An Analytical Modeling of Steel Fiber Reinforced Concrete as a Structural Member

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Abstract: *The purpose of this research work is to introduce the application of Steel Fiber Reinforced Concrete (SFRC) as a structural material in building structural load bearing elements like Columns and beams, for this purpose first the previous research work was referred that have been done to obtain various important mechanical properties of SFRC which helps us to understand its behavior as a structural element. After getting most appropriate properties obtained by experimental material testing on SFRC, the material was simulated using software approach. The software used in this analysis was ETABS 17.0.0. After modifying this SFRC material with Conventional M40 grade concrete, seismic analysis of G + 8 story RC frame building was performed and the results have definitely shown that SFRC building Model have performed better under seismic loading.*

Keywords: Steel Fiber, Concrete, Steel Fiber Reinforced Concrete Beams, Steel Fiber Reinforced Concrete Column, SFRC MODEL, Seismic Analysis

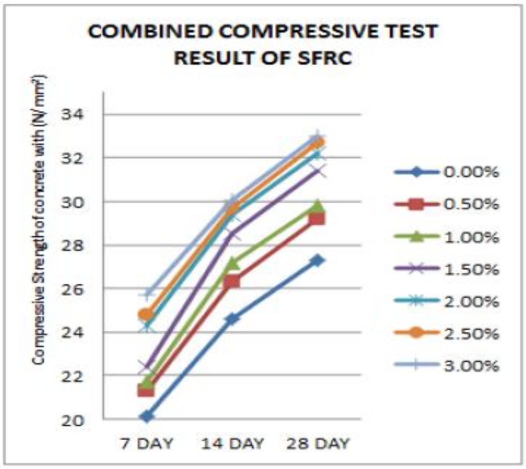
1. INTRODUCTION:

As the market for high-resistance concrete has risen, reinforced concrete's structural nature has become more brittle. To mitigate this side effect, steel fiber-reinforced concrete (SFRC) has emerged as a viable method for obtaining ductility not only during tensioned post-cracking behaviour, but also during compressed post-peak softening behaviour. Use of SFRC as a structural member has also found to increase its ductility to some extent that may be proved to be a better material under seismic loading as well. Steel fiber reinforced concrete (SFRC) has a distinctive tensile strength, impact resistance, resistance to fatigue, flexural resistance ductility and crack arrest capability. They also diminish concrete permeability and thus decrease water bleeding. It is, such building material is studied for over 40 years as well as for pavement construction [1]. Many experimental research in past have been performed that aims to collect data on the effect of steel fiber and its combination on workability, compressive strength , flexural strength and non-destructive testing (NDT) such as Rebound Hammer, in order to assess SFRC efficiency relative to traditional concrete[2- 12]. There are many types of steel Fiber available in the market but majorly used types are: traditionally straight, hooked, crimped, coned, etc. In the present framework various mechanical properties of hooked end steel fiber is used for the modeling of SFRC.

The experimental research performed by [13] shows that the rise in the proportion of steel fibers in concrete subjected to the moment of hogging increases their compressive power. As per experimental study done by [14], the strength enhancing ultra high reinforced steel Fiber capacity Concrete strength (SFRC) containing 0.5%, 0.75%, 1.0% and 1.5% volume of hooked-end steel Fibers. Steel Fiber reinforced concrete (SFRC) is utilized in various applications for broad blocks such as heaw vibrating machinery frames, dolos shield systems, spillways, bridge overlays, etc [15]. Also addition of Steel Fibers in concrete improves the resilience, ductility and durability of standard RC members under earthquake and blast loads (dynamic loads) [16]. In terms of minimizing the development of cracks in concrete by Adding SFs one can prevent crack growth and crack widening; this may allow the use of high-strength steel bars without undue crack width or duty load deformation [17, 18]. Spalling of concrete is seen many times due to excessive loading and low confinement, use of SRFC may reduce this problem to some extent by providing enhanced impact resistance to traditional RC members, enhancing local damage and spreading resistance [19].

