Investigation on the behaviour of prestressed concrete sleepers (PCS) under negative static loading

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Abstract. Railways in Malaysia are undoubtedly a various incorporated element that can possibly assume as an imperative part in the advancement of a manageable transportation framework in the nation. Therefore, failure of prestressed concrete sleepers under the negative static loading need to be investigate due to its role as one of the important part in railway. In this study, negative moment test was established to investigate the design load of the prestressed concrete sleeper (PCS) under negative static loading. Three (3) samples of PCS were used and one (1) PCS contains two rail seat, called KTMB and EPMI sides. It is found that new crack appeared on EPMI sides with the length of 100 millimeters. Meanwhile, the highest displacement for EPMI and KTMB sides were found to be 7.332 and 6.606 millimeters. From three (3) samples tested, only one PCS shows the failure to cater the design load of 176.94 kN subjected to rail seat.

1. Introduction

Prestressed Concrete Sleepers (PCS) are structures that support railway system and absorb variable loading from the train that pass along the rail [1]. The consistent railway connections associations with neighbouring states are a key trademark that may characterize the framework of the rail system. Malaysian railways are confronting tough challenge to enhance their unwavering quality and speed, keeping in mind the end goal to offer aspiring administrations and upgrade their significance as an alternative mode of transportation.

Many earlier researchers have conducted static test on the concrete sleeper such as Kumar D K et al. [2] and Kaewunruen S et al. [3]. However, the data they achieved cannot be relate completely with concrete sleepers in Malaysia due to several differences like standard and environment. This shows the results of failure of prestressed concrete sleepers under the static loading that can be completely relevant to the concrete sleepers available in Malaysia and use other foreign research’s results as references.

Static load will produce shear and flexure failure on prestressed concrete sleepers while impact load only produce shear failure [4]. Current practice shows that PCS is designed based on an Australian code of practice (AS1085.14) [5]. Referring to past research, cracks can develop internal frictions among cement, concrete, and aggregate so that the damping coefficients tend to increase with more crack incurrence [6]. Factors that influence the prestressed concrete sleepers are relative masses, velocities, contact zone stiffness, frequency of loading, precision of impact, and locally energy-absorbed area [7].

The objective of this study is to determine the capability of the prestressed concrete sleepers (PCS) to perform under design load through the negative static loading and produce the relationships between
load against displacement in form of graph. From the data obtained, the highest displacement that were produced on each rail seat sides can be analysed and compared to the load produced in negative moment test. Actual prestressed concrete sleeper samples have been provided by Eastern Pretech (Malaysia) Sdn. Bhd. The data obtained is helpful as references to assist any investigation regarding to railway sleepers research. Hence, this research may likewise give data on prestressed concrete sleeper and its configuration, if there is a need to enhance its current performances.

2. Methodology

Concrete sleepers can be in one piece of uniform or variable dimensions. For prestressed concrete sleepers that we used, they are beam-type and single-piece structure, roughly have the same dimensions as timber sleepers. Furthermore, the dimensions of the concrete sleepers used in this study accurately of 2000 mm and tensioned with 16 numbers of tendon. Concrete grade used is 60 and these sleepers have two rail seat side which figured as KTMB and EPMI side. Figure 1 shows the actual appearance of the prestressed concrete sleepers (PCS) that being used in research. Moreover, one (1) PCS contains two rail seat sides and be given by the name of KTMB and EP MI in this research.

![Figure 1. Actual appearance of the prestressed concrete sleepers.](image)

Reaction Frame was used to test the sleeper. Figure 2 shows the reaction frame used in the heavy structure laboratory.

![Figure 2. Reaction frame in heavy structure laboratory.](image)
High precision usb-plugged microscope can change its sharpness of the image, be able to zoom in 5x further and equipped with adjustable torchlight to help to see the crack more easy. It also can be use to take a picture and save directly into the computer. Besides, the microscope has certain limitations that it only be able to capture small crack and any large crack cannot be recorded fully. But, any large can be seen with eyes and can be measure with a regular ruler and recorded with regular camera. The Linear Variable Displacement Transducer or in short term LVDT, is also known as Differential Transducer as used to measure the displacement of the concrete sleeper when subjected with static load. For this research, a LVDT of 30 mm type was used.

