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STUDIES ON STRENGTHENING OF BRICK MASONRY STRUCTURES IN FIREWORKS INDUSTRIES AGAINST ACCIDENTAL EXPLOSIONS

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ABSTRACT

Man made accidents while handling explosives in fireworks industries cause loss of human lives and infrastructure due to collapse of walls which indicates that no fully safe manufacturing and construction procedures are followed in these industries. Hence, an attempt is made to suggest a cost effective construction by conducting analytical studies on brick masonry with strengthening measures using ANSYS and the results presented. It was observed that, by providing RCC vertical bands at door jambs, the resistance of brick masonry against accidental overloading can be improved considerably so that progressive collapse of the entire structure can be avoided.

Keywords: Explosion; brick masonry; RCC bands; ansys; deflection; collapse

1. INTRODUCTION

An explosion is a physical, chemical or nuclear action resulting in rapid release of stored energy associated with a bright flash and an audible blast. Major part of the energy is released as thermal radiation while remaining energy is coupled into the air or ground and causes shock waves. Conventional structures hardly withstand against damage from explosions, because the magnitudes of design loads are significantly lower than those produced by most explosions. Terrorist attack on the World Trade Center in New York City in 1993 caused severe damages in communication, transportation and utility systems besides removal of several thousand square feet of concrete floor slabs. However, the structure did not collapse due to the statical redundancy of the steel frames.

The terrorist attack in 1995 on the Alfred P. Murrah Federal Building in Oklahoma City revealed the vulnerability of conventional structural designs when subjected to blast loads.

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Accidental explosions in residential buildings, though the probability of occurrence is 10^{-7} to 10^{-5} per housing unit per year, it may cause either proportionate collapse or local damages. If the structure is not designed with adequate reserve strength to resist such accidental events, a chain of failures may cause progressive collapse of the entire structure. Hence, structures must be designed to resist against damages caused by an accidental event. Various design approaches include Specific Local Resistance (SLR) method, Alternate Path (AP) method and Indirect design approach.

Accidental explosions during the manufacture of fire crackers and safety matches are reported regularly in Sivakasi, well known as ***Mini Japan* (*Kutty Japan*)**, situated in the Virudhunagar District of Tamil Nadu State in India. Industries situated in and around Sivakasi satisfy about 90% of the global demand for fireworks products (for both civilian festival occasions and military needs for signaling) [1]. There are around 450 authorized firework factories employing about 40 000 direct laborers and 100 000 indirect laborers. There are probably an equal proportion of unauthorized factories manufacturing fireworks products [2]. During the manufacturing process of safety matches and fire crackers, explosive accidents occur frequently, resulting in heavy losses of human lives, injuries to workers, and of losses materials and money [3].

Clay brick masonry is used for the construction of industrial buildings for the manufacture of fireworks products. The existing construction guidelines as per The Explosives Act 1984 [4], The Explosives Rules [5] and Tamilnadu Factories Rules [6] do not possess any explosive resisting features. Hence it was felt to investigate the performance of brick masonry strengthened with RCC bands for explosive resistance so as to recommend the construction guidelines for the same.

The present construction practice of fireworks and match works industries is as below [7]: The room size is 3.6m (length)×3m(breadth)×3m (height). The walls are made of 230mm thick brick masonry without plastering. At the top, lean-to roof is provided using galvanized iron (GI) or tar coated light roofing sheets. Generally three doors are provided without any windows, ventilators and electrical fittings. These three doors are provided for safe exit in the event of an unexpected fire/explosion.

2. LITERATURE REVIEW

Chaf, [8] Salzano [9] suggested that when large amount of fireworks are stored in closed environment, explosive behaviour can be observed. Eamon, et al. [10] analyzed the behaviour of concrete masonry unit walls subjected to blast pressure using finite element method. Davidson et al. [11] discussed the use of the thin membrane elastomeric polymers on walls as blast reinforcement. Ward [12] proposed few techniques to make the existing masonry walls stronger and more capable of resisting safely the effect of explosions. Naito et al. [13] discussed push over analysis to assess the performance of structural elements subjected to explosive loading.