2. METHODOLOGY:

Based on previous research and experimental works performed by many researches on determination of various mechanical properties and behavior of SFRC under Flexural, Compression as well as Tension further seismic analysis for this research was done. Research has shown that behavior of SFRC is much similar to that of normal concrete with minor exception. In an experimental work on M20 concrete [9] observed that its superior resistance to cracking and crack propagation is one of the important properties of Steel Fiber Reinforced Concrete (SFRC). And the concrete is reinforced in various amounts with the steel fiber such as 0 percent, 0.5 percent, 1.0 percent, 1.5 percent, 2 percent, 2.5 percent and 3 percent by cement weight. Aspect Ratio 60 (30 mm long and 0.5 mm diameter) has been tested for all volume proportions. On the 7th, 14th and 28th day of curing the Compressive and Tensile Strength were analyzed as per IS standards. The results obtained were as follows:



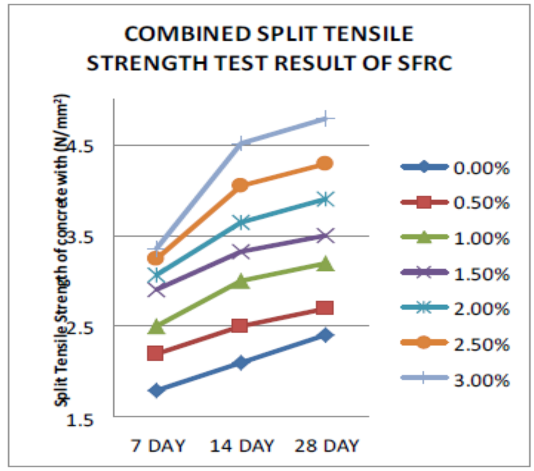


Figure: 2.1 Comparision of Strength parameters of SFRC [9]

It can be observed that the Compressive strength for M20 concrete is in increasing order from 0.0 % to 3 % of steel fiber use concrete and the maximum strength is gained at 3.0% that is 33 MPa. Also for the same samples the Split Tensile strength is in increasing order and the maximum strength is gained at 3.0 % that is 4.8MPa.

In an another experiment performed by [10, 11] in which Hook end steel fiber with different aspect ratio of 50, 60 and 67 were used in M40 grade concrete with with 0%, 1%, 2% and 3% Steel Fiber. For the same samples with different aspect ratios maximum increase in percentage flexural strength was found with Hook end steel Fiber Reinforced M40 concrete with aspect ratio 50. The results for the percentage increase in flexural strength and compressive strengths of different % of steel fiber containing SFRC for Aspect ratio 50 is represented by the graph shown in

FLEXURAL STRENGTH OF SFRC WITH 0%, 1%, 2% and 3% FIBERS				
Different aspect ratios of fibers	For Normal M40 with 0% fibers	For SFRC with 1% fibers	For SFRC with 2% fibers	For SFRC with 3% fibers
	Flexural strength (MPa)			
	Avg.	Avg.	Avg.	Avg.
	7.47	8.8	9.47	10.4
		8.4	9.2	10
		8.27	9	9.73

Table: 2.1 Flexural Strength of SFRC with 0% of steel fiber in M40 grade concrete

COMPRESSIVE STRENGTH OF SFRC WITH 0%, 1%, 2% and 3% FIBERS				
Different aspect ratios of fibers	For Normal M40	For SFRC	For SFRC	For SFRC
	with 0% fibers	with 1% fibers	with 2% fibers	with 3% fibers
	Comp. strength (MPa)			
	Avg.	Avg.	Avg.	Avg.
50	45.19	52	53.33	56.3
60		50.37	52.59	54.07
67		50.22	51.41	53.04

Table2.2 Compressive Strength of SFRC with 0% of steel fiber in M40 grade concrete

Hence from the experimental work based on different types, aspect ratio and % of steel fibers used in SFRCs we can say that SFRC with 3% of steel fibers is showing maimum flexural, tensile and compressive strength as compared to the normal conventional concrete [9, 10, 11].

It can be observed from the results that the flexural strength is maximum in the case of Hook end SFRC with 3% steel fiber and aspect ratio 50 i.e. 10.40 MPa. Also the compressive strength of the same sample was found to be maximum i.e. 56.30 MPa.

2.1 Modeling:

In the present research work, SFRC with Hooked shaped steel fiber(Aspect ratio= 50 and 3% steel fiber) is used as a Structural material in Beam and Column. Also the same was simulated and modelled in ETABS 17.0.0 sofware in which the a comparitive seismic analysis was performed to study the behaviour of M 40 grade SFRC based G+8 storey model in which only Beam and Column material was replaced with 3% SFRC, where as slab was same as conventional M40 grade. The same model was compared with conventional M40 grade concrete Reinforced Concrete model in which all structural elements such as Beam, Column and slab were of standard M 40 Grade (0% SFRC). Based on various Results Outcomes after seismic analysis of both the Models various Comparisons were done.

