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Static Behavior of Railway PSC sleepers using Next Generation Nano based Carbon Fiber Reinforced Concrete as Per IRS T-39

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***Abstract* – This paper presents the experimental study on static behavior of Railway Prestressed concrete (PSC) sleepers Using Next Generation Nano Based Carbon Fiber Reinforced Concrete. The next generation nano based carbon fiber reinforced concrete is prepared using cementatious materials (Cement, GGBS, Silica Fumes), Carbon fibers, Polypropylene fibers by preparing concrete mixes with integration of Carbon Nanotubes. CNTs with High Performance Concrete using a design mix of M60 grade of concrete. Five different PSC test specimens were casted viz. M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+PF+CF. Carbon Nanotubes were first dispersed in deionized water and surfactant using an ultrasonic mixer, then the CNTs, Carbon fibers, Polypropylene fibers were combined with concrete as per state-of-the-art techniques. The PSC sleepers are casted and tested at Sri Maruthi Builders and manufacturers of PSC railway sleepers, Yeshwanthpur, Bangalore, Karnataka, India in accordance to IRS T-39 for center top and rail seat bottom conditions. It is observed that experimental values of Load for Centre Top, Moment of resistance and Moment of Failure test were much higher than specified values**.

Key Words: Carbon Nanotubes(CNTs), Next Generation Nano Based Carbon Fiber Reinforced Concrete, Carbon fibers, Polypropylene fibers, Static Behavior of Railway PSC sleepers and IRS T-39.

1. INTRODUCTION

Indian Railways is the backbone of the country's transport infrastructure integrating market and connects communities all over the country. It is the fourth largest railway networks in the world (after USA, China and Russia). A major portion of the railway network in India is more than a century old. With the passage of time, this network is showing signs of ageing due to increased traffic, heavier wheel loads and improper maintenance. The premature deterioration of railway sleepers is due to rail-seat deterioration, cracking and damaging under different loading conditions and adverse environment conditions .The problem of cracking in concrete sleepers and corollary damage are largely due to the high intensity loads from wheel or rail irregularities such as wheel burns, dipped joints, rail corrugation, or defective track stiffness. All this calls for a development of an economically competitive material or structure of suitable strength which will satisfy the needs of the industry and all the requirements for serviceability, durability, maintenance and ease of construction. The key to damage-resistant concrete and long-life concrete structures, which has been known for a long time, lies in enhancing the tensile strength and fracture toughness of concrete material which is achieved by reinforcing fibers in concrete.

1.1. LITERATURE REVIEW

Concrete with strength of above 40 N/mm^2 is generally termed as high strength concrete, studied on High strength Prestressed Concrete sleepers. The materials used are Special grade cement conforming to IRS No, T-40,Portland Slag Cement, River sand, coarse aggregate, potable water, HTS wires (18nos of 3x3mm) and Super Plasticizer (Glenium ACE-30).They carried out Compression test, Flexural test, Static Bending test and Electrical Resistance test.(2,3) The cross section dimension of sleeper at rail seat 250x210x150 mm and at centre 220*180*150mm, the length of sleeper is 2750mm for broad gauge track. They carried out Compression test, Flexural test, Static Bending test, Electrical Resistance test, rail seat bottom & center top and center bottom respectively. The results of PSC sleepers satisfy all requirement of Railway specification and load values within the specified limit. The sleepers passed the electrical resistance test(1,5,8,9). Investigated experimentally and numerically, the behavior of prestressed concrete railway sleepers with M60 grade concrete modified with SBR latex and polypropylene fibres, The load deflection curves and failure modes was found to be in good agreement with the experimental results for all the sleepers. (4,10).The concrete structures rely largely on deformation and yielding of tensile reinforcement to satisfy the ductility demand. Although nano carbon fiber reinforced concrete modified with High Performance concrete is still a concern for practical application under seismic loading or severe service conditions. A few experimental results have shown the use of polypropylene and carbon fibers in improvement of strength capacity in concrete but this is still to be quantified with more experimental test which will change the design parameters with enhanced strength capability of structural

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members. Progress in the area of Next Generation Nano Based Carbon Fiber Reinforced Concrete has been fairly low, partly due to the high material cost which may discourage the industrial application and partly due to the lack of experimental data on new composite materials. The potential of Next Generation Nano Based Carbon Fiber Reinforced Concrete has been neglected. Hence, the present experimental investigation aims at full understanding of the influence of cementatious materials such as Cement, GGBS, Silica Fumes, Carbon fibers, polypropylene fibers, Carbon Nanotubes by preparing concrete mixes under static bending test .

