STRENGTHENING OF BRICK BUILDINGS IN SEISMIC ZONES

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ABSTRACT

This paper is in continuation with the work reported earlier(1)+ by the authors on strengthening of brick buildings against earthquake forces. A method is presented here for determining the necessary quantity of steel reinforcement in buildings so that economical and efficient performance is obtained. A maximum limit for percentage of steel is suggested based on energy considerations.

Experiments carried out on models for establishing the behaviour of reinforced brick elements, are reported.

INTRODUCTION

The traditionally constructed buildings in many seismic areas consist of unreinforced brick load bearing walls. For protection against weather, these walls are thick and floors heavy. Such buildings are rigid structures and have low natural period of vibration. Also, damping in such structures is low - about 3-5% in elastic range. During earthquakes, therefore, their spectral response is high, and since brickwork has low tensile resistance, it suffers heavy damage. If however the brickwalls are framed with timber scantlings, their collapse has often been prevented and the damage is mostly repairable. But timber has its own disadvantages with respect to cost, durability and lack of bond with masonry and therefore other methods of strengthening brick walls are needed. Recent developments have enabled manufacture of pre-tensioned concrete members that can replace timber scantlings in buildings. They are much cheaper than timber and have the advantage of bonding well with brickwork in cement mortar. Photograph 1 and 2 show the typical construction practices in Turkey and Kashmir (India), which indicates good performance of brickwork braced with timber scantling. Same has been the experience during Debar (Yugoslavia) earthquake of 1967.

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[+] Refers to the number of reference given at the end of the text.

Experience with reinforced concrete buildings has been generally good but the plain concrete structures have not faired better than those in unreinforced brickwork. This indicates the usefulness of introducing steel in brickwork or concrete to increase not only their resistance in tension, but also their energy absorbing capacity through ductility of steel. Also, it is necessary to keep in view while suggesting new methods that the general pattern of traditional construction is not disturbed since it has developed on the basis of many other factors like the cost, availability of materials and technical skill besides the weather requirements.

Simple reinforcing methods for brickwork were reported earlier(1) and it was shown that the overall resistance can be increased considerably at small cost. This paper extends the same work for designing such structures at ultimate capacity preventing collapse but accepting damage for reasons of economy. The cracks in this 'acceptable damage' can be effectively repaired by cement grouting in most cases.

BEHAVIOUR OF BRICK BUILDING DURING EARTHQUAKES

The usual type of cracks in earthquake damaged building (excepting those resulting from unequal settlement of foundations) are shown in Fig. 1. It will be seen that they are mostly in portions around the openings. They start horizontally due to tension being excessive and then move diagonally or horizontally as shown at A. The horizontal cracks occur due to shear failure at planes where rigidity changes suddenly and to a large extent. Therefore such cracks would appear at top or bottom of openings. Since earthquake force acts in both directions, cracks can occur along either diagonals or both. An ideal method of reinforcing a column such as BCDE would be to provide diagonal reinforcement in both directions tied to vertical reinforcement at corners and jambs. However, diagonal reinforcement makes brick construction difficult. It is convenient to provide steel vertically and horizontally at suitable places.

The earthquake force on the floors and walls is transferred as shear to the ground through wall elements - the weakest sections being the columns between openings such as BCDE (Fig.1). Such columns deform as shown in Fig.2. Section DE is subjected to a moment (F.a) and a shear (F). Cracking starts when due to moment (F.a), the tension in brickwork at the corners exceeds beyond its capacity. If the resistance of brickwork in tension was as good as in compression, the column would have taken large horizontal forces without damage. It therefore appears necessary that its energy capacity is increased by providing steel reinforcement on tension faces. Energy absorption can increased appreciably by accepting some damage through yield of steel and some inelastic deformations. Here it may be pointed out that the steel reinforcement will be useful only as long as brickwork does not fail. A criterion therefore may be defined which limits the maximum quantity of steel. It may be understood that the energy absorption of steel should not be more that of brickwork because it would be no use having this energy when brickwork in the structure has failed. In what follows, an analysis of the problem is presented in generalized form.

