15th Canadian Masonry Symposium
Ottawa, Canada
June 2-5, 2025

Seismic Analysis of Structure 86 at the Archaeological Site of Shivta in Israel

Michol Rampado[i], Yotam Tepper[ii], Michael Cohen[iii], and Francesca da Portoi[v]

ABSTRACT

In Israel, most of the historical buildings dating back to the 5th - 8th century CE consist of masonry constructions that present numerous vulnerabilities related to the construction techniques of the time. To preserve the state of these buildings of high historical, artistic and architectural value, specific analysis and evaluations are necessary. This is of great importance in sites which have been declared as world heritage site, like the Shivta National Park, Israel. However, the analysis of existing masonry structures presents many difficulties mainly related to the knowledge of the original construction technique, the mechanical characteristics of the material, and the intensity of the actions that affected the structures during time. This research aims to provide an overview of the seismic vulnerability of some structures in Shivta, focusing on a specific building (Building 86), dating back to the Roman period, which presents typical earthquake damage. Starting from a historical, archaeological and geometric analysis of the archaeological site of Shivta, also supported by Building Information Modeling of the existing structures, a detailed seismic analysis of building n.86 is carried out.

KEYWORDS

Masonry buildings, Seismic Vulnerability, Numerical Analysis, Earthquake, Late antiquity archaeology, Shivta abandonment.

[i] Depart. of Geoscience, University of Padova, Padova, Italy, michol.rampado@phd.unipd.it
[ii] Zinman Institute of Archaeology University of Haifa, Israel Antiquities Authority, Israel, yotamtepper@gmail.com
[iii] Israel Antiquities Authority, Israel, michaelcohen58@gmail.com
[iv] Full Professor, Padua University, Padova, Italy, francesca.daporto@unipd.it

INTRODUCTION

Defining the historical seismicity of an archaeological site is an articulated process that combines different approaches and methods [1]. Generally, the Archeoseismic and historical analysis of a site allow relating the history of the buildings, through their stratigraphic analysis, to the seismic activity of the area in the short and long term. However, the Archaeo-seismological analysis only provides qualitative information. Numerical and historical analysis are necessary to understand the behaviour of the analysed buildings, and in-depth investigations about the dimensional characteristics, the type and quality of the wall's elements and specific analysis about the connections between the structural elements are necessary. Since its establishment (beginning of the 2nd century CE) the archaeological site of Shivta [2] has been subject to numerous seismic events that led to the current state of damage [2]. Retaining walls were carefully built close to many buildings of the village in later times to contain structural failures and to ensure greater solidity. Moreover, on the nearest villages traces of collapse mechanisms of masonry structures have been identified [3]. These construction details and state of damage, together with various archaeological discoveries, define an important past seismic activity. The 363 A.D. earthquake is considered one of the main seismic events that occurred. Then, the events of the second period, between the 5th and the 11th century CE, follow [4].

Within a collaboration among the Israel Antiquities Authority, Conservation Department, the Nature Parks Authority of Israel, and the University of Padova, various inspections and analyzes on the Shivta site were carried out, with the aim of reconstructing the history of the place and identifying the most serious seismic events which, among other reasons could have led to its final abandonment during the Early Islamic period [5] [6]. The proposed research focused on a specific building (n.86), since it shows various damages related to seismic events on its structure. In particular, in the northeastern part of the building these typical seismic damages were recorded. The work presents a historical, archaeological and geometric analysis of the archaeological site of Shivta, followed by the definition of the construction techniques of the time and the identification of the mechanical parameters of some types of masonry. Subsequently, a detailed seismic analysis of building n.86 is carried out, with the support of BIM modelling and IFC database extraction. The results made it possible to make more hypotheses on the possible seismic sequence responsible for the damage, and to understand the original structural systems of the buildings, their typical vulnerabilities and therefore their kinematics.

METHODOLOGY

The current state of the Shivta buildings makes it difficult to identify the causes of damage, as most are collapsed or severely damaged, and the historical transformations are uncertain. Therefore, to properly identify the past events, a critical survey of the buildings has been implemented.

The evaluation of the seismic behavior of an existing masonry building requires analytical models to calculate the load carrying capacity and safety of the structures. Specific models must consider the building type, the construction techniques, and the masonry typologies. Among the available solutions, Heritage Building Information Modeling (HBIM) provides an opportunity to integrate the various disciplines involved within a single platform. Initially designed for new constructions, this digital information system includes design, authoring, verification, and simulation. The application of BIM to existing buildings (HBIM) as a research frontier extends from survey techniques to three-dimensional modeling, integration, and data linking. The preliminary diagnosis of an historical building behavior must consider its dimensional characteristics, the type and quality of the materials, their arrangement, and the connections between the building's elements. To maximize the dissemination and reusability of results, a robust knowledge base must be created using open and neutral protocols. The HBIM model of the current state is thereby realised and, through the adoption of IFC standard [7], the storage of any information collected on site and deduced from the historical analysis is ensured. In the construction industry, Industry Foundation Classes (IFC) offer shared, open, and standardized platforms. Applying IFC to historic buildings brings the benefits of structured data to the knowledge process of heritage buildings and enables the integrated management of interoperable files. The IFC system relies on defining entities (IfcObjectDefinition), each with qualitative and quantitative properties (PropertySets), and relationships (IfcRelationships), allowing it function as a database.

