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Impact Behaviour of Railway PSC Sleeper using Nano based Carbon with Fiber Reinforced Concrete

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Abstract

This paper presents the studies on under repeated low-energy horizontal impact loading through experimental programs of Railway PSC sleepers integrated with next generation Nano based Carbon along with Fiber Reinforced Concrete. Load-time variation, displacement-time history and energy absorption capacity were studied. Carbon nano tube, Carbon fibers, Polypropylene fibers integrated with High Performance Concrete using a design mix of M60 grade of concrete. Five different PSC test specimens were casted and tested 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 -art techniques. It can be seen that the properties of concrete matrix used in PSC railway sleepers were enhanced with respect to energy absorption capacity and peak load.
Keywords: Carbon Nanotubes (CNTs), Carbon fibers, Polypropylene Fibers, Load Time History, Displacement Time History, Energy Absorption Capacity, Impact Load, Railway PSC Sleepers

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I. Introduction

India is a land of diverse culture, and Railways play a key role in not only meeting the transport needs of the country. Indian Railways is the backbone of the country’s transport infrastructure integrating market and connects communities all over the country. Indian Railways is the fourth largest railway networks in the world (after USA, China and Russia) with a rail network length of 67,368 kilometers (In 2017) and runs approximately 11,000 trains in a day. 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; but it still has to cater to the ever-increasing rail traffic. Not only the total number of trains plying on the network is rising, also the speed, the axle loads and the number of bogies attached to the trains is also increasing. All this calls for a thorough and fast modernization of the sprawling railway network through development of new design concepts and use of advanced materials.Prestressed Concrete (PSC) railway sleeper is an imperative component of ballasted railway tracks. The primary function of the railway sleeper is to transmit the wheel load to the ballast medium. The premature deterioration of railway sleepers is due to rail-seat deterioration, cracking and damaging under different loading conditions and adverse environment conditions. The undetermined ultimate load capacity of track components has been under suspicion for some time, regardless of the fact that they are subjected to impact dynamics induced by wheel/rail interaction, irregularities, and so on along with the static loads. 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.

II. LITERATURE REVIEW

In general, the axle loading tends to physically behave like the dynamic impact pulses due to the continual moving ride over track irregularities and faster speeds .Concrete with strength of above 40 Mpa is generally termed as high strength concrete. Tough ness and ductility properties of conventional concrete can be significantly improved by addition of fibers such as carbon and polypropylene fibers into conventional concrete(1,2,3). Impact is a dynamic phenomenon. The impact event can be classified in to low velocity, intermediate velocity and high velocity regions. A combination of rigid target and flexible striker or rigid striker and flexible target can be used., impact problems can be classified as high energy impact loading problem or low energy repeated impact loading problems(12,13,14). The impact load was monitored and recorded by the dynamic load cell connected to the computer(4). the stiffness degradation of reinforced concrete beams under repeated low-energy impact load using Horizontal impact test on beam of size 100 X 200 X 2300mm with M40 concrete, Schrader's test device (as per ACI-544 committee) for impact test on concrete specimen 152mm dia and 62.5mm thick with M30 concrete matrix(5). PSC railway sleeper test specimen was placed on the base plate between four positioned lugs at the periphery, steel ball placed on top of the PSC railway sleeper test specimen and drop hammer was used to apply the impact load(6,11). Impact behaviour of structural elements can be increased by using higher toughness and high absorbed capacity can be achieved by inclusion of fibers. It was observed that, the Load-Time history under impact loading is essentially triangular. The duration of the impact pulse remains as a constant, while the peak force reduces with increased number of impact blows for a given energy of impact loading(7,8,9,10). Hence, the present experimental investigation aims at full understanding of the influence of cementitious materials such as GGBS, Silica Fumes, Carbon fibers, polypropylene fibers, Carbon Nanotubes by preparing PSC railway sleepers test specimens subjected to low velocity repeated impact loading to study load-time variation, displacement-time and energy absorption capacity.

III. EXPERIMENTAL PROCEDURE

A series of five PSC railway sleeper test specimens were casted as per IRS, T-39 . Cement (53-S conforming to IRS/T-40-1985), Multi wall Carbon nano tubes, fine aggregate (Zone II Grade), 20 mm down size coarse aggregate. Super plasticizer (AURACAST 270M) was added in the ratio of 0.4 liter per 100 kg of binder, 0.5% of carbon fiber, 900grams of polypropylene fiber for one bag of cement, 8% of Silica fume (as cement replacement) and 21.6 % GGBS were used. The mix ratio adopted is 1:1.061:2.499 with water binder ratio of 0.263 with characteristics strength of concrete 60 N/mm2. Each set of PSC railway sleepers test specimens were subjected to impact loading. The hammer is 170 mm in diameter and 320 mm in length, which forms the main striking mass. The hammer attached with the load cell strikes the test specimen with an effective mass equal to mass of the hammer and the mass of the load cell. The effective weight of hammer together with load cell is 50 tons. The impact responses and repeated impact loads are monitored and stored during 1, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200 and up to the failure of PSC railway sleepers test specimens were recorded load-time variation, displacement-time variation and energy absorption capacity were observed.

