International Journal of Engineering Research and Advanced Technology (IJERAT)

DOI: http://dx.doi.org/10.7324/IJERAT.2018.3220

E-ISSN : 2454-6135

Volume.4, Issue 3

March-2018

Use of Masonry as a Structural Material – A Review

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ABSTRACT

In the present scenario, the shortage of housing in the rapidly developing country India has been discussed along with the suitability of affordable masonry housing to Economically Weaker Section (EWS) and Low Income Group (LIG) people to fill the existing gap. Evolution of fly ash brick and its role in saving the environment from pollution has also been discussed. A brief account of masonry and its use as a structural material has been presented. Studies on stresses developed in axially loaded brick mortar composite and the experimental investigations on rat-trap bond along with its contribution in providing thermal comfort and economy in design are discussed. A case study of experimental investigation on masonry subjected to monotonic and cyclic loading is also discussed.

Keywords: *Masonry, Compressive Strength, Rat-Trap Bond, Stress-Strain Relationship, Envelope Curve*

1. INTRODUCTION

India is one of the most rapidly developing country of the word. The rapid growth of population in the developing country like India has compelled to develop its infrastructure in order to meet with the pace of development. This in turn has resulted in acute shortage of housing particularly in urban areas. India has been experiencing urbanization at an extremely rapid rate in the past two decades. Currently it has more than 53 million urban population. Our urban population is expected to reach a figure close to 600 million by 2031. The shortage of urban housing which is prominent within the Economical Weaker Section(EWS)and Low Income Group(LIG) people is estimated to 18.78 million households in 2012 and expected that it will reach to 34.1 million units by 2022 [1]

Besides this in India about 83 % of the population live in villages and reside in unreinforced masonry. In the present scenario, it has become critical to fill the existing gap in demand and supply with affordable housing.

In India most of the houses constructed either in villages or in towns are of one or two story high brick masonry. In such cases the stress in the brickwork is very nominal. For buildings up to three stories masonry is considered as the best option. It also meets the demand of affordable housing in the country.

2. HISTORY

Masonry has been in use as construction material since thousands of years. This is probably due to the various reasons like availability of materials, resistance to fire, durability, sustainability and good load bearing structural elements. The Egyptian pyramids (2500 B.C.), The Colloseum of Rome (70-72 A.D), Taj Mahal of India (1632 A.D), Great Wall of China (21196 km long -built, rebuilt and maintained between 221B.C.-206 B.C.), Elamite Ziggurat a choga zambil in Iran (a temple tower with mud brick masonry 1250 B.C.), Sun pyramid at Teotihucan, Maxico with 66 meter height - 600 A.D), are some of the world’s most significant architectural achievements which have been built with masonry.

Bricks are one of the oldest building material dating back to 7000B.C. where they were first found in southern Turkey in Jericho. Sun-baked clay bricks were used in the construction of buildings more than 6000 years ago. The evidence of which can be seen today in ruins of Harappa Buhen and Mohenjo-Daro. Initially bricks were made with mud and dried in sun. In India bricks have been in use for more than 5000 years. In order to prevent distortion and cracking of the clay shapes, chopped straw and grass were added to the clay mixture. The next big step in enhancing brick production occurred about 4000 B.C. At that time manufacturers began producing bricks in uniform shapes. Along with the shaping of brick, the move from sun baking to firing was another important change. The Roman further distinguished those which had been dried by the sun and air and those which were burnt in a kiln. They found the kiln-fired bricks were more durable in harsh weather condition, which made them much more reliable brick for use in permanent buildings where mud bricks would not have been sufficient. and they introduced kiln fired bricks to the whole of the Roman Empire. Fired bricks were also useful in absorbing any heat generated throughout the day, then releasing it at night. But the another aspect of fired bricks was that not only it consumed the high energy but also polluted air. It causes health hazards and global warming. On an average for manufacturing 100,000 bricks, the requirement of coal is 18 tones and about 24 million tons of coal is being consumed by the country per year which is about 8% of total consumption of coal in the country and hence became the third largest consumer after power and steel sectors. In addition to this it also consumes several million tons of biomass fuels. The contribution of energy in total cost of brick production is 35% to 50% [2].

