

# **Comparative Studies on Axial Load Ratio, Stiffness Degradation and Compression Behavior of Long RC Columns Made Out of NSC and SCC**

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**ABSTRACT:** Experimental study was conducted to know the behavior of long columns under axial load made out of NSC (Normal strength concrete) and SCC (Self compacting concrete). Main objective of this study was to compare the behavior of NSC long columns and SCC long columns for various percentage of steel. A total of six long columns with same cross sectional area of 125mm X 125mm were cast and tested. Axial load ratio, stiffness ratio were the main parameters which increased as the axial load increased. However in this study, special attention was given on stiffness degradation, energy absorption, ultimate load carrying capacity, shortening index of each long column. The results showed that shortening index, axial load ratio, stiffness ratio and stiffness degradation increased with increase in axial load. On the other hand as the percentage of steel increased the ultimate load carrying capacity increased while shortening index and stiffness degradation decreased. SCC had ultimate load carrying capacity and ultimate deformation more than NSC for same percentage of steel.

**KEYWORDS:** slenderness ratio, percentage of steel, axial load ratio, stiffness ratio, stiffness degradation, shortening index

## **I. INTRODUCTION**

Reinforced concrete (RC) structures have become more popular in last few decades due to wide availability of construction materials, relatively low cost and ease of construction. RC structures are constructed with proper design & detailing for better performance throughout its service life. RC structures have various structural elements, the integrated performance of which governs the overall performance of the structure. Columns are one of the major load transfer elements in RC structures. Understanding the behavior of columns under various conditions are important. The behavior of column is dependent on factors such as geometrical, material and structural. Columns are basically classified as long, intermediate and short. There are many literatures available on the structural performance of short column however on the long columns are limited. In view of development of new concretes such as SCC, High strength concrete (HSC). This study has gained importance because of structures have to be designed using new generation concretes.

Long column is subjected to bending moment in addition to direct compressive stress. Load carrying capacity of a long column is less than a short column and it depends upon slenderness ratio. (Slenderness ratio increases then capacity of column decreases). Failure pattern of long column is totally different than short column patterns. Buckling failure occurs when tall, slender column experience loads that cause them to buckle or shift upward to relieve stress. This is a geometric failure and will always be less than the compression failure limit. Slender columns are also becoming increasingly important and popular because of the following reasons: (i) the development of high strength materials (concrete and steel), (ii) improved methods of dimensioning and designing with rational and reliable design procedures, Version 2 CE IIT, Kharagpur (iii) innovative structural concepts – specially, the architect's expectations for creative structures. Accordingly, this lesson explains first, the behaviour of slender elastic columns loaded concentrically.

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Thereafter, reinforced concrete slender columns loaded concentrically or eccentrically about one or both axes are taken up. X. Zeng et al studied on axial compression behaviour of RC columns under rapid loading [1], Hugo Rodrigues et al studied on Behavior of reinforced concrete column under biaxial cyclic loading [2], R. Jansson et al conducted study on “Factor influencing fire spalling of self-compacting concrete[6]”, Jiaquan Zhong et al informed about “Stiffness degradation and time cracking of cover concrete in reinforced concrete structures subject to corrosion [8] and the author Biswajit Basu Identified of stiffness degradation in structures using wavelet analysis[9]. In this study axial load was applied to know the structural performance of long columns.

## II. SCOPE OF PRESENT INVESTIGATION

- 1) To obtain M30 grade NSC and SCC mix using 20mm and 12.5mm coarse aggregate respectively.
- 2) Long columns with different reinforcement were tested under axial load to observe the load transfer mechanism in NSC and SCC.
- 3) To observe the compression behaviour and variation in load deformation of long RC columns for different reinforcement ratio and slenderness ratio.
- 4) Understanding the stiffness degradation and the parameters which influence it in NSC and SCC.
- 5) To evaluate the shortening index over long RC column made out of NSC and SCC.
- 6) Analysing the data on the compression behaviour of RC columns with respect to geometric properties, concrete, reinforcement ratio.
- 7) Bench marking of experimental results with the available literature and codal equations.

## III. MATERIALS AND MIX PROPORTIONS

The following materials were used in the present investigation.

**Cement:** 43 Grade OPC as per IS 12269- 1989 with specific gravity 3.15. **Fly Ash:** Fly Ash conforming to Class F IS 3812:2003. **Coarse Aggregates:** 20mm downsize Aggregates with specific gravity 2.65 for NSC. 12.5mm down size aggregates with specific gravity 2.62 for SCC. Coarse aggregates were conforming IS 383:1970. **Fine Aggregates:** Manufactured Sand with specific gravity 2.57 and Fineness Modulus 3.05 conforming to zone II of IS 383:1970. **Super Plasticizers:** Naphthalene based polymer. Glenium B233 Modified poly-carboxylic ether for SCC. **Viscosity Modifying Agent:** Glenium Stream 2 for SCC. **Steel:** longitudinal reinforcement varied as 2.01%, 2.89% and 5.15%. and lateral ties 8mm at 125mm c/c. **Water:** Potable water conforming to IS 456:2000.

### Mix Proportions:

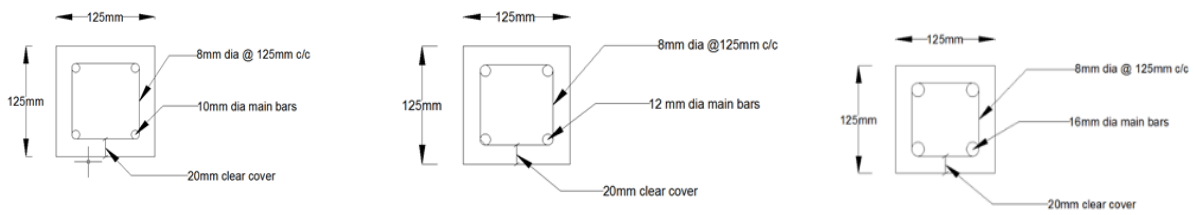
Mix design adopted for the present investigations are as follows: NSC M-30 as per IS 10262:2009; SCC M-30 NAN-SU method and it is shown in Table 1.