A. Instrumentation

The impact testing machine used in the present experimental investigation is of pendulum type instrumented horizontally impact testing machine as shown in Fig 1. The instrumented pendulum consists of steel impact hammer, which strikes the PSC railway sleepers test specimens horizontally at the mid span. The dimension of the hammer is 170 mm dia. and 320mm length, which is fitted with instrumented hammer head to record the dynamic responses. To record the different responses during impact loading . linear variable differential transformer (LVDT), Load cell are used and are as shown in Fig 2. The post processing of recorded data is carried out using a data acquisition system, which is equipped with MS Visual Basic 6.0 software.

IV. TEST PROCEDURE

Pendulum Type Horizontal Impact Testing Machine is used for repeated low-energy impact loading test on PSC railway sleepers test specimens. The specimens were held rigidly between two rigid steel supports such that spherical steel hammer head attached with load cell can hit the PSC railway sleepers test specimen exactly at its mid-width and at center of span. The mechanical stopper arrangement behind the hammer is adjusted and kept at a known distance so as to get the desired height of fall of 1.0 m for a required energy level and the hammer is held back manually after every hit to avoid a second impact on the sleeper. The load cell attached to the striking hammer gives the load-time variations and displacement-time variations are recorded using LVDT for the following PSC railway sleepers test specimens viz: M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5).

Fig. 1: Pendulum Type Horizontal Impact Testing Machine

Fig. 2: LVDT Instrumentation Used In Experiment

V. TEST RESULT

The experimental test results obtained for the dynamic response of PSC railway sleepers test specimens consists of responses like, load-time variation, displacement-time variation and energy absorption capacity.

A. Load-Time Variation

The load-time variation which has to be expressed in terms of pattern of variation in peak load and area under the load time curve. The peak load value and the duration of impact on the specimen is obtained at regular intervals using load cell attached to the impact hammer. Figure 3 shows the Load –Time variation for PSC sleeper test specimens obtained at first impact blows for M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) respectively.

Table – 1
Shows the Peak Load obtained at 1st, 100th and last impact blows

Test Specimen	*Peak Load at 1st Blow*	*Peak Load at 100th Blow*	*Peak Load at Last Blow*
M60	*335.34kN*	*138.1kN*	*121.43kN*
M60+CNT	*367.75kN*	*202.66kN*	*138.74kN*
M60+CNT+PF	*396.75 N*	*224.3kN*	*153.43kN*
M60+CNT+CF	*411.32kN*	*270.23kN*	*168.21kN*
M60+CNT+PF+CF	*455.00kN*	*301.2kN*	*178.23kN*

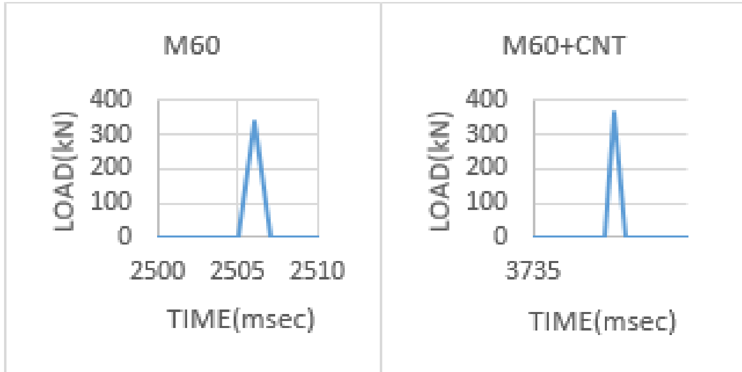

Fig. 3: Load- times variation for M60 (S1) and M60+CNT (S2) at 1st Blow

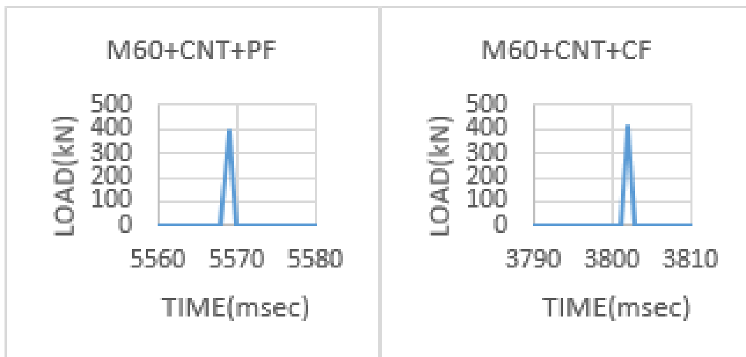

Fig. 4: Load- times variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at 1st Blow

