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Parametric Study on the Nonlinear Dynamic Response of Cold-Formed Steel Structure under Blast Loading

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Abstract: Cold formed steel (CFS) framing systems are increasingly used in modern construction due to their lightweight nature, high strength-to-weight ratio, and construction efficiency. However, their thin-walled sections are particularly susceptible to damage under extreme loading conditions such as blast events or also accidental loads. This study presents a numerical investigation on the finite element modelling and response analysis of composite cold-formed steel frame structures subjected to blast loading. A multi-storey CFS frame building is modelled using a global finite element approach to evaluate its overall structural response under gravity and blast loads. Blast effects are represented through idealized pressure-time histories applied to exposed structural components. Critical members identified from global analysis are further examined using detailed finite element models to capture local buckling, stress concentration, and material non-linearity. Composite action is induced through localized strengthening to enhance energy absorption and delay failure. The response is calculated in terms of displacement, stress distribution, and damage progression. The proposed methodology framework offers a practical approach for assessing and improving the blast performance of cold-formed steel frame structures. This study also contributes to the development of efficient numerical methodologies for blast-resistant design of cold-formed steel structures
Keywords: Cold-formed steel, finite element modelling, SAP2000, response analysis, blast loading, blast performance

I. INTRODUCTION

A. General Introduction

Cold formed steel refers to structural members produced by bending thin steel sheets at room temperature into cross-sections such as lipped channels, Z-sections, C-sections, and built-up or back-to-back assemblies. Due to their strength-to-weight ratio and ease of fabrication, CFS systems are widely used in light commercial buildings, floor and wall systems, secondary framing, and modular construction. (Rohola Rahnavard, 2025)

B. Blast Load Physics

The blast is defined as the quick releasing of energy in a large scale (Boyina sita Rama krishna, 2018). The blast is a phenomenon of quick and sudden releasing of energy. Which increases in size at designating its own velocity. The resulting of blast wave releases energy over a small duration and in a small volume, pressure will be distributed in all directions in a wave form. An explosion in air creates a rapidly expanding shockwave that produces a short-duration pressure rise (positive-phase) followed by a negative phase. The peak reflected pressure and impulse (area under the pressure-time curve) applied to a structure depend on the explosion charge, distance from the explosion, and orientation/shape of the structure. (IS 4991: 1968)

C. Standards and Guidelines for Blast Analysis

1) ASCE/SEI 59-11 (Blast protection of Buildings) provide guidance on planning, design and construction for blast-resistant buildings; includes methodologies for component design and retrofit.
2) AISI S100/ AISI Technical Guidance provides standards for cold formed steel member design, provide the core CFS member strength and buckling design rules which must be used in conjunction with blast loading. (AISI S100)
3) Eurocode EN 1993-1-3 gives provisions for cold-formed members and sheeting in Europe, used alongside EN 1991 actions (though specific blast provisions are supplemented by specialist guidance rather than embedded in Eurocode). (EN 1993-1-3, 2006)

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D. *Design Checks and Acceptance Criteria for Blasts*

1) Local Capacity- It ensures the plates, flanges and connections can resist peak reflected pressure without brittle fracture or immediate collapse.
2) Global Stability- Check for columns and primary gravity elements for plastic hinge formation; ensure overall stability and prevent progressive collapse.
3) Serviceability and Residual Capacity- For continuity-critical infrastructure, limit residual deformations and maintain some post-event capacity.

E. *Significance of Blast Loads*

1) Blast loads represent one of the most critical extreme actions that structures may encounter, as they generate highly intense pressure waves within milliseconds, causing sudden, dynamic, and often catastrophic effects on buildings.
2) Their significance lies in the necessity to ensure the safety of occupants, to prevent localized damage from escalating into progressive collapse, and to maintain the stability and functionality of essential infrastructure. Unlike conventional static or dynamic loads, blast loads require buildings to possess high ductility, redundancy, and energy-absorption capacity to withstand the rapid shock without failure. (UFC 3-340-02-Structures to resist the effects of accidental explosions, 2008)
3) Considering blast effects is especially important for facilities located near industrial, petrochemical, or high-risk zones where accidental explosions may occur, as well as for public, commercial, and strategic buildings that may be exposed to intentional threats.
4) Blast-resistant design also plays a vital economic role by reducing potential damage, downtime, and repair costs following an incident, thereby ensuring long-term resilience and operational continuity. Moreover, understanding blast loads is crucial for modern lightweight construction systems such as cold-formed steel, which are more vulnerable to high-strain-rate effects and buckling failures under impulsive loading.
5) Overall, incorporating blast load considerations into structural design significantly enhances life safety, protects critical assets, ensures regulatory compliance, and supports the development of robust, durable, and disaster-resilient infrastructure.

