Limitations of Simplified Analysis Procedures Used for Calculation of Blast Response of Structures

K. K. Anjani and Manish Kumar

Abstract The current state of practice in the blast-resistant design of structural members relies on simplified single-degree-of-freedom (SDOF) to calculate the response quantities. An equivalent SDOF representation of a structural member is obtained by assuming a deflected shape with equal deflection at the assumed degree of freedom. The blast load is approximated as a triangular pulse load. The response of an elastic and elasto-plastic SDOF system to triangular pulse is widely available in the literature. The utility of simplified SDOF procedures is mostly limited to calculating displacement response of regular-shaped members subject to far-field detonations. This paper investigates the limitations of the simplified SDOF method and role of various parameters (e.g., shape, standoff distance, boundary conditions, positive phase) on response quantities of interests (e.g., displacement, shear force). The simplified SDOF results are verified using advanced finite element model of the steel column in LS-DYNA. The findings of the study are summarized, and recommendations are provided for usage of simplified SDOF procedures for the blast-resistant design of structures.

Keywords Simplified SDOF analysis · Finite element analysis · Shape functions

1 Introduction

As the threat perception to the risks associated with accidental and malevolent blast loading to critical government and private facilities grows, the elements of blast-resistant design would need to be incorporated for these structures. The research in this area has mostly been confined to military structures, but recently there has been focus on civil structures due to the rise in terrorist threats. The challenges in the blast-resistant design of structures include accurate characterization of blast loads and reliable response estimation of structures. There are limited codes and standards

K. K. Anjani · M. Kumar (✉)
Indian Institute of Technology, Bombay 400 076, India
e-mail: 164040015@iitb.ac.in

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that provide information on analysis of structures subject to blast loads. ASCE 59-11 [1] provides guidelines for planning, analysis, and design of new and existing structures to resist blast loads. The Indian standard IS 4991 [2] presents the general criteria for blast-resistant design.

The current state of practice in blast-resistant design of structural components relies on simplified single-degree-of-freedom (SDOF) analysis. The accuracy of the analysis depends on the effectiveness in converting the real structure to an equivalent SDOF system. A detailed presentation on simplified SDOF analysis is provided in Biggs [3] and UFC-3-340-02 [4]. The response of elastic and elasto-plastic SDOF systems can be obtained using the shock spectra developed by Biggs [3] and reproduced in DoD [4].

The simplified SDOF procedures for blast-response analysis are mostly appropriate for calculating displacement response of regular-shaped members subject to far-field detonations characterized by uniform blast pressure. There are several limitations of the simplified SDOF analysis that must be addressed for reliable and safe design of structures against blast loading.

Li and Hao [5] proposed a two-step method that combines the traditional SDOF method with FEA to ensure computational efficiency and better accuracy. Al-Thairy [6] performed analytical study to obtain the blast response of steel column using simplified SDOF methods including the effects of axial compressive loading. A new resistance function was developed for beam-columns that consider the effect of axial loads. The accuracy of the developed resistance functions was verified using ABAQUS and validated with experimental results. Lee and Shin [7] extended the empirical chart of elasto-plastic material models for near field explosions. The developed charts were verified using the finite element code LS-DYNA.

The simplified SDOF procedures are used for blast analysis due to its simplicity, but the use of finite element analysis (FEA) is gaining popularity with increase in computational capabilities. However, there is significant effort involved with the development of a verified and validated FEA model, and the numerical precision of computation is much greater than input parameters of blast analysis to justify nonlinear FEA analysis. Hence SDOF method of blast analysis, with awareness of its limitations, would still be the way forward for blast-resistant design of regular structural members adopted by design practitioners. The goal of this paper is to highlight limitations of simplified SDOF procedures for response quantities of interest and provide recommendations on judicious use of response parameters. The rate dependent nature of the material models is neglected for the FEA in this study to allow comparison with the standard results available using SDOF analysis, which do not include the rate effects.

2 Methodology

2.1 *Blast Loads*

Blast is a rapid and violent chemical reaction that converts the solid or liquid explosive materials into a very hot, dense, and high-pressure gas. The rapid generation of the dense gas compresses the atmosphere ahead of it and generates a high-pressure blast wave. The blast wave propagates into the ambient atmosphere causing a pressure rise that comprises static overpressure and dynamic pressure. The static pressure is due to the compression of the atmosphere by shock front, while the dynamic pressure is caused by energy imparted to the air molecules as the blast wave propagates.

