RAILWAY STRUCTURES PERFORMANCE DUE TO FREIGHT INTERMODAL SERVICE AT BOJONEGORO – KALITIDU ROUTE

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### Abstract

Goods movement using container are quite efficiently assessed because it can carry a great amount of goods fit to container capacity. Freight transportations is a primary component of all supply-chain and logistics systems, but in contrary using a truck as its transportation means causing many problems such as air and noise pollutions, traffic congestions, road accidents and road damage. Depart from this facts, so government is looking for another means of freight transporter which more efficient with a bigger load capacity advantages. This options goes to train as a solutions of intermodal freight transportations lack. In order to supporting intermodal freight transportations, right now double track of railway is available for Jakarta – Surabaya route (Northern line route). By now, noted that freight transportation with double track railway frequency is potentially increase to 15 trip per days with capacity 500 TEU (Twenty feet Equivalent Units) per days and fuel consumptions (with truck) can be thrifted into 115 kl per days also reducing carbon monoxide emission amounts 350 tons per days. According with an official statements from Directorate General of Railways, Ministry of Transportations, explained that Jakarta – Bojonegoro route on double track railway is fully operated so this paper is conducted to determining feasibility of railway structure performance due to freight intermodal transportations at Bojonegoro – Kalitidu route. Railway structure performance feasibility is observed from loading distributions, rail strength, rail sleeper strength, and railway subgrade endurance to planned freight trains. As a result of this research obtained that tension force that occurred on rail is safe. Moment force that occurred on rail bottom is permitted tension on rail (first class rail) 1325 kg/cm². So, tension force that occurred on rail is safe. Moment force that occurred on rail bottom is 14521.25 kg.cm < permitted moment force (150,000 kg.cm) Moment force that occurred in the middle of rail sleeper is 58993.978 kg.cm < permitted moment force (93000 kg.cm). Tension force that occurred on above railway subgrade (σ2) is 4.17 kg/cm² < qu (29.671 kg/cm²). It means that railway subgrade is capable to supporting load of freight transportation operations along Bojonegoro – Kalitidu route.

Keywords: intermodal freight transportations, train, double track railway, railway structure performance.

### Article Info

Revised 25 April 2021
Accepted 29 April 2021

### INTRODUCTION

Goods movement using container are quite efficiently assessed because it can carry a great amount of goods fit to container capacity. When container is began to introduce as a secure considerations of goods packing methods, mostly held by truck. Then, truck become a main choice of freight transportations. Freight transportations is a primary component of all supply-chain and logistics systems, but in contrary using a truck as its transportation means causing many problems such as air and noise pollutions, traffic congestions, road accidents and road damage [1]. Now, in other hands existence of truck as a freight transporters becoming inefficient when causing traffic congestions increasing and road damage mainly at Java Islands Northern route. Depart from this facts, so government is looking for another means of freight transporter which more efficient with a bigger load capacity advantages. This options goes to train as a solutions of intermodal freight transportations lack. In order to supporting intermodal freight transportations, right now double track of railway is available for Jakarta – Surabaya route (Northern line route). Since 2012, northern line double track railway have already constructed and in April 2014 began to operate on several parts of route. Double track railway is a two railway track that designed to serve train operations on a both ways contrary, so risk of a railway accidents and departing schedule delays can be reduced in effectively [2]. Intermodal freight transport involves the transportation of freight in an intermodal container or vehicle, using multiple modes of transportation such as train with railway.
without any handling of the freight itself when changing modes [3]. By now, noted that freight transportation with double track railway frequency is potentially increase to 15 trip per days with capacity 500 TEU (Twenty feet Equivalent Units) per days and fuel consumptions (with truck) can be thrifited into 115 kI per days also reducing carbon monoxide emission amounts 350 tons per days [4]. According with an official statements from Directorate General of Railways, Ministry of Transportations, explained that Jakarta – Bojonegoro route on double track railway is fully operated so this paper is conducted to determine feasibility of railway structure performance due to freight intermodal transportation at Bojonegoro – Kalitidu route. Railway structure performance feasibility is observed from loading distributions, rail strength, rail sleeper strength, and railway subgrade endurance to planned freight trains. Planned freight trains refer to GAPEKA 2019. GAPEKA (Grafik Perjalanan Kereta Api) 2019 is a guidance of arrangement train trip operations which described on a line graphics that showing a stations, time, distance, speed and train trip positions start from departing, stopping, arriving, and following in order to controlling train trips [5].