To evaluate the quality of the vertical structures, firstly, a critical analysis of the masonry arrangements by the MQI method [8] was carried out. The Masonry Quality Index (MQI) method consists in evaluating the presence, the partial presence, or the absence of certain parameters that define the rule of the art in masonry construction. This method examines a masonry wall under vertical, out-of-plane, and in-plane loads, considering seven parameters like brick dimensions, wall connections, and mortar quality. These parameters are classified as Fulfilled, Partially Fulfilled, or Not Fulfilled, leading to a Masonry Quality Index for each load condition. The mechanical properties of the walls are calculated using empirical formulas based on this index [8].

The research analyses the common collapse mechanisms observed in Shivta and focuses on the analytical evaluation of local mechanisms refer to the east masonry wall of the 86 building [2][5]. The kinematic approach allows determining the value of the horizontal action that the structure is progressively able to withstand during the evolution of the mechanism. In particular, a capacity curve of the structure is defined through the seismic coefficient α as the ratio between the applied horizontal forces and the corresponding weights of the masses present. The seismic performance of the structure is analyzed until collapse (α=0) and then verified.

To compare the overall behavior of the building and the local collapse mechanisms a FEM analysis of the n.86 case study was also implemented. Various types of analyses were carried out for that purpose, in particular linear static analyses (LSA), modal frequency analyses (NFA) and non-linear static analyses (NLSA). Their results were compared with the actual state of damage of the building to identify the most likely phenomena occurred.

SEISMIC VULNERABILITY OF SHIVTA'S ARCHAEOLOGICAL SITE

The archaeological site of Shivta is located in the Negev Desert of Israel (Fig. 1). As in antiquity, the site is completely isolated [2]. These aspects make the village one of the world's best-preserved late antique sites and a UNESCO World Heritage Site. The settlement was apparently first established during the Roman period, and it reached its period of prosperity in the 5th – 6th Century, during the Byzantine period. The village was finally abandoned in the late 8th – middle of the 9th Century [5].

Combined paleo-seismic and geological data allows drawing a complete scene of the earthquake history of a site. Israel, located on the eastern side of the Mediterranean between the Arabian and African plates, has a long historical record of earthquakes [9]. The study area is located in the Negev highlands, southern Israel, between the Sinai Peninsula in the west and the Arava–Dead Sea depression in the east. The Arabah–Dead Sea depression is a major section of the Dead Sea Fault (DSF), forming the active boundary between the Arabian and African plates [10]. The average rate of slip between these two plates, during the last 5 Ma, is estimated to be 4–6 mm/yr [11] [12]. Shivta site, located within the Negev Highlands, ~70 km east to the DSF, is a rocky terrain located at an elevation of 600-1000 m.a.s.l. The site and its vicinity consist of rocky terrain, underlined predominantly by carbonate rock slopes. Limestone bedrock outcrops of the Turonian Nezer and Shivta formations make up the nearby anticlinal ridge flank (i.e., Boqer ridge), and the soft chalk outcrops of the Santonian Menuha Formation along with the chert Campanian Mishash Formation fill the synclinal structure. Located along the anticlinal flank, the site hosts short laminated to massive limestone slopes, covered by loess and stones colluvial deposits. Within the close vicinity of the site, no geological faults are located. Yet the location of poorly lithified sediments (e.g., loess soil) on dense massive bedrock (Shivta and Nezer formations), may increase the susceptibility to earthquakes for different structures [13].

Historical sources and archaeological sections excavated revealed the past two millennia seismic history of the Site. Our research focused on the seismic sequences occurred from the 5^{th} to the 11^{th} century. Starting from the 363 A.D. event, where the archaeologists found different interventions on the building's stratigraphy, the site of Shivta suffered the seismic sequence of 747, 749 and 757 CE and the 11^{th} century seismic sequence. The strong earthquake occurred on 749 A.D.. The epicenter of the earthquakes it was assumed to be on the northern part of the DST Similarly, the 1033 CE event occurred in the north, causing heavy damages in Tiberias [11]. The archaeological remains and discoveries found on Shivta's archaeological site suggest an interruption of some buildings after the 749 CE seismic sequence and a final abandonment in the late 9^{th} century. However, the specific characteristics of the occurred seismic events, such as the fault section ruptured or the extent of the seismic wave propagation, are unknown.

