



Analysis of Train Load Distribution on Concrete Sleepers on the Padang–Lubuk Buaya Rail Line

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Abstract

The increasing operational speed and axle load of railway transportation require railway track structures capable of distributing loads safely and efficiently. Concrete sleepers play a crucial role in transferring loads from the rails to the ballast while maintaining track stability. This study aims to analyze the distribution of dynamic loads acting on concrete sleepers due to train movement and to evaluate the structural response of the railway track using the Beam on Elastic Foundation (BoEF) approach. The research employed a quantitative analytical method using secondary data obtained from railway technical standards, locomotive specifications, and track geometric parameters in accordance with the Indonesian Ministry of Transportation Regulation No. 60 of 2012. Dynamic loading was determined using the Talbot dynamic factor, followed by calculations of rail deflection, maximum bending moment, shear force, and load distribution to the sleepers based on the Winkler elastic foundation model. The results indicate that train speed significantly influences the magnitude of dynamic loads transmitted through the rail structure. Under the analyzed operating conditions, the calculated dynamic wheel load reached 11.77 kN, while the distributed load acting on the concrete sleeper was approximately 6.44 tons. The analysis demonstrates that the concrete sleeper is capable of distributing loads effectively and maintaining structural stability within the design parameters. These findings provide valuable information for railway track planning, maintenance, and evaluation to improve the safety, durability, and performance of railway infrastructure.

Keywords: railway track, concrete sleeper, dynamic load, Beam on Elastic Foundation, railway engineering.

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1. Introduction

Railways are a mode of land transportation with high carrying capacity, good energy efficiency, and a relatively higher level of safety compared to road transportation. As public mobility and logistics distribution needs increase, the Indonesian government continues to develop the railway network through the construction of new lines, increased track capacity, and modernization of facilities and infrastructure. These efforts aim to improve the quality of national transportation services while supporting economic growth and interregional connectivity.

The reliability of a railway system is not only determined by the quality of its infrastructure but also depends heavily on the condition of the track structure. A track structure is a system consisting of rails, fasteners, sleepers, ballast, sub-ballast, and subgrade, all working in an integrated manner to absorb and distribute the dynamic loads resulting from train movement. Each component has an interrelated function, so the failure of one component can affect the stability of the entire track structure.

Among these components, concrete sleepers play a crucial role in transmitting the load from the rail to the ballast layer while maintaining the track geometry. They must be able to withstand vertical loads, lateral forces, and longitudinal forces arising from train axle loads, changes in operating speed, and the dynamic interaction between the wheels and rails. If load distribution on the sleepers is not optimal, it can lead to a decline in track quality, permanent deformation, ballast damage, and an increased risk of operational disruptions and train accidents.

Increasing train operating speeds mean that the loading characteristics of rail structures are no longer static but rather dynamic. These dynamic loads are influenced by train speed, axle configuration, rail condition, sleeper stiffness, ballast characteristics, and subgrade conditions. Consequently, the stresses and deflections in the rails and sleepers are greater than under static loading conditions. Therefore, dynamic load distribution analysis is a crucial aspect in the planning and evaluation of rail structures.

Various previous studies have discussed the behavior of railway structures using elastic approaches, *the*

Finite Element Method , and the *Beam on Elastic Foundation* (BoEF) model. The BoEF approach introduced by Winkler is still widely used because it is able to describe the behavior of rail structures simply but provides results that are representative enough to evaluate the load distribution on the rail structure. This model considers the interaction between the rail as an elastic beam with a support layer modeled as a continuous spring so that it can be used to determine rail deflection, bending moment, shear force, and load distribution towards the sleepers.

However, most previous research has focused on analyzing rail behavior or bearing characteristics separately. Research specifically examining the dynamic load distribution from train wheels to concrete bearings using design parameters aligned with national standards is still relatively limited. Furthermore, evaluating the effect of train operating speed on the magnitude of the load received by concrete bearings requires further study as a basis for planning and maintaining railway infrastructure in Indonesia.

Based on these conditions, this study was conducted to analyze the distribution of dynamic train loads on concrete sleepers using the *Beam on Elastic Foundation approach* based on technical parameters referring to the Regulation of the Minister of Transportation Number 60 of 2012. The analysis was carried out through the calculation of dynamic factors, rail deflection, maximum bending moment, shear force, and load distribution received by concrete sleepers. The results of the study are expected to provide an overview of the ability of concrete sleepers to distribute train operating loads and become a reference for the process of evaluating design, maintenance, and improving the reliability of railway structures in Indonesia.

Research Contribution

The main contributions of this research are:

1. Analyzing the dynamic load distribution of trains on concrete sleepers using the **Beam on Elastic Foundation approach** .
2. Evaluate the effect of operating speed on the magnitude of the load received by the bearing.
3. Presenting analysis results that refer to Indonesian railway technical standards so that they can be used as a reference in evaluating railway design and maintenance.