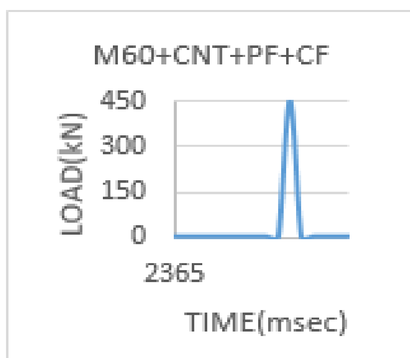

Fig. 5: Load- times variation for M60+CNT+PF+CF (S5) at 1st Blow

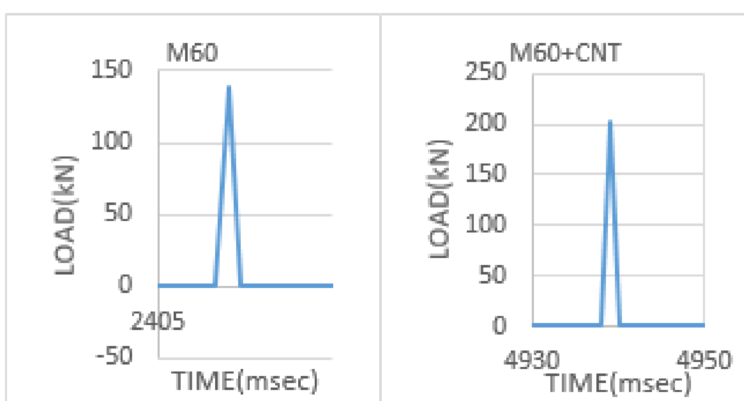

Fig. 6: Load- times variation for M60 (S1) and M60+CNT (S2) at 100^{th} Blows

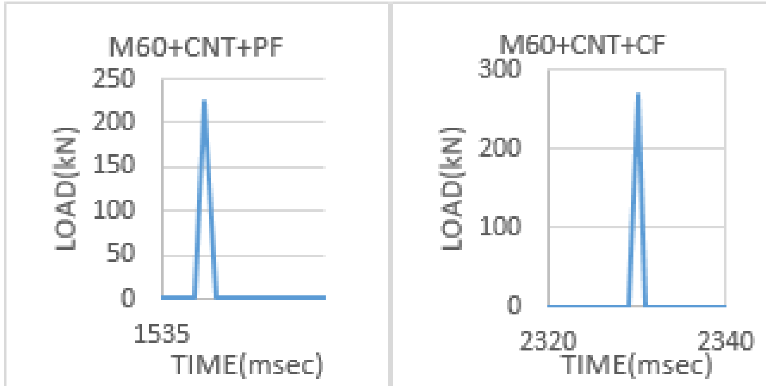

Fig. 7: Load- times variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at 100th Blows

