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A Critique on the Turkish Earthquake Code Regulations Regarding Masonry Construction

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ABSTRACT

Masonry is still a commonly used type of residential construction in rural and even in urban regions. Unfortunately, the strength and stability of masonry structures are critical in the case of high amplitude cyclic lateral loads such as earthquake ground motion. Hence, the masonry buildings with structural deficiencies belong to the most vulnerable class of structures which have experienced heavy damage or even total collapse in previous earthquakes, especially in developing countries like Turkey. The damage and loss in earthquakes are not only due to the lack of technological advances and knowledge, but also due to inappropriate design and construction of masonry structures ignoring code requirements and prohibitions. Considering all these facts, a comparative study is carried out based on the investigation of codes and standards for masonry design. The adequacy and feasibility of regulations in the last two and the current versions of Turkish earthquake code is assessed in comparison with the most commonly used codes in Europe and the United States. At the end of the study, the current status of the masonry related code regulations in Turkey among well-known international standards is emphasized and further recommendations for upgrading the current code regulations are given.

KEYWORDS

Earthquake code, masonry construction, unreinforced masonry, confined masonry.

1 INTRODUCTION

The term "masonry" covers a wide range of materials such as clay brick, stone, cellular concrete block, adobe or other approved units , joined by mortar or other accepted methods of joining, and in turn "masonry structures" are wall-bearing systems constructed by using such materials, which vary widely in form and mechanical properties. There are many advantages of masonry like widespread geographic availability in many forms, colors and textures, comparative cheapness in construction, fire resistance, thermal and sound insulation, durability, etc. For such reasons, it is still a commonly used type of residential construction in rural and even in urban regions. Unfortunately, the strength and stability of masonry structures are critical in the case of high amplitude cyclic lateral loads such as earthquake ground motion. Hence, the masonry buildings with structural deficiencies belong to the most vulnerable class of structures which have experienced heavy damage or even total collapse in previous earthquakes, especially in developing countries like Turkey. The damage and loss in earthquakes are not only due to the lack of technological advances and knowledge, but also due to inappropriate design and construction of masonry structures ignoring code requirements and prohibitions. Considering all these facts, a comparative study is carried out based on the investigation of codes and standards for masonry design. The adequacy and feasibility of regulations in the last two and the current versions of Turkish earthquake code is assessed in comparison with the most commonly used codes in Europe and the United States. At the end of the study, the current status of the masonry related code regulations in Turkey among well-known international standards is emphasized and further recommendations for upgrading the current code regulations are given.

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2 CODES AND STANDARDS FOR MASONRY DESIGN

Codes, standards and specifications are documents that represent “state-of-the-art” and translate the accumulated professional and technical knowledge, and complex research developments into simple procedures suitable for routine design process. Hence, codes and standards are authoritative sources of information for designers and they represent a unifying order of engineering practice (Taly, 2000).

Masonry is a basic, “low tech” material, for which generally traditional methods are preferred for construction. However, its fundamental behaviour is extremely complex most of the time. This complexity arises from the interaction between the masonry units, and the surfaces in between the materials as joints which act as planes of weakness. Hence the units, the mortar in between units and the masonry construction as an assemblage of these ingredients should be examined individually. Consequently, from codes and standards point of view, the requirements for masonry are mainly based on material, construction, quality assurance, and design in terms of structural and non-structural masonry.

Within the scope of this study, three national earthquake codes, namely the current code of practice (Turkish Ministry of Public Works and Settlement 2007) and the two previous versions of the Turkish earthquake code (Turkish Ministry of Public Works and Settlement 1975, 1998) are evaluated. In addition to this, international earthquake codes from the United States (Masonry Standards Joint Committee 2005; International Code Council 2006) and Europe (European Committee for Standardization 2003a and 2003b) are also employed for the sake of comparison.