The pressure history due to blast wave at a point located outside the fire ball is shown in Fig. 1. Blast wave reaches at a point after arrival time t_A, and the pressure rapidly increases to peak overpressure (P_{so}) at the point. As the blast wave travels, the pressure decreases gradually and reaches the ambient pressure after a time $t_A + t_0$, where t_0 is referred as positive phase duration. After reaching the ambient pressure, the pressure decreases up to the negative peak P_{so}^- due to overexpansion of gases. The time duration for the negative phase is represented as t_0^-. The blast pressure history is represented using the modified Friedlander equation as

$$p(t) = P_0 + P_s^+\left(1 - \frac{t}{t_0}\right)e^{-bt/t_0} \quad (1)$$

The blast parameters (e.g., peak incident and reflected pressure, positive phase duration, impulse) are obtained using the Kingrey-Bulmash charts available in the technical manual UFC-3-340-02 [4]. The charts provide blast parameters for far-field explosions as a function of scaled distance Z, which is defined as

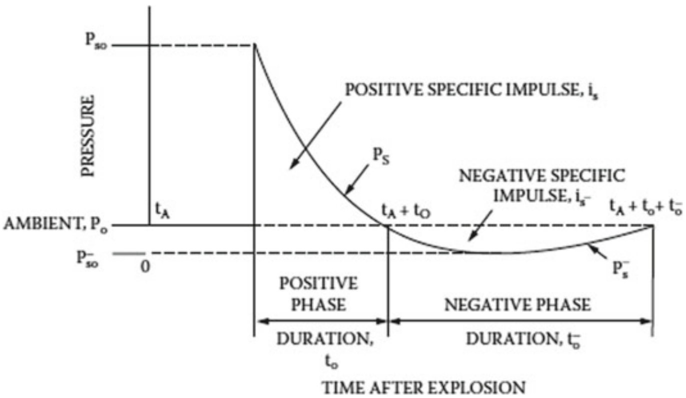


Fig. 1 Pressure history of a blast wave [4]

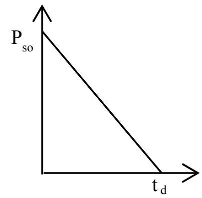


Fig. 2 Simplified representation of blast pressure history

$$Z = \frac{R}{m^{1/3}} \tag{2}$$

where m is the charge mass and R is the standoff distance.

The effect of negative phase is insignificant on blast response and often neglected so that a simplified triangular pulse representation of blast load can be considered for analysis. The response of a SDOF system to triangular pulse is readily available in literature as standard charts. The simplified representation of the blast load is shown in Fig. 2.

The blast waves undergo reflection and diffraction upon striking a solid structure. The reflected over pressure is developed during the reflection of blast wave from a surface. The reflected pressure depends on the incident over pressure and the angle at which the blast wave strikes the surface. The effective pressure at an angle is calculated based on the reflected pressure (P_r), incident overpressure (P_{so}), and the angle of incidence (θ). The expression for the effective reflected pressure is given as

$$P_{eff} = P_r \cos^2\theta + P_{so}(1 + \cos\theta - 2\cos^2\theta) \tag{3}$$

2.2 *Simplified SDOF Analysis*

The critical response of a structural member to blast load is obtained at the component level. The equation of motion of the forced vibration of a beam using distributed mass and elasticity is given as

$$m(x)\frac{\partial^2 u}{\partial^2 t^2} + \frac{\partial^2}{\partial^2 x^2}\left[EI(x)\frac{\partial^2 u}{\partial x^2}\right] = p(x,t) \tag{4}$$

where $p(x,t)$ is the applied force, EI is the flexural rigidity, m is the mass per unit length, and $u(x,t) = \psi(x)z(t)$ is the deflection of the beam expressed as the product of shape function $\psi(x)$ and normalized time coordinate $z(t)$.

