

RESPONSE OF STEEL FIBER REINFORCED CONCRETE COLUMNS UNDER BLAST LOADS

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Abstract - This paper presents the outcomes of the blast load performance of steel fiber reinforced and conventional steel reinforcement concrete columns. The results show that the usage steel fiber in column effectively develops the blast performance of RCC columns by reducing displacements and improving damage tolerance. The outcomes of the research also show that steel fiber, conventional steel reinforcement, intensity of the blast and standoff are important aspects that can affect the blast load performance of the concrete column. This study purposes in modelling and analyzing a steel fiber reinforced concrete column subjected to blast loading using finite element software LS-DYNA. It is modelled using LS Prepost and analyzed using LS-DYNA. The concrete and steel are represented using solid volume elements. The material models of concrete and steel are cautiously chosen to represent the actual behavior of the materials.

The verification of the developed model is carried out by relating its deflection result with those obtained by field experimental tests. The concrete column with conventional steel reinforcement and steel fiber as reinforcement is designed and effect of blast loading on this column is studied. Column is analyzed for variable standoff distance from the face of the column and variable mass of explosion to create blast explosion.

Resultant displacement of the column is analyzed. Results obtained in the end shows that use of steel fiber as an alternate to conventional reinforcement is effective. Steel fiber reinforced concrete column is improved in resisting displacement for close in blast.

Key Words: blast loads, displacements, steel fiber, LS-DYNA, LS Prepost, standoff

1. INTRODUCTION

A blast explosion in or near a structure can cause disastrous damages on the structure and on the internal objects, and most important can cause injuries and loss of life to occupants due to direct blast or structure collapse. Efforts have been made in the past few decades to develop methods to predict blast loading, predict the structural response to such extreme loads, and design the structure to resist or to withstand these loads and to prevent progressive collapse [1]. When any explosion takes place nearby the structure, expansion of hot gases produces pressure waves in the surrounding air known as the shock wave, which moves

outward from the center of the explosion with the same velocity as that of sound with very high pressure in front of the wave. Thus, hot gases and the high-pressure causes the wave to speed up to some level.

After a short period of time, pressure behind the front drops below the ambient pressure causing a partial vacuum in a negative phase. The front of the blast waves weakens as it progresses far from the explosion center, and its velocity drops so its peak pressure and can be treated as a sound wave [2].

Previous studies in this area have focused on slabs, with a limited number of investigations examining behavior of beams and columns. This research study was taken for further understanding of blast performance developments that may be achieved with the use of SFRC in columns. Parameters in the research study include concrete type, steel properties, fiber content, fiber properties, blast location and blast intensity.

There exists a need to explore the use of new and innovative materials that can improve blast resistant performance of reinforced concrete columns and steel fiber reinforced concrete column. Former research has shown that steel fiber-reinforced concrete (SFRC) can enhance many of the properties of traditional concrete. The inclusion of steel fibers to concrete improves post-cracking resistance, resulting improved strain capacity, toughness, and damage tolerance [3]. These properties make SFRC a desirable material to be use in blast-resistant design of structures. In columns, steel fiber reinforcement can be used to enhanced blast performance and control displacement of column.

Finite element analysis (FEA) software tools are of great help in the field of dynamic loads especially blast loads, because experimental tests on structures subjected to blast loads are more expensive as well hazardous. There are many finite element analysis software tools that are readily available in market for simulation of dynamic loads such as, ANSYS, ABAQUS, LS-DYNA, Dyna3D, etc. In this research work, LS-DYNA software is used which is very handy to use.

This research study is assumed for further understanding of blast performance enhancements when compared with reinforced concrete column that can be achieved from the use of SFRC in columns.

1.1 Earlier Research on Dynamic Performance of SFRC

As of now vast knowledge has been collected on the properties and behavior of SFRC subjected to dynamic loading, the properties and behavior of SFRC under very high strain rates is not understood. Some of the published research has focused on blast behavior and impact of SFRC structures. There is no such standardized test that exists for SFRC under impact loading; though, several researchers have studied and relate the behavior of SFRC using pendulum, drop-weight, and split Hopkinson pressure bar (SHPB) tests. This study has shown that the compressive strength, tensile strength, and flexural strength of SFRC improvised when subjected to blast loading. The behavior of SFRC has been influenced by strain rate, fiber content, and fiber properties in structure. However, some researcher's state that ductility and toughness when subjected to dynamic loading present in SFRC under static loading is absent or get reduced at high strain rates.