2.1 National Codes and Standards

In Turkey, the first earthquake design code was published in 1940, after the devastating Erzincan Earthquake in 1939. Although there had been some efforts to update this immature code in 1942, 1947, 1953, 1961 and 1968, these were not adequate to ensure the seismic safety of building structures until the release of “The Specifications for Structures to be Built in Disaster Areas” (TEC-75) by the Turkish Ministry of Public Works and Settlement in 1975. However economical and physical losses continued to increase with the occurrence of each earthquake even afterwards. Hence the next seismic design code (TEC-98) was published in 1998. This code included major revisions when compared to the previous specifications and it was more compatible with the well-recognized international codes. However earthquake codes should be periodically updated according to the needs of the construction industry and lessons learned during the use of the code. Hence TEC-98 has also been replaced by the current code (TEC-07) in 2007. The new version of the code also includes chapters related with repair and strengthening of existing buildings damaged by earthquakes or prone to be affected by disasters.

In TEC-75, there was a section about the design of masonry structures with very general terms including the number of stories, materials to be used in masonry walls, required wall thickness, stability of walls and openings in walls. In TEC-98, the section was edited and put into a more readable format with clear figures and there were some additions like the calculation of minimum total length of load-bearing walls in the direction of earthquake, recommendations for the values of the parameters to be used in the calculation of the equivalent elastic seismic load that is assumed to be acting on the structure and design of vertical bond beams. Finally in TEC-07, the most significant improvement in the design of masonry structures is the addition of simple procedures for the calculation of vertical and shear stresses in masonry walls. Furthermore the existing clauses are refined according to the current state of practice.

2.2 International Codes and Standards

As it has been stated by The Masonry Society (1989), masonry makes up approximately 70% of the existing building inventory in the United States. Although this percentage may have been slightly changed now, there is no doubt that the share of masonry structures in total building stock of the United States is still huge.

One of the most recognized design provisions in the United States is the International Building Code (IBC) that has been developed by the International Code Council (ICC). It references consensus design provisions and specifications. The first edition of IBC was published in 2000 whereas the current version has been published in 2006. One chapter of IBC is devoted to masonry structures with the requirements and definitions in terms of materials, construction, quality assurance, seismic design, working stress design, strength design, empirical design, and non-structural masonry (International Code Council, 2006). Another important code that is widely used in the United States is the “Building Code Requirements for Masonry Structures” that has been developed by Masonry Standards Joint Committee (MSJC). This committee has been established by three sponsoring societies: American Concrete Institute (ACI), American Society of Civil Engineers (ASCE) and The Masonry Society (TMS). The final version of the MSJC code (2005) covers general building code requirements and specifications of masonry structures, including allowable stress design, strength design, empirical design and prestressed design of masonry. In addition to this, one chapter is devoted to veneer and glass unit masonry.

Masonry construction is very common also in Mediterranean and Central European countries with numerous historical stone and brick masonry buildings. The design of masonry structures is covered by the Eurocode, which is an assembly of standards for structural design developed by the European Committee for Standardization (CEN). Eurocode 6 specially deals with masonry structures in three parts. First part consists of common rules for reinforced and unreinforced masonry structures, whereas the second part consists of design, selection of materials and execution of masonry. Final part contains simplified calculation methods for unreinforced masonry structures (European Committee for Standardization 2003a). Besides Eurocode 6, in Eurocode 8 there is a chapter that states specific rules for masonry buildings, including materials and bonding patterns, types of construction and behavior factors, structural analysis, design criteria and construction rules, safety verification, rules for simple masonry buildings (European Committee for Standardization 2003b).

3 COMPARISON OF CODES AND STANDARDS FOR MASONRY DESIGN

Design and construction of masonry requires consideration of properties and parameters that affect the structural behavior. Increasing awareness of the seismic risk, new geological and seismological evidences, as well as technological developments in materials results in a design assisted by building material properties, dynamic characteristics of the building and load deflection characteristics of building components. Consequently, some requirements about number of stories, story heights, strength of masonry units, minimum thickness of load-bearing walls, minimum total length of load-bearing walls, openings in load-bearing walls etc. are embedded in to the codes empirically or analytically.

