Behavior of PSC Railway Sleepers Using Next Generation Nano Based Carbon Fiber Reinforced Concrete

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***Abstract*—This research paper presents a detailed experimental study and finite element modelling (3D-FEM) of Prestressed Concrete railway sleepers using Ansys V16. The incresing demand of high speed trains and axle loads has resulted in the modification of existing railway prestressed concrete (PSC) sleepers andtheir rail components which in turn is demanding increased static and impact load capacity on rails and sleepers. Present experimental investigation consists of use of innovative new advanced materials such as integration of Carbon Nanotubes (CNTs), Carbon fibers(CF) and polypropylene fibers(PF) with High Performance Concrete of a design mix of M60 grade. Five different concrete mixes of PSC railway sleeper specimens viz. M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+PF+CF were studied. The emphasis of this paper is on load-deflection aspect of new advanced materials over conventional material used in the manufacture of railway PSC sleepers. From the experimental result it is evident that, there is enhancement in first crack load and ultimate load and decrease in deflection when compared to conventional materials of PSC railway sleepers and the same has been validated with Nonlinear modal analysis..**

***Index Terms*—PSC Railway Sleepers, ANSYS V16, Static behavior of PSC sleepers, Carbon nano tubes (CNT), Polypropylene fibres (PPF), Carbon fibre(CF), load deflection, Modal frequency, Modal shapes.**

I. Introduction

Various types of railway sleepers are used based on their requirement and material. Their work is to uniformly distribute the line load to earth's surface it helps in maintaining the gauge between the rails and contribute better geometric and aesthetic condition of the track[1]. There are a number of approaches for the study of the behaviour of concrete structures, viz., experimental, numerical, theoretical, etc. Finite Element Analysis (FEA)[2] is a numerical one which provides a tool that can accurately simulate the behaviour of concrete structural member. The use of computer software to model structural elements is much faster, accurate and cost-effective. Hence, to fully understand the capabilities of finite element computer software, one must look back to experimental data and simple analysis

A. Research Significance

The main aim of the present study is a detailed experimental investigation of conventional Pre-Tensioned PSC sleeper reinforced with Carbon Nanotubes (CNTs), Carbon fibers(CF), polypropylene fibers(PF) and new generation superplasticizer, to obtain enhanced structural properties such as ductility, durability and load carrying capacities, so introducing of such composite materials in the field of sleeper manufacturing industries will benefit in increased life span and load carrying capacity[3] of PSC sleepers with quality production and less frequent maintenance

II. Literature Review

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. Sunil Patel[4], Veerendra Kumar, Raji Nareliya[4], carried out work in fatigue analysis of rail joint using FEM. 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

Manuscript received July 15, 2019; revised March 10, 2020.

doi: 10.18178/ijscer.9.2.156-160

which is achieved by reinforcing fibers in concrete. G R Bharath[5], carried out work for Strengthening of post-tensioned beams by externally bonded and anchored Natural Sisal fiber reinforced polymer composites In this Experimental work the flexural behaviour, ductility characteristics and ultimate load carrying capacity of post-tensioned beams strengthened by NSFRPs were evaluated under two point loading. To achieve these 4 PT beams of size 200mmx200mmx2000mm were casted as per IS1343-1980 in that 3 beams are strengthened by NSFRP wrapping in flexure zone and anchored. The ultimate load carrying capacity of the anchored beams was found to be increased by 27.27% compared to control beams. From the test results and observations found that role of the anchorages is to transform a brittle type of failure into a more ductile failure. AKM Anwarul Islam [6], NurYazdani[6] (2008), tells about structurally deficient AASHTO type prestressed concrete bridge girder with FRP wrapping was analyzed using the ANSYS FEM software and the ACI analytical approach. Both flexural and shear FRP applications, including vertical and inclined shear strengthening, were examined. Results showed that FRP wrapping can significantly benefit prestressed concrete bridge girders in terms of flexure, shear capacity increase, deflection reduction, and crack control. The FRP strength was under utilized in the sections elected herein, which could be addressed through decrease of the amount of FRP and prestressing steel used, thereby increasing the section ductility. The ACI approach produced comparable results to the FEM and can be effectively and conveniently used in design. From the critical review of literature it is found that no one has attempted on modification of railway PSC sleepers using advanced materials such as Carbon nano tubes, Carbon Fibre and Poly propylene fibre.