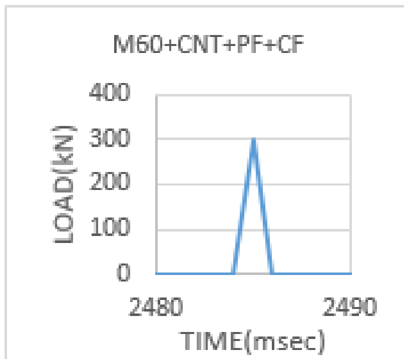

Fig. 8: Load- times variation for M60+CNT+PF+CF (S5) at 100th Blows

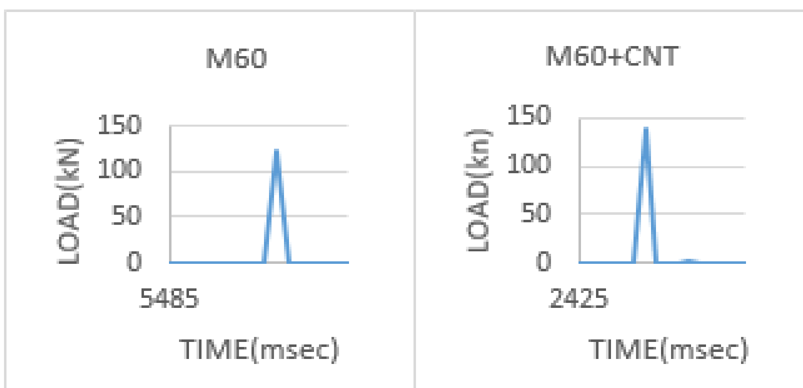

Fig. 9: Load- times variation for M60 (S1) and M60+CNT (S2) at last Blow

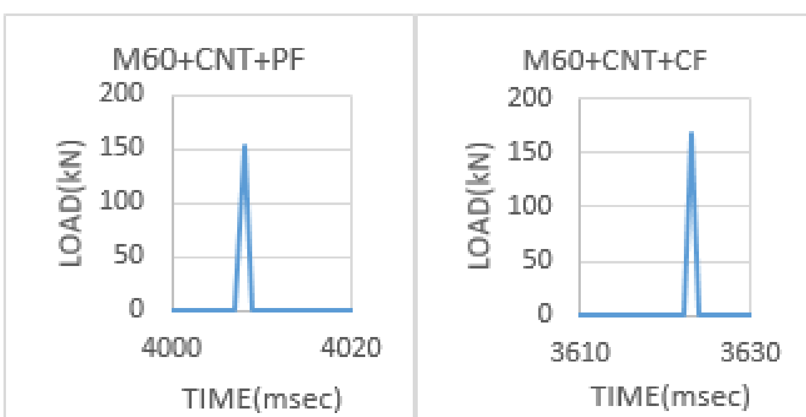

Fig. 10: Load- times variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at last Blow

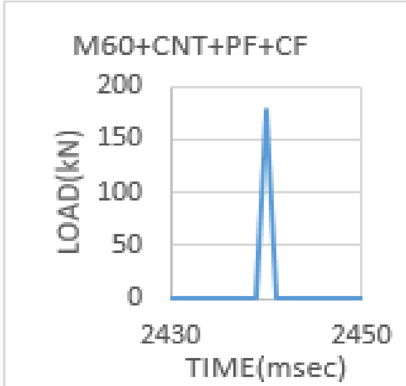

Fig. 11: Load- times variation for M60+CNT+PF+CF (S5) at last Blow

Figure 3 – 11 and table 1, shows the peak load obtained for 1st ,100th and last impact blows for M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5), it can be seen that as number of impact blows increase peak load decreases. The highest peak load obtained for the M60+CNT+PF+CF (S5). 455.00 kN for 1st blow and 178.23 kN for last blow (200th blow) as compared to PSC railway sleepers test specimen (S1, S2, S3 and S4)

1) Variation of Peak Load with Number of Impact Blows

The variation of peak load with no of impact blows for psc railway sleepers test specimens M60 (S1), M60+CNT (S2), M60+CNT+PF (S3) ,M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) are as shown in figure 12.

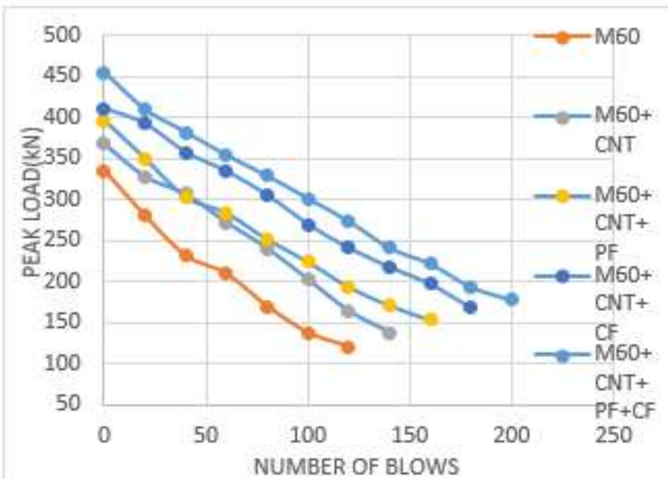

Fig. 12: Variation of Peak Load v/s Number of blows for all test PSC railway sleeper specimens

From figure 12, it can be observed that the duration of impulse during each impact essentially remains a constant and load-time variation on all PSC railway sleepers test specimens for M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5). The shape of pulse is always triangle. Peak load is registered at the center of impulse. The time duration of pulse ranges from 25 to 30 millisecond based on test results. Hence, in this experiment the duration of pulse loading can be considered as 30 milisecond. Further the peak load indicated by the load cell reduces with increase in no. of impact blows

B. Displacement Time History

The displacement-time variations for the M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) for different number of impact blows are recorded and are as shown in figure 13- 21 and table 2

