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Analysis of steel fiber reinforced concrete wall-column connection using headed bars subjected to blast loading

Mayuresh Suresh Nalawade *, Vaibhav Vilas Shelar, Sonal Vaibhav Shelar and Vijay Shivaji Shingade

Department Of Civil Engineering Trinity College of Engineering and Research, Pune, India.

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Abstract

The rising frequency of terrorist attacks and accidental explosions in recent years has underscored the necessity of incorporating blast-resistant design considerations into structural engineering. Blast loads, though uncommon, are highly dynamic in nature and can cause catastrophic failure in conventional reinforced concrete structures if not properly accounted for. This study focuses on analyzing the structural behavior of precast steel fiber reinforced concrete (SFRC) wall-column connections utilizing headed bars as the primary connection mechanism when subjected to blast loading. Four connection configurations are examined: (1) conventional dowel bar connections, (2) headed bar connections, (3) dowel bar connections with steel fibers, and (4) headed bar connections with steel fibers. The inclusion of steel fibers is intended to enhance ductility, energy absorption, and crack resistance under extreme loading. Numerical modeling and simulation are performed using ANSYS Workbench, employing nonlinear dynamic analysis to evaluate response parameters such as displacement, stress distribution, and failure mode under varying charge weights and standoff distances. Results are expected to demonstrate that SFRC with headed bar connections provides superior blast resistance compared to conventional systems due to improved anchorage, reduced stress concentration, and enhanced post-cracking behavior. The findings aim to contribute to the development of efficient, blast-resistant connection systems for precast structural elements, improving overall safety and resilience in modern construction practices.

Keywords: Blast Loading; Steel Fiber Reinforced Concrete; Headed Bar Connection; Wall-Column Joint; Dynamic Analysis

1. Introduction

The blast explosion around or within structure is due to pressure or vehicle bomb or quarry blasting. These leads to catastrophic damage to the building both externally and internally depending on the scenario. Which Results in collapse of walls, blowing out of windows, and shutting down of critical life-safety systems. Buildings, bridges, pipelines, industrial plants dam etc. are the lifeline structures and they play an important role in the economy of the country and hence they have to be protected from dynamic and wind loading.

Such buildings should be shielded from the effects of bombing, and are undoubtedly the targets of terrorist attacks. Because of the non-linear behavior of the material the dynamic response of the structure to blast loading is complex to analyses. Explosions result in high dynamic loads compared to the original design loads for which the structure is analyzed. Therefore, blast loading research and configuration requires a detailed understanding of blast and its phenomenon.

* Corresponding author: Mayuresh Suresh Nalawade

Terrorist activities and threats is a growing problem nowadays around the world. Hence the concept blast protection is found to assume an imperative part with the structural engineers. Consideration of blast load along with other dynamic loads like earthquake and wind loads is playing a vital role in the design of structures these days due to increase of terrorist activities happening since few years especially in metropolitan cities. Terrorist attacks target where human causalities and economic consequences are likely to be substantial. Structural buildings are considered to be attracting targets because of its potential impacts and accessibility on economic activities and human lives.

1.1. Steel Fiber Reinforced Concrete

Fiber reinforced concrete is a composite material comprised of Portland cement, aggregate, and fibers. Normal unreinforced concrete is brittle with a low tensile strength and strain capacity. The function of the irregular fibers distributed randomly is to fill the cracks in the composite. Steel fiber reinforced concrete is a composite material having fibers as the additional ingredients, dispersed uniformly at random in small percentages, i.e. between 0.3% and 2.5% by volume in plain concrete.

1.2. Headed Bars

Headed bars are formed by attachment of a steel anchor (known as head) at the end of reinforcement bar at a shallow embedment depth by welding, which provides large bearing area and anchorage.