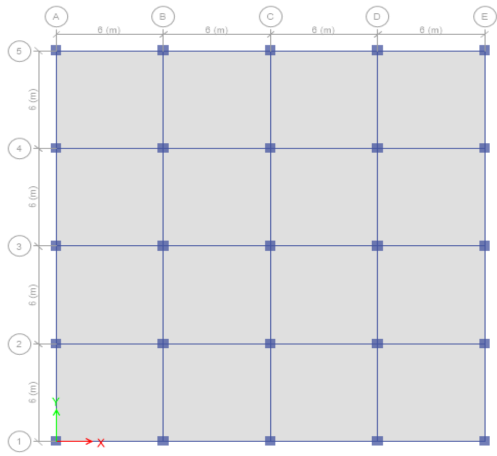
The other relevant data for modifying the material properties of M 40 grade concrete to M 40 SFCR- 3% (Molel-2) Model was referred to previous research work and literature available and mentioned in this paper. Some of the comparison of various Material properties of Conventional M40 Model (Model-1) is shown in the table below:

Propeties	Specific Weight Density (kN/m^3)	Mass per unit volume (kg/m^3)	Modulus of elasticity (Mpa)	Poisson's ratio	Coefficient of thermal expansion	Shear Modulus (Mpa)
MODEL- 1	24.9926	2548.538	31622.78	0.2	0.0000055	13176.16
MODEL - 2	26.59	2711.424	37516.661	0.2	0.0000055	15631.94

Table: 2.3 Material Properties of used for simulation: MODEL- 1 and MODEL- 2

MODEL-1: Conventional M40 Model

MODEL-2: M 40 SFCR- 3% Model in which M40 grade concrete with 3 % steel fiber was used in Beam and Columns only, Slab remains same as M 40 grade Conventional concrete)



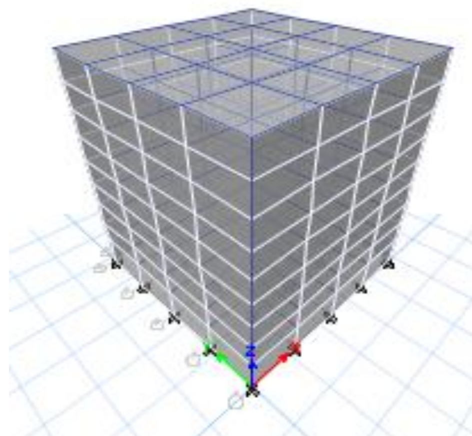


Figure: 2.1 **Figure: 2.2**

Figure: 2.1- Plan view of G+8 multi - story building Model

Figure: 2.2- 3-D view G+14 multi-story building Model

2.1.1 Loads:

The data here is showing the loading information as applied to the models.

The Following Loads were applied to both the Models:

1. Dead Load = 3 kN/m on slab
2. Live Load Load = 6 kN/m on slab
3. Cladding Load on exterior beams = 0.2 kN/m
4. Earthquake Load in X direction = As per IS 1893:2016
5. Earthquake Load in X direction = As per IS 1893:2016
6. Seismic Zone: V
7. Response reduction factor = 3
8. Soil Type = 2 (medium)
9. Importance Factor = 1

2.1.1.1 Load Patterns:

Name	Type	Self Weight Multiplier	Reference
Dead	Dead	1	Auto Load
Live	Live	0	
EQ	Seismic	0	IS 1893:2016

Table 2.4 - Load Patterns

2.1.1.2 Load Combination as per IS 1983: 2016:

- 1.2 [DL + LL + (ELx+ 0.3 Ely + 0.3 ELz)]
- 1.2 [DL + LL - (ELx+ 0.3 Ely + 0.3 ELz)]
- 1.2 [DL + LL+ (ELy+ 0.3 Elx + 0.3 ELz)]
- 1.2 [DL + LL - (Ely + 0.3 Elx + 0.3 ELz)]
- 1.5 [DL + (ELx + 0.3 Ely + 0.3 ELz)]
- 1.5 [DL - (ELx + 0.3 Ely + 0.3 ELz)
- 1.5 [DL + (Ely + 0.3 ELx + 0.3 ELz)]
- 1.5 [DL - (Ely + 0.3 ELx + 0.3 ELz)] 0.9 DL + 1.5 (ELx + 0.3ELy + 0.3ELz)
- 0.9 DL - 1.5 (ELx + 0.3Ely + 0.3 ELz) 0.9 DL + 1.5 (Ely + 0.3ELx+ 0.3ELz)
- 0.9 DL - 1.5 (Ely + 0.3ELx + 0.3 ELz)

