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Analysis of Blast Resistant Building

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***Abstract:** Blast loads generated by accidental industrial explosions or intentional explosive attacks can cause severe damage to structures and pose significant risks to human life. Conventional reinforced concrete (RCC) buildings are generally designed to resist gravity, wind, and seismic loads; however, they may not possess adequate resistance against the high-intensity, short-duration forces associated with blast events. Therefore, the development of blast-resistant structural systems has become an important area of research in structural engineering. The present study investigates the behavior of a three-storey reinforced concrete building subjected to blast loading using advanced nonlinear finite element analysis. The blast pressures are generated using the CONWEP (Conventional Weapons Effects Program) approach based on TNT equivalent charge weight and stand-off distance. A detailed three-dimensional numerical model of the RCC building is developed in ABAQUS/CAE, and the dynamic response is evaluated using ABAQUS. The analysis focuses on evaluating key structural response parameters such as displacement, stress distribution, concrete damage, and overall structural performance under various blast scenarios. The influence of blast intensity and stand-off distance on the structural response is examined to identify critical conditions that may lead to excessive deformation or damage. The results demonstrate that blast effects decrease significantly with increasing stand-off distance, while higher explosive charge weights produce greater structural stresses and displacements. The study further highlights the effectiveness of nonlinear dynamic analysis in predicting damage mechanisms and assessing the blast resistance of reinforced concrete buildings. The findings of this research contribute to the understanding of blast-resistant structural design and provide practical recommendations for improving the safety and resilience of RCC buildings located in industrial, strategic, and high-risk zones.*
***Keywords:** Blast Resistant, CONWEP, ETABS, Displacement, Storey drift.*

I. INTRODUCTION

Industrial facilities that store or process hazardous materials present a significant blast risk to adjacent structures. Explosions may originate from process equipment, storage tanks, or accidental release of flammable mixtures. Even when not intended as an attack, accidental blasts can generate high-pressure, short-duration loadings that produce immediate and catastrophic damage to building envelopes and structural systems. Designing structures to resist or mitigate blast effects is crucial for protecting life, limiting structural damage, and preserving critical functions. Traditional structural design addresses gravity loads, seismic events, and wind loading. Blast loads differ in intensity, duration, and spatial distribution, and often require specific analysis techniques (impulsive loading, high strain-rate response) and detailing that emphasize energy absorption and member ductility rather than stiffness alone. However, the threat of bombings has increased in recent years. Damage to the assets, loss of life and social panic are factors that must be minimized if the threat of terrorist action cannot be stopped. Designing the structures to be fully blast resistant is not a realistic and economical option, however current engineering and architectural knowledge can enhance the new and existing buildings to mitigate the effects of an explosion. This research addresses structural design for blast resistance of a building, using ETABS as the primary analysis tool. The emphasis is on developing practical, code compliant, and computationally validated design approaches for mid-rise buildings.

A. *Objectives*

Estimate blast load parameters for representative industrial explosion scenarios using TNT equivalency and CONWEP formulations.
Develop detailed structural models of a 3 Storey RCC building in ABAQUS and perform explicit dynamic analyses to assess global behaviour.
Propose member sizing enhance blast resistance and ensure life safety.
Prepare a comprehensive design methodology suitable for implementation in blast high risk zones.

B. Problem Statement

Many existing buildings near industrial facilities or at high risk areas were not designed to resist blast loads. There is a gap between conventional design practices and blast resistant requirements. This research aims to fill that gap by presenting investigation that results in actionable design guidance for civil engineers.

II. LITERATURE REVIEW

The reviewed literature indicates that blast loading produces highly complex dynamic responses in reinforced concrete structures, including cracking, spalling, scabbing, excessive deflection, and progressive collapse. Researchers have employed experimental investigations, analytical methods, and advanced numerical simulations to understand these phenomena. Key parameters influencing blast performance include explosive charge weight, standoff distance, concrete strength, reinforcement ratio, structural configuration, and boundary conditions. Several studies have demonstrated that increasing standoff distance, improving reinforcement detailing, incorporating shear walls, and using high performance materials significantly enhance blast resistance. Most previous studies focused on individual structural components such as beams and slabs or employed simplified analytical approaches. Although ETABS, STAAD Pro, LS-DYNA, and AUTODYN have been widely used, relatively fewer studies have investigated complete reinforced concrete buildings using detailed finite element analysis with ABAQUS and CONWEP blast modeling. Therefore, there remains a need for comprehensive numerical investigations of RCC buildings subjected to varying blast scenarios using advanced nonlinear material models such as Concrete Damage Plasticity (CDP). The present research aims to address this gap by evaluating the blast response of reinforced concrete structures through ABAQUS-based finite element simulations and CONWEP-generated blast loads.

