Sakarya University Journal of Science

ISSN : 2147-835X
Publisher : Sakarya University

Vol. 28, No. 4, 844-854, 2024
DOI: https://doi.org/10.16984/saufenbilder.1464317

Research Article

Impact of Iron Clamps and Dowels on the Vulnerability of Ancient Masonry Walls

Funda Gençer

Manisa Celal Bayar University, Faculty of Fine Arts, Design and Architecture, Department of Architecture, Manisa, Türkiye, funda.gencer@cbu.edu.tr

ARTICLE INFO

Keywords:
Ashlar masonry
Failure mechanisms
Metal connectors
Tilt analysis
Conservation

Article History:
Received: 03.04.2024
Accepted: 04.06.2024
Online Available: 01.08.2024

ABSTRACT

Various masonry wall organization techniques were used in ancient Anatolian buildings depending on the local characteristics and the kind of stone used in the region. Traces of iron clamps or dowels can be seen on numerous ancient walls. This study's main goals are to ascertain the impact of iron clamps and dowels on the vulnerability of various ancient wall organizations in Anatolia and investigate potential relationships between wall organization types and clamp or dowel usage. Another study objective is to gather information about using metal connectors for restoration or anastylosis studies in archaeological sites.

First, a site analysis was performed on ancient cities to document various types of masonry. Four types of walls, namely *isodomic*, *isodomic* with header and stretcher, pseudo *isodomic*, and *isodomic* in alternation header and stretcher row were determined. Quasi-static tilt analysis was performed on 3D models of walls without clamps and dowels, with clamps, and with dowels to compare the failure mechanisms of the wall types.

As a result, the wall type with the highest strength gain when metal connectors were utilized in the analysis was *isodomic* organization, which also includes numerous traces of clamps and dowels in ancient cities. This indicates that knowledge was gained because of experiences against lateral loads at that time. This information is not only significant in terms of understanding the history of architecture but also provides data to reinforce ancient walls during conservation work.

1. Introduction

In the past, builders were aware of the earthquake risks and had tried to develop techniques to minimize their impact on their constructions. They tried to use different methods to improve the resistance of masonry walls and prevent the horizontal shifting of blocks. For instance, they used iron elements such as dowels and clamps of various shapes between blocks. Iron clamps and dowels were typically used to fasten together the blocks of stone in *ashlar* dry masonry construction.

Throughout history, various cultures and regions have given rise to a diverse range of masonry styles. Initially, walls were constructed with dry-jointed stones, while for defensive purposes, such as polygonal Cyclopean structures. First, polygonal masonry became common, however, the processing of stones and construction of the walls in polygonal masonry had been difficult and time-consuming. Then, the *Ashlar* technique composed of finely cut and worked stones became common due to its advantage of simple construction.

There were different Aslar technique applications. *Isomodomum ashlar* technique, involved uniform height courses in construction. These different techniques were illustrated in Figure 1. When rows had different heights but continuous horizontal joints, it was called *Pseudisodomum*. Another way to arrange stone courses is by altering the block orientation, header, and stretcher position [1]. This header

Cite as: F. Gençer (2024). Impact of Iron Clamps and Dowels on the Vulnerability of Ancient Masonry Walls, *Sakarya University Journal of Science*, 28(4), 844-854. https://doi.org/10.16984/saufenbilder.1464317

and stretcher style of masonry was discussed by Vitruvius (1914) in his book "De Architectura" (first century B.C.) [1]. Headers were used to strengthen walls that were constructed with trapezoidal or rectangular masonry [2-3]. The headers, which are arranged perpendicular to the course wall, reinforce the wall, and hold the wall leaves together (Figure 1).

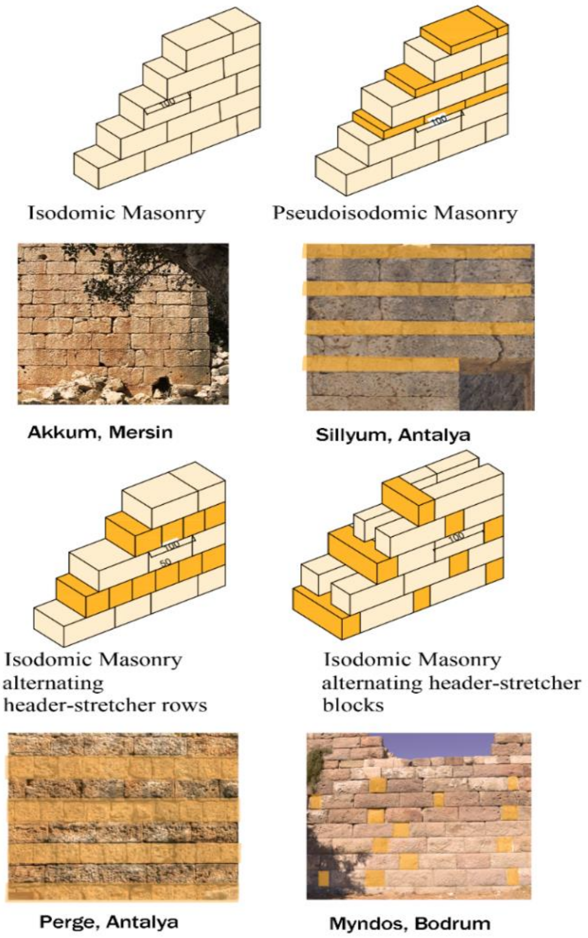
Isodomic Masonry
Pseudoisodomic Masonry
Akkum, Mersin
Sillyum, Antalya
Isodomic Masonry alternating header-stretcher rows
Isodomic Masonry alternating header-stretcher blocks
Perge, Antalya
Myndos, Bodrum