**Table 1: Mix Proportions of NSC, SCC.**

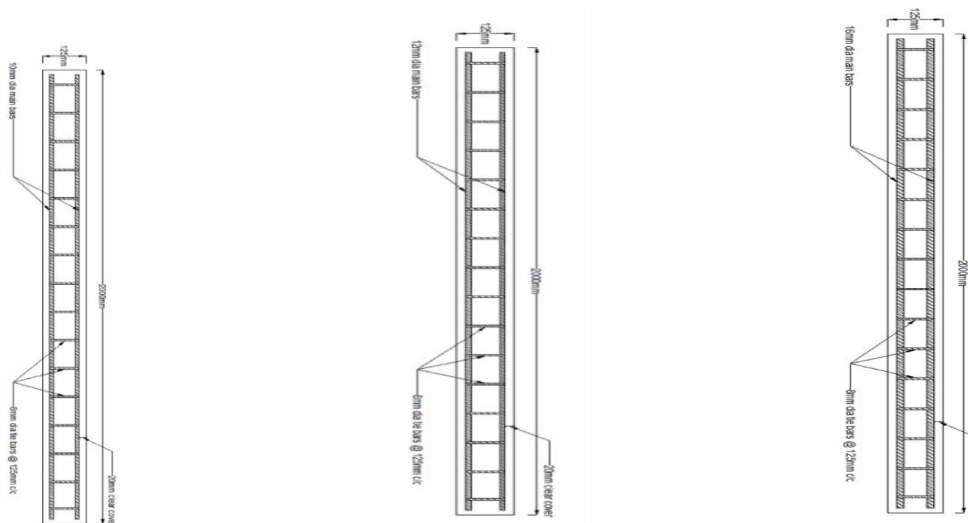
	NSC	SCC
Cement in kg/m <sup>3</sup>	348.33	214.28
Fly Ash in kg/m <sup>3</sup>	-	248.43
Fine Aggregates in kg/m <sup>3</sup>	681.66	925.63
Coarse Aggregates in kg/m <sup>3</sup>	1146.8 (20mm)	743.69 (12.5 mm)
Water in lit/m <sup>3</sup>	191.58	148.07
Super Plasticizer	-	1.3%
VMA	-	0.18%

**IV. MATERIALS AND MIX PROPORTIONS**

Based on the literature review and series of trial and errors the dimension of the column specimen was chosen. The specimens were cast using moulds of 125x125x1000mm. The specimens were reinforced with cage reinforcement of 8mm $\phi$  tie bars 125mm c/c and longitudinal reinforcement of 2.09%, 2.89% and 5.15%. (TORKARI) of Fe500.



**Fig 1:** Cross Section Details of Columns



**Fig 2** schematic diagram of column specimen with cage reinforcement

In the present investigation, a total of six column specimens were cast using different category of concretes such as NSC (M30) and SCC (M30). Slenderness ratio 16 was maintained to study the behavior of long RC columns. In all the columns a constant cross sectional area of 125mm $\times$ 125mm was maintained. Height of long column was 2m. The dimensions of the columns are arrived based on the literature and the facility available in the lab. The typical pattern of column with cross section (125mm $\times$ 125mm) and varying longitudinal reinforcement is as shown in Fig 1 and Fig 2.

The results of cube compressive strength of different grades of concretes NSC, SCC after trail mixes used to cast column specimens is as tabulated in the Table 2.

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Table 2: Cube Compressive Strength

Concrete type and max. aggregate size	Grade of concrete	Average Cube compressive strength, $f_{ck}$ (MPa)
		28days
NSC	M30	38.58
SCC	M30	43.93

### 4.1 TESTING ARRANGEMENT AND TESTING PROCEDURE

After the curing period was completed, the columns were white washed before mounting on the loading frame. All the columns were mounted and tested in the loading frame capacity of 1000 KN. All the columns were fixed on both ends with an effective span of 1.96m. A typical loading arrangement of long column is shown in the Fig 3. Two cross bars were provided for long columns to prevent the danger of sudden lateral movements.



NSC SCC

Fig 3: Test setup of a typical columns Fig 4: Cracked surfaces of failed column specimens

Load was applied using hydraulic jack and observations made on these parameters such as deformation, cracks and the failure pattern. This was continued for every increment of load till this structural or functional failure. Cracked surface of failed column specimens are shown in Fig 4.

All the long RC Columns were experienced crushing failure as shown in Fig 5.



Fig 5: Crack and failure patterns of long columns

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The Table 3 shows the test results of all the six columns. For each specimen by applying axial load, ultimate Load  $P_u$  (Exp) and axial deformation ( $\Delta u$ ) was observed. Using  $P_u$  (Exp) and  $\Delta u$ , Energy Absorption (EA), Shortening Index (SI), Axial Load Ratio (ALR) and Stiffness Ratio (SR) was calculated.  $f_{ck}$  is the cube compressive strength.

**Table 3:** Test results of the column Specimen

SPECIMEN	$f_{ck}$ (MPa)	$P_{cr}$ (kN)	$P_u$ (Exp) (kN)	$\Delta u$ (mm)	E A (kN-mm)	S I	A L R	S R	FAILURE
NSC/16/2.09	38.37	264.56	430.38	11.02	2426.84	0.0055	1.16	44.53	Buckle-Crush
NSC/16/2.89	39.67	354.4	455.70	10.65	2334.64	0.0053	1.20	46.25	Buckle-Crush
NSC/16/5.15	39.67	382.4	493.67	10.05	2665.28	0.0050	1.30	50.79	Buckle-Crush
SCC/16/2.09	43.6	303.8	468.35	12.54	2677.19	0.0063	1.15	44.11	Buckle-Crush
SCC/16/2.89	44.05	278.48	518.98	11.05	2916.33	0.0055	1.27	49.21	Buckle-Crush
SCC/16/5.15	44.04	354.43	600.00	10.85	2865.19	0.0054	1.47	58.71	Buckle-Crush

The specimens are named as follows. NSC/16/2.09 means type of concrete/slenderness ratio/longitudinal percentage of steel.