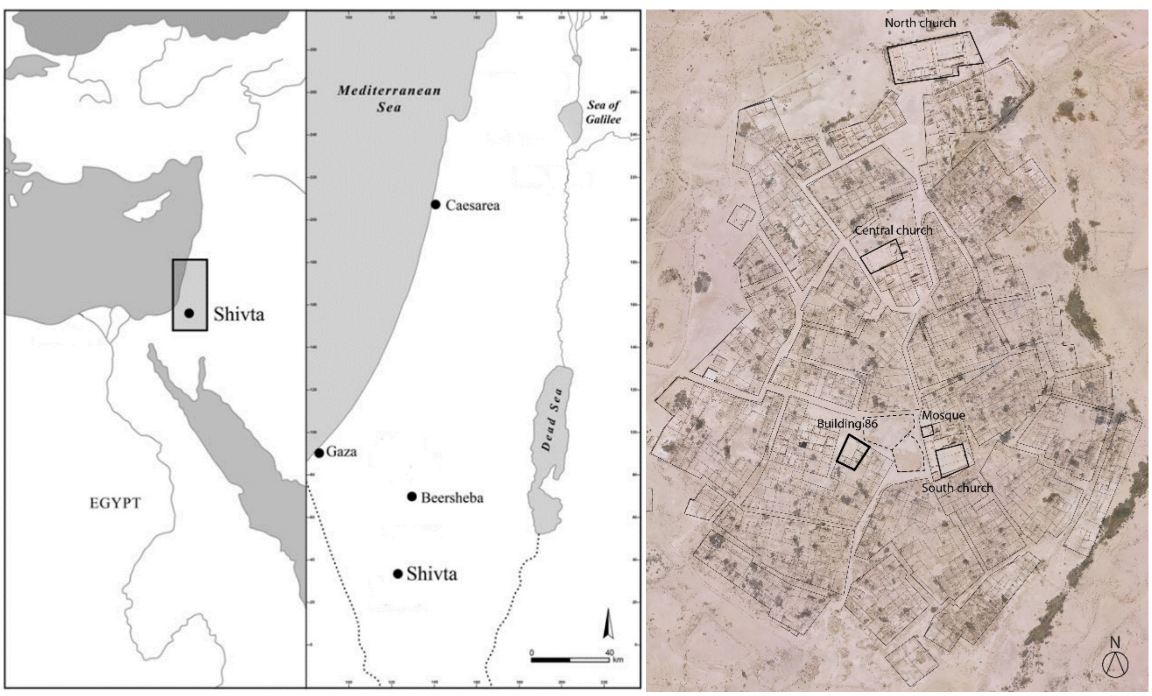


Figure 1: Shivta location map (left) [9]. Aerial photo of Shivta village (right).

Geometrical analysis and construction techniques

The structures of Shivta resume the typical construction techniques of the Byzantine. Masonry is made of local limestone (rubble masonry, 70-80 cm thick, with two leaves and an internal core), coming from surrounding caves, and mortar composed by mud made of clay, loess and sand. Mortar in its various forms was widely used as a plaster for walls and as a waterproofing topping for most of the flat roofs in private houses. Fig. 2 (above) shows two different construction techniques: the lower part of the walls, up to around 1-2 m., is built of hard, roughly hewn limestone, while the upper part of the walls is built of soft, well-worked limestone. Another typical aspect of the houses is the arch system (Fig. 2, below). Each room is characterized by different semicircular arches arranged transversally (every 90 cm) made with regular cut stones 20 cm height and 60 cm wide. The abutments, with the same voussoirs' dimensions, are approximately 1.5 m high and are inserted in the perimeter walls. To stabilize the arch and prevent kinematic mechanisms, regular stones and mortar are inserted between the extrados of the arch and the side walls. This spandrel, with the lower profile that follows the curvilinear course of the arch and the upper profile horizontal, locally increases the stiffness of the system and consequently is therefore a preferred way of transmitting the lateral thrusts to the walls. In addition, to connect the arch system and ensure greater stiffness of the roof, stone slabs with dimensions of 120 x 20 cm were placed orthogonally to the arches. Finally, the roof, 40 cm thick, was made with mortar and stones of various sizes.

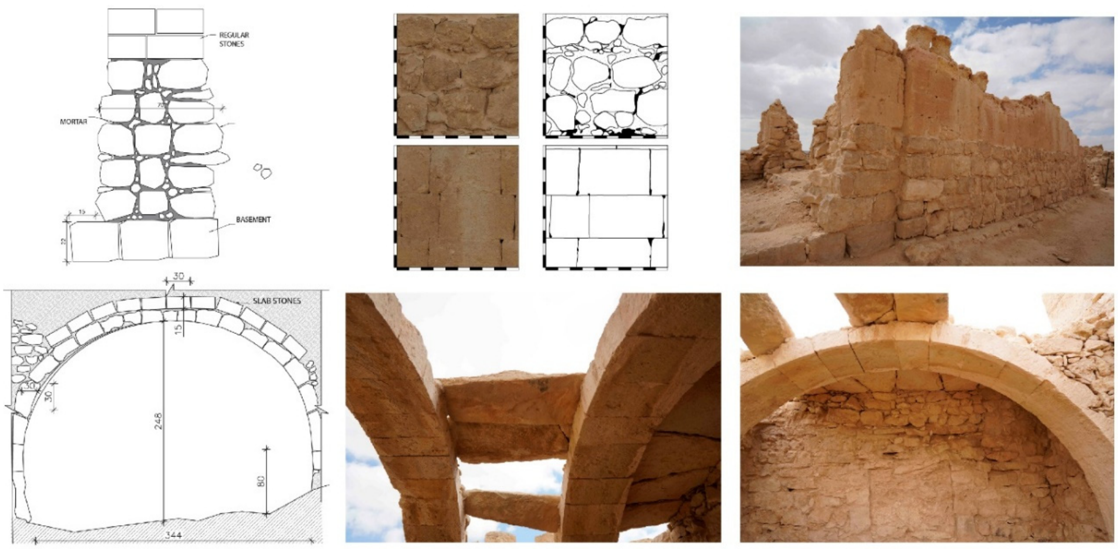


Figure 2: Masonry types (above) and arch structure (below).