1.2.1. Properties of headed bars

- The use of headed bars offers a higher bond capacity.
- Headed bars also provide adequate shear transfer.
- Headed bars eliminate the use of large hooks to develop stiff anchorage.
- Headed bar provide more ductility and ultimate strength on walls and columns than conventional dowel bars

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2. Materials and Methods

2.1. Explosion And Blast Phenomenon.

An explosion is a rapid release of potential energy characterized by eruption enormous energy to the atmosphere. A part of energy is converted to thermal energy radiation (flash) and a partis coupled as air blast and shock waves which expand radially. The material should have the following features to be an explosive; to be an explosive, the material will have the following characteristics. Must contain a substance or mixture of substances that remains unchanged under ordinary conditions, but undergoes a fast-chemical change upon stimulation. This reaction must yield gases whose volume under normal pressure, but at the high temperature resulting from an explosion is much greater than that of the original substance. The change must be exothermic in order to heat the products of the reaction and thus to increase their pressure. Common types of explosions include construction blasting to break up rock or to demolish buildings and their foundations, and accidental explosions resulting from natural gas leaks or other chemical/explosive materials

2.2. Problem Statement

The terrorist activities and threats have become a growing problem all over the world and protection of the citizens against terrorist acts involves prediction, prevention and mitigation of such events. In the case of structures an effective mitigation may also be thought in the terms of structural resistance and physical integrity.

Analysis of precast reinforced concrete wall-column system subjected to blast loading using Ansys Workbench Software. Precast RC wall-column system considered here consists of a 2260 mm high, 150 mm thick solid wall connected to 350 × 350 mm precast RC hollow columns and M30 concrete and Fe415 steel.

Carry out a comparative study of precast reinforced concrete wall-column system using dowel bars and headed bars as connection system with and without steel fibers.