This part of the study provides a comparison of the codes and standards for unreinforced masonry design. Since, earthquake resistant masonry design practice in Turkey is still characterized by a rather high level of empirical requirements only for unreinforced masonry, this part of the study is devoted to compare some basic geometrical and mechanical requirements on masonry structures by utilizing codes and standards given above.

3.1 Number of Stories

It has been observed that one of the important structural parameters that is related to seismic damage of masonry buildings is the number of stories, in accordance with the observations from previous major earthquakes in Turkey. The buildings with three or more stories suffered severe damage whereas the buildings with one or two stories generally exhibited adequate resistance under seismic action. In all three versions of the Turkish Earthquake Code, maximum number of stories permitted for masonry buildings (excluding a single basement) depends on the seismic zone (Table 1). In addition, the code allows a penthouse with gross area not exceeding 25% of the building area at foundation level. Adobe buildings are allowed with a single story excluding the basement in all seismic zones.

In European state-of-practice, limitations regarding number of stories have been relaxed based on the results of recent experimental and theoretical investigations and on improvements in technology and methods of design (Tomazevic 1999). Except for unreinforced masonry located in seismic zones with design ground acceleration (a_g) equal to or greater than 0.3g (g is the gravitational acceleration), which is not allowed for earthquake resistant walls in buildings higher than two storeys, no limitations regarding height of masonry buildings are specified in Eurocode 6. However in Eurocode 8, some limitations for maximum number of stories are given for a special class of masonry structures called as “simple buildings”. These are buildings with an approximately regular plan, where the ratio between the length of the long and short side is not more than 4, and the projections or recesses from the rectangular shape are not greater than 15% of the length of the side parallel to the direction of the projection. In short, simple buildings comply with the provisions regarding the quality of masonry materials and construction rules specified in Eurocode and for these buildings, explicit and detailed safety verifications are not mandatory. In definition, simple buildings are very much alike the masonry buildings designed according to the empirical rules of Turkish earthquake code; hence it is not very misleading to make a comparison between number of story limitations of simple buildings in Eurocode 8 and masonry buildings in Turkish earthquake code. Number of story limitations from Turkish code, Eurocode 6 and Eurocode 8 (simple buildings) are listed in Table 1. All comparisons are for unreinforced masonry buildings since reinforced masonry design is not explicitly reflected in Turkish earthquake code and also reinforced masonry construction is not very applicable in Turkey.

Table 1. Maximum permitted number of stories for unreinforced masonry buildings according to different earthquake codes. Seismic zones are defined according to TEC-07. NL means there is no limitation.

	Seismic zones in terms of design ground acceleration (a_g)			
	Zone 1 ($a_g \geq 0.4g$)	Zone 2 ($0.3g \leq a_g < 0.4g$)	Zone 3 ($0.2g \leq a_g < 0.3g$)	Zone 4 ($0.1g \leq a_g < 0.2g$)
TEC-75,98,07	2	3	3	4
Eurocode 6	2	2	NL	NL
Eurocode 8	1	1	2	3

In IBC 2006, there are provisions about the allowable building height (in terms of number of stories) and area, which depends on the occupancy group of building and type of construction. Type of construction is determined by considering whether the building components are made from non-combustible materials or not. Hence in IBC, the provisions regarding number of storeys are governed by fire resistance rather than seismic resistance. According to IBC 2006, adobe construction shall be limited to buildings not exceeding one story, except that two-story construction is allowed when designed by a registered design professional. Finally in MSJC 2005, it has been stated that buildings relying on masonry walls as part of their lateral load resisting system shall not exceed 10.67 m in height. Depending on the story height of the building, this crudely means that the maximum permitted number of stories regardless of any level of seismic action is 3 or 4.

3.2 Story Height

According to all the last three versions of Turkish earthquake code, story height of masonry buildings is limited to 3 m from one floor top level to the other. Height of the single storey adobe building can not be more than 2.7 m from ground to the rooftop. In the case where a basement is made, height of the adobe building is limited to 2.4 m.