Ruth et al. [14] discussed progressive collapse design guidelines and presented that the dynamic multiplication can be increased up to 2 for static analyses for a structure subject to blast loading. Ettouney et al. [15] provided details that improve ductility and structure response characteristics for buildings exposed to extreme blast pressures. Hayes et al. [16]

suggested that strengthening of an RC building to earthquake resistance will improve its resistance to blast and progressive collapse. However, Ma et al. [17] analyzed dynamic responses and damage of RC structures to underground-blasting-induced ground motions. Based on the simulated results of the two-story frame subjected to underground-explosion-induced ground motion, he concluded that (i) assessing concrete damage at the material level can obtain local failure of components; (ii) damage to high frequency excitation spreads over columns and beams and high vibration modes account for distributed concrete damage; (iii) damage assessment methods developed in earthquake engineering based on story drift and ductility ratio cannot effectively describe the distributed damage corresponding to high-mode responses; and (iv) vertical motion should be considered due to the strong vertical motion near field of detonation.

Scientific and technical publications are mainly available for high-energy explosives whereas less data are available for low-energy pyrotechnics. National Fire Protection Agency guidelines of flammable and explosive materials such as NFPA 1124, and NFPA1126 [18 &19] give several information on safety distances and recommendation for the handling of explosives and fireworks products. However the handling and storage design guidelines are neglected. Even the public military guidelines (TM 5-1300 and TM 9-1300-214 [20]) are not really useful for the producers and design engineers when safety of manufacture and large storage of low-energy pyrotechnics in brick masonry structures are considered.

3. PROBLEM DESCRIPTION

In order to suggest a cost effective construction strategy / a structure which can perform satisfactorily against accidental explosions in fireworks manufacturing industries, analytical studies were conducted using ANSYS [21] to study the deflection behaviour of brick masonry strengthened with RCC bands. Figure 1 shows the model structure of size 3.6m (L) x 3.0m (B) x 3.0m (H). Young's modulus of 12 GPa for brick masonry and 200 GPa for composite material, Poisson's ratio of v = 0.2 for brick masonry and 0.25 for composite material was used.

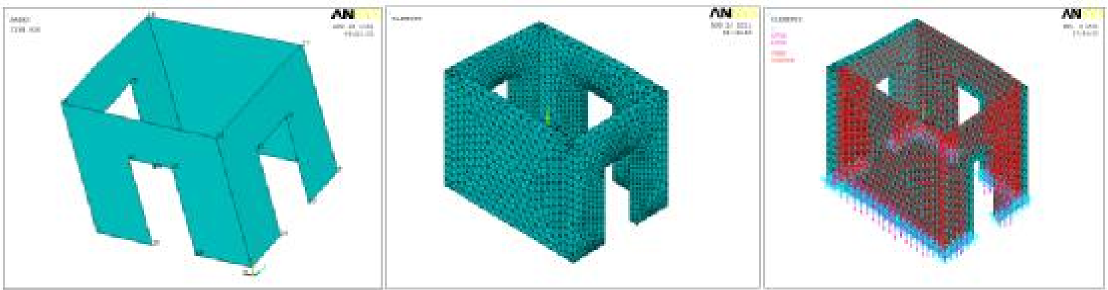

Figure 1. Finite element model showing model, meshing and bottom fixed conditions

Explosive loading of 600kPa was applied as uniform pressure acting normal to the inner wall faces. It was found that all the walls were stressed due to applied loading with severe deformation at door openings with a maximum of 4.263mm at front wall. This result is seen similar with the failure behaviour of experimental model unit as in Figure 2. The values of deflection of walls made of composite material (CM) 230mm, 200mm 150mm and 100mm thick respectively are 0.256mm, 0.324mm, 0.547mm and 1.206mm and given in figure 3.

