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Mediterranean Archaeology and Archaeometry
Vol. 19, No 3, (2019), pp. 63-78
Open Access. Online & Print.

DOI: 10.5281/zenodo.3541100

STRUCTURAL CHARACTERISTICS OF *ASHLAR* ROMAN WATCHTOWERS IN CILICIA REGION, ANATOLIA

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Received: 27/09/2019
Accepted: 27/10/2019

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ABSTRACT

Depending on requirements of the building type, *ashlar* masonry (that is a masonry technique composed of rectangular blocks); varies in terms of dimension of blocks, staggering ratio, wall profile, etc. Determination of impact of these variables on resistance is critical for the intervention decision process and sustainability of integrity and authenticity of dry masonry constructions. Therefore, the aim of the study is to determine characteristics effecting structural resistance and failure mechanisms of *ashlar* Cilician dry masonry watchtowers under lateral loading by quasi-static tilt analysis. Thus, the towers were documented in detail by traditional documentation techniques, the type of stone material were determined by Scanning Electron Microscope (SEM) equipped with X-Ray Energy Dispersive System (EDS) and X-ray Diffraction (XRD) analysis to identify friction coefficient and density values of stones to be used in simulation. Then virtual towers designed based on caharacteristics of case study towers were analysed by quasi-static tilting method.
The towers present differences in terms of staggering ratio, which is the ratio between horizontal distance between joints (s) and height of the related course (h), and proportional relationship between heigth (H) and length (L) of the tower. Consequently, it is seen that staggering ratio affected out-plane resistance of the towers, increase in staggering ratio increased structural resistance. High staggering ratio (s/bh=1.4) provided total behavior. When the H/L ratio increased (H/L ≥2), the collapse angle of the towers decreased and slenderness of the towers increased, bending was observed. These results demonstrate that ancient masons were probably aware of structural precautions for resistance, they tried to use these techniques within the limits of the sources of the area.

KEYWORDS: Dry masonry, Roman period, Watchtowers, Staggering ratio, Proportional Relationship

1. INTRODUCTION

In Cilicia Region, there are lots of towers constructed by different masonry techniques as *ashlar* or polygonal with different sized blocks (Durugönül, 1998). Ashlar masonry is a construction technique composed of tooled rectangular stones, while polygonal masonry is composed of polygonal stone with rounded or angular sides. In this study, the structural characteristics of four individual towers constructed out of *ashlar* masonry are focused.

The towers are located in Rough Cilicia (Figs.1, 2). There is limited information on Rough Cilicia in the 10th and 20th century BC. According to remains, Rough Cilicia might have been located in the borders of Tarhundaşşa Kingdom or Hittite Empire. In 10th century BC, this area had been probably within the boundaries of Assyria. The area was named as "Hilakku" (Zoroğlu, 1994). In 612 BC, Assyrian administration was terminated (Sevin 1984, 286). Colonies were established in the area (Mansel, 1970). Then, the region "Pirundu" until the border of Gazipaşa at the west was taken under the rule of Babylon (Zoroğlu 1994). After that, the area was taken under the rule of Persians (547-400 BC), Macedonian Empire (333 BC) and Seleucids. Towards the end of the 2th century BC, piracy and slave trade were prevalent. In this period, the watchtowers were constructed in the area for security. Romans fought against pirates, then in 67 BC, Romans took the control of the area over (Koşay, 1968).

In Rough Cilicia, particularly in the area between the river Kalykadnos (modern Göksu) and the Lamos (modern Limonlu), there are many Late Hellenistic and Roman towers. Some of these were free-standing, some were parts of fortresses. There are five free-standing towers in the *ashlar* style (Akkum, Boyan, Gömeç, Sarayın and Yalama). Except Yalama Tower, other towes had sustained their integrity. They were probably built between the end of Seleucid rule in 133 BC, the defeat of the pirates by Pompey in 65 BC (Durugönül, 1998; Kaplan, 2014).

The watchtowers are located in the district of Erdemli in Mersin province, about three kilometres at the north of Kızkalesi and 20 kilometres at the southwest of Erdemli (Figure 1). They were also located on the ancient Roman road from Korykos to Olba-Diocasearea. It also knows that these towers were also used for storing grain as well as watching around (Mitford-Andrews, 1980).

Figure 1. Location of towers (YandexMaps, 2018)

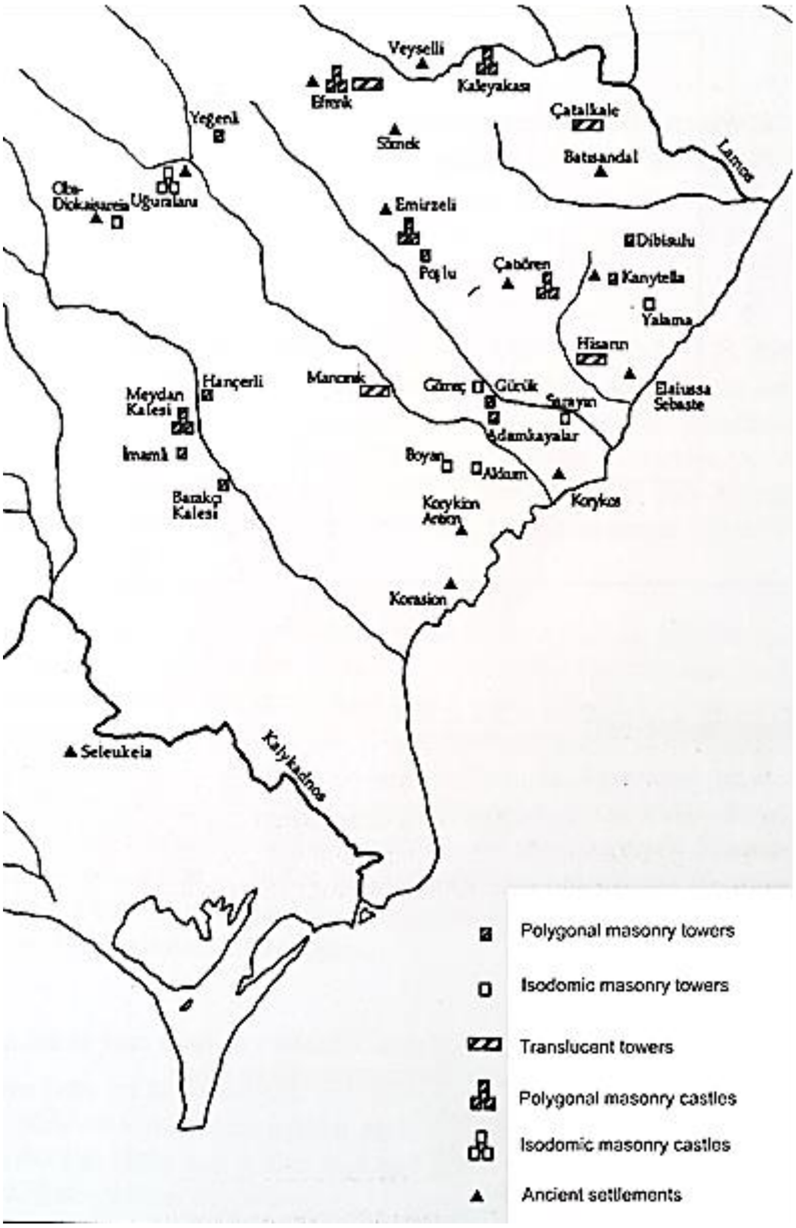

Figure 2. Location of towers in Cilicia (Durugönül, 1998)