Name	Type
Dead	Linear Static
Live	Linear Static
EQ	Linear Static

Table 2.5 - Load Cases - Summary

3.1.2 Model Sectional and Material Parameters:

Parameter	Rebar in all members (Main)	Rebar in all members (Confinement)	Beam Material (Concrete)	Beam Size	Column Material (Concrete)	Column Size	Slab material (Concrete)	Slab Thickness	Height of Building
Model-1	FE 500	FE 250	M40	600 x 600 mm	M40	600 x 600 mm	M40	150 mm	29.2 m (9 Storey)
Model-2			SFRC M40 3%		SFRC M40 3%				

Table 2.6 Material parameters of MODEL-1 & MODEL-2

3. RESULTS AND DISCUSSION:

The following Results were obtained after the Seismic analysis of both the Models (MODEL-1 and MODEL-2). Also the results compared here are only for Earthquake Load case.

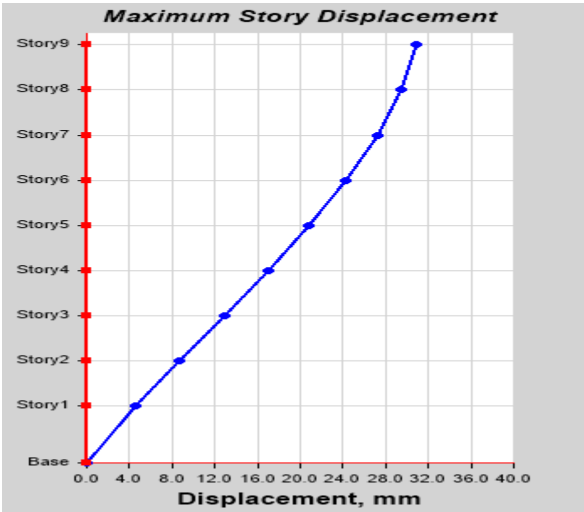


Figure: 3.1 **Figure: 3.2**

Figure: 3.1- Maximum storey Displacement for MODEL-1

Figure: 3.2- Maximum storey Displacement for MODEL-2

TABLE: Max Story Displacement						
Story	**Elevation**	**Location**	**MODEL-1**		**MODEL-2**	
			X-Dir	**Y-Dir**	**X-Dir**	**Y-Dir**
	m		mm	mm	mm	mm
Story9	29.2	Top	30.8123514	0.004962469	28.90062	0.00508
Base	0	Top	0	0	0.00000	0.00000

Table 3.1

- In Model- 2 the Maximum storey Displacement is decreased in X direction by 3.201529 % and increased in Y Direction by a very low margin of 1.2 % from Model-1 in the top storey

