CRITCAL REVIEW OF REINFORCED MASONARY IN SEISMIC PRONE AREA FOR DIFFERENT CODES

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ABSTRACT: Plain masonry has been used as a construction material since very old age. Reinforced brick masonry is a relatively new type of construction with specific design procedures and construction techniques. Building codes have made provisions for reinforced brick masonry since 1953. Codes selected for this study includes Uniform Building Code 1997(UBC), Euro code 2005 (EC-05), Turkish Code 1998 (TK-98) and National Building code of India 2005(NBCI-05) along with building code of Pakistan 2007 (BCP-07). The materials involved in reinforced brick masonry include bricks, mortar and reinforcement. The quality and size of bricks are different in different regions. The codes under consideration used different approach for reinforced brick masonry design. Few codes design, brick masonry using allowable stress design or empirical methods and others use ultimate strength design method. UBC-97 is the only code that designs reinforced brick masonry on empirical, allowable and ultimate strength design approach. UBC-97 was also found to be more economical than the other codes. This study also revealed that BCP-07 is based on UBC-97 and it may be revised to account for the construction practices and quality of masonry manufactured in Pakistan.

Keywords reinforced masonry, masonry codes, brick masonry design.

INTRODUCTION

The use of reinforced brick masonry (RBM) is very old and it is in practice for over more than 175 years. RBM is used in a wide variety of structural components like beams, columns, arches, culverts, retaining walls, chimney's, pavements and bridges. One of the remarkable use of brick masonry is in pyramids of Egypt with a height of 145m. According to Beamish (1862), Marc was the first person who first discovered the RBM. He used RBM in the construction of Thames Tunnel. In this tunnel two brick masonry shafts were constructed with dimensions 760mm in thickness, 15m in diameter and with a depth of 21m. Vertical reinforcement was used in this shaft using wrought iron rods of 25mm diameter. Iron hoops 230mm wide and 113 mm in thickness were laid in the brick masonry. Although there were unequal settlements of the shaft, however, no cracks developed in the masonry.

Colonel Pasley (1837) of the Crops of Royal Engineers conducted various tests on reinforced brick masonry beam. The results reported by him were comparable to those obtained by Marc. He casted three beams with same dimensions. The first beam was without reinforcement but only neat cement was used as a binding material. The second beam was casted using neat cement and hoop reinforcement and third one with hoop reinforcement but with lime mortar (1:3). Out of these three beams, the second one took the maximum load. Unfortunately this technique was not adopted for the RBM in case of different span lengths.

Corson (1872) published the article based on March and Paley's test results and recommended allowable tensile strength for masonry to be used in the design of lintels. This was the first published document on RBM. However, this article did not cover fully the effect of reinforcement in increasing the tensile strength of brick masonry. Brebner (1923) representative of Public works department of the Government of India, published research paper after carrying out extensive tests on various elements of reinforced brick masonry. He performed tests on 282 structural elements composed of reinforced brick masonry. He conducted tests on RBM slabs, beams, columns and arches. His published test results invited many researchers all over the world to further investigate the potential of RBM in construction. Fillipi (1933) also recommended the use of reinforced brick masonary in culverts, dams, circular structures, bridges etc.

The significance of RBM was appreciated after the Long beach earthquake (1933). This earthquake revealed to the researchers that ordinary brick masonry is of no use in case of earthquakes. Hence lot of work was done on RBM after that and correspondingly separate provisions were made in all codes regarding the use of RBM in construction.

METHOD

There are four main codes which have been selected for the critical review of RBM which are Uniform Building code 1997 abbreviated as (UBC-97), European Code 2005 abbreviated as (EC-05), Turkish Code 1998 abbreviated as (TC-98) and National Building code of India2005 abbreviated as (NBCI-05).

General: Reinforced brick masonry (RBM) is composed of bricks, mortar and reinforcement. There are various requirements for each of the components of RBM which has been discussed below. The size of the bricks for various codes is shown in Table-1

Table-1 Brick sizes for various codes

Code	Size (mm)
NBCI	228x107x69
UBC	203x102x57
EC	215x103x65
TC	215x103x65

The salient features for the design of brick masonry are given in Table -2 for standard construction.

Table -2 Salient features for design of brick masonry

Limitations	UBC	EC	NBCI	TC
Building Height (m)	10	N-A	N-A	12
Storey Height(m)	N-A	N-A	5	3
No. of Storey's	N-A	N-A	N-A	4
Minimum Wall thickness(mm)				
N=1	150	N-A	100	100
N=2	150		100	150,100,100
N=3	200		100	150,150,100,100
N=4	200		200	150,150,150,100,100
Slenderness ratio (h/t)	20 (Solid walls) 18 (All other) 18 NB(Exterior) 36 NB(Interior)	27	27 (Cement mortar) 13 (Lime mortar)	N-A

NB = Non Load bearing walls

The compressive strength of the brick masonry is very significant for their use in construction. The compressive strength requirement for different codes is shown in Table-3.