General survey of Shivta

Ten damage mechanisms were chosen as representative of the damage pattern in the dwellings of Shivta site. In particular, eight masonry walls and two arches were analyzed (Fig. 3). Recurrent damage mechanisms have been identified in the nearby archaeological sites like Mamshit and Avdat: the overturning of the building corner, deformation of the arches, sliding of the walls and cracking of internal stairs. The study of these structures, built with the same construction criteria and local materials, has proved to be of great relevance to identify specific damage that are more probably related to the past seismic events [14]. The typical behavior of these buildings involved immediate collapse or the formation of cracks in the three loading directions: in plane, out of plane, and vertical. Although the ten identified cases studies have different history, location in the site, and role in the building to which they belong, the crack patterns are definitely very similar to those associated to collapse mechanisms due to seismic events in general, and also in the other analyzed sites.

The results obtained in terms of masonry quality and mechanical parameters by the MQI method and observed masonry behavior have shown a strong relationship. Most of the masonry analyzed belong to category C, both for in-plane actions and out-of-plane actions. The walls analyzed are, in fact, characterized by inconsistent and poor quality materials. The mortar is almost absent and the transversal toothing of the walls is partially respected only for some buildings. Then follow the poor resistance of the blocks and the absence of a correct distribution of the vertical joint. The rubble masonry is certainly among the most critical. For a C type category, an out-of-plane horizontal action can lead to the disintegration of the wall, even if there are partial connections. Similarly, for an in-plane horizontal action, the possibility of very large cracks on the wall is high. These damage patterns can be found in the sample of buildings analyzed where the 80% corresponds to the out-of-plane mechanisms and the remaining 20% to deformations of the arches. Another important aspect for the purposes of this research concerns the direction of collapse of the investigated masonry walls: two main directionalities have been identified: SW-NE and W-E or W-SE.

SEISMIC ANALYSIS OF THE CASE STUDY BUILDING 86

Building 86 is located near the southern center of the Shivta village (Fig. 1, right). The building follows a regular plan. The height is supposed to be 4.20 m including the ceiling section. It consists of 8 small spaces probably roofed for the biggest part. The archaeological remains suggest the presence of a second floor above the two rooms located in the south-east part of the house. The floor consists of a layer of compact soil and medium-size stone slabs that level the walking surface at the main living floors.

Most of the rooms present the typical arch system spaced at 1.0-1.2 m intervals, supporting the thick layer of the roof. The semicircular arches are placed in the rooms located in the perimeter of the building, with part of the abutment inside the adjacent walls. From archive drawings and site inspections, the HBIM model provided the basis to be enriched with on-site surveys and from the archaeologists' discoveries [6]. No diagnostic campaigns have been carried out to define the mechanical properties of the materials included in the three-dimensional model within the material properties. For this reason, the mechanical properties used in the subsequent analyses were first obtained from the MQI analysis of the masonry portions, and subsequently compared with literature values, taking into account a low level of knowledge (KL1, CF=1.35). Thanks to the IFC data structure, mechanical properties of materials are included as specific parameters (Pset_MaterialMechanical and Pset_MaterialCommon).

Figure 3: Aerial photo of building 86 (left). Collapsed masonry portion on the eastern side of the building and view of the Southern Church tower behind (right).

Observed damage and kinematic analyses

The building 86 is in a state of advance deterioration, most of the walls are collapsed and the remaining masonry walls have various problems linked to weather conditions and human interventions. Most of the perimeter walls are collapsed, except for the north-east walls located in the corner of the building. The typical mechanisms observed in the building is the out-of-plane overturning of the masonry walls (Fig. 3, right). The study focuses on the single wall located in the north-eastern part of the building (M1) which shows a trapezoidal gap on its center that starts from the upper corners of the wall and ends on the basement. This horizontal flexural mechanism typically affects the upper part of the walls, since the wall corners were blocked in the east-west direction, and the thrust of the roof under horizontal actions could act also perpendicularly to the masonry wall. Assuming that M1 collapsed due to seismic actions in the east-west direction, the walls behind (M2 and M3), which are parallel to M1, could also have collapsed as a result of the seismic event acting in the west-east direction.