2.2.1. There are three types of headed bars

- Plain headed bar
- Grooved headed bar and
- Ribbed headed bar

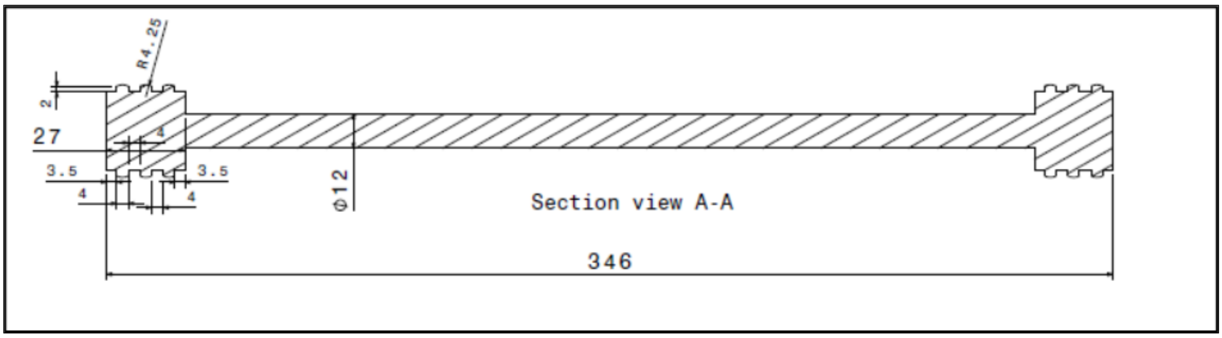

Figure 1 Detailing of headed bar

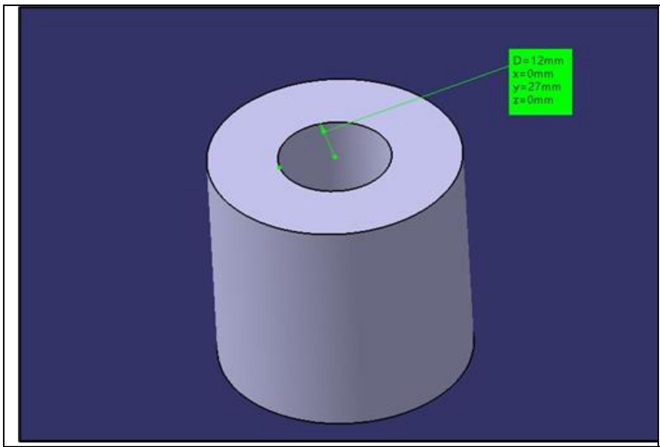

Figure 2 Plain headed bar

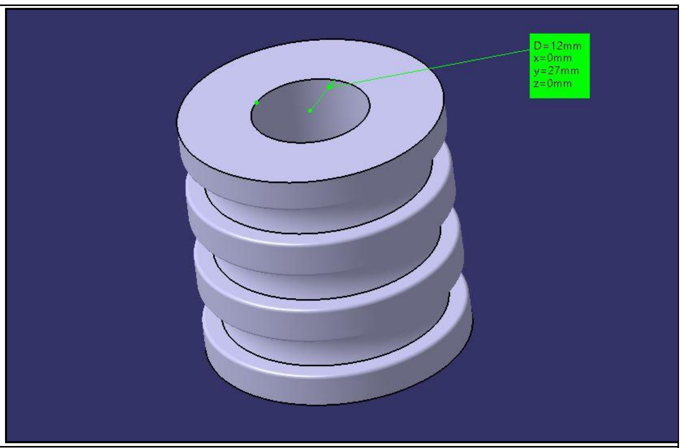

Figure 3 Grooved headed bar

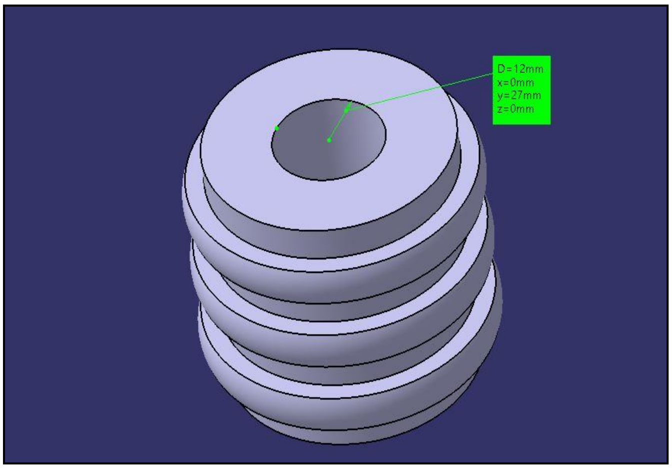

Figure 4 Ribbed headed bar

ACI 318-14 recommends net bearing area to be at least 4 times the area of bar. Thus, the head anchor or head of bar of equal length and diameter of 27 mm is used as the diameter of the rebar is used is 12mm. Thus, total length (embedment in both wall and column) for headed bar and dowel bar connection is 346 mm and 866 mm respectively.

Table 1 Modeled specimens for numerical analysis

Specimen notation	Connection details	Embedment depth in wall (mm)	Embedment depth in column (mm)
DB	Dowel bar (without head)	433	257
PHB	Plain headed bar (27 mm dia. and 27 mm length)	173	173
GHB	Grooved headed bar (27 mm dia. and 27 mm length)	173	173
RHB	Ribbed headed bar (27 mm dia. and 27 mm length)	173	173