## V. RESULTS AND DISCUSSIONS

A detailed analysis has been carried out on the following parameters to understand structural performance of RC columns.

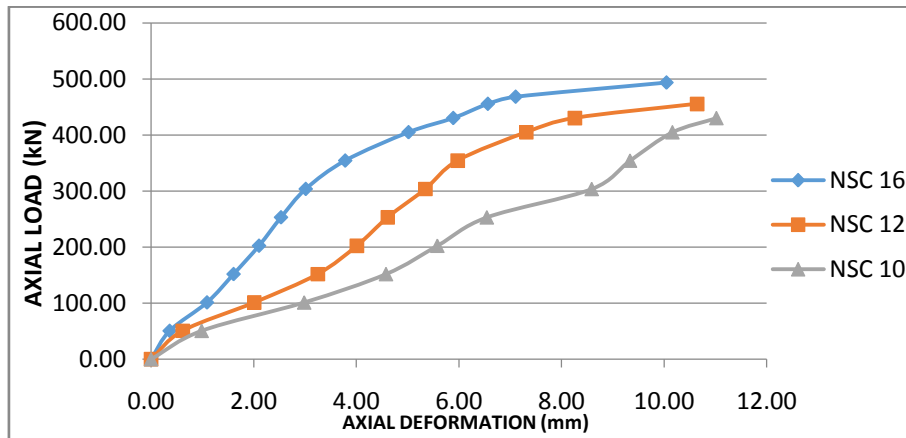
- a) Load deformation
- b) Stiffness degradation
- c) Axial load ratio and stiffness ratio
- d) Ultimate load
- e) Energy absorption
- f) Shortening index

### 5.1 LOAD DEFORMATION BEHAVIOR OF RC COLUMNS

An important aspect in the analysis and design of structures relates to the deformations caused by the loads applied to a structure. Clearly it is important to avoid deformations so large that they may prevent the structure from fulfilling the purpose for which it is intended. But the analysis of deformations may also help us in the determination of stresses. To determine the actual distribution of stresses within a member, it is necessary to analyze the deformations which take place in that member. This project deals with the deformations of column under axial loading. Section 5.1.1 covers the compression behavior of long RC columns.

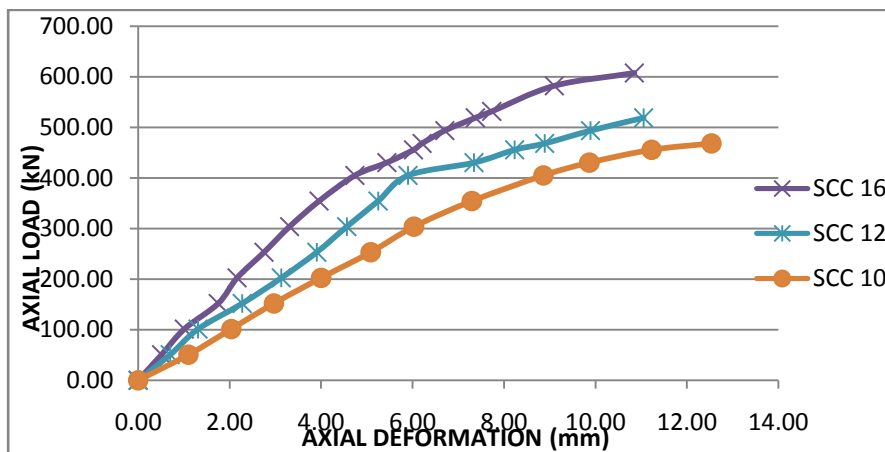
#### 5.1.1 LOAD DEFORMATION BEHAVIOR OF LONG RC COLUMNS.

The graphical representation of load-deformation behavior for long columns is as shown in Fig 6 and Fig 7.



**Fig 6:** Combined load-deformation curve for NSC long RC columns

From the Fig 6, it has been observed that NSC10, NSC12 and NSC16 long columns have maximum axial deformations 11.025mm, 10.65mm and 10.05mm at an ultimate loads of 430.38kN, 455.7kN and 493.67kN respectively. Also it was evident that with increase in percentage of steel, axial load carrying capacity has been increased whereas axial deformations decreased.



**Fig 7:** Combined load-deformation curve for SCC long RC columns

Fig 7 shows the graphical representation of the axial load vs axial deformation for SCC with varying percentage of reinforcement. Also it was noticeable that, SCC10, SCC12 and SCC16 long columns have maximum axial deformations 12.54 mm, 11.054mm and 10.85mm at an ultimate loads of 468.35 kN, 518.98kN and 594.18kN respectively. With increase in percentage of steel axial deformation decreased whereas load carrying capacity increased.

Following graphs show the comparison of axial load vs axial deformation NSC and SCC Long columns with same percentage of steel reinforcement.