No limitations regarding height and size of masonry buildings are specified in Eurocode 6 and Eurocode 8. Instead there are some limitations on method of analysis with respect to the maximum building height as well as maximum story height. Furthermore, there are no story height limitations in IBC 2006 and MSJC 2005.

3.3 Strength Requirements for Masonry Units

There are similar considerations about the strength requirements for masonry units in the last three versions of Turkish earthquake code. In TEC-75, the minimum compressive strength of structural masonry materials should not be less than 5 MPa for artificial blocks and 35 MPa for natural stones. Compressive strength of natural stones to be used in basements shall be at least 10 MPa. The minimum compressive strength of artificial masonry structural materials to be used in basement should not be less than 7.5 MPa. According to TEC-98, masonry materials to be used in the construction of load-bearing walls should be natural stone, solid brick, bricks with vertical holes satisfying the maximum void ratios defined in the relevant Turkish standards at that time (TS-2510 and TS-705), solid concrete blocks and other similar blocks. The minimum compressive strength of structural masonry materials was limited to 5 MPa on the basis gross compression area. Similarly, compressive strength of natural stones to be used in basements should be at least 10 MPa. Finally in TEC-07, masonry materials to be used in the construction of load-bearing walls are defined in the same manner as it was in TEC-98 with one exception: Turkish standard TS-705 has been replaced by TS EN 771-1. The same values have been considered for the minimum compressive strength of structural masonry materials and compressive strength of natural stones to be used in basements. But in addition to the minimum compressive strength of masonry structural materials, there are requirements about allowable normal strength of masonry walls in TEC-07, which may be obtained from compressive strength of masonry units. It is worth to mention that, this part is absent in two previous versions, TEC-75 and TEC-98.

According to Eurocode 6 and Eurcode 8, the use of fired clay units, calcium silicate units, concrete units, autoclave aerated concrete units, manufactured stone units and dimensioned natural stone units are allowed for the construction of masonry buildings in seismic zones. In all cases, the strength of masonry units should comply with the requirements of relevant European Standards (EN 771-1 to EN 771-6). Relatively low minimum mean values of compressive strength of masonry units to be used for the construction of structural walls are specified in the relevant standards. Accordingly, the normalized compressive strength values of masonry units are 2.5 MPa for clay units, 5.0 MPa for calcium silicate units, 1.8 MPa for concrete aggregate and autoclave aerated concrete units and 15 MPa for manufactured stone units. The term “normalized compressive strength” is defined as the mean value of a reference strength determined by testing at least ten equivalent, air-dried, 100mm×100mm specimens cut from the related unit. Shape factors are also introduced in Eurocode 6 in order to convert normalized compressive strength to the compressive strength of a unit with actual dimensions.

In IBC 2006, the strength requirements of masonry units are determined by making references to related specifications of the American Standards (ASTM). However, the masonry wall strengths can be determined by using tables in IBC 2006, which are based on the strength of masonry units and the type of mortar. In MSJC 2005, for the strength design of masonry it is required that, except for architectural components of masonry, the specified compressive strength of masonry should be equal to or exceed 10.3 MPa. Moreover, for the empirical design of masonry walls, the masonry wall strength can be determined as a function of the compressive strength of the masonry unit and the type of mortar, as in the case of IBC 2006.

3.4 Minimum Thickness of Load-Bearing Walls

With respect to the minimum wall thicknesses required to be applied to load-bearing walls, excluding plaster thicknesses, there have been some changes in the last two versions of Turkish earthquake code (TEC-98 and TEC-07) in comparison with TEC-75. The corresponding values are given in Table 2 depending on the number of stories. In all three versions of the code, it has been stated that in the basement and ground floor walls of the building, only natural stone or concrete should be used as the load-bearing wall material in all earthquake zones. In addition to this, when there is no basement, minimum wall thicknesses given in Table 2 for ground story and for upper stories should be applied.

