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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Conventional track and asphaltic underlayment track mechanical behavior under Indonesia's Babaranjang freight trains loading

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Received 28 February 2022
Revised 1 June 2022
Accepted 20 June 2022

Abstract

A new rail track design for Indonesia's railway systems is essential to increase freight trains capacity and operation speeds and to minimize possible damage that generally found in conventional track. The two-dimensional numerical modeling was implemented on existing Indonesia's conventional track and new asphaltic underlayment track design according to four cyclic loading conditions by varying the train speeds and bogie loads to simulate Babaranjang freight train loads. Three mechanical behavior parameters were measured and compared, i.e., horizontal strains, vertical stress, and deformation, to evaluate the performance of the studied rail tracks and the possibility of Babaranjang freight trains operated with higher speed and heavier axle load with the new asphaltic underlayment track design proposed through this study. The numerical simulations results confirm the capability of the new asphaltic underlayment track in serving Babaranjang freight trains with the speed of 120 km/h, or 70% higher than the existing operating speed, and in allowing each coal wagon to carry the maximum payload up to 75 tons, or 50% higher than the existing maximum payload. It can be predicted that the application of asphaltic underlayment tracks in Indonesia's railway systems could be beneficial for optimizing the Babaranjang freight train capacity and operation speed.

Keywords: Asphaltic underlayment track, Babaranjang freight trains, Conventional track, Deformation, Horizontal strain, Vertical stress

1. Introduction

Known as one of the world's largest producers of coal, Indonesia is the leading exporter in terms of thermal coal with a significant portion of the low- and medium-quality type. The large demand of Indonesia's exported thermal coal comes from China and India. In the past three decades, Indonesia observed a vigorous growth in the production and export of coal, as well as the sales of domestic coal, especially when the coal mining sector was reopened for foreign investment. Since three decades ago, the domestic coal sales have always been rather insignificant due to the relatively small domestic consumption of coal in Indonesia. Nevertheless, there has been an increase in the sales of domestic coal in recent years because the Indonesian government is committed provide plenty of coal reserves to its ambitious energy project, such as the construction of several power plants which is mostly coal fired. Moreover, because of continued low commodity prices made it unattractive to remain focused on coal exports, several well-known Indonesian mining companies have developed into an integrated energy companies that consume their coal. Around 20-30 percent of Indonesia's coal production is sold domestically, and the remainder is exported abroad. If the current coal production rate continues, coal reserves in Indonesian are predicted to last around 83 years. South Sumatera, South Kalimantan, and East Kalimantan province are the three largest regions of Indonesian coal resources, while several smaller resources of coal reserves are existed in Java, Papua, and Sulawesi islands [1].

The potency of coal owned by the South Sumatera province is about 85% of the total reserves contained in Indonesia or about 22.24 billion tons. Even if the mining maxed out up to 50 million tons annually, coal in South Sumatera would not run out mined for 200 years [2]. Unfortunately, the abundant content of coal in South Sumatera is not supported by the robust transportation systems. The distance between the mining site to the shelter (stockpile), the differences in the selection mode of transportation, and the low capacity of the coal transport are several issues in Indonesia's coal industry.

In transporting and distributing the coal, big companies use the train mode, namely PT Bukit Asam Tbk, while those using truck mode are the smaller private company. However, the trucks carrying coal cargo exceed their reasonable capacity. The trucks carry coal cargo as much as 25-30 tons, while the reasonable limit is only 20 tons. Therefore, coal transportation from South Sumatra to Lampung using truck mode damages road infrastructure due to the overload and brings some negative effects detrimental to society such as pollution, traffic congestion, and accidents [2]. On another side, due to the low performance of Indonesia's existing conventional rail track, the maximum axle load of Babaranjang freight trains in Sumatera, Indonesia (see Figure 1) is only 18 tons, and its hauling capacity is only 50 tons per wagon. In addition, every day, the train operator only runs a maximum of nine series of Babaranjang freight trains, where each Babaranjang freight train series consists of 46 to 60 coal wagons [3, 4].

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doi: 10.14456/easr.2022.64

Figure 1 Babaranjang freight train in Sumatera, Indonesia

Common damage to the ballast layer in the existing conventional track in Indonesia is dirty ballast material and lost or reduced ballast so that the stability of the conventional track will decrease. In addition, the presence of ballast pockets under the ballast can cause mud pumping. If a train passes, the soil from the ballast pocket will contaminate the clean ballast at the top of the ballast layer. Therefore, several lab experimental works have been conducted to evaluate the mechanical behavior of Indonesia's existing conventional track and investigate the effect of asphalt binder, 60/70 penetration grade bitumen, as a binding material and stabilization of ballast structures [5-9]. The 60/70 penetration grade bitumen is the only bitumen types used in the design and the construction of Indonesia's pavement system. They found that asphalt is expected to solve the problems related to the ballast layer's maintenance work and service life. They concluded that asphalt could improve ballast stiffness, minimize ballast layer vertical deformation, and reduce ballast materials abrasion.

Several studies were utilized cement asphalt mortar as a filling layer between the concrete slab and concrete base or supporting layer to reduce the vibrations induced by slab track railways laid on different infrastructure systems such as a bridge or normal subgrade [10-21]. Bituminous sub-ballast or hot mix asphalt railway substructures with various performance grade (PG) bitumen types has been used by Huang et al. [22], Rose and Bryson [23], Fang et al. [24], Gallego et al. [25]; Ramirez Cardona et al. [26], Bouraima et al. [27], Soto et al. [28], Soto and Di Mino [29], and Hassan et al. [30], to substitute granular sub-ballast material. They found that bituminous sub-ballast or hot mix asphalt railway substructures are suitable for enhancing stress distribution, improving resilient performance, weakening dynamic loading, reducing noise, lowering the vibration, and preventing mud pumping. Considering these aspects, the use of bituminous sub-ballasts improves the track quality and durability due to higher subgrade protection in terms of load dissipation. This reduces maintenance interventions, improving adherence to track geometric parameters [31]. In the case of conventional or ballasted tracks, sub-ballast layers are determining elements in the mechanical performance of the track and for the protection of the ballast. Using bituminous mixtures for sub-ballast layers has been identified as a possible solution for the necessary enhancement of the track structure. Asphalt underlayment is applicable to track features with weak subgrades, soft soils, and poor drainage [29].

Liu [32] stated that asphalt overlayment track and asphalt underlayment track are two types of asphalt track-bed design applied in the railway industry. Railroad engineers prefer the latter in some countries such as the United States [24, 33, 34], France [26, 35], China [36], Germany [37], Japan [38], and Italy [39] because the asphalt is protected below the ballast layer so this design can minimize the sunlight exposure and temperature variances to asphalt layer [40]. However, asphaltic underlayment track has never been used in Indonesia's railway systems, especially for the freight train operation [41].