Figure 1. Examples of masonry organizations (drawings were drawn and photos taken by the author in 2017)

According to historical sources by Vitruvius (1914), Ceradini (1992), and Saner (1995) [1, 4, 5], the wall's thickness increases as there is a gap between the parallel stretchers. For thicker walls, three leaves were used, with a space in the middle of two parallel stretchers. To fill this space, stone fragments were used, or it was left unfilled. In some cases, headers were used to provide flexibility in the block arrangement. Throughout the third century BC, alternating layers of headers and stretchers were favored in most of Greece. In these wall sections, stretchers alternate with headers in all courses [6].

The primary requirement for *ashlar* building techniques was the organization of the stones to provide integrity. This type of organization was commonly employed in classical studies by scholars [7-10].

In the past, construction involved merely placing dry-jointed blocks together. However, the Romans also adopted the Greek technique of using metal or wooden clamps and dowels to strengthen the components of a stone block construction. These were designed to prevent joints from enlarging due to potential movements caused by shifts in foundation settlement or seismic shocks [11]. Various metallic connections, including dowels and clamps, were used between the stone blocks to prevent horizontal movement in *ashlar* dry masonry construction. Iron clamps and dowels were commonly used to fasten stone blocks together. The blocks were joined horizontally with an iron clamp that slid into grooves cut into the ends of the stone blocks. Similarly, iron dowels were used to fasten the drums of columns or blocks vertically to prevent sliding under shear. Clamps and dowels were also utilized to prevent any stone movements caused by earthquakes or foundation settlements [12-13].

Due to their ability to provide the building with plasticity and allow for energy dissipation through plastic deformation, metal connectors decrease friction forces even before the blocks begin to move relative to each other [14]. Structural analysis, simulations, etc. have been used in conservation studies of cultural heritage in recent years [14-19]. Numerous studies have been conducted to examine the structural strength of various masonry arrangements, in addition to typological examinations [4, 16-20]. There are studies demonstrating types of iron connectors in historical buildings [20-21].

Kurugöl, Küçük (2015) discuss the various forms and applications of iron in traditional architecture, as well as the production techniques and shaping methods used throughout history. The paper also highlights some of the problems that have arisen with iron materials over time [20]. Also, in some studies, the effect of the size and position of the iron clamps and dowels on the behavior of the masonry walls is investigated

[22-33]. Tanrıverdi, Çelik, Ural, Fırat (2022) investigated the effect of clamps with different widths on lateral load behavior and determined the ideal seam width [22]. The study by Tanrıverdi, Çelik, Ural, Fırat (2022) investigates the impact of clamp immersion points on the shear strength of stones [23]. In a study by Uslu (2013), walls that were constructed using metal clamps and dowels were subjected to the diagonal pressure effect to examine their behavior under the shear effect [24].

Additionally, Smoljanovic, Nikolic, Zivaljic (2015) analyzed the seismic performance of a historical masonry structure strengthened with steel clamps and bolts [25]. Karabork, Kocak (2014) conducted a study on stone masonry walls supported by various iron clamps and dowels to test their structural integrity under diagonal compression and investigate failure modes [26]. Nikolić, Krstevska, Marovic (2017) investigated the behavior of the model of the stone masonry structure in Diocletian's Palace in Split, Croatia under lateral loading [27]. There are some studies discussing the development of the usage of iron clamps and dowels in ancient temples and monuments. The effect of iron connectors on the strength of the monuments and conservation studies were discussed [28-33].

