Dynamic analysis of fireworks industrial buildings under impulsive loading

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Abstract. 90% of fire crackers are manufactured in firework industries situated in and around sivakasi town of virudhunagar district, Tamiladu. The fire work and match work industries are constructed by clay brick masonry. Where the accidental explosion may occur due to the mishandling of chemicals during manufacturing of fire crackers and is reported regularly. Since the clay brick masonry is brittle in nature, the failure of masonry often leads to flying debris resulting in loss of life/ injury to a large number of people and property. Existing structures are lack in explosion resistance features and hence the structures are needed to be strengthened. Clay brick masonry models with 230mm & 300mm thickness were considered in this study and it is retrofitted with GFRP sheets of 3mm because of its low cost, corrosion resistance, high strain at failure and high tensile strength. This study mainly focuses on the performance of masonry unit retrofitted with GFRP sheets in different blast loading. The static & dynamic analysis were carried out using ANSYS software, The test result indicates that the deformation of a retrofitted unit is 67.8% less as compared to conventional unit.

Keywords: Explosion, Firework industries, Clay brick masonry,GFRP sheet, Strengthening.

1.Introduction
Sivakasi, a quaint little town in Tamil Nadu, is the biggest home to the fireworks industry.90% of India’s fireworks is produced here. The fireworks industry in Sivakasi is worth between Rs.800-1000 crores. The market for fireworks is likely to grow at the rate of 10% per annum. Around 600 fireworks factories giving direct employment to about 40,000 workers and indirect employment to about 1 lakh, almost the entire population of Sivakasi depends on the firework industry[1 , 7, 8]. The fire work and match work industry units are constructed by clay brick masonry. The accidental explosion may occur in these industries due to the mishandling of chemicals during manufacturing of fire crackers. Since the clay brick masonry is brittle in nature, the failure of masonry often leads to the disintegration and fragmentation of walls/roof,shattering of windows resulting in loss of life/ injury to a large number of people and property. During explosion, fragments ejected from the pyro work unit leads to causalities and progressive collapse of the adjacent structure than the explosion happened inside the unit. These leads to loss of continuity in production thereby the livelihood of workers is affected [2, 3, 10, 11].

To avoid the progressive collapse mount wall system ie., a compound wall with 450mm thickness provided all round the each unit in the firework industry. Mount wall system is costlier one and it is not an effective solution to minimize the progressive collapse. Yanchao Shi et al., carried the study on the local damage and fragments of unreinforced masonry walls under close in explosion. Two unreinforced masonry walls were tested under blast loads generated by 1kg and 6Kg of TNT charge separately to investigate the failure mechanism. T.Ngo et al. [6] presents a overview on the effect of explosions, mechanism of blast waves and how to calculate the blast load etc., S.Hashemi Rafsanjani et al., carried out the analysis on the unreinforced brick work masonry walls subjected to low velocity impact and the results obtained are compared with field test data and good agreement is found.Saleh H. Alsayed, et al., studied the performance of the infill masonry walls strengthened with GFRP sheets under terrorist attack. This project aims at studying the effectiveness of using GFRP...
sheet as strengthening material for improving blast resisting of firework units.

2. Materials

2.1 Cement
Cement is the substance which is used in construction that helps to adhere with other materials and to bind them together. According to IS 4031-1988 the specific gravity of cement is 2.92 and consistency of cement is 34%. The initial and final setting time is 35 minutes and 132 minutes.

2.2 Fine aggregate
Fine aggregate is passing through 2.36mm sieve. As per IS 383-1991 the sieve analysis of sand was done and the fineness modulus is 3.42.

2.3 Brick
Brick is the one of the constructing material which is used in masonry construction. Brick is made up of clay-bearing soil, sand, lime or concrete materials and it is produced in numerous class types, materials and sizes which vary with region and time period.

2.4 Glass fibre sheet
Strengthening with Glass fiber reinforced composites is an effective technique due to the high strength-to-weight ratio, easy installation and no significant increasing in mass [9].