NOTATION

The following notation will be used -

b - Width of the section

c - Compressive stress in brickwork

d - Depth of the section

m - Modular ratio

p - Percentage of steel

t - Tensile stress in steel

E_b - Modulus of elasticity of brickwork

E_s - Modulus of elasticity of steel

N - Distance of neutral axis from compression edge (fraction of d)

β - Bilinearity factor

μ - Ductility of steel

μ' - Ductility of brickwork

ϵ_b - Strain in brickwork

ϵ_{yb} - Yield strain in brickwork

ϵ_s - Strain in steel

ϵ_{ys} - Yield strain in steel

EG_s, EG_b - Energy absorbed by steel and brickwork respectively

USEFUL QUANTITY OF REINFORCEMENT

For obtaining the quantity of reinforcement that should be provided for making the best use of the energy absorbing capacity of brickwork, it is assumed that:

(i) Brickwork has the stress-strain curve shown in Fig. 3 and it behaves as an elastic material upto a certain limit. The 'bilinearity' is a generalised one and suitable choice of parameters can reduce it to either linear or elasto-plastic system.

(ii) Tension is resisted by steel only and its stress-strain diagram is assumed to be elasto-plastic as shown in Fig. 4.

(iii) Plane section remains plane after bending. Fig. 5 shows the distribution of stresses and strains along the depth of brick pier.

The above assumption gives that

$$N = \frac{1}{1+\mu t/mc\mu'} \qquad \dots (1)$$

(iv) Bond between steel and brickwork is perfect within the range of strain.

On the basis of these assumptions, it can be seen that energy absorbing capacity of steel in tension per unit height of column, when it is permitted to yield to a strain equal to μ times the strain at yield level (Fig. 4) is given by

$$EG_s = \frac{t^2}{2\ E_s}(2\mu - 1)\ p.\ bd \qquad \dots (2)$$

Energy absorbed by brickwork in compression per unit height of column is computed by considering energy absorbed by each fibre in attaining the stress levels shown in Fig. 6. According to the notations used in this figure,

$$EG_b = \frac{c^2 bd.x.}{6E_b} + \frac{c^2}{2E_b}.bd.(N-x)\left[\frac{\beta\mu'^2}{3N}(N^2+Nx+x^2)\right.$$
$$\left.+\beta-1+\mu'(N+x)\left\{\frac{1}{N}-\beta\frac{N+1}{2N}\right\}\right] \qquad \dots (3)$$

Energy absorbed by steel in tension should not be more than that absorbed by brickwork in compression i.e.

$$EG_s \not> EG_b$$

Other equations which govern the behaviour can be written on equating the total tension to total compression in the section, which gives

$$p.bd.t = \frac{c}{2}\left[bd.x + bd\ (N-x)\left\{2+\beta(\mu'-1)\right\}\right] \qquad \dots (4)$$

In the above equations 'x' is the fraction of depth which defines the linear region of material and is given by

$$x = \frac{N}{\mu'} \qquad \ldots (5)$$

With the help of above equations a maximum limit of 'p' can be calculated on the basis of energy consideration. This is designated as p_{max}. If the quantity of steel provided in a structure is more than this, it will be found that steel will not be put to full use of its strength because of the limited strength of brickwork.

On the other hand, it has to be seen that a member does not fail due to excessive deformations of steel. Therefore, there is a needn to specify certain minimum quantity of steel which will be necessary to check failure in the above manner. Considering the same reinforced brick section, it will be seen that if deformations in steel are large, the column will start rotating about the compression edge as a rigid body and will cause a functional failure. To safeguard against this, it is considered desirable that the neutral axis of the section is not allowed to move up beyond a value $N = 0.25$. If this is done, then from equation 1,

$$\mu = 3\,\frac{mc\mu'}{t} \qquad \ldots (6)$$

Using equations 4, 5 and 6, the value of 'p' can be determined. This is designated 'p_{min}'.

As an example, we take the case of a material which is elasto-plastic ($\beta = 0$). For this, p_{max} will be calculated from the following equations. These are derived from equations 1-5.

$$N = \frac{1}{1 + \dfrac{t\mu}{mc\mu'}} \qquad \ldots (7)$$

$$p = \frac{cN}{2t}\left[2 - \frac{1}{\mu'}\right] \qquad \ldots (8)$$

$$p = \frac{mN}{3(2\mu - 1)}\left[\frac{1}{\mu'} + 3(\mu' - 1)\right]\left(\frac{c}{t}\right)^2 \qquad \ldots (9)$$

Fig. 7 shows the solution of equations (7), (8) and (9) for $m = 165$ $c = 1500$ p.s.i. and $t = 80000$ p.s.i. Line AB determines the ductility factor for steel (μ) for available ductility of brickwork (μ'). Curve CD gives the value of p_{max} for a known value of μ. For the tests carried out, brickwork had properties mentioned above.

