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INVESTIGATION AND ASSESSMENT OF JOINT MORTAR MIXING RATIOS USED IN MASONRY STRUCTURES

Musa Yetkin*[1], Kürşat Esat Alyamaç[2], Yusuf Calayır[3]
[1]Firat University, Civil Engineering Department, musayetkin@firat.edu.tr
[2] Firat University, Civil Engineering Department, kealyamac@firat.edu.tr
[3] Firat University, Civil Engineering Department, ycalayir@firat.edu.tr
* Corresponding author: musayetkin@firat.edu.tr

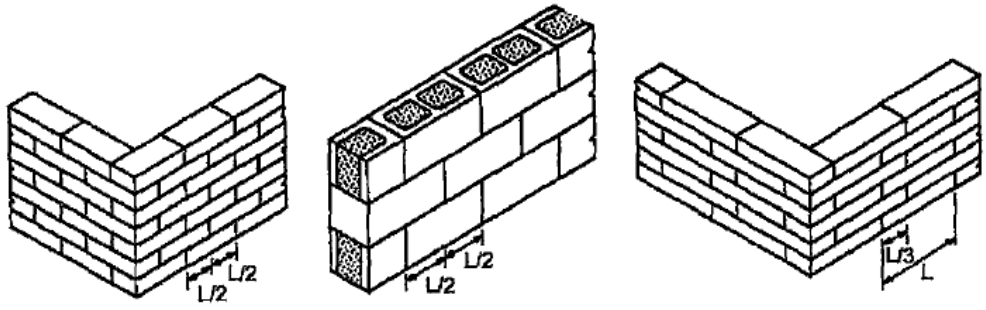
Abstract: *Masonry structures are brittle structures due to the materials that make up it. This causes the masonry structures to collapse suddenly when exposed to earthquake etc. forces. When the damages seen in masonry structures are examined, it will be seen that the damages mostly originate from masonry unit, joint mortar unit and carrier system. In order to minimize these damages, the properties of the units used to form the masonry structure should be well known. In this study, joint mortar unit used to connect the masonry units to each other and to ensure the interlocking of the system was examined. The factors affecting the joint mortar unit are; joint thickness, mortar material properties, mortar mixing ratios and workmanship. Mortar mixing ratios of these factors were investigated in detail. Cement: lime: sand: water ratios frequently used in experimental studies were determined. Findings obtained as a result of the researches were evaluated.*
Keywords: *Mortar mixing ratios; Joint mortar; Masonry structures*

1. Introduction

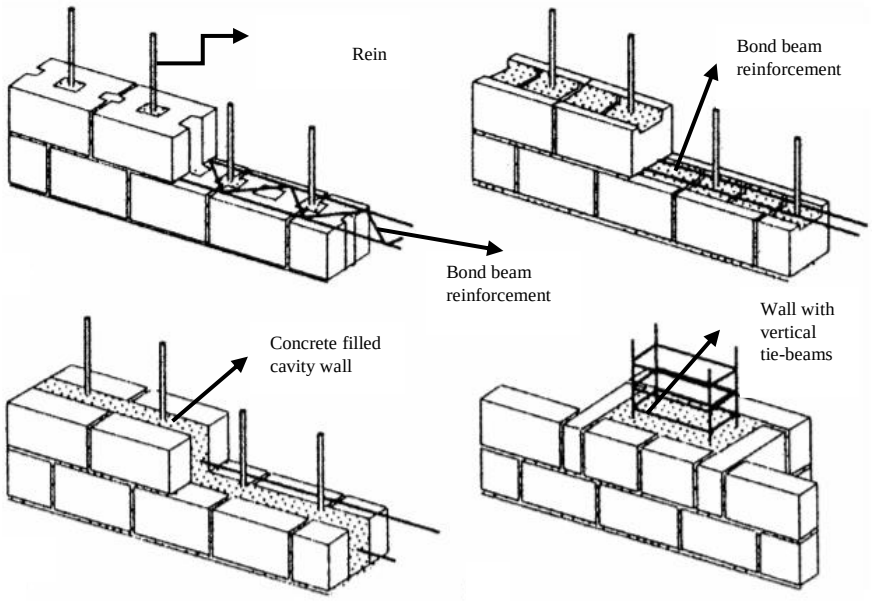
Masonry structures are the oldest building types that have an important place in human history. These traditional buildings, which have emerged as a result of thousands of years of building culture and are arranged with walls that are load bearing, have survived to the present day since they are produced with materials resistant to external influences and have facilitated our knowledge about their technologies. In construction of masonry walls, structural components as well as workmanship are of great importance. These walls have been widely used as load bearing wall from the past to the present, but load bearing frameworks have become more widely used in the modern era. Today, infill wall (partition wall) as still used in the world and in Turkey (Figure 1).