RESEARCH METHOD

In order to determining amount of train loading that occurred on this paper explained about rail loading analysis procedures, that is [6]:

a. Calculation of loading distribution from designed locomotive (CC 206):
   \[
   \text{P}_{\text{axle group}} = \frac{\text{W}_{\text{locomotive}}}{2} \tag{1}
   \]

   \[
   \text{P}_{\text{axle}} = \frac{\text{P}_{\text{axle group}}}{\text{number of axles}} \tag{2}
   \]

   \[
   \text{P}_{\text{wheel}} = \frac{\text{P}_{\text{axle}}}{\text{number of wheels}} \tag{3}
   \]

b. Calculation a value of dumping factor (λ), formulated as following:
   \[
   \lambda = \sqrt{\frac{k}{AEI}} \tag{4}
   \]
   with:
   \[ k = \text{railway modulus of stiffness (kg/cm)}^2 \]
   \[ E = \text{modulus of elasticity of rail (2.1x10}^6 \text{ kg/cm)}^2 \]
   \[ I_x = \text{moment of inertia at x-x axis of designed rail (cm}}^4 \]

c. Calculation of maximum moment force that occurred on rail formulated as following:
   Maximum moment force on rail
   \[
   \text{P}_{\text{Mxx}} = \frac{\text{P}_{\text{d}}}{44} \tag{5}
   \]
   with:
   \[ \text{P}_{\text{d}} = \text{dynamic load of train (kg)} \]
   \[ \text{P}_{\text{d}} = \text{I}_p \times \text{P}_s \tag{6} \]
   \[ \text{I}_p = \text{dynamic load calculation factors} \]
   \[ \text{I}_p = 1 + (0.01 \times \frac{V}{600} - 5) \tag{7} \]

   \[ V = \text{average speed of train at straight line (km/h)} \]
   \[ \lambda = \text{dumping factors value} \]

d. Calculation of tension analysis that occurred on rail formulated as following:
   \[
   \sigma = \frac{\text{M}_{\text{axx}}y}{I_x} \tag{8}
   \]
   with:
   \[ M_x = 0.85 \times \frac{\text{P}_{\text{d}}}{44} \tag{9} \]
   \[ y = \text{distance of rail bottom edge to neutral line of rail profile (cm)} \]
   \[ I_x = \text{moment of inertia at x-x axis of designed rail (cm}}^4 \]
   Value of \( \sigma \) must be less than the value of permitted tension on rail which required that is for first railway class 1325 kg/cm².

e. Calculation of moment and tension force that occurred on below rail bottom and in the middle of rail sleeper formulated as following:
   i. Value of moment force on below rail bottom:
   \[
   M_1 = \frac{1}{4} b (2\text{cos}^2\lambda_2(\text{cos}2\lambda c + \text{cos}\lambda L) - 2\text{cos}^2\lambda_2(\text{cos}2\lambda c + \text{cos}\lambda L) - \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) - \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L)) \tag{10}
   \]
   ii. Value of tension force on below rail bottom:
   \[
   \sigma_1 = \frac{1}{2B} \times \frac{1}{\text{sin}\lambda c + \text{sin}\lambda(L - c) + \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) - \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) + \text{cos}\lambda c. \text{cos}\lambda(L - c) - \text{cos}\lambda c. \text{cos}\lambda(L - c)} \tag{11}
   \]
   iii. Value of moment force in the middle of rail sleeper:
   \[
   M_2 = \frac{1}{2B} \times \frac{1}{\text{sin}\lambda c + \text{sin}\lambda(L - c) + \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) - \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) + \text{cos}\lambda c. \text{cos}\lambda(L - c) - \text{cos}\lambda c. \text{cos}\lambda(L - c)} \tag{12}
   \]
   iv. Value of tension force in the middle of rail sleeper:
   \[
   \sigma_1 = \frac{1}{2B} \times \frac{1}{\text{sin}\lambda c + \text{sin}\lambda(L - c) + \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) - \text{sin}2\lambda_2(\text{sin}2\lambda c + \text{sin}\lambda L) + \text{cos}\lambda c. \text{cos}\lambda(L - c) - \text{cos}\lambda c. \text{cos}\lambda(L - c)} \tag{13}
   \]
   with:
   \[ Q = \text{load distributions that received by rail sleeper amount 60% from P}_a \]
   \[ a = \text{distance between rail pad side with outer side on rail sleeper type N-67 (40 cm)} \]
   \[ c = \text{half distance between rail pad on rail sleeper type N-67 (60 cm)} \]
   \[ b = \text{width of rail sleeper type N-67, on below rail bottom side (25 cm), in the middle of rail sleeper side (22.6 cm)} \]
   \[ L = \text{length of rail sleeper type N-67 (200 cm)} \]
Specifications of rail sleeper type N-67 shown as figure 1 below [7]:

