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Numerical Evaluation of Dry-Stacked Masonry Walls Against Blast Loading

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ABSTRACT. *This research intends to numerically study the out-of-plane behaviour of confined dry-stacked masonry (CDSM) walls against blast loading. CDSM is a mortar-less interlocking masonry system consisting of Interlocking Compressed Earth Block (ICEB) laid in stretcher bond with reinforced concrete (RC) confining elements. A nonlinear numerical model is developed using advanced finite element software ABAQUS to study the response of CDSM walls subjected to explosive loads of 8 kgs Trinitrotoluene (TNT). The blast load was detonated at 2m from the walls of confined masonry at a height of 1m above ground. The resulting damage distribution and displacement time history were compared for two walls with different reinforcement. This study helps to visualize the effect of diagonal reinforcement along with the performance of CDSM walls against blast loading using ABAQUS. The results shows less damage for diagonally reinforced wall.*

Keywords: Masonry, FEM, ICEB, Reinforcement, Trinitrotoluene,Diagonal

1. INTRODUCTION

Buildings during the period of their functioning lives are sometimes exposed to a number of dynamic loadings which includes earthquakes, explosions, collisions, and wind loads. Recent example is blast attack in Peshawar at a mosque. Therefore, buildings must be sufficiently strong enough to withstand the damage caused by these explosions. A new mortar less interlocking block masonry method, also known as dry stack masonry, has been used in modern practices in addition to traditional brickwork. This masonry system is known as a CDSM system if it is confined by reinforced concrete (RC) beams and columns. The performance of masonry walls is crucial for building structural integrity. Due to the multiple input characteristics, limited financial resources, time limits, and safety issues, studying the effects of blast load on buildings experimentally is extremely difficult. As a result, the best option for such costly tests is to use efficient computer software and codes such as ABAQUS. The numerical modelling of CDSM walls is complex and computationally expensive. The analysis complexity reasons are modelling of the nonlinear behaviour of an RC confining frame, modelling of the nonlinear behaviour of a dry-stacked masonry panel, and modelling the interaction between frame and masonry [1]. In this research, we numerically simulated the dry stack masonry walls with confining elements using ABAQUS. Modelling was done by considering the friction between blocks units along with consideration to nonlinear behaviour of RC confining frame and dry-stacked masonry panel with appropriate interaction between frame and masonry. The damage distribution and deformed shape of two confined masonry structures, Wall-1 with-out diagonal reinforcement and Wall-2 with diagonal reinforcement, were analyzed using numerical modeling tools.

2. MATERIALS AND METHODS

2.1. Confined Effects Concrete With Strain Rate

Concrete is modeled with well-known concrete damaged plasticity model [2] where Table 1 provides the material properties used for concrete behaviour modelling. The strain rate of 1 s^{-1} [3] is used assuming dynamic increase factor (DIF) values of 2 and 6 for compression and tension damage, respectively [4].

Table-1: Non-linear properties of concrete

Properties	Compressive strength (*fc'*)	Tensile strength (*ft*)	Poisson's ratio	density
variables	45.2 MPa	3.2MPa	0.19	2230 m^3

2.2. Steel Constitutive Model

For the present study, the DIF of 1.2 was adopted from the previous research [5] and material properties of steel are provided in table 2.

Table-2: Material properties of steel

Loading Condition	**Static load**	**Blast Load**
Yield strength	414 MPa	475 MPa
density	7869 kg/m^3	7869 kg/m^3
Tensile strength	620 MPa	751 MPa
Young's modulus	$2*10^5$ MPa	$2*10^5$ MPa
Poisson's ratio	0.3	0.3
Elongation	18%	35%

2.3. Geometry And Model Parameters

This study considered two numerical models for the analysis. The cross-sectional dimensions of the beam and the column in these models were taken as 216 mm×240 mm and 216 mm×216 mm, respectively. The Interlocking Hydro Form Dry Brick Masonry wall-1 (IHDBMW-1) was design with the longitudinal steel ratio of 0.04 times of gross area of the beam cross-section with #3 (10mm) stirrups at 9'' (230mm) c/c spacing in the middle portion of beam. The spacing of stirrups from joints to distance *2d* was reduced to 102 mm for increased shear strength. The longitudinal steel ratio of 0.038Ag (gross area of the column cross-section) with #3 (10mm) ties at 9'' (230mm) c/c spacing were used in the middle portion of column while stirrups were placed at 102 mm spacing near joints. Four longitudinal reinforcement bars of #4 (13mm) size were used in beam and column of the confine masonry structure without any splice. Tooting was provided between the masonry and confining elements. The wall IHDBMW-2 was the replica of IHDBMW-1, with the addition of 2-#3 (10 mm) diagonal steel bars at the beam-column joints of confining elements. Table summaries both these models with reinforcement detailing schemes used in this study.