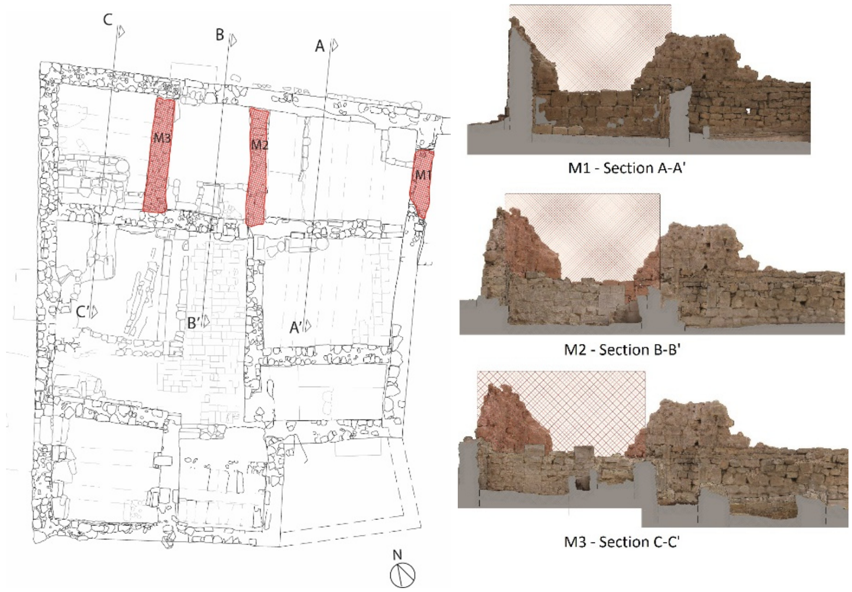


Figure 4: Representation of the kinematic mechanism analyzed in plan (left) and in section (right).

From the information emerged from the damage analysis of the building, a limit analysis of the M1, M2, and M3 walls was carried out. Tab. 1 shows the verifications, in terms of acceleration (linear kinematic approach), of the walls investigated.

Table 1: Results of the out-of plan kinematic analysis

1° Mode		
Kinematics	α	ζ (ULS)
M1- Horizontal flexure	0.101	0.95
M2- Global overturning	0.088	0.98
M3- Global overturning	0.141	1.59

FEM analyses

The numerical analysis of the building 86 was implemented by using the Midas FEANX software, starting from the BIM model. In particular a linear static analysis and a modal analysis (NFA) of the global structure was first implemented and subsequently a pushover analysis, i.e. a non-linear analysis, of a specific part of the building (north-east room) was carried out.

To facilitate the work and decrease the computational costs of the analyses carried out, the model of the structure has been simplified. The basement, the cistern and the small intermediate level have been neglected therefore the support plane of the structure coincides with the ground floor level.

2D shell elements have been adopted in the model, i.e. rectangular and triangular elements consisting of four/three nodes on a curve surface; the mesh was set to 0.15 m fixed size (Fig. 5, left). The definition of the geometry and the linear mechanical properties of the materials follow the above-described analysis of the construction details and damage performed on the structure, based on the BIM model representation and on the IFC database. To reproduce the non-linear behaviour of the materials, the Concrete Smeared

Crack model was chosen. This model describes the compression and tensile behavior of a material through the stress-strain relation and it follows an approach based on the fracture energy. In this analysis, the linear function for the tensile behavior and the parabolic function for the compression behavior were adopted (Tab. 2). The tensile and compressive strength parameters were obtained from the values given for masonry of similar arrangement by the Italian standard [15], while the energy parameters were obtained from literature references [16] . After defining the geometry and materials, the boundary conditions were assigned. The structure had fixed constraints at the base and, in addition, unidirectional constraints were applied in all those points that have a connection with other buildings.

Table 2: Mechanical properties used in the analysis.

	f_t [N/mm^2]	$G_{f'}$[N/mm]	f_C [N/mm^2]	G_{fc}[N/mm]	E [MPa]	ρ [KN/ m^3]
Masonry walls	0,05	0,025	2	0,75	1100 1300	20 22
Arches	0,05	0,025	2	0,75	1300	22
Roof	0,05	0,025	2	0,75	1300	20

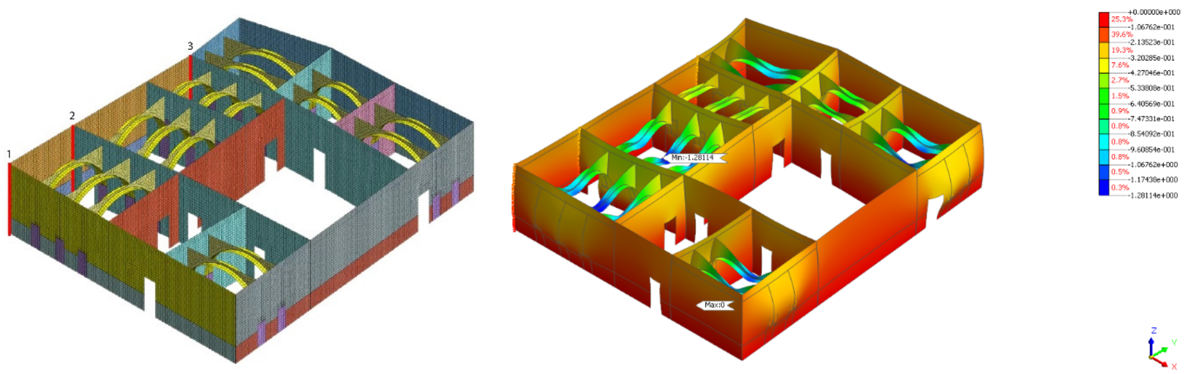


Figure 5: Mesh of the model (left) and vertical displacements due to the structure self-weight (right).