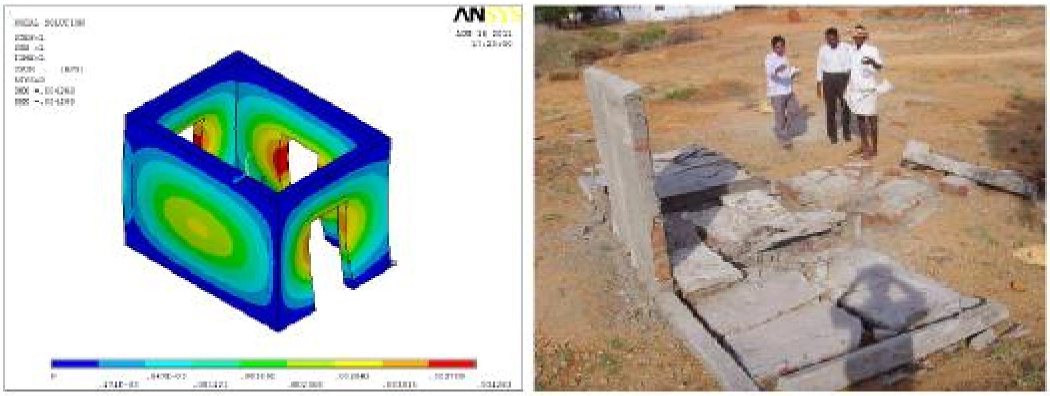

Figure 2. Performance of brick walls – ANSYS model and actual behaviour

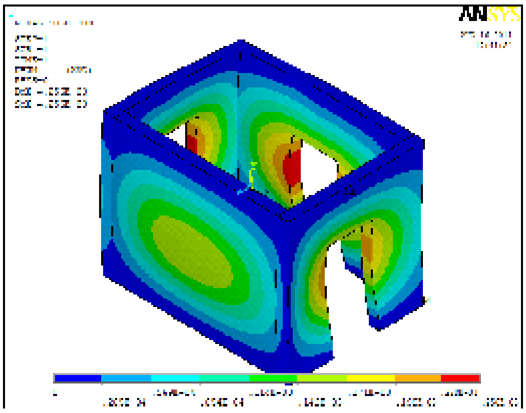

Figure 3(a). CM 230mm thick

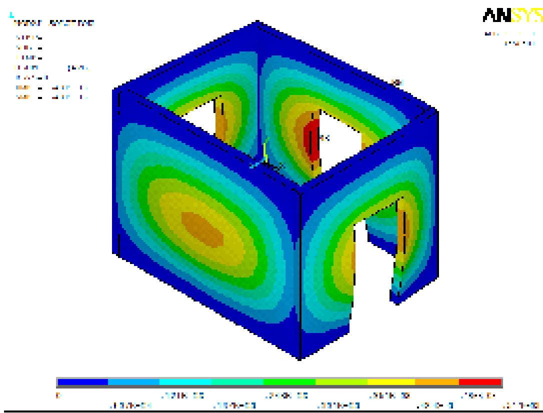

Figure 3(b). CM 150mm thick

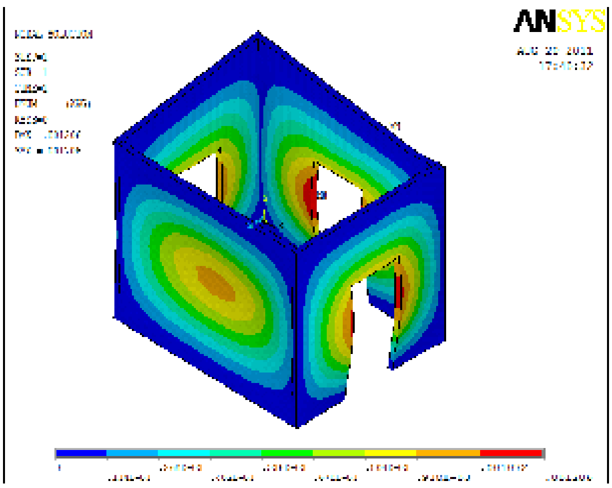

Figure 3(c). CM 100mm thick

If horizontal RCC bands are provided at door sill level and lintel level, it was noticed as in figure 4(a) that maximum distortion occurred only on the front walls and other walls are free from any damage. Introducing 230×230mm RCC columns at all the four corners and 150mm thick lintel alround, the severity of stresses reduced and the maximum deflection occurred at front wall door opening of 8.11mm as seen in figure 4(b). By providing 230mm wide columns at door opening, the deformation