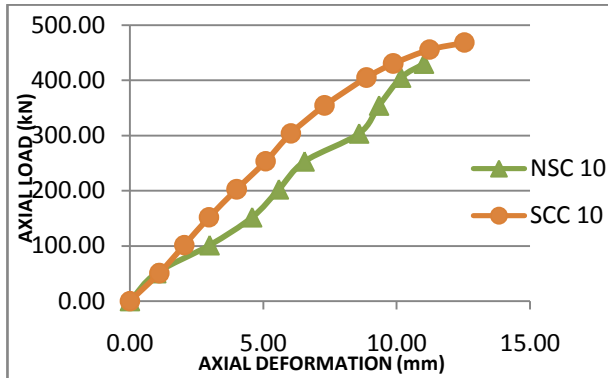


Fig 8: Combined load-deformation curve-2.09%

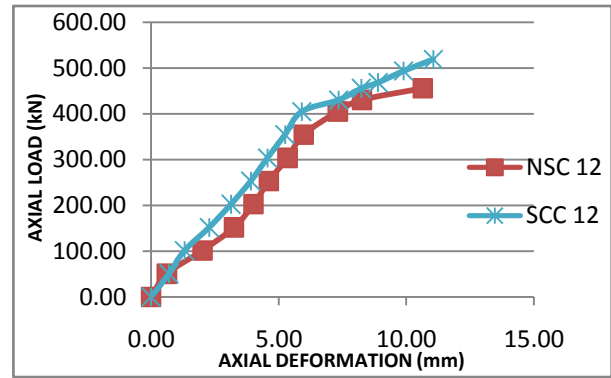


Fig 9: Combined load-deformation curve-2.89%

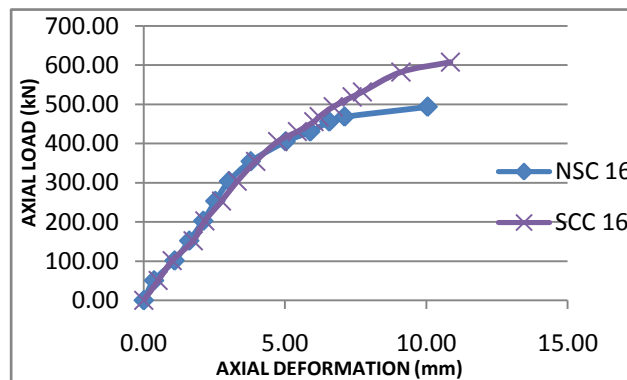


Fig 10: Combined load-deformation curve- 5.15%

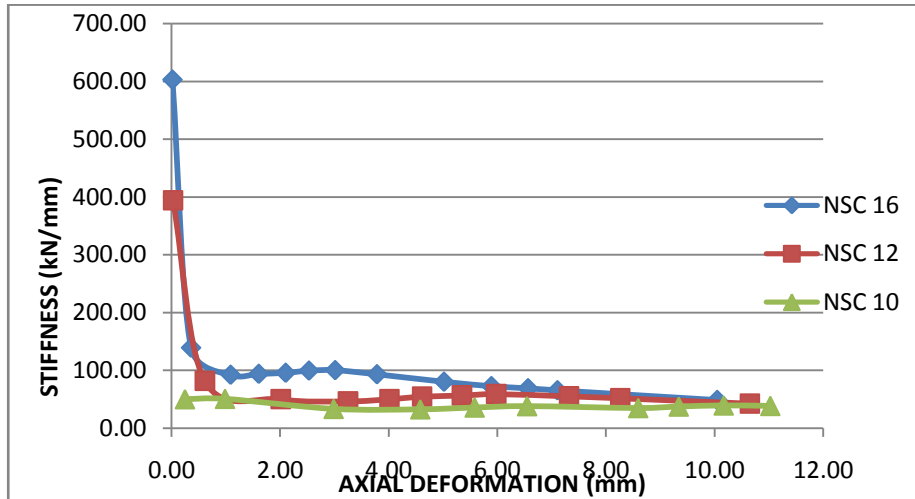
From the above figures it has been noted that, the SCC long columns carried more load than the NSC long columns with same reinforcement percentage. But ultimate deformation of SCC long columns was more than NSC long columns of same reinforcement percentage (this is because SCC has less young's modulus 'E' than NSC, thus its flexural rigidity 'EI' is less). Load carrying capacity for SCC/16/2.09 was 8.1% higher, SCC/16/2.89 was 12.19% higher and SCC/16/5.15 was 17.72% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively. Axial deformation for SCC/16/2.09 was 13.68% higher, SCC/16/2.89 was 3.75% higher and SCC/16/5.15 was 1.2% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.

## 5.2 STIFFNESS DEGRADATION OF RC COLUMNS

Stiffness is defined as load required for producing unit deformation in a member and stiffness degradation is defined as the damage to engineering materials essentially results in a decrease of the free energy stored in the body with consequent degradation of the material stiffness. To understand the stiffness degradation of RC columns, it is required to plot the graph between stiffness and axial deformation with varying percentage of steel reinforcement for both NSC and SCC. Section 5.2.1 covers the stiffness degradation of long, intermediate and long columns respectively.

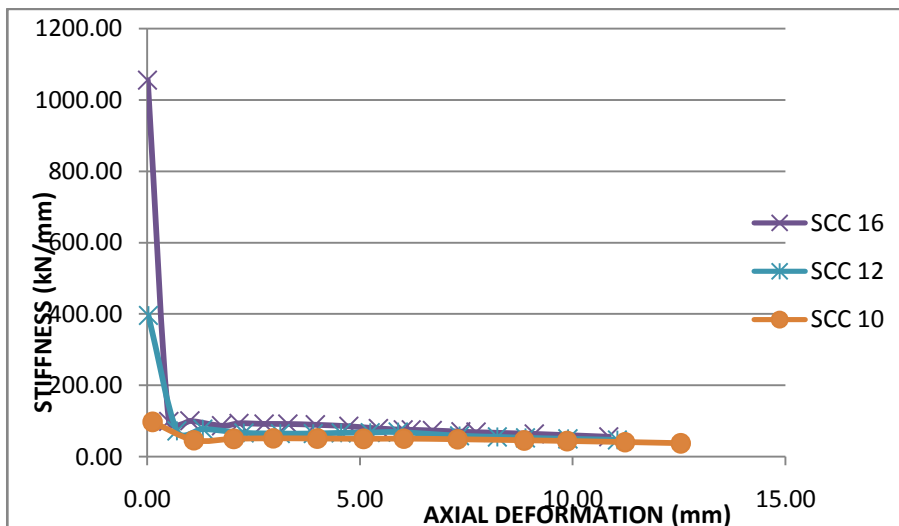
### 5.2.1 STIFFNESS DEGRADATION OF LONG RC COLUMNS.

The stiffness degradation curves for long columns have been plotted as shown in Fig 11 and Fig 12.



**Fig 11:** Combined Stiffness degradation curve for NSC long RC columns

As the axial load and axial deformation increased, the stiffness of columns having higher percentage of steel reinforcement decreased suddenly up to a deformation value of 0.34mm and the decrement became marginally slow after this. Whereas the stiffness of columns with lesser percentage of steel reinforcement for NSC decreased constantly for all values of axial deformation as shown in Fig 11.