Fig.1: Specifications of rail sleeper type N-67

Hyperbolic function table is necessary to accomplish calculation of moment and tension force that occurred on below rail bottom and in the middle of rail sleeper.

f. Calculation of tension force that occurred on above subgrade \((\sigma_2)\) formulated as following:

\[
\sigma_2 = \frac{58 \times \sigma_1}{10 + d^{0.35}}
\]

with:
- \(d\) = Total of ballast layer thick (cm)
- \(\sigma_1\) = tension force that occurred on below rail sleeper (Kg/cm²)
- \(\sigma_2\) = tension force that occurred on above subgrade (Kg/cm²)

with requirements:
- \(q_{uln}\) > \(\sigma_2\)

with:
- \(q_{uln}\) = ultimate soil support capability (kg/m³)
- \(\sigma_2\) = tension force that occurred on above subgrade (Kg/cm²)

Specific information about designed load of container is also attached from reliable company which serve freight transportations. Weight of 20 feet size container is 10 tons and weight of 40 feet size container is 20 tons. This detail are used to calculating load distribution that compared with designed load from operating locomotive.

**RESULT AND DISCUSSION**

Load distributions analysis of locomotive and container as freight transportations. Freight transportations that served by train usually using locomotive type CC 206 which have specifications as shown at table 1 following [8]:

From table 1 which have presented obtained that designed locomotive weight is 90 tons. So, load distributions of hauling locomotive can be calculated:

<table>
<thead>
<tr>
<th>Model</th>
<th>GE CM20EMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company maker</td>
<td>General Electric Transportation</td>
</tr>
<tr>
<td>Length</td>
<td>15.500 mm</td>
</tr>
<tr>
<td>Width</td>
<td>2.642 mm</td>
</tr>
<tr>
<td>Axle load</td>
<td>15 tons</td>
</tr>
<tr>
<td>Locomotive weight</td>
<td>90 tons</td>
</tr>
<tr>
<td>Machine type</td>
<td>GE 7FDL-8, diesel, 4-stroke, turbocharger</td>
</tr>
<tr>
<td>Maximum power</td>
<td>2.250 HP</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>140 km/hrs</td>
</tr>
</tbody>
</table>

Table 1. Designed locomotive specifications

\[
P_{bogie} = \frac{W_{locomotive}}{2}
\]

\[
= \frac{90}{2} = 45 \text{ tons}
\]

\[
P_{axle} = \frac{P_{bogie}}{\text{number of axles}}
\]

\[
= \frac{45}{3} = 15 \text{ tons}
\]

\[
P_{wheel} = \frac{P_{axle}}{\text{number of wheels}}
\]

\[
= \frac{15}{2} = 7.5 \text{ tons}
\]

Load distributions of container as freight transportation with 20 feet size container can be calculated:

\[
P_{bogie} = \frac{W_{container wagon}}{2}
\]

\[
= \frac{10}{2} = 5 \text{ tons}
\]

\[
P_{axle} = \frac{P_{bogie}}{\text{number of axles}}
\]

\[
= \frac{5}{2} = 2.5 \text{ tons}
\]

\[
P_{wheel} = \frac{P_{axle}}{\text{number of wheels}}
\]

\[
= \frac{2.5}{2} = 1.25 \text{ tons}
\]
Load distributions of container as freight transportation with 40 feet size container can be calculated:

\[ P_{\text{bogie}} = \frac{W_{\text{container wagon}}}{2} = \frac{20}{2} = 10 \text{ tons} \]

\[ P_{\text{axle}} = \frac{P_{\text{bogie}}}{\text{number of axles}} = \frac{10}{2} = 5 \text{ tons} \]

\[ P_{\text{wheel}} = \frac{P_{\text{axle}}}{\text{number of wheels}} = \frac{5}{2} = 2.5 \text{ tons} \]