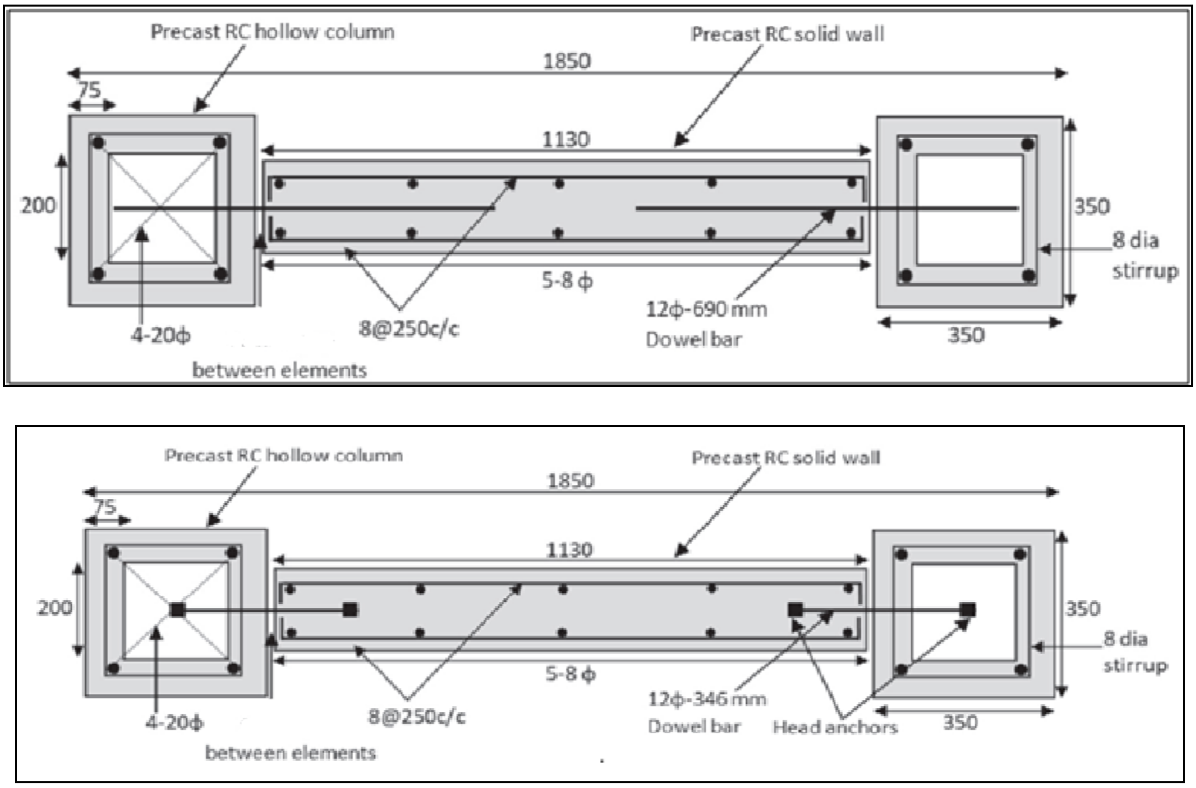

Figure 5 Precast RC wall and columns connected through (a) dowel bar system; and (b) headed bar system

2.3. Model details

- Size of foundation – 2.15 x 3.65 x 0.4 m
- Size of column – 0.35 x 0.35 x 2.26 m
- Size of wall – 3.11 x 1.15 x 0.15 m

Table 2 Modelling in ANSYS

Model 1	**Plain headed bar**	**2 Bars**
		3 Bars
		4 Bars
Model 2	Grooved headed bar	2 Bars
		3 Bars