The above table indicates that for preliminary design, minimum compressive strength of masonry should be in the range of 3.5-5 MPa. UBC does not provide any minimum value for compressive strength and it is linked with the type of masonry unit and mortar type. In thing wind area, minimum value of compressive strength of masonry units recommended by UBC is very high compared other codes.

Table-3 Minimum compressive strength requirements for brick masonry.

UBC	EC	TC	NBCI
No indication about unit strength of bricks Strenght of masonary based on masonry unit strength For areas subjected to high wind pressure minimum recommended strength is 13MPa	F_b= 5MPa F_{bh}= 2MPa	5 MPa	3.5 MPa Higher strength depends on a) No. of storey's b) Wall thickness

The shear and Elastic properties of brick masonry are shown in Table-4.This table shows that shear and elastic parameters have been defined for Uniform building code and Euro code however the Turkish and Indian code is silent on these two important properties.

Table-4 Comparison of elastic and shear properties for brick masonry

Property	UBC	EC	TC	NBCI
Elastic Modulus(E)	750 f_m' 600 f_m'	1000 f_k	No specification	No specification
Shear Modulus (G)	40% of E	40% of E		

Note:- f_m and f_k is compressive strength of masonry.

Mortar: The comparison of mortar in different codes is given in Table 5-7. The comparison of different mortars indicates that EC and UBC recommend the same proportion of aggregates used in the preparation of mortar i.e. 2.25-3 times the volume of cementitious material. However for same proportion of cement and lime, compressive strength of mortar at 28 days is different in various codes. For example for S-type mortar in UBC, cement lime proportion is 1: 0.25-5 and the compressive strength is 12 MPa and for M10 mortar in EC, the cement lime proportion is same but the compressive strength is 10 MPa. In NBCI, the comparable mortar is H2 with cement lime proportion 1:0.25 and the compressive strength is 7.5MPa. From this comparison, it can be established that UBC predicts higher value of strength of

Table-5 Mortar proportions and strength recommended by UBC

Mortar Type	composition (by volume) (cement : Lime)	Average compressive strength at 28 days (MPa)
M	1: ¼	17
S	1: ¼ - ½	12
N	1: ½ - 1¼	5.0
O	1: 1¼ - 2 ½	2.5

Table-6 Mortar proportions and strength recommended by Euro Code

Mortar Type	Composition (by volume) (cement : Lime)	Average compressive strength at 28 days (MPa)
M2	1: 1.25-2.50	2.5
M5	1: 0.50-1.25	5.0
M10	1: 0.25-0.50	10
M20	1: 0-0.25	20

Table-7 Mortar proportions and strength recommended by Indian Code

Mortar Type	Composition (by volume) (cement : Lime : Sand)	Average compressive strength at 28 days (MPa)
H1	1:0.25:3	10
H2	1:0.25:4	7.5
M1	1:1:6	3.0
M2	1:2:9	2.0

mortar for same proportions of constituents than Euro and Indian codes. Turkish code does not give any indication regarding the strength of mortar.

Reinforcement: Reinforcement requirement for masonry are different in all codes. EC and UBC have somewhat similar provisions for reinforcement but TC and NBCI only talk about masonry reinforced through horizontal and vertical bond beams. Wall reinforcement has not been discussed in these codes. The detailed reinforcement provision requirements are given in Table-7 as follows.

It is clear from the comparison of reinforcement from UBC and EC that horizontal and vertical steel requirements are in terms of gross area of the section. Minimum reinforcement recommended by EC is more than that described in UBC. Maximum bar spacing recommended in EC is also on lower side than in UBC. The comparison of TC and NBCI reveals that Indian code is based on storey height and seismic zones of the country; however the TC provides typical reinforcement in these band beams irrespective of span and other requirements.

Design Methods: There are three design methods

a) Empirical method.
b) Allowable stress design method.
c) Strength design method.

The empirical method was recognized by UBC, TC and NBCI. Allowable stress design provisions are given for the codes from UBC and NBCI while strength design approach is given for UBC and EC. Therefore we may compare UBC, TC and NBCI for empirical methods, UBC and NBCI for allowable stress design approach and finally UBC and EC for strength design method can be compared.