From the result of load distributions of designed locomotive and two kinds of freight transportations (20 feet size and 40 feet size container) noticed that the load distributions of operating locomotive 7.5 tons (7500 kg) is fixed as designed load to rail endurance analysis.

**Dumping factor (λ) analysis**

*Dumping factor (λ) calculation* is a procedure that must be done on rail loading analysis. Railway modulus of stiffness (k) obtained from calculations [9]:

\[ k = b \times ke \]

with:
- \( b = \) width of rail sleeper type N-67, on below rail bottom side (25 cm)
- \( ke = \) ballast layer modulus of reaction (kg/cm³)

From specifications of rail sleeper type N-67 that shown at figure 1 noticed that width of rail sleeper type N-67, on below rail bottom side (b) is 25 cm, and ballast layer modulus of reaction (ke) on existing conditions is 7.18 kg/cm³. So value of railway modulus of stiffness is:

\[ k = b \times ke \]

\[ k = 25 \times 7.18 \]

\[ k = 179.5 \text{ kg/cm}^2 \]

Double track of railway existing at segment Bojonegoro – Kalitidu is using rail type R54, so the value of moment of inertia is 2346 cm⁴ and modulus of elasticity is 2.1 x 10⁶ kg/cm². Then dumping factor (λ) can be calculated as following:

\[ \lambda = \frac{4}{\sqrt{3EI}} \]

\[ \lambda = \frac{4}{\sqrt{3 	imes 179.5}} \]

\[ \lambda = 0.009769 \]

\[ \lambda \approx 0.0098 \]

**Moment and tension force on rail analysis**

Before calculating maximum moment and tension force that occurred on rail, first step is determining speed design of train at segment Bojonegoro – Kalitidu. From GAPEKA 2019 noticed that train passing through at mentioned segment is 75 – 80 km/h. So, calculation of design speed according to Official Regulations No 10 from PJKA 1986 is:

\[ \text{Speed design} = 1.25 \times \text{straight line operation speed} \]

\[ \text{Speed design} = 1.25 \times 80 \]

\[ = 100 \text{ km/h} \]

Calculation of train design speed at curve is:

\[ \text{Speed design} = \text{curve line operation speed} \]

\[ = 75 \text{ km/h} \]

Then, before calculating dynamic load of designed locomotive, dynamic load coefficient (Ip) analysis is required:

\[ I_p = 1 + (0.01 \left( \frac{V}{1.609} - 5 \right)) \]

\[ I_p = 1 + (0.01 \left( \frac{100}{1.609} - 5 \right)) \]

\[ I_p = 1.5715 \]

Dynamic load of designed locomotive (Pd):

\[ P_d = I_p \times P_s \]

\[ P_d = 1.5715 \times 7.5 \]

\[ = 11.78625 \text{ tons} \]

\[ = 11786.25 \text{ kg} \]

Maximum moment on rail = \( \frac{P_d}{\lambda} \)

Maximum moment on rail = \( \frac{11786.25}{0.0098} \)

Maximum moment on rail = 300669.64 kg.cm

Existing rail is using type R54, with moment of inertia 2346 cm⁴ and value of \( y \) is 76.20 mm (7.62 cm), so tension force that occurred on rail is:
\[\sigma = \frac{Max \cdot y}{I_x}\]

\[\sigma = \frac{0.85 \times Mmax \cdot x \cdot y}{I_x}\]

\[\sigma = \frac{0.85 \times 300669,64 \cdot x \cdot 7.62}{2346}\]

\[\sigma = 830,10 \text{ kg/cm}^2\]

Tension force that occurred on rail is 830.10 kg/cm² < permitted tension on rail (first class rail) 1325 kg/cm². So, tension force that occurred on rail is safe.