III. Objective of Work

The objective of this work is to conduct the detailed analysis of the PSC railway sleepers using ANSYS16 software and experimental study of their behaviour under standard static loading condition using standard dimension having trapezoidal cross section 150x270x235mm at the end and 150x220x180mm at the centre and 150x250x210mm at the rail seat with the overall length of 2750mm (as per T39-2016 specification). A finite element model of sleeper designed by providing suitable ballast reaction i.e sleepers resting on elastic foundation has been considered and the experimental program was extended on five different modified concrete mixes using advanced materials of PSC railway sleeper specimens viz. M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+PF+CF to determine load deflection relation [7], model shapes and frequency of PSC sleepers at both cracked and un cracked conditions.

A. Design Consideration of Sleepers

The conventional PSC railway sleepers were manufactured as per IRS T-39 (Fifth revision, February 2016), standard dimension having trapezoidal cross section 150x270x235mm at end and 150x220x180mm at centre and 150x220x180mm with the overall length of 2750mm having prestressed tendon of 18 numbers 3mm diameter 3plyhigh tensile strands prestressed with 241KN Prestressing force. For the analysis purpose tendon has been replaced with equivalent of 5mm diameter tendons as each 3ply.

B. Numerical Aalysis of PSC Railway Sleepers Using ANSYS v16

The brief step by step procedure of FEA analysis is as follows:

The basic material properties are defined in engineering data namely poission ratio, compressive strength, young's mudulus of both concrete and High tension strands as input data. Then static structural analysis in workbench is adopted and the same has to be extruded in third dimension to get the 3D model of concrete of the PSC railway sleepers, the lines from sketches commands is used to get the solid body of high tension strands of 18 number of 5mm diameter (equivalent of 18nos. 3mm 3 ply). As per IRS T-39 standard load acting at a distance of 0.4975m from both the ends with standard support conditions, distance between the supports is 1.195m and same loading criteria has been considered in static FEM analysis and model analysis is shown, the positions of prestressing force on the given tendons of magnitude 241KN on the sleeper model is as shown in Fig. 1 and meshing is as shown in Fig. 2.

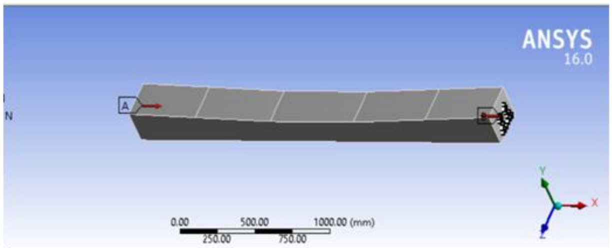

Figure 1. Prestressing force

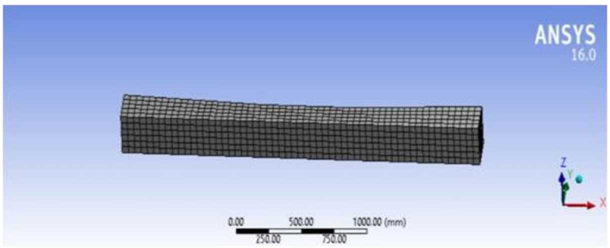

Figure 2. Meshing

C. Properties of Materials Used

In the present experimental investigation and Static finite element analysis the following material properties for five concrete matrices viz. M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+PF+CF are under consideration for PSC railway sleepers. Which are tabulated in Table I.