In Table 2, there is also a comparison between the minimum wall thicknesses required by different versions of Turkish earthquake codes. The numbers in parenthesis are taken from TEC-75 whereas other numbers are the same for TEC-98 and TEC-07. As it is observed, in TEC-75 the required minimum wall thicknesses for masonry units other than natural stone or brick are almost twice of the minimum wall thicknesses required in TEC-98 and TEC-07. This is due to the fact that there has been a significant technological advance in the construction materials, such as autoclave aerated concrete, with improved mechanical properties so that the required minimum thicknesses of load-bearing walls can be reduced accordingly. Furthermore, since a simple procedure in order to check the vertical stress in the walls has been introduced in TEC-07, it is much more possible to adjust the thicknesses of masonry walls in the design of a masonry building accordingly. Another interesting observation about the minimum required thickness of load-bearing walls is that no distinction has been made between exterior and interior walls or between solid and hollow clay brick in any version of the earthquake codes. However such details can be obtained from another Turkish Standard, abbreviated as TS-2510 and titled as "design and construction methods for masonry".

Table 2. Minimum thicknesses of load-bearing walls according to the last three versions of Turkish code.

Seismic Zone	Stories Permitted	Natural Stone (mm)	Concrete (mm)	Brick (thickness)	Others (mm)
1, 2, 3, 4	Basement	500	250	1 *(1.5)*	200 *(400)*
	Ground story	500	-	1	200 *(300)*
1, 2, 3, 4	Basement	500	250	1.5	300 *(400)*
	Ground story	500	-	1	200 *(300)*
	First story	-	-	1	200 *(300)*
2, 3, 4	Basement	500	250	1.5	300 *(400)*
	Ground story	500	-	1.5	300 *(400)*
	First story	-	-	1	200 *(300)*
	Second story	-	-	1	200 *(300)*
4	Basement	500	250	1.5	300 *(400)*
	Ground story	500	-	1.5	300 *(400)*
	First story	-	-	1.5	300 *(400)*
	Second story	-	-	1	200 *(300)*
	Third story	-	-	1	200 *(300)*

Eurocode 8 specifies that the effective thickness of unreinforced masonry load-bearing walls should not be less than 350 mm in the case of natural stone, 240 mm for masonry units made of materials other than stone and 170 mm for masonry units made of materials other than stone in areas of low seismicity.

According to IBC 2006, the minimum thickness of masonry bearing walls more than one story high should be 203 mm. Bearing walls of one-story buildings should not be less than 152 mm thick. For rough, random or coursed rubble stone walls, the minimum thickness should be 406 mm. For shear walls, which is defined as masonry walls upon which the structure depends for lateral stability, the minimum thickness should be 203 mm. The minimum thickness requirements for MSJC 2005 are exactly the same as the IBC 2006.

3.5 Minimum Required Length of Load-Bearing Walls

In TEC-07, the ratio of the minimum total length of masonry load-bearing walls in any of the orthogonal directions in plan (excluding window and door openings) to gross floor area (excluding cantilever floors) is calculated by considering the following criterion

$$L_d / A \geq 0.20\, I \ (m/m^2) \tag{1}$$

where L_d denotes minimum total length of load-bearing walls in any orthogonal direction, A stands for the gross floor area and I represents building importance factor which is equal to unity for residential buildings. Hence Equation (1) indicates that for a residential building with a plan area of 100 m^2, total length of load-bearing walls should be at least 20 m in both orthogonal directions. This criterion was slightly different in the previous version of the code, TEC-98, where the constant term was 0.25 instead of 0.20. Hence this means a reduction of 5 m in the total length of the walls in one direction for a building with a plan area of 100m^2. Finally it should also be noted that there was no such a criterion in TEC-75.

