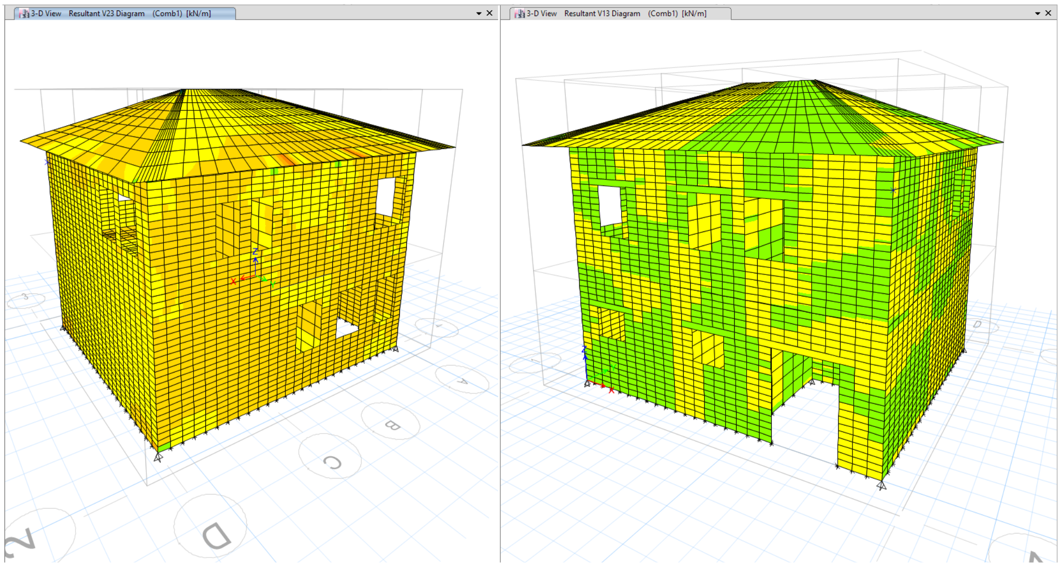

Fig. 6 / Shear force distributed on 2 directions, V13 and V23 (ETABS, 2019)
Source / the author, ETABSv, 2019

Case	Mode	Period sec	Frequency cyc/sec	Circular Frequency rad/sec	Eigenvalue rad²/sec²
Modal	1	0.239	9.209	57.8588	3347.6435
Modal	2	0.198	11.037	69.3504	4809.4787
Modal	3	0.179	12.737	80.0311	6404.9764
Modal	4	0.155	18.296	114.9557	13214.8155
Modal	5	0.106	21.648	136.0198	18501.39
Modal	6	0.093	22.999	144.5062	20882.0292
Modal	7	0.072	23.622	148.4242	22029.7463
Modal	8	0.068	26.518	166.6168	27761.1618
Modal	9	0.055	28.257	177.5427	31521.4194
Modal	10	0.043	30.652	192.5904	37091.0649
Modal	11	0.041	32.16	202.0664	40830.8201
Modal	12	0.04	32.876	206.5639	42668.6276

Tab. 1 / Modal Periods and Frequencies
Source / the author, ETABSv19

Analysis and Results

Given the above explanation in methodology, the traditional houses of Derviçan were analyzed to define their load carrying capacity. Minimum principal stresses amount to about 4.77 MPa at the beam-timbers and they occur in the transition zone between the ground floor and the upper floor (Figure 5). Maximum principal stresses amount to about 3.19 MPa and they occur above the top of the ground floor and at the first-floor panels. The maximum principal stresses also occur at the roof and edges of the windows (Figure 5). Maximum displacements occur at the roof of the structure and amount to about 12.80 mm (Figure 4). Maximal displacement according combination 1 is 18.4mm on X-direction and 32.3mm on Y-direction[8].

Modal analysis was conducted in order to determine fundamental mode shapes and natural frequencies of the structure during free vibration. The purpose of the modal analysis is to obtain the maximum response of the structure in each of its important modes, which are then summed up in an appropriate manner. Modal analysis of the structure included different modes of vibrations in combination.

Allowed period (CEN Eurocode 8, 2008):
[T]= 0.075 x Hb ^ 0.75 = 0.207s

First mode of vibrations:
T1=0.239s > [T]=0.207s
Translation move on Y-direction

First mode of vibrations:
T2=0.198s
Translation move on X-direction

Third mode of vibrations:
T3=0.179s
Torsion

Conclusions

This study focused on historical stone masonry structures situated in the Derviçan Village, located in an active seismic zone. The objective was to analyze the damage mechanisms and seismic vulnerability of these buildings. The modelling one of the most typical traditional houses visualized structural response of these houses to seismic events. A 3D model was prepared in order to show the behavior of the structure and its probable local and global weaknesses under seismic actions. The modal analysis was applied to predict possible damages and seismic vulnerability in the weak zones of the structure under expected seismic intensity.
The static and modal analysis results revealed that the critical section of Derviçan's stone-house is the transition zone between the ground floor and first floor, and the area where the first floor is connected to the roof. The most critical stresses calculated during the static analysis occurred at the timber beams connecting points and slabs.

Results showed that the node interaction between the supports and stone walls played an important role in the dynamic behavior of the structure. It may be considered as risky in terms of creating structural stability problems. The results also show that the structural problems generally occur in the critical stress parts, and these results prove the accuracy of the numerical approach, by verifying the problems that were identified on site.
These computational analyses should be compared to quick vulnerability assessment methods in order to detect possible problems of numerical model environment. To avoid this, scientists should be aware and conscious if the knowledge level and survey related to a generic study gathers all data necessary to obtain feasible results.
When this knowledge requirement is considered insufficient, it is preferable to conduct the analysis through empirical methodologies, which are proven to give satisfactory predictions about both damage predictions and seismic vulnerability assessment of either individual buildings or building aggregates. (Maio, et al., 2014)
The findings of this study can serve as a model for other similar cases in historical villages.

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