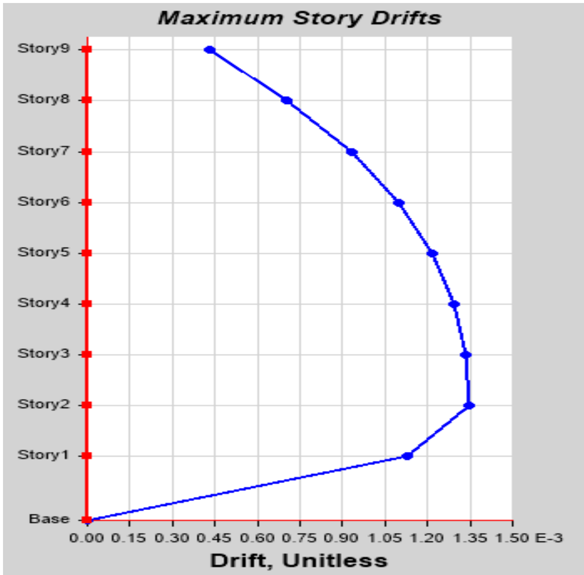


Figure: 3.3

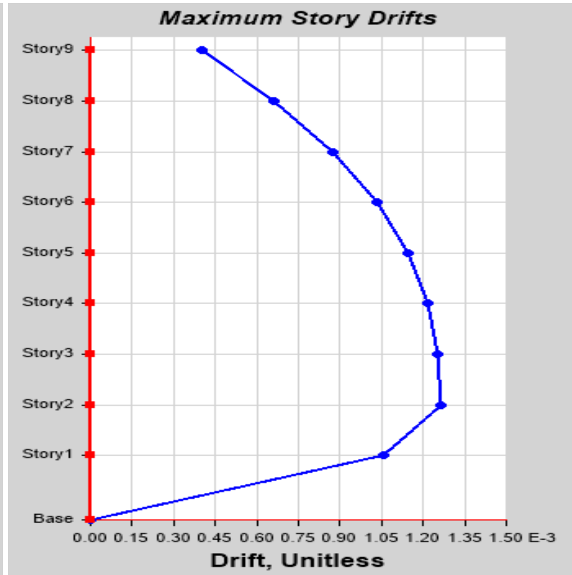


Figure: 3.4

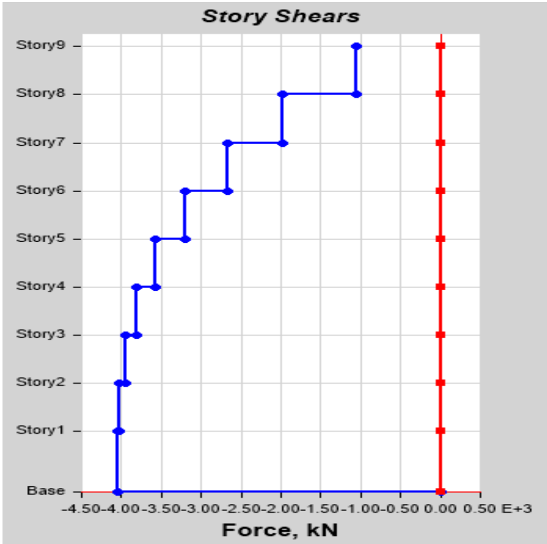
Figure: 3.3- Maximum Storey Drift for MODEL-1

Figure: 3.4- Maximum Storey Drift for MODEL-2

TABLE: Max Story Drift						
Story	**Elevation**	**Location**	**MODEL-1**		**MODEL-2**	
			X-Dir	**Y-Dir**	**X-Dir**	**Y-Dir**
	m					
Story9	29.2	Top	0.000431	1.29E-07	0.000404	7.64E-08
Story3	10.3	Top	0.001332	1.86E-07	0.00125	1.67E-07
Story2	7.15	Top	0.001346	1.35E-06	0.001263	1.18E-06
Story1	4	Top	0.001129	1.12E-06	0.001056	9.99E-07
Base	0	Top	0	0	0	0

Table 3.2

- In Model- 2 the Maximum storey Drift is decreased in X direction by a average 3.22% throughout the height and decreased in Y Direction by 5.857194 % at story 1 and 25.50189 % at top story from Model-1