Figure 1. The oldest known structure in history (Göbekli Tepe Temple, Şanlıurfa (10000 B.C) [1]

The main loads are transferred to the foundations via the internal load bearing wall, in typical masonry construction, and the bearing walls can be designed as reinforced or unreinforced (Figure 2). Reinforced masonry structures, is not preferred dramatically in Turkey due to needing qualified labor and difficulties in reinforcement placement. Unreinforced masonry structures have more advantages than reinforced masonry structures because of the labor and the materials used to build the wall and are a preferred type in Turkey. But the number of masonry structures that made by engineer service have been decreased in Turkey, especially since 2000. The main reason for this situation is the perception that masonry structures have poor earthquake performance.



a) Unreinforced masonry wall [2]



b) Reinforced masonry wall [3].

Figure 2. Masonry wall samples

2. Earthquake Behavior of Masonry Structures

In Turkey significant part of the residential area are placed on high earthquake zones. In the past, destructive earthquakes happened in these dangerous zones. After these devastating earthquakes, numerous loss of life occurred. These losses of life were repeated due to collapsed or heavy damaged

buildings. Until 2000, in the rural area, unreinforced masonry structures were commonly used in Turkey like all over the World because of both economical construction and easy labor. Masonry structures built in rural areas have not been taken enough engineer services. When these structures experienced heavy damages in earthquakes, people thought that masonry structures have poor earthquake performance and using of masonry structures have been decreased. Nowadays, masonry structures are generally constructed in the districts and villages where the population is low, far from the city center.

The main causes of earthquake damage in masonry structures are listed below:

1. Damages caused by wall elements: One of the important causes of damage seen in masonry structures is the wall bond types and material characteristics of bricks used as wall elements. Non-standard and poorly manufactured walls couldn't carry the incoming loads [4].

2. Damages caused by wall mortar: Shear stresses on the load bearing walls under earthquake effects; it is carried by adherence and friction stresses between brick and mortar. In the masonry structures damaged in the earthquake, it was observed that mortars with low strength were used to a great extent. Therefore, the properties of the mortar are highly effective on the performance of the structure.

3. Damages caused by load bearing system design: One of the most important causes of masonry structure damages is that the load bearing system of the structure doesn't suitable with the relevant standards and regulations. These unsuitable issues can be listed as follows: High proportion of void in the walls, failure to construct horizontal and vertical girder properly, and the presence of cantilever elements to increase the loads coming to the structure.

When the articles 1 and 2 of the above mentioned earthquake damages are examined carefully, it is clear that the earthquake resistance of the masonry structures depends on the wall type and the properties of the materials used. Therefore, in order to improve the behavior of the load bearing walls under earthquake loads, the wall element and mortar properties should be examined. In this study, mortar properties were investigated in detail.

3. Mortar

The material that interlock the masonry units such as stone and brick is called mortar. The definition for mortar in TS 2510 [5] is as follows: The wall mortar is obtained by using mortar sand in accordance with TS 2717 [6] with cement, lime paste, hydrated lime, mortar cement separately or in combination, and mixed with sufficient water and, if necessary, with additives is the building material used. Mortars are divided into five classes as A, B, C, D, and E according to their mixing ratios. When the compressive strength test is applied for the consistency of the mortars to form a spread of $110 \pm 5\%$ in the shaking table test, the result to be obtained should be in accordance with the values given below for the mortar classes (Table 1).

Mortars can be classified according to the place of production, the binding material contained and the place of application (Figure 3) [7].