**Moment and tension force analysis that occurred on below rail bottom and in the middle of rail sleeper**

From specifications of rail sleeper type N-67 that shown at figure 1 as a components of analysis are:

a = distance between rail pad side with outer side on rail sleeper type N-67 (40 cm)

c = half distance between rail pad on rail sleeper type N-67 (60 cm)

b = width of rail sleeper type N-67, on below rail bottom side (25 cm), in the middle of rail sleeper side (22.6 cm)

L = length of rail sleeper type N-67 (200 cm)

Q = load distributions that received by rail sleeper amount 60% from \(P_d\)

\[Q = 60\% \times 11786,25\]

\[Q = 7071,75 \text{ kg}\]

Value of permitted bending moment on rail sleeper edge (below of rail bottom) that required is 1500 kg.m or 150.000 kg.cm. Whereas permitted bending moment in the middle of rail sleeper that required is 930 kg.m or 93000 kg.cm [10].

Existing rail sleeper is using concrete quality K-500 (\(f_c = 50 \text{ MPa}\)) and moment of inertia (I) on below of rail bottom is 15113,437 cm², so modulus of elasticity of rail sleeper material (E) is:

\[Ec = 6400 \times \sqrt{f_{cu}}\]

\[Ec = 6400 \times \sqrt{500}\]

\[Ec = 143108,35 \text{ kg/cm}^2\]

Dumping factor (\(\lambda\)) value can be calculated:

\[\lambda = 4 \times \frac{k}{\sqrt{4EI}}\]

\[\lambda = 4 \times \frac{179.5}{4 \times 143108,35 \times 15113,437}\]

\[\lambda = 0.012\]

Then, trigonometric hyperbolic function in radian is shown at table 2 as following:

**Table 2. Trigonometric hyperbolic function**

<table>
<thead>
<tr>
<th>Trigonometric hyperbolic function</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>sinh(\lambda)</td>
<td>5.4662</td>
</tr>
<tr>
<td>sinh(\lambda)</td>
<td>0.6754</td>
</tr>
<tr>
<td>cosh(\lambda)</td>
<td>1.1174</td>
</tr>
<tr>
<td>cosh(2\lambda)</td>
<td>1.0266</td>
</tr>
<tr>
<td>cosh(2\lambda)</td>
<td>0.13</td>
</tr>
<tr>
<td>cosh(\lambda)</td>
<td>5.5569</td>
</tr>
<tr>
<td>cosh(\lambda)</td>
<td>0.9735</td>
</tr>
<tr>
<td>cosh(2\lambda)</td>
<td>0.2288</td>
</tr>
<tr>
<td>Cos(\lambda)</td>
<td>-0.7374</td>
</tr>
<tr>
<td>sinh(\lambda)</td>
<td>1.1144</td>
</tr>
<tr>
<td>sinh(\lambda)</td>
<td>0.9915</td>
</tr>
<tr>
<td>sinh(\lambda)</td>
<td>0.8192</td>
</tr>
<tr>
<td>sinh(2\lambda)</td>
<td>1.9918</td>
</tr>
</tbody>
</table>

a. Moment force that occurred on rail bottom can be calculated:

\[M_1 = \frac{Q \times 1}{\sinh(\lambda L) + \sinh(\lambda L)} [2\cosh^2(\lambda a)(\cos(2\lambda c + \cosh(\lambda L)) - 2\cos^2(\lambda a)(\cosh(\lambda c + \cos(\lambda L)) - sinh(2\lambda a)(\sin(2\lambda c + sinh(\lambda L)) - sin(2\lambda a)(\sin(2\lambda c + sin(\lambda L)))]\]

\[M_1 = 147328,125 \times 0,1628 \times 11,676 - 2,9 - 7,19646 - 2,18497\]

\[M_1 = 14521,25 \text{ kg.cm}\]