A. Identified Research Gap

The reviewed literature shows that considerable research has been carried out on the blast response of reinforced concrete structural elements and buildings using experimental, analytical, and numerical methods. Most studies have focused on individual components such as beams, slabs, and columns or have employed simplified analysis techniques using software like ETABS and STAAD Pro. However, limited research has been conducted on complete RCC buildings using advanced nonlinear finite element analysis capable of accurately capturing concrete damage and failure under blast loading. Furthermore, only a few studies have utilized ABAQUS with the Concrete Damage Plasticity (CDP) model and CONWEP blast loading to investigate the behavior of reinforced concrete structures. Therefore, the present study aims to bridge this gap by performing a detailed nonlinear dynamic analysis of an RCC building subjected to different blast scenarios using ABAQUS, thereby providing a better understanding of structural response and blast-resistant design.

III. METHODOLOGY

A. Research Approach Overview

For the design and analysis of the blast resistant building the following workflow is adapted to simplify and streamline the process,

1) Define representative blast scenarios (charge quantity, location, and standoff distance).
2) Use CONWEP (Kingery & Bulmash empirical relations) to estimate time dependent surface pressures on building faces.
3) Apply blast pressure time-histories as external loads (converted into nodal forces or shell pressures) and perform nonlinear time-history analyses.
4) Evaluate global performance (inter-story drift, floor accelerations) and local damage (member hinge formation, slab punching) and propose design measures.

B. Blast Analysis Of Structures

The analysis of structures subjected to blast loading is significantly different from conventional static analysis because blast loads are characterized by extremely high pressures acting over a very short duration. To accurately predict the structural response, several analytical and numerical methods have been developed. The selection of an appropriate analysis method depends on the complexity of the structure, desired level of accuracy, and available computational resources.

Analysis Method Adopted in the Present Study

In the present research, the blast response of a reinforced concrete residential building is investigated using ABAQUS/CAE. The blast load is generated through the CONWEP (Conventional Weapons Effects Program) approach, which calculates blast pressure based on explosive charge weight and standoff distance.

The structural response is evaluated using ABAQUS/Explicit, which is specifically designed for high-speed dynamic events such as explosions and impacts. The analysis performed in this study is a Nonlinear Dynamic Time-History Finite Element Analysis. The reinforced concrete components are modeled using three-dimensional finite elements, while the nonlinear behavior of concrete is represented through the Concrete Damage Plasticity (CDP) model. This approach enables the simulation of concrete cracking, crushing, stiffness degradation, and damage progression under blast loading. By combining CONWEP blast loading, nonlinear material modeling, and finite element analysis, the present study provides a detailed assessment of structural performance, displacement response, stress distribution, and damage characteristics of reinforced concrete buildings subjected to blast loads.

C. Blast Load Characterization

There are 3 kinds of explosions

1) Unconfined explosions: Unconfined explosions can occur as an airburst or a surface burst. In an air burst explosion, the detonation of the high explosive occurs above the ground level and intermediate amplification of the wave caused by ground reflections occurs prior to the arrival of the initial blast wave at a building (Figure 1). As the shock wave continues to propagate outwards along the ground surface, a front commonly called a Mach stem is formed by the interaction of the initial wave and the reflected wave.
2) Confined explosions: When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called a confined explosion. In addition, and depending on the degree of confinement, the effects of the high temperatures and accumulation of gaseous products produced by the chemical reaction involved in the explosion will cause additional pressures and increase the load duration within the structure. Depending on the extent of venting, various types of confined explosions are possible
3) Explosions caused by explosives attached to the structure: If detonating explosive is in contact with a structural component, e.g. a column, the arrival of the detonation wave at the surface of the explosive will generate intense stress waves in the material and resulting crushing of the material. Except that an explosive in contact with a structure produces similar effects to those of unconfined or confined explosions.