Table – 2
Shows the Displacement variation obtained at 1st, 100th and last blow

Test Specimens	*Displacement at 1st Blow*	*Displacement at 100th Blow*	*Displacement at Last Blow*
M60	*3.12 mm*	*9.03 mm*	*10.34 mm*
M60+CNT	*2.90 mm*	*7.65 mm*	*9.25 mm*
M60+CNT+PF	*2.69 mm*	*7.24 mm*	*8.87 mm*
M60+CNT+CF	*2.43 mm*	*5.76 mm*	*8.42 mm*
M60+CNT+PF+CF	*2.21 mm*	*5.0 mm*	*7.26 mm*

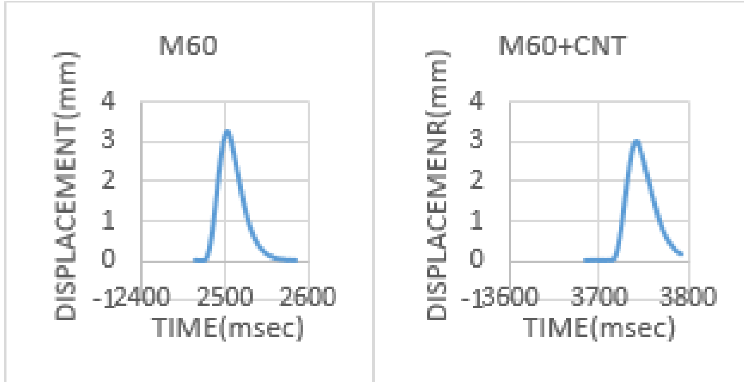

Fig. 13: Displacement variation for M60 (S1) and M60+CNT (S2) at 1st Blow

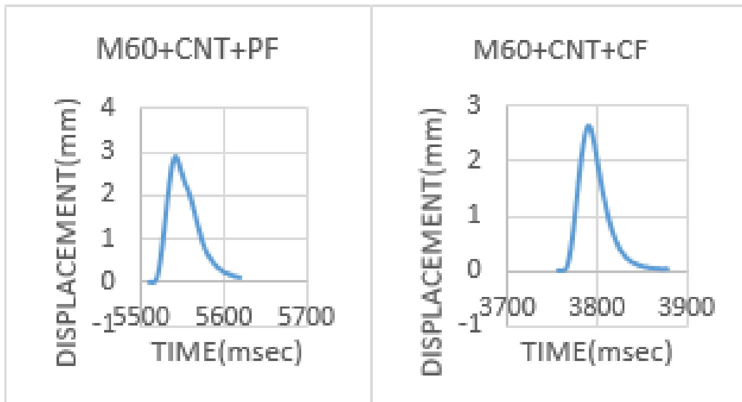

Fig. 14: Displacement variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at 1st Blow

