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Assessment of Blast-Induced Damage in ReinforcedConcrete Slabs: A Comparative Study between NumericalSimulation and Advanced Structural Analysis Software

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Abstract: This research paper presents a comparative study on the assessment of blast-induced damage in reinforced concrete slabs, focusing on the comparison between numerical simulation and advanced structural analysis software. The objective is to evaluate the accuracy and reliability of both approaches in predicting structural damage caused by blast loading. The study utilizes numerical simulation techniques to model the dynamic behaviour of reinforced concrete slabs subjected to blast loading. Material properties, reinforcement details, and blast loading characteristics are incorporated into the simulations. The resulting structural response and damage are evaluated. In parallel, advanced structural analysis software, specifically MIDAS Civil software selected for its capabilities in blast analysis, is employed to analyse the same set of reinforced concrete slabs under blast loading. The software provides advanced modelling and analysis tools for assessing structural response and calculating blast-induced damage. By comparing the results obtained from the numerical simulations and the advanced structural analysis software, the study evaluates the agreement and capabilities of both approaches. Parameters such as displacements, strains, stress distributions, and damage patterns are examined. The findings contribute to the understanding of the accuracy and limitations of numerical simulation and advanced structural analysis software for blast-induced damage assessment. The results of this comparative study provide valuable insights for practitioners and researchers in blast engineering and structural assessment. The implications for blast-resistant design and recommendations for future research are discussed, aiding in the advancement of effective strategies for assessing and mitigating blast-induced damage in reinforced concrete structures.

Keywords: Blast Analysis, Dynamic Linear Analysis, Response Spectrum Analysis, Prestressed Concrete.

INTRODUCTION

Reinforced concrete structures are widely utilized in various industries, including infrastructure and building construction, due to their inherent strength and durability. However, these structures face potential threats from extreme events such as blast loading, which can result in significant structural damage and compromise their integrity. Assessing the blast-induced damage accurately is crucial for ensuring the safety and resilience of reinforced concrete slabs. Numerical simulation has emerged as an effective tool for studying the dynamic behaviour of structures under blast loading conditions. Additionally, advanced structural analysis software, such as MIDAS, offers sophisticated capabilities for analysing and evaluating structural responses. This research paper presents a comparative study that aims to assess the blast-induced damage in reinforced concrete slabs by comparing the results obtained from numerical simulation and MIDAS software analysis. The primary objective is to evaluate the accuracy and reliability of both approaches in predicting and quantifying the structural damage caused by blast loading. The research methodology entails conducting numerical simulations of reinforced concrete slabs subjected to blast loading conditions. The simulations incorporate factors such as material properties, reinforcement details, blast loading characteristics, and boundary conditions. Through these simulations, the dynamic response and resulting structural damage are evaluated. Furthermore, MIDAS software, renowned for its advanced capabilities in structural analysis, is employed to analyse the same set of reinforced concrete slabs subjected to blast loading. The software provides robust modelling and analysis tools specifically designed to assess structural response and quantify blast-induced damage. By comparing the results obtained from the numerical simulations and the MIDAS software analysis, this study aims to determine the level of agreement and the effectiveness of both approaches in accurately assessing blast-induced damage in reinforced concrete slabs. The comparison will encompass various parameters, including displacements, strains, stress distributions, and damage patterns. The findings will contribute valuable insights into the capabilities and limitations of numerical simulation and MIDAS software analysis for blast-induced damage assessment, aiding engineers and researchers in the field of blast engineering and structural assessment. The subsequent sections of the research paper will present and discuss the research methodology, including the modelling techniques employed, the numerical simulations conducted, and the MIDAS software analysis. The results of the comparative study will be comprehensively analysed, and the implications for structural damage assessment and blast-resistant design will be discussed. Finally, the conclusions drawn from the study will be summarized, and recommendations for future research and practical applications will be provided.