was seen severe only at front door column – lintel junction with maximum value of 3.9mm only as in Figure 4(c). Also, by providing 100 or 150mm thick RCC band at plinth level below brick masonry (without bands at door sill level), it was noticed that severe stresses occur only at door opening- lintel junction. Due to the applied pressure, part of the energy is resisted by bands and walls while remaining part of the energy were bounced back, hitting front wall. However, the maximum deflection value is increased to 0.035045 and 0.035061m. This performance is found suitable since only the front wall will get damaged which can be rehabilitated with minimum efforts on time and cost.

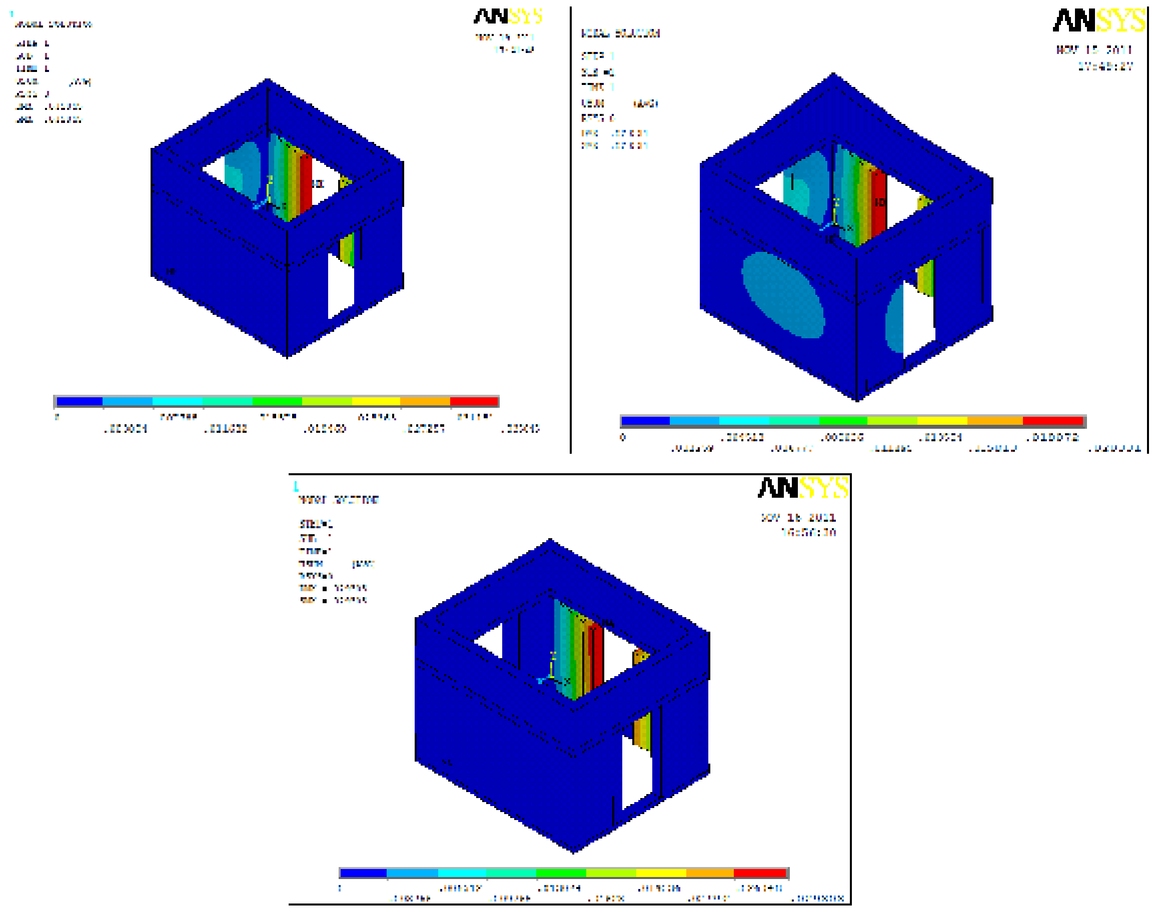

Figure 4. BM (a) without columns (b) 230 mm columns @ corner (c) 230 columns @ door opening