TABLE I. MATERIAL PROPERTIES OF VARIOUS CONCRETE MATRIXES

Concrete matrix	M60	M60+CNTs	M60+CNTs+PF	M60+CNTs+CF	M60+CNTs+PF+CF
Compressive strength MPa	67.53	69.47	70.31	72.15	74.9
Young's mudulus MPa	34800	38700	38700	39000	39900
Density (KN/m3)	24	24	24	24	24
Poissions ratio	0.18	0.17	0.17	0.16	0.154

D. *Prestressing Tendon*

As per IRS T-39,the prestressing tendons consists a diameter of 5mm and ultimate tensile strength of 1600MPa along with modulous of elasticity of 2x105MPa and Poission ratio: 0.3 also Density of prestressing tendon is 7.8x104KN/m3. 18 numbers of prestressing wires with 3mm and 3 ply were used. Whereas, in FEA 5mm equivalent diameter has been considered.

IV. LOAD DEFORMATION CHARACTERISTICS OF PSC RAILWAY SLEEPERS

From the FEA analysis, deformation models are obtained for PSC railway sleepers for all five material models viz.

M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+CF+PF which are tabulated in Table II.

TABLE II. YIELD DEFLECTION VALUES

Concrete matrix	ANSYS (mm)	Experimental (mm)	A/E
M60	0.86	0.86	0.996
M60+CNTs	0.93	0.93	1.00
M60+CNTs+PF	0.97	0.97	1.006
M60+CNTs+CF	1.01	1.01	1.008
M60+CNTs+PF+CF	1.18	1.15	1.027

A. *Load Deflection Models*

The load deformation curves as obtained from FEA ANSYS v16 for all five models viz. M60(D1), M60+CNT(D2),M60+CNT+PF(D3), M60+CNT+CF(D4), M60+CNT+CF+PF(D5) has been plotted and 5th modal curve has been shown in Fig. 3. And the combined load deformation curve of all five models has been plotted in Fig. 4.

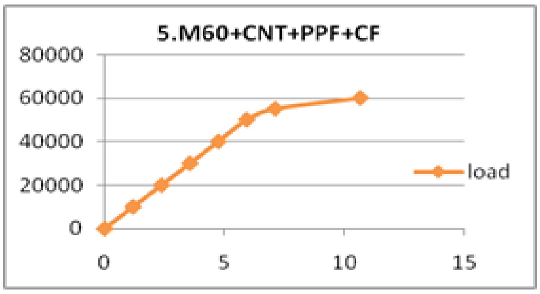

Figure 3. M60+CNTs+PPF+CF(typical)

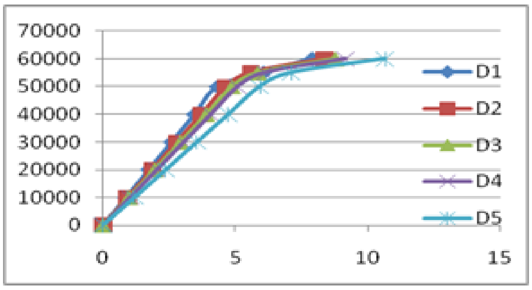

Figure 4. Combined curve of all five models

V. MODAL ANALYSIS OF PSC SLEEPERS

A modal analysis determines the vibration characteristics [8](natural frequencies[9] and mode shapes[10]) of the structures or a machine component, which can be used as an indicator of the structure safety and health monitoring. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. In the present work, the modal analysis is done on PSC railway sleepers to obtain the frequency of first 10 modes. In modal analysis only linear behavior is valid, damping and any applied loads are ignored.

A. *Modal 1 for M60:*

First 10 mode shapes of M60 model 1 are analyzed and the frequencies arrived in the range of 1.242Hz to 73.911 Hz, and the 3 mode for respective frequencies has been shown in Fig. 5 and Fig. 6.

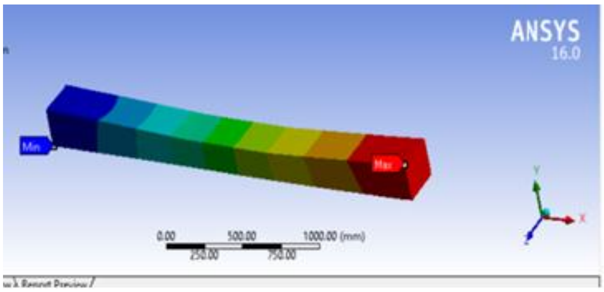

Figure 5. Mode 1. F= 1.242Hz (typical)