Such a huge consumption of coal by the brick production industries are responsible for the addition of the significant pollution in the environment. This includes carbon dioxide (CO2), Carbon monoxide (CO), Sulphur dioxide (SO2) and Suspended Particle Matters (SPM). This considerable quantity of coal used in the firing of bricks leave bottom ash behind it as residue. The air pollution and bottom ash produced so, causes health hazards especially affecting the respiratory system of the body. The problem increases with the increase of demand of bricks from construction industry. Apart from this preparation of traditional clay bricks require good quality of clay which is obtained from the excavation of top fertile soil. In this process every year around 350 million tons of top fertile soil is consumed for making bricks. The extraction of top fertile soil in Asian countries significantly affects the present and future agricultural productivity as well as the functioning the irrigation schemes thereby endangering livelihood and food security [3]. In the last several decades, attempts have been made to find a suitable material as a substitute of clay in order to reduce the consumption of this virgin material in the preparation of bricks without compromising its qualities and strength.

In India a huge amount of fly ash is generated every year from different thermal power stations as bi product, which has become a serious threat for the environment. About 184.14 million tons of fly ash was generated from 145 thermal power stations during 2014-15[4]

Keeping in mind a solution to difficult and expensive waste disposal problem of Fly ash in India, in the month of September 1999, a law came into the force, according to which at least 25% of fly ash was made mandatory to mix with clay for the manufacture of clay bricks for the use of construction work within the radius of 50 km from thermal power plants. The restriction was put to excavate top soil for the same. This resulted the Fly ash bricks to come into the existence[5].

Fly ash brick also called green brick as it is made up of waste materials such as Fly ash and requires no burning, which is the solution for all the above mentioned problems. These bricks can be used in all construction activities where clay bricks are used. It has numerous advantages over clay bricks including its superior quality to clay bricks, eco-friendly nature and most importantly helps in good utilization of large quantity of fly ash, reducing the consumption of top layer of soil. Mostly the production of fly ash bricks is done with machine which are having uniform shape and size. This ultimately reduces the consumption of mortar for covering joints and surface by 50%. It has been observed experimentally that the Fly Ash bricks made from class- C fly ash absorb carbon dioxide (CO2) from atmosphere called carbonization thus great contribution in saving the environment from global warning. Also they emit radon gas only to the extent of 50% to that of emitted by concrete and hence safer than concrete. The leaching of pollutants due to rain is also so small that it can be considered as negligible[6].

3. BONDING IN MASONRY

In addition to masonry unit, the another factor which controls the properties and behavior of masonry is the bonding in masonry. The manner in which bricks are laid in a wall is known as bond. Earlier people found that the walls constructed with more than one brick thick are more stable if the bricks are laid in a regular manner rather than in a haphazard manner. The course in which bricks are laid along the wall facing their sides are called stretcher course whereas the course in which bricks are laid across the wall facing their heads are called header course. Over the years different bonds came into the existence depending upon their strength, cost, ease of laying and appearance. Laying good quality of bricks on face and cheaper low quality bricks in the interior of wall was the outcome of further development.

Among the more common types of bond are the English bond in which bricks are laid in alternative course of stretchers and headers; the Flemish or Dutch bond which consists of headers and stretcher laid alternately within each course, each header being centered over the stretcher below it and the American bond, in which only every fifth or sixth course consists of headers and stretcher, the rest being stretchers. The Herring bond is a variety of racking bond in which units are laid at an angle of 45 degrees to the direction of the row instead of horizontally. Alternate courses lie in opposite direction, resulting in a zigzag pattern. Other types of bond are the Blind, Block-in-Course, Chain, Cross, Cross and English, Ranging, Running and Split.