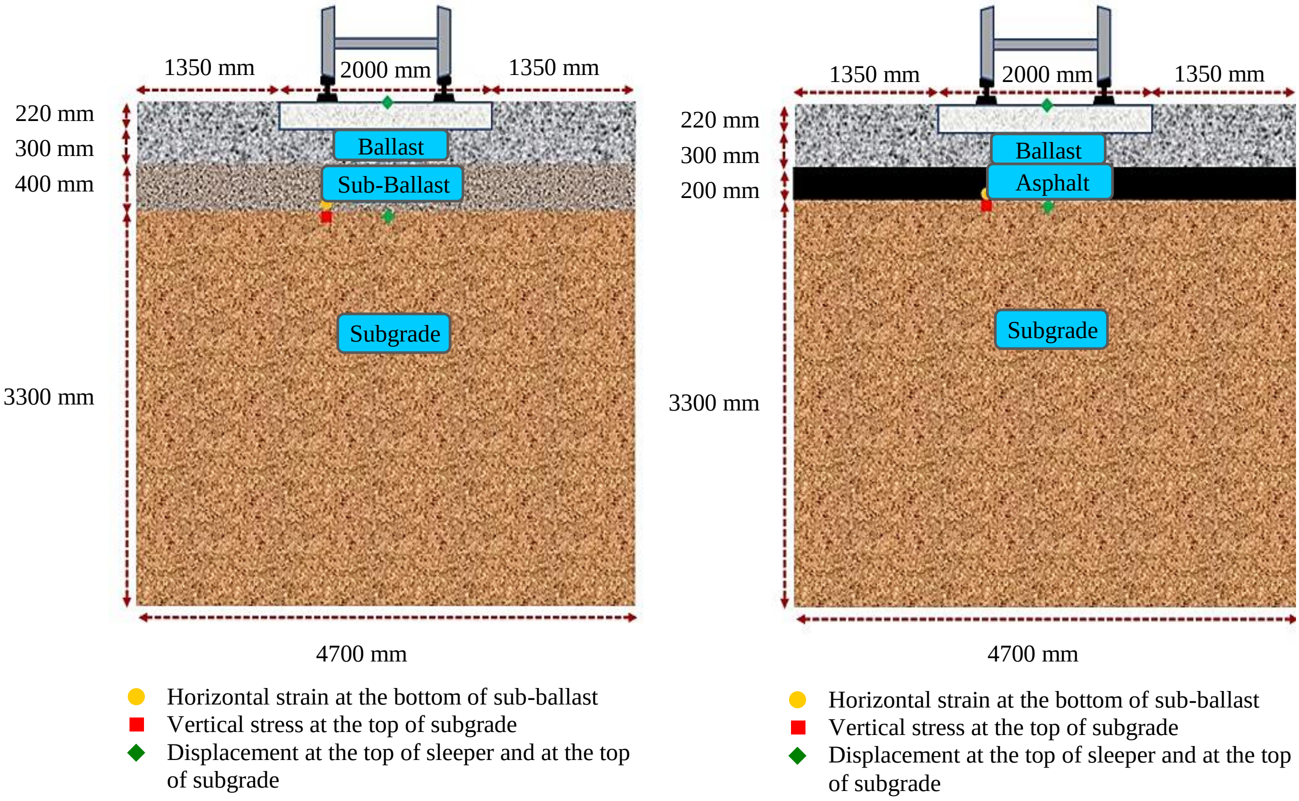
Significant work has been carried out by various researchers to investigate rail track performance under medium to high-speed passenger trains loadings which are generally operated with smaller traffic load and faster traffic loadings [24, 26, 30, 33, 35, 42-44]. In contrast, relatively few asphaltic rails track simulation have been performed to predict the stress, strain, and deformation behavior under heavy freight trains loadings which are generally operated with larger traffic load and slower traffic loadings. Asphalt's durability makes it popular choice for roads. However, large, and slow traffic load may lead to deformation issues in asphalt layer from time to time [45].

Furthermore, in designing Indonesia's conventional track, the rail track engineers need to look at a regulation that has been developed by Indonesia's railway regulator using empirical performance concepts. The determination of Indonesia's conventional track structural layer thickness and material properties only based on the estimation of passing tonnage per year. The mechanistic performance of structural components was not considered in this regulation which is important in ensuring the optimum structural materials properties and layer thicknesses. Therefore, this research performs a more mechanistic approach to evaluate the performance of asphaltic underlayment track as a new proposed rail track design considering the utilization of 60/70 penetration grade bitumen for Indonesia's railway systems track subjected to the Babaranjang freight trains. The results will be compared with the response of the existing conventional track in Indonesia railway systems. The various loading conditions of Babaranjang freight trains in terms of train speed and bogie load were applied and compared in this study. The objective is to model the existing Indonesia's conventional track and the new asphaltic underlayment track design for Indonesia's railway systems using the ABAQUS software to investigate their response to the cyclic loading of the Babaranjang freight train. This study will help Indonesia's railway stakeholders develop a new rail track design that can support Indonesia's coal industry by enhancing the carrying capacity and the operating speed of Babaranjang freight trains to maximize and optimize the production of coal mining in Indonesia.

2. Materials and methodology

2.1 Geometric and dimension of tracks

The geometric and thicknesses of the existing Indonesia's conventional track and the new asphaltic underlayment track design as well as the measurements positions of horizontal strain, vertical stress, and displacement are shown in Figure 2a and Figure 2b, respectively.



(a) Existing Indonesia's conventional track (b) New asphaltic underlayment track

Figure 2 Measurement position and 2D sketch

In the new asphaltic underlayment track design, the thickness of the asphalt layer is 20 cm to replace the 40 cm of the sub-ballast layer in the existing Indonesia's conventional track. The geometric and thicknesses of sleepers, ballast, and subgrade in existing Indonesia's conventional track and in the new asphaltic underlayment track are the same.

2.2 Material properties

All materials in Indonesia's conventional track and the new asphaltic underlayment track design investigated in this study are considered linear elastic behavior. Linear elasticity is a simplification of the more general nonlinear theory of elasticity to show how solid objects deform and become internally stressed due to the set loading conditions. In this study, the materials parameters are the elastic modulus, Poisson's ratio, and mass density. Material inputs for both track types are shown in Table 1 and Table 2, respectively. The elastic modulus of asphalt is 4000 MPa used as the reasonable and typical modulus of asphalt layer in Indonesia.