There are studies investigating structural resistance of different types of mortared masonry buildings in different periods (Elyamani and Roca, 2018a; Elyamani and Roca, 2018b; Abdel-Aty 2019) but there are limited studies about the behaviour of dry masonry constructions (Giuffre, 1991; Ceradini, 1992; D'ayala and Speranza, 2003). Therefore, *ashlar* dry masonry constructions must be documented, material type must be determined (Ramrez et. al. 2019) and statistical analysis must be done before conservation studies. To understand behaviour, plan organization, proportional relationship between height (H) and length (L) of the buildings, staggering ratios, stone types, dimensions of blocks and wall profile must be focused in detail for each building type separately. Staggering ratio, which is the ratio between horizontal distance between joints (s) and height of the related course (h), is critical for organization of stone blocks (D'ayala, and Speranza, 2003) (Figure 3).

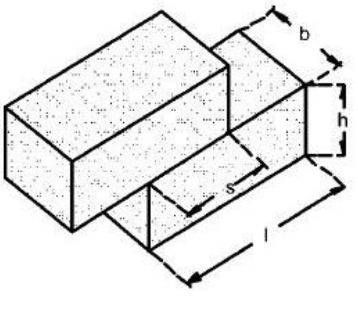

Figure 3. Staggering of blocks (s/h) (D'ayala, and Speranza, 2003)

The aim of the study is to determine characteristics effecting structural resistance and failure mechanisms of *ashlar* dry masonry watchtowers under lateral loading by quasi-static tilt analysis. First the towers, with their proportional relationship, plan and facade organizations, organization of stone blocks were documented, and stone type was determined. Different characteristic features were identified, and then to compare effect of these characteristics, virtual towers were designed. The effect of characteristics on resistance was determined by analysis of virtual towers. To prove the consciousness of preferred techniques, simulation of towers under lateral loading were done.

2. METHOD

The study was realized in three phases: documentation of characteristics of case study towers, comparison of characteristics, design of virtual towers by using characteristics, investigating effect of characteristics by rigid block simulations of virtual towers.

Structural and morphological characteristics of towers were documented by traditional documentation techniques and material usage of case study towers was investigated with laboratory analysis. Documentation is composed of series of phases. Laser meter, steel tape, range rod and ladder were used. At towers on inclined topography, wall thicknesses of the upper stories were reached from the exterior by standing on the bedrock. Wall thickness of upper portions of towers at plane areas were measured from the inside with the help of a ladder and a steel tape. Dimension of stone blocks and position of joints were measured with a steel tape at the lower parts, but photos parallel to facades were taken without tilting the camera in horizon direction. Then, these photos were rectified by Zoner Photo Studio X and used to draw the arrangement of stone blocks at the upper parts. Data coming from rectifications were combined with measured data at Autodesk 2018 by overlapping the reference points.

For the characterization of stone used in towers, mineralogical and chemical compositions were determined. Type of stone is important for the determination of friction coefficient and density values to be used in simulations. For determination of mineralogical compositions of the stones, stone samples taken from the case study towers were investigated with X-ray Diffraction (XRD) analysis performed by using a Philips X-Pert Pro X-ray Diffractometer. Chemical compositions of the samples were determined by Philips XL 30S-FEG Scanning Electron Microscope (SEM) equipped with X-Ray Energy Dispersive System (EDS).

After documentation, the virtual towers designed based on characteristics of case study towers were analysed. MS Physics 0.9.9 software was used for the quasi-static tilt analysis simulation based on the equilibrium state. MS Physics software provides rigid block, group, and component densities based on connection states, and physical simulation. In MSPhysics, an object can be modelled with a specific shape, specific state, density, contact and magnet characteristics. Gravity, update timestep, and solver model values can be adjusted (Extension Warehouse 2017). In the simulations, friction coefficient is taken into consideration, but elasticity coefficient is ignored based on studies in literature (D'Ayala and Speranza 2003). The update time step is taken as 1/120 since smaller update time step provides more accurate simulation results and prevents collisions from deteriorating. Since the towers are composed of many moving blocks, the iterative value is taken as 16 (Synytsia 2016). Friction coefficient of limestone was accepted as 0.7 (Concrete Institute, 1909). Common density values for limestones were accepted (limestone: 2560 kg/m^3) (Colas et al., 2016).

Constant horizontal acceleration was applied to each virtual model by tilting the ground plane of the model. The amount of tilt was increased one degree by one degree, until total collapse occurred. Critical angles of collapses were determined.

In tilt analysis, base of each tower is quasi-statically tilted until collapse occurs. The horizontal component of the ground acceleration (how much the velocity changes) at the level of collapse may be interpreted as a value corresponding to the peak ground acceleration (the largest increase in velocity). The horizontal acceleration (λ) equals the horizontal component of the gravitational acceleration: $\lambda = mg \times \sin \Theta$ (DeJong 2009). While this equivalent static loading does not represent the effects of dynamics as presented through seismic loading, it makes possible to measure the lateral load bearing capacity of the structure until it collapses. Friction coefficient value equals to tangent of the angle θ (Figure 4).