NUMERICAL SIMULATION

The following information is based on a “Numerical simulation of reinforced concrete slab subjected to blast loading and the structural damage assessment” research paper and will be incorporated into the present study:

The structural dynamic response and failure behaviour of reinforced concrete slabs subjected to TNT blasts under various conditions were investigated numerically. A three-dimensional finite element model

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was developed, which included the TNT, air, and reinforced concrete slab. The solid hexahedral separation common node modelling technique was used to represent the reinforced concrete structure. To ensure accurate analysis, a fluid-structure coupling algorithm, appropriate constitutive model, and failure algorithm were employed. Numerical simulations were performed considering different combinations of TNT mass (ranging from 0.1 kg to 3.5 kg), blast distance (from 100 mm to 800 mm), and reinforced concrete slab thickness (from 40 mm to 120 mm). The relationship between these explosion conditions and the resulting damage levels (Low damage, medium damage, and Severe damage) in the reinforced concrete structure was established. To validate the numerical model and material parameters, the simulation results were compared with experimental data. The fracture and collapse of the reinforced concrete structure subjected to TNT blasts were well represented in the simulation results. Furthermore, the peak pressure of the shock wave obtained from the numerical simulation aligned closely with the prediction results derived from Henry's Formula. By incorporating these findings into the present study, a deeper understanding of the response of reinforced concrete structures to TNT blasts will be obtained. This knowledge will contribute to the design and assessment of blast-resistant structures, enhancing construction practices and promoting the development of more resilient structures capable of withstanding explosive events.

The dimensions of the reinforced concrete board used in the study are 1000 mm × 1000 mm × 40 mm. The board contains one level of orthogonal reinforcement, with the rebar having a diameter of 6 mm. The reinforced mesh size is 75 mm × 75 mm. For the experimental setup, a standoff distance of 400 mm was selected. These specific dimensions and configurations were chosen to investigate the response of the reinforced concrete board under the specified blast loading conditions.

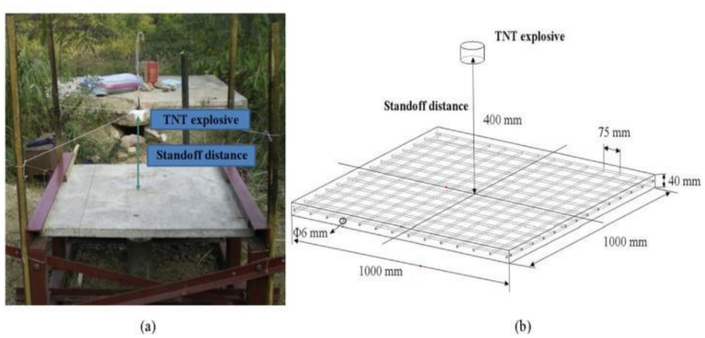

Fig. 1. The test setting (a) and the geometry of the reinforced concrete board (b)

In this study, a detailed 3D model was constructed to simulate an experiment involving TNT explosive, air, and a reinforced concrete slab. The model employed a sophisticated modelling method known as the "Solid Hexahedral Separation Common Node Modelling Method" to accurately capture the mechanical properties of reinforced concrete structures. While this approach provided realistic results, it necessitated a large number of solid hexahedra and presented challenges in the modelling process.To generate the model, multi-block structured meshes were initially created. For circular sections such as the rebar, a butterfly topology method was pplied to map the block structured meshes onto the geometric surfaces. Through Boolean manipulation, the co-nodes between the rebar and surrounding concrete were established, completing the hexahedral three-dimensional element modelling for the entire system. The numerical model adopted a quarter model for symmetry, reducing computational complexity. It consisted of eight-node solid elements for the TNT/air/concrete/rebar system, resulting in a total of 1,608,072 elements. The element size was set at 2 mm to ensure reliable and accurate results. The simulation employed different calculation methods: the Lagrangian method was used for the concrete slab and rebar, whereas the Arbitrary Lagrange-Euler (ALE) method was employed for the high explosive and air. By using a fluid–solid coupling algorithm, fluid-structure interactions were effectively modelled. Boundary conditions were set according to the experiment, with fixed node displacements for the reinforced concrete board and non-reflective boundaries for the air. The study's findings and experimental details, including the number of elements and specific boundary conditions.

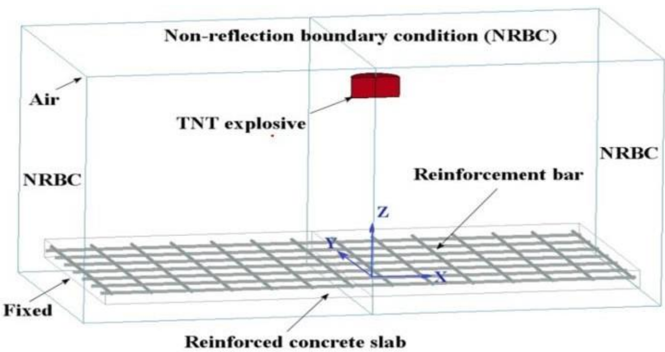

Fig. 2. Finite element model.