The equation is solved to obtain the deflected shape of the beam as

$$\psi(x) = C_1 \sin\beta x + C_2 \cos\beta x + C_3 \sinh\beta x + C_4 \cosh\beta x \tag{5}$$

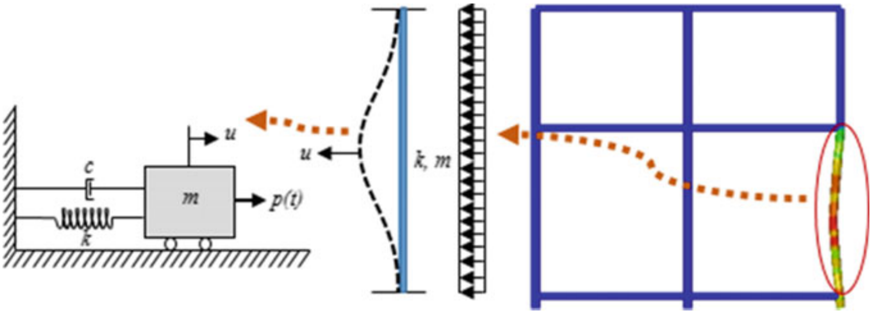


Fig. 3 SDOF analysis of a structural components subject to blast load (Adapted from Hai, 2007)

$$\beta^4 = \frac{\omega_n^2 m}{EI} \tag{6}$$

where C_1, C_2, C_3 and C_4 are the unknown parameters, β is the eigen value parameter, and ω_n is the angular frequency of the column. These parameters are obtained enforcing the boundary conditions. The deflection $u(x, t)$ is obtained by substituting the initial conditions.

It is not always possible to obtain a closed form analytical solution for $u(x, t)$ by solving the partial differential equation. Hence, an alternative approach is adopted where the shape function $\psi(x)$ is assumed based on expected deflected shape, and $z(t)$ is obtained by solving the equation of motion of an equivalent SDOF system. Figure 3 summarizes the equivalent SDOF analysis of a structure subject to blast loads.

The parameters for the equivalent SDOF system (e.g., mass, stiffness and load) are derived using a shape function with equal deflection to the real system at the assumed DOF. The expressions for equivalent mass, stiffness, and load for the SDOF system are

$$\tilde{m} = \int_0^L m(x)[\psi(x)]^2 dx, \ \tilde{k} = \int_0^L EI(x)[\psi''(x)]^2 dx, \ \tilde{P} = \int_0^L P(x)\psi(x) dx \tag{7}$$

Transformation factors are calculated as the ratio of properties of the equivalent SDOF to the real system:

$$mass\ factor\ K_M = \frac{\tilde{m}}{\int_0^L m(x)dx}; \quad load\ factor\ K_L = \frac{\tilde{P}}{\int_0^L P(x)dx}; \quad K_{LM} = \frac{K_M}{K_L} a \tag{8}$$

The shape function is selected to have some physical significance for the given boundary condition at different stages of response (e.g., elastic, elasto-plastic). The transformation factors for the one-way elements and two-way elements for different boundary conditions are presented as standard tables in Biggs [3].

The equation of motion of the equivalent elastic SDOF system is

$$\tilde{m}\ddot{x} + \tilde{k}x = \tilde{P} \tag{9}$$

The peak response depends on the ratio of the positive phase (t_d) duration of the triangular blast load to the natural period of the equivalent SDOF system ($T_n = 2\pi/\omega_n$). The loading is considered as impulsive for $t_d/T_N < 0.2$, for which the elastic response is obtained as

$$u(t) = u(0)\cos\omega_n t + \frac{\dot{u}(0)}{\omega_n}\sin\omega_n t \tag{10}$$

where $u(0)$ and $\dot{u}(0)$ are the initial displacement and velocity, respectively, and $\omega_n = \sqrt{\tilde{k}/\tilde{m}}$ is the natural frequency of the system. For impulsive loading, $u(0) = 0$ and $\dot{u}(0) = I_r/\tilde{m}$, where I_r is the reflected impulse. The peak displacement is

$$u\text{max} = \frac{I_r}{\tilde{m}\omega_n} \tag{11}$$

For non-impulsive loading, Biggs [3] has developed charts (shock spectra) of peak displacements vs t_d/T_N (reproduced in DoD [4]) for elastic and elasto-plastic systems.

The reactions of the real system cannot be obtained using the SDOF system as the equivalent system is selected to match the peak deflection and not the force. The dynamic reactions are obtained using the dynamic equilibrium of the real system. Figure 4 shows the free-body diagram of simply supported beam under uniform load for calculation of dynamic reaction.