So moment force that occurred on rail bottom < permitted moment force (150.000 kg.cm)

b. Tension force that occurred on rail bottom can be calculated:

\[\sigma_1 = \frac{P_d \times 1}{\sinh(\lambda L) + \sinh(\lambda L)} [2\cosh^2(\lambda a)(\cos(2\lambda c + \cosh(\lambda L)) + 2\cos^2(\lambda a)(\cosh(\lambda c + \cos(\lambda L)) + sin(2\lambda a)(\sin(2\lambda c - sinh(\lambda L)) - sin(2\lambda a)(\sin(2\lambda c - sin(\lambda L)))]\]

\[\sigma_1 = 235,725 \times 0,1628 \times 11,676 - 2,9 - 3,6656 + 2,846\]

\[\sigma_1 = 31,9825 \text{ kg/cm}^2\]

c. Moment force that occurred in the middle of rail sleeper can be calculated:
Existing rail sleeper is using concrete quality K-500 (f'c = 50 MPa) and moment of inertia (I) in the middle of rail sleeper is 10599,425 cm⁴

Dumping factor (λ) value can be calculated:
\[ \lambda = \frac{k}{4EI} \]

\[ \lambda = \frac{4}{4E1} \]

λ = 0,013

Then, trigonometric hyperbolic function in radian is

\[ \lambda = 0,013 \]

Cosλ(L

Coshλ(L

Sinhλ(L

Sinλ(L

SinhλL

SinλL

Coshλc

Sinhλc

Sinλc

SinλL

SinhλL

Coshλa

Sinhλa

Sinλa

SinλL

SinhλL

hyperbolic function

Trigonometric

Can be calculated

Tension force that occurred in the middle of rail sleeper can be calculated:

\[ \sigma_2 = \frac{P_L}{2L} \times \frac{1}{\sinh \lambda L + \sin \lambda L} \quad [2 \cosh^2 \lambda a (\cos 2 \lambda c + \cos \lambda L) + 2 \cos^2 \lambda a (\cosh 2 \lambda c + \cos \lambda L) + \sin 2 \lambda a (\sin 2 \lambda c - \sinh \lambda L) - \sin 2 \lambda a (\sinh 2 \lambda c - \sin \lambda L)] \]

\[ \sigma_2 = \frac{11786,25}{222,6} \times \frac{1}{6,947 \times 0,5155} \quad [2,1 \times 0,01 - 0,85688] + 2,09636(2,4845 - 0,85688) + 0,8624(0,9999 - 6,6947) - 0,8624(2,2743 - 6,6947)] \]

\[ \sigma_2 = 260,76 \times 0,1386 \times [-1,756 + 3,137 - 4,911 + 3,812] \]

\[ \sigma_2 = 10,192 \text{ kg/cm}^2 \]

Calculated working load on subgrade (σ2).

Before determining value of working load on subgrade (σ2), a value of ultimate soil support capability (qu) on railway subgrade must be obtained with existing data of soil test as following:

(i). Soil cohesion (c) : 1
(ii). Soil specific gravity (γ) : 26,80 KN/m³
(iii).Depth of loading test (D) : 2,5 m
(iv). Width of test area (B) : 1,0 m
(v). N value as SPT result : 17

And find the result of qu with using Terzaghi’s equations as following [11]:

\[ q_u = \frac{c}{n + \gamma \cdot D \cdot N_q + 0,5 \cdot B \cdot y_N} \]

\[ q_u = (1 \times 52,6) + (26,80 \times 2,5 \times 36,5) + (0,5 \times 1 \times 26,80 \times 35) \]

\[ q_u = 2967,1 \text{ kN / m}^2 \times 0,01 \]

\[ q_u = 29,671 \text{ kg / cm}^2 \]

Tension force that occurred on above railway subgrade can be obtained as following:

\[ \sigma_2 = \frac{58 \times \sigma_1}{10 + d1 \times 35} \]

With:

\[ \sigma_1 = \text{tension force that occurred on rail bottom (kg/cm}^2\]

= 31,9825 kg/cm²

\[ d = \text{Total of ballast layer thick (cm)} \]

From field data retrieved that total of ballast layer thick on observed site is 90 cm (0,90 m), with detail as upper

\[ \text{Table 3. Trigonometric hyperbolic function} \]