In addition, it exhibited brittle behaviour ($\mu' = 1$). For this combination, p_{max} and p_{min} are obtained from equation (7), (8) and (9)

$$p_{max} = 0.00625$$

$$p_{min} = 0.00234 \qquad \ldots (10)$$

The reinforcing steel that was used in the experiments had unusually high yield stress level. For commonly available reinforcing steel $t = 40000$ p.s.i. Further with the properties of brickwork in 1:3 cement sand mortar(1) i.e. $c = 1340$ p.s.i. and $m = 90$ we have

$$p_{max} = 0.01111$$

$$p_{min} = 0.00416 \qquad \ldots (11)$$

These values are considered as the limits of the quantity of steel in brick structures.

EXPERIMENTAL WORK

For verification of the ideas presented herein, some experiments were performed on models of brick columns reinforced with different quantities of steel. For the specific models tested, the values of m, c and t were determined experimentally. It was seen that brickwork in 1:3 cement sand mortar did not exhibit the bilinear character. The brittle behaviour, however, is also covered by the general expressions developed earlier. Steel used for reinforcement exhibited elasto-plastic behaviour. Characteristics of both the materials are shown in Figs 8 and 9.

The model columns were 10" deep and 6.75" wide reinforced with one bar 3/8", 1/2" and 3/4" diameter giving $p = 0.0018$, 0.0032 and 0.0072 respectively. Strains were measured in brickwork and steel when load was applied laterally at the top of column. Photograph 3 shows the experimental set up. Fig. 10 shows the strain diagram for a column section near the base for $p = p_{min}$ and $p = p_{max}$.

All the tests carried out at the school confirmed the theoretically predicted behaviour on the lines suggested in this paper.

CONCLUSIONS

It is seen that for useful utilization of the strength of steel and brickwork, the quantity of steel reinforcement should be such the energy absorbed by steel during an earthquake is not more than the energy absorption capacity of brickwork. It is important to note that steel will not be put to its full use if brickwork fails earlier. Also, the quantity of steel should not be too small, so that excessive deformations occur in steel. This will result in failure of structure while brickwork has a stress much lower than its ultimate strength. The experiments carried out at the school confirm this. It is recommended that the two limits as suggested in this paper may be used as guide lines for providing steel in brick structures.

REFERENCES

1. Krishna, Jai & Brijesh Chandra "Strengthening of Brick Buildings Against Earthquake Forces", Proc. Third World Conference on Earthquake Engineering, New Zealand, 1965.

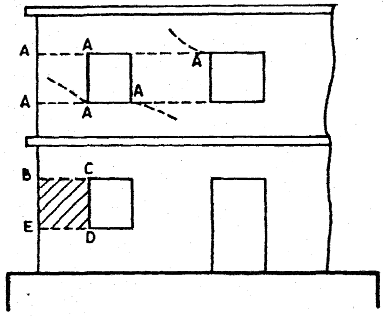


FIG. 1 _POSITION OF CRACKS IN A BRICK BUILDING

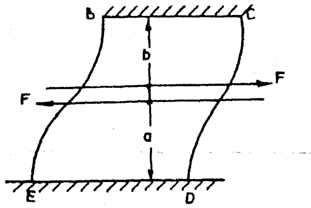
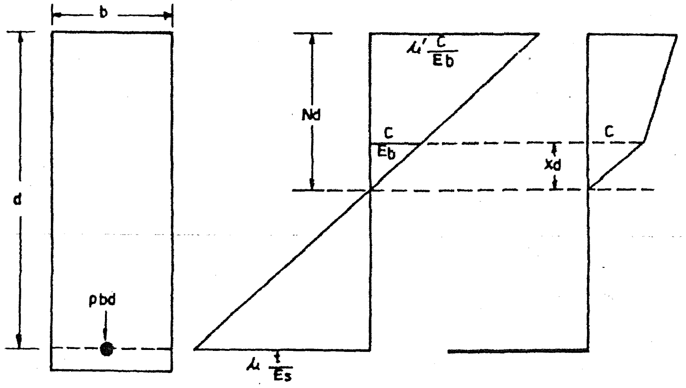