D. Damage Plasticity Model For Concrete

The plastic behaviour of concrete was defined using the Concrete Damage Plasticity (CDP) model, which provides a general capability for modelling concrete and other quasi-brittle materials. The CDP model assumes two primary failure mechanisms: compressive crushing and tensile cracking. The stress–strain relations under uniaxial loading are expressed as, for tension $\sigma_t = (1 - d_t) E_0 (\varepsilon_t - \varepsilon_t^{pl})$ & for compression $\sigma_c = (1 - d_c) \cdot E_0 \cdot (\varepsilon_c - \varepsilon_c^{pl})$ where d_t and d_c are the tensile and compressive damage variables, respectively, and E_0 is the initial modulus of elasticity.

E. Johnson–Cook Model For Reinforcement

The nonlinear elasto-viscoplastic behaviour of steel reinforcement bars was modelled using the Johnson–Cook material model, which is widely applied in high strain-rate problems such as impact and blast loading. This model is based on the von Mises yield criterion and incorporates the effects of strain hardening, strain rate sensitivity, thermal softening, and damage evolution. The yield stress in the Johnson–Cook model is expressed as:

$\sigma y = (A + B \cdot \varepsilon^n) \cdot (1 + C \cdot \ln\varepsilon^*) \cdot (1 - (T*)^m)$

F. Analysis Tools

Software used for blast analysis of structures with the advancement of computational techniques, several software packages have been developed for analyzing the behavior of structures subjected to blast loading. These software tools enable engineers and researchers to evaluate structural response, damage patterns, and failure mechanisms under explosive loading conditions. The selection of software depends on the complexity of the problem, desired level of accuracy, and available computational resources.

ABAQUS Software: ABAQUS is a powerful Finite Element Analysis (FEA) software developed by Dassault Systèmes for solving complex engineering problems involving structural, thermal, fluid, and dynamic analyses. It is widely used in research and industry due to its ability to accurately simulate nonlinear material behavior, contact interactions, large deformations, and high-rate dynamic loading conditions. ABAQUS provides a comprehensive environment for modeling, analysis, and post-processing through its graphical user interface known as ABAQUS/CAE (Complete Abaqus Environment).

The software consists of several analysis modules, among which ABAQUS/Standard and ABAQUS/Explicit are the most commonly used. ABAQUS/Standard is generally employed for static and low-speed dynamic problems, whereas ABAQUS/Explicit is particularly suitable for highly nonlinear transient events such as impacts, crashes, and blast loading. Since blast loads involve extremely high pressures acting over very short durations, ABAQUS/Explicit is preferred for accurately capturing the dynamic response of structures subjected to explosive effects. In the present study, ABAQUS/CAE is utilized to develop a three-dimensional finite element model of the reinforced concrete structure. The geometric dimensions of structural components such as beams, columns, slabs, and walls are defined according to the selected building configuration. Appropriate material properties for concrete and reinforcing steel are assigned to represent their actual behavior under dynamic loading conditions. The Concrete Damage Plasticity (CDP) model is employed to simulate the nonlinear behavior, cracking, crushing, and stiffness degradation of concrete subjected to blast-induced stresses. The blast loading is applied using the CONWEP (Conventional Weapons Effects Program) approach available within ABAQUS. The CONWEP model generates blast pressure-time histories based on the explosive charge weight and standoff distance specified by the user. This method eliminates the need for detailed modeling of the surrounding air domain and significantly reduces computational effort while maintaining acceptable accuracy for engineering applications. Meshing of the structural model is performed using suitable finite elements to ensure accurate stress and displacement predictions. Boundary conditions and constraints are applied to represent realistic support conditions. The analysis is then executed using ABAQUS/Explicit to capture the transient response of the structure during and after the blast event. The results obtained from ABAQUS include displacement-time histories, stress distributions, strain contours, reaction forces, damage patterns, and energy absorption characteristics. These outputs are used to evaluate the structural performance under different blast scenarios and to identify critical regions susceptible to damage or failure. The numerical simulations provide valuable insight into the blast-resistant behavior of reinforced concrete structures and assist in assessing the effectiveness of various design parameters. Thus, ABAQUS serves as the primary analytical tool in this research, enabling detailed investigation of structural response under blast loading and facilitating the development of safer and more resilient structural designs.