The dynamic reactions for the fixed–fixed support beam with elastic material properties for point load and uniformly distributed load are [3]

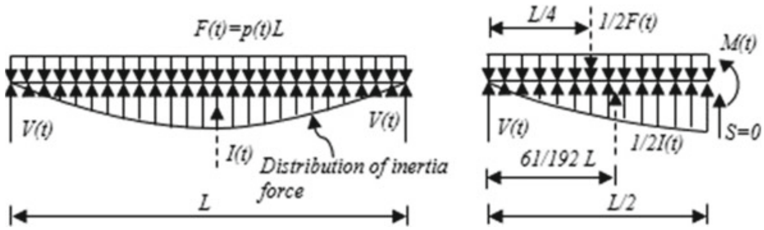


Fig. 4 Calculation of dynamic reaction (adapted from [3])

$$V(t) = 0.71R(t) - 0.21F(t) \tag{12}$$

$$V(t) = 0.36R(t) + 0.14F(t) \tag{13}$$

The internal forces (shear force and bending moments) are also obtained using the static analysis of the real structure subject to an equivalent static force, which is obtained for the given displacement $u(x, t)$ is given as

$$f_s(x, t) = [EI(x)\psi''(x)]''z(t) \tag{14}$$

where *z(t)* is the displacement of the equivalent SDOF system. The internal forces obtained using this static force are less accurate than displacements, because it depends on the differential of the shape function which is less accurate than the shape function.

2.3 Finite Element Analysis

Finite element analysis is popularly used to solve complex nonlinear dynamic problems. LS-DYNA [8] is a popular commercial FEA package that is used to obtain blast response of structures. Its strength lies with a robust explicit solver, vast library of materials and inbuilt blast loading functions. The challenge is to define the boundary conditions and specifies material parameters accurately. The response of structural members can be obtained using FEA to gain insight into the dynamic behavior and verify the response obtained using the simplified SDOF procedure. Verified FE models are used to highlight the limitations of the simplified SDOF procedure and provide recommendations on using the analysis results for blast-resistant design.

3 Analysis

3.1 Analysis Model

A series of numerical studies are performed using steel columns of an I and square cross-Sect. (0.406 m × 0.406 m) subject to blast loading are obtained. Geometric and material properties of the columns are presented in Table 1. Fixed boundary conditions with elastic and elasto-plastic material properties are used in the analysis.

Table 1 Geometric and material properties of the steel columns

Properties	Notation	Value	
		I section	Square section
Length (*m*)	L	5	5
Cross-sectional area (m^2)	A	0.049	0.165
Moment of inertia-strong axis (m^4)	I_{xx}	1.42×10^{-3}	2.26×10^{-3}
Mass density (kg/m^3)	ρ	7850	7850
Young's modulus of elasticity (N/m^2)	E	2×10^{11}	2×10^{11}
Mass per unit length (*Kg/m*)	m	385	1294
Total mass (*Kg*)	M	1923	6470
Plastic moment capacity (*Nm*)	M_p	2.7×10^6	5.9×10^6

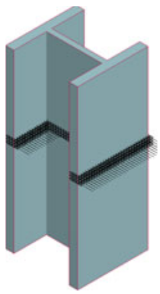
3.2 Load Cases

There are several ways in which blast load can be applied to a structural member. The blast load due to a far-field explosion is almost uniform over the height of the member but a close-in detonation results in a concentrated load. The variation of blast load along the length of the member in an actual blast depends on the standoff distance.

A blast load of 10 MN is considered for the present study, which simulates a detonation at the mid-height of the column. Three spatial distributions of the blast load are considered: (1) point load, (2) uniformly distributed load, and (3) spatially varying load. The column response to the first two load distributions are obtained using SDOF and FE methods, but the spatially varying blast load could only be applied in FE methods.

Total blast load of 10 MN is distributed to the nodes at the mid-section and over the height of the FE model for the point and distributed load as shown in Figs. 5 and 6, respectively. A triangular time variation of blast load is considered for the point and uniformly distributed load, but an exponential (Friedlander) is considered for the spatially varying blast load. The spatially varying blast load along the height is applied in LS-DYNA using the *LOAD_BLAST_ENHANCED keyword

