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Study on the Response of RC Frames Subjected to Blast Loading

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***Abstract*— Nowadays considerable attention has been given to the behaviour of structures under blast loading. The use of explosives by terrorist groups is becoming a great threat to the society. The analysis and design of structures subjected to blast loads require a detailed understanding of the blast phenomena and the dynamic response of various structural elements. This paper aims on an overview of the effects of blast loading on reinforced concrete frames. The negative phase of the blast wave is usually not taken into consideration as the main structural damage is associated with the positive phase. But the negative phase of the blast wave should be taken into account if the overall structural performance of the structure is assessed and not only its structural integrity. The negative phase can either increase or decrease the deflections. In this paper a comparison and assessment was done to present the differences between the standard blast load model, neglecting the negative phase, and the blast load model, which takes both the positive phase and the negative phase into account. The responses of the frames were studied for two charge weights. The finite element package ANSYS was used to model the RC frames.**

Keywords*— *Blast loading; dynamic loading; negative pressure phase.

I. INTRODUCTION

The use of vehicle bombs to attack city centers has been a feature of campaigns by terrorist organizations around the world. A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. The indirect effects can combine to inhibit or prevent timely evacuation, thereby contributing to additional casualties. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads, of many structures. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements.

II. METHODOLOGY

A. General

The methodology adopted is as follows:

- Design of the RC frame
- Modeling of the RC frame using ANSYS
- Finite element discretization
- Application of loads and boundary conditions
- Analysis of the RC frame using ANSYS
- Results and discussion
- Conclusion

B. Design of the RC Frame

For the purpose of the study, five models were selected viz., three storey-three bay bare frame, three storey-three bay frame with 230 mm thick brick infill wall, with and without openings, and three storey-three bay frame with 115 mm thick brick infill wall, with and without openings. Storey heights and bay widths are considered as 4.0 m and 4.0 m respectively for the frame. The two dimensional RC bare frame, was designed to withstand normal gravity and lateral loads as per IS codes. Design has considered the frame as ordinary moment resisting frame. The RC frame was modeled with reinforcement and appropriate materials for the purpose of analysis. Column and beam sizes are fixed as 300mm×300mm. Longitudinal and lateral reinforcement details of the frame are taken from the design obtained as per IS codes. The reinforcement details are shown in figure 1.

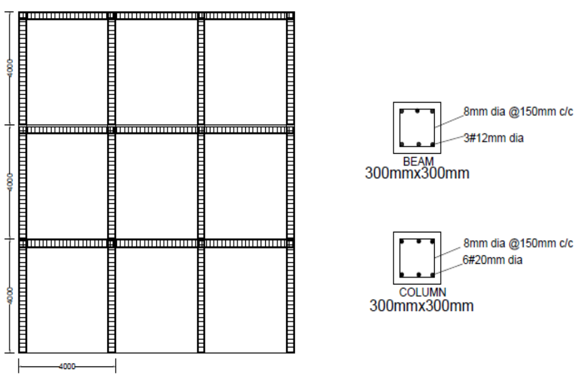

Fig. 1. Reinforcement details of Three storey- Three bay frame

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C. Modeling

Material properties used in the modeling are described in table 1.

TABLE 1 MATERIAL PROPERTIES

Properties	Value
Concrete	
Characteristic compressive strength of concrete beam	30 N/mm^2
Characteristic compressive strength of concrete column	40 N/mm^2
Principle tensile failure stress	3400 kPa
Crack softening fracture energy	104.7J/m^2
Erosion strain	2
Reinforcing steel	
Yield stress	43000kPa
Hardening constant	257000
Hardening exponent	0.26
Plastic strain	0.1
Erosion strain	0.1
Shear modulus	76923000Pa

The models are shown in figures 2, 3, and 4.