Experimental data showing the behavior of SFRC structural components under blast loading is extremely limited, however some limited research has been conducted on slab panels and beams. Lok and Xiao (1999) tested a series of simply supported (one-way) and fully fixed (two-way) SFRC panels subjected to varying blast loads. The panels he tested were reinforced with hooked-end steel fiber. It is observed that the SFRC panels demonstrated improved damage tolerance. Reduction in the residual displacements was observed in both the cases.

There is limited published data on blast behavior of SFRC structural components, with test data lacking on SFRC columns. Table- 1 shows some authors and their testing type on concrete structure for blast loading. Clearly more research and study are needed in the concerned area.

Table-1: Earlier Dynamic Tests on SFRC

Authors	Testing Type
Naaman and Gopalaratnam (1983) Gopalaratnam and Shah (1986) Banthia et al. (1996)	Impact test on SFRC with drop-weight or pendulum setup
Lok and Zhao (2004) Wang et al. (2007)	Impact test on SFRC with SHPB setup
Lok and Xiao (1999)	Blast test on SFRC slab panels by live explosive testing
Magnusson and Hallgren (2010)	Blast test on SFRC beams by air-blast loading

2. THEOROTICAL BACKGROUND

In this research blast loading is applied on the concrete column. There are several types of explosions that need to study. Blast wave phenomena is also an important parameter that must take into consideration. To model the blast which is to be applied on concrete column in LS-DYNA several techniques are defined.

2.1 Explosions

As stated, an explosion is a pressure disturbance caused due to the sudden release of energy in the form of flash and high sound. The produced pressure moves away from the explosion centre in the form of a wave generally known as shock wave or blast wave. The source of explosions may be physical, chemical, or nuclear. Several types of explosions are defined below. Explosions can be differentiated based on confinement of the explosive charge [5].

2.2 Unconfined Explosions

In this type of explosions, the shock wave reaches the structure directly with or without reflection and amplification as shown in fig-1. There are three subgroups present in the unconfined explosions,

(A) Free Air Burst Explosions

The explosion takes place far above the building so that the blast wave propagates away from the explosion centre and hit the structure directly without reflection and amplification of the initial shock wave.

(B) Air Burst Explosions

This type of explosion takes place above the structure and therefore the produced shock waves reaches the ground surface first and then reflects and reaches the structure.

(C) Surface Burst Explosions

This type of explosion takes place on or near the ground and thus the produced shock wave reflects first and then amplifies and get merged with the reflected wave finally reaching to the structure.

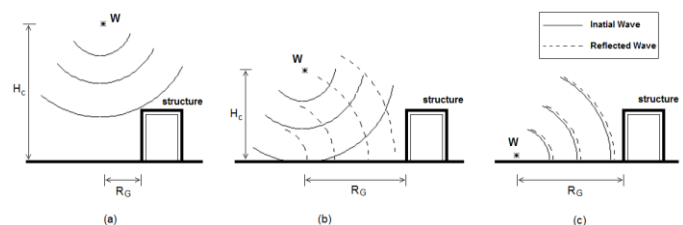


Fig- 1: (a) free air burst, (b) air burst, (c) surface burst explosions [6]

2.3 Confined Explosions

In this type of explosion charge detonates inside a fully or partially enclosed structure as shown in fig-2. The internal surfaces of the structure reflects and increase the amplitude of the produced shock wave many times and thus the value

of the pressure increased to higher values, the confined explosions [7] can be divided to,

(A) Fully Vented Explosions

In fully vented explosion type, explosive charge detonates in a structure with one or more than one opened surface. The initial shock wave reflects and get amplified by the closed surfaces and vents to the atmosphere from the opened surfaces.

(B) Partially Confined Explosions

In this type of explosions, the explosive charge detonates in a structure with specific size openings. The initial wave is amplified by the surfaces and vents to atmosphere from the openings after some time.

(C) Fully Confined Explosions

In this type of explosion, the explosive charge detonates in a totally closed structure. This type of blast is highly hazardous due to absence of vents to move the blast waves to the atmosphere.