Table 1 Material inputs for modeling of existing Indonesia's conventional track

Conventional track layer	Elastic modulus E (MPa)	Mass density ρ (kg/m^3)	Poisson's ratio ν
Sleeper	30,000	1833.3	0.20
Ballast	130	1,530	0.20
Sub-ballast	120	1,900	0.30
Subgrade	60	2,000	0.25

Table 2 Material inputs for modeling of new asphaltic underlayment track

Asphaltic underlayment track layer	Elastic modulus E (MPa)	Mass density ρ (kg/m^3)	Poisson's ratio ν
Sleeper	30,000	1833.3	0.20
Ballast	130	1,530	0.20
Asphalt layer [36]	4000	2,400	0.35
Subgrade	60	2,000	0.25

2.3 Cyclic loading

The mathematical calculation of the vertical force generated by the axle load of the locomotives, trains, and carriages is a static load, whereas in the real loading conditions, the load that occurs on the railroad structure is a dynamic load that is influenced by geometric conditions and train speed [46]. Therefore, there needs to be a transformation of static load (P_s) into a dynamic load (P_d) in more realistic load planning. The dynamic load of the Babaranjang freight train considered in this study was computed according to Talbot Formula using Eq. 1 and Eq. 2. The Talbot Formula is the mathematical equation as a transformation of the force or load in the form of dynamic factor multiplier [47, 48]. The specification of the Babaranjang freight train's wagon set is presented in Table 3.

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

$$P_d = P_s \times I_p \tag{2}$$

where: I_p = Conversion factor;
V = Design speed, km/hour;
P_s = Static load, kg;
P_d = Dynamic load, kg.

Table 3 Specification of Babaranjang freight train's wagon set [4, 49]

Technical characterization	Specifications
Maximum load capacity	50 tons
Empty load	22 tons
Total load	72 tons
Number of axle per wagon	4
Axle load	18 tons
Number of axle per bogie	2
Bogie load	36 tons
Gauge	1.067 m
Distance between Centre of two bogies	10.676 m

Table 4 illustrates the results of dynamic load calculation and the detail of the simulated cyclic load on each side of the rail track. Figure 3 illustrates the configuration of coal wagon in Babaranjang freight train set, while Figure 4 shows the cyclic loading configuration from the Babaranjang freight train according to the variation of train speed and bogie loads.

Table 4 Simulated cyclic load

Rail track types	Train speed "V" (km/h)	Bogie load (kg)	Static load (kg)	Dynamic load (kg)	Dynamic load (N)	Case	Bogie passage frequency (Hz)	Loading cycles
Conventional track	70	36,000	18,000	24,931	244,489	A1	1.8	40,000
	120			30,524	299,338	A2	3.1	40,000
	70	48,500	24,250	33,588	329,385	A3	1.8	40,000
	120			41,123	403,278	A4	3.1	40,000
Asphaltic underlayment track	70	36,000	18,000	24,931	244,489	B1	1.8	40,000
	120			30,524	299,338	B2	3.1	40,000
	70	48,500	24,250	33,588	329,385	B3	1.8	40,000
	120			41,123	403,278	B4	3.1	40,000

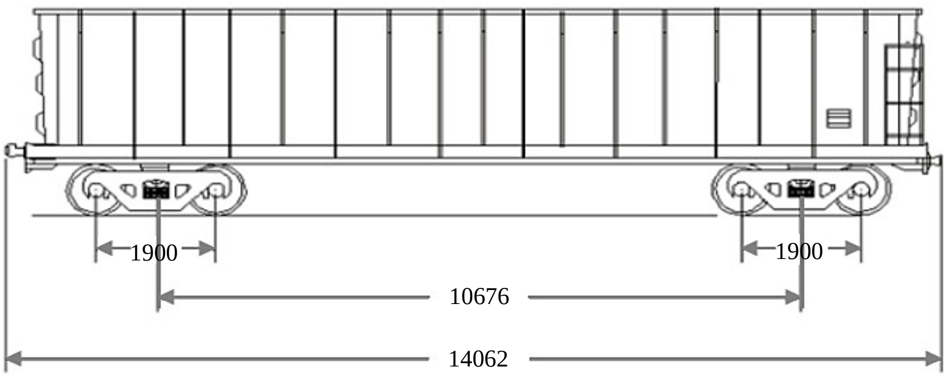
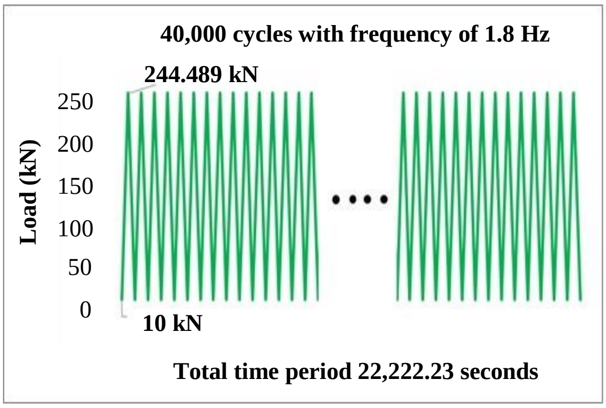
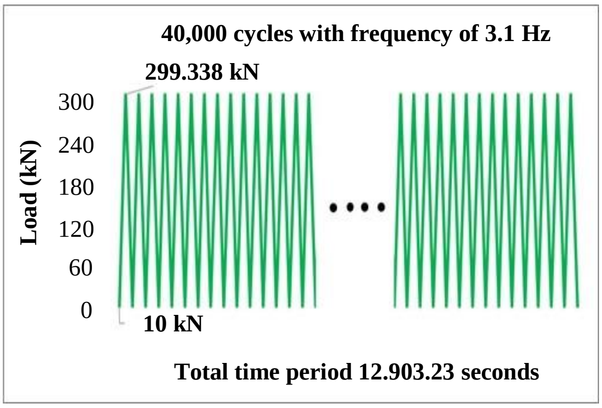


Figure 3 Distance between two bogies (L_b) in the coal wagon of Babaranjang freight train [4]