These studies investigate the potential impact of the size, position, and type of clamps and dowels within the same masonry structure. However, considering the variety of masonry organization types found in Anatolia, figuring out the optimal size and placement of metal connectors has proven to be difficult. Although clamps and dowels have been used in various wall types, there is a need for research on how these metal elements contribute to the strength of different wall types and how they affect damage mechanisms. The primary objective of this study is to determine the effect of iron clamps and dowels on different ancient wall organizations in Anatolia and investigate if there is any correlation between wall organization types and the usage of clamps and dowels. The study explores whether iron clamps and dowels were used intentionally. Results should be used as a base for restoration or anastylosis applications in archaeological sites.

1.1. Clamps and dowels

The Egyptians were the first to use strong hardwood clamps shaped like double dovetails to provide integrity to masonry walls. Bronze clamps, shaped like a double T, were also used in pre-Columbian Andean construction in the eighth century AD. Roman builders used fewer double-T clamps than Greek architects, who extensively used them in Greek constructions up until the Hellenistic era. The double-T clamps were first utilized in Athens at the beginning of the fifth century BC. The stones in the course were firmly attached using clamps. Occasionally, and more frequently among the Greeks than the Romans, a vertical bonding was added to the horizontal bonding [34]. Clamps are typically made of iron flats that have tails, forks, and other shapes that are created through the shaping process. Types of clamps were demonstrated in Figure 2. To reinforce the connection, lead was poured on the curved ends that entered the holes made in the stone [20].

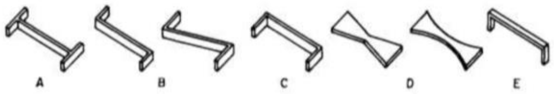

Figure 2. Clamp types [35]

The clamping method involves placing two blocks side by side in the slots on the connecting edges, which are only 3-4 mm wide. Iron pieces are inserted, and molten lead is poured over them to secure the irons tightly into the stone slot and prevent rusting. To facilitate the lead flow, channels may be created that extend to the edge of the block, and the molten lead is poured into clay chambers at the end of these channels to cover the seam with lead. Clamps and dowels were typically made of iron, rarely bronze, and placed in rectangular cuttings in stone. They were fixed with lead to ensure cohesion of courses, to prevent the connection from breaking due to any possible movement, and to isolate the metal element inside from air [13, 34] The size of the clamps used depends on the size of the stones being connected.

Traces of iron connectors were widely observed in *isodomic* masonry structures consisting of single-walled stretcher blocks, such as Cnidus, Sard, Lairbenos, Pergamon, and Gölyazı, etc. in the site surveys. However, their use was rare in *isodomic* structures with headers and stretchers and *pseudoisodomic* masonry. Clamps and dowels were primarily used in the walls of temples, bouleuterions, stadiums, etc., rather than in the city walls. Their use on the ground levels of buildings, such as the Priene Athena Temple and Theater, the foundation of a grave building in Pergamon was particularly noteworthy.

The walls of the Sard Artemis Temple had clamps and dowels in both *isodomic* and *isodomic* with header and stretcher block wall types. In the ancient city of Cnidus, both *pseudoisodomic* and *isodomic* walls had traces of clamps and dowels. However, no clamps were found on the *isodomic* walls with alternating header and stretcher blocks, which are commonly used in Mediterranean ancient cities such as Perge and Side. The traces of clamps and dowels from Anatolian ancient cities were given in Figure 3.

Figure 3. Traces of clamps and dowels in different ancient Anatolian cities (photos taken by the author in 2024)

2. General Methods

First, a site analysis was performed on ancient cities such as Perge, Side, Pergamon, Aigai, Sillyum, and Sardes, to document various types of masonry. The relationships between stone blocks were examined. To analyze why they were employed or not, wall types with and without iron connecting traces have both been chosen. The study has focused on four types of walls, namely *isodomic*, *isodomic* with header and stretcher, pseudo *isodomic*, and *isodomic* in alternation header and stretcher rows. Only the *isodomic* wall with alternation header and stretcher rows exhibited no traces, whereas the other three types have traces. Table 1 demonstrates different wall types and usage of clamps and dowels in different ancient cities.

In the second phase, 3D models were created for different types of walls. These walls are 500 cm tall and 560 cm long and were modeled with clamps and dowels separately. Connectors, clamps, and dowels were used to connect two blocks. Clamps have dimensions of 20 cm in length and 6 cm in width. They are arranged in the stones' center axes of width. Dowels have dimensions of 5 by 5 cm. One dowel was placed in the center of the header blocks, and two dowels were placed on each stretcher block. The 3Dmodels of the wall types and the position of metal connectors were given in Figure 4 and 5 respectively. The clamps and dowels were modeled as Hinge Joint.