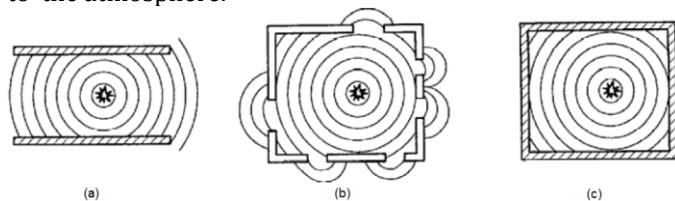


Fig-2: (a) Fully vented explosion, (b) Partially confined explosions, (c) Fully confined explosions [7]

2.4 Blast Wave Phenomena

Fig-3 shows a plot between pressure and time of blast wave from a free-air burst type of explosion, which includes two impulse phases on designated structure. The characteristics of this shown plot are dependent on blast loading parameters such as shape and mass of explosive used in the work, standoff distance and also the height of explosion from the ground [5]. Structural parameters like as the geometry of the structure, weight and size of the structure plays an important role in the characteristics of the given plot.

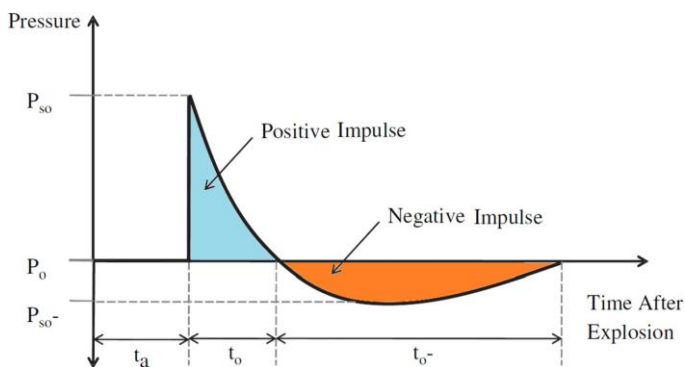


Fig-3: plot of free-field blast pressure-time history [5]

2.5 Modelling Techniques for Blast Loading

The blast loads can be modelled by different techniques. Simple calculation of the pressure produced from an explosive and applying the pressure to structural member. Also complicated technique is available includes modelling the charge, modelling the air domain around the charge and modelling the air domain around the structure independently.

(A) Empirical Blast Method

The air blast pressure is computed empirically with data from [5], and then the pressure is directly applied to the structural elements. This method requires modelling of concrete and steel elements only, modelling of air domain and explosives is not required. This method is very effective, requires less time.

(B) Multi Material Arbitrary Lagrangian Eulerian (MM-ALE) method

In this method, explosive and air domain has to be modelled independently in addition to concrete and reinforcement elements. The explosive charge is detonated within the air domain which is modelled and the shockwave is transferred through air to get in contact with the structure. The number of elements in this method is very high and thus requires very high simulation time.

(C) Coupling of empirical and MM-ALE method

This method is a combination of empirical and MM-ALE methods. The air domain is modelled and minimized. The blast pressure is modelled using the empirical method and applied to the air then transferred through air domain to get in contact with the structure. This method requires less time than MM-ALE method as number of elements are less than MM-ALE method but slightly higher than empirical method and gives almost the same results.

3. MODEL DESIGNING

The modern development of the finite element method (FEM) began in the 1940s in the field of structural engineering. The finite element method is a numerical method for solving problems of engineering. The finite element method was used to solve complicated structural problem to some extent, but not very complicated. With the invention of computers, it becomes very easy to analyse the complicated structural problems using finite element method. On the basis of geometry and the physical nature of the structural member, structural elements can be discretized using line, plane or volume elements. Line element are two-nodded or higher. Line elements typically used to represent a bar or beam element. Plane elements are two-dimensional elements with corner nodes typically used to represent plane stress/strain. Volume elements are Simple three-dimensional elements typically used to represent three-dimensional stress state.

3.1 Modelling in Ls-Dyna

Model of concrete column which is subjected to blast loads can be construct using the finite element analysis software Ls-Dyna. Individual modelling of reinforcement, concrete and fiber is to be done. After this all the individual parts are then put together using contact command to get the composite structure.