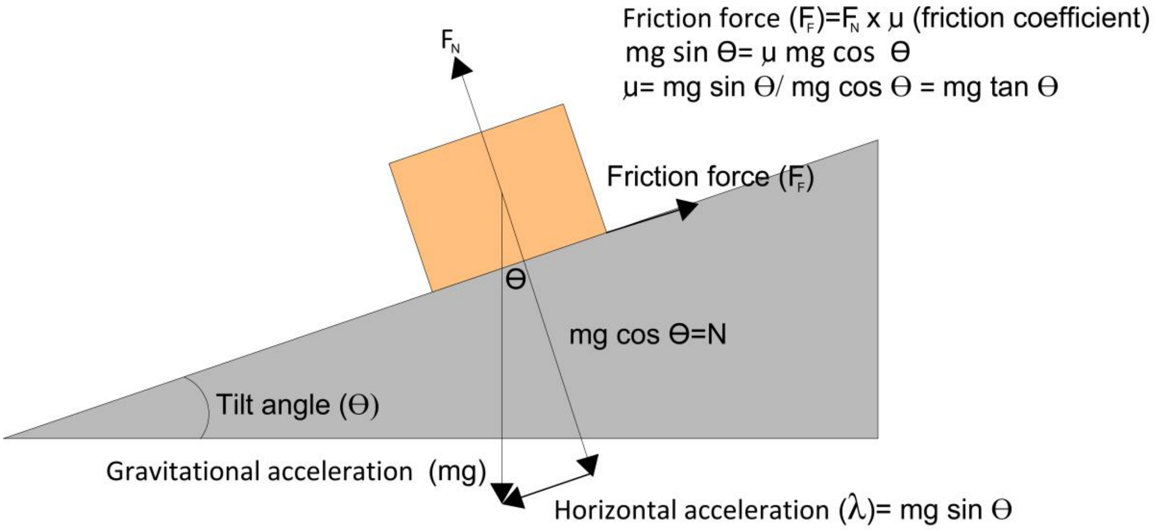

Figure 4. Horizontal acceleration (λ) as a component of gravitational acceleration.

3. STRUCTURAL CHARACTERISTICS OF TOWERS

There are a number of towers constructed polygonal or *ashlar* style in the area. Polygonal towers were mostly demolished, the relation between morphologic and structural characteristics cannot be investigated. *Ashlar* towers have sustained its integrity except timber floors and roof. *Ashlar* towers are Sarayın, Akkum, Boyan and Gömeç Tower. Sarayın Tower is two kilometres southeast, and Akkum Tower is three kilometers southwest of the Gömeç Tower. Boyan is on the west of the Akkum Tower (Durugönül, 1998) (Figure 5). In this study, these four ashlar towers were studied.

The towers are squared or nearly squared planned and two or three storied. The height of the towers shows differences due to security reasons. Depending on the fields of their view, number of stories and height could probably change.

Some openings of ashlar towers have been filled in with cut and rubble stones, and joints were filled with mortar in some places. Floor system of the tower is examined with the help of the beam holes (15-20x15-20 cm). The direction of the beams changes in each story level; beams are located from east to west direction at the first and third stories, while beams are located from north to south direction at the second story. According to finishing blocks of the tower, the roof seems to be designed as a terrace.

The main structural problem is erosion of sides of rectangular blocks and this causes formation of wide joints between the blocks.

Gömeç Tower; front and side facades

Sarayın Tower; front and side facades

Akkum Tower; front and side facades

Boyan Tower; front and side facades

Figure 5. Case study towers

3.1. Gömeç Tower

The squared planned (4.75x4.75 m) tower is constructed *ashlar* masonry. The tower is approximately 22.6 square meters. It has four storeys with ground storey. Beam holes in each storey are observed at the inner walls. The height of the tower is approximately 11.35 meters. City wall remains have not been observed around the tower. There is an asymmetrical entrance (100x180 cm), and small (100x100 cm) openings in the middle and upper storeys of the western facade. However, the openings in the middle were closed by cut stone blocks. There are small sized openings (100x100 cm), which have been closed later, at the upper stories of the northern and southern facades (Figure 6).

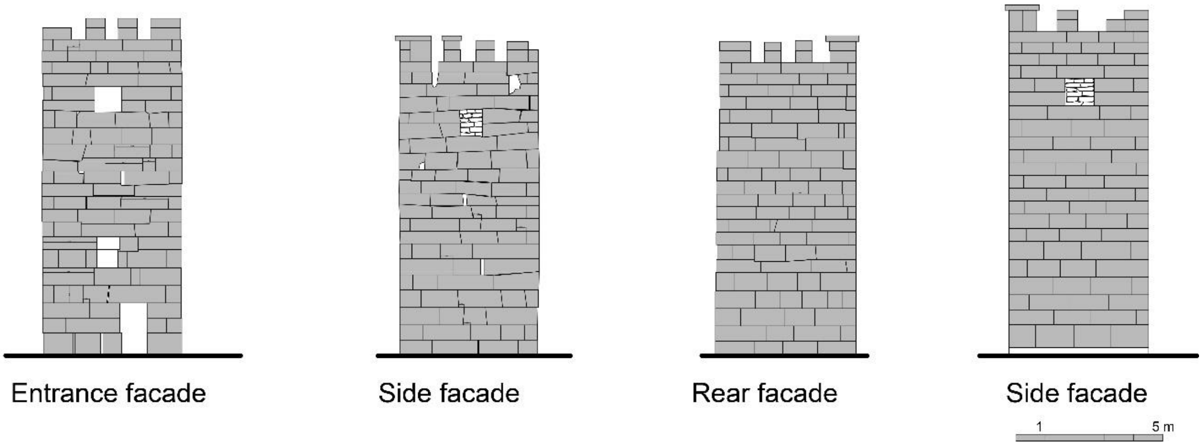

Figure 6. Facade organizations of Gömeç Tower

The masonry system is mostly composed of rectangular blocks (75-100x25-50x60 cm) and limited number of trapezoidal blocks (35-100x50x60 cm). Trapezoidal blocks are distributed randomly between the rectangular blocks. Staggering ratio changes between 0.2 and 0.6. Upper and lower courses' joints are overlapped randomly. Joints are not always at the same line due to high stone blocks. While height of the upper rows is 25-35 cm, lower rows change between 50 and 60. Therefore, staggering ratio at the upper parts (1.1) is higher than lower parts.

The thickness of the wall is equal to depth of the stone blocks (60 cm), thus wall profile is composed of a single leaf. The number of trapezoidal joints is between 2 and 8 at the western, eastern and southern walls, while 20 joints are observed at the northern wall.

3.2. *Sarayın Tower*

The approximately squared planned (5.9x5.8 m) tower is constructed as *ashlar* masonry. It is approximately 34 square meters. It has four stories including the ground story. Projected stone blocks are observed at the inner walls at each story level. The height of the tower is approximately 12.55 meters. No city wall remains are observed around the tower. There is an asymmetrical entrance adjacent to corner (150x200 cm), a small asymmetrical opening (100x100 cm) in the middle, and a small symmetrical opening at the upper story of the western facade. There are small sized (100x100 cm) symmetrical openings, which are filled in, on other facade walls (Figure 7).

The masonry system is composed of rectangular blocks (45-120x50x 25,30,35,60 cm). Staggering ratio changes between 0.4 and 0.8. Upper and lower course joints overlap randomly in some places. while height of the upper rows is 25-35 cm, lower rows change between 50 and 60. Therefore, staggering ratio at the upper parts is higher than lower parts (s/h=1.4).

The wall thickness of the ground floor is 75 cm, while the thickness of upper floors is 60 cm.