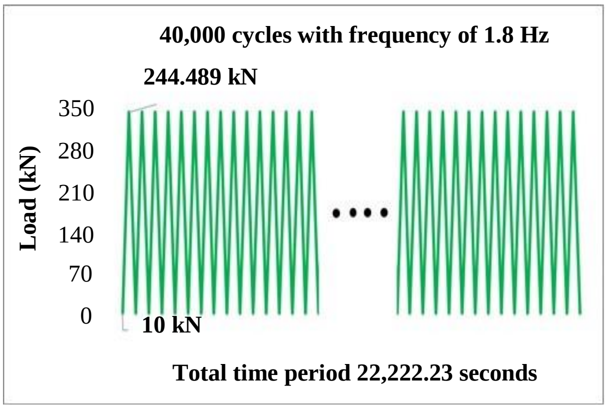
This study attempted to analyze the response of existing Indonesia's conventional track (Case A) and the new asphaltic underlayment track design (Case B) under four different cyclic loading simulations. As the baseline, the existing system operation of Babaranjang freight trains running on existing Indonesia's conventional track (Case A1) was considered. Case B1 is the simulated cyclic load from the existing system operation of Babaranjang freight trains running on the new asphaltic underlayment track. Case A2 and Case B2 are the simulated cyclic load from the Babaranjang freight trains with higher operational train speed, 120 km/h, and existing bogie loads, 36 tons, running on Indonesia's conventional track and the asphaltic underlayment track, respectively. In addition, Case A3 and Case B3 are the simulated cyclic load from Babaranjang freight trains with existing operational train speed, 70 km/h, but heavier bogie load, 48.5 tons, running on Indonesia's conventional track and the asphaltic underlayment track, respectively. Finally, Case A4 and Case B4 are the simulated cyclic load from the Babaranjang freight trains with not only higher operational train speed, 120 km/h, but also heavier bogie load, 48.5 tons, running on existing Indonesia's conventional track and the asphaltic underlayment track, respectively.



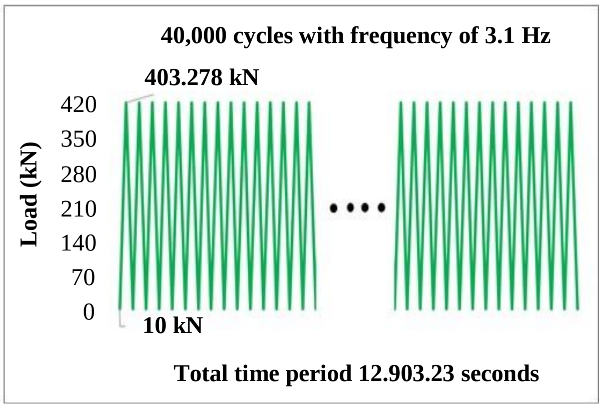
(a) Train speed 70 km/h and bogie loads 36,000 kg



(b) Train speed 120 km/h and bogie loads 36,000 kg

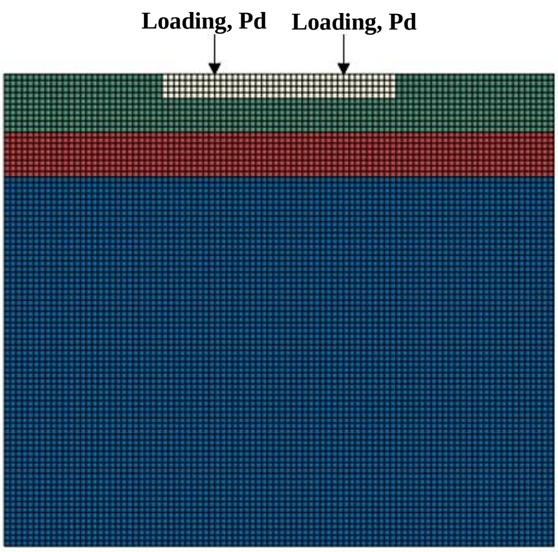


(c) Train speed 70 km/h and bogie loads 48,500 kg

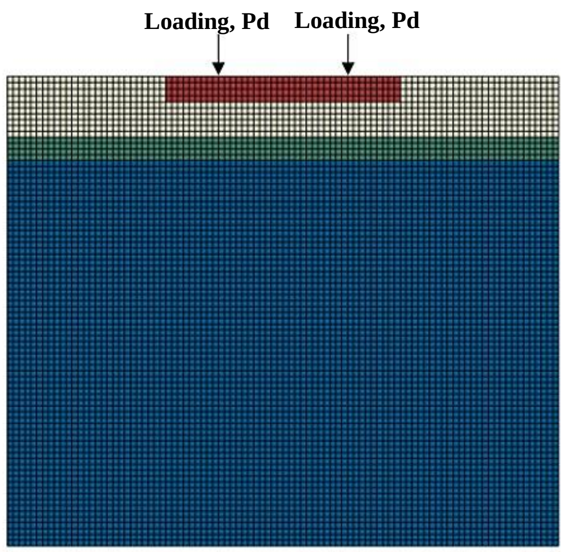


(d) Train speed 120 km/h and bogie loads 48,500 kg

Figure 4 Various cyclic loading configuration from Babaranjang freight train



(a) Existing Indonesia's conventional track



(b) New asphaltic underlayment track

Figure 5 The 2-dimensional meshing

2.4 Mechanistic approach

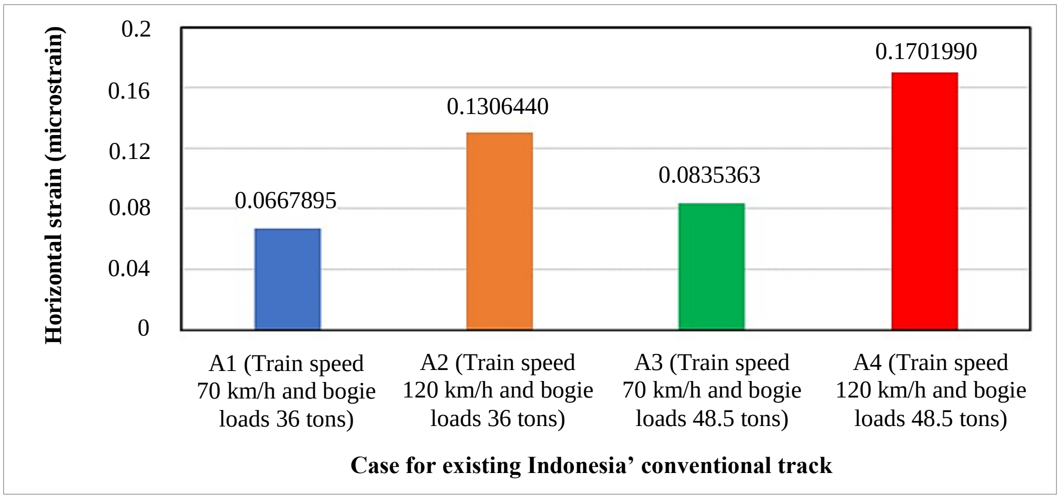
The empirical modeling aims to understand a natural phenomenon using statistical model between the measured variables. This approach is based on the assumption and depended on the data base. A combination of graphical techniques such as monograph and least squares regression were generally used to develop the empirical equations. In contrast, the mechanistic modeling aims to understand a natural phenomenon using fundamental and constitutive laws. This method able to calculate the primary response a structural layer in terms of stresses, strains, and displacements with more accurate results [50]. The conventional track and asphaltic underlayment track were simulated in two-dimensional using the Abaqus/CAE's finite element package. Figure 2a and Figure 5a illustrate the conventional track's geometries and 2D mesh, respectively. Figure 2b and Figure 5b illustrate the geometries and the 2D mesh of the asphaltic underlayment track, respectively. The mesh 50 by 50 mm was used in the ballast, sub-ballast, and subgrade, while the mesh 55 by 50 mm was used in the sleeper for predicting conventional track and asphaltic underlayment track response under cyclic loading.