3.2 Steel Reinforcement Modelling

In LS-Prepost steel reinforcement model can be made using plane or volume elements. Modelling of steel using plane elements is easy and simple to model. As model will have less number of elements than in the volume elements, therefore their analysis does not need much time. But, use of volume elements to model steel in LS-Prepost is a good choice because it reflects the behaviour of steel as more accurately when compared with practical structural element. In this research, the steel bars were first modelled in LS-Prepost as volume tubes. The elements created using the meshing function. Meshing function requires entering size of the element that is needed. The size of the element is the average length of the element in all directions. The auto meshing function in the software automatically selects the appropriate element shape and generate it.

3.3 Concrete Modelling

Concrete was modelled and meshed in one step by using shape mesher function in LS Prepost.

3.4 Materials modelling

Modelling is done in Ls-Dyna Prepost, with selecting proper materials type so that it behaves as a practical model.

(A) Concrete material

A wide variety of material models for concrete exist in LS-DYNA material library. Some of the models are specialized and can be used in the exceptional condition and some of them are for modelling of concrete for general purpose. The concrete in this research was modelled as solid elements using material type 159(MAT_CSCM_CONCRETE) where fewer inputs parameters for the concrete model such as the unconfined compression strength, the aggregate size, and the units.

(B) Steel material

The steel reinforcement was modelled using material type 24 (MAT_PIECEWISE_LINEAR_PLASTICITY). This material model represents steel reinforcement behaviour, with plastic deformation, strain rate effects, and failure. The material model for steel reinforcement requires input of mass density, modulus of elasticity, yield stress, and tangent modulus for simple modelling of steel.

(C) Steel Fiber Material

In this study the steel fiber are designed as 1D line bodies. Fibre reinforcement was then generated for the given volume. The reinforcement is of the "straight end" type, with a length of 50 mm and a diameter of 1 mm. The

reinforcement is generated using a random distribution algorithm in such a way that it fills the volume of the cylinder as regularly as possible [8].

3.4 Blast Loads Model

The blast load was applied using empirical method by using keyword LOAD_BLAST_ENHANCED, it uses equivalent mass of TNT located in well-defined coordinates for the purpose of generating the blast load. The blast load was applied to the surfaces of the face of the concrete column structure by using LOAD_BLAST_SEGMENT_SET keyword.

4. SIMULATED COLUMN SPECIFICATIONS

The column used in this study is of rectangular cross-section with dimensions as 300*300*3000 mm. To restrict the column rotation and translation when blast waves reach on it the top and bottom ends of columns are fixed using the SPC_SET parameter in Ls-Dyna Prepost.

4.1 Concrete

Table 2 shows the concrete model parameter values that has been used in the study for the formation of concrete part.

Table-2: Concrete Model Parameters

Parameter	Value	Unit
Mass Density	2.5e ⁻⁶	Kg/mm ³
Compression Strength	0.028	GPa
Max Aggregate size	9.525	mm

Concrete is modelled and meshed using shape mesher function.

4.2 Reinforcement

Longitudinal reinforcement of the column is of 25mm diameter and transverse reinforcement diameter is 10mm. Clear cover is 30mm. Table 3 shows the reinforcement model parameter values that has been used in the study for the formation of reinforcement part.

Table-3: Reinforcement Model Parameters

Parameter	Value	Unit
Mass density	7.85e ⁻⁶	Kg/mm ³
Modulus of Elasticity	200	GPa
Poisson's Ratio	0.3	
Yield Stress	0.42	GPa
Tangent Modulus	0.19	GPa

4.3 Blast Load

To produce the blast wave, TNT of 45Kg and 90Kg are used in this study. Standoff distance is taken as 1m and 2m to relate the effect of variable blast loading on the concrete

column. Table 4 shows the blast model parameter values that has been used in the study for the formation of blast.

Table-4: Blast Load Parameters

Parameter	Value	Unit
Equivalent mass of TNT	45	Kg
X-coordinates of point of explosion	1300	mm
Y-coordinates of point of explosion	150	mm
Z-coordinates of point of explosion	100	mm
Detonation Time	0	ms
Unit conversion flag	6	
Conversion factor for time	1	

4.4 Elements and Fixity of Column

Composite model is then formed by defining contact between steel reinforcement and concrete, for this purpose (CONSTRAINED_LAGRANGE_IN_SOLID) function is used. Table 5 shows the material and number of respective elements of the model.

