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Comparative Displacement Analysis of Laced Reinforced Concrete and Conventional Reinforced Concrete Slabs under TNT Blast Loading using ABAQUS

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Abstract:

Blast loading is one of the most severe dynamic loading conditions affecting structural systems, particularly in defence and high-risk infrastructure. Conventional reinforced concrete (RC) slabs exhibit brittle behaviour and excessive deformation under such extreme conditions. This study investigates the displacement behaviour of Laced Reinforced Concrete (LRC) slabs compared to conventional RC slabs using finite element analysis in ABAQUS/Explicit. A three-dimensional model of slabs (1200 mm × 1200 mm × 150 mm) is developed and subjected to TNT blast loading of 0.55 kg at a standoff distance of 0.4 m. The Concrete Damage Plasticity (CDP) model is used to simulate nonlinear behaviour. Results indicate that LRC slabs significantly reduce displacement due to improved confinement, enhanced stiffness, and better energy dissipation. The study demonstrates that LRC systems offer superior blast resistance compared to conventional RC slabs

Keywords: Laced Reinforced Concrete, Blast Loading, ABAQUS Explicit, CDP Model, Displacement Behaviour, Energy Absorption.

1.INTRODUCTION

Structural safety under extreme loading conditions has become an important consideration in modern civil engineering design. In recent decades, several accidental explosions and intentional blast incidents have caused severe damage to buildings, bridges, transportation infrastructure, and industrial facilities. Blast loads differ significantly from conventional static loads due to their very high intensity and extremely short duration. The sudden release of energy during explosion produces shock waves that propagate rapidly through air and interact with structural surfaces, generating high pressure impulses. When blast waves impact reinforced concrete structures, complex dynamic response occurs involving stress wave propagation, crack formation, concrete crushing, reinforcement yielding, and large deformation. Conventional reinforced concrete structures are designed primarily to resist gravity loads, wind loads, and seismic loads. However, their performance under blast loading conditions is often inadequate due to limited ductility and insufficient energy absorption capacity. To improve structural performance under dynamic loads, researchers have introduced various reinforcement techniques such as fiber reinforced polymer composites, steel plate strengthening, layered concrete systems, and hybrid reinforcement configurations. Among these techniques, Laced Reinforced Concrete (LRC) has shown promising potential due to its ability to enhance confinement and improve interaction between

reinforcement layers. Laced reinforcement consists of diagonal steel bars placed between longitudinal reinforcement meshes, forming an internal truss mechanism that improves stiffness and load transfer efficiency. This arrangement helps in distributing stresses more uniformly and reduces stress concentration in localized regions. The presence of lacing bars also improves crack control and delays failure progression. The present study aims to evaluate the effectiveness of Laced Reinforced Concrete slab in resisting blast induced displacement compared to conventional RC slab using finite element modelling approach. ABAQUS explicit dynamic solver is used to simulate blast loading conditions and capture nonlinear material behaviour.

Objectives of the study include:

- To develop numerical models of conventional RC slab and LRC slab
- To apply TNT blast loading using CONWEP blast function
- To evaluate displacement behaviour under identical loading conditions
- To compare structural performance of LRC and conventional RC

2. LITERATURE REVIEW

The response of reinforced concrete (RC) slabs under blast loading has been widely investigated due to the increasing demand for blast-resistant structural design. Blast loads are characterized by high peak pressures and short durations, resulting in complex behaviour involving stress wave propagation, strain-rate effects, nonlinear material response, and damage mechanisms such as cracking, spalling, and crushing (Lu et al., 2014). Conventional RC slabs exhibit limited resistance under such extreme loading conditions. Numerical and experimental studies have shown that blast loading leads to severe localized damage and excessive displacement, particularly under close-in explosions (Draganić et al., 2025). Increasing slab thickness and reinforcement ratio improves stiffness and reduces deformation; however, conventional RC systems still tend to exhibit brittle behaviour with limited energy absorption capacity (Yao et al., 2018). Furthermore, the presence of pre-existing cracks accelerates stiffness degradation and increases displacement, emphasizing the importance of crack control mechanisms (Zhang et al., 2018). To enhance structural performance, advanced materials and reinforcement techniques have been explored. Fibre-reinforced composites improve tensile strength and crack resistance, resulting in reduced displacement under blast loading (Lee et al., 2023). Similarly, modified reinforcement configurations enhance energy dissipation capacity and reduce stress concentration by improving load transfer mechanisms within the structural system (Jin et al., 2020). Laced Reinforced Concrete (LRC) has emerged as an effective reinforcement system for improving structural behaviour. In LRC, diagonal lacing bars connect longitudinal reinforcement layers, forming a truss-like mechanism that enhances confinement, stiffness, and stress redistribution. Studies have shown that laced reinforcement improves ductility, energy absorption capacity, and crack resistance compared to conventional RC systems (Silva et al., 2019). Finite element modelling using ABAQUS is widely adopted for analysing RC structures under blast loading. The Concrete Damage Plasticity (CDP) model effectively simulates nonlinear concrete behaviour, while the CONWEP model is commonly used for blast load representation. Despite these advancements, limited research has focused on the displacement behaviour of LRC slabs under blast loading. Therefore, this study aims to evaluate and compare the displacement response of LRC and conventional RC slabs using numerical simulation.