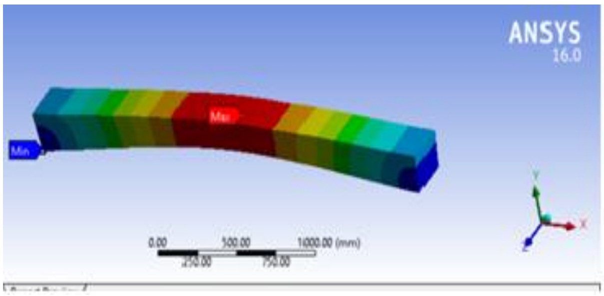

Figure 6. Mode 2: f= 3.3188Hz(typical)

Similarly the analytical results of modal analysis of first 10 modes(M1 to M10) and its frequency obtained for all five models namely M60, M60+CNT, M60+CNT+PF, M60+CNT+CF, M60+CNT+CF+PF has been tabulated below in the Table III.

TABLE III. FREQUENCY (HZ) OF ALL FIVE MODEL AND THEIR FIRST 10 MODES (M1-M10)

Mode Shapes	M60	M60+CNT	M60+CNT+PPF	M60+CNT+CF	M60+CNT+PPF+CF
M1	1.2410	1.2425	1.244	1.2455	1.247
M2	3.3188	3.3229	3.3269	3.331	3.3351
M3	7.5482	7.5573	7.5665	7.5757	7.585
M4	8.3884	8.3986	8.4089	8.4191	8.4295
M5	16.499	16.519	16.539	16.559	16.58
M6	16.787	16.808	16.829	16.849	16.87
M7	17.314	17.335	17.357	17.379	17.4
M8	36.118	36.162	36.206	36.25	36.295
M9	44.157	44.211	44.265	44.32	44.375
M10	73.911	73.912	73.914	73.916	73.918

B. Model Frequencies Based on Empirical Formula

The Compared values of analytical results with empirical formula has been tabulated in the Table IV.

TABLE IV. EMPIRICAL FREQUENCIES OF ALL MODELS

Mode No.(n)	Frequency Hz				
	M60	M60+CNT	M60+CNT+PPF	M60+CNT+CF	M60+CNT+PPF+CF
M1	0.866	0.904	0.913	0.92	0.93
M2	3.463	3.62	3.65	3.66	3.71
M3	7.79	8.14	8.22	8.25	8.34

The above values in Table IV are in a range of ±20% of the analytical values obtained using FEA ANSYSV16.0. First three (M1-M3) values out of 10 modes are considered for comparison and same has been validated.

VI. CONCLUSION

Based on the results obtained from FEA ANSYS v16 analysis following conclusions has been drawn:

The dimensions obtained in prestressed concrete sleepers is lesser than other conventional PSC sleepers with enhanced performance under service loads compared to PSC sleeper with the use of advanced materials which help in the reduction of dead weight of specimen which contributes to the ease of handling and transportation.

The yield deflection obtained during FEA ANSYS v16 and experimental process is nearly the same and the ratio of analytical to experimental (A/E) is nearly unity.

The modal frequencies obtained for the first 10 modes M1 to M10 is in the range of ±20% of empirical values.

There is a incremental increase in stiffness since stiffness is directly proportional to young's modulus and here the young's modulus taken is in the increasing order from 3.48x104 to 3.99x104Mpa in model 1 to 5, hence there is an increase in frequencies with respective modal shapes in both analytical as well as empirically.

It may be evident that higher the frequency lower is the displacement in model 5 (M60+CNT+CF+PPF) among all the five models considered, hence, the model 5 is best among all the other models chosen for FEA analysis as well as experimental work.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The analytical work on the ANSYS v16 workbench is done by Mr. Ashutosh Ranjan and Dr. N. Jayaramappa whereas the experimental work is carried out by Dr. Sadath Ali Khan Zai and Mr. Guruswamy j. And the paper typing work has been performed by Mr. Ashutosh Ranjan under the guidance of Dr. Sadath Ali Khan Zai.

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