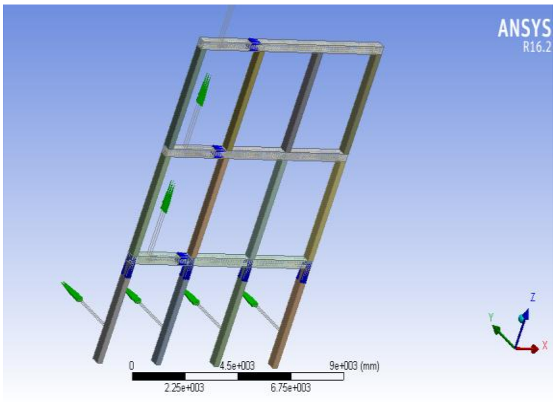

Fig. 2. Three-Storey Three-Bay Bare Frame

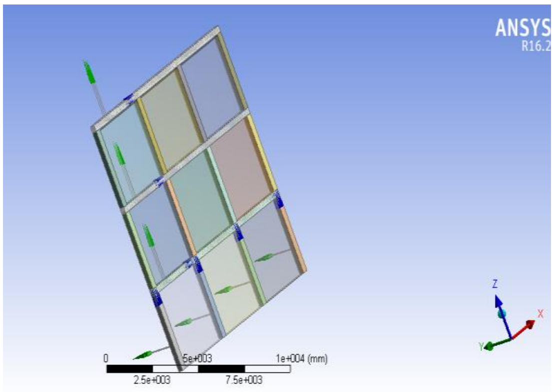

Fig. 3. Three-Storey Three-Bay Frame with brick infill wall

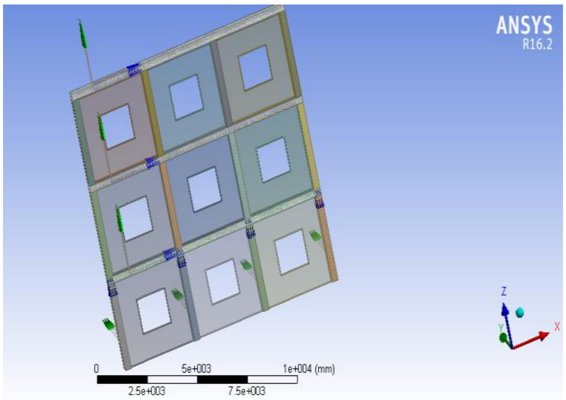

Fig. 4. Three-Storey Three-Bay Frame with infill wall with opening

D. Meshing

To obtain good results, the use of a rectangular mesh is recommended. Therefore, the mesh is set up such that square elements of size 500mm×500mm are created. The overall mesh of the three storey - three bay bare frame created in ANSYS is shown in figure 5.

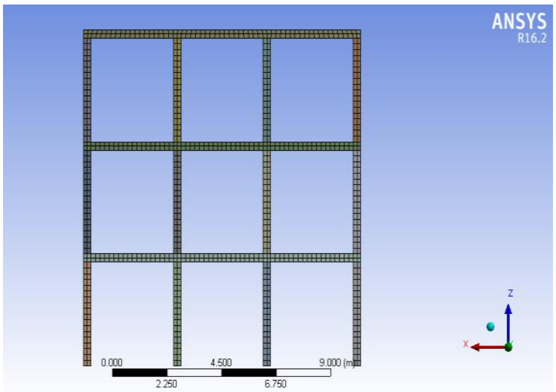

Fig. 5. Meshing of Three-Storey Three-Bay Bare Frame

E. Loads and Boundary Conditions

The TNT load is created in ANSYS autodyn and is exported to ANSYS Workbench and applied on the frames. Flow out boundary condition is applied.

F. Analysis

The five models viz., three storey-three bay bare frame, three storey-three bay frame with 230 mm thick brick infill wall, with and without openings, and three storey-three bay frame with 115 mm thick brick infill wall, with and without openings were analyzed for two blast load cases, 500 kg and 1500 kg TNT charge weight. The analysis is performed with ANSYS. For numerical modeling element size is taken as 500 mm x 500 mm for all the frames.

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III. RESULTS

A. *General*

The various findings of the research are presented. The performance of the frame is studied by giving blast loads. Detailed studies of the results have been conducted and have been graphically presented. Responses are studied for three storey-three bay bare frame, three storey-three bay frame with 230 mm thick brick infill wall, with and without openings, and three storey-three bay frame with 115 mm thick brick infill wall, with and without openings. The linear responses of the frames are studied for two blast load cases i) 10m range, 500Kg TNT charge weight. ii) 10m range, 1500Kg TNT charge weight.

B. *Test Specimen 1: (Three Storey-Three Bay Bare Frame)*

The variation of displacement with time of the three storey-three bay bare frame for 500 kg and 1500 kg charge weights are shown in the figures 6 and 7 respectively.