As for structural test, the prestressed concrete sleeper was in inverted position for negative moment test. The reasons of the PCS being inverted in this test because negative moment test only testing the capability of the PCS to cater the designated design load of the samples. Furthermore, negative moment test does not include the PCS to reach the ultimate failure of the samples because it can only examine the durability of the PCS under design load during inverted position according to [7]. The concrete sleeper was inspected to identify any existing defect (cracking). By wiping the surface of the concrete sleeper with wet cloth, the crack will be more visible. Location of the support and its loading condition were figured by referring to [7]. Neoprene is some type of synthetic rubber that been put between the support and concrete sleeper as shown in Australian Standard and exhibits good chemical stability and maintains flexibility over a wide temperature range. In this research, neoprene was used as a load bearing base, to evenly guide the force acting on the concrete sleeper. Figure 5 shows the location of the support to put neoprene and its loading condition for this test, provided with the dimensions in millimeter. Marker was used to mark the location where to put the neoprene during the test. For rail seat vertical load test, there have two supports only and one loading subjected on the rail seat one side at the time. So, the other end will be in free hanging condition. Figure 3 shows the side of the prestressed concrete sleeper with its tendons (16 totals) and the location to assign the LVDT and its callsign number. For negative moment test, 3 LVDT was used and one at the bottom of the concrete sleeper directly under the applied load, assigned as LVDT 1 (CH 001) to check the deflection of the concrete sleeper and 2 LVDT at the side and on the last tendon of the concrete sleeper, assigned as LVDT 2 and 3 (CH 002 & 003) to check the deflection of the prestressing tendon in the PCS as shown in figure 4. When static load subjected on PCS, there will have displacement occurs on the concrete and the prestressing tendon as PCS is categorized as composite structures.

![Figure 3](image_url)  
**Figure 3.** Side of the concrete sleeper with its tendons and dimensions (negative).

Data logger were used to connect the LVDT with the computer and using software to set up and calibrate LVDT’s reading. Then, the data in the computer was recorded in form of excel file. After that, load was applied at a rate not greater than 25 kN/min (0.42 kN/sec) about 7 minutes until the design load, 176.94 kN required to produce the proof rail seat negative moment. Following the Australian Standard, the test load (P) was maintained for not less than 3 minutes in this test and during the maintaining test load process, any micro structural cracking was inspected by using High Precision Microscope and the image and its location was recorded with its measurement (length of the crack). Any
camera and video recorder were also used to record the data to produce the results and evidences. Lastly, the load was released and the deflection results were saved into computer. The same steps were repeated for the other end of the rail seat.

![Figure 4](image)

**Figure 4.** Location of LVDT at one side of the rail seat of the concrete sleeper (negative).

### 3. Result and discussion

Negative moment test was applied to prestressed concrete sleeper to achieve load against deflection data to obtain whether the concrete sleeper itself achieve its design load capacity to cater load and to see if any changes in earlier cracks. High precision microscope only being used in negative moment test because the crack is too small to be visible to naked eyes. Earlier cracks were only comparable in negative moment test because the test will only produce micro cracks which can be compare with. When maintained the design load given 176.94 kN, subjected onto concrete sleeper for 3 minutes, any crack produced were recorded. The results found that one crack appeared during the test on EPMI sides. Figure 5 shows the cracks appeared with the length of 10 mm after been measure by ruler. However, after using high precision microscope, it can only record until 3.267mm due to its limitation.