First, the linear static analysis (LSA) was performed considering the self-weight of the structure only. Regarding the reaction forces, the maximum value at the foundation is 28.88 kN. The vertical deformation on the middle plane of the arches is approximately 1.28 mm. Lastly, the maximum compression stress is located between the abutment of the arch and the wall, and it is equal to 0.4 MPa.

To analyze the effects of seismic action in terms of vibrating modes, and to verify the formation of the collapse mechanisms identified for building 86, a modal analysis was performed. The analysis was organized in two phases.

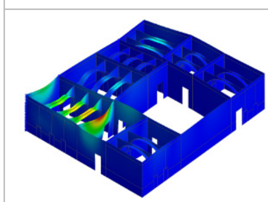
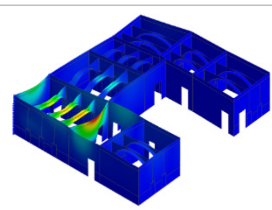
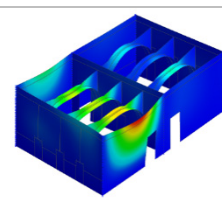
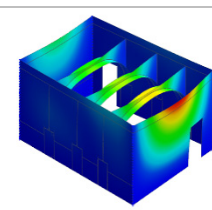
The first phase concerns the effects of the boundary conditions caused by the adjacent buildings on the global behavior of the structure. This model configuration has been compared with that without any boundary condition. The results obtained from the two analyses showed how lateral constraints can influence the vibration modes of the building. In particular, the lateral springs give rise to more local mode shapes than the building model without lateral constraints that, on the contrary, presents a greater number of global mode shapes.

The second phase of the analysis regards the sub-structuring of the building. The aim of this analysis is to identify the more appropriate model for conducting the subsequent pushover analysis. Three models were step-by-step adopted to simplify the overall model of the building. The first partial model discards the free wall of the central courtyard, located on the western side of the building, which is characterized by the main local mode (out-of-plane flexure) of the structure. Starting with this model, a two-room model containing the two rooms located on the eastern part of the building was created. Lastly, a one-room model, characterized by the room on the east side of the building where the main collapse mechanisms previously described are concentrated, was made.

Given the limited information available regarding the mechanical properties of the materials, additional sensitivity analyzes were carried out on the elastic modulus E of the roof (100 MPa, 500 MPa, 1300 MPa). First, a completely rigid roof was considered and subsequently the case of a deformable roof was analyzed. The sub-structuring analysis show the high influence of the roof when it is considered as a completely rigid block. On the contrary, by reducing the elastic modulus of the roof to 100 MPa, it is possible to better identify local modes on the building (Tab. 3). In particular, the horizontal flexure mechanism is easily recognizable. In summary, the results obtained from this analysis are described below.

The results, in the first phase of analysis, showed that the interaction with an adjacent building favors the development of local mechanisms; in the second case the analysis showed that by lowering the elastic modulus of the roof and by attributing constraints to the walls, the participating mass and the frequency of the various substructure models are the same. It has therefore been shown that the roof affects the structural behavior of the building more as a mass on the kinematic mechanism than as a stiffness in a global building behaviour. These conclusions have made it possible to focus the attention on the eastern room only, to better analyze the collapse mechanisms on its masonry walls.

Table 3: Description of the participating mass (kN) and frequency (Hz) for the various substructures with a value of 100 MPa (first case) for the Young modulus (E) of the roof.

TOTAL MODEL		PARTIAL MODEL		2 ROOMS		1 ROOM	
Young modulus (E)= 100 MPa							
							
MODE N.	13	MODE N.	13	MODE N.	5	MODE N.	3
MASS(TX) KN	537,7	MASS(TX) KN	565,5	MASS(TX) KN	593,4	MASS(TX) KN	551,3
FREQ.	14,7	FREQ.	14,7	FREQ.	15,1	FREQ.	14,8

The pushover analysis of the chosen model consists on a Construction Stage Analysis carried out considering the non-linear properties of the materials and by applying the loads in sequence. In a first phase, the self-weight is applied in a single step, followed by the application of a global acceleration (proportional to the masses) in the X direction. The iterative process adopted to derive the equilibrium curve is the secant method; fifty iterations for each increment were specified. In order to obtain correct results, a sensitivity analysis regarding the tensile fracture energy and the tensile strength was carried out (0.025; 0.05; 0.1 N/mm).