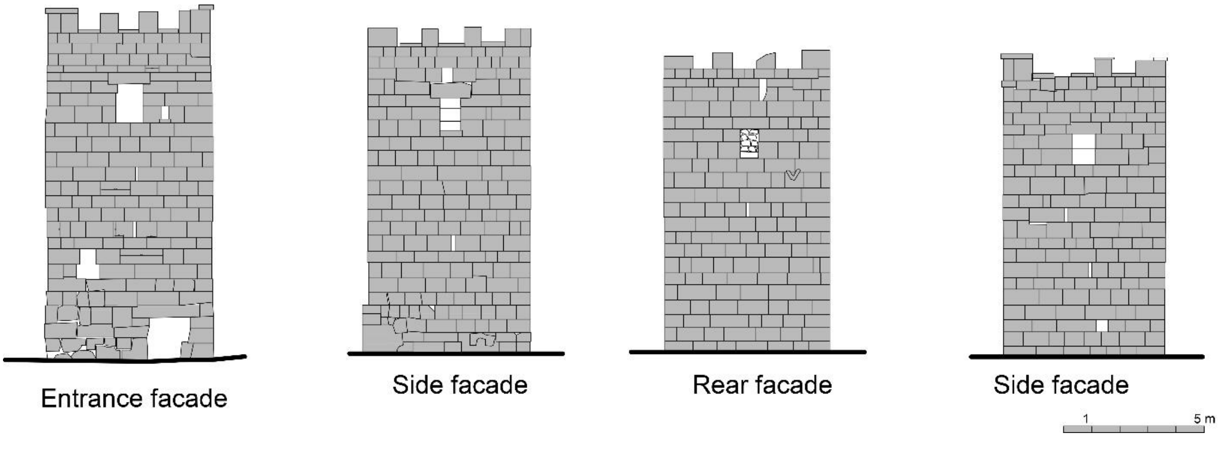

Figure 7. Facade organizations of Sarayın Tower

3.3. Boyan Tower

Rectangular planned (5.6x6.1 m) tower is constructed as *ashlar* masonry. It is approximately 34 square meters. It has three stories including the ground story. Projected stone blocks are observed at the inner walls at each story level. The height of the tower is approximately 9.5 meters. There is an asymmetrical entrance (150x200 cm), a small asymmetrical opening (100x100 cm) at the upper story of the entrance facade. There is a small sized (100x100 cm) symmetrical openings at the rear façade (Figure 8).

The masonry system is composed of rectangular blocks (45-120x50-60x50 cm). Staggering ratio is 0.2-0.6. Upper and lower course joints overlap randomly in some places. The wall thickness is 55 cm.

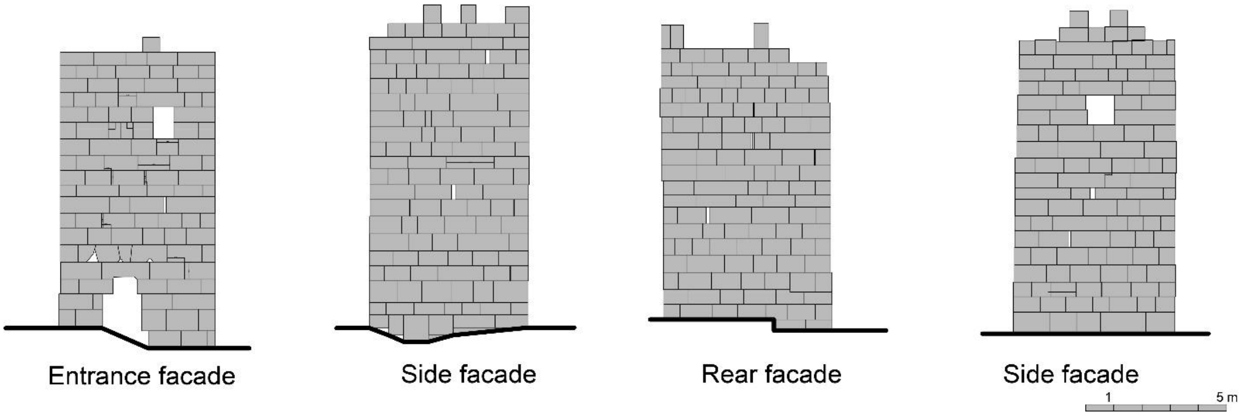

Figure 8. Facade organizations of Boyan Tower

3.4. Akkum Tower

Rectangular planned (app. 5.8x6 m) tower is constructed as *ashlar* masonry. It is approximately 36 square meters. It has three stories including the ground story. Projected stone blocks are observed at the inner walls at each story level. The height of the tower is approximately 9.5 meters. There is an asymmetrical entrance (150x200 cm), a small symmetrical opening (100x100 cm) at the upper story of the entrance facade. There are also asymmetrical small sized (75x100 cm) openings at the side facades. There are two upper openings at the rear façade (100x100 cm) (Figure 9).

The masonry system is composed of rectangular blocks (45-100x50-60x50 cm). Staggering ratio is between 0.2- 0.6. Upper and lower course joints overlap randomly in some places. The wall thickness is 55 cm.

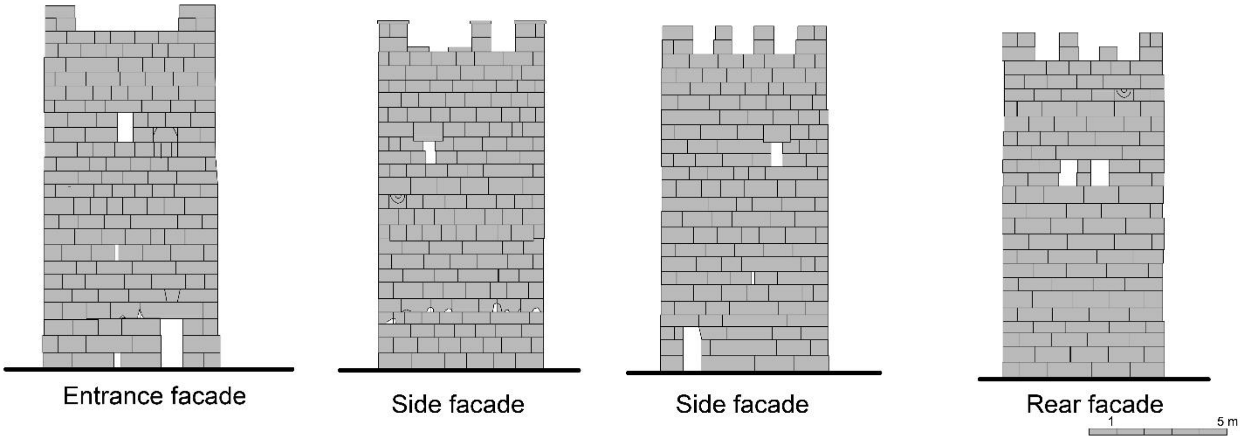

Figure 9. Facade organizations of Akkum Tower

3.5. Discussion of morphological, structural characteristics and material usage of the towers

Plan and façade organizations, stone lengths, ground conditions, material types and organization of blocks of the towers are compared with each other.