Then, quasi-static analysis was performed on wall types with and without metal connectors, as well as those with clamps and dowels to analyze the effect of metal connectors on the lateral load behavior of the walls. Using SketchUp 2017, the walls were modeled as distinct rigid blocks arranged in a certain order without any connecting elements. Next, a quasi-static tilt analysis simulation based on the equilibrium state was conducted using MS Physics 1.0.3. This made it possible to simulate discrete elements physically in real time, giving each piece unique attributes like shape, density, and friction, among others. The equilibrium problem was solved using a static rigid body method (Figure 4).

Initial analyses were performed to verify the accuracy of the MS Physics software. The literature's experimental results and the simulation's results were compared. Using SketchUp software, 3D models were generated based on the wall sizes and material properties reported by Restrepo Velez, Magenes, Griffith (2014) [36].

Table 1. Wall types observed in ancient cities

Ancient Cities	Wall types	Clamps	Dowels
Aigai	Isodomic	√	
	Isodomic header and stretcher blocks		
Pergamon	Isodomic	√	
Sillyum	Pseudoisodomic		
Sard	Isodomic	√	√
	Isodomic Header and Stretcher blocks	√	√
Lairbenos	Isodomic		√
Aiolis	Isodomic		√
Cnidus	Isodomic header and stretcher blocks	√	√
	Isodomic	√	√
	Pseudoisodomic	√	√
Perge	Isodomic header and stretcher rows		
Side	Isodomic header and stretcher rows		
Myndos	Isodomic header and stretcher blocks	√	
Akkum	Isodomic header and stretcher blocks	√	

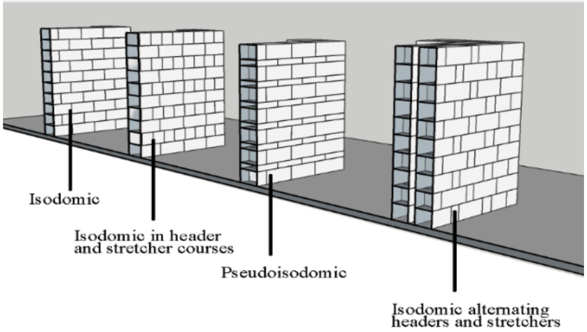

Figure 4. *Ashlar* masonry types (drawn by the author via SketchUp 2017)

The failure mechanisms were examined by tilting these models using a virtual table in MsPhysics. Using marble units, Restrepo Velez, Magenes, Griffith (2014) carried out an extensive quasi-static testing program that considered 1:5 scale models of dry-joint stone masonry walls and structures [36]. Their marble blocks measured 80 mm by 40 mm by 30 mm. Blocks' unit weight was 2680 kg/m^3, and their friction coefficient was calculated to be 0.77 [37].

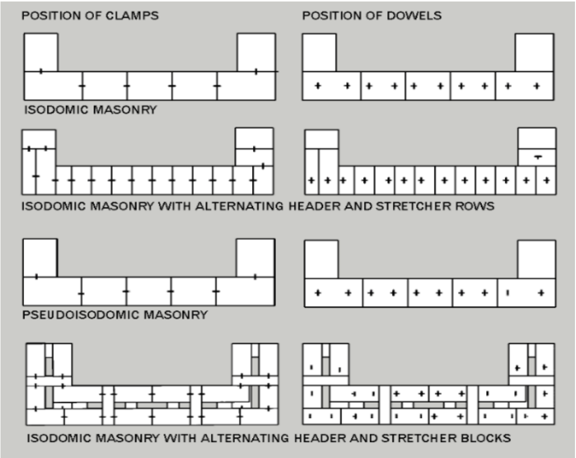

Figure 5. Position of clamps and dowels (modeled by the author via SketchUp 2017)

In this quasi-static testing regimen, 0.6 m, or 21 courses, was the average height of a specimen. The examples featured a two-story building with openings, as well as one-, two, or three-sided walls with or without openings. The iterative value of 16 was selected, and an update time step of 1/120 was used to guarantee accuracy in the computer simulations of the 3D models. It was discovered that the real verses of the virtual models' damage mechanisms and collapse angles were nearly equivalent. The simulation results were compared in Figure 6.

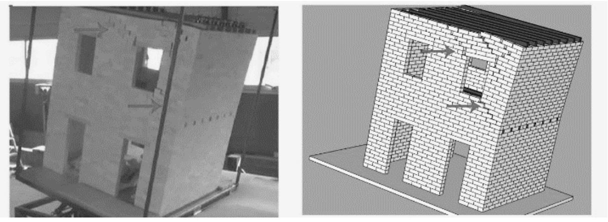

Figure 6. Wall behavior observed from experimental analysis [36] and simulation

Rigid block, group, and component densities are provided by MS Physics software, which is based on physical simulations and connection states. The modulus of elasticity is disregarded in the simulations, but the friction coefficient is considered. Since a smaller update time step yields more accurate simulation results and keeps collisions from getting worse, 1/120 was chosen as the update time step. Given that the towers were made up of numerous movable blocks, 16 was chosen as the iterative value [38].