During transition between the solid and cavity wall, a number of hollow walls also came into the practice which contained the bricks laid on edge. The wall remains single brick thick but the brick laid along the length of wall has thickness less than half its width on both faces leaving a gap between them. The gap is enclosed by laying cross bricks on edge after every neighboring brick. (presumably because a rat gets into the spaces). The commonest form of Rat-trap bond is the Flemish bond but the principle can be applied to any bond (except Header bond).

The Rat-Trap bond is developed by the Architect Laurie Baker with HABITAT Research center in India. This technology has been used in India for over 40 years and has been successfully adopted in Sri Lanka by practical action in partnership with Rural Center for Development. The air medium that is created by bond inside capable of acting as an insulator reducing the indoor temperature unlike other bond patterns. Thus, it helps in maintaining a good thermal comfort inside the building. The interior remains cooler in summer and warmer in winter. The validity of the bond was examined in reference to the cost effective housing.

A series of tests were conducted on a full scale 23cm Rat-Trap bond wall specimen and the results were compared with 23cm solid wall specimen. The results showed that there is 25% saving in bricks and 30% saving in mortar in Rat-Trap bond compared to solid wall bond. Also, the dead load on the foundation is reduced at least by 20%. Apart from that as the construction is appearing pleasant to the eye both internally and externally plastering is not necessary. The building is successively adopted for normal building. This type of wall also can be reinforced keeping in view the construction of masonry in earthquake or cyclone prone areas. The considerable reduction in the dead load allows the economical design of the structure. This adds the technology to the list of Green building. The main advantage of this bond is the economy in use with proper thermal comfort inside the building.

Due to presence of internal cavity in the Rat-Trap bond the virgin materials like brick, clay and cement can be considerably saved. Also, considerable reduction in the dead load allows the economical design of the structure[7].

4. STRESSES IN BRICK-MORTAR COMPOSITE

Conventional masonry is a composite material composed of stiff masonry unit and relatively soft mortar. The mortar has a tendency to expand more in lateral direction than that of brick due to lower young's modulus. But, due to bonding and friction between brick and mortar, the mortar is confined laterally by the bricks. This platen effect induces shear stress at the brick-mortar interface resulting in internal state of stresses, which consist of tri-axial compression in the mortar and biaxial tension coupled with vertical compression in the brick, as shown in Fig 1. The lateral tensile stress produced
would eventually cause failure in the brittle brick parallel to the axis of loading. As a result, the strength of brickwork in compression is much smaller than nominal compressive strength of the bricks and greater than the compressive strength of the mortar cube [8].

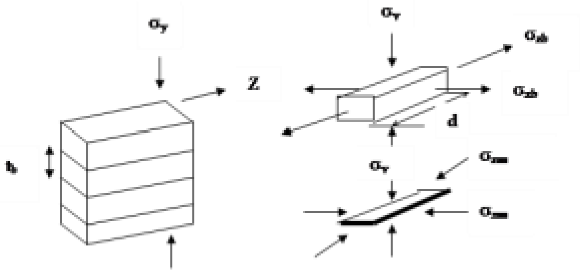

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Fig.1 Stresses in brick-mortar composite (Source: Hendry 1990)

In case of soft clay bricks the behavior is found contradictory to the above theory. It was experimentally observed that the tri-axial compression developed in the soft bricks (modulus of elasticity ~500MPa) and axial compression with lateral tension developed in mortar joints in the prism of masonry [9].

The variation of brickwork strength and brick strength with respect to mortar strength was expressed with the help of graph shown in figure 2. It was observed that the compressive strength of brickwork is in the range of 0.3 to 0.4 of brick strength. The variation is very nominal with mortar strength [10]

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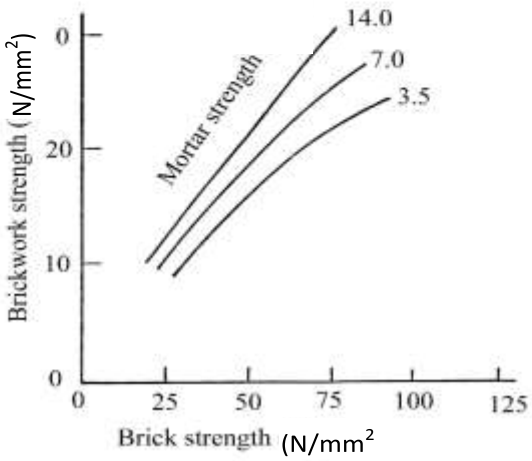