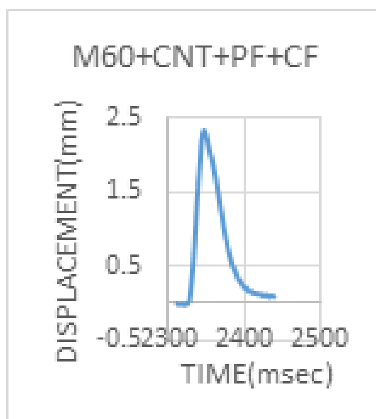

Fig. 15: Displacement variation for M60+CNT+PF+CF (S5) at 1st Blow

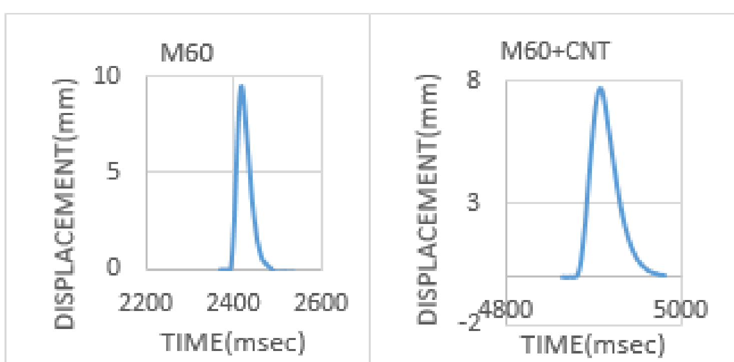

Fig. 16: Displacement variation for M60 (S1) and M60+CNT (S2) at 100th Blows

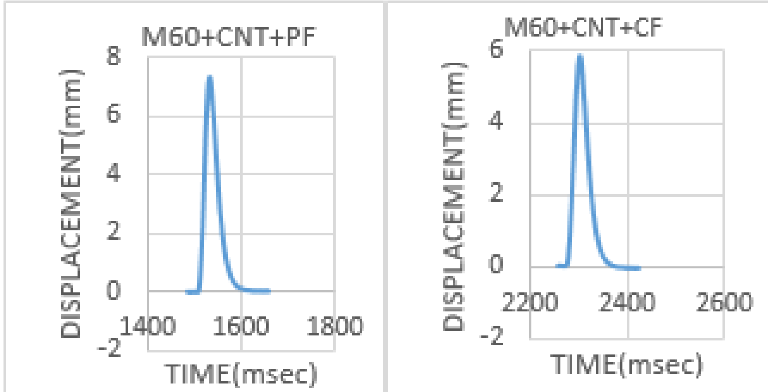

Fig. 17: Displacement variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at 1st Blow

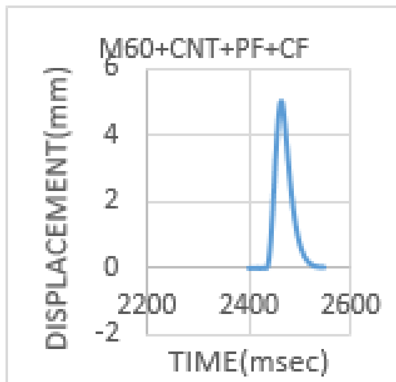

Fig. 18: Displacement variation for M60+CNT+PF+CF (S5) at 100^{th} Blows

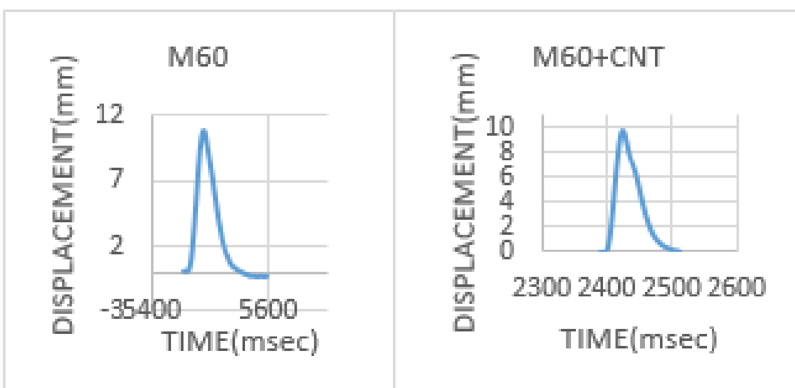

Fig. 19: Displacement variation for M60 (S1) and M60+CNT (S2) at last Blow

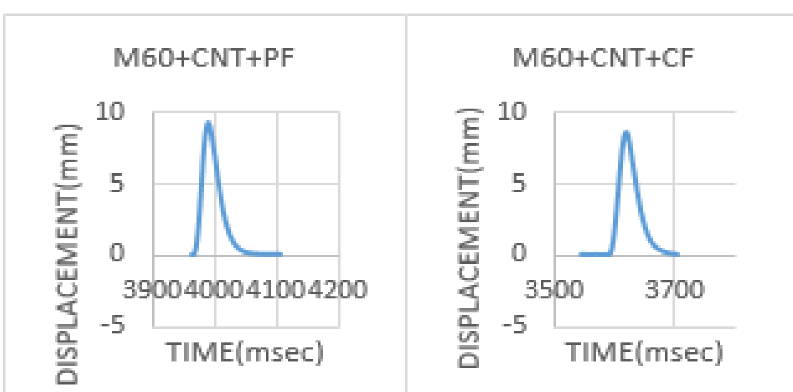

Fig. 20: Displacement variation for M60+CNT+PF (S3) and M60+CNT+CF (S4) at 100^{th} Blows

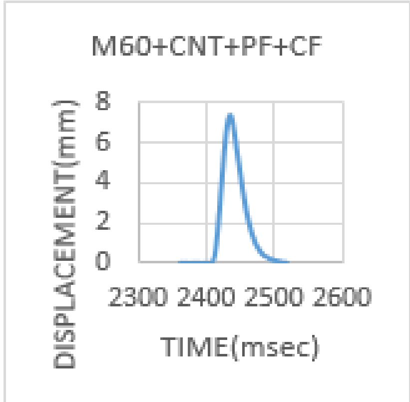

Fig. 21: Displacement variation for M60+CNT+PF+CF (S5) at last Blow

Figure 13– 21 and table 2, shows the displacement variation obtained for 1st ,100th and last impact blows for M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5). It can be seen that as number of impact blows increases displacement increases. The displacement obtained for the M60+CNT+PF+CF (S5) is 2.21mm at 1st blow and 7.26mm for last blow (200th blow). Whereas 3.12mm, 2.90mm, 2.69mm and 2.43mm for 1st blow obtained for other test specimens (S1, S2, S3 and S4).