IV. RESULT AND DISCUSSION

A. Numerical Modelling And Analysis Procedure

1) Selection Of Structure

A reinforced concrete (RCC) residential building is selected for the present study to investigate its behaviour under blast loading. The building consists of reinforced concrete beams, columns, and slabs designed according to relevant Indian Standard codes. A three dimensional model of the structure is developed for detailed blast analysis. The building dimensions were 3.2 × 3.2 × 2.4 M, with beams and columns having a cross-section of 0.32 M × 0.32 M. The roof slab thickness was 0.10 m. The RCC Building has 3 number of storeys having a building height 7.2 M.

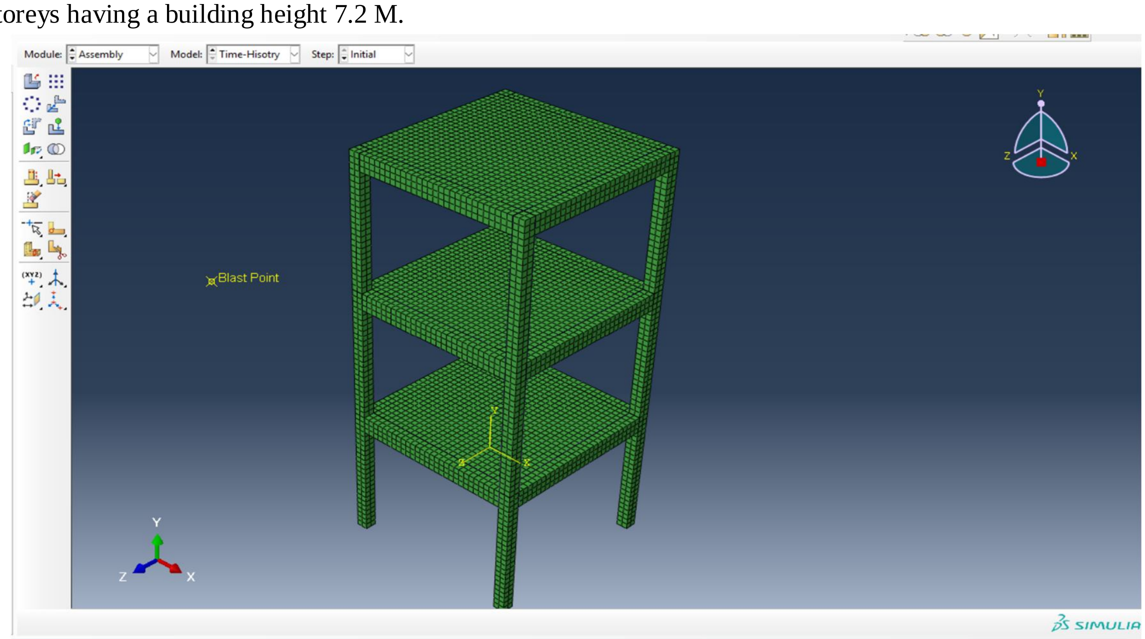

FIGURE 4.1 ASSEMBLY OF A RCC BUILDING

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2) Material Properties

The structural model consists of reinforced concrete and steel reinforcement. Concrete is assigned appropriate mechanical properties, while reinforcing steel is modelled to represent its elastic and plastic behaviour. The Concrete Damage Plasticity (CDP) model is used to simulate concrete cracking, crushing, and stiffness degradation under blast loading conditions.

Concrete Damage Plasticity (CDP) Model

Parameter	Value
Mass Density (ρ) (kg/m^3)	2400
Youngs Modulus (E) (Pa)	24 X 10^9
Poisson's Ratio	0.18
Dilation Angle	30
Eccentricity	1
	1.16
K	0.666
Viscosity parameter	0.1

Table 1. Concrete Damage Plasticity (CDP) Model Values for Concrete

Yield Stress	Cracking Strain	Damage Parameter
3.3 X 10^9	0	0
3.2 X 10^9	0.003	0.15
3.1 X 10^9	0.005	0.21
3 X 10^9	0.007	0.28
2.95 X 10^9	0.01	0.3

Table 2. Tension Damage Values for Concrete Damage Plasticity (CDP)