		4 Bars
Model 3	Ribbed headed bar	2 Bars
		3 Bars
		4 Bars

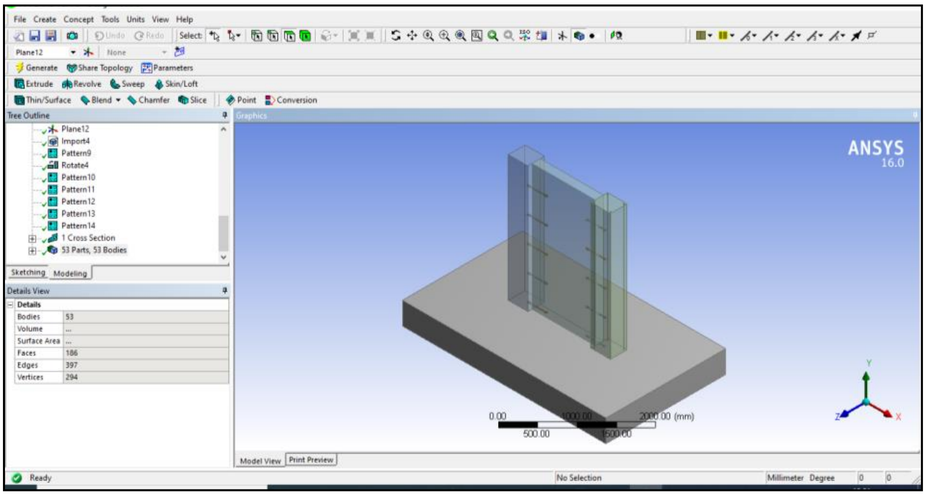

Figure 6 Model as u required sizes in Geometry option

3. Results and Discussion

3.1. Total Deformation

Table 3 Common result table of Total Deformation

Connection Bars	**Total Deformation**			
	2 Bar	3 Bar	4 Bar	Steel Fibre 4 Bar
Dowel bar	38.06	32.623	28.545	22.203
Plane bar	30.448	26.099	22.836	18.873
Groove bar	27.785	23.644	20.911	17.282
Ribbed bar	28.063	23.881	21.12	17.455

From Table 3, it is observed that the Groove bar connection exhibits the least total deformation, followed by the Ribbed bar, while the Dowel bar shows the highest deformation under blast loading. Increasing the number of bars from 2 to 4 significantly reduces deformation for all connection types, indicating improved stiffness and load distribution. The inclusion of steel fibres further decreases total deformation, enhancing ductility and energy absorption. Among all configurations, the steel fibre reinforced Groove bar connection achieves the lowest deformation, proving to be the most effective in resisting blast-induced stresses and maintaining structural integrity.

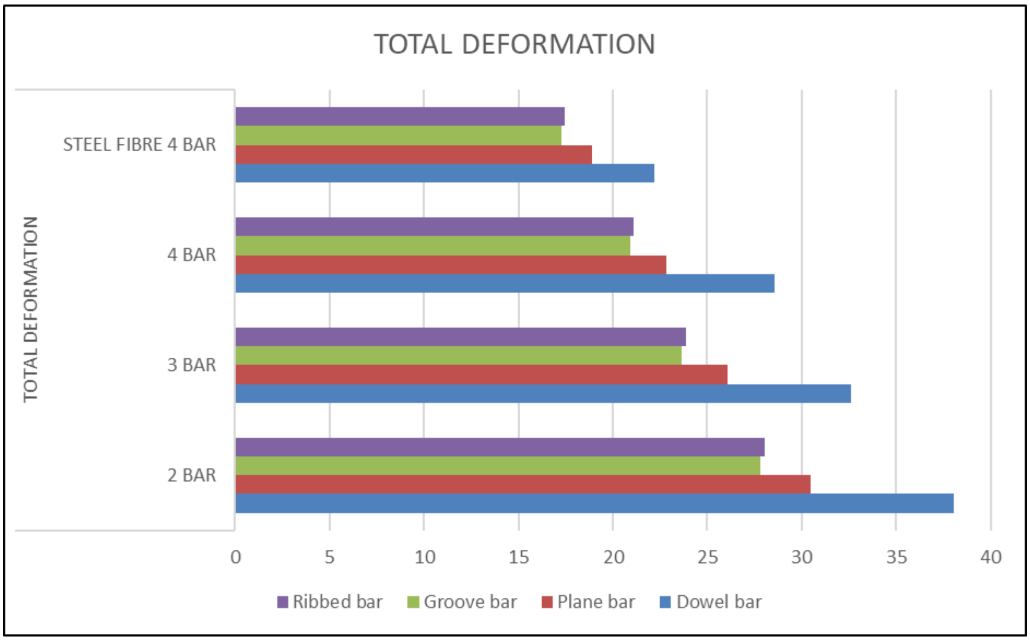

Figure 7 Common result of Total Deformation

4. Validation

Table 4 Validation of models

Name	**Values**	**Units**
Force (V)	1000000	N
Distance	1850	mm
Moment	1850000000	N·m
Column Breadth(b)	350	mm
Column Width(d)	350	mm
Wall Breadth(b)	150	mm
Wall Width(d)	1130	mm
Area(A)	414500	mm2
I	1250520833	mm4
Z	7145833.333	mm3
y	175	
E	25000	
Total Deformation mm (PL/EA)	0.178528347	mm