II. RESEARCH GAP

Although substantial progress has been made in understanding progressive collapse behaviour, blast resistance, and composite strengthening techniques independently, limited research has examined the blast performance of cold-formed steel frame structures. Existing studies predominantly focus on isolated structural components, gravity-driven collapse scenarios, or conventional sheathing materials, while the combined influence of blast loading, nonlinear dynamic response remains insufficiently explored. Additionally, the effects of negative-phase blast loading and damage propagation mechanisms in multi-storey composite CFS frames have not been comprehensively investigated. Therefore, a detailed finite element study is required to evaluate the blast resistance and overall structural performance of cold-formed steel frame systems.

III.PROBLEM STATEMENT

To perform finite element modelling and evaluate non-linear dynamic behaviour, damage mechanisms, and structural performance cold form steel frames under blast loading.

IV.MODELLING AND PARAMETRIC DATA

TABLE I
PARAMETERS FOR ANALYSIS

PARAMETER	VALUES
Building Type	Cold Form Steel Moment Resisting Frame
Plan Size (X*Y*Z)	34*37.5*38.5 m
No. of bays (X)	4
No. of bays (Y)	5
No. of stories (Z)	G+10 (11)
Bay Spacing (X)	8.5 m

Bay Spacing (Y)	7.5 m
Story Height (Z)	3.5 m
Beam Section	Beam_Box- 350*300*50 mm
Column Section	Column_Box- 400*350*50 mm
Slab Section	Lightweight Concrete 130 mm
Wall Section	i) Cold Formed Steel Wall
Live Load	5 kN/m^2
Weight of TNT Charge W (Kg)	50
Standoff Distance R (m)	15
Friedlander Beta	1.3
Negative Phase Pressure Factor (P_r)	-0.2
Negative Phase Duration Factor ($t_{0)}$	1.5
No. of time points	600
Time Step dt (seconds)	0.0005
Scaled Distance, Z (m)	4.071
Incident Overpressure, P_i (kPa)	35.202
Reflected Overpressure, P_r (kPa)	275.951
Positive Phase Duration, t_0 (s)	0.1425
Negative Phase Duration, t_n (s)	0.21375
Negative Peak Pressure, P_n (kPa)	-55.190