In Eurocode 8, minimum sum of cross sectional areas of horizontal shear walls in each direction as percentage of the total floor area per story is given instead of minimum total length of load bearing walls in each orthogonal direction. The requirements for unreinforced masonry buildings are given in Table 3 below. The parameter S is the soil factor that depends on the site class and ranges between 1.0-1.8. The parameter k is a correction factor that is used in cases where at least 70% of the shear walls under consideration are longer than 2 m, otherwise equal to unity. For the sake of comparison, the last four rows of Table 3 are devoted to typical values obtained from Equation (1) of Turkish codes, assuming constant thicknesses of 200 mm and 300 mm for all load-bearing walls in a typical story and I=1 (residential building). As it is observed both versions of TEC yield safer values than Eurocode 8 in most of the cases, hence the relaxation about the above criterion (Equation (1)) in the final version of the code is not very critical if and only if all the other criteria regarding the arrangement of load-bearing walls and the openings in walls are satisfied.

Table 3. Comparison of minimum total cross-sectional area of load-bearing walls as percentage of total floor area according to the criteria in Eurocode 8, TEC-98 and TEC-07. The abbreviation N/A means "not acceptable"

Acceleration at site $a_g S$ (in g)		≤ 0.07k	≤ 0.10k	≤ 0.15k	≤ 0.20k
Earthquake Code	No. of stories	Minimum total cross-sectional area of load-bearing walls as percentage of total floor area			
Eurocode 8	1	2.0 %	2.0 %	3.5 %	N/A
	2	2.0 %	2.5 %	5.0 %	N/A
	3	3.0 %	5.0 %	N/A	N/A
	4	5.0 %	N/A	N/A	N/A
TEC-98 (t=200mm)	5.0 %				
TEC-98 (t=300mm)	7.5 %				
TEC-07 (t=200mm)	4.0 %				
TEC-07 (t=300mm)	6.0 %				

In IBC 2006, the minimum cumulative length of masonry shear walls provided in each orthogonal direction should be 0.4 times the long dimension of the building. Cumulative length of shear walls is calculated without including the openings. According to MSJC 2005, the minimum cumulative length requirement is similar to the requirement in IBC 2006.

3.6 Openings and Maximum Unsupported Length of Load Bearing Walls

According to TEC-07, unsupported length of a load-bearing wall between the connecting wall axes in the perpendicular direction shall not exceed 5.5 m. in the first seismic zone and 7.5 m in other seismic zones whereas according to TEC-98 and TEC-75, the clear span of bearing walls measured between the centers of two consecutive perpendicularly connecting walls providing stability shall not exceed 5.5 m in earthquake zone 1 and 7.0 m in other earthquake zones.

TEC-98 and TEC-07 have similar requirements in terms of the placement of openings in masonry walls. According to the TEC-75, in the case where the building height is less than 7.5 m, plan length of the load-bearing wall segment between the corner of a building and the nearest window or door opening to the corner may be reduced to 1.0 m in seismic zones 1 and 2 whereas this width can be reduced to 0.80 m in seismic zones 3 and 4. Excluding the corners of buildings, plan lengths of the load-bearing wall segments between the window or door openings shall not be less than 25% of the width of the larger opening on either side, nor less than 0.80 m in seismic zones 1 and 2 and 0.60 m in seismic zones 3 and 4 according to TEC-75. This width shall not be less than 1.0 m in seismic zones 1 and 2 and 0.8 m in seismic zones 3 and 4 according to TEC-98 and TEC-07.

In Eurocode 8, the ratio of the length of the wall, to the greater clear height of the openings adjacent to the wall, can not be less than a minimum value. For unreinforced masonry, this value is equal to 0.5 for walls made of natural stone units, 0.4 for walls made of any other type of unit and 0.35 for walls made of any other type of unit in areas of low seismicity.

4 CRITIQUE

In Turkey, a considerable percentage of the existing building stock is composed of masonry construction. There are many masonry structures which were built in 60s and 70s, and they are still in use, including governmental buildings. Also, a significant number of well-preserved old masonry structures still exist, proving that masonry can successfully resist loads and environmental impacts. In rural regions, one or two story masonry buildings are still being constructed. However in Turkey, masonry construction is no longer popular because of the following reasons:
(a) High strength masonry units are not produced in Turkey. Therefore it is difficult to construct seismically safe masonry buildings with large plan areas in earthquake prone regions.
(b) It is not economical to construct one or two story masonry housings while it is possible to construct multi-story reinforced concrete frame buildings instead.