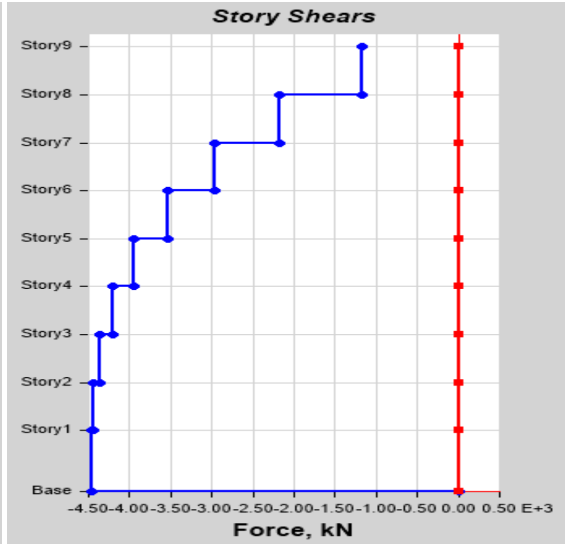


Figure: 3.5 **Figure: 3.6**

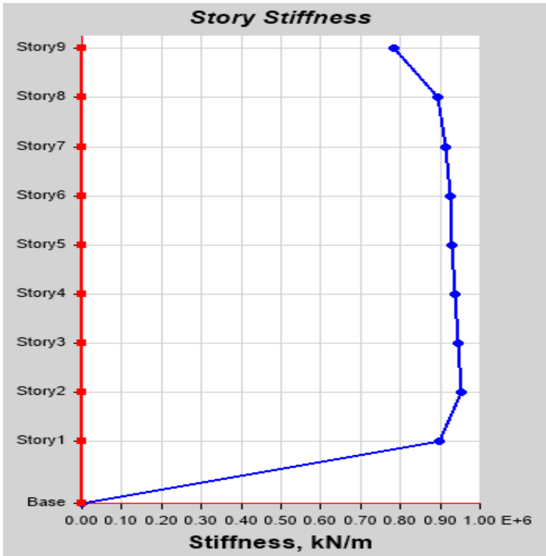
Figure: 3.5- Storey Shear for MODEL-1

Figure: 3.6- Storey Shear for MODEL-2

TABLE: Story Shear						
Story	**Elevation**	**Location**	**MODEL-1**		**MODEL-2**	
			X-Dir	**Y-Dir**	**X-Dir**	**Y-Dir**
	m		kN	kN	kN	kN
Story9	29.2	Top	-1061.24	1.82E-09	-1169.63	1.79E-09
		Bottom	-1061.24	1.82E-09	-1169.63	1.79E-09
Base	0	Top	0	0	0	0
		Bottom	0	0	0	0

Table 3.3

- In Model- 2 the storey Shear is increased in X direction by a average 4.24% throughout from Story 1 to the top story Y Direction it was increased by 2.822787 % at story 1 and 0.803174 % at top story as compared to Model-1



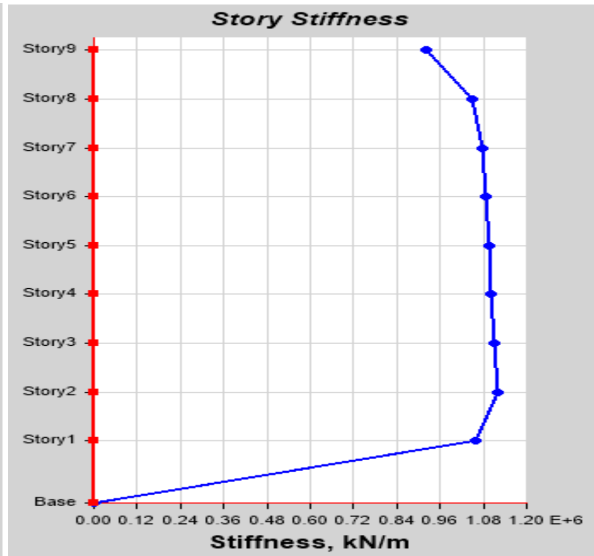


Figure: 3.7 **Figure: 3.8**

Figure: 3.7- Storey Stiffness for MODEL-1

Figure: 3.8- Storey Stiffness for MODEL-2

TABLE: Story Stiffness						
Story	Elevation	Location	MODEL-1		MODEL-2	
			X-Dir	Y-Dir	X-Dir	Y-Dir
	m		kN/m	kN/m	kN/m	kN/m
Story9	29.2	Top	783624.5	0	921479	0
Story8	26.05	Top	892646.3	0	1050285	0
Story2	7.15	Top	951902	0	1119758	0
Story1	4	Top	897860.3	0	1060064	0
Base	0	Top	0	0	0	0

Table 3.4

- In MODEL-2 Story Stiffness is observed to be increases by an average of 8.11 % in X direction from Story 1 to Top Story as compared to MODEL- 1

4. CONCLUSION AND FUTURE SCOPE:

- Maximum storey Displacement is decreased in case of SFRC Model (MODEL-2)
- Maximum storey Drift at both top and 1st story of the building was found to be decreased in case of SFRC model (MODEL-2)
- Storey Shear is increased at respective stories in case of SFRC Model (MODEL-2)

- Story Stiffness is observed to be increased by an average of 8.11 % in case of SFRC Model (MODEL-2)
- Performance of the Steel Fiber Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete
- Behaviour of SFRC based model has shown significantly better performance under seismic loads, hence it can be opted as a seismic resistant material in future research work.

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