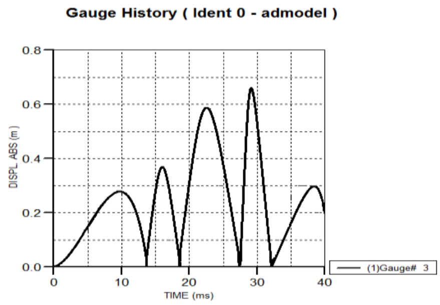

Fig. 6. Displacement- Time variation (three storey- three bay bare frame, 500kg charge weight)

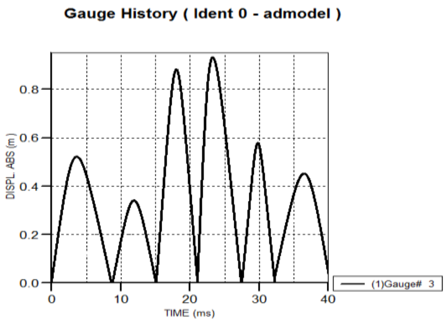

Fig. 7. Displacement- Time variation (three storey- three bay bare frame, 1500kg charge weight)

C. *Test Specimen 2: (Three Storey-Three Bay Frame with 230 mm Thick Infill Wall)*

The variation of displacement with time of the three storey-three bay frame with 230 mm thick infill wall for 500 kg and 1500 kg charge weights are shown in the figures 8 and 9 respectively.

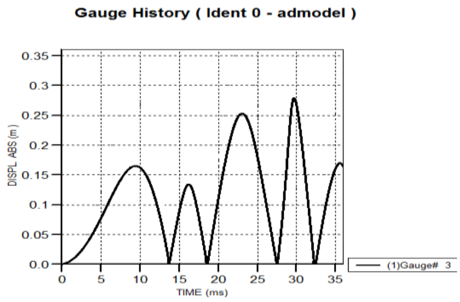

Fig. 8. Displacement- Time variation (three storey- three bay frame with 230 mm thick infill wall, 500kg charge weight)

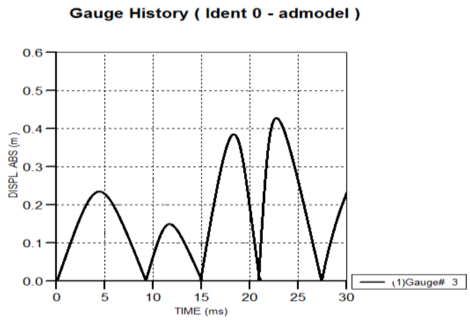

Fig. 9. Displacement- Time variation (three storey- three bay frame with 230 mm thick infill wall, 1500kg charge weight)

D. *Test Specimen 3: (Three Storey-Three Bay Frame with 230 mm Thick Infill Wall with Openings)*

The variation of displacement with time of the three storey-three bay frame with 230 mm thick infill wall with opening for 500 kg and 1500 kg charge weights are shown in the figures 10 and 11 respectively.

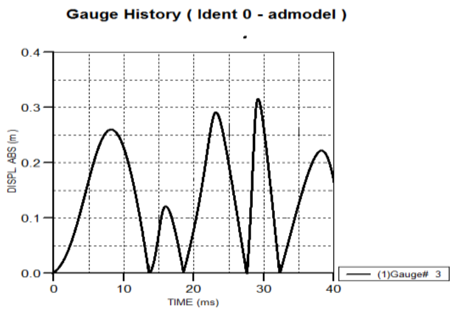

Fig. 10. Displacement- Time variation (three storey- three bay frame with 230 mm thick infill wall with opening, 500kg charge weight)

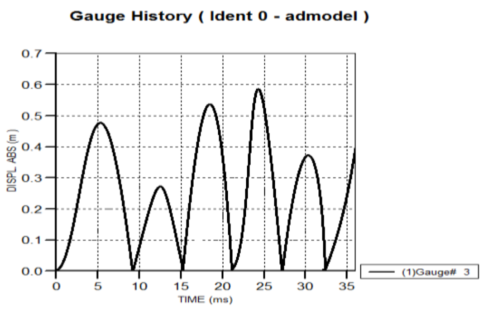

Fig. 11. Displacement- Time variation (three storey- three bay frame with 230 mm thick infill wall with opening, 1500kg charge weight)

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E. Test Specimen 4: (Three Storey-Three Bay Frame with 115 mm Thick Infill Wall)

The variation of displacement with time of the three storey-three bay frame with 115 mm thick infill wall for 500 kg and 1500 kg charge weights are shown in the figures 12 and 13 respectively.