This has also been reflected in the Turkish earthquake code. The section for the seismic design of masonry structures has not been significantly improved in previous versions of the code and it is still limited to some empirical provisions for unreinforced masonry construction. The masonry section of the code was very primitive in 1975 version with very conservative limits as it should be. Then new clauses have been added to versions in 1998 and 2007. Therefore some of the limitations have been relaxed due to the introduction of new rules. However as it is observed in the above sections, the design rules are still strict and conservative when compared to other international codes. This is not surprising, though, since the masonry part of the code relies on empirical design provisions only.

There are no recommendations for reinforced, confined or prestressed masonry construction, in other words these types of construction are not encouraged in Turkish state of practice. However, just the opposite is true for international codes. These codes have detailed design provisions including different approaches (allowable stress design, strength design and empirical design) and different construction types of masonry (unreinforced, reinforced, confined and prestressed masonry). Then it becomes possible to construct robust masonry buildings with more than 5 stories as it is encountered in many cities of Europe and the United States.

In Turkey, current unreinforced masonry construction is limited to low-rise small dwellings in rural parts or in suburbs of large cities. However it is also possible to encounter confined masonry buildings, especially in outskirts of Istanbul, a city under high seismic risk. Confined masonry is a construction system where masonry structural walls are confined on all four sides with reinforced concrete vertical and horizontal confining elements, which are not intended to carry either vertical or horizontal loads, and are eventually not designed to behave like moment resisting frames. There are clauses in the current Turkish code for the placement of horizontal and vertical confining members around masonry walls but these are empirical rules that do not rely on any engineering background and they are not sufficient to ensure the seismic safety of this type of construction in regions of high seismic hazard. Therefore such structures are very vulnerable to seismic damage, and in turn to physical losses after an earthquake, as many examples of this have been observed during the major earthquakes in Turkey in the last two decades.

In the light of above discussions, the following points should be addressed:

- The masonry design part of TEC depends on empirical rules for unreinforced masonry only. Therefore the design rules are eventually more conservative and strict than the ones in international codes.
- According to the empirical design philosophy, the engineer is constrained since he/she cannot violate the strict rules regarding the structural system like number of stories, geometry in plan, arrangement of

walls, or in dimensioning of masonry members with standard sizes of masonry units. However since international codes encourage the construction of other masonry systems like reinforced, confined and prestressed masonry, they are more flexible and allow different approaches to be used in the design stage of masonry construction.

- Due to the encouragement of design of different masonry construction systems like reinforced or confined in the earthquake code, it would have been possible to design and construct earthquake resistant low-rise and mid-rise residential dwellings which may be an alternative for comparatively vulnerable RC moment resisting frame systems.

5 CLOSURE

The aim of this study is to give a general overview of the state of the Turkish earthquake code for masonry design among the widely used international codes from Europe and the United States. Since Turkish earthquake code only refers to empirical design of unreinforced masonry, the comparison is limited to some major structural parameters like number of stories, story height, strength requirements of masonry units, minimum thickness and minimum total length of load-bearing walls.

Masonry design section of the Turkish code was primitive in earlier versions (TEC-75). However the contradiction is that in 70s, unreinforced masonry construction was much more popular than it is today. Due to seismic damage and losses induced by masonry structures after major earthquakes in Turkey, the masonry design section of the code was improved with some additional clauses in order to ensure the seismic safety of unreinforced masonry construction. The latest version of the code even contains some basic calculations regarding the state of vertical stress and shear stress in masonry walls. However since the masonry section of the code is still based on empirical design rules, it is naturally more conservative than the other international codes, which are more flexible in design of masonry structures, also allowing the construction of different masonry systems like reinforced, confined or prestressed masonry. Therefore, in order to follow up with the current advances and technology in masonry construction, such alternatives should also be present in future versions of the Turkish code since an earthquake resistant masonry building is always a good alternative for a moment-resisting frame, especially for mid-rise dwellings in rural and urban regions of Turkey.

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