3. Experimental programme
Mortar is prepared with dry mix of 1:6 ratio and it is cast in 70.6x70.6x70.6 cube mould. As a result 3.17N/mm² strength is obtained for 7 days and 6.89N/mm² strength is obtained for 28 days. According to IS 3495-1992 the compressive strength of brick is 3.61N/mm². Water absorption for brick is 20% and obtained result is 13.38%. Presence of effloresce is moderate. As per ASTM E 447, the compressive strength of the brick masonry is calculated by creating the brick prisms. The minimum height of brick prism is 380 mm, and also the thickness of the prism is depends upon the h/t ratio. The h/t ratio ought to be between two to five. Our model height is 400 mm and thickness of the prism is 190 mm. Thus the h/t ratio is among the limiting value of 2 to 5. After 28 days of curing the prism are tested and the density, young’s modulus and poisons ratio are 1867 kg/m³, 1.17x10⁴N/mm² and 0.2 obtained for brick masonry for retrofitted brick masonry 1970 kg/m³, 3.4x10⁴N/mm² and 0.25.

4. Problem description:
In firework units, the current practice is: The room size of 3.6m X 3m X 3m is followed with the wall thickness of 230 mm. There are four numbers of exits are provided. For safety concern windows, ventilators and electrical fittings are not provided. Minimum of 15m distance is provided between the each unit [4].

The earlier studies deal with the vehicle driven high energy explosive loading on concrete composite masonry wall buildings, to know the effect of terrorist attack. The amount of work related to the firework unit explosion is very less. Still brick masonries are used to construct the firework/Match work industries. Even the codal provisions deals with the how the units should be arranged, Size of the room etc.[5] not with the strengthening of the firework unit to avoid the progressive collapse due to the pyrotechnical explosion. In this study we are dealing with the strengthening of firework units by using GFRP sheet.

5. Design parameters
As per explosive act 1884 and the explosive rules 2008, the maximum capacity of explosives can be handled is limited to 5 to 12 kg at a time in manufacturing or processing unit [5]. Hence our study is limited to 12 kg. In this study the blast pressure is calculated form the Newmark and Hansen formulae[6], it is applied on the inner side of the masonry unit uniformly. Both static and dynamic analysis was done in this study.
\[ P_\omega = 6784 \frac{W}{R^3} + 93 (W/R^3)^{1/2} \]

As per Newmark and Hansen formulae, the peak over pressure for 2kg, 4kg, 6kg, 8kg, 10kg and 12kg is 0.628N/mm², 1.124N/mm², 1.598N/mm², 2.061N/mm², 2.516N/mm² and 2.967N/mm² respectively. For the numerical simulation of structure, a solid model of 8 node brick element was used and also consider as a homogeneous model. In the analysis the conventional units with 230mm and 300mm wall thickness were named as C and C1. The GFRP strengthened units with 230mm and 300mm wall thickness were named as R and R1. The static and dynamic deflection of conventional and retrofitted units is shown in figure 1.
6. Results & Discussion

The conventional, retrofitted buildings of 230mm and 300mm wall thickness were statically and dynamically analyzed by using the ANSYS Software version 18.2 and the test results are given in table 1, table 2.

Table 1. Deflection of 230mm Wall Thickness

| Pressure in N/mm² | Conventional Building | Retrofitted Building |
|-------------------|-----------------------|----------------------|
|                   | Static Deformation(mm)| Dynamic Deformation(mm) | Static Deformation(mm) | Dynamic Deformation(mm) |
| 0.628             | 8.077                 | 8.467                 | 2.647                 | 3.014                 |
| 1.124             | 14.457                | 15.831                | 4.738                 | 4.995                 |
| 1.598             | 20.554                | 21.906                | 6.732                 | 6.924                 |
| 2.061             | 56.509                | 28.694                | 8.687                 | 9.099                 |
| 2.516             | 32.361                | 33.779                | 10.605                | 11.027                |
| 2.967             | 38.162                | 40.131                | 12.506                | 12.912                |