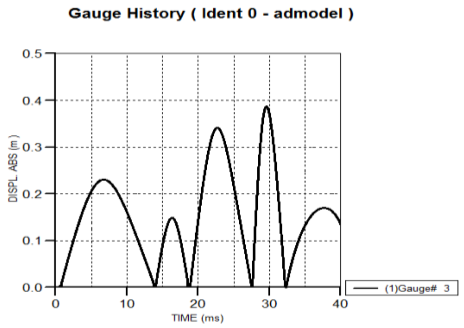

Fig. 12. Displacement- Time variation (three storey- three bay frame with 115 mm thick infill wall, 500kg charge weight)

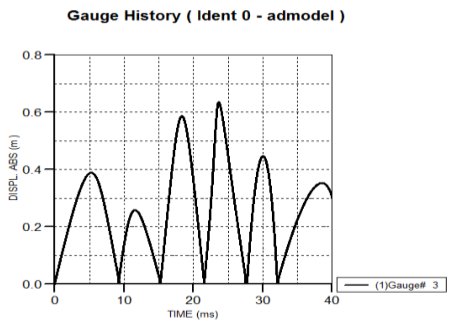

Fig. 13. Displacement- Time variation (three storey- three bay frame with 115 mm thick infill wall, 1500kg charge weight)

F. Test Specimen 5: (Three Storey-Three Bay Frame with 115 mm Thick Infill Wall with Openings)

The variation of displacement with time of the three storey-three bay frame with 115 mm thick infill wall with opening for 500 kg and 1500 kg charge weights are shown in the figures 14 and 15 respectively.

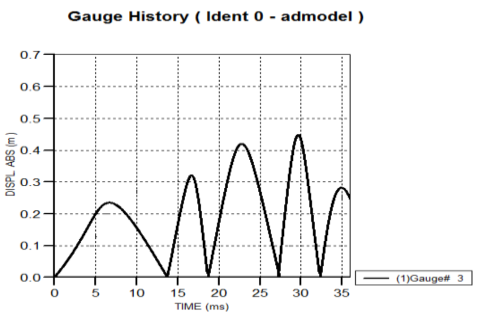

Fig. 14. Displacement- Time variation (three storey- three bay frame with 115 mm thick infill wall with opening, 500kg charge weight)

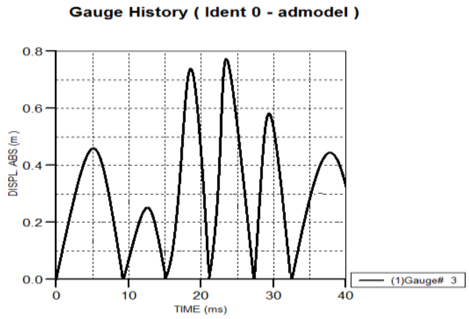

Fig. 15. Displacement- Time variation (three storey- three bay frame with 115 mm thick infill wall with opening, 1500kg charge weight)

IV. DISCUSSION

A comparison between the blast load model which takes the positive phase alone and the blast load model which takes both the positive phase and the negative phase into account is done for 500 kg and 500 kg charge weight and the findings are tabulated in table 2 and table 3 respectively.

The positive and negative phase end time for 500 kg charge weight is 23 ms and 28 ms respectively and that for 1500 kg charge weight is 18 ms and 24 ms respectively. The maximum displacement considering only the positive phase and considering both the positive and negative phase for the three storey-three bay bare frame, three storey-three bay frame with 230 mm and 115 mm thick infill wall, and three storey-three bay frame with 230 mm and 115 mm thick infill wall, with openings are shown in the table.