Yield Stress	Inelastic	Damage Parameter
20 X 10^9	0	0
15 X 10^9	0.0011	0.2
12 X 10^9	0.004	0.24

Table 3. Compression Damage Values for Concrete Damage Plasticity (CDP)

Johnson-Cook (J-C) Material Model

Parameter	Value
Mass Density	7850
Youngs Modulus	203 X 10^9
Poisson's Ratio	0.33

Table 4. Material Model Values for Steel Bar

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Parameter		Value
Yield Stress Constant (A) (Pa)		304.33 X 106
Yield Stress Constant (B) (Pa)		422.007 X 106
Strain Hardening Constant (n)		0.345
Thermal Softening Constant (m)		0.87
Fraction Strain Constant	d1	0.1152
	d2	1.0116
	d3	-1.7684
	d4	-0.05279
	d5	0.5262
Melting Temperature		1800
Transition Temperature		293
Viscous effect (C)		0.0156

Table 5. Johnson Cook Damage Model Values for Steel Bars

B. *Structural Modelling*

The building dimensions were 3.2 × 3.2 × 2.4 M, with beams and columns having a cross-section of 0.32 M × 0.32 M. The roof slab thickness was 0.10 m. The RCC Building has 3 number of storeys having a building height 7.2 M. The reinforcement details for the RCC structure where the beam has size of 200 x 200 mm. Number of bars are 4 and size of bars is 10 MM in diameter, stirrups are in 6 MM diameter @ 200 MM centre to centre and size of stirrups 160 MM X 160 MM. Size of column is 200 MM X 300 MM with number of bars is 4. The size of bar is 10 MM diameter, stirrups are 6 MM diameter @ 200 MM centre to centre with size of stirrups 160 MM X 260 MM.

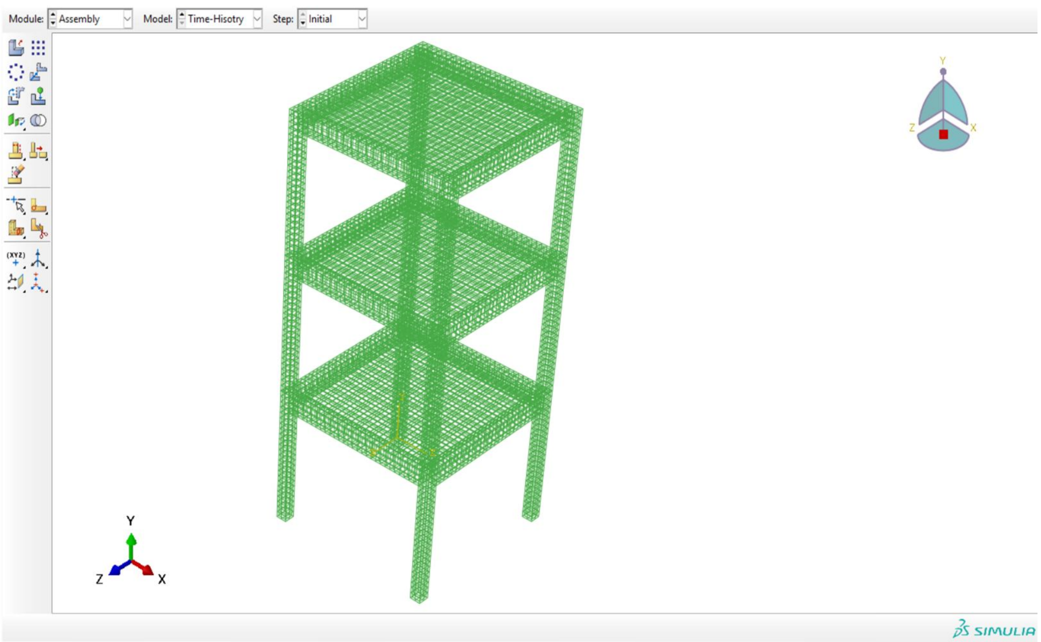

Figure 4.2 Rcc Structure Reinforcement Detailing

Important Note :- The parameters in Table1 to Table 5 were adopted from the work of Mohamed Talaat et al. 2022, Finite Element Analysis of RC Buildings Subjected to Blast Loading, Ain Shams Engineering Journal, who successfully used these values for blast analysis of reinforced concrete structures. (Reference Number 11)

1) Support Conditions

Fixed support conditions are assigned at the base of all columns using the ENCASTRE boundary condition in ABAQUS. Under this condition, all translational (U_1,U_2,U_3) and rotational (UR_1,UR_2,UR_3) degrees of freedom are restrained. This represents a rigid foundation system and prevents any displacement or rotation at the support level during blast loading.