The mortar should be able to easily transfer the horizontal and vertical forces coming to the wall element. In order to achieve this, the type, quantity, quality of the binder material, the water content in the mixture, and the surface texture of the elements such as stone and brick are very important. However, if cracks occur in the wall elements, the reason for this cannot be known exactly. The most important factors affecting the formation of the crack are the masonry unit (dimensions, material type and

mechanical properties) and joint (binder materials used, joint thickness, workability, strength and adherence) [8]. The main failure modes seen in the wall elements are as follows (Figure 4).

Table I. Mortar mixing ratios and minimum compressive strengths of each class

Class of Mortar	Type No	Sand	Cement	Mortar Cement	Lime Mud	Powdered Lime	Minimum Compressive Strength (MPa)
		1.3 t/m^3	1.2 t/m^3	1.0 t/m^3	1.3 t/m^3	0.6 t/m^3	
A	-	3	1	-	-	-	15
B	1	4	1	-	-	-	11
	2	4	1	1/2	-	-	
	3	4	1	-	-	1/2	
	4	4	1	-	-	1	
C	1	7-9	1	2	-	-	5
	2	5	1	-	-	-	
	3	5	1	-	1	-	
D	1	6-8	1	-	2	-	2
	2	6-8	1	-	-	3	
	3	2-3	-	1	-	-	
E	-	3	-	-	1	-	0.5
* The values given in t/m^3 are the unit volume weights of the materials.							

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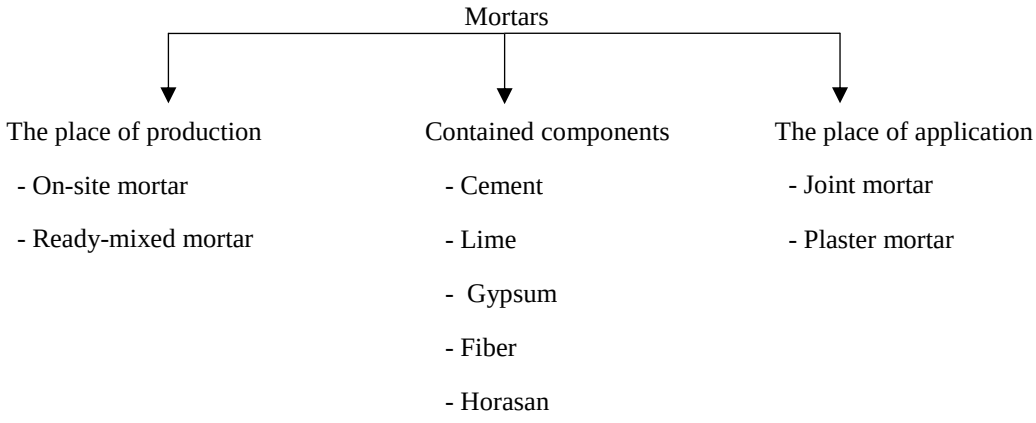
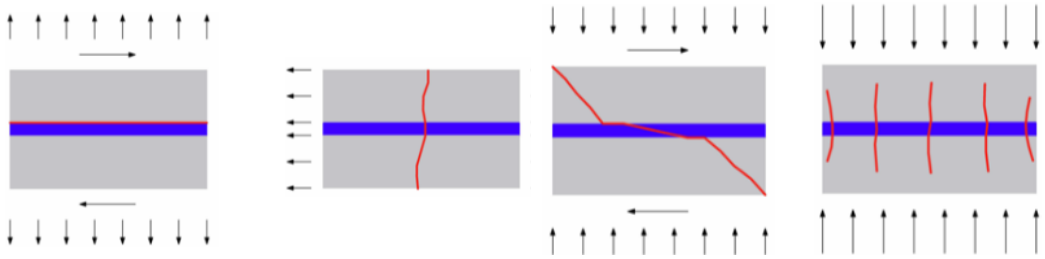


Figure 3. Classification of mortars



a) mixed-mode cracking of mortar joints | b) vertical tensile cracking of bricks | c) diagonal tensile cracking of bricks | d) masonry crushing

Figure 4. Principal masonry failure modes [9]

3.1 Mortar Mixing Ratios

The first use of mortar is known as applying mud between adobe materials. After the mud, it is seen that the lime mortar was used by the Romans. Over time, mud mortar developed and became a horasan mortar. In horasan mortar, there are granulated and fired clay, lime and water. In addition, materials such as fine gravel, stone powder, marble powder, goat hair and egg whites were found in mortar mixtures [10-12].

