Site Investigation on Rail Track Modulus of Ballasted Rail Track

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Abstract: With the demand for increasing capacity and efficiency of mass transportation system, railways provide a decent solution being an artery in a country’s economy. Compared to the advancement of locomotive, the development of rail track structure lags behind due to the varying nature of the track components compromising the essential safety and efficiency of the whole system. Thus the continuous understanding of the behaviour of rail track is necessary for engineers to design and maintain the rail tracks to meet the expectations. The vertical deflection of the track under the exerted forces of moving train is a good performance indicator of a rail track structure. This deflection is depending upon the collective properties of fasteners, sleepers, ballast and underlying layers. The amount of deflection the track experience under the load reflects the stability of the track and its quality of maintenance. In rail track design, this force and the vertical deformation are related by the track modulus or modulus of elasticity of the track. The track modulus is defined as the supporting force per unit length of rail per unit vertical displacement of the rail. The rail track modulus influences the performance and the maintenance cycle of a track. Higher the track modulus, higher the stresses transferred on to the track components causing more fatigue and wear. On the other hand low track modulus cause high differential settlements and making the track need to be frequently maintained. Different methods have been proposed and being used by various agencies for calculation and measurement of track modulus theoretically and experimentally. In this paper, Track modulus and deflection charts were generated using the method proposed based on continuous beam on elastic foundation approach. Field investigation was conducted using a four axle Class M7 locomotive with weight 66 ton and measured the vertical deflection of sleepers at the passage of locomotive. The measured deflection of the track was used to obtain the track modulus from the deflection and track modulus charts. The calculated track modulus value suggested the track segment is moderately fouled.

Keywords: Track modulus, Track deflection, Ballast, Subgrade.

1. INTRODUCTION

There are the two types of deformations occurring in a rail track structure and which are identified as resilient and permanent deformations. Both these deformations represent two most important aspects of design and performance of track structure. The recoverable deformation of the structure at the passage of train is known as the resilient deformation. The majority of the deformation caused by the imposed load from wheels is recovered after the train has passed. Permanent deformation which is not recovered will be contributed to the total track settlement over the time under repeated loading. In this paper the concern is on the resilient deformation of the track and is an indication of the condition of the track foundation. The structural state of the track could be assessed by measuring the vertical deformation of the track under the wheel load and express in terms of track stiffness or track modulus.

Track modulus has been considered as one of the accepted indicators of the quality and safety of the track structure and defined as the supporting force per unit length of rail per unit vertical displacement of the rail (Selig & Waters, 1994). Track modulus is influenced by many factors such as the quality of rails, ties, rail joints, ballast, and sub-grade and is usually represented by the letter “u” or “k” in literature.

Even though the track modulus is considered as an important parameter it is seldom measured and
The magnitude is mostly unknown for the most of the sections of a track. For a given track there is an optimum track modulus and it should neither be too high nor too low. Higher track modulus value would lead to fatigue, fracture, wear and excessive vibrations of all the track components. On the other way too low track modulus value would cause excessive deflections of the track and even permanent deformations. Studies over the years have related the track modulus to the type of track structure and its subsequent behaviour. But, an upper limit for the track modulus has not been set and need more research and field experiments in defining a value. The track modulus values could range from 3 Mpa to over 100 Mpa (Selig & Li, 1994).

The most commonly known and recommended method of analysis of cross tie track is the beam-on-elastic foundation approach originally proposed by Zimmermann (Esveld, 2001). Based on the theoretical formulation of beam on elastic foundation model, several methods have been developed by various researchers for the determination of track modulus. The approach assumes that the rail responds like an elastic beam which is supported by closely spaced elastic springs attached to a continuous base as shown in Figure 1.