The interactions between layers were expected to be fully bonded, and the sleeper was expected to be a rigid material. Therefore, the deformation in the conventional track and asphaltic underlayment was determined by subtracting the displacement at the top of the sleeper with the displacement at the top of the subgrade. In addition, the boundary condition in this numerical modeling was specified as the soil box condition. Therefore, the vertical displacement at the bottom and the horizontal displacement at the side of the model were fixed.

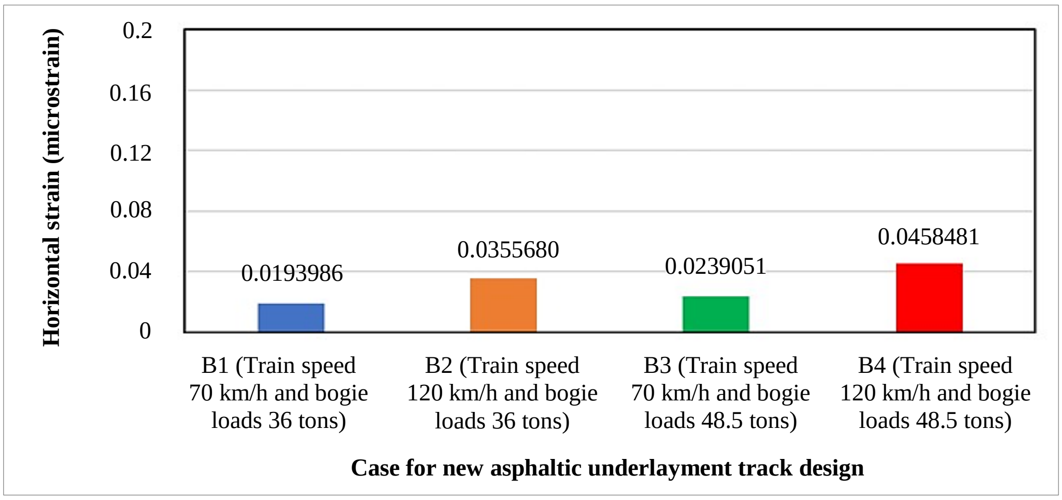
3. Results and discussion

3.1 Measurement of horizontal strain component

According to Soto and Di Mino [29], Setiawan [41], and Setiawan [51], the horizontal strain at the bottom of the sub-ballast in conventional track and the asphalt layer in the asphaltic underlayment track is considered as an indicator of fatigue effects and reduction of service life. The higher the horizontal strain at the bottom of the sub-ballast and asphalt layer, the higher possibility for the water to infiltrate the ballast layer; therefore, the higher the risk of mud pumping.



(a) At the bottom of sub-ballast in existing Indonesia's conventional track



(b) At the bottom of asphalt layer in new asphaltic underlayment track

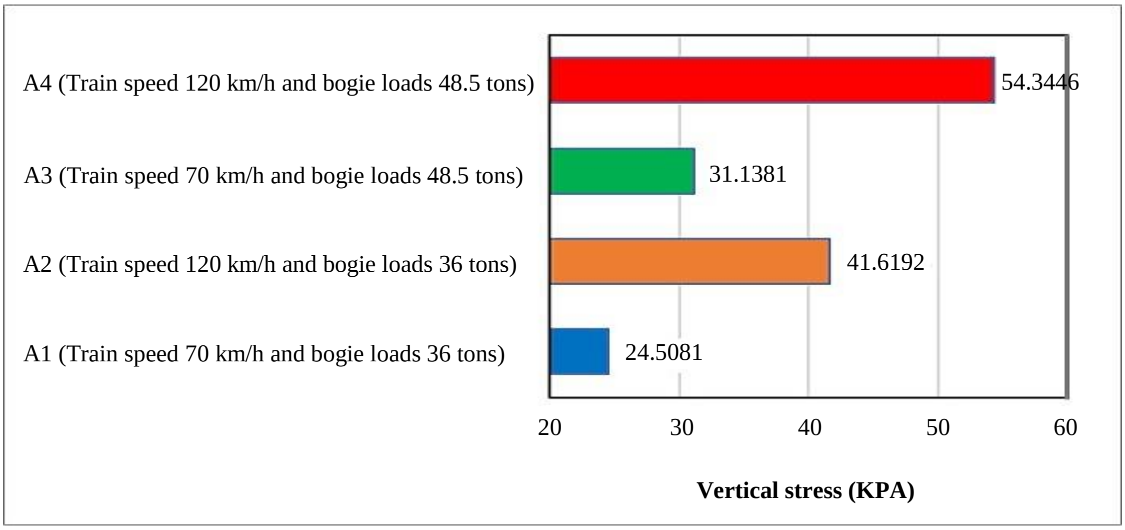
Figure 6 Horizontal strain

Figure 6a shows the recapitulation of horizontal strain at the bottom of the sub-ballast layer in existing Indonesia's conventional track after forty thousand loading cycles. As expected, Case A4 has the highest horizontal strain, which is 0.1701990 microstrain (2.5 times higher than the baseline in Case A1 as the lowest), followed by Case A2 and Case A3. The same pattern can be found in the four cases for the new asphaltic underlayment track design in Figure 6b. In addition, the results show that the new asphaltic underlayment track design produces significantly lower horizontal strain than Indonesia's conventional track. For each loading condition (A1 vs. B1, A2 vs. B2, A3 vs. B3, and A4 vs. B4), the reduction of horizontal strain magnitude due to replacing the 40 cm sub-ballast layer with 20 cm asphalt layer is around 70%.