Fig. 5 Point load



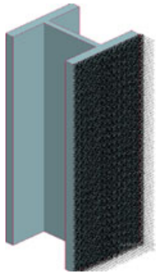


Fig. 6 Uniform load

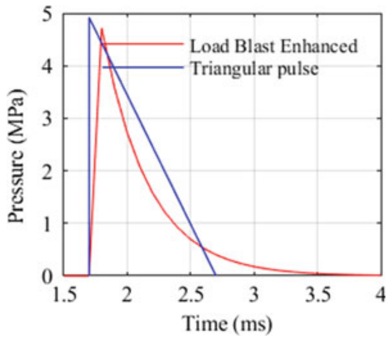


Fig. 7 Pressure history

Table 2 Load cases considered for the analysis

S. No:	Load	Spatial variation	Time variation	Load durations	
				I section	Square section
1	Point	Concentrated	Triangular	1, 5, 10 ms	5, 15 ms
2	Uniform	Uniform	Triangular	1, 10 ms	5, 15 ms
3	LSDYNA	Variable	Exponential	1, 10 ms	NA

option, which takes charge mass and standoff distance as input parameters. These two parameters are obtained by equating the peak reflected pressure and impulse with the triangular pulse load of 10 MN (for $t_d = 1$ ms). This gives a charge mass of 6.01 kg of equivalent TNT at a standoff distance of 1.81 m. Figure 7 shows the pressure history for uniformly distributed load and *LOAD_BLAST_ENHANCED keyword option. Different load cases considered for the analysis are summarized in Table 2.

3.3 Simplified SDOF Model

The elastic shape functions for a fixed-end column under point load (ψ_1) at mid-height and uniformly distributed load (ψ_2) are assumed to be their deflected shape

Table 3 Transformation factors for SDOF analysis

Material model	Transformation factors	ψ_1 (point load)	ψ_2 (uniform load)
Elastic	K_L	1	0.53
	K_M	0.37	0.41
Elasto-plastic	K_L	1	0.64
	K_M	0.33	0.50

Table 4 Parameters of resistance curve of the steel columns

Properties	Notation	Point load		Distributed	
		I section	Square section	I section	Square section
Equivalent stiffness (*N/m*)	k	4.35×10^8	6.96×10^8	6.95×10^8	1.11×10^9
Ultimate resistance (*MN*)	R_u	4.44	9.36	8.64	18.72
Yield displacement (*mm*)	y_{el}	10.2	13.4	12.4	16.9

under static loading, and are given as

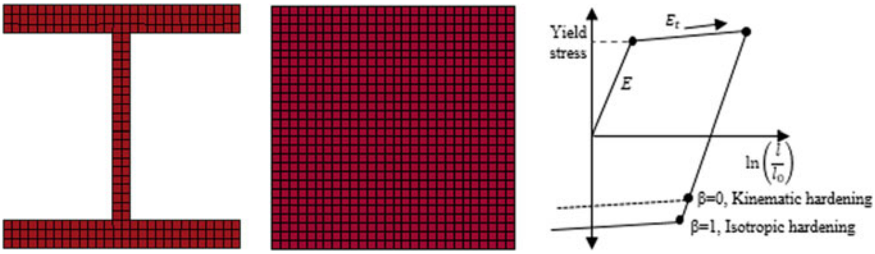
$$\psi_1(x) = 4\left[\frac{3x^2}{L^2} - \frac{4x^3}{L^3}\right] \tag{15}$$

$$\psi_2(x) = 16\left[\frac{x^2}{L^2} - \frac{2x^3}{L^3} + \frac{x^4}{L^4}\right] \tag{16}$$

Values of the transformation factors for fixed–fixed boundary condition for point load and distributed load conditions are presented in Table 3. The parameters of the resistance curve of the columns are presented in Table 4.

3.4 Finite Element Model

The FE model of the column is developed in LS-PrePost. A uniform mesh size of 15 mm is used for the analysis. Figure 8a and b presents the cross section of the I and square section developed in LS-PrePost. The column is modeled using eight noded hexahedron solid elements with constant stress formulation. Analysis is performed using elastic and plastic kinematic material properties. The stress–strain plot for the elasto-plastic (*PLASTIC_KINEMATIC) material model is shown in Fig. 8c.