2. EXPERIMENTAL PROGRAM

The present experimental program was designed to investigate the static behavior of railway PSC sleepers as per IRS T-39. PSC sleepers were reinforced with Carbon fibers, polypropylene fibers and CNTs. The concrete mix ingredients consists of Cement, GGBS, Silica Fumes, Carbon fibers, polypropylene fibers and CNTs on five different mixes with the following PSC railway sleeper test specimens as shown in table 1. The experimental setup were carried out in accordance with IRS T-39.

The materials, mix proportions, test specimens, experimental procedure and test setup used in the present investigation to study the static behavior of railway PSC sleepers are illustrated in the following subsections

Table 1: Test specimens

Test specimens	S1	S2	S3	S4	S5
Concrete matrices	M 60	M60+CNT	M60+CNT+PF	M60+CNT+CF	M60+CNT+PF+CF

2.1 MATERIALS

In this experiment, Special Grade Portland cement (53-S) conforming to IRS/T-40-1985 was used, to ascertain the physical characteristics of the cement, tests were conducted in accordance with the Indian standards confirming to IS-12269:1987. Locally available crushed sand was used. The tests on the fine aggregate were conducted in accordance with IS 2386 Part 1 to Part 4-1964 (Reaffirmed-2002) for requirement as per IRS T-39 Specifications to determine Specific gravity, Bulk density and Fineness modulus. The results conform to IS : 2383 (Reaffirmed 1990). Crushed angular of 20 mm and 10mm maximum size has been used as coarse aggregate. The sieve ana1ysis of combined aggregates confirms to the specifications of IS 383: 1970 for well graded aggregates. The tests on the coarse aggregate were conducted in accordance with IS 2386 Part 1 to Part 4-1963 (Reaffirmed-2002) to determine Specific gravity, Bulk density and Fineness modulus. Auracast 270M as Super Plasticizer (chemical admixture) was used. Silica fumes supplied by Elkem India Pvt. Ltd, Navi Mumbai and Ground Granulated Blast Furnace Slag (GGBFS) supplied by Nuvoco Vistas Corporation Limited, (formerly Lafarge India Ltd.), Bangalore were used as mineral admixtures. Carbon fibres of 6mm chopped length supplied by M/s Baseer Fibres Private Limited, Bengaluru was uesd. Polypropylene fibers (Recron 3S) supplied by Ranka Udyog, Pvt, Ltd, Bangalore was used. CNTs supplied by Sigma-Aldrich was used. Ordinary potable water was used for mixing and curing purpose.

2.2 MIX PROPORTIONS

The concrete mix having a compressive strength of 60 N/mm^2 was aimed in the present research investigation, the design mix proportion was obtained by **ACI 211.4R-93 Method** of mix design for high strength concrete. Based on the same, the mix proportions arrived are tabulated in table 2. The Polypropylene fibre, carbon fiber, Auracast 270M, Silica Fumes, GGBS and CNT's were included in this mix proportion as per the predetermined optimum percentages subject to the required workability. 8% of Silica Fumes is replaced by weight of cement, 21.6% of GGBS as replacement, 0.125% of weight of cement of carbon nano tube, 900gm/cubic meter of volume of concrete of polypropylene fibres, 0.5% of volume of concrete of carbon fibers and 0.4% of Super plasticizer by weight of cement were included into the concrete mix in the present investigation. Based on the trial mixes following compressive strength has been arrived for different concrete mixes under considerations and the same has been tabulated in table 3.