![Figure 1 Beam on elastic foundation model, Kerr (1998)](image)

The governing differential equation for this model is as follows,

$$EI \frac{d^4w}{dx^4} + uw(x) = p(x)$$  \hspace{1cm} (1)

in which, \(w(x)\) is the vertical deflection of the rail axis at \(x\), \(EI\) is the vertical flexural stiffness of one rail, \(u\) is the track modulus (for one rail), and \(p(x)\) represents the vertical wheel loads.

Then, the vertical deflection \(w\), for a given point load \(P\) as a function of the distance \(x\),

$$w(x) = \frac{P \beta}{2u} e^{-\beta x} (\cos \beta x + \sin \beta x)$$  \hspace{1cm} (2)

where,

$$\beta = \frac{4}{\sqrt{4EI}}$$  \hspace{1cm} (3)

![Figure 2 Typical influence line for deflection of rail under single point load](image)

The expression 2 is for a single wheel load and typical influence line for rail deflection caused by a single wheel load is shown in Figure 2. For more than one wheel load, the rail deflections have to be obtained by superposing the effects of the various wheel loads. Using the approach of superposition, Kerr (1998) proposed expression 4 for the rail deflection caused by all four wheels of a two-axle truck based on beam on elastic foundation method.
In the expression, \( P_1 = P_2 = P \) and \( P_3 = P_4 = nP \), \( l_i \) is the distance to each wheel from left wheel of truck I shown in Figure 3 and the number \( n \) is obtained by weighing the two trucks in track scale.

From the above expression, the rail track modulus \( u \) to be obtained by equating the measured deflection \( w(0) = w_{\text{measured}} \) as below.

\[
w_m = \frac{P}{2u} e^{-\beta l_2} (\cos \beta l_2 + \sin \beta l_2) + n e^{-\beta l_3} (\cos \beta l_3 + \sin \beta l_3)
\]

For a given field test, \( u \) is the only unknown in equation 5. But it is seen that the expression cannot be solved explicitly for \( u \). Therefore Kerr (1998) proposed \( w_m \) to be evaluated numerically for a given set of \( E, I \) and \( P \) with a known range of \( u \) and produce a graphical representation of deflection against track modulus. Then the measured deflection is known, the track modulus could be directly obtained using the graph. According to equation 5, it is clear that there will be separate graphs for different rails and loading vehicles due to the influence of \( E, I \) and \( l \). In this research, deflection moduli charts for rail sections 36.2 kg/m (80 lb/yd), 40.8 kg/m (90 lb/yd) and 60 kg/m were generated and used to obtain the track modulus of the test segment of the track by measuring the sleeper deflection.

2. FIELD MEASUREMENT METHODOLOGY

Tests were conducted in Kelanivelley railway line between 6.5th and 7th kilometre posts. Two class M7 locomotives each weight 66 ton were provided by Sri Lanka Railways. Class M7 locomotive has four axels and therefore the axel load is 16.5 ton and wheel load is 8.25 ton. The locomotives were run at low speeds to minimize the dynamic effects. The schematic representation of the locomotive with the axel loading arrangement is shown in Figure 4 and locomotive at site is shown in Figure 5.

In this field investigation, linear variable differential transducers (LVDT) were used for accurate measurement of linear deflection of the each sleeper at the passage of train. LVDT equipment were mounted on firm supports and fixed at the end of selected sleepers. The time history data of vertical deflection of sleeper were acquired by connected data logger and recorded by a computer. LVDT instruments are capable of measuring least 0.005 mm deflection and maximum 50 mm. The used data logger is capable of recording up to 1000 data per second. A load cell with a capacity 200 kN was planted beneath the sleeper directly under the rail to read the load at sleeper ballast interface and connected to the computer via data logger. The sleepers at site were standard timber sleepers with cross section dimensions 127 x 254 mm and 2740 mm long. Line was broad gauge track with 1676 mm gauge. The rail section was 36.2 kg/m (80 lb/yd). At site, the sleeper intervals were different to each other and the detailed schematic diagram of test setup is shown in Figure 6.
Figure 4 Class M7 Locomotive used for the field investigation with axle loads