ADVANCED STRUCTURAL ANALYSIS SOFTWARE

Problem Statement: Perform the blast on reinforced concrete board with one level of orthogonal rebar is 1000 mm × 1000 mm × 40 mm in size. The diameter of the rebar is 6 mm and the reinforced mesh size is 75 mm × 75 mm. Standoff distance of 400 mm is chosen for TNT detonation of 0.31kg. Referring to the journal "Numerical simulation of reinforced concrete slab subjected to blast loading and the structural damage assessment." from Elsevier Ltd Publication

Items	Specification
Grade of Concrete	M40
Grade if Steel	Fe440
Ec	28.3 GPa
Es	200 GPa
Unit Weight of steel	78.3 KN/m3
Unit Weight of Concrete	25.5 KN/m3

Table no.1: Data from research paper

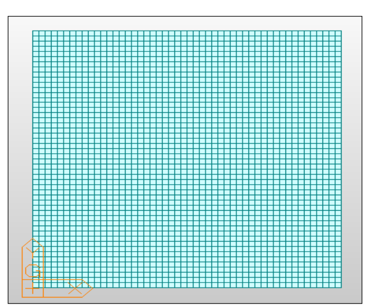

Fig. 3: Plan View of geometry

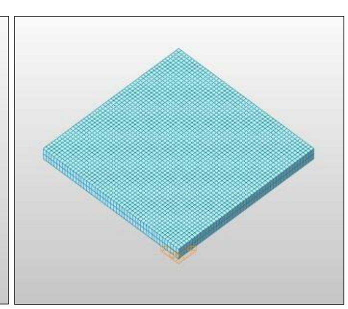

Fig .4. 3D Model.

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1000X1000 mm plan dimension. 50 divisions in X, Y direction respectively. (20mm each) ,40mm thickness 2 divisions in Z direction. (20mm each) As per IS 4991:1968 Peak positive intensity quickly drops down to zero; the total duration of the positive phase being a few milliseconds. The maximum negative overpressure is much smaller than the peak positive overpressure. But the negative phase duration is 2 to 5 times as long as that of the positive phase.

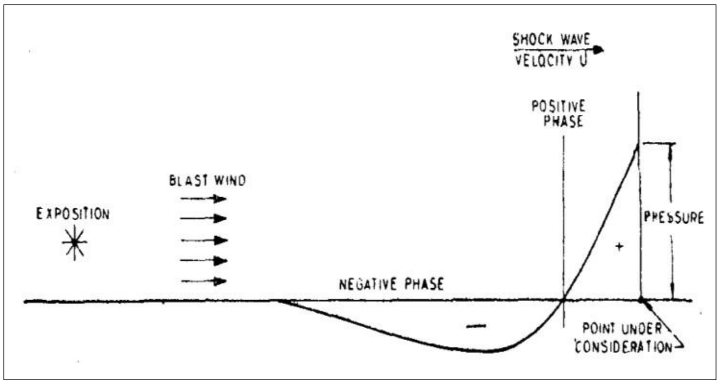

Fig. 5. Shock Wave Propagation (IS 4991:1968)

Scaled distance= Actual distance/(W)1/3
Scaled time = Actual time/(W)1/3
Blast Pressure: For open structure:Cd =1.3
P=Pso+Cd.q

Characteristics of the Blast	
case 2:0.31kg	
detonation	0.31kg
distance from ground zero.	400mm
scaled distance	5.910253m
Cd	1.3
Pao	1kg/sq.cm
As per table 1	
Pso	8 kg/sq.cm
Pro	41.6 kg/sq.cm
q	10.667 kg/sq.cm
As per IS 4991	
Pso + Cd*q	21.8671 kg/sq.cm

Table no.2: Pressure calculation from Excel sheet.