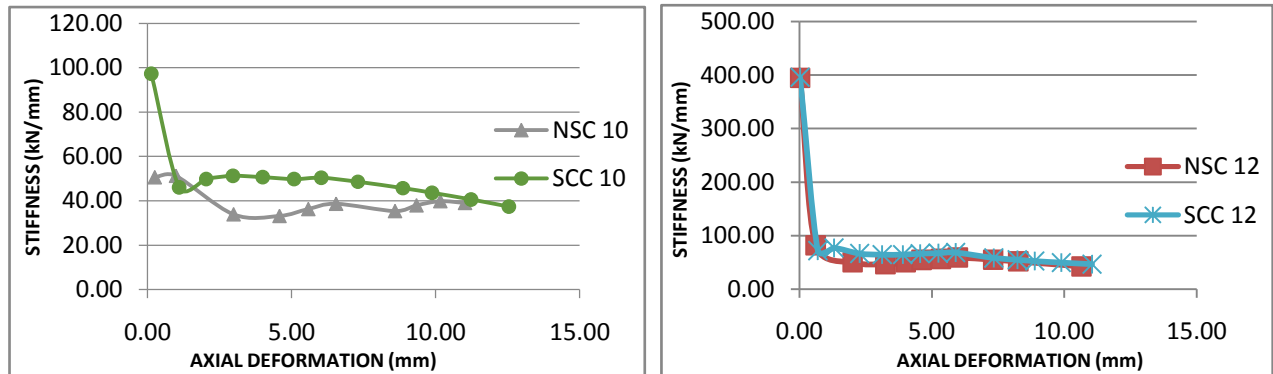
**Fig 12:** Combined Stiffness degradation curve for SCC long RC columns

It is conspicuous that there was a sudden drop of stiffness for all the SCC long columns up to a certain deformation value and stiffness degradation beyond these values was marginally constant which is shown in Fig 12.

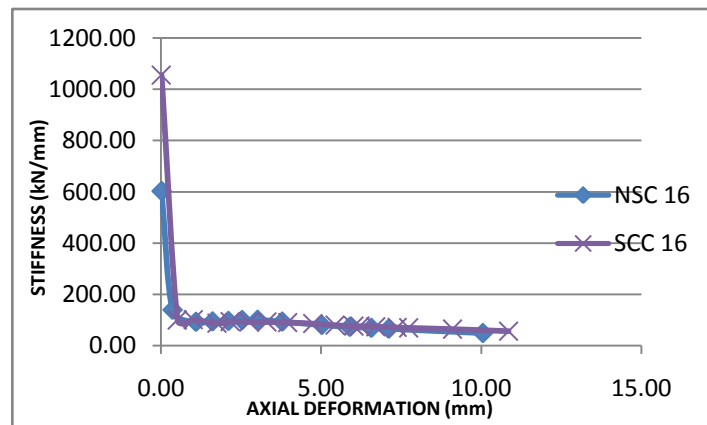
It was observed from the above graphs that as the percentage of steel increases, the stiffness of column increases and the stiffness degradation decreases for both NSC and SCC. The rate of stiffness degradation of SCC is low in comparison with other types.



Following graphs show the stiffness degradation for both NSC and SCC intermediate columns with same percentage of steel reinforcement.



**Fig 13:** Combined Stiffness degradation curve-2.09% **Fig14** Combined Stiffness degradation curve 2.89%



**Fig 15:** Combined Stiffness degradation curve-5.15%

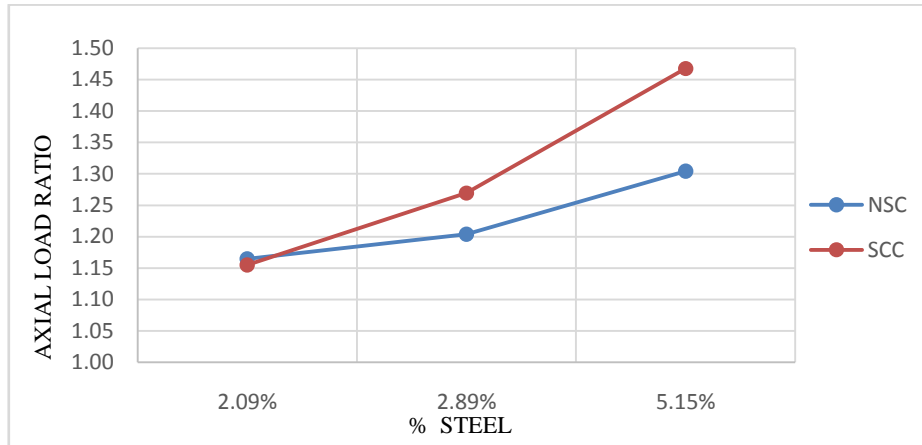
From the Fig 13, Fig 14 and Fig 15 it was observed that, for 2.09%, 2.89% steel and 5.15% steel, SCC long columns had more stiffness value than NSC long columns. After comparing all the above graphs it was observed that, stiffness value of column with 5.15% steel was much greater. And also stiffness degradation of column with 5.15% steel was rapid than columns with 2.09% and 2.89% steel. Stiffness at ultimate load for SCC/16/2.09 was 4.4% lesser, SCC/16/2.89 was 8.89% higher and SCC/16/5.15 was 12.28% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.

**5.3 STIFFNESS RATIO V/S AXIAL LOAD RATIO OF RC COLUMNS.**

Axial load ratio i.e. the ratio of applied load to the theoretical load and the stiffness ratio are very important parameters which play an important role in the column behavior. In order to study the influence and the relationship between the above mentioned parameters, it is necessary to plot the graph between axial load ratio and stiffness ratio. Section 5.3.1 covers the stiffness ratio and axial load ratio relationship for long columns respectively.