Fig.2 Relationship between crushing strength of brick work and brick (Source: Thomas 1953)

Based on the series of tests conducted on the prism constructed with very soft clay bricks (modulus of elasticity ~500MPa) with different combination of mortar grade, it was reported that the compressive strength of masonry increases with the increase in bond strength, which increases with the mortar strength along with other factors [11].

FA comparison of stress-strain curve for brick unit, mortar cubes for different grades of mortar (weak, strong and intermediate) based upon experimental results is depicted by figure 3

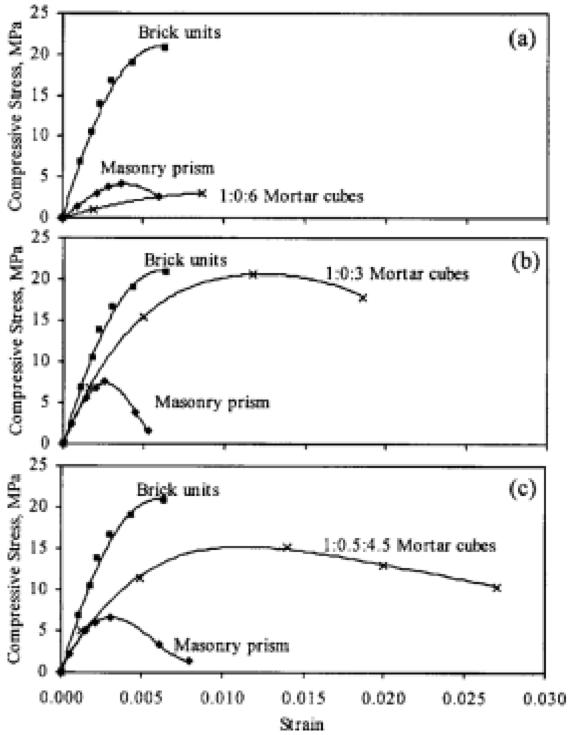

Fig.3 Comparison of stress-strain curves for brick units, mortar cubes, and masonry prisms for different grades of mortar: (a) weak; (b) strong; and (c) intermediate. (Data points represent experimental results and solid lines represent corresponding trend lines)

It was concluded that stress-strain curve of masonry constructed with weak mortar falls in between those of bricks and mortar. However, for masonry constructed with intermediate and strong mortar, the stress- strain curves of masonry fall on the lower side of those corresponding to bricks and mortar which is not in accordance with the generally accepted compressive behavior of masonry and therefore experimental study is required with different combinations of brick type and mortar grade to develop a generalized model for compressive behavior of masonry [12].

The parabolic nature of stress-strain curve of a brick masonry for four types of bricks when loaded normal to the bed joint in compression was observed in an experiment [13].

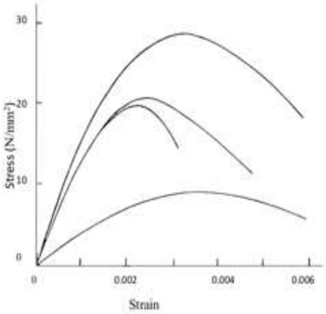

Fig.4 Stress-Strain curve for brick masonry (Source: Powell and Hodgkinson 1976)

An experimental study was carried out on axial compressive strength of the unreinforced/reinforced clay and fly ash brick masonry. Results are depicted in Fig 4. The outcome of the study was that the mortar with the ratio of 1:6 cement mortar with 20% replacement of fine aggregate with fly ash exhibited a higher compressive strength than the control mix after 28 days of curing. Incorporation of fly ash in the brick masonry results in the reaction of pozzolanas with the calcium hydrate which forms produced strong calcium silicate hydrates, thus enhancing the bond strength of the brick masonry with the modification of the microstructure of the mortar-brick unit interface. The compressive strength of unreinforced fly ash brick masonry was 34% more than the unreinforced clay brick masonry. The compressive strength reinforced fly ash brick masonry was 20.7% more than the reinforced clay brick masonry. The introduction of wire mesh in the clay brick masonry resulted in an increase of load carrying capacity by 25%, while the introduction of mesh in fly ash brick masonry resulted in an increase of load carrying capacity by 10% as the strength of the fly ash brick contributed more in the brick masonry strength [14].

