The behaviour of Prestressed Concrete Sleeper (pcs) sitting on railway track

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Abstract. Prestressed concrete sleeper (PCS) is one of the important components for railway structural system. PCS sits on ballast (ground) and the load from the train wheel will be transferred through it thus distributed to the ground. In Malaysia, the ground condition from one place to another is unique. If the PCS sits on an uneven or unstable ground base, the load from the train may not be transferred smoothly to the ground and when that happened, the PCS might be damaged or broken into half. In this research, the researchers, with the help of the Keretapi Tanah Melayu Berhad (KTMB) personnel, studied about some problematic PCS that sit on an uneven ground base. By using the state-of-the-art on-site equipment, results were obtained and strengthened the KTMB assumption on their problematic sites. The data collection shows that the value of deflection is higher at KM20.75 compared to KM26.25 which is 18.90mm and 1.48mm respectively for 6-coach commuter and 8.45 mm and 1.36mm respectively for Electric Train Service (ETS). This result may be affected by the existence void under the rail track structure at KM20.75 due to soil settlement caused by the underground water stream.

1. Introduction

Malaysia is a developing country that has more than 30 million hectares of land. The change of status from a low urbanisation country to a big city contributes to a lot of economic outcomes to the state. One of the most critical factors in helping the economic activities in Malaysia is transportation infrastructure, which is being upgraded from time to time to ensure the delivery of people needs and demands. It includes the usage of train as a transportation mode across the country [1]. Train has been used in Malaysia since 1885, and until now, this kind of traffic is one of the first choices by the Malaysians whether for transportation in the city or for the intercity usage [2]. Thus, it was imperative to perform good construction and to upgrade the rail track quality to deliver good and comfortable journey for the public. Sudden fracture or failure of track or other railway components can contribute to the derailment [3]. One of the ways to improve the rail track system may start with better data collection which leads to a correct maintenance decision. This investigation was carried out to obtain the deflection of the concrete sleepers when receiving the load waves from the moving train.
This research focuses on the behaviour of concrete sleepers when receiving a load from the train. The variables being considered for this experiment were the type and condition of the underlying soil strata. The measurement of concrete sleepers behaviour was obtained in terms of acceleration and vibration of the concrete sleepers [4]. The instrument, Sirius M was selected to measure those parameters. Theoretically, the value of acceleration can be double integrated to convert into the deflection value. The site location for collecting the data was at Sungai Petani – Tasek Gelugor line which consists of a few types of soil bed. Two locations had been identified. The first site was located at KM20.75 of Sungai Petani – Tasek Gelugor route. The second site was located at a bridged railway at KM26.25 along the route of Sungai Petani – Tasek Gelugor. The site locations were determined by considering the soil strata such as in a paddy field area, hilly area and well-structured area like flyover or bridge. The train type involved in the data collection was the 6-coach commuter train and Electric Train Services (ETS).

Furthermore, this study will provide a better insight into the impact of soil conditions on the behaviour of concrete sleepers when receiving a load from a moving train. This research also can demonstrate the performance of concrete sleepers in terms of deflection located on different two soil conditions and propose new considerations for the maintenance work of the rail track [5]. In addition, this study can be used to help other researchers to design concrete sleepers by taking into consideration the type of soil, especially for problematic soil in Malaysia. The method used in this research may also be useful in the future of the commuter industry especially for measuring the performance of prestressed concrete sleepers under rail track.

2. Site investigation work
In this investigation, Sirius M instrument was selected to collect the data at the site location. Sirius M consists of a few parts such as IEPE sensor to detect the vibration of prestressed concrete sleepers. The IEPE sensor was linked to the edge of prestressed concrete sleepers by binding with specific ‘glue’ without affecting the value of vibration. It was connected to the software in the computer to observe the chart of the acceleration of prestressed concrete sleepers. The position of IEPE sensor must be consistent throughout the investigation. The IEPE sensor can record a tri-axis direction (x, y and z). This will provide acceleration data for prestressed concrete sleepers when receiving a load wave carried by the train. Direct data collection will be in a unit of mm/s² which is in term of acceleration. By the data recorded, the value of deflection can be obtained by means of double integration of the value of acceleration. Figure 1 shows the site location chosen for the experimental work.

![Figure 1. Collecting acceleration data of concrete sleepers receiving load from moving train.](image)

3. Mathematical integration
From the data recorded, the value of deflection can be obtained by double integration the value of acceleration. Dewesoft software application can be used to interprete and convert the data from
acceleration to the displacement value. In theoretical view of mathematical integration, the acceleration is the rate of change of the velocity of an object. At the same time, the velocity is the rate of change of the position of that same object [6]. In other words, the velocity is the derivative of the position and the acceleration is the derivative of the velocity [7], thus:

\[ a = \frac{dv}{dt} \quad (1) \]
\[ v = \frac{ds}{dt} \quad (2) \]
\[ a = \frac{d(ds)}{dt^2} \quad (3) \]

As \( a \) is for acceleration and \( v \) as velocity, the integration is the opposite of the derivative. If the acceleration of an object is known, the position data can be obtained if a double integration is applied (assuming initial conditions are zero):

\[ v = \int (a) dt \quad (4) \]
\[ s = \int (v) dt \quad (5) \]

As \( s \) is for displacement, the concept of double integration was used to convert the obtained data into deflection value.

4. Result and discussion
This section compares all trains that passed through KM26.25 and KM20.75 which consisted of a 6-coach commuter and an ETS. The site condition of KM26.25 has a stable soil condition. The data was taken during a sunny day in a dry condition. The data was taken using Sirius-M instrument and then being integrated to transform into the deflection term by using Dewesoft software. During data acquisition, the device can record tri-axis data mainly x, y and z. However in this study, the researcher only focussed analysing the data only in y-axis.