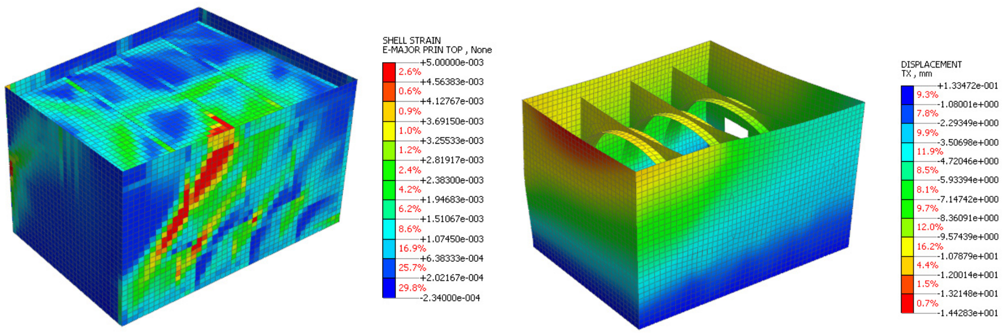


Figure 6: Principal Strain (left) and displacements (right) of the one-room model in the –X direction.

The pushover analysis in the east direction (-X) shown greater deformations on the intersections between the masonry wall and the arch (abutment), on the roof and on the eastern wall (Fig. 6). The evolution of the tensile stresses on the structure suggests a possible overturning and detachment of the wall M1 and of its corner. However, it must be considered that the implemented model does not consider the constraints given by the two walls of the historically adjacent building, which, on the contrary, would act as a counterthrust on the two longitudinal walls avoiding the possible overturning of the corner. From the displacements on the other hand, in agreement with the damage observed on the on-site survey, a horizontal flexure mechanism is identified centrally on the transverse façade.

By applying the acceleration in the western direction (+X) the higher tensile stresses concern the abutment of the arches, the roof and the western masonry wall, especially on the door's corners (Fig. 7). In this case, the out-of-plane mechanism of the corner is identified not only by the distribution of the principal tensile stresses but also by the displacements.

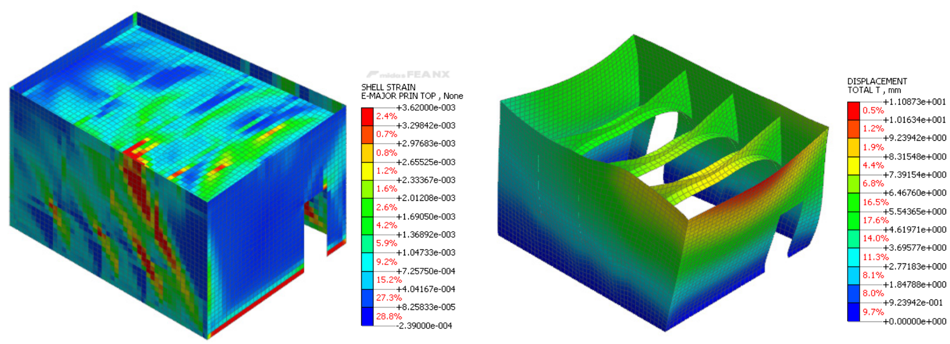


Figure 7: Representation of the Major Principal Strain (left) and the displacement (right) of the one-room model in the +X direction.

Comparison between observed damage and numerical analyses

The results obtained from these analyses support the thesis of a masonry collapse in the west-east direction. The analysis of the strains allowed confirming that the cracking state of the wall (M1) is consistent with a hypothesis of horizontal flexure mechanism, and the role of the roof, as a rigid mass acting perpendicular to the walls, in activating the collapse mechanisms. Regarding the M2 wall, both the strain results of the numerical model and the damage observed suggest a mechanism of overturning of the wall with the detachment of the corner.

CONCLUSIONS

The first part of the paper, concerning the large-scale knowledge of the Shivta site, turned out to be of fundamental importance for the purposes of defining all the analysis work. The study of the geometric characteristics and materials helped to identify the construction techniques, the structural systems of the buildings, and therefore their vulnerability. The Masonry Quality Index (MQI) method and the identification of the kinematics highlighted a poor wall quality and a trend to damage and collapse in case of seismic events. The geometrical and structural analysis of Building 86, characterized by an evident out-of-plane collapse mechanism, allowed to carry out a virtual reconstruction of the building, also supported by BIM methodology, fundamental to determine its seismic response. The pushover and modal analyses, supported by limit analysis of the collapsed wall, defined the specific mechanism activated on the eastern masonry wall of the building and the behavior of the structural part involved in the mechanism. Finally, this type of modeling has proved to be a reliable approach in order to evaluate the behavior of the building during seismic actions, reaching a result close to that of reality. This research can be considered as a first step for a future seismic analysis in a macro-scale view, with the aim of reconstructing the historical seismic events occurred on the Shivta village. If the earthquake of mid-8th Century (747, 749 or 757 CE), given the coincidence of the historical event with the abandonment of the site and of the near archaeological sites, seems to be the most reliable cause of Shivta decline, it is not however to be considered with certainty the primary cause of the site abandonment. By analysing more structures of the site and by extending the same seismic analysis procedure also to the archaeological sites suddenly abandoned in the same period, it would be possible to identify more clearly which seismic events have caused a strong destructive impact in the villages of the Negev desert. Future research could explore reinforcement strategies, considering both traditional and modern seismic retrofitting techniques suited to archaeological sites.