Table-3: Description of two walls

Model	**Name**	**Description**
M1	IHDBMW-1	Control specimen of Interlocking Hydro Form Dry Brick Masonry wall-1
M2	IHDBMW-2	Addition of the 2-#3 (10mm) diagonal reinforcement at beam column joints in IHDBMW-1

The geometry of the confined masonry structural components was created as deformable solid body. The bottom surface was assigned with the fixed boundary conditions. The elements of concrete and steel were discretized for FEM using 3-Dimensional wire elements for reinforcement and 3-Dimensional solid elements for concrete components. The details of FEM masonry structure are shown in Figure 1.

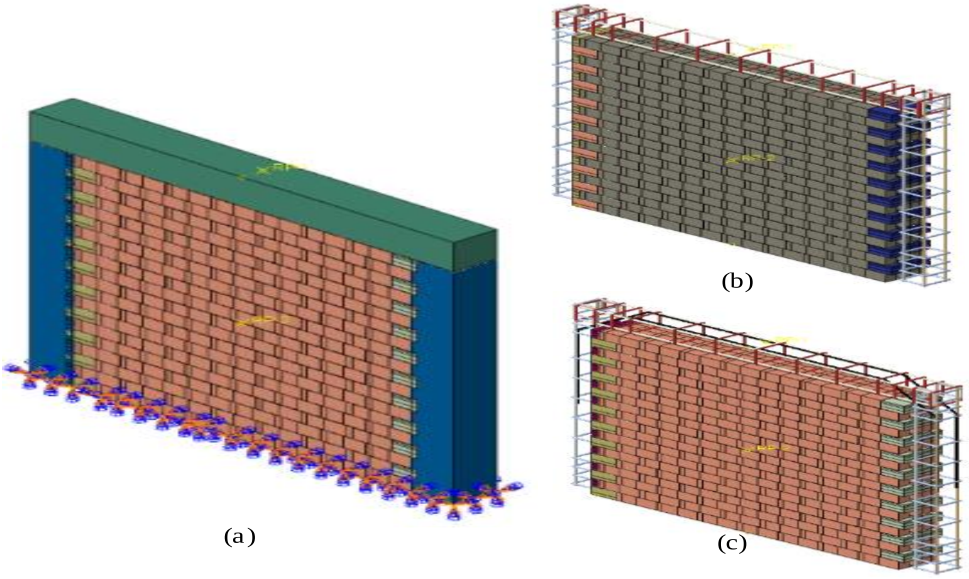


Fig-1: Details of FEM of Interlocking Hydro Form Dry Brick Masonry Wall (a) Model geometry with constraints (b) IHDBMW-1 (c) IHDBMW-2

3. RESULTS

The influence of blast loading on two walls with different reinforcement detailing was investigated using both models in table 3. The source of TNT is placed at the hight of 1m from the base of the wall and 2 m away from the centre of the wall. These models were subjected to a blast load of 8 kgs of TNT. The models suffer significant damage at this load of TNT. The damage distribution of these walls is provided in figure 2. From the figure, it can be observed that the damage in the specimen M1 is maximum. When additional diagonal reinforcement was introduced in the structure at joint, damage redistribution and decrease was observed. Furthermore, the deformation behaviour of walls under blast loading is compared in figure 3. The diagonal reinforcement in wall-2 limited the deformations in wall-2 and it showed the relatively rigid behaviour than wall 1. Moreover, the displacement time history of both walls at the location of maximum deformation is compared in figure 4. The results exhibited that the overall displacements in wall-1 could be reduced due to the provision of diagonal reinforcement.