Firstly, to determine stone types, SEM and XRD analysis were discussed. SEM/EDS analyses of the stone samples from Gömeç, Sarayın, Akkum and Boyan Towers showed that stones were composed primarily of calcium oxide (CaO: 97 %). The minor elements were silica (SiO_2) and aluminium oxide (Al_2O_3). Limestone contains higher than 56 % calcium oxide. In the study of Boynton (1966), Gay and Parker (1932); Nath and, Dutta (2010), limestones contain high percent of calcium oxide similar with stones types of towers.

XRD analyses of stone samples from towers showed that the stones were dominated by the minerals of calcite. Limestone was composed of mainly calcite (Karayazılı 2013) similar to stones from Akkum, Boyan Gömeç and Sarayın Towers (Figure 10). In the study of Budak (2005) and Karayazılı (2013), XRD spectrum of limestone is similar results of analysis taken from towers.

These results demonstrate that limestone blocks were used for the construction of case study towers.

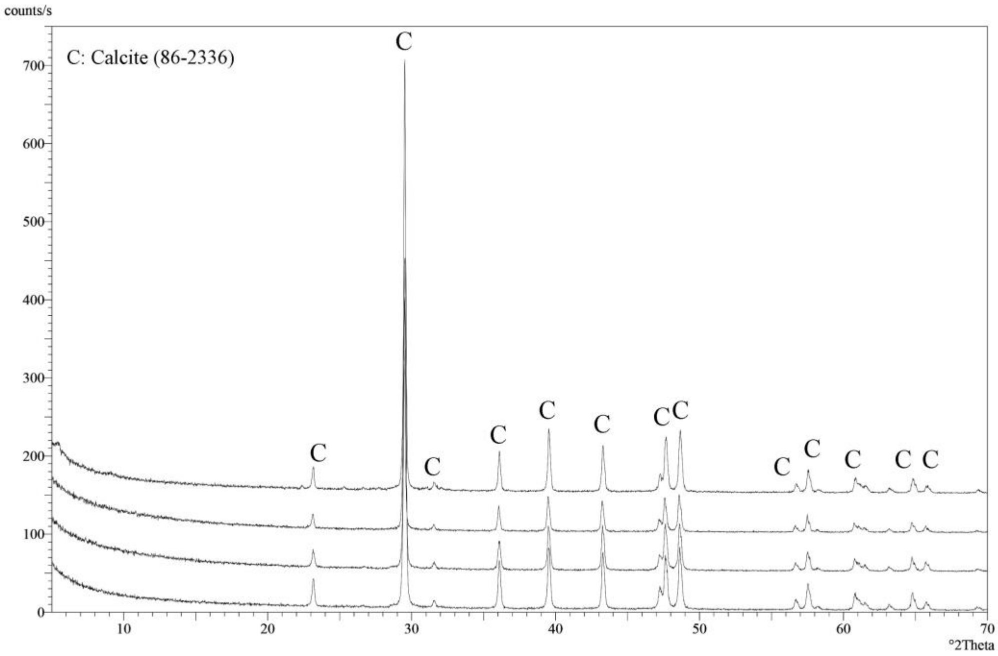

Figure 10. XRD pattern of stones from Towers

Stone lengths, and ground conditions of the towers are almost similar. The towers have also small sized opening (100x100, 75x100 cm) that do not affect structural resistance (Gençer, 2019). Plan organization of the towers are square or nearly squared. However, the towers have different proportional relationship due to the height of the towers and block organization due to the staggering ratios.

Height of the towers change between 950 and 1250. Therefore, height to length ratios present differences. The ratio of Sarayın and Gömeç is higher than 2, ratio of Boyan and Akkum is lower than 2.

Gömeç and Sarayın Towers have staggering ratio higher than 1 at the top levels of the towers, while on ground level, staggering ratio decrease up to 0.2. However, Akkum and Boyan tower have similar staggering ratio at the lower and upper levels, the height of the rows does not present differences.

Decrease row height at the top levels provides increase in staggering ratio at the upper levels (Figure 11, Table 1).

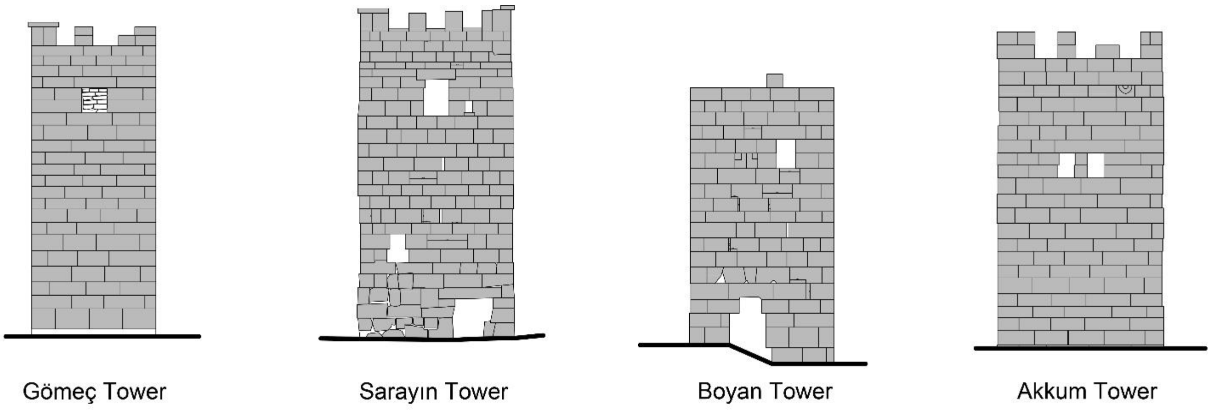
Gömeç Tower Sarayın Tower Boyan Tower Akkum Tower

Figure 11. Comparison of H/L ratios and staggering ratios

Table 1. Comparison of characteristics of towers

Characteristics of towers		**Gömeç**	**Sarayın**	**Boyan**	**Akkum**
Plan dimensions		475x475 cm	590x580 cm	560x610 cm	580x600 cm
Height		1135 cm	1255 cm	950 cm	1200 cm
Ratio between height and lenght		2.4	2.1	1.55-1.7	1.9
Stone length	Longest	175 cm	150 cm	175 cm	150 cm
	Shortest	35 cm	45 cm	45 cm	45 cm
	Majority	100 cm	120 cm	120 cm	100 cm
Row height	Lower levels	60 cm	60 cm	50 cm	60 cm
	Upper levels	35 cm	35 cm	50 cm	50 cm
Staggering ratio	Lower levels	0.2-0.6	0.4-0.8	0.2-0.6	0.2-0.6
	Upper levels	1.1	1.4	0.2-0.7	0.2-0.7
Stone type		Limestone	Limestone	Limestone	Limestone
Wall thickness		60 cm	Lower: 75 cm Upper: 60 cm	55-60 cm	55-60 m

4. ANALYSIS OF VIRTUAL TOWERS TO DETERMINE EFFECT OF CHARACTERISTICS

Effect of s/h and H/L ratios on structural resistance are discussed by designing virtual towers composed of rigid blocks (by considering properties of limestone). While designing virtual towers, when effect of a characteristic was tested, the other one was kept constant. The behaviour of towers under lateral loading was investigated by simulation of quasi-static analysis. Ten (10) virtual towers were designed by using the characteristic parameters of case study towers.