C. TNT Charge Weight

The blast load is generated using an equivalent TNT explosive charge. Different TNT charge weights are considered to study the effect of blast intensity on the structural response of the building.

TNT Charge Weight Cases

- 20 kg TNT
- 30 kg TNT
- 40 kg TNT

Standoff Distance

The standoff distance is defined as the distance between the explosive charge and the structure. Standoff distance 10M is selected to evaluate the variation in blast pressure and corresponding structural response.

D. Evaluation Of Results

The results obtained from the analysis are examined to assess the blast-resistant performance of the RCC building. Parameters such as maximum displacement, stress distribution are evaluated. The effect of varying TNT charge are as follows,

For 20 kg TNT Charge, the structure exhibited a maximum Von Mises stress of 2.50 MPa and a maximum displacement of 40.3727 mm at 0.0172 seconds. The stress and deformation levels remained relatively low, indicating stable structural behavior. The results suggest that the RCC building is capable of safely resisting the applied blast load without significant damage.

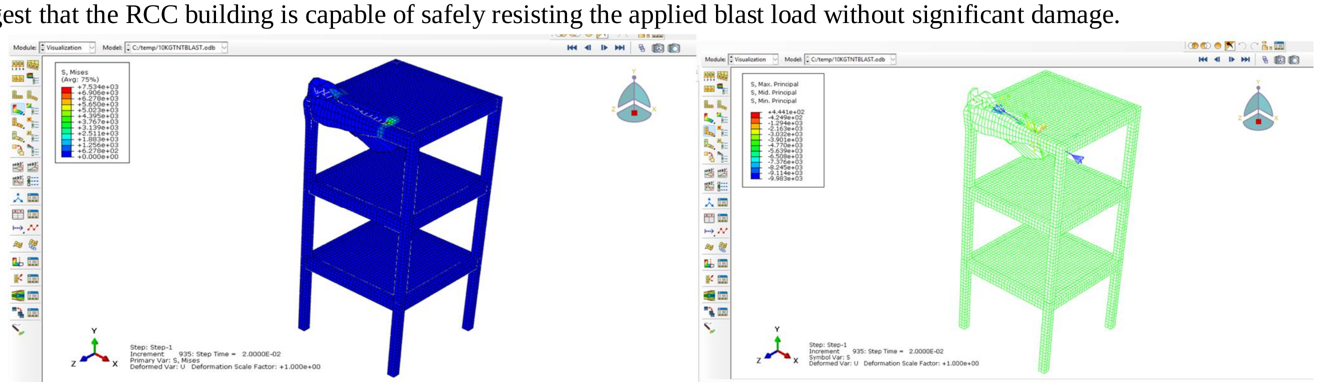

FIGURE 4.3 SIMULAYION OF 20KG TNT BLAST

For 30 kg TNT Charge, the maximum Von Mises stress increased to 5.155 MPa, while the maximum displacement reached 52.2512 mm at 0.0159 seconds. Compared to the 20 kg TNT case, higher deformation and stress concentrations were observed due to the increased blast intensity. However, the structure maintained its integrity and demonstrated satisfactory blast-resistant performance.