(a) I section (b) Square section (c) Plastic kinematic material (adapted from [9])

Fig. 8 Details of FE model in LS-DYNA

4 Results and Discussion

4.1 Modal Analysis

The modal frequencies of the equivalent SDOF system are calculated for the assumed shape functions and compared with the frequencies of the finite element models. The frequencies can also be obtained analytically by solving the beam vibration problem in Eq. (4). The modal frequencies and time-periods obtained using these methods are presented in Table 5. The frequencies obtained using the simplified SDOF and analytical methods are greater than frequencies of the FE model for I column. Simplified procedure and analytical procedures are based on flexural response that neglects in-plane shear deformation in the columns and hence results in a stiffer model. In addition, the boundary condition in LS-DYNA is simulated restraining the nodes at the end section of the I column. This results in a model that is less stiff than the analytical model for which a perfect fixed boundary condition is assumed. The frequencies obtained using different procedures are much closer for the square column due to smaller contribution of shear deformation and better simulation of boundary conditions of the FE model. The modal results provide insight into the dynamic behavior of the columns. The simplified SDOF procedure is more accurate for blast analysis

Table 5 Modal properties of the column

Modal property	I section				Square section			
	Analytical	SDOF		LS-DYNA	Analytical	SDOF		LS-DYNA
		ψ_1	ψ_2			ψ_1	ψ_2	
Frequency (Hz)	123	125	122	97	87	90	83	83
Time period (ms)	8.2	8.0	8.2	10.3	11.5	11	12	12

of regular-shaped member (e.g., square), and provide results that are closer to FEA results than irregular-shaped members (e.g., I shape).

4.2 Response of I Column

4.2.1 Concentrated Load

The peak displacements and dynamic reactions of the I column subject to concentrated load are presented in Table 6 for elastic and elasto-plastic material model.

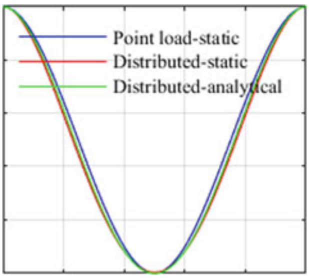
For the elastic material, comparable peak displacements are obtained using simplified SDOF analysis and LS-DYNA analysis for the three load durations. For impulsive loading ($t_d = 1$ ms), the SDOF analysis underpredicts the dynamic reactions. The variation can be attributed to the difference between the actual and assumed deflected shape of the element when subjected to blast loading. The static deflected shape and analytical shape obtained by solving Eq. (5) for the fixed boundary conditions are shown in Fig. 9. Figure 10 shows the actual and assumed deflected shape of the column for blast loading.

During initial response, the actual deflected shape has much higher gradient than the shape function assumed for the SDOF analysis. The dynamic reactions and internal forces in the SDOF analysis depend on higher order derivates for the shape function. The arrival time of peak reactions is smaller than the peak displacements. The actual deflection does not initially resemble the assumed shape function

Table 6 Response of the I column subject to blast loading

t_d (ms)	Elastic				Elasto-plastic			
	Disp. (mm)		Reactions (MN)		Disp. (mm)		Reactions (MN)	
	SDOF	LS-DYNA	SDOF	LS-DYNA	SDOF	LS-DYNA	SDOF	LS-DYNA
1	9.2	10.6	2.9	8.5	11.3	16.5	3.4	2.9
5	31.1	41.6	9.0	11.3	102.2	147.2	3.4	2.9
10	45.0	55.4	10.2	11.8	357.9	383.6	3.4	3.6

Fig. 9 Shape functions for fixed-end beam or column



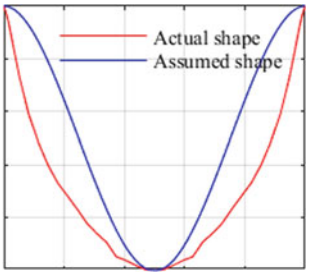


Fig. 10 Assumed and actual (FE) deflected shape of column

but converges to it at higher deflections. This leads to greater differences for reactions than displacements as forces are obtained as multiple derivatives of the shape function. Therefore dynamic reaction is generally less accurate during early time response for short duration loadings [10]. For higher t_d value, shape becomes close to the assumed shape function. Morison [11] provides coefficients for resistance of the column and applied force (Eq. (12)) derived from dynamic force equilibrium equations using Mathcad calculations. The difference between Biggs [3] and Morison [11] coefficients is less than 20% for most cases. The dynamic reactions obtained for 5 ms and 10 ms show better agreement between simplified SDOF and LS-DYNA results.