2. Research Methodology

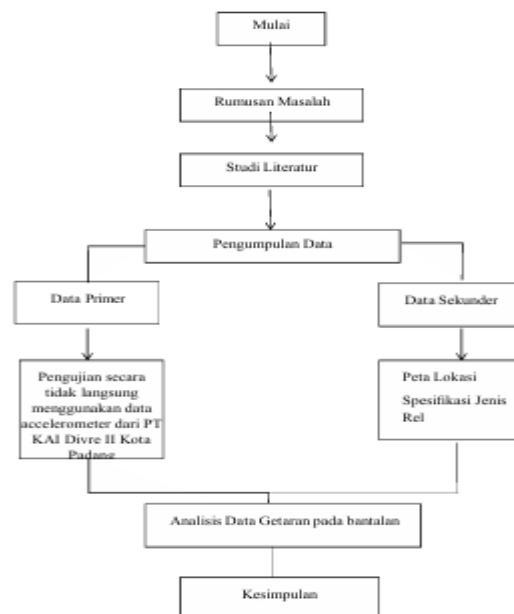
This study uses a **quantitative method** with a structural analysis approach to evaluate the distribution of dynamic train loads on concrete sleepers on the **Padang–Shelter Lubuk Buaya Station line, West Sumatra** . The analysis was conducted using the **Beam on Elastic Foundation (BoEF) method** which models the rail as an elastic beam supported by a continuous elastic medium (Winkler).

The research data consists of **primary data** in the form of observations of rail track conditions and measurements of track geometric parameters, as well as **secondary data** which includes the specifications of the CC-201 locomotive, characteristics of the R54 rail, N-67 type concrete sleepers, as well as the Minister of Transportation Regulation Number 60 of 2012 and various supporting literature.

The analysis phase begins with calculating the static wheel and axle loads, then determining the **dynamic loads** using the Talbot dynamic factor based on the train's operating speed. Next, a rail structure analysis is performed using the **Beam on Elastic Foundation method** to obtain deflection values, maximum bending moments, and shear forces. The obtained deflection values are used to calculate the load distribution received by the concrete sleepers so that the sleepers' ability to distribute loads according to the rail track design parameters can be evaluated.

The general research flow is shown in Figure 1.

Figure 1. Research Flowchart



3. Results and Discussion

3.1 Dynamic Load Analysis of Trains

On moment train crossing road rail, burden train will give burden dynamic to rail. This force can cause vertical deflection in the rail track structure. The following is dynamic load calculation of trains based on the Regulations Minister of Transportation No. 60. Year 2012:

A. Train Force and Loading

1. Vertical Force of the Train

The calculation of the vertical force generated by the axle, train locomotive and train carriage is a static load, whereas in reality the load that occurs on the rail track is a dynamic load that is influenced by aerodynamic factors (air resistance and wind load).

According to PT.KAI, it is known that the locomotive on the CC-201 type train has the following specifications:

Weight (W)	= 84 Tons
Distance Between Axles	= 8.68 mm
Height	= 36 36 mm
Width	= 2 642 mm
Length	= 1 4.134 mm

Until can calculated as follows:

1. Accumulated by 2 bogie which each consists of from 3 axle and each axle consists of 6 wheels.

Locomotive weight (Wlok) = 84 Ton

Static Wheel Force (Pstatic)

$$= \frac{\frac{W_{lok}}{2}}{Jumlah\ Gandar} = \frac{\frac{84}{2}}{3} = 14 \text{ Ton}$$

$$\text{Style to Bogie (Pb)} = \frac{W_{lok}}{2} = \frac{84}{2} = 42 \text{ Ton}$$

Axle Force (Pg) = 15 Ton

$$\text{Static wheel force (Ps)} = \frac{Pg}{2} = \frac{15}{2} = 7.5 \text{ Tons}$$

2. Dynamic Factor (Ip) and Dynamic Load (Pd)

If using a CC-20 1 locomotive with a Vmax of 80 km/hour, then:

$$\begin{aligned} \text{Design Speed (Vr)} &= 1.25 \times V_{max} \\ &= 1.25 \times 80 \\ &= 100 \text{ Km/hour} \end{aligned}$$

$$= 27.77 \text{ m/s}$$

$$\text{Static/Permanent Load (Ps)} = 7.5 \text{ kN}$$

$$\text{Design Dynamic Load (Pd)} = Ps \times Ip$$

$$= 7.5 \times 1.57$$

$$= 11.77 \text{ kN}$$

The values of the dynamic factor equation include: TALBOT Equation: Talbot's equation (1918) provides a force transformation in the form of a dynamic factor multiplier as follows:

$$\text{Dynamic Factor (Id)}$$

$$= 1 + 0.01 ((V_{plan}/1.609)^{-5})$$

$$= 1 + 0.01 ((100/1.609)^{-5}) = 1.57 \text{ kg}$$

a. Loading on Rails

Loading on railway tracks uses the Beam on Elastic Foundation (BoEF) concept developed by Winkler in 1867 to calculate the stress on railway track components. To calculate the dumping factor, it can be expressed in the following equation:

$$\begin{aligned} \lambda &= \sqrt[4]{\frac{k}{4 \times E \times I}} \\ &= \sqrt[4]{\frac{180}{4 \times 2.1 \times 10^6 \times 2346}} \\ &= 0.00987 \text{ cm} \end{aligned}$$

And to taking into account the maximum moment value, deflection and shear force at each point along the rail due to concentrated point forces can be written as:

$$\begin{aligned} M_m &= \frac{Pd}{4\lambda} \\ &= \frac{11.77}{4 \times 0.00987} \\ &= 298.12 \text{ kN.cm} \end{aligned}$$

$$\begin{aligned} Y_m &= \frac{Pd}{2k} \\ &= \frac{11.77}{2 \times 180} \\ &= 0.032 \text{ kN} \end{aligned}$$

$$F_m = K \times Y$$

$$= 180 \times 0.0032$$

$$= 5.76 \text{ kN}$$

With,

Mm = maximum moment (kg.cm)

Ym = Dynamic Load (Kn)

Fm = Maximum Shear Force (Kn)

For the reduction of moment calculations, it can be stated as follows:

$$\begin{aligned} Ma &= 0.85 \times \frac{Pd}{4\lambda} \\ &= 0.85 \times \frac{11.77}{4 \times 0.00987} \\ &= 253.40 \text{ kg.cm} \end{aligned}$$

With,

Ma = Reduction Moment (Kg.cm)

3.1.1 Bearings

a. Loading on Bearings

According to Doyle (1980), before the bearing structure is analyzed and its capacity to receive the load from the rail is calculated, it is necessary to first examine the distribution of pressure received by the bearing itself.

The following calculation can be written for the load on the bearing as follows :

Axle Load (Pg) = 15 Ton

Train speed (Vrenc) = 100 km /hour

Rail Width = 106.7 mm

Bearing Length (L) = 2000 mm

Bearing Width (b) = 210 mm

Bearing Distance (S) = 60 c m

Rail Type = R.54

Bearing Type = N-67

Concrete Quality Fc' = 600 Kg/cm²

The load distributed to the bearing structure is a uniform load on the lower edge of the rail. The BoEF equation for determining the maximum rail load (qr) at the rail position is written as follows:

$$qr = S \times k \times Ym \times F$$

$$= 60 \times 180 \times (0.032) \times 1$$

$$= 345.6 \text{ kN}$$

With,

S = Bearing distance (m),

k = Rail track modulus (kg/cm²),

Ym = maximum rail deflection

F1 = The safety factor value (F1) is equal to 1

Determining the load on the bearing is then rewritten and adjusted as:

$$\begin{aligned} F &= k \times Ym \\ &= 180 \times 0.032 \\ &= 5.76 \end{aligned}$$

The calculation of Ymaks is taken into account and influences the super axle position on the train, so the Load Distribution (Q) to the bearings can be calculated using the following formula:

$$\begin{aligned} Q &= 0.786 \times \frac{Pd \times S}{x} \\ &= 0.786 \times \frac{11.77 \times 44}{80.3} \\ &= 6.44 \text{ Tons} \end{aligned}$$

So the distribution of the load caused by the train on the bearings is 6.44 tons at a speed of 100 km/hour.

4. Conclusion

Based on the analysis results using the **Beam on Elastic Foundation (BoEF) method**, it can be concluded that the railway structure is able to distribute the dynamic load of the train effectively from the rail to the concrete sleeper. The calculation results show that at a design speed of **100 km/h**, the dynamic wheel load is **11.77 kN**, while the load distribution received by the concrete sleeper reaches around **6.44 tons**. This value indicates that the concrete sleeper still has adequate capacity to withstand and transmit the load to the ballast layer according to the design parameters used.

Increasing train operating speeds have been shown to increase the magnitude of dynamic loads acting on railway structures, so that the dynamic loading aspect needs to be an important consideration in the planning and maintenance of railway infrastructure. This research contributes to explaining the load distribution mechanism on concrete sleepers through an analytical approach and can be used as a reference in evaluating

railway structure designs. Further research is recommended to develop analysis using numerical methods such as **the Finite Element Method (FEM)** or field testing to obtain a more comprehensive representation of structural behavior.

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