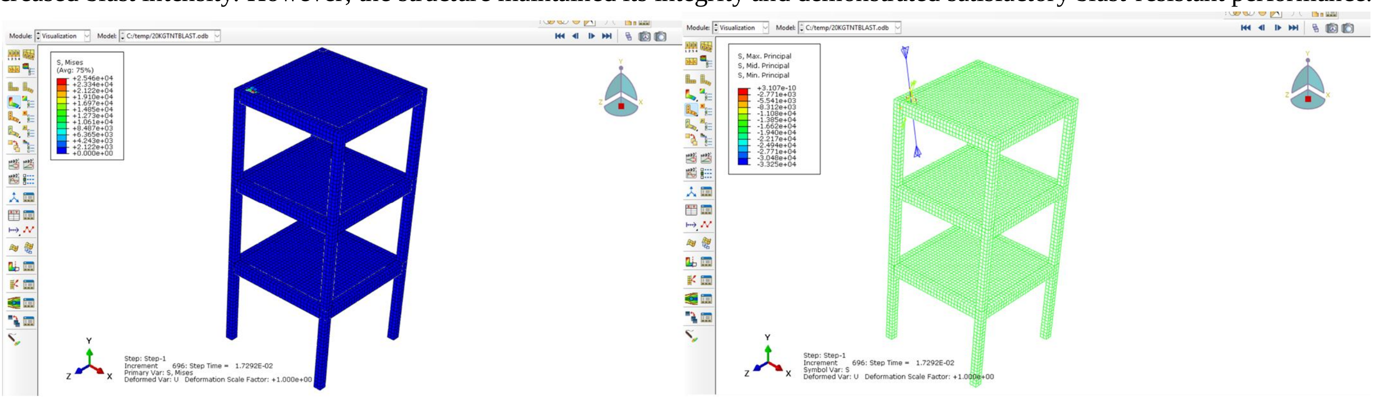

FIGURE 4.4 SIMULAYION OF 30KG TNT BLAST

For 40 kg TNT Charge, the structure experienced a maximum Von Mises stress of 7.185 MPa and a maximum displacement of 63.123 mm at 0.0149 seconds. The increase in stress and displacement confirms the direct influence of blast intensity on structural response. Despite the higher loading, the RCC building remained stable and showed adequate resistance against the applied blast pressure without evidence of structural collapse.

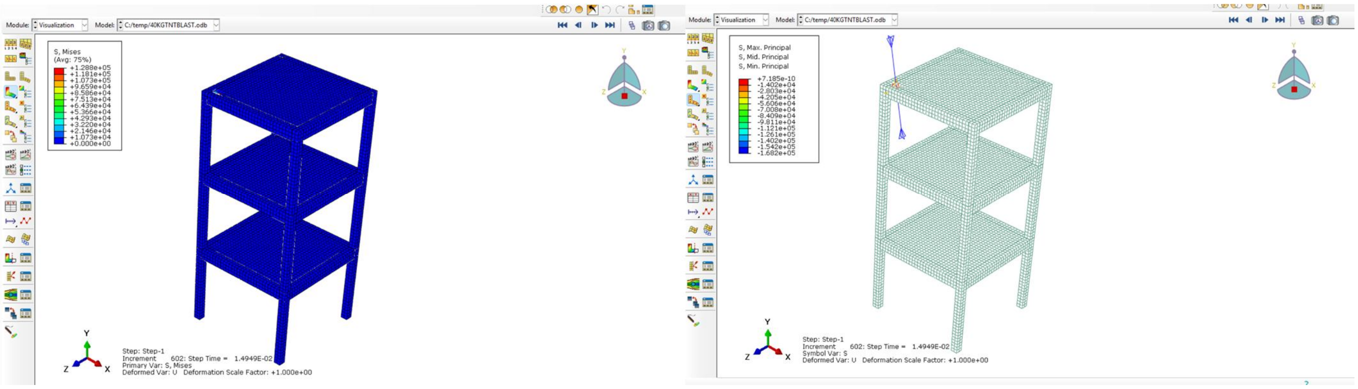

FIGURE 4.5 SIMULAYION OF 40KG TNT BLAST

V. CONCLUSION

A detailed three-dimensional finite element model of the RCC building was successfully developed in ABAQUS/CAE and analyzed using the ABAQUS/Explicit solver. The nonlinear dynamic time-history analysis enabled accurate assessment of the transient response of the structure under blast loading. Parameters such as displacement, stress distribution, and structural damage were evaluated to understand the behavior of the building during and after the blast event. The analysis results showed that the structural response increased with increasing TNT charge weight. The maximum displacement increased from 40.3727 mm for the 20 kg TNT charge to 63.123 mm for the 40 kg TNT charge, while the maximum Von Mises stress increased from 2.50 MPa to 7.185 MPa. The increase in stress and displacement values confirmed the direct influence of blast intensity on structural behavior. However, the structure remained stable under all loading cases considered in the study. Overall, the results confirm that the selected three-storey RCC building possesses adequate blast-resistant characteristics for the loading conditions considered in this investigation. The use of ABAQUS together with the CONWEP blast loading model proved to be an efficient and reliable approach for evaluating structural performance under explosive loading. The findings of this study contribute to the understanding of blast-resistant design and provide useful guidance for the planning, analysis, and design of structures in blast high-risk zones.