Table-5: total elements of model

Material	No. of elements
Steel reinforcement	416
Steel fiber	6572
Concrete	17280
Total	24268

In the model steel fibers are defined as 1D elements. To restrained the column in translation and rotation, top and bottom ends are made fixed and to apply the blast loading on the column empirical method is used.

5. RESULTS

When the concrete column is subjected to blast loads, displacement of column is analysed . To relate the difference between conventional steel reinforcement and steel fiber reinforcement, displacement of column is checked at two different locations with two different standoff distances and also two different masses of TNT. Standoff distance of 1m and 2m is taken in this study. For the purpose of blast loading masses of TNT are taken as 45Kg and 90Kg.

Displacement of the column is measured at two different locations, one at the center of column and another at the distance of 400mm from bottom of column.

5.1 Steel Reinforcement and 45Kg TNT

Here the column with steel reinforcement and mass of TNT 45Kg is taken as shown in fig.4 to analysed the blast loading on column. In this case the blast explosion location is taken as 1m and 2m from the face of the column. Fig.5 shows the results obtained from the simulation of blast loading at two different locations.

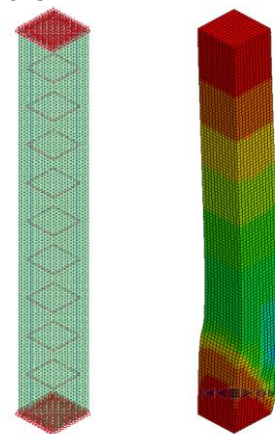


Fig-4: RCC column before and after blast

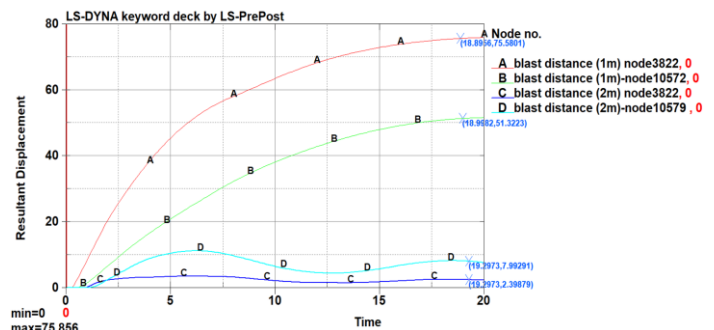


Fig-5: RCC column displacement for 45Kg TNT for standoff distance of 1m and 2m

5.2 Steel Fiber Reinforcement and 45Kg TNT

Here, steel fiber reinforcement and mass of TNT 45Kg is taken as shown in fig.6 to analysed the blast loading on column. In this case the blast explosion location is taken as 1m and 2m from the face of the column. Fig.7 shows the results obtained from the simulation of blast loading at two different locations.

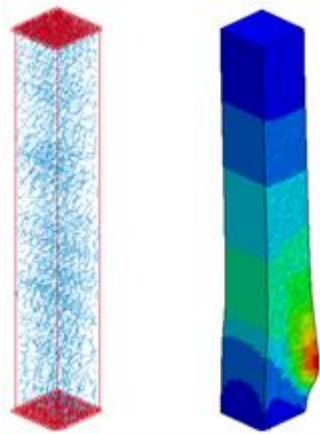


Fig-6: steel fiber reinforced column before and after blast

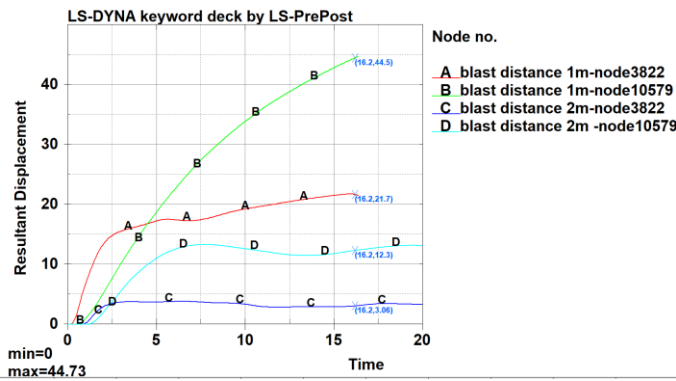


Fig-7: Steel fiber reinforced concrete column displacement for 45Kg TNT for standoff distance of 1m and 2m

5.3 Steel reinforcement and 90Kg TNT

Column with steel reinforcement and mass of TNT 90Kg is taken as shown in figure to analyzed the blast loading on column. In this case the blast explosion location is taken as 1m and 2m from the face of the column. Fig. 8 shows the results obtained from the simulation of blast loading at two different locations.