Today, the use of reinforced mortar in the construction of walls is quite common. Lime delays the hardening of the mortar and slows the water loss of the mortar. Cement increases the strength of the mortar. The mortar should not harden rapidly during the construction of the walls. The amount of water added to the mortar should be added taking into account the amount of water absorbed by the poorly fired brick. Poorly fired bricks cause insufficient mortar strength [7].

Considering the damages in the masonry structures, it is clearly seen that collapse and cracks are mostly in the joint area. This shows that the physical and mechanical properties of the joint should be accurately determined. Within the scope of the study, a data pool has been established by considering the previous experimental studies and it has been tried to present the mortar mixture ratios frequently used in the literature to the researchers [Table 2].

Table 2 shows the ratios of cement, lime, sand and water previously used in experimental studies. Mixing ratios of different binding materials used in the studies are not given. In addition, some studies did not find any ratio for water in the mixing ratio. In the studies where the water ratio was not given, it was been thought that the amount of water was adjusted by the researcher considering the plasticity and workability of the mortar. In some of the studies, it was seen that no cement or lime was used. It should be noted that while cement increases the strength of the mortar, lime will delay water loss and hardening of the mortar.

Table II. Most commonly used mixing ratios

Reference	Year	Mixing Ratios			
		Cement	Lime	Sand	Water
Lourenco P.B., [13]	1996	1	2	9	
		1	1	6	
Mohamad G., et al. [14]	2007	1	1	6	
		1	2	9	
		1	0.5	4.5	
		1	0.25	3	
Capozucca R., [15]	2011	1	1	5	
		1	0.25	5	
		0	1	5	
		1	1	6	
		0	1	3	
Alecci V., et al., [16]	2013	0	2	8	2
		1	1	8	2
		2	0	8	2
		1	0.5	4	2
Farooq S.H., et al., [17]	2015	1	0	4	
Bankir Ş., [18]	2014	0	1	3	
		0	1	2	
		0	1.5	2.5	
Janaraj, T., [19]	2014	1	1	6	
Singhal V., and Rai D.C., [20]	2014	1	1	6	
Shabdin M., et al., [21]	2018	1	0	5	0.5
Radovanović Ž., et al. [22]	2015	1	0.75	5	
		1	0.5	6	
		1	0.25	4.25	
		1	0.2	3	
Leeanansaksiri A., et al. [23]	2018	1	0	4	
		1	0	2	
Wang X., et al. [24]	2018	1	0	3	0,6
Kariou F.A., et al. [25]	2018	1	0	4	2.5
Costigan A., et al.[26]	2015	1	0	5	4
Shahzada K., et al. [27]	2012	1	0	6	

4. Conclusions and Assessment

Masonry structures are a building system that has existed in the life of human beings from past to present. The fact that it can be made using regional materials makes masonry structures advantageous. However, when these structures saw heavy damages after earthquakes, there was insufficient perception of earthquake resistance of masonry structures and usage of masonry structures gradually decreased. When the earthquake damages in the masonry structures are examined, it was seen that the main causes of the damage are caused by the wall element, wall mortar and load bearing system design.

Within the scope of the study, the determination of mortar mixture ratios by considering the damages caused by wall mortar in masonry structures was discussed. Some of the mortar mixture ratios (cement:lime:sand:water) used in the literature are given.

Cement and lime were not used in some studies. It should be known that mortar strength will be low in mortars without cement. If lime is not used in the mortar, the workability of the mortar will decrease and the mortar will harden earlier. The studies in the literature can be used to determine the amount of water to be added to the mortar. In addition, considering the plasticity and workability of the mortar, the water content can be determined by the researcher during the experiment. However, if the researcher is using poorly cooked bricks, the amount of water to be absorbed by the brick should be considered when adding water to the mortar.

In the literature, there is a need for studies showing multiple relationships between mortar strength, joint thickness and wall strength.

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