Figure 5 Image of test set up & Class M7 Locomotive

Figure 6 Schematic representation of the test set up
Track deflection and modulus chart was developed using equation 5 proposed by Kerr, 1998 for 36.2 kg/m (80 lb/yd), 40.8 kg/m (90 lb/yd) and 60 kg/m rail sections which are currently available in Sri Lanka. Class M7 locomotive was used as the loading vehicle in generating the curves. At the test segment in Kelanivelley line, the rail section was 36.2 kg/m (80 lb/yd). Produced chart is shown in Figure 7.

Results obtained after the passage of train from LVDTs were further processed and presented graphically to compare the deflections at the stations. When the loading vehicle (the M7 locomotive) passed over the sleeper which LVDTs were installed, the data logger records the sleeper deflection as a time history and graph for Station D1 is shown in Figure 8. From the data it is possible to obtain the track deflection of the sleeper at any moment.

In this study, the mass of the locomotive was assumed to be evenly distributed over the axles and therefore the average of deflection caused by the wheels were considered for the calculation of track foundation modulus. The dynamic factors were assumed to be negligible since the speed of the train was very low for this particular test. It is possible to have a opening between the sleeper and the ballast bed due to the permanent deformation of foundation layers or a gap between the rail and the sleeper due to fastening defects where there is no contact in between. This gap is usually referred in the literature as “slack”. The deflection caused by the slack excluded in the track foundation modulus calculation described above. Therefore, the measured deflection by LVDT shall be corrected for an existing slack at the measuring station. In this test, for stations D2 and D3, slack was observed and considered as 15% from the maximum deflection caused by wheel load (Louis M. and Hannes G, 2013) and no slack was observed at station D1. For this test, the recording stations were close and therefore average of the maximum deflections directly underneath the wheel from all three stations were used to obtain more realistic track foundation modulus for the track segment.

After corrected for the slack, the average deflection ($\delta_m$) was 1.06 mm for wheel load 80.9 kN (8.25 ton). Then using the curve for 36.2 kg/m (80 lb/yd) rail section in Figure 7, the track foundation modulus for 80 lb/yd and 90 lb/yd rail.
modulus was obtained as 62 MPa.

The obtained value of track foundation modulus 62 Mpa is exceeding the recommended value 30 Mpa to 53 Mpa, set by Ministry of Railways, India for designing broad gauge traks. The increase of track modulus indicates the state of fouling of the ballast. The ballast bed of the test location was not replaced since the major rehabilitation carried out in 1996. The effect of fouling on the foundation modulus was demonstrated by Zakeri et al. (2012). The findings indicated that the foundation modulus tends to increase at higher fouling degrees. For 25% fouling the foundation modulus was at 90 Mpa and at 62% it was around 110 Mpa. Considering the above values, It could be suggested that the degree of fouling at the test location was moderate.

3. CONCLUSION

Track deflection and modulus charts for 36.2 kg/m (80 lb/yd), 40.8 kg/m (90 lb/yd) and 60 kg/m rail section was generated. Track deflection was measured at the passage of class M7 locomotive and the measured deflection was used to obtain the track modulus of the test location using the track deflection and modulus chart. The obtained track modulus value 62 Mpa for the track segment tested between 6.5th and 7th km posts in Kelani velley track is high compared to the Ministry of Railways, India. This high value of track modulus is an indication of ballast bed fouling. The produced curve for Class M7 Locomotive and for 36.2 kg/m (80 lb/yd), 40.8 kg/m (90 lb/yd) and 60 kg/m rails allows for a rapid and economical determination of assessing the the track modulus u at various track locations and hence assess the structural state of local tracks in the aspect of rehabilitation or upgrading. It should be noted that the curves were generated neglecting the slack and when using the chart the deflection to be corrected for slack.

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5. REFERANCE

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