C. *Energy Absorption Capacity*

During the low velocity repeated impact load on PSC railway sleepers test specimens, impact input energy (Eb_o = mgh) partly get absorbed by the dynamic behaviour of that element. This absorbed energy capacity gives its ability to sustain the dimensional integrity or internal resistance capacity during the low velocity impact experiment. The load-time variation data are used to calculate energy absorption capacity for M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) are given in figures 22-26 and table 3.

Table – 3
Shows the Energy Absorbed obtained at 1st and last blow

Test Specimens	*Energy absorption in 1st blow*	*Energy absorption in last blow*
M60	*573.04 J*	*148.23 J*
M60+CNT	*578.30 J*	*158.15 J*
M60+CNT+PF	*581.63 J*	*172.89 J*
M60+CNT+CF	*584.72 J*	*187.13 J*
M60+CNT+PF+CF	*589.13 J*	*160.54 J*

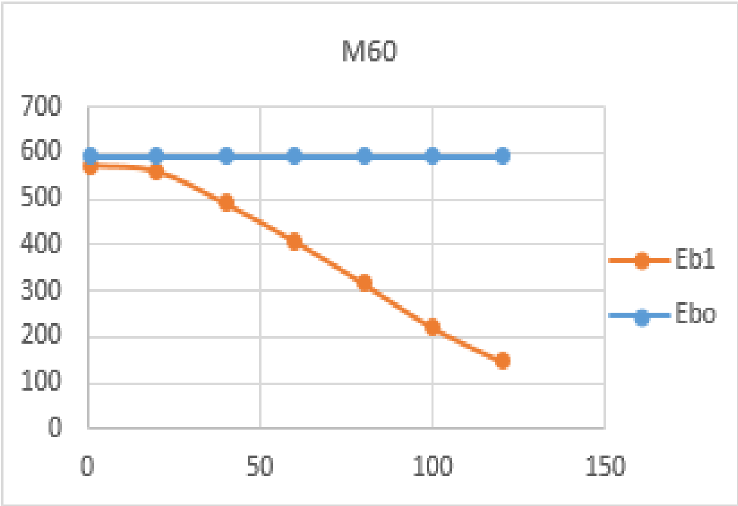

Fig. 22: Variation of Energy (Ebo and Eb1) with increased number of blows for PSC sleeper test specimen M60

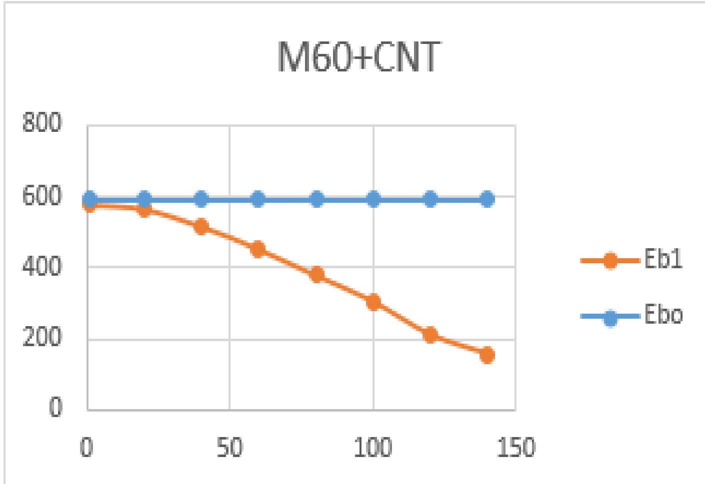

Fig. 23: Variation of Energy (Ebo and Eb1) with increased number of blows for PSC sleeper test specimen M60+CNT

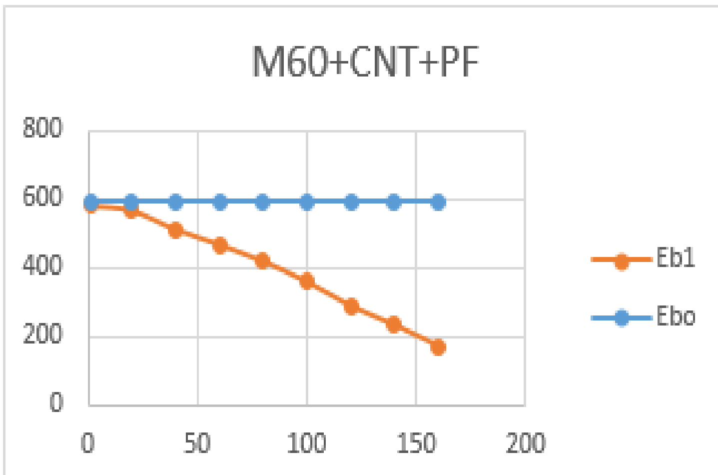

Fig. 24: Variation of Energy (Ebo and Eb1) with increased number of blows for PSC sleeper test specimen M60+CNT+PF