First, the towers that have different staggering ratios; 0.4, 0.7, 1, 1.4 and constant H/L ratio (2) were tested. For 0.4, 0.7, 1, height of blocks was accepted 50 cm, while for 1.4 ratio, the height of blocks decrease up to 35 cm as Gömeç and Sarayın Towers (Figure 12).

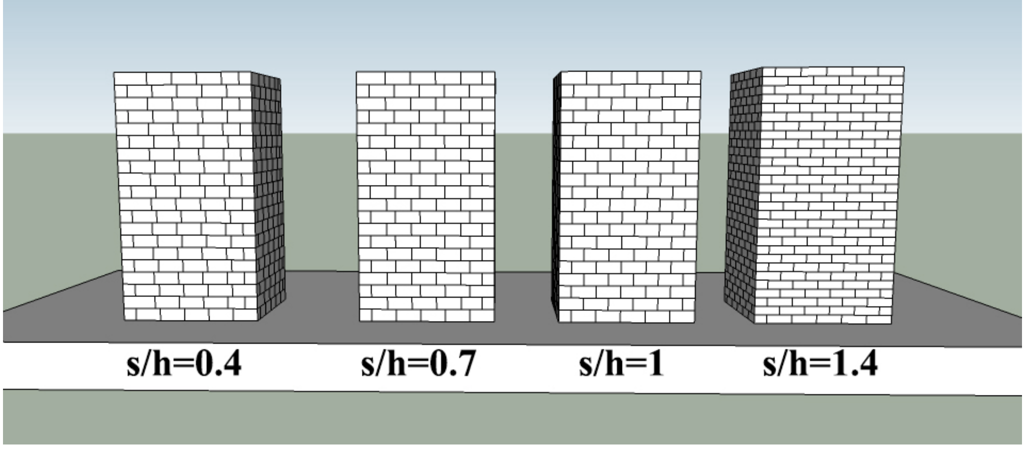

Figure 12. Virtual towers with different staggering ratios

Each staggering ratio caused different failures. If the ratio increased, the collapse angle of the tower increased (Table 2). The towers that have small staggering ratio (0.4) presented overturning of the façade wall with vertical cracking at the corners. Vertical cracking was observed at the corners, since the joints are so closed to each other. Therefore, façade wall separated from the side walls. Small staggering ratio decreased out-of-plane resistance.

The tower has 0.7 staggering ratio presented only collapse of side walls with diagonal in-plane cracking, while staggering ratio 1 caused collapse of side walls combined with total overturning.

The highest staggering ratio (1.4) provided total overturning at highest collapse angles (18 °). Since the distance between joints are far away from each other, diagonal and vertical cracking were not seen, the tower presented total behaviour (Figure 13).