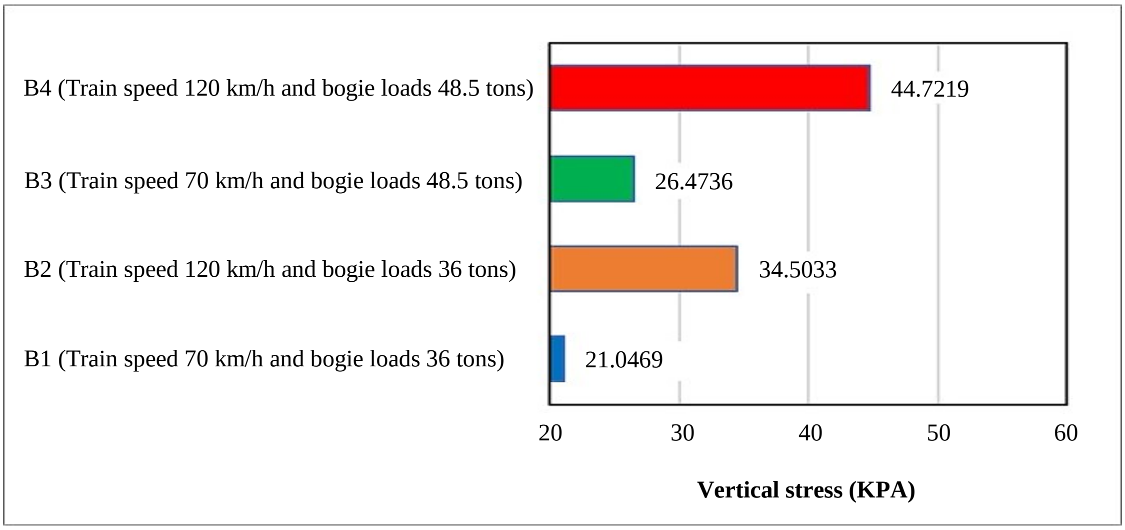
Interestingly, the horizontal strain in Case B4 is around 30% lower than the horizontal strain in Case A1 (0.0458481 microstrain vs. 0.0667895 microstrains), which is the baseline or the existing condition of the Babaranjang freight train operation in Indonesia in terms of the train speed and bogie load. It means that the new asphaltic underlayment track design shows superior performance in preventing the mud pumping occurrence even though the structure was subjected to the significantly higher train speed, 120 km/h, and heavier bogie load, 48.5 tons. According to Ramirez Cardona et al. [26], the strain magnitude at the bottom of the bituminous sub-ballast layer is close to two micro strains to pass French TGVs at commercial circulation speeds near 320Km/h. This order of magnitude could estimate the fatigue life of bituminous materials in sub-ballast layers under high-speed railway solicitations.

3.2 Measurement of vertical stress

Fang et al. [24] concluded that hot mix asphalt is a suitable material for the railway substructure to enhance resilient performance and improve the stress distribution. According to Soto and Di Mino [29], Setiawan [41], and Setiawan [51], the vertical stress at the top of the subgrade indicates potential subgrade long-term settlement failure performance and track maintenance costs. The higher the vertical stress at the top of the subgrade layer, the higher possibility of subgrade failure and the higher risk of track-bed settlement. Figure 7a shows the recapitulation of vertical stress at the top of the subgrade layer in Indonesia's conventional track as the load reaches forty thousand cycles. As expected, Case A4 has the highest vertical stress, 54.3446 kPa (2.2 times higher than the baseline in Case A1 as the lowest), followed by Case A2 and Case A3.



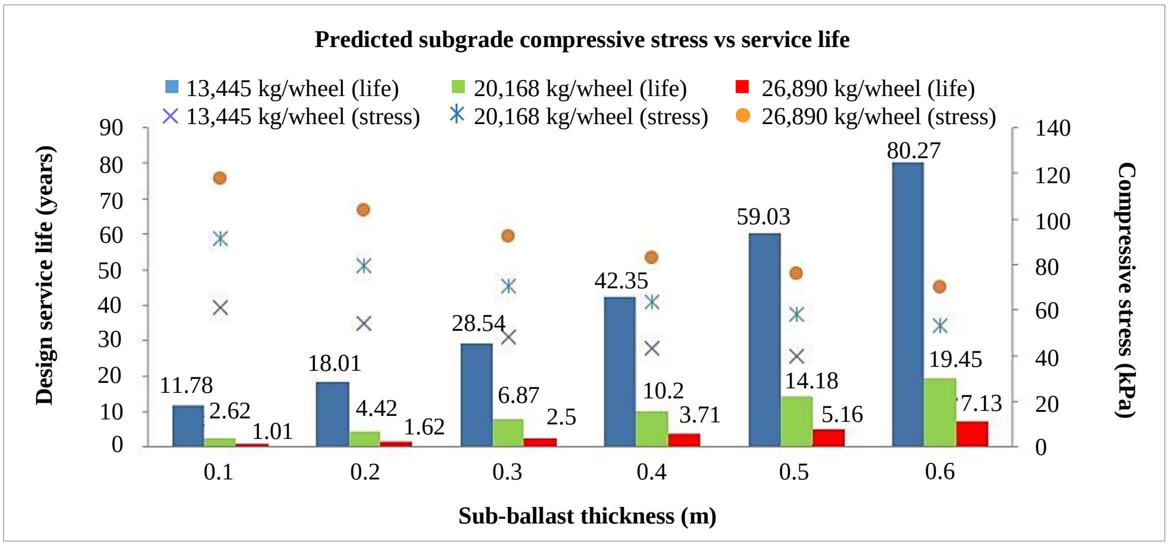
(a) At the top of subgrade in existing Indonesia's conventional track



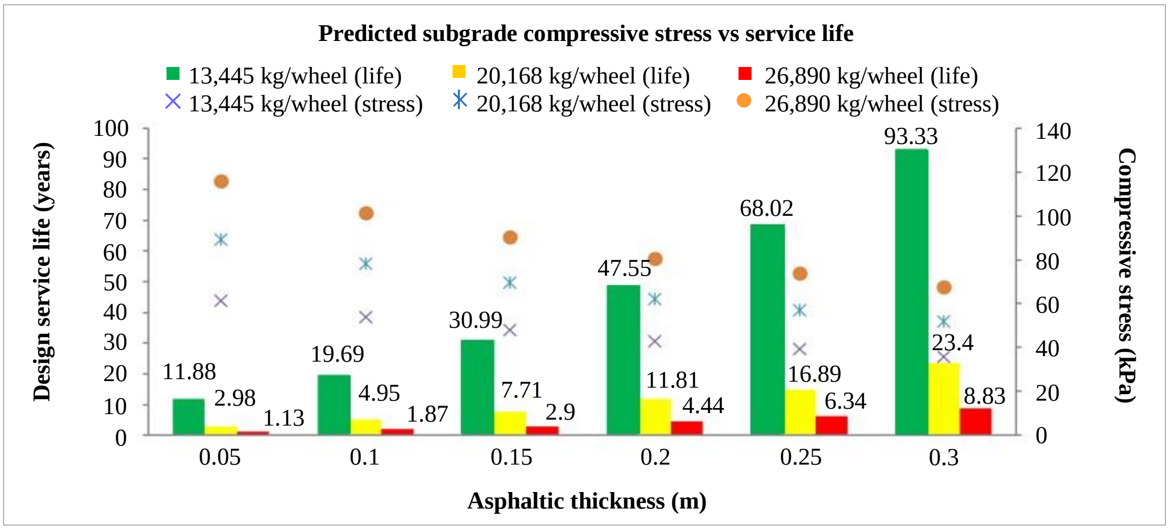
(b) At the top of subgrade in new asphaltic underlayment track