VI. ACKNOWLEDGMENTS

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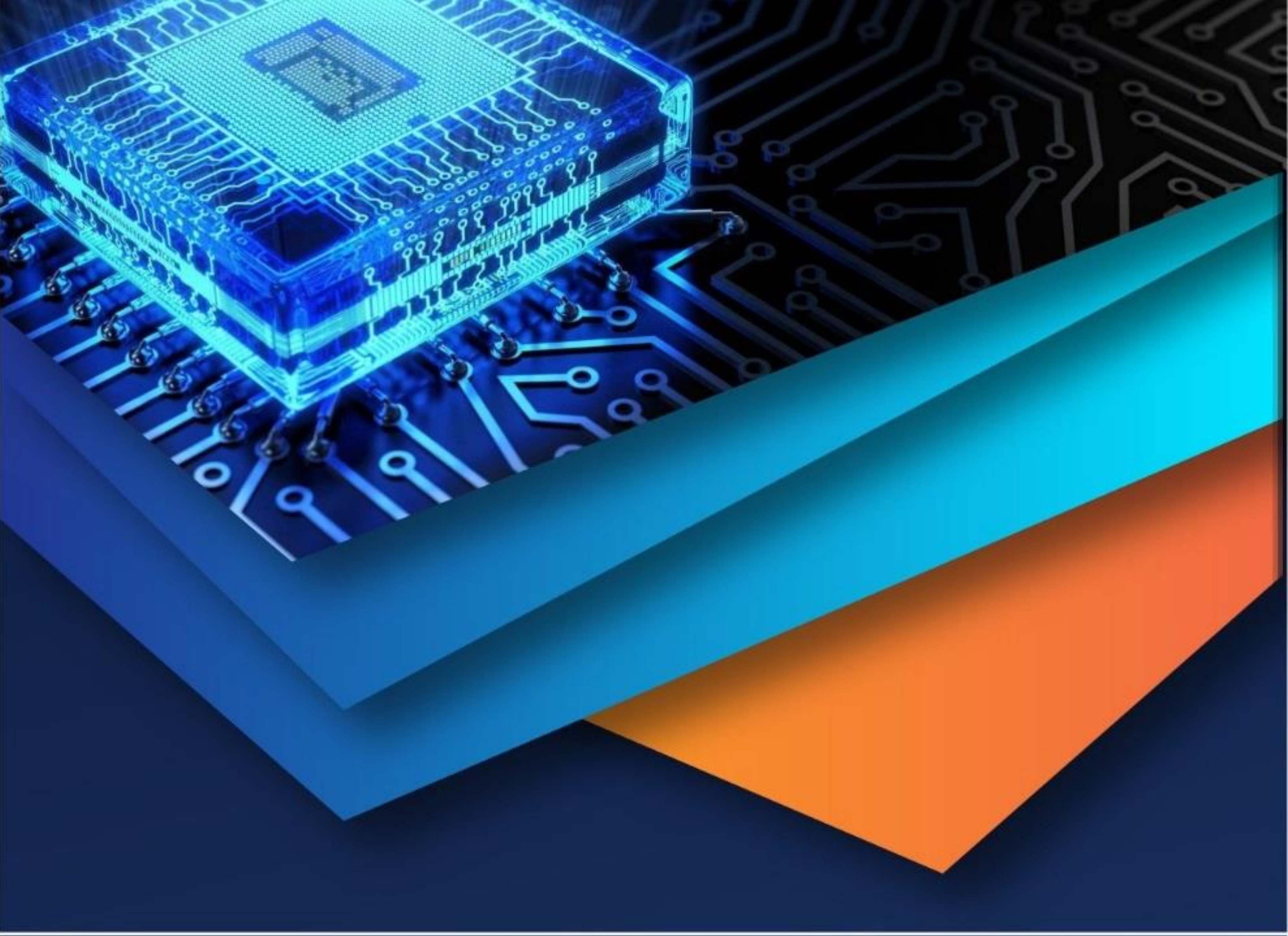

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