![Figure 5](image)

**Figure 5.** Crack that appeared during negative moment test on EPMI sides.
Figure 6 and 7 shows earlier cracks on EPMI and KTMB side during negative moment test. In this result, no changes to earlier cracks and new crack produced on EPMI side when the design load subjected to the concrete sleeper. This indicates that the concrete sleeper itself does not achieve its design load capacity to cater design load. During load placed on rail seat, displacement and crack will occur to the PCS, deteriorating their lifespan to use in actual site. From the Table 1, it proves that the sample cannot be used in actual site due to its crack length produced was too large. Crack observation only occurs at the rail seat, namely KTMB and EPMI in this research because rail seats are the most critical area of the PCS when in actual site. In industry, only rail seat of the PCS is directly subjected to the train load. So, crack that produced at the rail seat needed to be recorded and analyse to determine the quality and design life of the PCS itself. Also, from table 1, there is no effect of design load towards earlier cracks, proving earlier defect are not critically involved with the quality and behaviour of the PCS towards negative static loading.
Table 1. Results of crack length from both KTMB and EPMI rail seat of prestressed concrete sleeper.

| Rail seat | Crack Length Before Negative Moment Test (mm) | Crack Length After Negative Moment Test (mm) |
|-----------|-----------------------------------------------|---------------------------------------------|
| KTMB      | 2.693                                         | 2.693                                       |
| EPMI      | 2.807                                         | 2.807                                       |
|           | 0.000                                         | 10.000                                      |

As for load against deflection data, they are shown in form of graph and table to see their relationships, representing both KTMB and EPMI rail seat sides as shown in Figure 8 until Figure 11. A PCS may be strong enough to resist safely the bending moments and shear forces and yet be unsuitable because its deflection under the calculated safe load is excessive [8]. The amount a PCS deflects depends on the way it is supported, the amount and position of the load, the span of the beam, the size and shape of its cross-section and the nature of the material. For a given amount of material, the deepest beam is the best for limiting deflection as well as being the most economical for resisting the bending moments due to the loads on the beam. For large spans, beams may have to be of larger sizes than are necessary for resisting bending moments in order that the deflections may be kept to reasonable limits. Hooke's Law states, that for an elastic material, stress is proportional to strain and that stress divided by strain is called modulus of elasticity, E. The greater the value of E, the stiffer is the beam, i.e. the greater is its resistance to being bent. From the data obtained, the displacement from KTMB and EPMI shows its stiffness towards design load of the PCS at the rail seat. Meanwhile, the highest displacement for EPMI and KTMB sides were found to be 7.332 and 6.606 millimetres.

![Figure 8. Load against deflection at KTMB rail seat section for LVDT 1 (CH 001).](image)

![Figure 9. Load against deflection at KTMB rail seat section for LVDT 2 & 3 (CH 002 & 003).](image)
Figure 10. Load against deflection at EPMI rail seat section for LVDT 1 (CH 001).

Figure 11. Load against deflection at EPMI rail seat section for LVDT 2 & 3 (CH 002 & 003).

CH001 – LVDT 1, at the bottom of the concrete sleeper, CH002 – LVDT 2, at the left first tendon of the concrete sleeper and CH003 – LVDT 3, at the right first tendon of the concrete sleeper. As shown in the figure, the load – displacement curve of the actual prestressed concrete sleeper were gradually increased.

4. Conclusions
Based on the results, this research has determined the behaviour of prestressed concrete sleepers under negative static loading. From negative moment test, crack appeared on EPMI side with the length of 10 mm when the design load of 176.94 kN subjected to concrete sleeper, maintained for not less than 3 minutes. Also, no changes in length for the earlier crack for both sides as well. However, the crack is only visible when the load is applied. During unloading, the crack is not visible to naked eyes, but only can be seen through the high precision microscope. Meanwhile, the highest displacement for EPMI and KTMB sides were found to be 7.332 and 6.606 millimetres. To ensure the PCS to be at upmost quality, its deflection need to be in lowest value possible. For recommendation, equipment that will be use in the experiment need to be prepared earlier to increase the accuracy and reducing errors to obtain the results.

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