3. METHODOLOGY

3.1 Finite Element Modelling Approach

Finite element modelling provides an efficient numerical approach to simulate structural response under complex loading conditions. ABAQUS explicit solver is used to analyse dynamic response of reinforced concrete slabs subjected to blast loading. Explicit analysis is preferred for high strain-rate problems due to its ability to capture transient effects and nonlinear material behaviour.

3.2 Geometry Details

The slab considered in the present study has dimensions 1200 mm length, 1200 mm width, and 150 mm thickness. Two different reinforcement configurations are considered:

1. Conventional Reinforced Concrete slab
2. Laced Reinforced Concrete slab

Both slabs are modelled with identical geometry to ensure accurate comparison of displacement behaviour.

3.3 Reinforcement Configuration

In conventional RC slab, reinforcement bars of diameter 12 mm are provided in orthogonal directions at spacing of 90 mm centre to center. Reinforcement is placed at top and bottom layers to resist tensile stresses.

In LRC slab, double reinforcement mesh layers are connected using diagonal lacing bars arranged in zigzag pattern. The lacing reinforcement improves stiffness and enhances load transfer between reinforcement layers.

3.4 Material Properties

Concrete material is defined using Concrete Damage Plasticity model available in ABAQUS material library. The model considers both compressive crushing and tensile cracking behaviour of concrete.

Material properties include:

Concrete Properties:

- Density = 2400 kg/m³
- Young's modulus = 35355 MPa
- Poisson's ratio = 0.2
- Compressive strength = 40 MPa
- Tensile strength = 3.5 MPa

Steel Properties:

- Density = 7850 kg/m³
- Young's modulus = 200000 MPa
- Yield strength = 500 MPa

Concrete Damage Plasticity parameters are defined to simulate stiffness degradation under cyclic loading.

3.5 Blast Load Definition

Blast loading is applied using CONWEP blast function available in ABAQUS. TNT explosive charge of mass 0.55 kg is considered. The explosive is placed above the slab surface at stand-off distance of 0.4 m from reference point located at centre of slab.

Blast pressure variation with time is calculated using empirical equations based on Hopkinson scaling law. The pressure-time curve consists of rapid increase in pressure followed by exponential decay.

3.6 Meshing Technique

Concrete slab is discretized using C3D8R solid elements with reduced integration technique. Reinforcement bars are modelled using truss elements embedded inside concrete elements.

Mesh convergence study is performed to ensure accuracy of results. Finer mesh is used near centre region where maximum stress concentration occurs.

3.7 Boundary Conditions

All edges of slab are assigned fixed boundary conditions to simulate realistic support condition. Constraints are applied to restrict translational and rotational degrees of freedom.

3.8 Analysis Procedure

Explicit dynamic step is defined with small time increment to capture blast wave propagation effects. Output parameters include displacement, stress distribution, strain energy, and damage contours.

4. RESULTS AND DISCUSSION

Finite element simulation results show significant difference in displacement behaviour between conventional reinforced concrete slab and Laced Reinforced Concrete slab. The conventional RC slab shows higher deformation due to limited confinement and stress redistribution capability. Maximum displacement observed in conventional RC slab is approximately 5.283 mm at centre of slab. LRC slab shows significantly reduced displacement of approximately 1.371 mm due to presence of diagonal lacing reinforcement. Lacing bars improve stiffness and provide additional load path for stress transfer. The percentage reduction in displacement is significant, indicating improved structural resistance against blast loading.

5. CONCLUSION

The study presents comparative displacement analysis of conventional Reinforced Concrete slab and Laced Reinforced Concrete slab subjected to TNT blast loading using ABAQUS explicit dynamic solver.

Results indicate that Laced Reinforced Concrete slab performs better than conventional RC slab under identical blast loading conditions.

Major conclusions include:

- LRC slab shows significantly lower displacement than conventional RC slab
- diagonal lacing reinforcement improves confinement of concrete
- stress distribution is more uniform in LRC slab
- energy absorption capacity is higher in LRC slab
- LRC slab demonstrates improved blast resistance
- ABAQUS explicit analysis effectively simulates blast loading conditions

The study confirms that Laced Reinforced Concrete system can be effectively used in design of blast resistant structures such as defence buildings, bunkers, industrial structures, and high-risk infrastructure.

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