TABLE 2 Comparison Between The Blast Load Model Which Takes Only The Positive Phase Into Consideration And The Blast Load Model Which Takes Both The Positive And Negative Phase Into Account For 500 Kg Charge Weight

Model	Bare frame	With 230 mm thick infill wall	With 230 mm thick infill wall with openings	With 115 mm thick infill wall	With 115 mm thick infill wall with openings
Maximum displacement considering positive phase alone (mm)	590	250	290	350	420
Maximum displacement considering both positive and negative phase (mm)	660	275	310	390	450

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TABLE 3 Comparison Between The Blast Load Model Which Takes Only The Positive Phase Into Consideration And The Blast Load Model Which Takes Both The Positive And Negative Phase Into Account For 1500 Kg Charge Weight

Model	Bare frame	With 230 mm thick infill wall	With 230 mm thick infill wall with openings	With 115 mm thick infill wall	With 115 mm thick infill wall with openings
Maximum displacement considering positive phase alone (mm)	910	390	540	590	740
Maximum displacement considering both positive and negative phase (mm)	980	420	590	630	780

The variation of displacement with time for all the frames for 500 kg and 1500 kg charge weights is graphically represented in figures 16 and 17 respectively.

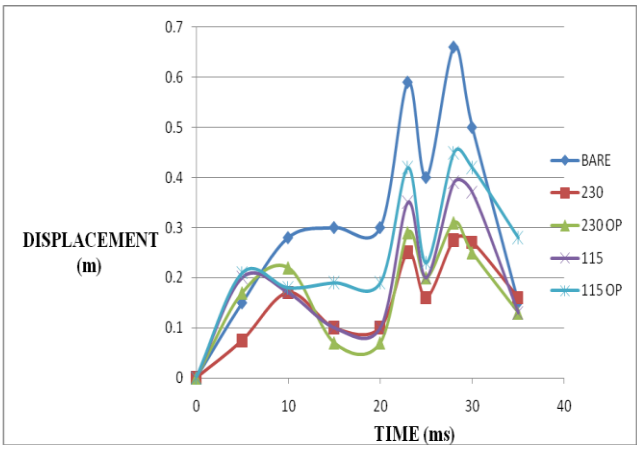

Fig. 16. Displacement-Time Variation for 500 kg charge weight

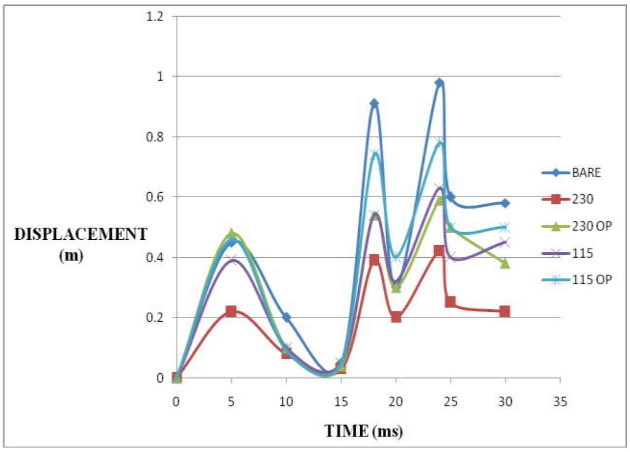

Fig. 17. Displacement-Time Variation for 1500 kg charge weight

From the graphs it is clear that the maximum displacement is obtained for the three storey-three bay bare frame and the minimum displacement is for the three storey-three bay frame with 230 mm thick infill wall without opening.

V. CONCLUSIONS

- Deflection of all the frames increases while considering both the positive and the negative phase of the blast load wave compared to the deflection of the frames considering only the positive phase
- Deflection of the three storey-three bay bare frame is about 2.4 times that of the three storey-three bay frame with 230 mm thick infill wall without opening and 1.9 times that of the three storey-three bay frame with 230 mm thick infill wall with opening
- Deflection of the three storey-three bay bare frame is about 2.1 times that of the three storey-three bay frame with 115 mm thick infill wall without opening and 1.35 times that of the three storey-three bay frame with 115 mm thick infill wall with opening
- Deflection of the three storey-three bay frame with 230 mm thick infill wall with opening is about 1.3 times that of the three storey-three bay frame with 230 mm thick infill wall without opening
- Deflection of the three storey-three bay frame with 115 mm thick infill wall with opening is about 1.2 times that of the three storey-three bay frame with 115 mm thick infill wall without opening
- Deflection of the three storey-three bay frame with 115 mm thick infill wall without opening is about 1.5 times that of the three storey-three bay frame with 230 mm thick infill wall without opening
- Deflection of the three storey-three bay frame with 115 mm thick infill wall with opening is about 1.4 times that of the three storey-three bay frame with 230 mm thick infill wall with opening

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