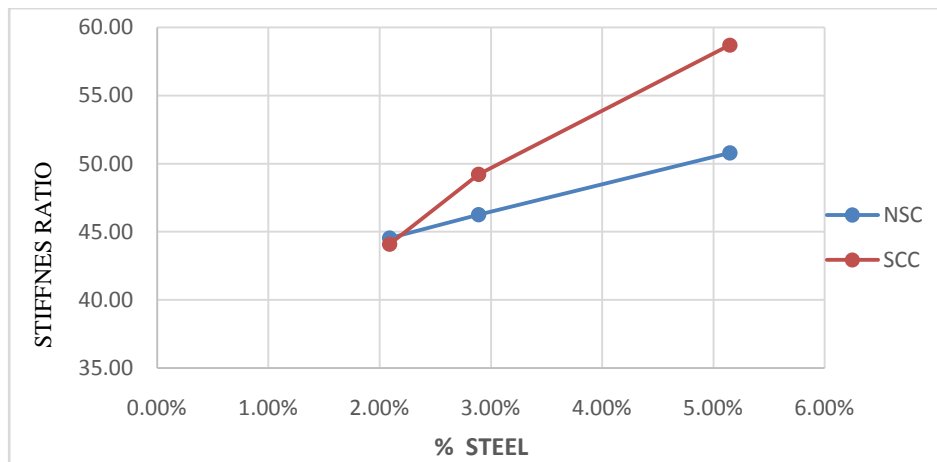
**5.3.1 STIFFNESS RATIO V/S AXIAL LOAD RATIO OF LONG RC COLUMNS.**

The graphical representation of stiffness ratio and axial load ratio for both NSC and SCC is as shown in Fig 16 and Fig 17.



**Fig 16:** Combined Axial load ratio curve for NSC long RC columns

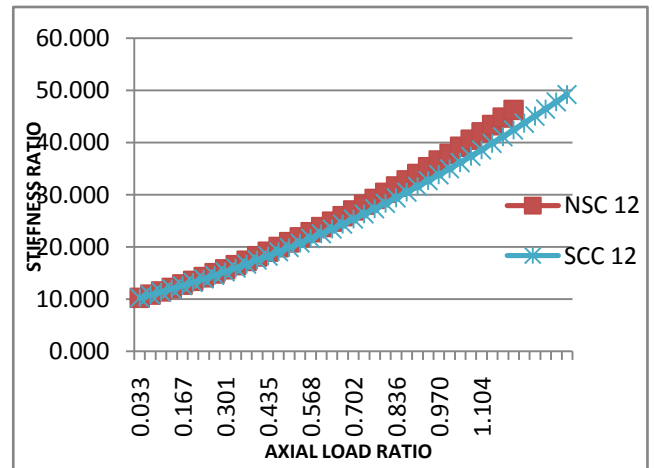
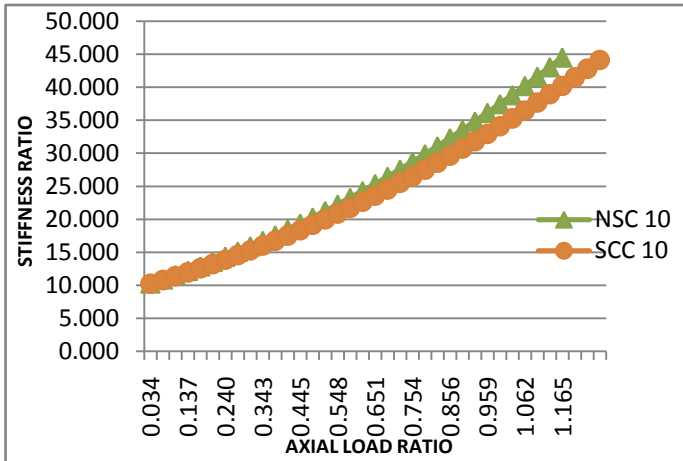
From the Fig 16 it has been observed that, NSC10, NSC12 and NSC16 long columns achieved an axial load ratios 1.16, 1.2 and 1.3. SCC10, SCC12 and SCC16 long columns achieved an axial load ratios 1.15, 1.27 and 1.46 respectively at ultimate axial load. It was observed that, axial load ratio and stiffness ratio for all NSC long columns increased linearly.



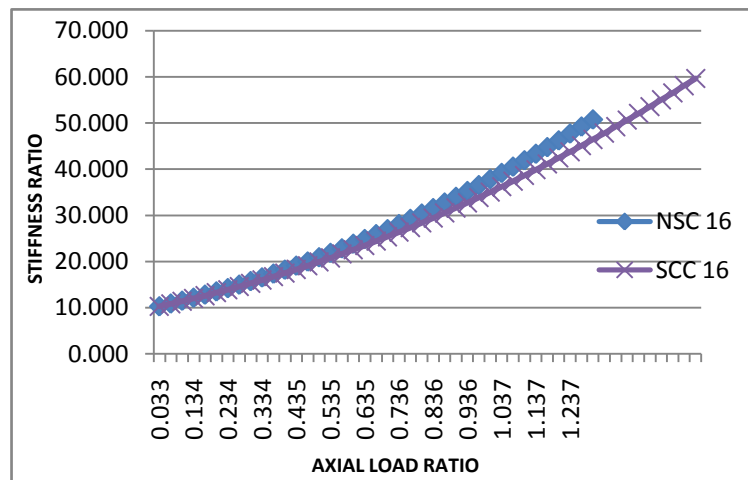
**Fig 17:** Combined Stiffness Ratio curve for SCC long RC columns

From the Fig 17 it has been observed that, NSC10, NSC12 and NSC16 long columns achieved stiffness ratios 44.11, 49.21 and 58.71 and SCC10, SCC12 and SCC16 long columns achieved stiffness ratios 44.53, 46.25 and 50.8 respectively at ultimate axial load. It is observed that, axial load ratio and stiffness ratio for all SCC long columns increased linearly.

Following graphs show the variation of axial load ratio and stiffness ratio for both NSC and SCC long columns with same percentage of steel reinforcement.