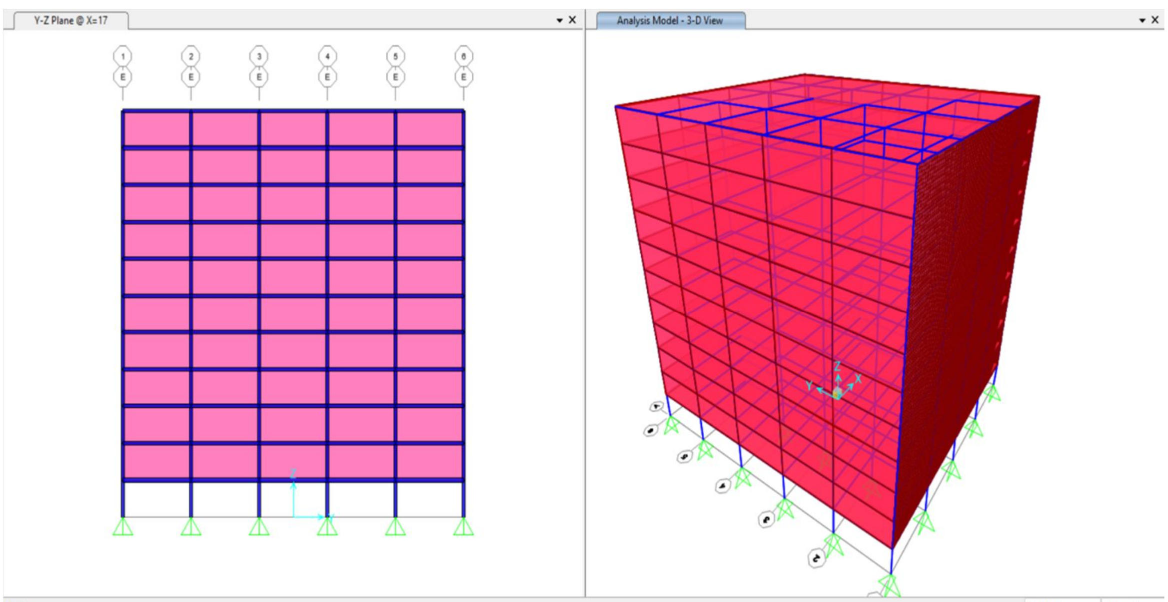

Fig. 1 G+10 Cold Form Steel Model

V. PROPOSED METHODOLOGY

A. Detailed Workflow

1) Validation of finite element model present in literature- Modelling the previously done work in FEM software and analyse for the loads given in literature and validate results obtained in the analysis. (Sang-Wook Bae, 2008)
2) Selection of Material Properties- Selecting cold form steel sections for the appropriate structural members like columns, beams, composite slabs, composite wall, etc. The sections will be designed and analyzed with respect to standards and specifications from American Iron and Steel Institute (AISI S100, AISI S220, Bureau of Indian Standard (IS801: 1975, IS811: 1987), Eurocode (EN 1993-1-3, EN 1993-1-5).

3) Global Finite Element Modelling- Carrying out finite element modelling in FE software for an 11-story Steel Building using cold form steel sections in replacement of conventional steel sections. This finite element model will help us to assign different sections to different structural members as per our design requirements and structural compatibility.
4) Gravity Load Analysis- Calculation of loads to be applied on structure comprising of self-weight, live loads, combination loads, earthquake loads, etc. After application of all the necessary loads analysis will be carried out to check the stability of the structure under gravity loadings as above. This analysis will help us understand that is there any scope for structural section revisions in our structural members. (Ruwan Jayasooriya, 2011)
5) Blast Load Definition- After performing gravity load analysis and checking structural stability, blast loads are to be defined on the structure. Blast load calculations will be done with respect to codal provisions present in IS 4991: 1968. Applying the blast loads on the structure in form of triangular loading. (Jingsheng Zhou, 2025)
6) Non-Linear Dynamic Blast Analysis- After application of blast loading on the structure, analysis is to be performed to study the behavior of structure under extreme dynamic blast loading and also to identify the damage and critical regions of the structure. (David C. Weggel, 2025)
7) Extraction of Global Response Parameters- Non-linear dynamic analysis will give us results for various factors like story drifts, story shear, damages in members, critical zones which are damaged beyond the permissible limit and need to be redesigned. (Neda Mozafari, 2025)
8) Identification of Critical Components- After extracting the results, it is important to identify the critical components in the analyzed structure. Identifying the critical regions by their damage potential and 3D Finite Element Modelling software helps us to assess them by various in-software methods for easier identification and with accuracy.