By tilting the ground plane of each 3D model, the lateral acceleration applied to each model could be changed. Until complete collapse, the tilt value was raised by one degree. The component that is parallel to the gravitational acceleration's tilted ground plane at the collapse level can be understood to represent the maximum ground acceleration that the structure must be able to withstand. According to DeJong (2009) and Jimenez (2011), the lateral component of the gravitational acceleration equals the horizontal acceleration (λ), where $\lambda = mg \times \sin\theta$.

Although the impacts of dynamics as shown by seismic loading are not represented by this equivalent static loading, it does allow one to quantify the structure's lateral load-bearing capability in terms of acceleration [39-40]. Every designed wall has an in-plane and an out-of-plane tilt. When evaluating, the smallest collapse angle was always considered.

3. Results and Discussion

When the damages of different wall organizations were compared, the wall with the highest structural strength was the *isodomic* wall with headers and stretchers, followed by the *isodomic* wall and *pseudoisodomic* walls, which had similar strengths. The walls alternating header and stretcher rows had the lowest strength under lateral loading.

When the lateral load was in the in-plane direction, the use of clamps or dowels increased the strength of the wall significantly. Dowel additions improved resistance more than clamp additions. Moreover, in the *isodomic* wall, the contribution of both the clamps and the dowels to the structure strength was found to be the highest. The usage of clamps resulted in a 35% increase in strength, whereas using dowels resulted in an 80% increase in strength. The analysis results were given in Table 2.

The strength of the walls increased by about 25% when clamps were used, and by up to 60% when dowels were used. But dowels, used in the walls alternating header and stretcher courses, contributed only 5% of the wall's strength.

Table 2. Collapse angles of walls under lateral force in the in-plane direction.

	Without clamps	With clamps	Percentage of increase in resistance	With dowels	Percentage of increase in resistance
Isodomic masonry	20°-collapse	28°-crack 29°-collapse	35 %	36°-collapse	80 %
Isodomic with alternating header and stretcher courses	18°-collapse	23°-collapse	28 %	19°-crack 20°-collapse	5.5 %
Pseudoisodomic masonry	20°-collapse	24°-crack 25°-collapse	20 %	35°-collapse	75 %
Isodomic alternating header and stretcher blocks	22°-collapse	27°-crack 28°-collapse	27 %	36°-collapse	68 %

The contribution of clamps and dowels to wall strength was less when the lateral load occurred in an out-of-plane direction. The strongest wall, *isodomic* alternating stretchers and headers, increased in structural strength by 15% when dowels were used. On the other hand, the use of dowels did not affect the resistance of walls with alternating header and stretcher rows. The analysis results were given in Table 3.

Four different types of failures were observed in the walls based on analysis results: flexural failure, diagonal/stair-stepped cracking, vertical cracking, and sliding failure (Figure 7), [41]. Diagonal cracks or stair-stepped cracks occurred in *isodomic*, *isodomic* alternating header stretcher, and *pseudoisodomic* walls when clamps or dowels were not used, and when the lateral load came in the in-plane direction. On the other hand, both vertical and diagonal cracks were observed on the walls alternating header stretcher rows.

Table 3. Collapse angles of walls under lateral force in the out-of-plane direction

	Without clamps	With clamps	Percentage of increase in resistance	With dowels	Percentage of increase in resistance
Isodomic masonry	13° -collapse	15° -collapse	15%	15° -collapse	15%
Isodomic with alternating header and stretcher courses	14° -collapse	15° -collapse	7%	14° -collapse	0%
Pseudoisodomic masonry	14° -collapse	15° -collapse	7%	15° -collapse	7%
Isodomic alternating header and stretcher blocks	18° -collapse	21° -collapse	17%	23° -collapse	28%

When clamps were used, flexural failures and diagonal cracking were observed in the walls connected with clamps. The walls presented both sliding and cracking along the length of the wall. The study by Karabork, Kocak (2014) was supported by the results obtained. The study found that a failure mechanism like the *isodomic* wall developed with clamps when tested for shear strength under diagonal compression [26]. However, it is worth noting that block sliding in the upper parts was not observed since the walls were mortared. The failure mechanisms were given in Figure 8.

The use of dowels did not result in flexural failure like clamps did. However, cracks (approximately 1 cm) were observed in *isodomic* and *pseudoisodomic* walls due to sliding, while partial collapse was seen in the *isodomic* walls that used alternating header and stretcher without any diagonal cracking. Dowels considerably strengthened the walls when headers and stretchers were used (Figure 8).