Table 2: Mix proportions for different concrete matrices

Mix	cement	Fine aggregate	Coarse aggregate	w/c	water	Carbon fiber	Polypropylene fiber	Super plasticizer	GGBS	Silica fumes	CNT
Test specimen	(kg/m^3)	(kg/m^3)	(kg/m^3)		(kg/m^3)	(kg/m^3)	(kg/m^3)	(litres/m^3)	(kg/m^3)	(kg/m^3)	(litres/m^3)
S1:M60	450	477.69	1124.64	0.373	168.15	-	-	2.02	138.2	51.15	-
S2:M60+CNT	450	477.69	1124.64	0.373	168.15	-	-	2.02	138.2	51.15	0.631
S3:M60+CNT +PF	450	477.69	1124.64	0.373	168.15	-	0.9	2.02	138.2	51.15	0.631
S4:M60+CNT +CF	450	477.69	1124.64	0.373	168.15	8.8	-	2.02	138.2	51.15	0.631
S5:M60+CNT +PF+CF	450	477.69	1124.64	0.373	168.15	8.8	0.9	-	138.2	51.15	0.631

Table 3: Compressive strength obtained for different concrete matrices

Properties	Age	M60	M60+CNT	M60+CNT +PF	M60+CNT+ CF	M60+CNT+P F+CF
	(Days)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(N/mm^2)	(N/mm^2)
Compressive strength	7	39.60	40.20	40.80	41.40	42.00
	15	60.12	60.94	61.55	62.98	65.22
	28	67.53	69.47	70.31	72.15	74.90

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Table 4: Materials required for respective test sleeper specimen

Mix	cement	Fine aggregate	Coarse aggregate	water	Carbon fibre	Polypropylene fiber	Super plasticizer	GGBS	Silica fumes	CNT
Test specimen	(Kg)	(Kg)	(Kg)	(litres)	(Kg)	(gm)	(ml)	(Kg)	(Kg)	(ml)
S1:M60	54.93	58.25	137.25	9.63	-	-	220	16.86	6.2	-
S2:M60+CNT	54.93	58.25	137.25	9.63	-	-	220	16.86	6.2	68.66
S3:M60+CNT+PF	54.93	58.25	137.25	9.63	-	108	220	16.86	6.2	68.66
S4:M60+CNT+CF	54.93	58.25	137.25	9.63	1.06	-	220	16.86	6.2	68.66
S5:M60+CNT+PF+CF	54.93	58.25	137.25	9.63	1.06	108	220	16.86	6.2	68.66

2.3 TEST SPECIMENS

As per IRS-T 39 standard PSC railway sleepers were casted with trapezoidal cross sections with details as shown in the table 4 with a span of 2750mm,the general section details of conventional railway PSC sleepers is as shown in table 6, the sleepers were casted at Sri Maruthi Builders, Yeshwanthpur, Bangalore. The PSC railway sleeper test specimens consists of five different matrices as shown in table 5.

Table 5: Dimension of Test Specimens

Details of Mix	Dimension (mm) as per RDSO		
	At Centre	At Railseat	At Ends
S1:M60	150x220x180	150x250x210	150x270x235
S2:M60+CNT	150x220x180	150x250x210	150x270x235
S3:M60+CNT+PF	150x220x180	150x250x210	150x270x235
S4:M60+CNT+CF	150x220x180	150x250x210	150x270x235
S5:M60+CNT+PF+CF	150x220x180	150x250x210	150x270x235

Table 6: General section Details

Mass (kg)	Gauge Length (mm)	Total Length (mm)	Top Width (mm)	At centre (mm)		At Rail Seat (mm)		At Ends (mm)	
				Soffit Width	Depth	Soffit Width	Depth	Soffit Width	Depth
206.0	1675	2750	150	220	180	250	210	270	235

2.4 EXPERIMENTAL PROCEDURE

The experimental process consists of two phases i.e primary phase and secondary phase.

