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Research Paper

Comparison of the Masonry Building Codes Turkish, Euro and USA Building Codes

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Abstract: The term 'masonry' covers a wide range of materials such as clay brick, stone, cellular concrete block and adobe and in turn masonry structures are wall-bearing systems constructed by using such materials, which vary widely in form and mechanical properties. Seismic safety of masonry structures deserves special consideration in view of the fact that a high percentage of the population has been living in such buildings in moderate-to-severe seismic zones of the world. Although most of the life losses during earthquakes have occurred due to collapse of masonry buildings, the efforts to quantify the seismic performance of masonry structures and to increase their performance are still inadequate when compared with the current advances in the area of reinforced concrete (RC) technology and construction. In this study Paper we chose three design codes of buildings in Europe, America and Turkey Code to compare between their codes about ancient masonry building properties we explain their manners and rules that they depend on it during the masonry building design. As the result it seen different manners that belongs to the zone condition of every code. We study three mechanical properties included Materials Strength, Compressive strength and shear force strength.

Keywords: *Masonry, Building, Code, Earthquake*

Introduction

Masonry is the word used for construction with mortar as a binding material with individual units of bricks, stones, marbles, granites, concrete blocks, tiles etc. Mortar is a mixture of binding material with sand. Binding materials can be cement, lime, soil or any other.

The durability and strength of masonry wall construction depends on the type and quality of material used and workmanship. Based on the type of individual units used for masonry walls and their functions, the types of masonry walls are brick wall, construction and stone masonry wall.

Load bearing masonry walls are constructed with bricks, stones or concrete blocks. These walls directly transfer loads from the roof to the foundation. These walls can be exterior as well as interior walls. The construction system with load bearing walls are economical than the system with framed structures (Figure 1).

Figure1. Load bearing masonry wall

The thickness of load bearing walls is based on the quantity of load from roof it has to bear. For example, a load bearing wall with just a ground floor can have its outer walls of 230 mm, while with one or more floors above it, based on occupancy type, its thickness may be increased.

The load bearing walls can be reinforced or unreinforced masonry walls. Reinforced masonry walls can be load bearing walls or non-load bearing walls (Figure 2). The use of reinforcement in walls helps it to withstand tension forces and heavy compressive loads will be (Anonym., 1994). The un-reinforced masonry walls are prone to cracks and failure under heavy compressive loads and during earthquakes.

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They have little ability to with stand lateral forces during heavy rain and wind. Cracks also develop in un-reinforced masonry walls due to earth pressure or differential settlement of foundation.

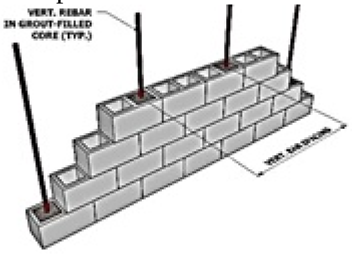

Figure 2. Reinforced masonry wall

To overcome such problems, reinforced masonry walls are used. Reinforcement in walls are at required intervals both horizontally and vertically is used. The size of reinforcement, their quantity and spacing are determined based on the loads on the walls and structural conditions (Anonym., 1994).

The construction of the stones bonded together with mortar is termed as stone masonry where the stones are available in abundance in nature, on cutting and dressing to the proper shape, they provide an economical material for construction of various building components such as wall, column, footings, arches, beams, etc. (Anonym., 1996; Figure 3).