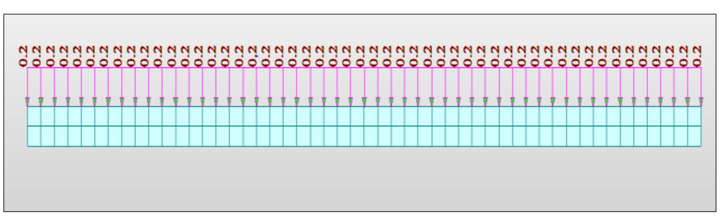

Fig no.6: Pressure Load

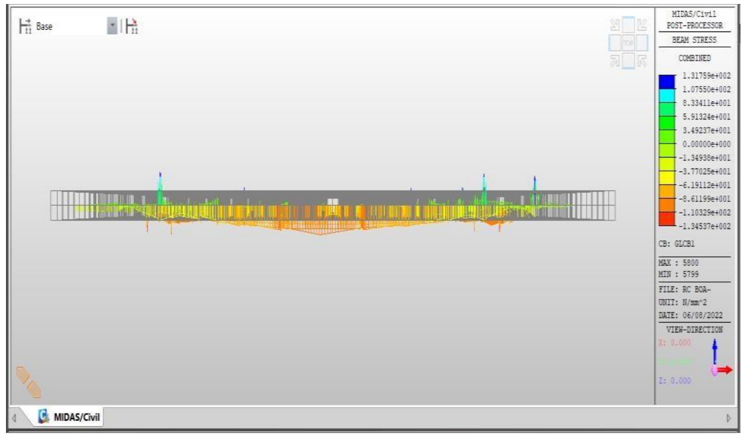

Fig no.7: Stress distribution for combined load combination

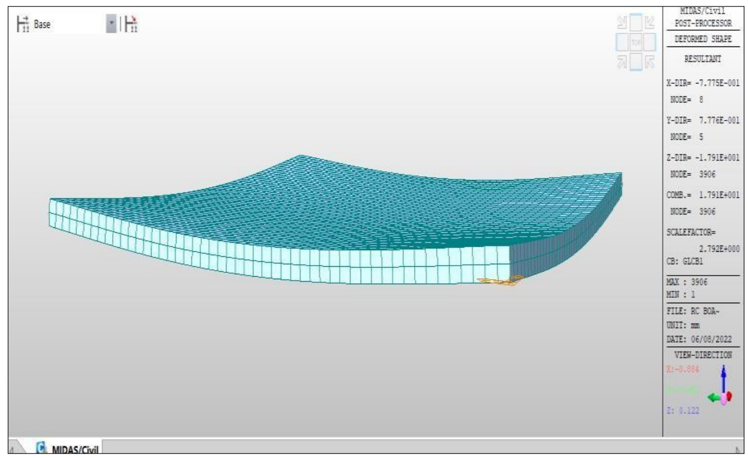

Fig no.8: Deflected shape of RC slab

CONCLUSION

The study delved into the critical domain of blast-induced damage assessment in reinforced concrete slabs, employing a comparative analysis between numerical simulation and advanced structural analysis software. Through meticulous investigation, it became evident that both methodologies offer valuable insights, yet their applicability varies based on specific circumstances and objectives.
The numerical simulation approach, characterized by its ability to simulate complex blast scenarios with precision, demonstrated its potential in capturing intricate structural behaviours and damage patterns. This approach's capacity to offer a visual representation of the blast effects, coupled with its adaptability to various blast scenarios, contributes significantly to its suitability for preliminary assessments and design optimizations.
On the other hand, the advanced structural analysis software exhibited its strengths in efficiently handling large-scale structural models and incorporating intricate material behaviours. Its utilization of advanced algorithms and meshing techniques allows for comprehensive evaluations of blast effects and structural response. Moreover, the software's integration of various loading conditions beyond blast events extends its utility to broader structural analyses.
However, both approaches also possess limitations. Numerical simulations demand a meticulous calibration process, necessitating accurate material properties and blast parameters to ensure reliable outcomes. Conversely, the extensive computational requirements of advanced structural analysis software might limit its applicability in time-sensitive situations or resource-constrained environments.

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In the pursuit of comprehensive blast-induced damage assessment, a judicious combination of these methodologies could potentially yield more holistic insights. By leveraging the advantages of both numerical simulation and advanced structural analysis software, engineers and researchers can capitalize on their respective strengths while mitigating their limitations.

In essence, the comparative study underscores the significance of context-specific selection between numerical simulation and advanced structural analysis software. A robust understanding of the objectives, resources, and constraints is pivotal in determining the most appropriate approach for assessing blast-induced damage in reinforced concrete slabs. As advancements in simulation technologies continue, further research can refine and expand the scope of these methodologies, ultimately enhancing our ability to safeguard critical infrastructure in the face of dynamic blast events.

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