FIG. 2 _DEFLECTION OF A COLUMN NEAR AN OPENING



SECTION STRAIN DIAGRAM STRESS DIAGRAM

FIG. 5 _STRESSES AND STRAINS IN THE SECTION

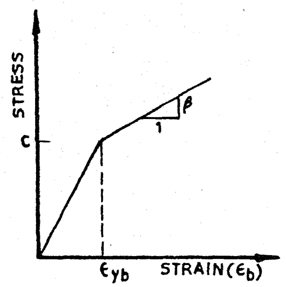


FIG. 3 _STRESS-STRAIN CURVE FOR BRICK WORK

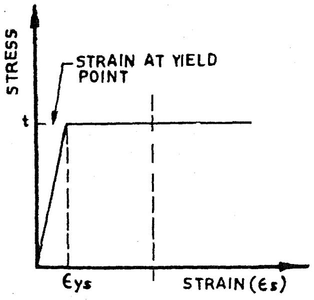


FIG. 4 _ STRESS-STRAIN CURVE FOR STEEL

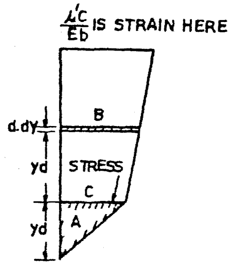


FIG. 6 _ STRESS IN BRICK WORK (SECTION ABOVE NEUTRAL AXIS)

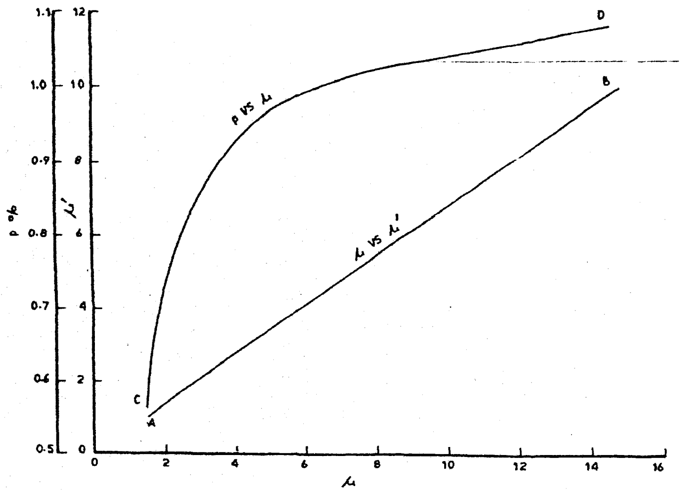
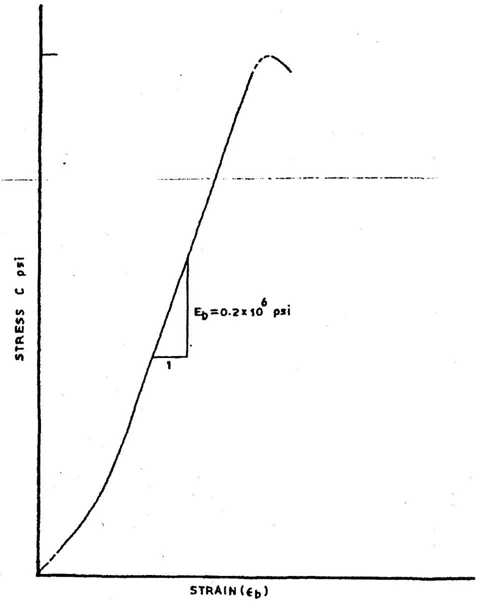