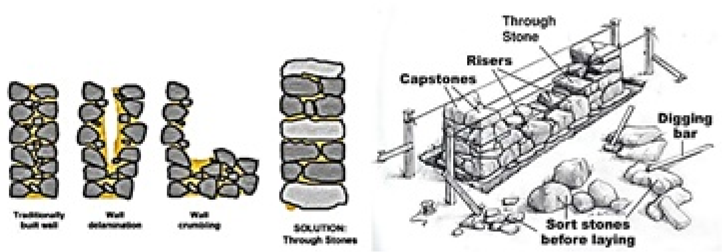

Figure 3. Stone masonry

Materials and Methods

Euro Code 6

Material properties in EN 1996-1-1

It provides the data on the material properties of the masonry to be used in the design process.
The initial clauses deal with the standards with which the units must comply and their strength, as well as the Groupings of the units. As part of this process, it sets out the criteria which are used to Group the units. These Groupings are used to identify the appropriate equations to be used when determining the properties of the masonry, in compression, shear, and flexure basically, the units are placed into one of four Groups which are dependent on a combination of:
(1) P Masonry units shall comply with any of the following types:
-ƒ Clay units in accordance with EN771-1. ƒ
- Calcium silicate units in accordance with EN771-2. ƒ
-Aggregate concrete units (dense and lightweight aggregate) in accordance with EN771-3. ƒ
-Autoclaved aerated concrete units in accordance with EN771-4.
- Manufactured stone units in accordance with EN771-5. ƒ
- Dimensioned natural stone units in accordance with EN771-6.
(2) Masonry units may be Category I of II ƒ
Category I
Units with a declared compressive strength with a probability offailure to reach it not exceeding 5 % ƒ
Category II
Lower confidence level than for I
(3) Masonry units should be grouped as Group 1, Group 2, Group 3, Group 4
ƒ volume of all holes ƒ volume of any hole multiple holes grip holes ƒ declared value of thickness of web and shells ƒ declared value of combined thickness of web and shells Disadvantage ƒ always units that will not fit (Anonym., 2000).

Mortars

This section covers mortars and sets out the requirements for the types of mortars that can be used with EN 1996-1-1. They are general purpose mortar, thin layer mortar and light weight mortar.

ƒ Method of specification; designed , prescribed ƒ,

Method of production (all in accordance with EN 998-2), factory made, semi-finished factory made, site made mortars so covers mortar classification.

In EN 1996-1-1, mortars are classified according to their compressive strength, with the letter M followed by the compressive strength being used to define them e.g. “M5” refers to a mortar with a compressive strength of 5.0 N/mm^2. Where a prescriptive mortar is used in the UK, it will be classified according to both its M number and a strength assigned to its prescribed constituents -e.g. a 1: 1: 6 cement: lime: sand, by volume mortar will be described as “M4” as it has been assumed that its compressive strength will be 4.0 N/mm^2 (Anonym., 2002;)

Table 1. Mortar properties (Eurocode 6., 2009)

BS 5628-1: 1991 mortar designation	EN 1996-1-1 classification	Mortar compressive strength
(i)	M12	12.0 N/mm^2
(ii)	M6	6.0 N/mm^2
(iii)	M4	4.0 N/mm^2
(iv)	M2	2.0 N/mm^2

Characteristic compressive strength of the masonry

The characteristic compressive strength of masonry can be based on the results of tests carried out in accordance with EN 1052-1 which tests may be carried out for the project or be available from tests previously carried out e.g. a database; the results of the tests should be expressed as atable, or in terms of the following equation (1);

$$f_k = K\, f_b f_m \quad (1)$$

where

$\mathbf{f_k}$ is the characteristic compressive strength of the masonry,

K is a constant,

$\mathbf{f_b}$ is the normalised mean compressive strength of the masonry unit,

$\mathbf{f_m}$ is the compressive strength of the mortar. Alternatively,

The relationship can be defined by the equations and conditions found inclauses (Compressive strength) and (Shear strength). These two parameters have the values 0.7 and 0.3, respectively; K values.

There are a number of limits put on the compressive strengths of both the units and the mortar, depending on the usage and the combinations of materials used. It is currently anticipated that the approach used in the UK will be the one that uses the K values in combination with the equations.