ACKNOWLEDGMENTS

The excavation at Shivta was conducted (Permit Nos. G-82/2018, G-5/2019; map ref. 16400–555/53100–450), on behalf of the Zinman Institute of Archaeology of the University of Haifa, was supported by the Crisis on the Margins of the Byzantine Empire Project (supported by research grants from the Israel Science Foundation - Grant 340-14 - and the European Research Council under the EU's Horizon 2020 research and innovation program - Grant 648427), and funded by the Israel Nature and Parks Authority (Rakefet Foundation). The two excavations seasons at the Building 86 were directed by Y. Tepper and G. Bar-Oz. Special thanks go to Yaacov Schaffer, Amos Salamon, David Zell, Michael Turner, Motti Zohar, Orit Bortnik, Tali Erickson Gini for their collaboration and support.

REFERENCES

[1] N. N. Ambraseys, "Earthquakes and archaeology," *J. Archaeol. Sci.*, vol. 33, no. 7, pp. 1008–1016, 2006, doi: https://doi.org/10.1016/j.jas.2005.11.006.

[2] Y. Hirschfeld, "Social aspects of the late-antique village of Shivta," *J. Roman Archaeol.*, vol. 16, pp. 395–408, Jan. 2003, doi: 10.1017/S1047759400013210.

[3] A. Korzhenkov and E. Mazor, "Seismogenic Origin of the Ancient Avdat Ruins, Negev Desert, Israel," *Nat. Hazards*, vol. 18, pp. 193–226, Oct. 1998, doi: 10.1023/A:1026488932377.

[4] M. Zohar, A. Salamon, and R. Rubin, "Damage patterns of past earthquakes in Israel – Preliminary Evaluation of historical sources," 2013.

[5] Y. Tepper, T. Erickson-Gini, and Y. Farhi, "Probing the Byzantine/Early Islamic Transition in the Negev: The Renewed Shivta Excavations, 2015–2016," *Tel Aviv*, vol. 45, pp. 120–152, Jan. 2018, doi: 10.1080/03344355.2018.1412058.

[6] Y. Tepper and G. Bar-O, "Shivta preliminary Report," Vol. 132, 2020. [Online]. Available: http://www.hadashot-esi.org.il/Report_Detail_Eng.aspx?id=25825

[7] *ISO 16739—Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries*. 2024.
[8] A. Borri, M. Corradi, G. Castori, and A. De Maria, “A method for the analysis and classification of historic masonry,” *Bull. Earthq. Eng.*, vol. 13, Sep. 2015, doi: 10.1007/s10518-015-9731-4.
[9] M. Zohar, A. Salamon, and R. Rubin, “Reappraised list of historical earthquakes that affected Israel and its close surroundings,” *Journal of Seismology*, vol. 20, no. 3. pp. 971–985, 2016. doi: 10.1007/s10950-016-9575-7.
[10] Z. Garfunkel, “Internal structure of the Dead Sea leaky transform (rift) in relation to plate kinematics,” *Tectonophysics*, vol. 80, no. 1, pp. 81–108, 1981, doi: https://doi.org/10.1016/0040-1951(81)90143-8.
[11] L. Alfonsi, “the kinematic of the 1033 A.D. earthquake revealed by the damage at Hisham palace (Jordan valley, dead sea transform zone),” *Seismol. Res. Lett.*, vol. 84, pp. 997–1003, Nov. 2013.
[12] T. M. Niemi, H. Zhang, M. Atallah, and J. B. J. Harrison, “Late Pleistocene and Holocene slip rate of the Northern Wadi Araba fault, Dead Sea Transform, Jordan,” *J. Seismol.*, vol. 5, no. 3, pp. 449–474, Jul. 2001, doi: 10.1023/A:1011487912054.
[13] “SI 413.” [Online]. Available: https://www.gov.il/BlobFolder/generalpage/suspected-of-excessive-urination/he/maps_24-4_map(1).jpg
[14] A. M. Korjenkov and E. Mazor, “Seismogenic Origin of the Ancient Avdat Ruins, Negev Desert, Israel,” *Nat. Hazards*, vol. 18, no. 3, pp. 193–226, Oct. 1998, doi: 10.1023/A:1026488932377.
[15] Italian Ministry of Infrastructures, *Circolare Esplicativa 21 gennaio 2019, n. 7 C.S.LL.PP. Istruzioni per l’applicazione dell’«Aggiornamento delle “Norme tecniche per le costruzioni”» di cui al decreto mi-nisteriale 17 gennaio 2018*. 2019.
[16] J. Milosevic, M. Lopes, A. S. Gago, and R. Bento, “Testing and modeling the diagonal tension strength of rubble stone masonry panels,” *Eng. Struct.*, vol. 52, pp. 581–591, 2013, doi: https://doi.org/10.1016/j.engstruct.2013.03.019.