Table 2. Deflection of 300mm Wall Thickness

| Pressure in N/mm² | Conventional Building | Retrofitted Building |
|-------------------|-----------------------|----------------------|
|                   | Static Deformation(mm)| Dynamic Deformation(mm) | Static Deformation(mm) | Dynamic Deformation(mm) |
| 0.628             | 4.197                 | 4.994                 | 1.371                 | 1.465                 |
| 1.124             | 7.513                 | 8.523                 | 2.467                 | 2.619                 |
| 1.598             | 10.681                | 11.23                 | 3.489                 | 3.625                 |
| 2.061             | 13.776                | 14.275                | 4.499                 | 4.613                 |
| 2.516             | 16.817                | 17.035                | 5.492                 | 5.580                 |
| 2.967             | 19.831                | 20.695                | 6.477                 | 6.638                 |

The deformation results shows that, by increasing the wall thickness the deformation of the masonry is reduced and by increasing the pressure the deformation value is increased.
Figure 2 and 3 shows that, the retrofitted unit with the 2mm GFRP sheet increased the mechanical property of the unit; hence the deformation values are reduced dramatically.

Table 1 shows the deflection for 230mm wall thickness:

- For 0.628N/mm² pressure, conventional building shows 8.077mm and 8.467mm deformation for static and dynamic respectively similarly the retrofitted building shows 2.647mm and 3.014mm deformation for static and dynamic respectively.
- For 1.124N/mm² pressure, conventional building shows 14.457mm and 15.831mm deformation for static and dynamic respectively similarly the retrofitted building shows 4.738mm and 4.995mm deformation for static and dynamic respectively.
- For 1.598N/mm² pressure, conventional building shows 20.554mm and 21.906mm deformation for static and dynamic respectively similarly the retrofitted building shows 6.732mm and 6.924mm deformation for static and dynamic respectively.
- For 2.061N/mm² pressure, conventional building shows 26.509mm and 28.694mm deformation for static and dynamic respectively similarly the retrofitted building shows 8.687mm and 9.099mm deformation for static and dynamic respectively.
- For 2.516N/mm² pressure, conventional building shows 32.361mm and 33.779mm deformation for static and dynamic respectively similarly the retrofitted building shows 10.605mm and 11.027mm deformation for static and dynamic respectively.
- For 2.967N/mm² pressure, conventional building shows 38.162mm and 40.131mm deformation for static and dynamic respectively similarly the retrofitted building shows 12.506mm and 12.912mm deformation for static and dynamic respectively.
Table 4 shows the deflection for 300mm wall thickness

- For 0.628N/mm² pressure, conventional building shows 4.197mm and 4.994mm deformation for static and dynamic respectively similarly the retrofitted building shows 1.371mm and 1.461mm deformation for static and dynamic respectively.
- For 1.124N/mm² pressure, conventional building shows 7.513mm and 8.523mm deformation for static and dynamic respectively similarly the retrofitted building shows 2.467mm and 2.619mm deformation for static and dynamic respectively.
- For 1.598N/mm² pressure, conventional building shows 10.681mm and 11.230mm deformation for static and dynamic respectively similarly the retrofitted building shows 3.489mm and 3.625mm deformation for static and dynamic respectively.
- For 2.061N/mm² pressure, conventional building shows 13.776mm and 14.275mm deformation for static and dynamic respectively similarly the retrofitted building shows 4.499mm and 4.613mm deformation for static and dynamic respectively.
- For 2.516N/mm² pressure, conventional building shows 16.817mm and 17.035mm deformation for static and dynamic respectively similarly the retrofitted building shows 5.492mm and 5.580mm deformation for static and dynamic respectively.
- For 2.967N/mm² pressure, conventional building shows 19.831mm and 20.695mm deformation for static and dynamic respectively similarly the retrofitted building shows 6.477mm and 6.638mm deformation for static and dynamic respectively.

7. CONCLUSION
Finite element studies were conducted on the brick masonry models with the wall thickness of 230mm and 300mm. The deflection behaviour of the conventional and retrofitted masonry unit under blast pressure loading was done in both static and dynamic method. The analytical result shows that the deflection of the masonry unit with 300mm wall thickness is lesser than that of 230mm wall thickness. Hence 300mm wall thickness is preferred than the 230mm wall thickness for the construction of fire work units. The masonry structure strengthened with 2mm GFRP sheet reduces the deformation about 70%. It is an effective solution to minimize the failure of pyrotechnic unit under accidental explosion.

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