Characteristic shear strength

For the characteristic shear strength of masonry - contained in clause 1-4 the following equation is used (2);

$$f_{vk} = f_v k_o + 0{,}4 < d \quad (2)$$

where:

$\mathbf{f_{vko}}$ is the characteristic initial shear strength, under zero compressive stress,

$\mathbf{f_{vlt}}$ is a limit to the value of f_{vk},

is the design compressive stress perpendicular to the shear in the member at the level under consideration, using the appropriate load combination;

and $\mathbf{f_b}$ is the normalized compressive strength of the masonry units for the direction of application of the load on the test specimens being perpendicular to the bed face.

The decision on whether to use [$0{,}065f_b$ or f_{vlt}] in a country, and the value of f_{vlt} if this option is chosen, is contained in a note, so it is a Nationally Determined Parameter. As result, guidance on the appropriate method and values will be included in the UK's National While the form of the equation used here is the same as that used BS 5628-1, the value of the constant is not the same - for example, a value of 0,6 is used for μ in the UK rather than the value of 0.4 will be (Anonym., 2002).

Characteristic flexural strength

Information on f_{xk}, the characteristic flexural strength of masonry, is contained in clause1 - 5. The first thing to note is that the symbol used to represent the flexural strength having a plane of failure parallel to the bed joints, is f_{xk1}, while f_{xk2} is used for flexural strength having a plane of failure perpendicular to the bed joints (Figure 4). This symbol is essentially the reverse of the UK's f_{kx} will be (Anonym., 2002).

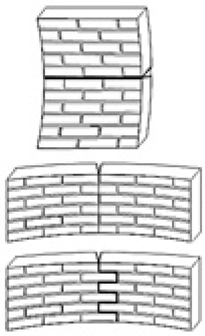

Figure 4. Bed joints

Building Code Requirements for Masonry Structures (ACI 530-05/ASCE 5-05/TMS 402-05)

Material Properties

Proper evaluation of the building material movement from all sources is an important element of masonry design. Brick and concrete masonry may behave quite differently under normal loading and weather conditions. The effect of stresses in reinforcement shall be neglected according to the table below that include allowable flexural tensile stresses for clay and concrete masonry, psi(KPa) will be (Anonym., 2007)

Table 2. Mortar types (ACI 530, 2012)

Direction of flexural tensile stress and masonry type	Mortar types			
	Portland cement/lime or mortar cement		Masonry cement or air entrained portland cement/lime	
	M or S	N	M or S	N
Normal to bed joints				
Solid units	40 (276)	30 (207)	24 (166)	15 (103)
Hollow units[1]				
Ungrouted	25 (172)	19 (131)	15 (103)	9 (62)
Fully grouted	65 (448)	63 (434)	61 (420)	58 (400)
Parallel to bed joints in running bond				
Solid units	80 (552)	60 (414)	48 (331)	30 (207)
Hollow units				
Ungrouted and partially grouted	50 (345)	38 (262)	30 (207)	19 (131)
Fully grouted	80 (552)	60 (414)	48 (331)	30 (207))
Parallel to bed joints in stack bond	0(0)	0(0)	0(0)	0(0)

Characteristics of compressive strength

Members subjected to axial compression, flexure, or to combined axial compression and flexure shall be designed to satisfy Eq. (3) and Eq. (4) will be (Anonym., 2001).

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1 \quad (3)$$

$$P \leq \left(\tfrac{1}{4}\right) P_e \quad (4)$$

where:

a) for members having an h/r ratio not greater than 99:(5)

$$F_a = (1/4) f'_m \left[1 - \left(\frac{h}{140r} \right)^2 \right] \tag{5}$$

b) for members having an h/r ratio greater than 99: (6)

$$F_a = (1/4)\ f'_m \left(\frac{70r}{h} \right)^2 \tag{6}$$

c)

$$F_b = (1/3)\ f'_m \tag{7}$$

d)

$$P_e = \frac{\pi^2 E_m I_n}{h^2} \left(1 - 0.577 \frac{e}{r} \right)^3 \tag{8}$$