FIG. 7 _ REPERESENTATION OF EQUATIONS 7, 8 AND 9



IG. 8 _ STRESS-STRAIN CHARACTERISTICS OF BRICK WORK IN 1:3 CEMENT SAND MORTAR

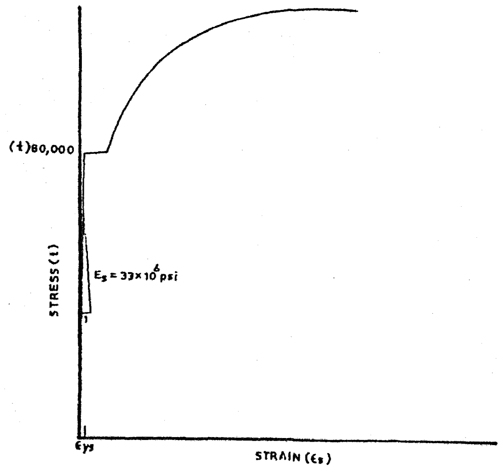


FIG. 9 _ STRESS STRAIN CURVE FOR REINFORCING STEEL

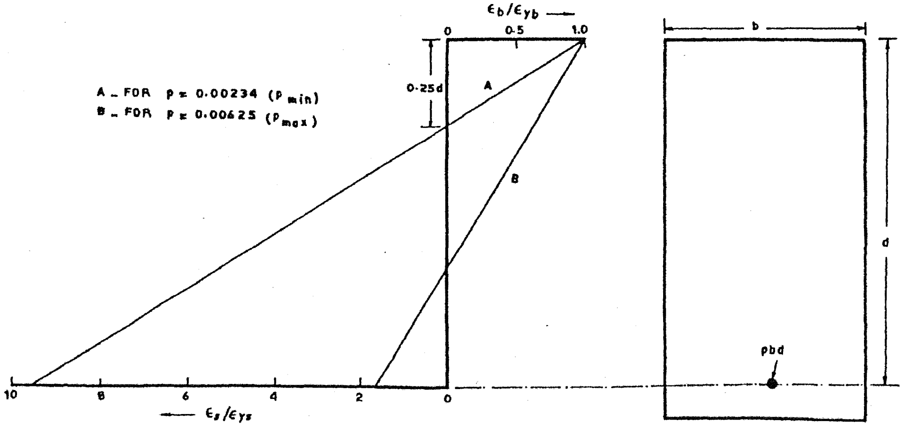


FIG.10 _ A TYPICAL STRAIN DIAGRAM NEAR THE BASE OF COLUMN (AT FAILURE)

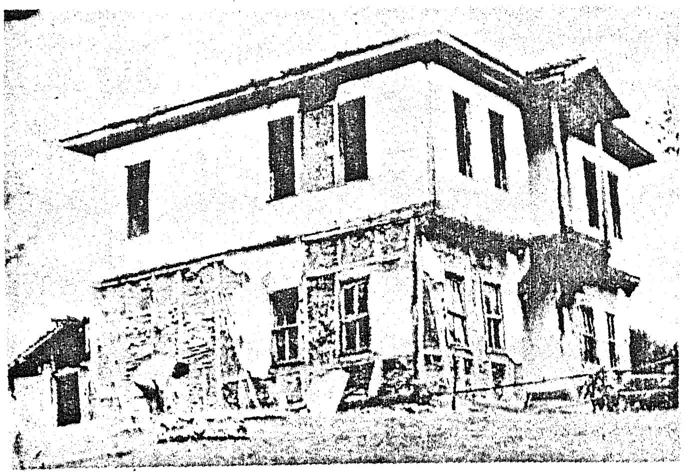


Photo 1- A TYPICAL HOUSE IN TURKEY AFTER AN EARTHQUAKE

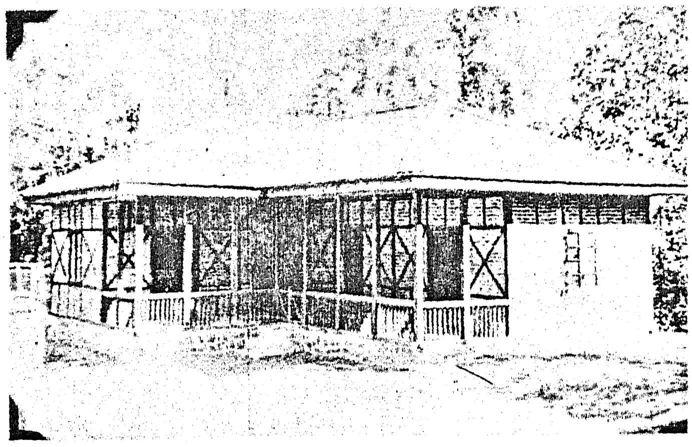


Photo 2- A TYPICAL HOUSE IN KASHMIR (INDIA)

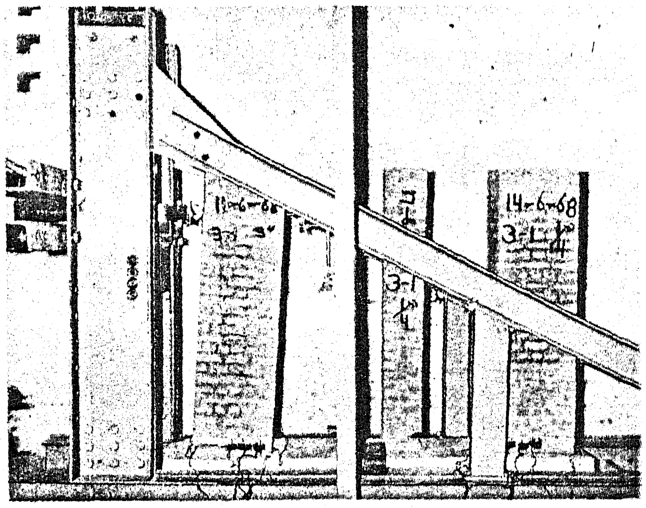


Photo 3 - SHOWING THE BRICK COLUMN AFTER THE LATERAL LOAD TEST