<table>
<thead>
<tr>
<th>Trigonometric hyperbolic function</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SinhλL</td>
<td>6,6947</td>
</tr>
<tr>
<td>SinλL</td>
<td>0,5155</td>
</tr>
<tr>
<td>Sinλa</td>
<td>0,8615</td>
</tr>
<tr>
<td>Sinλc</td>
<td>0,7</td>
</tr>
<tr>
<td>Sinλ(L-c)</td>
<td>0,9691</td>
</tr>
<tr>
<td>Sinhλ(L-c)</td>
<td>3,00</td>
</tr>
<tr>
<td>Coshλa</td>
<td>1,3199</td>
</tr>
<tr>
<td>Coshλ(L-c)</td>
<td>3,1669</td>
</tr>
<tr>
<td>Cosλa</td>
<td>0,71</td>
</tr>
<tr>
<td>Cosλ(L-c)</td>
<td>-0,2466</td>
</tr>
</tbody>
</table>

Moment force that occurred in the middle of rail sleeper can be calculated:

\[ M_2 = \frac{9}{2L} \times \frac{1}{\sinh \lambda L + \sin \lambda L} \quad [\sinh \lambda c (\sin \lambda c + \sin \lambda (L - c)) + \sin \lambda c (\sinh \lambda c + \sinh (L - c) + \cosh \lambda c. \cos (L - c) - \cos \lambda c. \cosh (L - c))] \]

\[ M_2 = \frac{7,071,75}{20,013} \times \frac{1}{6,6947 + 0,5155} \quad [0,8615(0,7 + 0,9691) + 0,7(0,8615 + 3,00) + (1,3199 \times -0,2466) - (0,71,3,1669)] \]

\[ M_2 = 271990,3846 \times 0,13869 \times [1,4379 + 2,7 + (-0,3255 - 2,2485)] \]

\[ M_2 = 58993,978 \text{ kg.cm} \]

So moment force that occurred in the middle of rail sleeper < permitted moment force (93000 kg.cm)

d. Tension force that occurred in the middle of rail sleeper can be calculated:

\[ \text{Table 4. Trigonometric hyperbolic function} \]

<table>
<thead>
<tr>
<th>Trigonometric hyperbolic function</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SinhλL</td>
<td>6,6947</td>
</tr>
<tr>
<td>SinλL</td>
<td>0,5155</td>
</tr>
<tr>
<td>Coshλa</td>
<td>1,1382</td>
</tr>
<tr>
<td>Cosh^2λa</td>
<td>1,0368</td>
</tr>
<tr>
<td>Cos2λc</td>
<td>0,01</td>
</tr>
</tbody>
</table>

\[ \text{Cos}^2\lambda a = 0,9636 \]

\[ \text{Cosh}^2\lambda c = 2,4845 \]

[2,85688]

\[ \text{Sin}^2\lambda a = 1,23788 \]

\[ \text{Sin}^2\lambda c = 0,9999 \]

\[ \text{Sin}^2\lambda c = 0,8624 \]

\[ \text{Sin}^2\lambda a = 2,2743 \]
ballast layer is 40 cm thick and lower ballast layer is 50 cm thick.

\[
\sigma_2 = \frac{58 \times \sigma_1}{10 + \sigma_1^{1.35}}
\]

\[
\sigma_2 = \frac{58 \times 31.9625}{10 + 90^{1.35}}
\]

\[\sigma_2 = 4.17 \text{ kg/cm}^2\]

As the result of tension force that occurred on above railway subgrade (\(\sigma_2\)) is 4.17 kg/cm\(^2\) < qu (29.671 kg/cm\(^2\)). It means that railway subgrade is capable to supporting load of freight transportation operations along Bojonegoro – Kalitidu route.

**CONCLUSION**

From several recent analysis about railway structure performance due to freight transportations load expressed that:

a. Tension force that occurred on rail is 830,10 kg/cm\(^2\) < permitted tension on rail (first class rail) 1325 kg/cm\(^2\). So, tension force that occurred on rail is safe.

b. Moment force that occurred on rail bottom is 14521.25 kg.cm < permitted moment force (150.000 kg.cm)

c. Moment force that occurred in the middle of rail sleeper is 58993.978 kg.cm < permitted moment force (93000 kg.cm)

d. Tension force that occurred on above railway subgrade (\(\sigma_2\)) is 4.17 kg/cm\(^2\) < qu (29.671 kg/cm\(^2\)). It means that railway subgrade is capable to supporting load of freight transportation operations along Bojonegoro – Kalitidu route.

**REFERENCES**