Characteristics of shear strength

Shear stresses due to forces acting in the direction considered shall be determined by Eq. (9) will be (Anonym., 2007) .

$$f_v = \frac{VQ}{I_n b} \tag{9}$$

İn plane shear stresses shall not exceed any of:

a) $1.5\sqrt{f'_m}$

b) 120psi (827KPa)

c) For running bond masonry not grouted solid;

   37psi +0,45 N_v / A_n

d) For stack bond masonry with open end units and grouted solid;

   37psi + 0,45N_v / A_n

e) For running bond masonry grouted solid

   60psi + 0,45N_v / A_n

f) For stack bond masonry other than open and units grouted solid;

   15psi (105KPa)

Stress strain relationship

Modulus of elasticity for clay and concrete masonry has traditionally been taken as 1000 f $'_m$ in previous masonry codes has indicated, however, that there is a large variation in the relationship of elastic modulus versus compressive strength of masonry, and that lower values may be more typical.

However, variation in procedures between one research investigation and another may account for much of the indicated variation. Furthermore, the type of elastic moduli being reported (that is, secant modulus, tangent modulus, chord modulus, etc.) is not always identified. The committee decided the most appropriate elastic modulus for working-stress design purposes is the slope of the stress-strain curve below a stress value of 0.33 f_m , the allowable flexural compressive stress. Data at the bottom of the stress strain curve may be questionable due to the seating effect of the specimen during the initial loading phase if measurements are made on the testing machine platens. The committee therefore decided that the most appropriate elastic modulus for design purposes is the chord modulus from a stress value of 5 to 33% of the compressive strength of masonry as the figure below. The terms chord modulus and secant modulus have been used interchangeably in the past. The chord modulus, as used here, is defined as the slope of a line intersecting the stress-strain curve at two points, neither of which is the origin of the curve. For clay and concrete masonry, the elastic modulus is determined as a function of masonry compressive strength using the relations developed from an extensive survey of modulus. Code values for E_m are higher than indicated by a best fit of data relating E_m to the compressive strength of masonry. (Figure 5) The higher Code values are based on the fact that actual compressive strength significantly exceeds the specified compressive strength of masonry, f_m, particularly for clay masonry. By using the Code values, the contribution of each weather to composite action is more accurately accounted for in design calculations than would be the case if the elastic modulus of all parts of a composite wall were based on one specified compressive strength of masonry will be (Anonym., 2007).

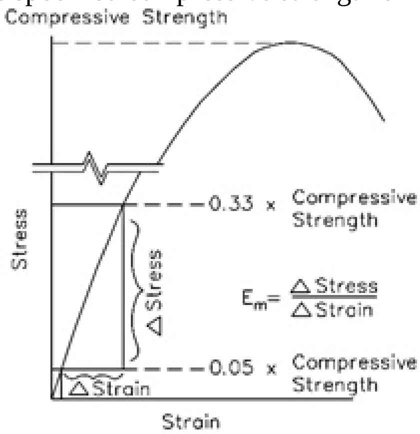

Figure 5. Stress and Strain Graphics

Turkish Building Code Requirements for Masonry Structures

Masonry buildings are classified in turkey according to their major structural parameters considering local construction practices. A set of fragility curves are generated for each class by considering in plane failure modes only. Then the fragility information is employed for the damage estimation of a group of masonry buildings, exposed to the 1995 Dinar, Turkey earthquake. Finally, the estimated damage is compared with the actually observed damage after the Dinar Earthquake (Erberik, 2008).