In primary phase which consists of mixing of CNT with state-of-the-art procedure as shown below

2.4.1. Dispersion of CNTs

Dispersion of CNTs has been done at AZYME BIOSCIENCE PVT. LTD. BANGALORE, firstly water, surfactant, and CNTS are measured, and then mixed together. In order to ensure a well-dispersed solution, an ultrasonic mixer was used, which can deliver up to 500 watts at 20 kHz. An ultrasonic mixer is a device that uses a high frequency driver to transmit acoustical energy throughout a liquid medium. The energy in the shock waves is extremely high and significantly accelerates chemical reactions and breaks the clumps and agglomerations of particles. To reduce the chances of breaking the nanofilaments, CNTS were mixed for 20 minutes.

In secondary phase casting of PSC railway sleepers as per IRS T-39 with the mix proportions as stated in table 1.

2.4.2. Casting the specimens

First of all, the moulds were cleaned, greased and oiled using mould release oil. The next step involves fixing the mould end plates using nuts and bolts. Then HTS 18no's of 3 ply 3mm dia strands reeled through all four moulds via bulk heads as well as the bench end plates. The stress bench was brought to the tensioning bed. The tensioning was carried out using hydraulic jack. Then initial pre-stressing force of 241KN was applied through the ends of the jack. The stress bench is then brought to the casting bed. Two high-frequency shuttering vibrators (8000 rpm) were fixed onto each mould. The mixed concrete with Carbon fibers, polypropylene fibers, CNTs, Silica fumes, GGBS, Auracast-270M was poured into each mould layer by layer, compacted with the help of shuttering vibrators. The stress bench was then put into the steam chambers, where each bench is subjected to steam curing for a period of about 11 ½ hours. If the required strength was achieved, the stress bench was taken out of the steam chamber. The end plate bolts were loosened, transferring the prestress to concrete. The mould end plates were opened, and the HTS wires were cut using welding electrodes. The long line method of prestressing is used to cast the railway PSC sleepers in the casting yard. The individual sleepers were then loosened using a tackle. The sleepers were demoulded from the moulds using demoulding tackle. The demoulded sleepers were put into sleeper-carrying trolleys.

2.4.3 Experimental Setup

Static Bending Strength Test of Railway Sleepers are per IRS T-39

The static bending test of prestressed concrete railway sleeper test specimens under monotonic loading until ultimate stage is to establish the following parameters:

- Moment of resistance (MR) test at Rail seat bottom
- Moment of resistance (MR) test at centre top
- Moment of failure (MF) test for rail seat bottom
- Electrical Resistance Test

Moment of resistance (MR) test (Rail seat bottom, centre top)

The PSC sleepers were supported on two rollers (38mm Φ) and tested .Two rollers of each 38mm Φ served as the loading points were kept on the PSC sleeper at a distance of 280mm from either supports. All PSC sleepers were tested in the loading frame of capacity 500 KN and were loaded gradually, 30-40 kN/min upto the specified load, which were retained at this level for one minute for observing cracks, if any. For the purpose, a crack is defined as one which is barely visible to the naked eye and is at least 15mm long from the tension edge of the sleeper. However, if crack appears at a load smaller than the specified load, that values were recorded. In case of 'Moment of Resistance' (MR) test, the PSC sleepers were deemed to have passed the test if it sustains the loads specified in IRS T-39: Fifth revision Feb 2016 Annexure-III, as shown in Table 7, without cracking. Sleepers were subjected to loading till the appearance of first cracks. In the present investigation the prestressed concrete railway sleeper specimen was rejected if the sleeper fails in any of the tests conducted as per the Clauses of IRS T-39 and repeated on a new sleeper specimen.