Figure 7 Vertical stress

The same pattern can be found in the four cases for the new asphaltic underlayment track design in Figure 7b. The numerical modeling results show that the new asphaltic underlayment track design produces lower vertical stress than Indonesia's conventional track. For each loading condition (A1 vs. B1, A2 vs. B2, A3 vs. B3, and A4 vs. B4), the reduction of vertical stress level due to the utilization of 20 cm asphalt below the ballast layer to replace 40 cm of sub-ballast is between 14% to 17%. This result agrees with the output from Ramirez Cardona et al. [26]. They found that bituminous sub-ballast layers were highly efficient in reducing the vertical stress transmitted to the soil layer up to 30%. Also, Setiawan [41] found that the conventional track (see Figure 8a) has the shorter subgrade service life with lower subgrade vertical compressive stress than asphaltic underlayment track (see Figure 8b), even though the sub-ballast below the ballast layer in the conventional track is 100% thicker than the sub-ballast below the asphalt layer in the asphaltic underlayment track.



(a) Conventional track



(b) Asphaltic underlayment track

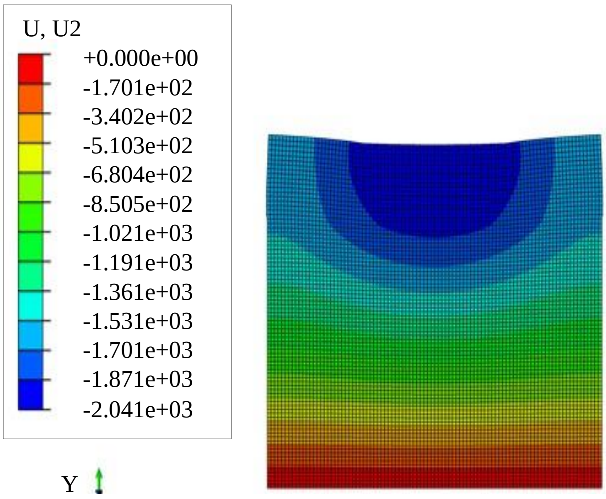
Figure 8 Relationship between predicted subgrade vertical compressive stress, subgrade service life, and sub-ballast and asphalt layer thickness [41]

In addition, it was interesting to know that the vertical stress in Case B4 (new asphaltic underlayment track design under higher train speed 120 km/h and heavier bogie load 48.5 tons) is only 7% higher than the vertical stress in Case A2 (44.7219 kPa vs. 41.6192 kPa), where existing Indonesia's conventional track was subjected to the same train speed, 120 km/h, but lighter bogie load, 36 tons. It means that the new asphaltic underlayment track design shows a relatively similar performance with existing Indonesia's conventional track even though it was subjected to 35% heavier bogie load.

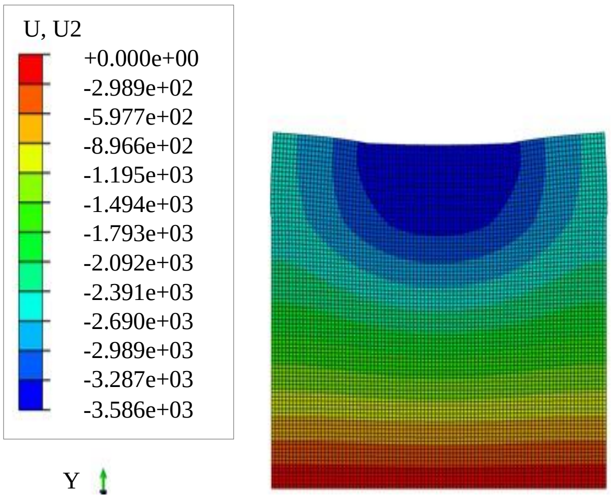
3.3 Measurement of deformation

Teixeira et al. [38] stated that deformation and possible track settlement are considered indicators of posterior maintenance needs. Ramirez Cardona et al. [26] found that using a bituminous sub-ballast increase the vertical stiffness of the railway track while allowing a reduction of the structure's height. This can be particularly advantageous for tunnels and low-level crossings with low-quality platforms as the rail gauge is limited.

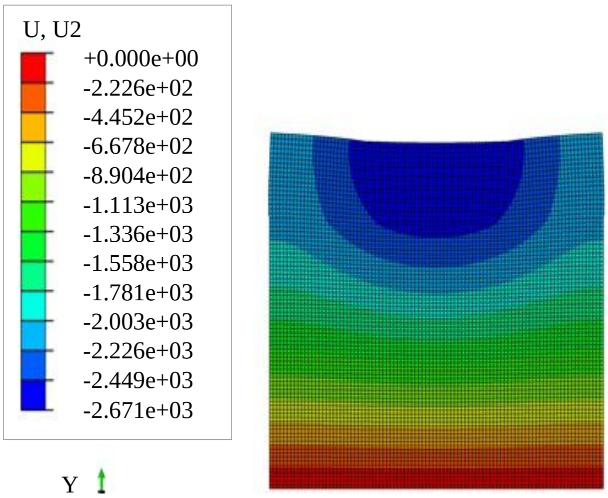
Figure 9 (a, b, c, and d) and Figure 10 (a, b, c and d) present the numerical simulation results of the ballast and sub-ballast layer's deformation in existing Indonesia's conventional track, and ballast and asphalt layer's deformation in the new asphaltic underlayment track design, respectively, for four different cases. In this paper, the deformation was measured based on the relative displacement between the surface of the sleeper and the surface of the subgrade.