Material

The major parameters explained in the previous section have been used for the classification of masonry buildings in Turkey. The structures are classified as N1, N2, N3, N4 and N5 according to the number of stories. For instance, N3 subclass includes masonry buildings with three stories. The second parameter used for classification is the wall material. In this classification, two different criteria are considered: material strength and inspected quality. These two criteria are combined together to obtain the material subclasses D1, D2, D3 and D4 as shown in Table I. The values in parentheses represent the average compressive strength of that particular material subclass in accordance with previous studies, field observations and the related Turkish Standards (DBYYHY, 2007). For example, D2 material subclass is assumed to have an average compressive strength of 6 MPa and it includes the masonry structures with hollow clay brick walls of good quality and solid clay brick walls of moderate quality. The third classification parameter is the regularity in plan and masonry buildings are classified as regular (R1 subclass) or irregular (R2 subclass) regarding their plan geometry. Accordingly, rectangular buildings or buildings with re-entrant corners but that do not violate the plan irregularity dictated by TEC are considered in R1 subclass whereas all the other buildings (L- or U-shaped buildings, buildings that have non-parallel axes of structural walls, etc.) are considered in R2 subclass. The fourth parameter is a combination of the requirements regarding the wall length and openings in walls and it is employed to distinguish the buildings that comply or do not comply with the five aforementioned code criteria abbreviated as C1–C5. Accordingly, the following subclasses are established: W1 subclass (masonry buildings that obey the code principles and possess adequate lateral wall resistance): L_d/A is considered as 0.30 (C1). Furthermore, this building subclass complies with the code criteria C2–C5 (Erberik 2008; Table 3).

Table 3. Material sub-classes (D1-D4) according to material strength and quality

Load-bearing wall material	Material quality		
	Good (MPa)	Moderate (MPa)	Poor (MPa)
Solid clay brick	D1 (8)	D2 (6)	D3 (4)
Hollow clay brick	D2 (6)	D3 (4)	D4 (2)
Cellular concrete block, stone or adobe	D3 (4)	D4 (2)	D4 (2)

Characteristics of compressive strength

Pushover analyses are conducted in order to determine the strength capacities of masonry buildings. A triangular lateral force distribution is imposed. Lateral force components are applied at the master points of stories. Compressive strength of masonry is taken as a random variable in order to account for the uncertainty in the determination of the capacity of masonry buildings [5] will be Erberik (2008).

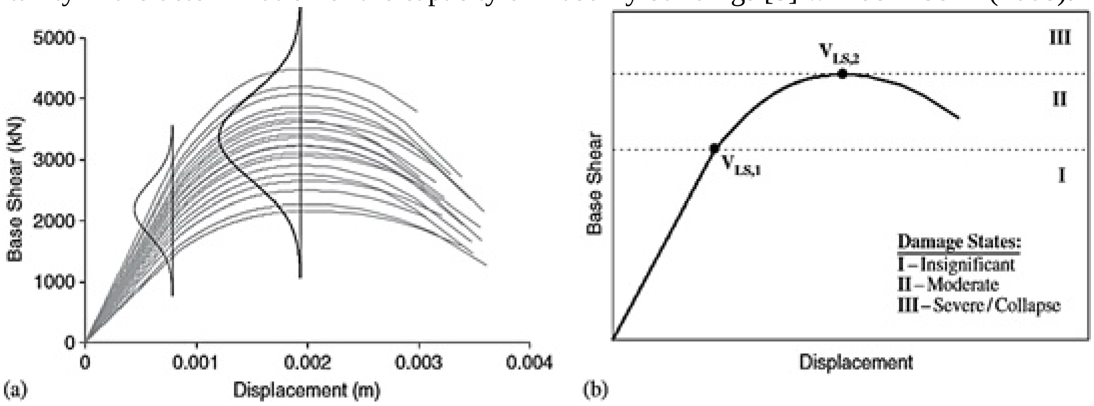

Figure 7 (a) The capacity curves for building subclass M1111 for different material properties and (b) the damage and limit state definitions