Table 7: Specified values of Load for Centre Top, Centre bottom, Rails Seat Bottom test

Sleeper	Center Top (kN)	Center Bottom (kN)	Rail Seat Bottom	
			Cracking (kN)	Failure (kN)
BG	60	52.5	230	370
MG	25	40	150	250

Moment of failure (MF) test (for rail seat bottom)
In case of 'Moment of failure' (MF) test, the prestressed railway sleeper specimens were placed in the loading frame and were gradually loaded, the sleepers are said to have passed the test if it was able to take load beyond the specified test load 370 kN. The entire lot of PSC railway sleepers, from which samples tested in accordance with IRS: T-39, Clause 5.3.7.1 and passing the entire acceptance criterion provided in IRS: T-39, Clause 5.3.7.2, to be accepted for use under rail track. Flow chart for the testing of PSC railway sleepers of a lot can be referred in IRS T-39: Fifth revision Feb 2016 Annexure IV.

Electrical Resistance Test on PSC railway Sleeper test specimen
Electrical Resistance Test is carried out on PSC railway Sleeper test specimens in order to test their fitness for use in track circuited area (track circuits allow railway signalling systems to operate semi- automatically, by displaying signals for trains to slow down or stop in the presence of occupied track ahead of them, in other words it helps us to know if the line is occupied or free). Tests were conducted as per IRS: T-39 (annexure V) specifications . The prestressed concrete railway sleepers shall be checked for electrical resistance at 230 volts AC supply. The 230 volts AC supply will be passed through a not less than 300 W test lamp in series with the pairs of inserts being tested. For the sake of comparison, another comparator bulb of the same watt is directly connected to the 230 volts AC supply will be fitted along side. All the sleeper test specimens were tested for electrical insulation between two inserts and all those with minimum electrical resistance of 200 ohms was said have passed the test.

3.0 RESULTS AND DISCUSSIONS

The Moment of Resistance test at Rail seat bottom and Center Top and Moment of Failure test at Rail seat bottom were conducted on the specimens for the following PSC railway sleeper test specimens : (i) S1:M- 60 (M-60 Grade of concrete, control mix), (ii)S2: M-60+CNT (Carbon Nano Tubes combined with M-60 Grade of concrete), (iii)S3: M-60+Fiber+CNT (Polypropylene Fibers and Carbon Nano Tubes combined with M-60 Grade of concrete), (iv)S4: M-60+CNT+Fiber (Carbon Nano Tubes and Carbon Fibers combined with M-60 Grade of concrete), (v)S5: M-60+CNT+Fiber+Fiber (Carbon Nano Tubes, Carbon Fibers and Polypropylene Fibers combined with M-60 Grade of concrete) and the results obtained are tabulated below.

Table 8: Details of Static bending strength test values

SLEEPER	CENTER TOP (KN)	RAIL SEAT BOTTOM			
		MOMENT OF RESISTANCE (KN)		MOMENT OF FAILURE (KN)	
		LHS	RHS	LHS	RHS
STANDARD LOAD	60	230	230	370	370
S1:M- 60	85.2	235.5	240.1	426.4	429.5
S2:M-60+CNT	88.2	239.3	238.5	428.1	432.5
S3:M-60+CNT +PF	95.8	246.3	248	436.7	437.2
S4:M-60+CNT+CF	102.4	246	250.6	436.8	441.4

Figure1 : Crack Propagation at Center Top

The Load values for Center Top of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF are 85.2kN, 88.2kN, 95.8kN, 102.4kN and 102.6kN respectively. The increase in load value w.r.t **standard load value of 60kN** as specified by IRS T-39 is 42%, 47%, 60%, 71% and 71% respectively. The percentage increase in load value w.r.to **M-60 specimen** is 4%, 12%, 20% and 20% for M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF.

The load values of Moment of resistance (MR) test (Average of RHS and LHS) of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF test specimen is **237.8kN, 238.9kN, 247.15kN, 248.3kN and 250.65kN** respectively. The increase in load values of Moment of resistance (MR) test(Average of RHS and LHS) w.r.to **standard load value 230kN** as specified by IRS T-39 is

3%, 4%, 7%, 8% and 9% respectively. The percentage increase in load values of Moment of resistance (MR) test (Average of RHS and LHS) w.r.to **M-60 specimen** is 0.46%, 3.93%, 4.4% and 5.4% respectively.