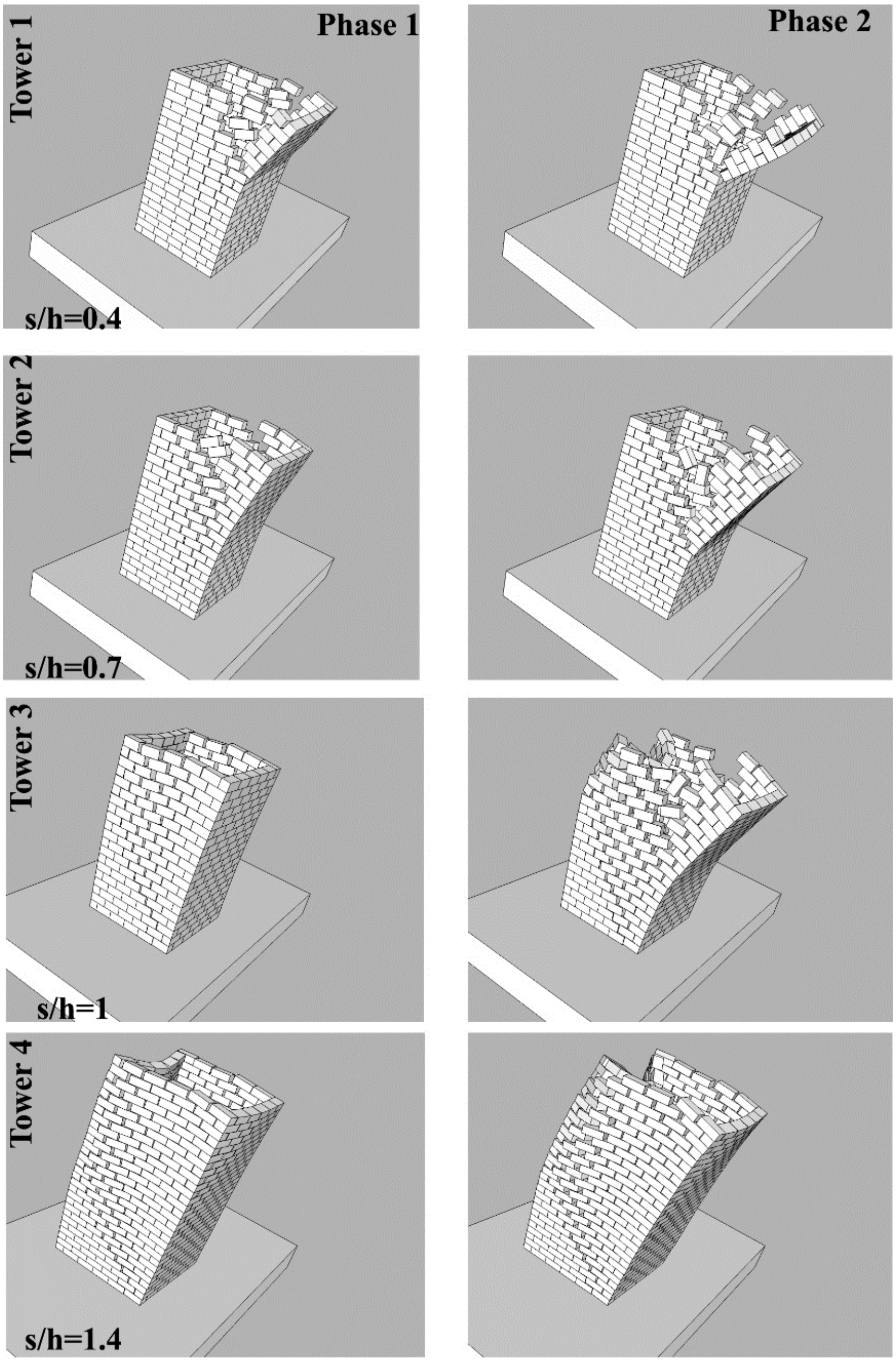

Figure 13. Behaviour of virtual towers with different staggering ratios

Table 2. Results of analysis of virtual towers with different staggering ratios

	Staggering ratio	H/L Ratio	Resistane		Failure
			Angle	λ	
Tower 1	0.4	2	13°	0.22 g	Overturning of the facade wall due to the vertical cracking at the corners
Tower 2	0.7	2	15°	0.26 g	Collapse of side walls due to the diagonal in-plane cracking
Tower 3	1	2	16 °	0.275 g	Collapse of side walls followed by total overturning
Tower 4	1.4	2	18 °	0.31 g	Total overturning

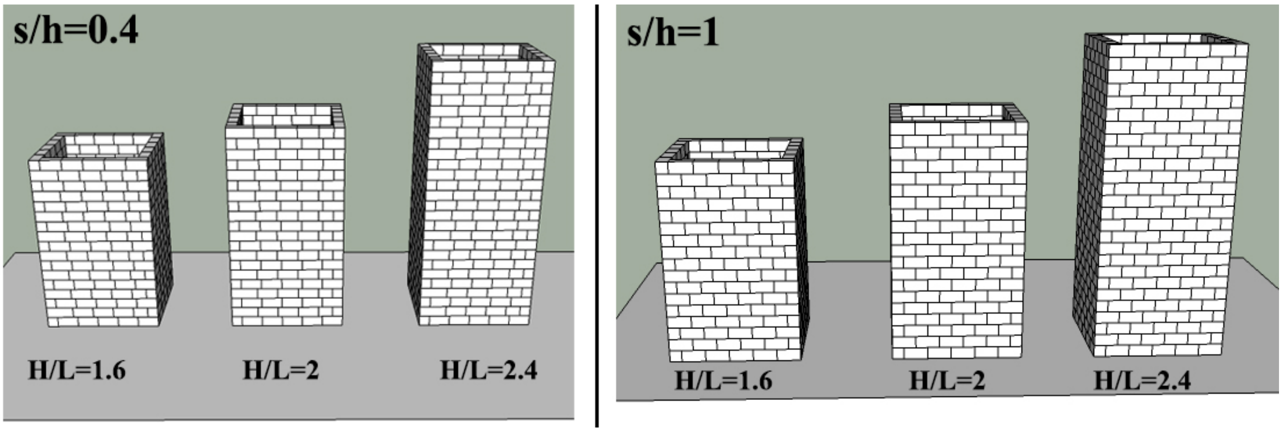

Figure 14. Virtual towers with different H/L ratios

When effect of H/L are investigated, staggering ratio was kept constant as 0.4 and 1, respectively, H/L ratios; 1.6, 2 and 2.4 were tested (Figure 14).

When the H/L ratio increased, the collapse angle of the towers decreased. However, the towers that have high staggering ratio collapsed at higher angles in comparison to the tower that have lower staggering ratio (Table 3).

When the behaviour of towers was compared, effect of small staggering (0.4) ratio were seen at all ratios, out-of-plane resistance decreased and overturning of the façade wall with vertical cracking were seen. However, for 2.4 H/L ratio, as well as vertical cracking, total overturning was observed at low collapse angles. High H/L ratio increased slenderness of the towers and total overturning caused by bending were observed (Figure 15).

Table 3. Results of analysis of virtual towers with different H/L ratios

	Staggering ratio	**H/L Ratio**	**Resistance**		**Failure**
			Angle	λ	
Tower 5	0.4	1.6	15°	0.26 g	Overturning of the facade wall due to the vertical cracking at the corners
Tower 6	0.4	2	13°	0.22 g	Collapse of side walls due to the diagonal in-plane cracking combined with vertical cracking
Tower 7	0.4	2.4	12 °	0.2 g	Bending combined with overturning of the facade due to the verticak cracking
Tower 8	1	1.6	17 °	0.29 g	Collapse of side walls due to the diagonal in-plane cracking
Tower 9	1	2	16 °	0.275 g	Collapse of side walls due to the diagonal in-plane cracking
Tower 10	1	2.4	15 °	0.26 g	Bending combined with collapse of side walls due to the diagonal in-plane cracking

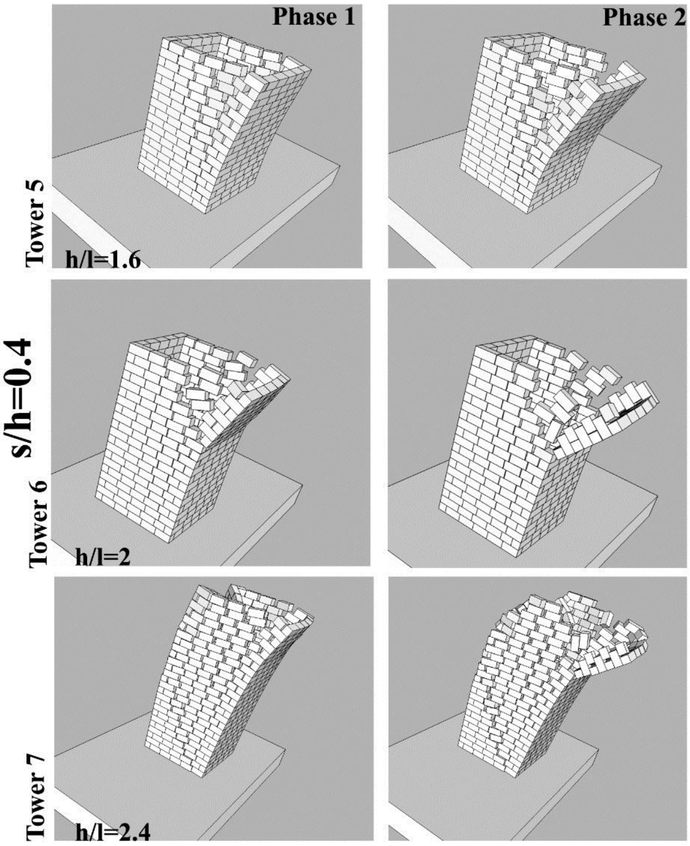

Figure 15. Behaviour of virtual towers with different H/L ratios

5. DISCUSSION

Collapse angles of virtual towers, designed with different s/h and H/L ratios, changed between 12° and 18° degrees. The highest collapse angles were seen in the virtual towers that have highest staggering ratio (1.4). Average staggering ratios of wall profiles vary between 0.4 and 1.4. Increase in staggering ratio provided increase in resistance and out-of-plane resistance. In the studies of Restrepo-Velez, Magenes, and Griffith (2014) and Shi, D'ayala, and Jain (2008), overturning of the facade wall is observed as well due to the small staggering ratio (≤0.7). Increase in staggering ratio (≥1) supports behaviour as revealed in in-plane wall or body behaviors.