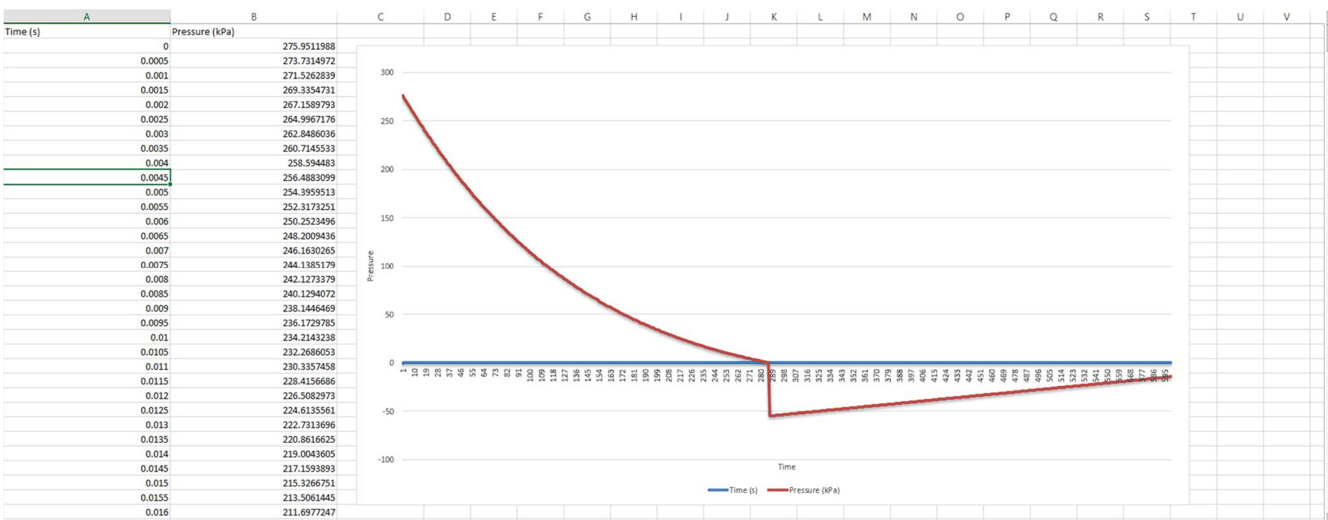

Fig. 2 Pressure-Time History Graph for Blast Loading

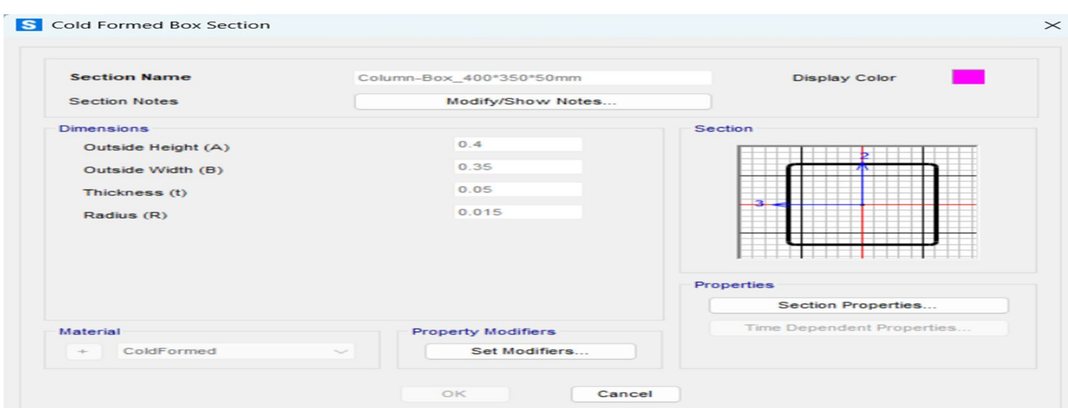

Fig. 3 Cold-Formed Steel Column Section

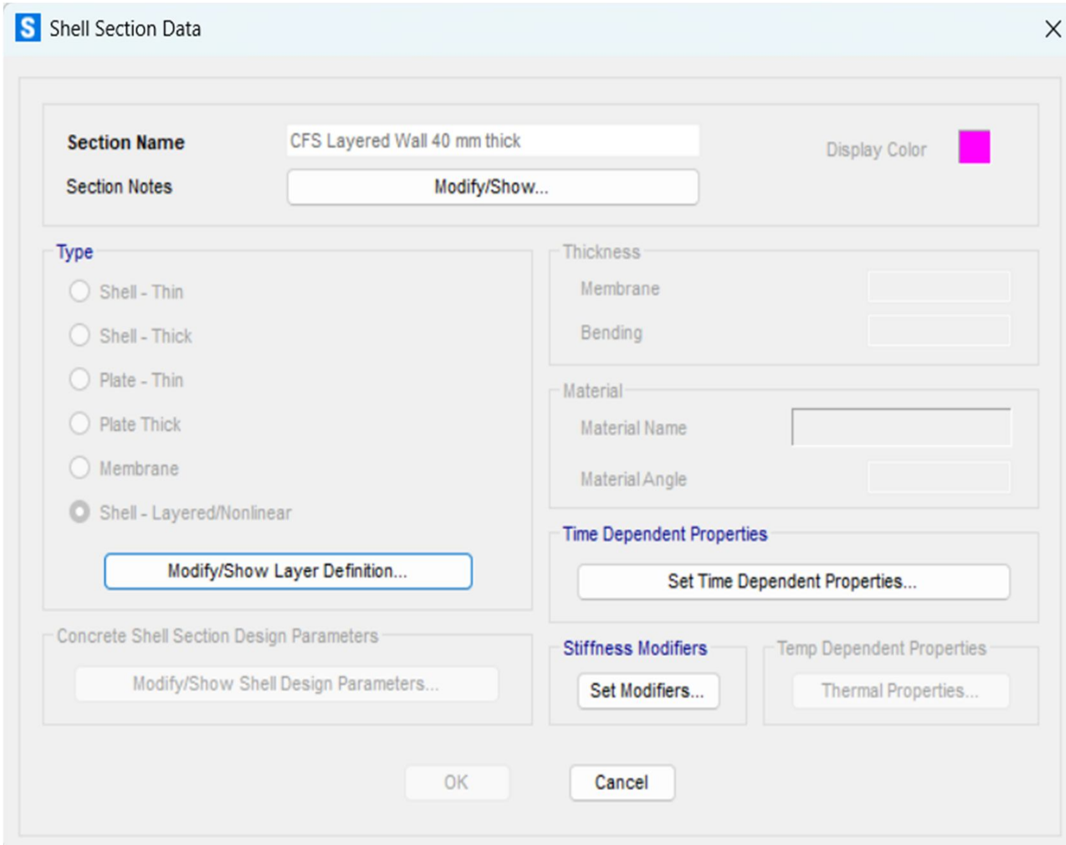

Fig. 4 Cold-Formed Steel Beam Section

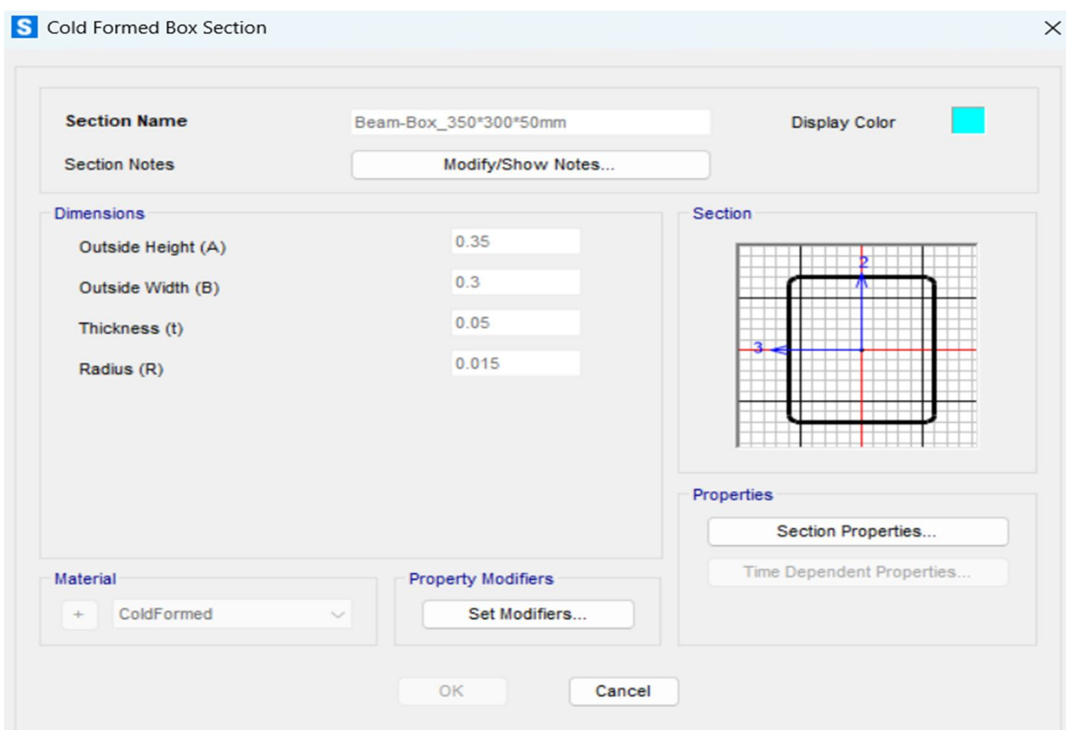

Fig. 5 Cold-Formed Steel Wall Section

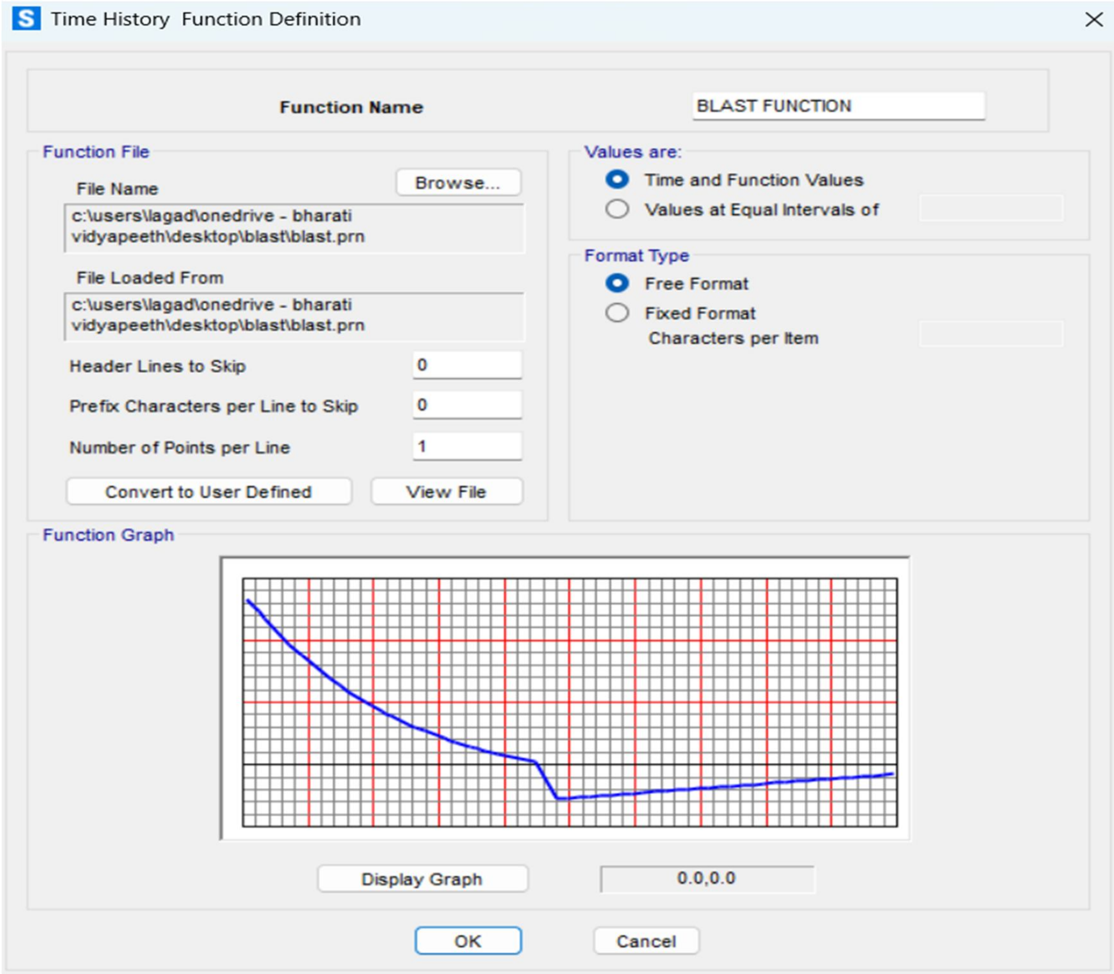

Fig. 6 Load Case Definitions

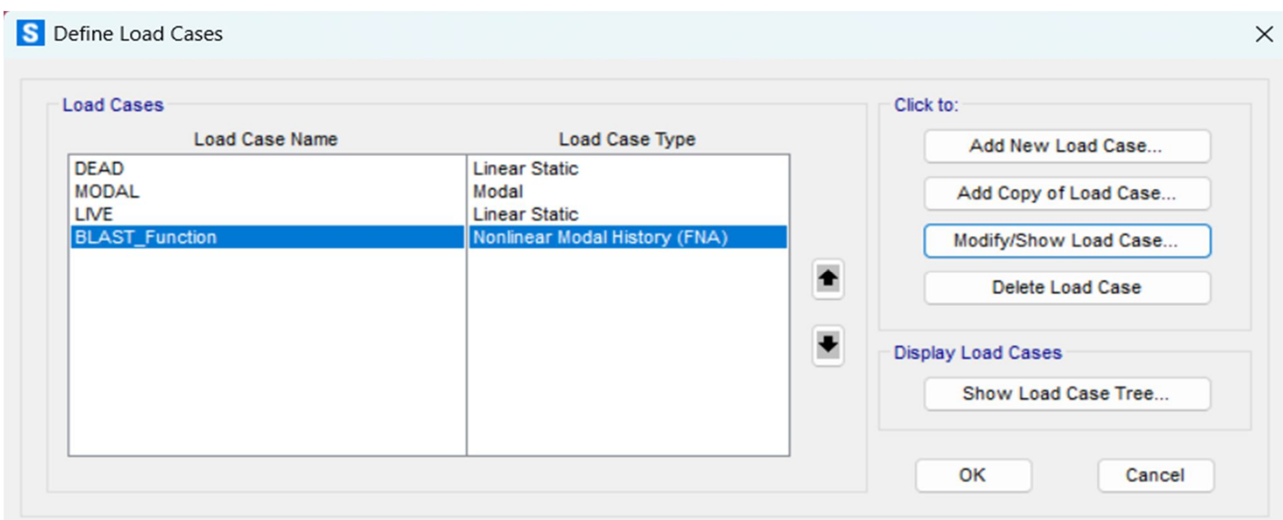

Fig. 7 Imported Time-History Function

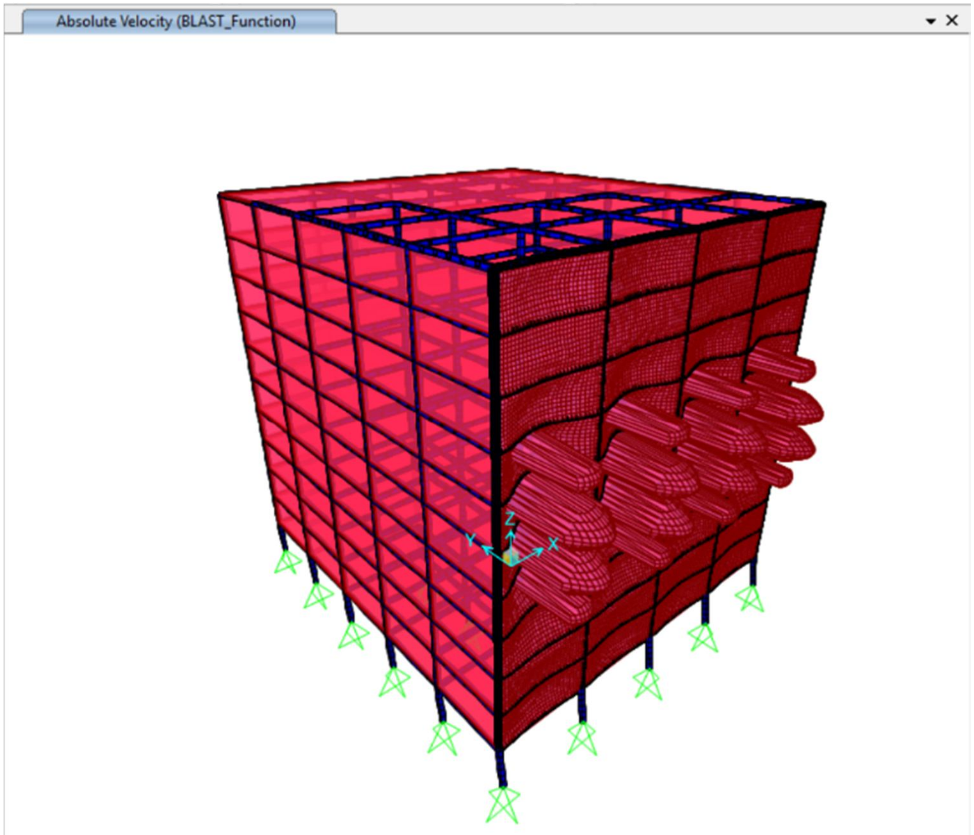

Fig. 8 Absolute Displacement corresponding to Cold Formed Steel Structure

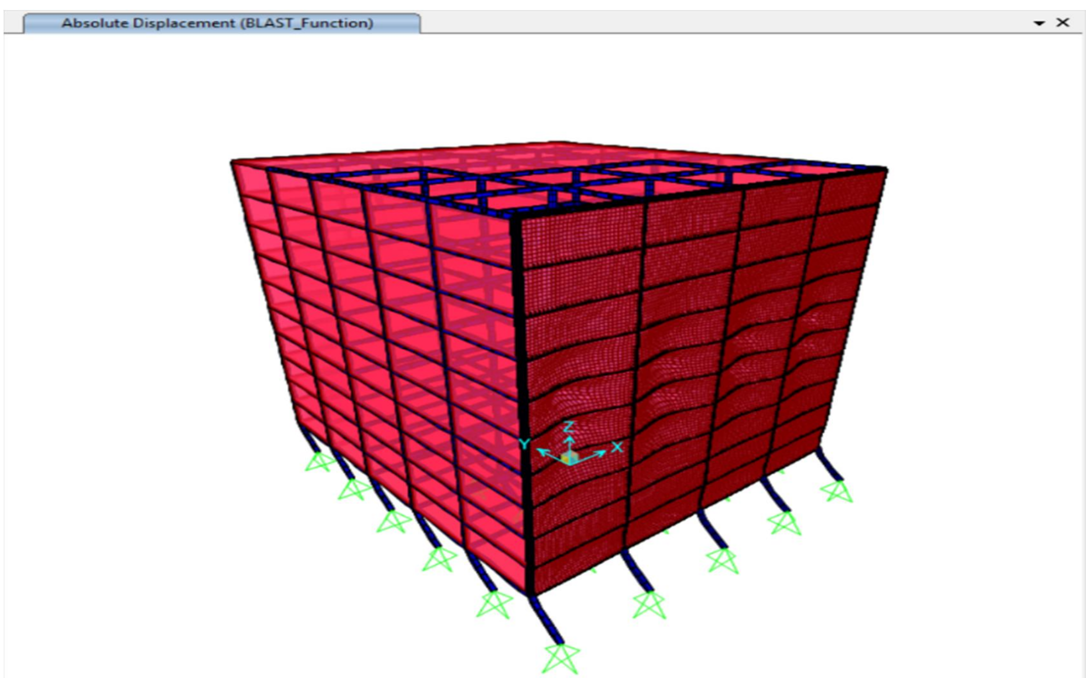

Fig. 9 Absolute Velocity corresponding to Cold-Formed Steel Structure

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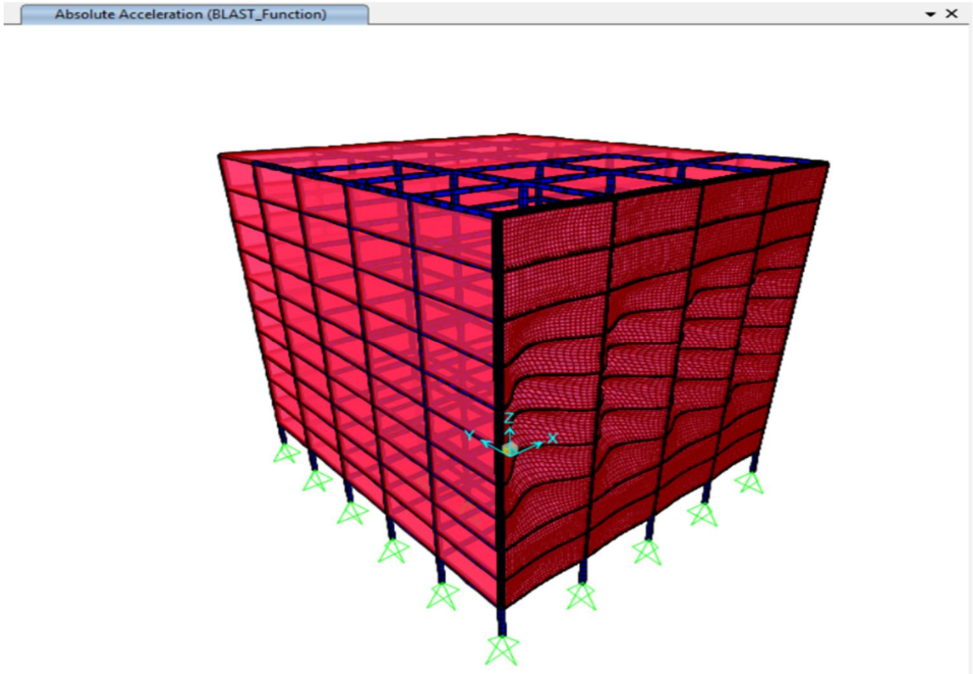