However, by providing RCC columns at corners along with 100mm or 150mm RCC bands alround at plinth level, it was seen that the centre portion of the long wall was also stressed and remaining walls behaved in a similar way. It was observed that RCC column at corner of the room is lesser effective than that provided in door opening. Hence, by providing RCC columns at door opening, we can totally eliminate the possibility of damage of three sides of the wall so that it is easy to repair and rehabilitate the front side wall alone. The comparison of deflection of brick masonry strengthened with RCC bands and columns is given in Figure 5.

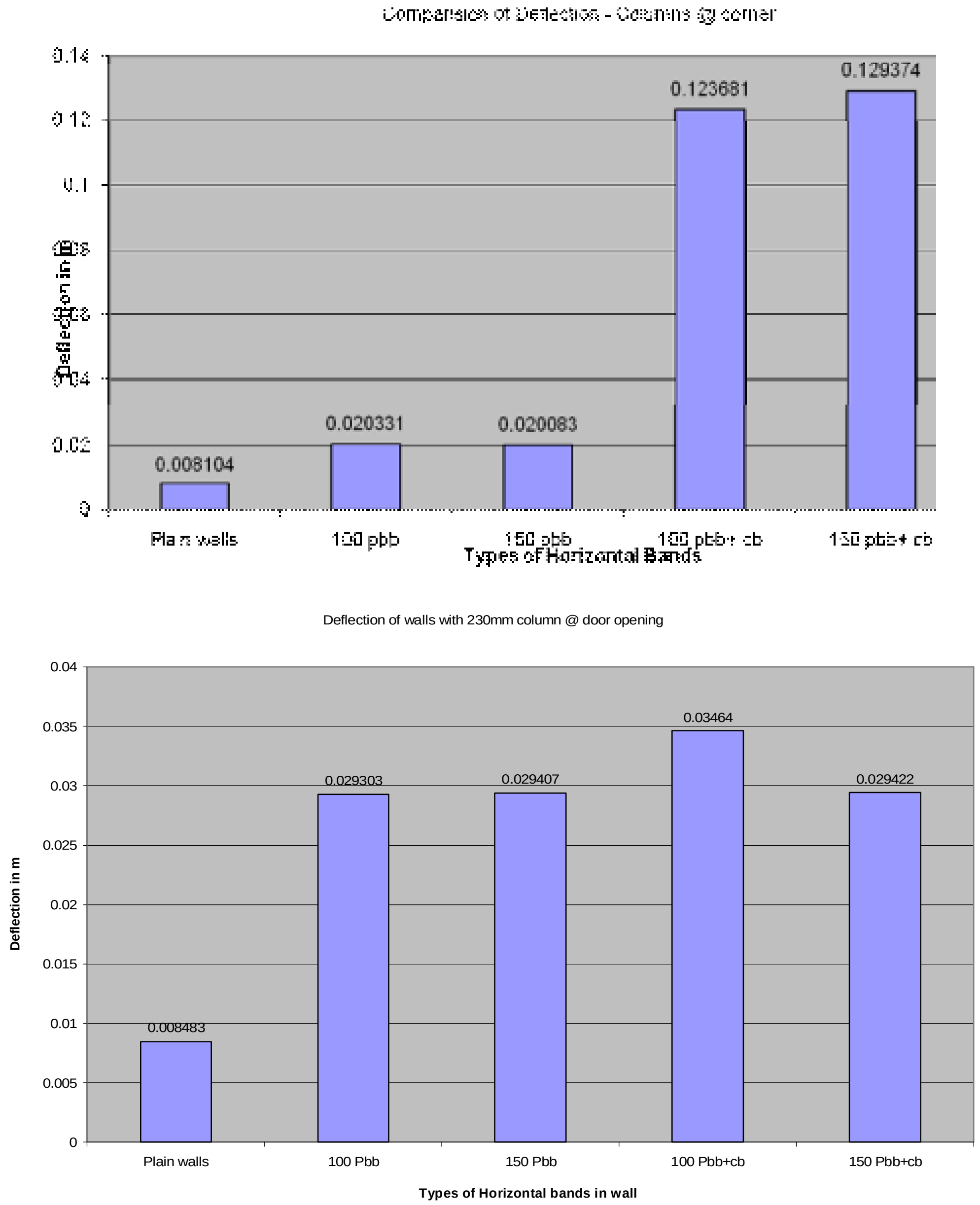

Figure 5. Comparative deflection-RCC bands and columns at (a) corner (b) door opening

Further studies were carried out by providing 100mm thick RCC horizontal bands at mid height between plinth and lintel level. In this case, the bottom portion of the long wall was stressed severely. It is practically difficult to repair this wall and hence this method of construction may not be effective. The summary of analytical studies on brick masonry incorporating RCC vertical and horizontal bands using ANSYS is tabulated in Table 1.

Table 1: Summary of failure behaviour of brick masonry

S.No	Reference	Description	Result	Remarks – location of failure
1a	Plain walls without columns	No column	0.004263	All walls stressed from centre to door opening- lintel junction, more at front wall
1b		BW on 100mm beam	0.014787	Uniform stressing at centre for three walls. Failure at front wall at lintel – Door opening (DO) junction
1c		BW on 150mm beam	0.012306	@ lintel –DO junction in all the openings with severe failure at front wall
1d		BW on 100mm floor beam & lintel alround	0.035045	Failure occurred only on the front wall. Other walls are stressed minimally
1e		BW on 150mm floor beam & lintel alround	0.035061	Failure occurred only on the front wall. Other walls are stressed minimally
2a	Brick walls with columns	230mm columns @ corner	0.008104	All walls stressed from centre to DO - lintel junction, more at front wall
2b		230 column @ Door opening	0.008483	All walls stressed with more stress at front wall at door opening- lintel junction
2c		300 column @ Door opening	0.003986	All walls stressed with more stress at front wall at door opening- lintel junction