Code	Reinforcement Provisions
UBC	a) Wall ties in cavity walls (i) Max. Vertical distance b/w ties = 610mm (ii) Max. Horizontal distance b/w ties = 914mm b) Vertical and horizontal wall reinforcement in Seismic Zone-2 a. Min. Vertical reinf. = 130 mm^2 (support to support) and shall be provided at top and bottom of wall openings. c) Vertical and horizontal wall reinforcement in Seismic Zone-3&4 a. The sum of vert. and horiz. reinforcement shall not be less than 0.002 x(wall width)x(wall thickness) b. At least 1/3rd of above reinf. Is to be placed in vertical and horizontal direction. c. Min. reinforcement as per UBC = 0.007 x gross X-Sectional area d. Max. bar spacing = 1219mm c/c either vertically or horizontally e. Min. bar spacing > 1.5 x d_b or 38 mm.
EC	a) Minimum horizontal reinforcement = 0.05% of gross area b) Minimum vertical reinforcement = 0.08% of gross area c) EC-08 recommends that rebars with minimum X-Sectinal area of shall be placed at free edges of the walls and at every wall intersection. d) Max. bar spacing = 600mm c/c both for horizontal and vertical reinf. e) Min. bar spacing> (i) max . size of agg. + 5mm, (ii) Bar dia (iii) 10mm f) Min. bar diameter = 5mm g) Min. cover = 19 mm.
NBCI	a) Concrete of Grade M15 shall be used for horizontal beams and if masonry is used then it must be used with 1:3 C-S mortar b) Requirement for vertical steel is based on number of storey's and it increases with increase in number of storey's (Refer to table-16, NBCI-05)
TC	a) Reinforcement requirement of horizontal bands are as follows a. Min. longitudinal bars = 6 bars having dia. of 10mm for stone walls b. Min. longitudinal bars = 4 bars having dia. of 10mm for other walls c. 8mm diameter hoops with a maximum spacing of 250mm. b) Reinforcement requirement for vertical bands are as follows a. Min. longitudinal bars = 6 bars having dia. of 12mm for stone walls b. Min. longitudinal bars = 4 bars having dia. of 12mm for other walls c. 8mm diameter hoops with a maximum spacing of 200mm

Authors considered an example of a single component in order to compare the different design approaches in the next section.

RESULTS AND DISCUSSIONS

The comparison of strength design method for Uniform building code and Euro code was carried out to determine the effectiveness of these two codes. Since the Building code of Pakistan is also based on the UBC code, therefore, we may say that the comparison of BCOP and EC is also carried out.

A design of brick masonry column was done to compare the two design approaches. The X-Section of the column is shown in figure-1.

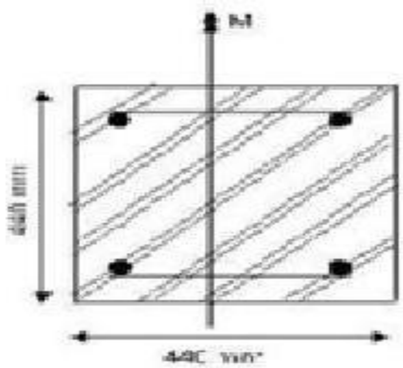

Figure-1 Trial reinforced masonry column section.

The other design parameters for the column shown in figure-1 is as follows

Height of column	=	3.0 m
Vertical load on column	=	400 KN
Design Moment	=	45 KN-m
Brick unit compressive strength (fb)	=	18.55 MPa
Mortar Strength	=	class M6 (6MPa)
Execution control	=	class 1
Trial Column size	=	440 x 440
Reinforcement in column	=	4 dia. 20 mm bars

Table 8: Results of Design Example

Design	UBC	EC
Design compressive strength of masonry	4 MPa	3.64 MPa
Column Section 440 x 440 mm	Adequate	Adequate
Longitudinal Reinforcement (4 bars of 20 mm diameter)	Adequate	Adequate
Column Section 300 x 300 mm	Adequate	Not adequate
Longitudinal Reinforcement (4 bars of 16 mm diameter)	Adequate	Not adequate
Shear reinforcement	Required by design	Min. required
Min. Shear reinforcement (%age)	0.0007 of gross area	0.0005 of effective area
Economy	Economical	uneconomical

The detailed analysis for the above data was carried out using UBC and EC codes and the summary of the results is shown below in Table -8.

The above table clearly indicates that strength design method of UBC gives economical solution whereas EC strength design approach is uneconomical.

Conclusions: There is a variation among the codes reviewed here regarding the properties of masonry. Following material properties of masonry which vary are

a. Min. Compressive strength of brick masonry units
b. Mortar Strength
c. Min. Reinforcement requirements
d. Grout strength

i. Turkish code designs only on the basis of Empirical approach and that in some cases may become uneconomical.
ii. Indian code and Turkish code use the concept of horizontal and vertical bond beams instead of wall reinforcement.
iii. ASD for masonry design has been entertained by Indian code which is realized as an uneconomical design approach.
iv. UBC is the only code that makes provision for all three methods of design i.e. empirical, ASD and USD
v. UBC is the only code that gives special provisions in areas of seismic risk for various zones.
vi. EC approach for the design of masonry is more comprehensive compared to other codes but it gives conservative design.
vii. Reinforced brick masonry column has been designed by strength design method and their design shows that UBC design approach using strength design method is economical compared to EC.

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