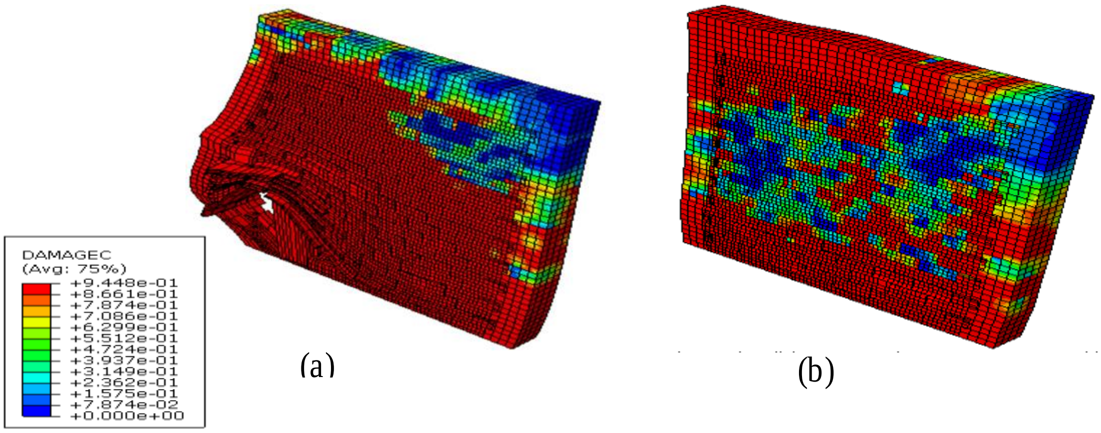
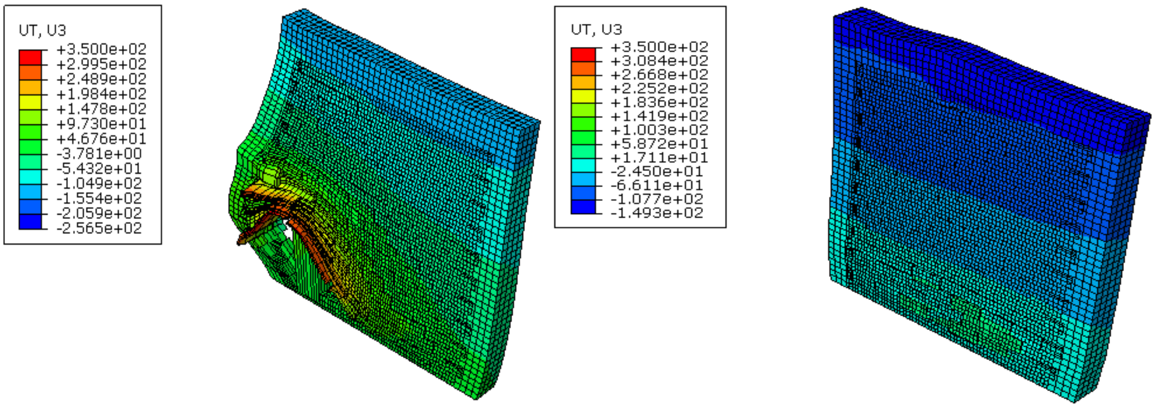


Fig-2: Damage distribution on walls (a) damage in IHDBMW-1 (b) damage in IHDBMW-2



(a) **(b)**

Fig-3: Deformation in walls (a) IHDBMW-1 (b) IHDBMW-2

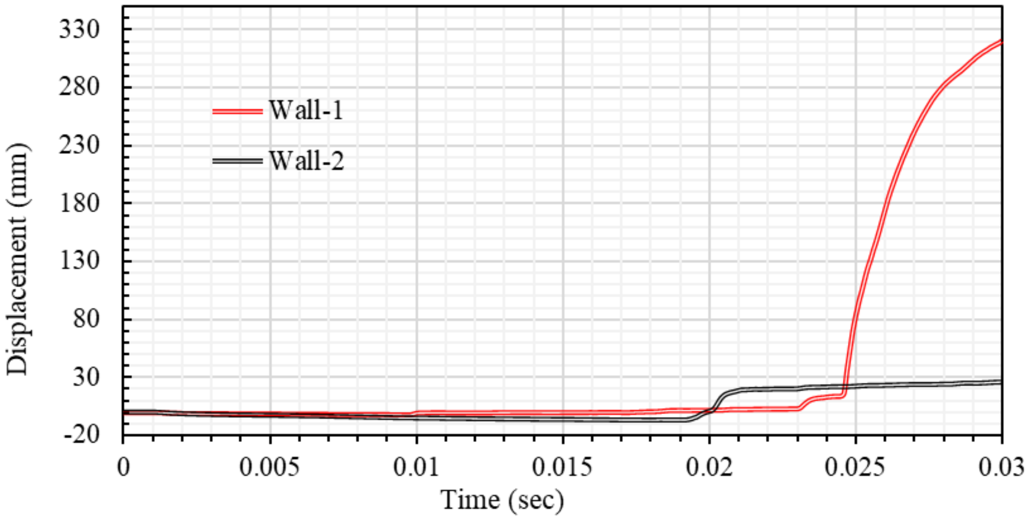


Fig-4: Displacement of the walls under blast loading at the location of maximum deformation

4. CONCLUSIONS

In the present study, the damage distribution and deformed shape of CDSM walls, Wall-1 and Wall-2, were analyzed using numerical modeling tools. Wall-1 was constructed without diagonal reinforcement, while Wall-2 was constructed with diagonal reinforcement. The results of the analysis were used to evaluate the effectiveness of diagonal reinforcement in reducing damage and improving the overall stability of confined masonry structures. The damage distribution of Wall-1 and 2 was obtained and the deformed shape was analyzed.

- Wall-2 exhibited less displacement compared to Wall-1 making diagonal reinforcement a viable design approach.
- The results suggest that the use of diagonal reinforcement in confined masonry structures can effectively redistribute stresses under loading and reduce damage, thus improving the overall stability of the structure.
- For walls and buildings open to blast events the confinement detailing of IHDBMW-2 is recommended for enhanced structural performance.

Further studies can be conducted to investigate the behavior of confined masonry structures with different types and configurations of diagonal reinforcement. The research can be extended to analyze the effect of different loading scenarios and boundary conditions on the behavior of confined masonry structures with diagonal reinforcement. The methodology used in this study can be applied to real-world confined masonry structures to evaluate their current state and predict their behavior under different loading conditions.

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