A study on stress-strain characteristics of brick masonry under compressive cyclic loading, revealed that character of envelope for monotonically loaded masonry wallets are different from the masonry wallets subjected to cyclic loading. The character of envelope is considerably more non- linear in case of cyclic loading than monotonic loading [15].

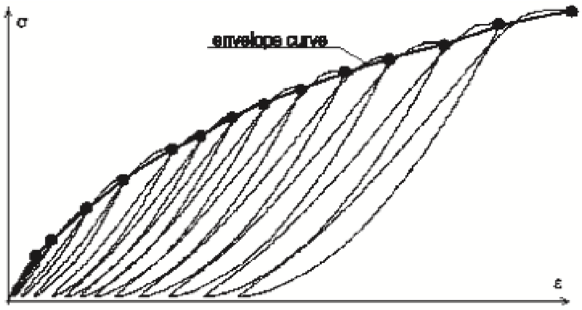

Fig.5 Typical σ−ε relationship for masonry subjected to cyclic loading with the construction of the envelope curve

Experimental investigation of Stress-Strain characteristics of brick masonry under uniaxial cyclic loading revealed that the plastic strain level present in the material plays an important role in defining the permissible stress level of the material under cyclic loading (Fig 5). Load cycles with peak stress greater than the peak stress of the stability point curve lead to failure as a result of plastic strain accumulation [16].

An experimental study of Fly-Ash brick masonry wall panel was carried under cyclic loading along with the effect of H/T ratio was carried out. It is perceived that the strength of Fly- Ash brick masonry is 1.3 times the strength of conventional brick masonry and can be inferred that the strength of masonry is about 40 to 45% of the strength of brick units. Also the peak stress corresponding to the common point curve are 80% to that of corresponding envelop curve and the peak stress corresponding to stability point curve are about 60% of that corresponding to envelop curve. The stress versus H/T ratio shows an increase in the stress with increasing H/T ratio attaining a peak value at H/T ratio 3. Later on stress falls gradually with the increasing H/T ratio. This behavior found to be peculiar when compared to the ordinary brick masonry [17].

The failure criterion on full-scale grouted unreinforced brick masonry square panel with the different orientation of principal compressive stress with respect to the bed joint was studied. A number of uni-axial and biaxial tests was conducted on the panel. It was concluded that the behavior of grouted unreinforced brick masonry panel was isotropic and the orientation of bed joint has no significant role in the failure criterion. Whereas the ratio of the horizontal to the vertical load has significant influence on the failure mode of clay bricks and hollow clay brick layers of panels. It was also observed that the masonry strength under equal biaxial compression is higher by about 36%on average than that under uniaxial compression [18].

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5. CONCLUSIONS

In order to bridge the existing huge gap between demand and supply of housing units in India, Brick Masonry has been considered as a very good option of affordable housing for Economically Weaker Section (EWS)and Low Income Group (LIG) people residing either in villages or in towns where most of the houses are constructed one or two story high. In such cases the stresses in brick masonry is very low. The use of fly ash bricks in masonry not only saves the consumption of top fertile soil but also has great role in saving the environment from pollution. Failure of brick masonry occurs due to development of biaxial tension coupled with vertical compression in the brick as per brick mortar composite action. Different H/T ratio or different pattern of bonding, uniaxial/biaxial compression are some important factors influencing the strength of brick masonry besides all other factors. Load cycles with peak stress greater than the peak stress of the stability point curve lead to failure as a result of plastic strain accumulation.

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