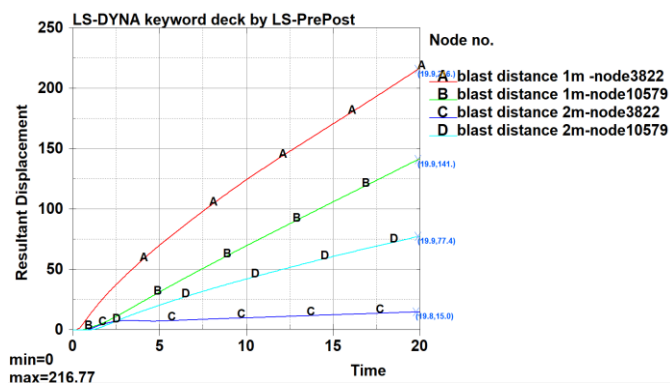


Fig-8: RCC column displacement for 90Kg TNT for standoff distance of 1m and 2m

5.4 Steel Fiber Reinforcement and 90Kg TNT

Here the column with steel fiber reinforcement and mass of TNT 90Kg is taken to analysed the blast loading on column. In this case the blast explosion location is taken as 1m and 2m from the face of the column. Fig.9 shows the results obtained from the simulation of blast loading at two different locations.

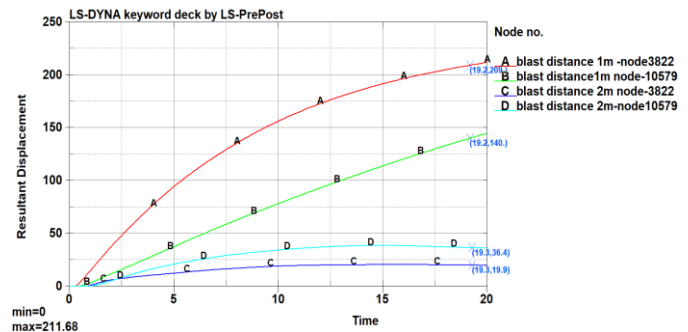


Fig-9: Steel fiber reinforced concrete column displacement for 90Kg TNT for standoff distance of 1m and 2m

5.5 Comparison of Results

Based on the different conditions, how concrete column will react to the blast loads is shown in table 6. Displacement results of the concrete column are compared and relative study of reinforcement i.e., steel fiber and conventional steel, standoff distance and quantity of TNT used is made.

Table-6: Column Displacement Comparison

Standoff Distance (mm)	Mass of TNT	Steel Reinforcement Resultant displacement		Steel Fiber Resultant displacement	
		Node 3822	Node 10579	Node 3822	Node 10579
1000	45Kg	75.58	51.32	21.7	44.5
2000		2.39	7.99	3.06	12.3
1000	90Kg	216.77	141	209	140
2000		15	77.4	19.9	36.4

Node number 3822 is at the distance of 400mm from the bottom of column and node number 10572 is at the middle of the column. Lines A and B in the figures shows the displacement for the blast location 1m from column and lines C and D shows the displacement for the blast location 2m from column.

6. DISCUSSION

1. Central deflection is more when standoff distance increases because blast wave propagates and reaches the column.

2. As the standoff distance is 1m, it is near to the column and therefore maximum deflection occurs at the distance of 400mm from the bottom.

7. CONCLUSIONS

1. When standoff distance increases from 1m to 2m, deflection at center is more in both cases of TNT.
2. As compared to steel reinforcement, steel fiber reinforcement shows better resistance to displacement when close blast is applied.
3. When mass of TNT increases to 90kg from 45kg, results for fiber and steel reinforcement are nearly same.
4. For close in blast, steel fiber column shows significantly good results.

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