The response of the I column is also obtained with the plastic kinematic material model. The equivalent SDOF responses are obtained assuming perfect hinge formation and corresponding suitable shape function at different stages of response. However, the column might undergo partial yielding at the assumed hinge location for small duration loads. The stress vs strain plot at the mid-span cross section of the column for the three load durations are plotted. Figure 11 shows the element locations at the cross section used for plotting stress vs strain graph. The stress vs strain plots for 1 ms and 10 ms load durations are shown in Figs. 12 and 13, respectively.

LS-DYNA provides higher value of peak deflection compared to simplified SDOF analysis using plastic kinematic material model. The dynamic reactions in the column are obtained assuming complete yielding at the ultimate resistance capacity of the

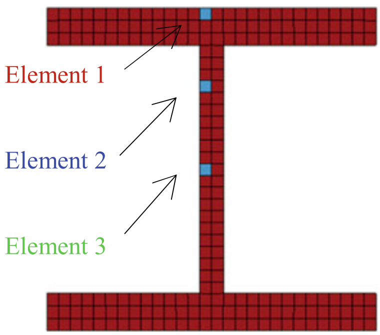


Fig. 11 Elements monitored at mid-height

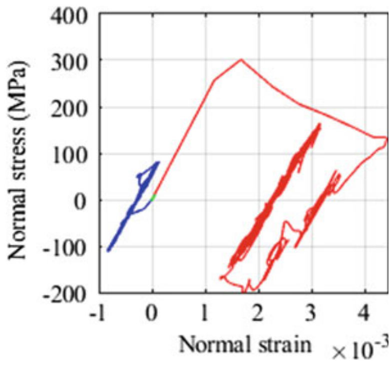


Fig. 12 Element response (t_d= 1 ms)

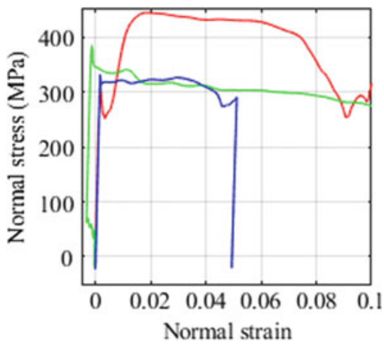


Fig. 13 Element response (t_d= 10 ms)

cros-section. The reactions obtained using SDOF analysis is higher compared to LS-DYNA due to partial cross-sectional yielding for 1 and 5 ms load durations. Good agreement is obtained for dynamic reactions for 10 ms load duration with complete yielding of the cross section. Figure 14 shows displacement histories obtained using SDOF and LS-DYNA analysis for different durations of blast loading for elastic material.

4.2.2 Distributed Load

Responses of the I column subject to uniformly distributed point loads and spatially varying *LOAD_BLAST_ENHANCED options are obtained here using SDOF and FE models for blast load durations 1 and 10 ms.

The peak displacements and dynamic reactions are presented in Table 7 for elastic and kinematic plastic material models. Comparable values of the peak displacement and dynamic reactions are obtained using simplified SDOF and LS-DYNA analysis

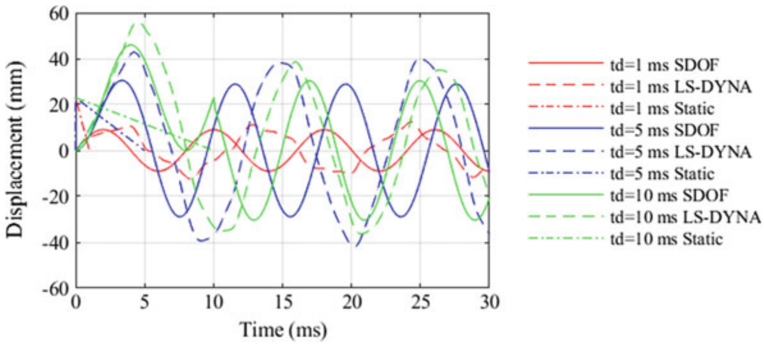


Fig. 14 Displacement history at mid-height of the column (elastic material)

Table 7 Peak response of the I column subject to distributed blast loads

Material model	Displacement (mm)			Dynamic reactions (MN)		
	SDOF	LS-DYNA		SDOF	LS-DYNA	
		Uniform	Variable		Uniform	Variable
Elastic (1 ms)	4.9	5.9	5.0	1.18	1.42	1.79
Plastic (10 ms)	49.7	59.9	45.4	4.1	3.24	3.15

for elastic material. Higher dynamic reaction is obtained using simplified SDOF method for elasto-plastic material. As the section is partially yielded, the reaction obtained assuming hinge formation is higher than the LS-DYNA result. Figure 15 shows displacement history for distributed blast load for elastic material.