**Fig 18:** stiffness ratio vs axial load ratio-2.09%    **Fig 19:** stiffness ratio vs axial load ratio curve 2.89%



**Fig 20:** Combined stiffness ratio vs axial load ratio curve-5.15%

It has been observed from the Fig 18, Fig 19 and Fig 20 that, Stiffness ratio and axial load ratio for NSC and SCC long columns having 5.15% steel was found to be greater than that of columns with 2.89% and 2.09% steel. As studied from the graphs, it has been observed that for all the long columns, stiffness ratio and axial load ratio were marginally same. Axial load ratio at ultimate load for SCC/16/2.09 was 0.87% lesser, SCC/16/2.89 was 5.51% higher and SCC/16/5.15 was 10.96% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively. Stiffness ratio at ultimate load for SCC/16/2.09 was 0.97% lesser, SCC/16/2.89 was 6.01% higher and SCC/16/5.15 was 13.49% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.

#### 5.4 COMPARISON OF ULTIMATE LOAD CARRYING CAPACITY OBTAINED FROM EXPERIMENTAL DATA AND ANALYTICAL METHOD

Reinforcement percentage, type of concrete and slenderness ratio are the key parameters which influences the load carrying capacity of columns and it is shown in the following graphs. Analytically ultimate load carrying capacity of RC column was obtained using the formula as per IS 456 (Eq 1)

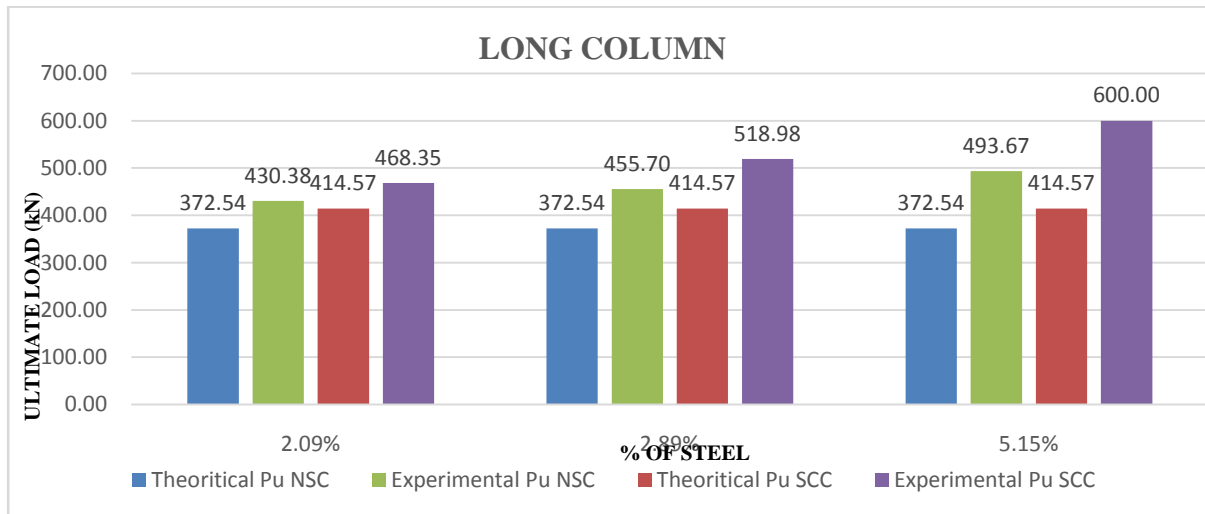
$$P_u = 0.45f_{ck} + 0.67 f_y A_{st} \dots \dots \dots \text{Eq 1.}$$

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Following graphs show the comparison of theoretical and experimental ultimate load carrying capacity for NSC and SCC long columns with same percentage of steel reinforcement as shown in Fig 21.

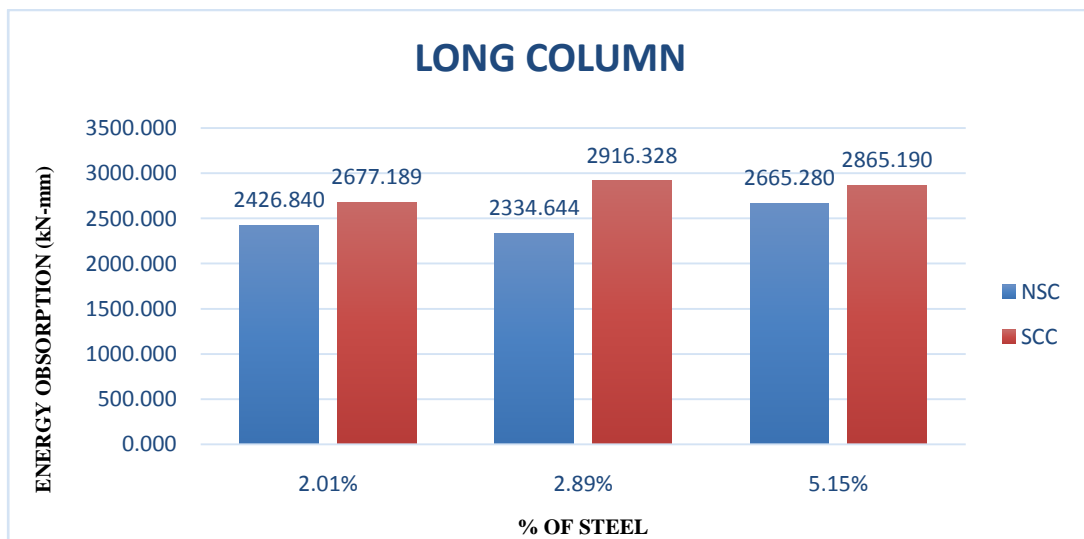


**Fig 21:** Combined Ultimate Load Carrying Capacity V/S steel percentage for long column

From the Fig 21 it was observed that as the percentage of steel increased, ultimate load carrying capacity increased in case of both NSC and SCC columns.

## 5.5 ENERGY ABSORPTION

Energy absorption is represented by the area enclosed under the load-deformation curve. The failure mechanism of RC columns is found to be very dependent on the loading path, which strongly affects both the ductility and energy dissipation capacity of the columns. The influence of reinforcement ratio on the energy dissipated in compression is shown in Fig 22.