Table 5 Validation -Total Deformation

Total Deformation mm	
Analytical	Ansys
0.178528347	0.18374

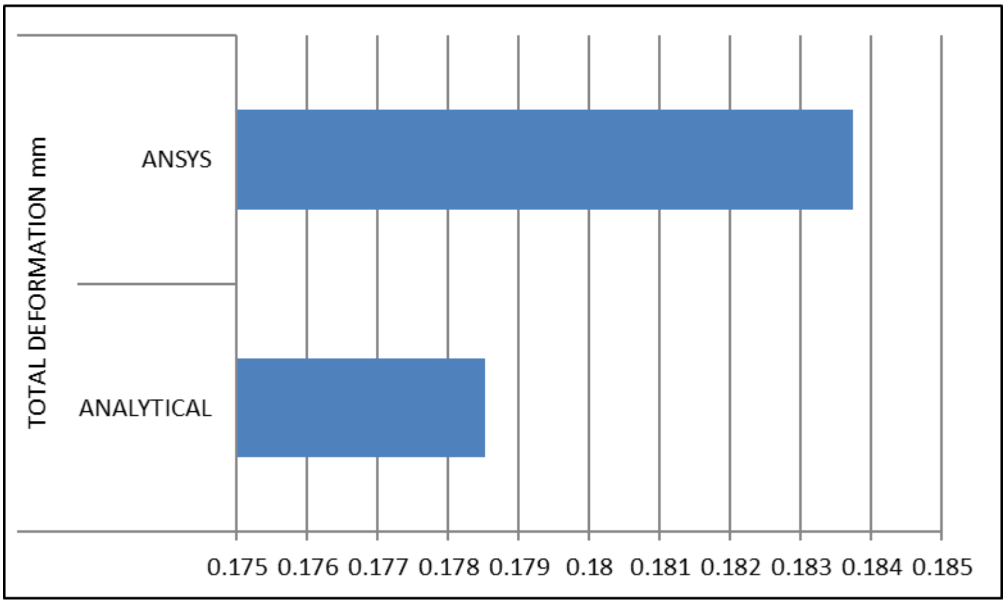

Figure 8 Total deformation (validation)

Table 5 presents the validation of total deformation results obtained from analytical calculations and ANSYS simulation. The analytical value of total deformation is 0.1785 mm, while the ANSYS result is 0.1837 mm. The small variation between the two values (approximately 2.9% difference) indicates a strong correlation and validates the accuracy of the numerical model. This close agreement confirms that the modeling assumptions, boundary conditions, and material properties used in ANSYS are reliable and consistent with theoretical expectations. Therefore, the simulation results can be confidently utilized for further parametric and comparative analysis.

5. Conclusion

The present study focused on analyzing the blast performance of precast steel fibre reinforced concrete (SFRC) wall-column connections using headed bars as the primary connection system. Numerical simulations were carried out using ANSYS Workbench to evaluate the deformation and stress response of various connection types under different blast loading conditions.

From the results, it was observed that bar configuration, connection type, and inclusion of steel fibres significantly influence the overall deformation and energy absorption capacity of the structure. Among the four connection types analyzed—Dowel, Plane, Groove, and Ribbed bars—the Groove bar connection exhibited the least total deformation, followed closely by the Ribbed bar, demonstrating superior bond strength and energy dissipation characteristics. The inclusion of steel fibres further enhanced the ductility and reduced deformation across all connection types, confirming their effectiveness in improving the blast resistance of precast systems.

Validation of analytical and ANSYS results showed close agreement, reinforcing the reliability of the simulation model. The findings suggest that steel fibre reinforced groove or ribbed bar connections offer the best performance under blast loading, providing a balanced combination of strength, ductility, and resilience.

Overall, this study emphasizes the importance of adopting improved connection detailing and material enhancement techniques to ensure the safety of precast concrete structures exposed to extreme dynamic loads such as explosions. The outcomes serve as a valuable reference for future design and optimization of blast-resistant structural systems.

Compliance with ethical standards

The authors confirm that the present study adheres to the ethical standards of academic and research integrity. All methods and analyses have been conducted responsibly and without any form of academic misconduct.

Disclosure of conflict of interest

The authors declare that there is no conflict of interest to disclose regarding the publication of this paper.

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