Isodomic walls consist of alternating header and stretcher rows, wherein the vertical joints are situated close to each other in the upper and lower rows. The blocks on top of one another displayed a monolithic behavior and created vertical cracks when dowels were used to join them. Therefore, the use of dowels did not affect the structure's behavior and strength in the walls with alternating header stretcher courses. Clamps reduced the vertical cracking of the close-jointed blocks stacked on top of one another, hence increasing the strength of the walls. Stair-stepped cracks began to form in place of vertical cracking. The failure mechanisms were given in Figure 9.

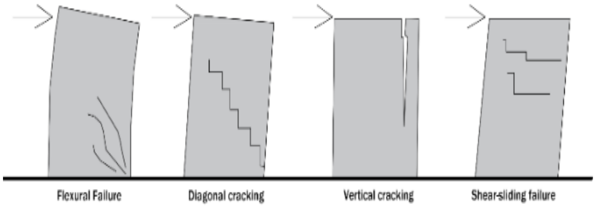

Figure 7. Determined failure types in the walls (drawn by the author via Autocad 2024)

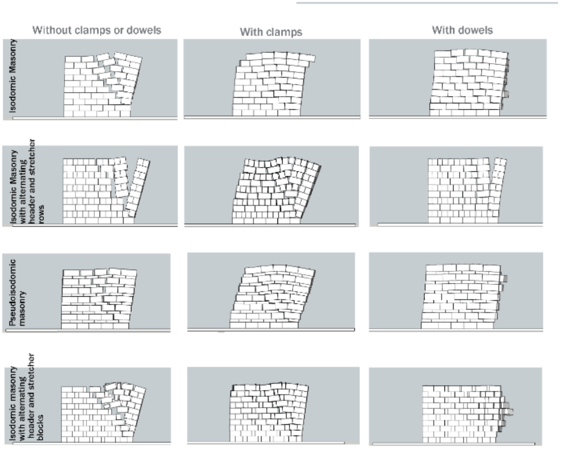

Figure 8. Failure types when the lateral load at the in-plane direction (modeled by the author via SketchUp 2017 and MsPhysics 1.0.3.)

Similar failure mechanisms were observed in the models when the walls were tilted in an out-of-plane direction. However, bending shear was observed when dowels were used in alternating header and stretcher rows. In cases where clamps and dowels were used in alternating header and stretcher blocks, bending shear formation was also observed. Shear cracking was observed in other wall types, as well as in dowel usage. The failure mechanisms were given in Figure 10.

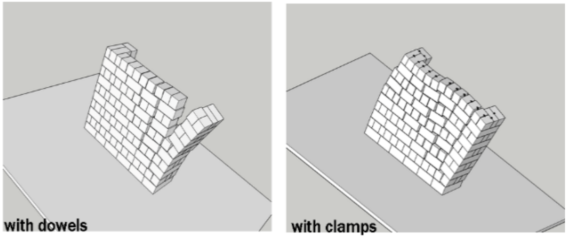

Figure 9. Different behavior of walls alternating header and stretcher rows connected with dowels and clamps (modeled by the author via SketchUp 2017 and MsPhysics 1.0.3.)

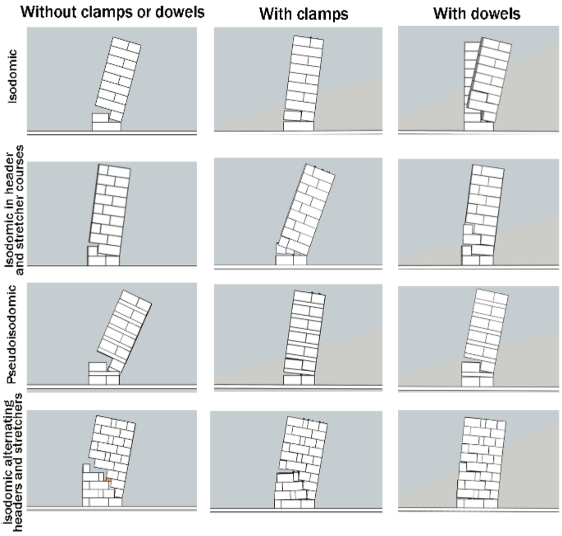

Figure 10. Different behavior of walls connected with dowels and clamps (modelled by the author via SketchUp 2017 and MsPhysics 1.0.3.)

4. Conclusion

The impact of metal connections on different types of masonry walls was investigated through research. As a result, the wall type with the highest utilization of clamps and dowels in ancient cities was isodomic organization, which also offered the greatest strength gain when metal connectors were tested in the analysis.

The use of dowels in *isodomic*, *isodomic* header stretcher blocks, and *pseudoisodomic* walls significantly increased the strength of the structure. However, it also caused shifts in horizontal rows between the blocks and changes in failure types. Stair-stepped cracks in the structure were reduced to a minimum.