**Fig 22:** Combined Energy absorption V/S steel percentage for long column

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Energy absorption for NSC/16/2.01 was 10.31% lesser, NSC/16/2.89 was 24.91% higher and NSC/16/5.15 was 7.5% lesser compared to SCC/16/2.09, SCC/16/2.89 and SCC/16/5.15 column respectively as shown in Fig 22.

## 5.6 SHORTENING INDEX

Shortening index is a dimensionless property and is defined as the ratio of ultimate deformation to the length of column. Graphs of shortening index vs steel percentage have been plotted for all long columns as shown in Fig 23.

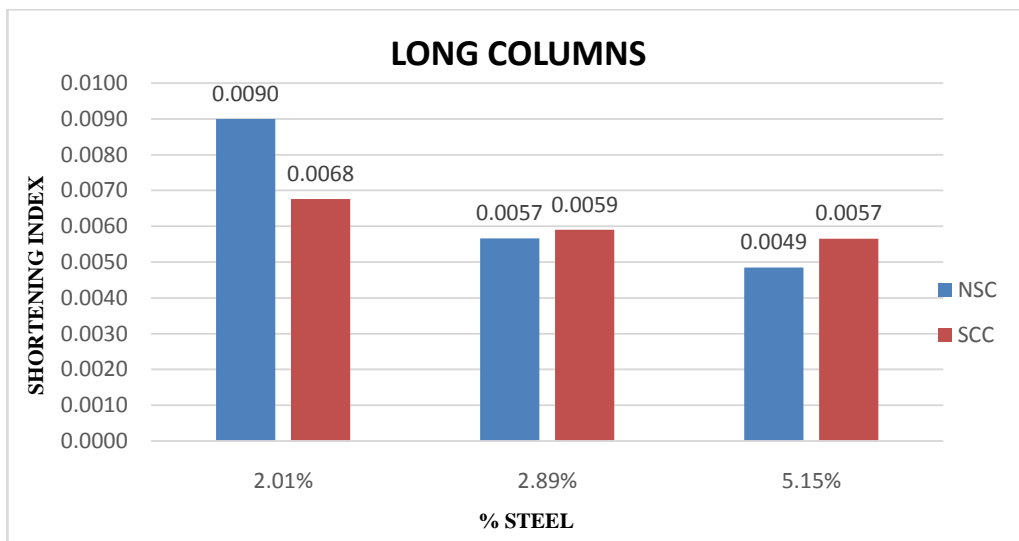


Fig 23: Combined shortening index V/S steel percentage for long column

From the Fig 23 it was observed that, the shortening index of both SCC and NSC long columns decreased with increase in percentage of steel. However in case of long columns, the shortening index of SCC with 2.01% was found to be less than NSC with same steel percentage. However the shortening index of SCC 2.89% and SCC 5.15% was more than NSC columns with same steel percentage.

Shortening index for SCC/16/2.09 was 12.70% higher, SCC/16/2.89 was 3.63% higher and SCC/16/5.15 was 7.4% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively Fig 23.

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## VI. CONCLUSIONS

Experimental investigation has been carried out on long RC columns to study the load deformation behavior, stiffness degradation, axial load ratio and stiffness ratio, ultimate load, energy absorption and shortening index. Summary and conclusions are outlined below.

- The mix proportion for NSC (M30) was obtained from the IS 10262-2009. Also slump test was followed as per IS 1199-1959 and the average slump value was found to be 85 mm.
- The mix proportion for SCC (M30) was obtained as per Nan Su method [16] and flow properties observed were within the limit.

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- For every mix three companion cubes were cast for both NSC and SCC and an average 28 days cube compressive strength was found to be 38.58 MPa for NSC and 43.93 MPa for SCC respectively.
- The cross sections of all the columns were 125mm X125 mm. The height of the column was fixed as 1m and the Slenderness ratios of long column was maintained as 16.
- The varied percentage of steel in each column (long, intermediate and long) was 2.09%, 2.89% and 5.15%.
- It was found that, with increase in steel percentage for same cross sectional area of column, the load carrying capacity increased and ultimate deformation reduced.
- Load carrying capacity for SCC/16/2.09 was 8.1% higher, SCC/16/2.89 was 12.19% higher and SCC/16/5.15 was 17.72% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.
- Axial deformation for SCC/16/2.09 was 13.68% higher, SCC/16/2.89 was 3.75% higher and SCC/16/5.15 was 1.2% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.
- It was noticed that stiffness of columns for higher percentage of steel was higher than columns with lesser percentage of steel and initially stiffness degradation increased suddenly and later marginal stiffness degradation was observed up to ultimate load.
- Stiffness at ultimate load for SCC/16/2.09 was 4.4% lesser, SCC/16/2.89 was 8.89% higher and SCC/16/5.15 was 12.28% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively
- Axial load ratio at ultimate load for SCC/16/2.09 was 0.87% lesser, SCC/16/2.89 was 5.51% higher and SCC/16/5.15 was 10.96% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.
- Stiffness ratio at ultimate load for SCC/16/2.09 was 0.97% lesser, SCC/16/2.89 was 6.01% higher and SCC/16/5.15 was 13.49% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively.
- In case of long columns, energy absorption was found to be greater for SCC/16/2.89 column whereas NSC/12/2.89 column showed least value.
- Energy absorption for NSC/16/2.01 was 10.31% lesser, NSC/16/2.89 was 24.91% higher and NSC/16/5.15 was 7.5% lesser compared to SCC/16/2.09, SCC/16/2.89 and SCC/16/5.15 column respectively
- In case of long columns, energy absorption was found to be greater for NSC/8/2.09 column whereas SCC/8/2.89 column showed least value.
- It was observed that, NSC long columns had more energy absorption than SCC long columns for all percentage of steel.
- Shortening index for SCC/16/2.09 was 12.70% higher, SCC/16/2.89 was 3.63% higher and SCC/16/5.15 was 7.4% higher compared to NSC/16/2.09, NSC/16/2.89 and NSC/16/5.15 columns respectively

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