The study of De Felice and Giannini (2001, 270) demonstrates the decreasing in resistance in parallel with the decreasing block height, thus, staggering ratio. As long as the staggering ratio decreases, out of plane behaviour; overturning of the facade wall due to the vertical cracking at the corners are observed (Figure 16).

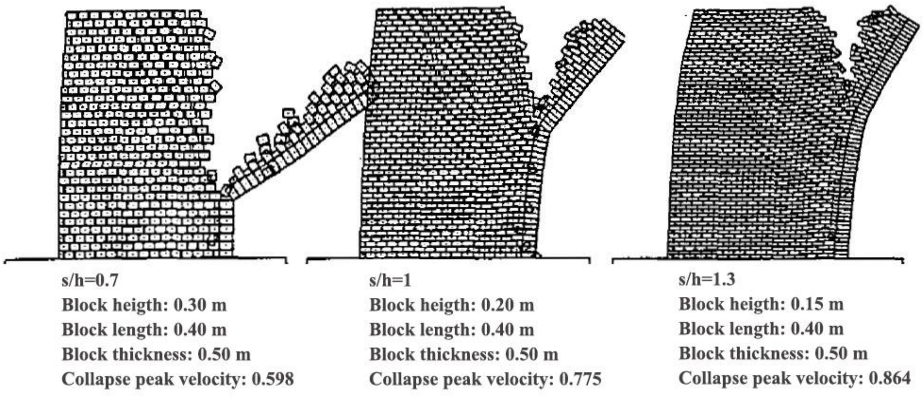

Figure 16. Impact of block height, directly staggering ratio, on failure mechanisms and resistance (De Felice and Giannini 2001)

Proportional relationship of virtual towers between height (H) and length (L) changed between 1.6 and 2.4. Increase in H/L ratio decreased resistance of virtual towers and caused bending. Studies in literature demonstrate that for the high buildings as towers, the ratio between height and length (slenderness) is a critical sub-quality in terms of behaviour of the building (Shi, D'Ayala, and Jain, 2008; Romaro, 2011; Casolo et al., 2013).

In the study of Jimenez (2011, 77), while a square box with 0.4 H/L ratio presents out-of-plane failure; detachment of facade walls due to the arch effect, a square tower with 1.6 H/L ratio presents in-plane behaviour. Failures are observed at smaller accelerations at the square box (λ: 0.131 g).

In the study of D'ayala and Speranza (2003), both increase in staggering ratio and decrease in H/L ratio provide increase in structural resistance similar to results of virtual towers.

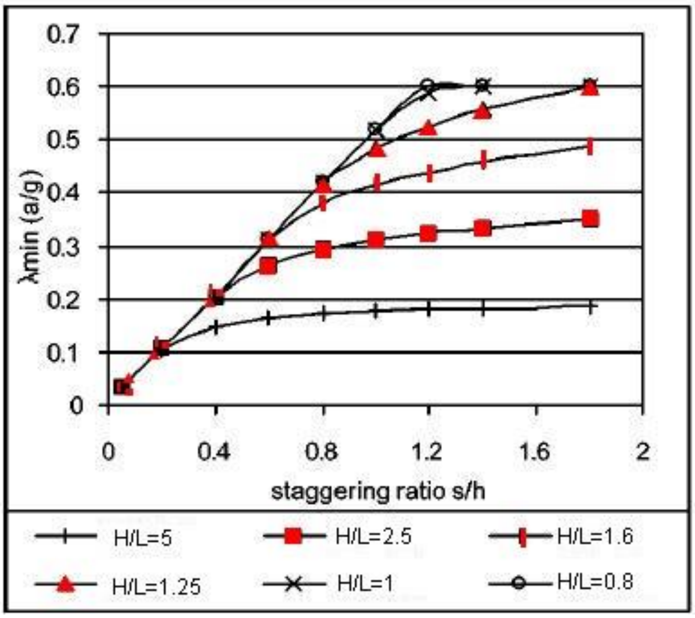

Figure 17. Impact of staggering ratio on structural resistance (revised from D'Ayala and Speranza 2003)

6. CONCLUSION

According to results of analysis, collapse angles of virtual towers changed between 12° and 18° degrees depending on different s/h and H/L ratios. The highest collapse angles (18°) were seen in the virtual towers that have highest staggering ratio (1.4). Virtual towers with high H/L (2.4) ratio or small staggering ratio (0.4) caused decrease in collapse angles up to 12 degrees.

High staggering ratio (higher than 1.4) increased out-of-plane resistance of virtual towers, the towers presented total behaviour. However, H/L ratio higher than 2 decreased resistance of the virtual towers, thus, slenderness increased, and the towers were bending at lower collapse angles.

When these results are related to the properties of real towers, it is seen that masons probably took precautions for higher towers by designing blocks with high staggering ratios. Gömeç and Sarayın towers have higher H/L ratio (≥2), however, to increase the resistance of the towers, at the upper levels, height of rows decreases, the staggering ratio increases (1-1.4), so the resistance of towers could try to be increased.

Akkum and Boyan Towers have H/L ratios smaller than 2, masons did not probably require block organizations with higher staggering ratios at the upper levels. Higher towers are probably supported with high staggering ratios at the upper levels, while the towers that do not have critical proportional relations, any precautions are not preferred.

Since these watchtowers were constructed for watching around, the simple and fast masonry technique; *ashlar* was preferred by using local material. However, masons probably designed towers by taking into consideration relation between morphologic and structural characteristics. They tried to design high towers supported with systematic block organization. These results demonstrate that ancient masons were probably aware of structural precautions for resistance, they tried to use these techniques within the limits of the sources of the area.

These results also demonstrate that masonry techniques should be investigated in detail with all sub-qualities as staggering ratio, stone length, morphology.

ACKNOWLEDGEMENTS

This study has been supported by Scientific Research Project Department of İzmir Institute of Technology within the scope of the project, 2016G_IYTE83.

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