3a	RC beam below Brick Masonry	100 pb No column	0.014787	Uniform stressing at centre for three walls. Failure at front wall at lintel – Door opening junction
3b		150 pb No column	0.012306	@ lintel –DO junction in all the openings with severe failure at front wall
4a	100mm plinth beam alround brick masonry	No column	0.035045	Failure occurred only on the front wall. Other walls are stressed minimally
4b		Corner column	0.020331	Uniform failure at centre for three walls. Front wall severely stressed
4c		230 column @ Door opening	0.029303	**Failure occurred only on the front wall. Other walls are not stressed**
5a	150mm plinth beam alround brick masonry	No column	0.035061	Failure occurred only on the front wall. Other walls are stressed minimally
5b		Corner column	0.020083	Uniform failure at centre for three walls. Front wall severely stressed
5c		230 column @ Door opening	0.029407	**Failure occurred only on the front wall.**

5. CONCLUSIONS

The following conclusions can be drawn based on the above research. The deflection behaviour of brick masonry under pyrotechnic explosive loading is more than one tenth of the wall thickness. Conventional brick masonry cannot offer adequate ductility. Hence alternate materials such as ferrocement, fibre reinforced plastics, etc can be considered for the construction of walls in fireworks and match works industries which can also offer adequate ductility and resistance against failure in the event of any accidental explosive loading in these industries. Brick masonry walls strengthened using RCC vertical bands at door opening jambs perform better than that provided at corners. Horizontal RCC bands provided alround at plinth level is most efficient to resist the explosive loading. Horizontal RCC bands provided at mid height of lintel level is neither efficient nor economical to resist the explosive loading. Performance of models made of composite material can resist effectively against deformation. New brick masonry structures for the manufacture of fireworks products can be constructed with 230 x 230mm RCC columns at door opening jambs and 100mm thick RCC bands at plinth level and 150mm thick RCC lintels alround with 100mm thick RCC roofing.

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