The load values of Moment of Failure (MF) test (Average of RHS and LHS) of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF test specimen is **427.95kN, 430.3kN, 436.95kN, 439.1kN and 439.3kN** respectively. The increase in load values of Moment of Failure (MF) test(Average of RHS and LHS) w.r.to **standard load value 370kN** as specified by IRS T-39 is 16%, 16%, 18%, 19% and 19% respectively. The percentage increase in load values of Moment of Failure (MF) test (Average of RHS and LHS) w.r.to **M-60 specimen** is 0.55%, 2.1%, 2.6% and 2.7% respectively.

All prestressed concrete railway sleeper test specimens tested in this present investigation passed the acceptance test in accordance to the Clauses of IRS T-39 specifications. The experimental values of Load for Centre Top, Moment of resistance and Moment of Failure test were much higher than specified values.

Results of Electrical Resistance Test

The test was conducted at Sri Maruthi Builders and manufacturers of PSC railway sleepers. All prestressed concrete railway sleeper specimens were tested for electrical resistance for their fitness for use in track circuited area. The prestressed concrete railway sleeper specimens were checked for electrical resistance at 230 volts AC supply. The circuitry is as per IRS T-39 specification: Fifth Revision February 2016 Annexure-V. The test lamp emitted light dimmer than the comparator lamp in all the prestressed concrete railway sleepers of various matrices - (i) M- 60 (M-60 Grade of concrete, control mix), (ii) M-60+CNT (Carbon Nano Tubes combined with M-60 Grade of concrete), (iii) M-60+Fiber+CNT (Polypropylene Fibers and Carbon Nano Tubes combined with M-60 Grade of concrete), (iv) M-60+CNT+Fiber (Carbon Nano Tubes and Carbon Fibers combined with M-60 Grade of concrete), (v) M-60+CNT+Fiber+Fiber (Carbon Nano Tubes, Carbon Fibers and Polypropylene Fibers combined with M-60 Grade of concrete) test specimens. All prestressed concrete railway sleeper specimens passed the Electrical Resistance Test and were ‘FTC’ (Fit for Track circuit).

4.CONCLUSION

Based on the results of the experimental investigation the following conclusion were drawn.

1. The Load values for Center Top of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF are 85.2kN, 88.2kN, 95.8kN, 102.4kN and 102.6kN respectively. The increase in load value w.r.t **standard load value of 60kN** as specified by IRS T-39 is 42%, 47%, 60%, 71% and 71% respectively. The percentage increase in load value w.r.to **M-60 specimen** is 4%, 12%, 20% and 20% for M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF.
2. The load values of Moment of resistance (MR) test (Average of RHS and LHS) of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF test specimen is **237.8kN, 238.9kN, 247.15kN, 248.3kN and 250.65kN** respectively. The increase in load values of Moment of resistance (MR) test(Average of RHS and LHS) w.r.to **standard load value 230kN** as specified by IRS T-39 is 3%, 4%, 7%, 8% and 9% respectively. The percentage increase in load values of Moment of resistance (MR) test (Average of RHS and LHS) w.r.to **M-60 specimen** is 0.46%, 3.93%, 4.4% and 5.4% respectively.
3. The load values of Moment of Failure (MF) test (Average of RHS and LHS) of M-60, M-60+CNT, M-60+CNT+PF, M-60+CNT+CF, M-60+CNT+PF+CF test specimen is **427.95kN, 430.3kN, 436.95kN, 439.1kN and 439.3kN** respectively. The increase in load values of Moment of Failure (MF) test(Average of RHS and LHS) w.r.to **standard load value 370kN** as specified by IRS T-39 is 16%, 16%, 18%, 19% and 19% respectively. The percentage increase in load values of Moment of Failure (MF) test (Average of RHS and LHS) w.r.to **M-60 specimen** is 0.55%, 2.1%, 2.6% and 2.7% respectively.
4. All PSC railway sleeper test specimens passed the Electrical Resistance Test and were ‘FTC’ (Fit for Track circuit)

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