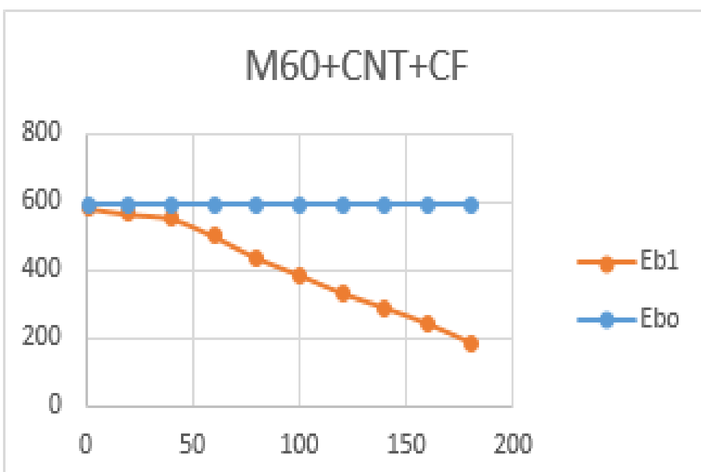

Fig. 25: Variation of Energy (Ebo and Eb1) with increased number of blows for PSC sleeper test specimen M60+CNT+CF

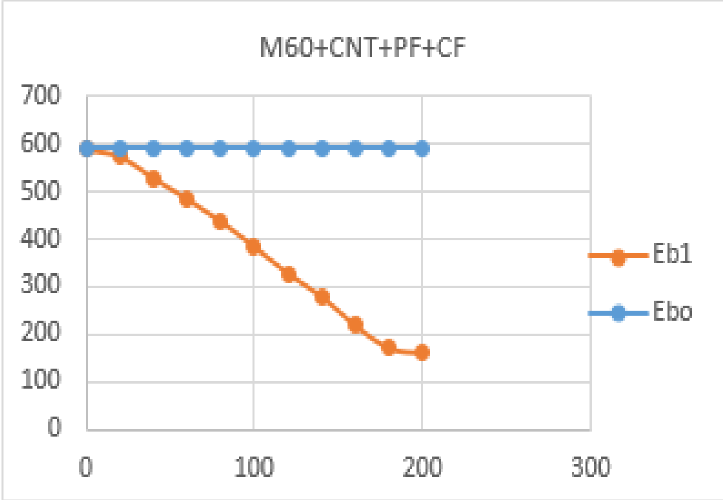

Fig. 26: Variation of Energy (Ebo and Eb1) with increased number of blows for PSC sleeper test specimen M60+CNT+PF+CF

Figure 22-26 and table 3, shows the energy absorption capacity for PSC railway sleeper test specimen M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5). It is observed that the highest energy absorption capacity is obtained for M60+CNT+PF+CF (S5).

VI. CONCLUSIONS

1) From the experimental results of load carrying capacity obtained for PSC railway sleeper test specimens for M60 (S1:Control), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) are 335.34kN, 367.75kN, 396.75kN, 411.32kN and 455kN respectively. It is observed that load carrying capacity has been increased by 9.6%, 18.31%, 22.65%, and 35.68% for M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) with respect to M60 (S1:Control),. Hence it can be concluded that there is a significant increase of 35.68%, in the load carrying capacity for M60+CNT+PF+CF (S5) w.r.t M60 (S1:Control).
2) Displacement time records for M60 (S1:Control), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) at different number of impact blows. The peak amplitude of the displacement increases with increase in number of impact blows., maximum displacement obtained for the last impact blows for, M60 (S1), M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) are 10.48mm, 9.70mm, 9.40mm, 8.62mm and 7.4mm respectively
3) The energy absorption capacity obtained for the test sleeper specimens of M60 (S1), is 573.04 Joules and whereas for the M60+CNT (S2), M60+CNT+PF (S3), M60+CNT+CF (S4) and M60+CNT+PF+CF (S5) are 578.30 Joules, 581.63 Joules, 584.72 Joules and 589.13 Joules respectively. It is experimentally evident that M60+CNT+PF+CF (S5) gives highest energy absorption capacity as compared to the other PSC sleeper test specimens.

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