Material subclass (D1–D4) the mean (μ) and standard deviation (σ) values for compressive strength of masonry (fm) are given as: μ=8MPa, σ=1.6MPa for D1 subclass; μ =6MPa, σ=1.5MPa for D2 subclass; μ=4MPa, σ=1.2MPa for D3 subclass and μ=2MPa, σ=0.7MPa for D4 subclass. Figure 7(a) presents a sample set of capacity curves obtained for building subclass M1111 by using the computer program MAS. There exist 20 different structural simulations that account for the variability in material properties. The sampling data for the random variable f_m are obtained by using Latin Hypercube Sampling Method, which was originally developed by. A normal distribution is assumed, with the statistical characteristics given above. Two different limit states are monitored. The parameter VLS, 1 represents the base shear capacity at the threshold of linear elastic behaviour, whereas the parameter $V_{LS,2}$ stands for the ultimate base shear capacity of the considered masonry building (Figure 7(b)). These capacity values are determined for each pushover curve and the median values are employed in Equation (10) to generate the fragility curves for the building class under consideration. The ß parameter in the denominator that represents the uncertainty associated with capacity (ßC) is also determined by using the same statistical capacity data will be Erberik (2008).

$$Ld/A=0.25I\ (m/m^2) \tag{10}$$

Characteristics of shear strength

Among many different ground motion parameters, peak ground acceleration (PGA) has been considered as the fragility hazard parameter because it is simple, straightforward and a good candidate as fragility hazard parameter for non-ductile and rigid structural systems like masonry buildings, which cannot go far beyond the elastic range due to their limited deformation capacity. Fifty ground motion records with stiff site characteristics are selected with PGA values that range between 0.01 and 0.8g, where g is the gravitational acceleration. Fragility curves for masonry buildings have been generated by using the relationship given in Equation below (11)

$$P(\mathrm{LS}_i/\mathrm{PGA}) = 1 - \Phi\left[\frac{\ln(V_{\mathrm{LS},i}) - \ln(V_\mathrm{D})}{\sqrt{\beta_\mathrm{C}^2 + \beta_\mathrm{D}^2 + \beta_\mathrm{M}^2}}\right] \tag{11}$$

The variation of the shear modulus and its viscous counter paret with shear strain (Figure 8)

a - for the secant shear modulus G
b - for the viscous counterpart G

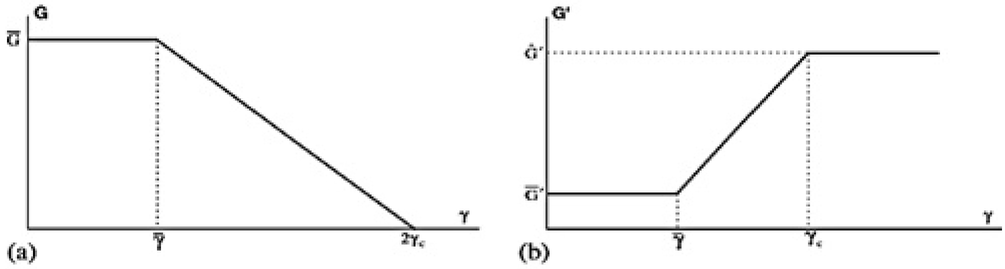

Figure 8. The variation of the shear modulus

Summary and Conclusions

During studying three Codes Euro Code, American Code & Turkish Code about the Masonry Building Properties in comparison materials, compressive strength, shear strength. The study present deferent rules for each Code because of their different environment position zone condition for each region. The results are given below;

1-) Material properties are indicated in 3 different cases in Euro Code.
2-) The mortar characteristics are determined in 4 different types in Euro Code.
3-) Formulas for compressive and shear stress calculations are made in euro code.
4-) Material specifications are selected from the table in the American Code.
5-) According to the American Code, compressive and shear stress are calculated in different formulas according to other building codes.
6-) The selection of materials in the Turkish Code is similar to other regulations.
7-) Compressive and shear stresses in Turkish regulations are determined with the aid of graphics.
8-) As seen for example Turkish code take the rules depends seismic zone of the building because its seismic region. On the other hand, the American & Euro Code take the rules of masonry building according to the available Materials used in the building.

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