![Figure 2. Location of IEPE sensor (edge of concrete sleepers) with correct orientation.](image)

Figure 2 shows the location of the sensor at its correct orientation to collect the data. The commuter consisted of 6-coaches and was travelling at the speed of 90km/h. The highest acceleration recorded was 91.325m/s\(^2\) and the highest deflection was 1.482mm. The graph of the 6-coach commuter’s acceleration was shown in figure 3. The value of deflection and acceleration was tabulated in table 1.
Meanwhile, for the analysis of ETS at KM 26.25, the travelling speed recorded was 110km/h and the highest acceleration recorded was 96.4m/s². The highest deflection was 1.36mm. The graph of the ETS’s acceleration was shown in figure 4. The value of deflection and acceleration was tabulated in table 1.

![Figure 3. Time vs acceleration from 6-coach commuter at KM26.25 collected by using Sirius-M.](image)

![Figure 4. Time vs acceleration from ETS at KM26.25 collected by using Sirius-M.](image)

**Table 1.** Comparison of deflection at KM26.25 for 6 coaches commuter and ETS.

| Type of train          | Speed (km/h) | Highest acceleration (m/s²) | Highest deflection (mm) | Percentage difference (%) |
|------------------------|--------------|----------------------------|-------------------------|---------------------------|
| 6-coach commuter       | 90           | 91.325                     | 1.482                   | 8.23                      |
| Electric train service | 110          | 96.4                       | 1.36                    | -                         |

For the second data collection on site KM20.75, the soil condition is different from earlier site. The site KM20.75 soil condition was suspected to have soil settlement due to an underground water stream. Thus, the outcome of soil settlement would produce a void in between the ballast and concrete sleepers. The collection of data was taken during a sunny day in a dry condition. The data was taken using Sirius-M instrument and then being integrated to transform into the deflection term by using Dewesoft software. For the commuter, it consisted of 6-coaches and was travelling at the speed of 90km/h. The highest acceleration recorded was 245.82m/s² and the highest deflection was 18.910 mm. The graph of acceleration of 6-coach commuter was shown in figure 5. The value of deflection and acceleration was tabulated in table 2. As for ETS, it also consisted of 6-coaches and was travelling at the speed of 110km/h. The highest acceleration recorded was 237.22m/s² and the highest deflection was 8.450mm. The graph of acceleration of ETS was shown in figure 6. The value of deflection and acceleration was also tabulated in table 2.
Figure 5. Time vs acceleration from 6-coach commuter at KM20.75 collected by using Sirius-M.

Figure 6. Time vs acceleration from ETS train at KM20.75 collected by using Sirius-M.

Table 2. Comparison of acceleration and deflection of PCS at KM20.75 for 3 types of train.

| Type of train          | Speed (km/h) | Highest acceleration (m/s²) | Highest deflection (mm) | Percentage difference (%) |
|------------------------|--------------|------------------------------|-------------------------|---------------------------|
| 6-coach commuter       | 90           | 245.82                       | 18.910                  | -                         |
| Electric train service | 110          | 237.22                       | 8.450                   | 55.31                     |

The comparison between the deflection and acceleration from all commuters and ETS that passed through both site conditions at KM26.25 and KM20.75 is tabulated in Table 3 and 4 respectively. The data was taken using Sirius-M instrument and then being integrated to transform into the deflection term using Dewesoft software.

Table 3. Comparison of acceleration and deflection of PCS for 6-coach commuter at KM26.25 and KM20.75.

| Type of train          | Speed (km/h) | Highest acceleration (m/s²) | Highest deflection (mm) | Percentage difference (%) |
|------------------------|--------------|------------------------------|-------------------------|---------------------------|
| 6-coach commuter       | 90           | 91.325                       | 1.482                   | 8.23                      |
| 6-coach commuter       | 90           | 245.82                       | 18.91                   | -                         |
### Table 4. Comparison of acceleration and deflection of PCS for ETS at KM26.25 and KM20.75.

| Type of train         | Speed (km/h) | Highest acceleration (m/s²) | Highest deflection (mm) | Percentage difference (%) |
|-----------------------|--------------|------------------------------|-------------------------|---------------------------|
| Electric train service (KM26.25) | 110          | 96.4                         | 1.36                    | 83.91                     |
| Electric train service (KM20.75) | 110          | 237.22                       | 8.45                    | -                         |

### 5. Conclusion
Findings from this research show that the deflection of concrete sleepers was affected by the soil condition. This research shows the relationship and correlation between the deflection of concrete sleepers and the soil condition under the rail track, and contributes in knowing further the behaviour of concrete sleepers on problematic soil and becomes a benchmark for the performance of concrete sleepers in delivering the services.

The recorded deflection is an indicator of the behaviour of concrete sleepers when receiving the load waves from a moving train. The deflection consists of three directions, namely x, y, and z, however in this study, the direction of deflection being taken was only in y-direction which experienced the highest value of forces and produced larger deflection value.

This research can differentiate the value of deflection for concrete sleepers on both sites. The analysis showed more than 90% difference in deflection values from two different locations. Thus, it was clear that soil condition plays a big role in maintaining the performance of rail track structure. From the obtained value, further research for the design of rail track can be done based on soil condition. The encouragement on necessary remedies to be taken at the located areas and the maintenance of rail track can also be planned to ensure the safety of the passengers and prevent unwanted disaster from happening.

As the conclusion, the soil settlement or problematic soil also needs major attention in determining the maintenance work together with the consideration of others such as steel corrosion, wear and tear of railway structure and the crack of concrete sleepers.

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