Fig. 10 Absolute Acceleration corresponding to Cold-Formed Steel Structure

VI. RESULTS

TABLE II
Result Comparison for CFS and FGM Models

Parameters	Cold-Formed Steel Model
Absolute Displacement (m)	0.281
Absolute Velocity (m/sec)	8.619
Absolute Acceleration (m/sec^2)	640.855
Kinetic Energy Component (kN-m)	9306.761
Potential Energy Component (kN-m)	7798.874

1) Absolute Displacement- The maximum displacement recorded by the cold-formed steel model was 0.281 m, indicating the extent of structural movement under the applied blast load.
2) Absolute Velocity- The model attained a maximum absolute velocity of 8.619 m/s during the blast event. This parameter reflects the rate of structural motion and provides insight into the dynamic response of the structure under blast loading
3) Absolute Acceleration- The peak absolute acceleration recorded was 640.855 m/sec^2. Acceleration is directly related to inertia forces developed within the structure and is an important indicator of the severity of dynamic effects caused by blast.
4) Kinetic Energy Component- The kinetic energy component was found to be 9306.761 KN-m. This value represents the energy associated with the motion of the structure during the blast response and indicates the magnitude of dynamic activity experienced by the system.
5) Potential Energy Component- The potential energy component was 7798.874 KN-m, representing the energy stored within the structure due to deformation. This parameter reflects the structural capacity to absorb and store energy during loading.

The results provide a quantitative measure of the structural response of the Cold-Formed Steel model under Blast Loading. The recorded displacement, velocity, acceleration, kinetic energy, and potential energy values collectively characterize the deformation, dynamic motion, and energy behavior of the structure during the blast event.

VII. CONCLUSIONS

This study investigated the structural and dynamic performance of a Cold-Formed Steel (CFS) structural system. Finite element modelling and dynamic analysis were carried out to evaluate key response parameters including absolute displacement, absolute velocity, absolute acceleration, kinetic energy, and potential energy components under the selected blast loading. The results are demonstrated in the above Table II. Evaluation of the energy response parameters provided additional insight into the structural behavior of Cold-Formed Steel Structural system. The obtained results provide a clear understanding of the deformation characteristics, dynamic response, and energy absorption behavior of the CFS model. The study demonstrates the capability of numerical analysis to evaluate the structural response under extreme blast loading conditions and offers a foundation for future research on improving blast-resistant structural systems through material optimization, structural modifications, and advanced design approaches like the provision of Functionally Graded Material Composites through material gradation.

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