In *isodomic* alternating header and stretcher rows, the vertical joints in the upper and lower rows were near to one another thus, vertical cracks were seen. Clamps prevented vertical cracks by connecting blocks horizontally. Thus, using clamps was crucial to maintaining the structural integrity of walls with narrow vertical joint distances. However, the blocks, on top of each other, connected with dowels behaved monolithically, and vertical cracks were observed right away. In the site surveys, no traces of dowels were observed on the walls alternating header and stretcher rows commonly used in the Side and Perge regions. This led to the question of whether stonemasons made a conscious decision regarding this.

Consequently, results are crucial for comprehending the evolution of structural design, and they show which types of ancient walls should be supported by clamps or dowels while doing conservation works. Rather, distinct safety measures ought to be implemented to augment the structural robustness of disparate wall types.

Article Information Form

Funding

The author has not received any financial support for the research, authorship, or publication of this study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical, and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

Copyright Statement

References

[1] Vitruvius, The Ten Books on Architecture, Translated by Morgan M. H. Cambridge: Harvard University Press, 1914.

[2] A. Orlandos, Les Matèriaux de Construction: Et la Technique Architecturale das Anciens Grecs, Paris: E. de Boccard, 1968.

[3] S. K. Nossov, Greek Fortifications of Asia Minor 500-130 BC: From the Persian Wars to the Roman Conquest, UK: Osprey Publishing, 2012.

[4] V. Ceradini, "Modellazione, Sperimentazione per lo Studio della Struttura Muraria Storica," Ph.D. Dissertation, Department of Architecture, University of Rome, Rome, Italy, 1992.

[5] T. Saner, "Some Remarks on the Hellenistic Masonry Techniques in Asia Minor," in Archéomatériaux Marbres et autres roches, Actes de la IV e Conférence internationale ASMOSIA IV, University of Bordeaux, France, 1995, pp. 347-350.

[6] L. Karlsson, "Fortification Towers and Masonry Techniques in the Hegemony of Syracuse, 405-211 B.C," in Acta Instituti Romani Regni Sueciade, 40, XLIX, B. Alroth, Ed. Stockholm: Minab, 1992.

[7] S. Clarke, R. Englebach, Ancient Egyptian Masonry, London: Oxford, 1930.

[8] R. L. Scranton, Greek Walls, Cambridge: Harvard University Press, 1941.

[9] A. W. Lawrence, Greek Architecture. England: Penguin, 1957

[10] R. Martin, Living Architecture-Greek. London: Oldbourne, 1967.

[11] J. P. Adam, Roman Building, Materials, and Techniques, translated by Anthony Mathews, London, and New York: Routledge, 2005.

[12] R. Mark, Architectural Technology up to the Scientific Revolution. The Art and Structure of Large-Scale Buildings. Cambridge: The MIT Press, 1993.

[13] O. Bingöl, Arkeolojik Mimaride Taş, İstanbul: Homer Yayınevi, 2004.

[14] S. Alaçam, İ. Karadağ, O. Z. Güzelci, "Reciprocal style and information transfer between historical Istanbul Pervititch Maps and satellite views using machine learning," Journal of the Faculty of Architecture and Urbanism of University of Cuenca, vol.11, no.22, pp. 71-81, 2022.

[15] K. A. Papadopoulos, "The restoration study of the connections between the stone blocks in the steps of the temple of Apollo Epikourios," in 5th International Conference on Structural Analysis of Historical Constructions, New Delhi, India, 2006, pp. 1389-1396.

[16] A. Giuffre, Letture sulla meccanica delle murature storich, Rome: Kappa, 1991.

[17] P. Fuentes, S. Huerta, "Geometry, Construction and Structural Analysis of the Crossed-Arch Vault of the Chapel of Villaviciosa, in the Mosque of Córdoba," International Journal of Architectural Heritage, vol.10, no.5, pp. 589-603, 2016.

[18] S. Huerta, "The Analysis of Masonry Architecture: A Historical Approach," Architectural Science Review, vol.51, no.4, pp. 297-328, 2008.

[19] M. A. Keller, "The early Phrygian gate at Gordion, Turkey: An investigation of dry-stone masonry in seismic regions and recommendations for stabilization," Master Thesis, Department of Historic Preservation, University of Pennsylvania, USA, 2009.

[20] S. Kurugöl, S. G. Küçük, "Tarihi eserlerde demir malzeme kullanım ve uygulama teknikleri," in 5. Tarihi Eserlerin Güçlendirilmesi ve Geleceğe Güvenle Devredilmesi Sempozyumu, Erzurum, 2015, pp. 521-536.