Fig. 15 Displacement history at mid-height of the I column subject to distributed blast load (elastic material, $t_d = 1$ ms)

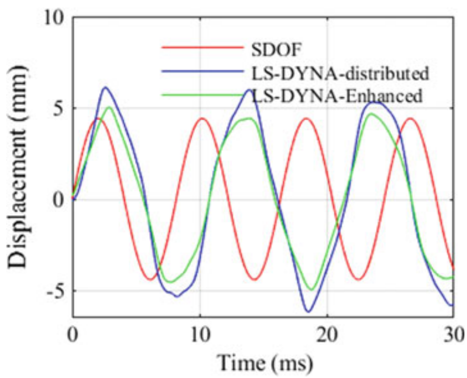


Table 8 Peak response of the square column subject to blast load

t_d (sec) (ms)	Point load				Uniformly distributed			
	Disp (mm)		Reactions (MN)		Disp (mm)		Reactions (MN)	
	SDOF	LS-DYNA	SDOF	LS-DYNA	SDOF	LS-DYNA	SDOF	LS-DYNA
5	19.1	19.8	7.6	10.1	7.5	7.6	4.2	4.77
15	23.7	27.3	9.7	8.5	11.9	11.5	7.0	7.24

4.3 Response of Square Column

The effect of structural shape on accuracy of response calculation using simplified SDOF procedure is investigated. Kinematic plastic material models are used for the analysis. The peak displacements and dynamic reactions of the square column obtained using simplified SDOF analysis and LS-DYNA are presented in Table 8.

A good comparison is obtained for peak displacement using LS-DYNA and simplified SDOF methods. The dynamic reactions for point load shows variation for elastic and elasto-plastic material properties. Good agreement is obtained for dynamic reactions for uniformly distributed load. The column behavior is elastic for kinematic plastic material for 5 and 15 ms load durations. Displacement histories for point load and uniformly distributed load for 5 ms load duration are plotted in Fig. 16. Comparing the response of I section to the square section, it is clear that the shape of the structural member significantly affects the accuracy of simplified SDOF procedure, especially the dynamic reactions. The role of shape of the structure member on blast response becomes less significant when load is applied as uniformly distributed instead of point load.

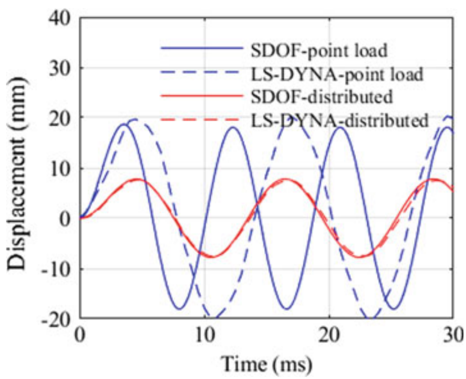


Fig. 16 Displacement history at mid-height of the square column subject to blast load (elastic material, $t_d = 5$ ms)

5 Summary and Conclusions

The limitations of the simplified SDOF analysis used to estimate blast response of structures are investigated by comparing results with finite element analysis in LS-DYNA. The effect of modeling assumptions and parameters on the accuracy of the simplified SDOF procedure is also discussed.

The key conclusions of this study are

1. The simplified SDOF procedure for blast analysis provides a reasonable estimate of the peak displacement but underpredicts the dynamic reactions.
2. The SDOF calculations for inelastic stage of response are inaccurate when there is incomplete hinge formation due to partial yielding of the section for short duration blast loads.
3. Greater difference is observed between the SDOF and LS-DYNA responses when blast load is modeled as concentrated point load than uniform load, because an idealized point load used for simplified SDOF method cannot exactly be simulated in FE models, especially for I section.
4. A reasonable agreement between the SDOF and LSDYNA analysis is obtained for peak response, but differences are observed between response histories. The difference in response histories is greatly diminished for square column with uniformly distributed load.
5. The shape (e.g., I vs. square) of a structural member has a significant effect on accuracy of its blast response obtained using simplified SDOF method, which is more suited to members dominated by flexural response.

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