[21] İ. E. Usta, H. İ. Alpaslan, "Batı Anadolu'daki Antik Yapılarda Taş ve Taşçı İzleri," in IV. Uluslararası Taş Kongresi, İzmir, 2017, pp. 615-637.

[22] Ş. Tanrıverdi, T. Çelik, A. Ural, F. K. Fırat, "Kenet Genişliğinin Yığma Taş Bloklarının Kayma Davranışı Üstündeki Etkisinin İncelenmesi," Düzce Üniversitesi Bilim ve Teknoloji Dergisi, vol.10, pp. 1811-1825, 2022.

[23] T. Çelik, Ş. Tanrıverdi, A. Ural, F. K. Fırat, "Yığma Yapılarda Kullanılan Kenetlerin Yapı Davranışına Etkilerinin İncelenmesi," Afyon Kocatepe University Journal of Sciences and Engineering, vol. 21, pp. 650-659, 2021.

[24] S. Uslu, "Tarihi yığma yapılarda kullanılan metal bağlantı elemanlarının deneysel metotlarda incelenmesi," M.S. Dissertation, Aksaray University, Aksaray, Turkey, 2013.

[25] H. Smoljanovic, A. Nikolic, N. Zivaljic, "A finite-discrete element model for dry stone masonry structures strengthened with steel clamps and bolts," Engineering Structures, vol.90, pp. 117–129, 2015.

[26] T. Karabork, Y. Kocak, "New metal connectors developed to improve the shear strength of stone masonry walls," Structural Engineering and Mechanics, vol. 50, no.1, pp. 121–135, 2014.

[27] Z. Nikolić, L. Krstevska, P. Marovic, H. Smoljanović, "Shaking table test of scaled model of Protiron dry stone masonry structure," Procedia Engineering, vol.199, pp. 3386-3391, 2017.

[28] G. Varoufakis, "The iron clamps and dowels from the Parthenon and Erechtheion," The Journal of Historical Metallurgy Society, vol. 26, 1992.

[29] K. Papadopoulos, "The Restoration Study of the Connections Between the Stone Blocks in the Steps of the Temple of Apollo Epikourios," in 5th International Conference on Structural Analysis of Historical Constructions, New Delhi, India, 2006, pp.1389-1396.

[30] S. Kourkoulis, E. Pasiou, "Epistyles connected with "I" connectors under pure shear," Journal of the Serbian Society for Computational Mechanics, vol.2, pp. 81-99, 2009.

[31] E. E. Toumbakari, "Analysis and Interpretation of the Structural Failures of the Orthostate in the Northern Wall of the Athens Parthenon," Strain, vol. 45, pp. 456-467, 2009.

[32] G. Varoufakis, "The rapid Development of Technology in making iron Clamps of three Ancient Temples in the Archaic and Classical Period," Journal of Chemistry and Chemical Engineering, vol.6, pp. 1136-1141, 2012.

[33] D. Triantis, I. Stavrakas, E. Pasiou, G. Hloupis, S. Koukoulis, "Innovative Experimental Techniques in the Service of Restoration of Stone Monuments - Part II: Marble Epistyles under Shear," Procedia Engineering, vol.109, pp. 276-284, 2015.

[34] Masonry. (2024, March 20). Available: http://www.ime.gr/chronos/04/en/culture/314arts_arch_masonry.html

[35] W. B. Dinsmoor, Ancient Athenian Building Methods, Vermont: American School of Classical Studies at Athens, 1984.

[36] L. F. Restrepo Velez, G. Magenes, M. C. Griffith, "Dry Stone Masonry Walls in Bending—Part I: Static Tests," International Journal of Architectural Heritage: Conservation, Analysis, and Restoration, vol.8, no.1, pp.1-28, 2014.

[37] T. Bui, A. Limam, V. Sarhosis, M. HJiaj, “Discrete Element Modelling of the In-Plane and Out-Of-Plane Behavior of Dry-Joint Masonry Wall Constructions,” Engineering Structures, vol.136, pp. 277-294, 2017.

[38] A. Synytsia, (2017, March 15). MSPhysics 1.0.3 [Online] Available: https://sketchucation.com/forums/viewtopic.php?f=323&t=56852&start=660.

[39] M. J. DeJong, “Seismic Assessment Strategies for Masonry Structures,” Ph.D. dissertation, Department of Architecture, Massachusetts Institute of Technology, United States, 2009.

[40] D. D. Jimenez, “Empirical Analysis of Masonry Walls: Structural Design and Seismic Reinforcement through Tilting Experiments,” M.S. Dissertation, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, United States, 2011.

[41] I. Caliò, Ivo, M. Marletta, B. Pantò, “A Simplified Model for the Evaluation of the Seismic Behaviour of Masonry Buildings,” in The Tenth International Conference on Civil, Structural and Environmental Engineering, pp.2-17.