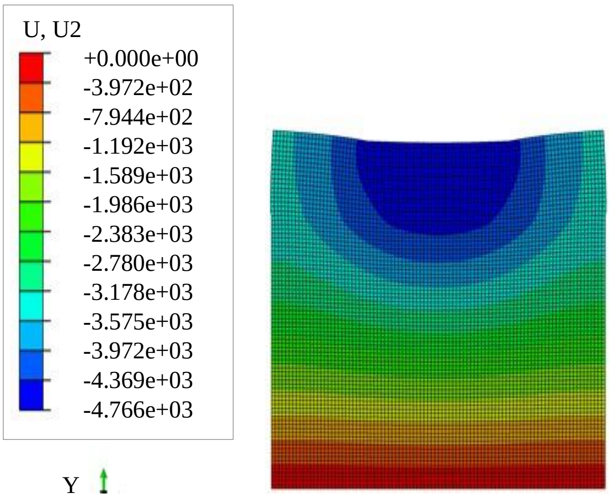
(a) Train speed 70 km/h and bogie loads 36,000 kg



(b) Train speed 120 km/h and bogie loads 36,000 kg

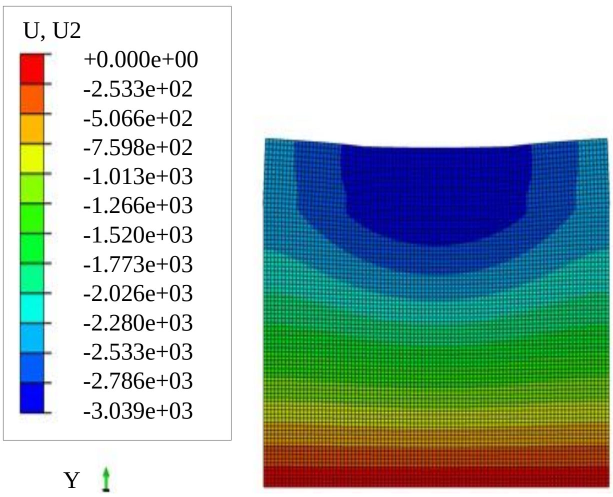


(c) Train speed 70 km/h and bogie loads 48,500 kg

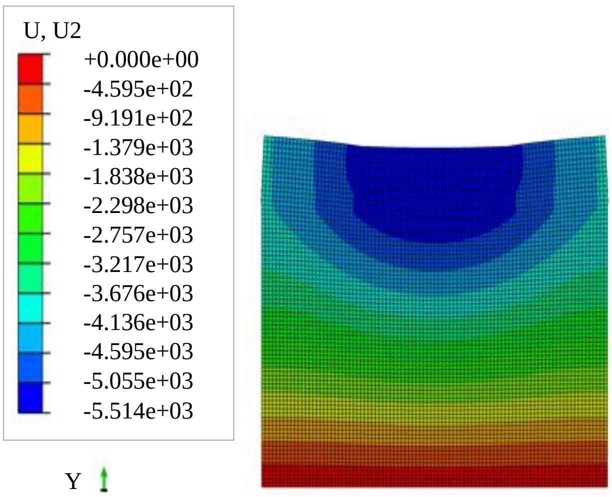


(d) Train speed 120 km/h and bogie loads 48,500 kg

Figure 9 Numerical simulation results of ballast and sub-ballast layer's deformation in existing Indonesia's conventional track

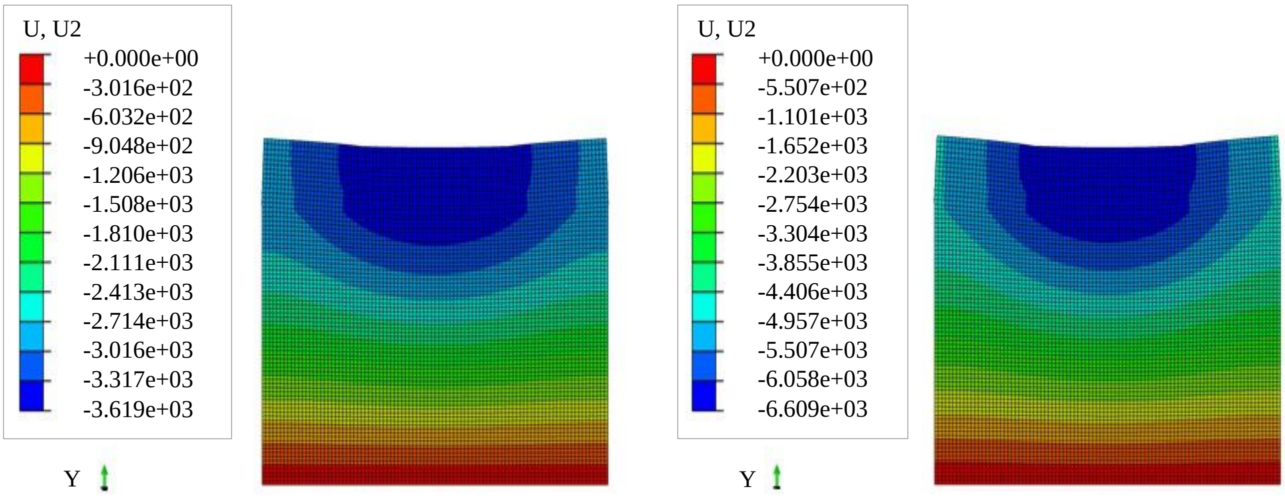


(a) Train speed 70 km/h and bogie loads 36,000 kg



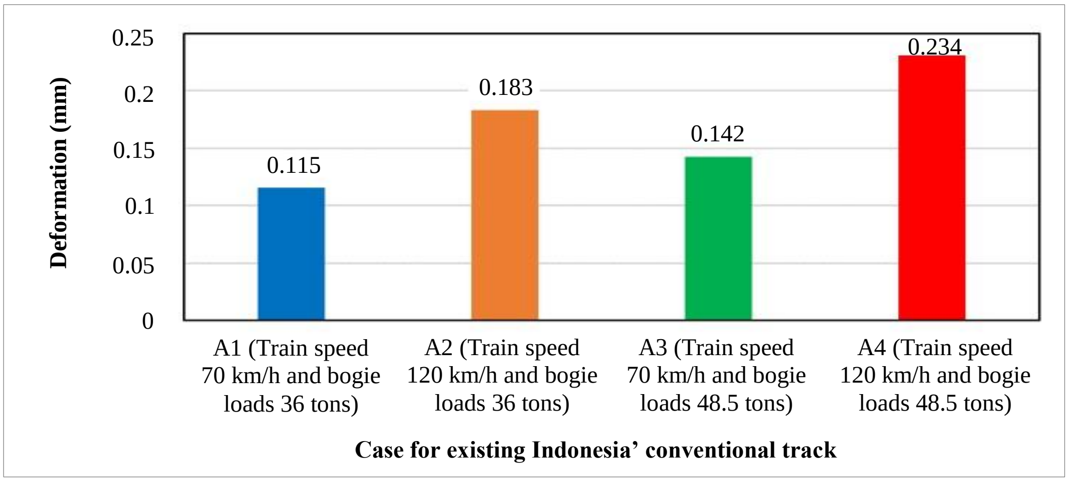
(b) Train speed 120 km/h and bogie loads 36,000 kg

Figure 10 Numerical simulation results of ballast and asphaltic layer's deformation in new asphaltic underlayment track design

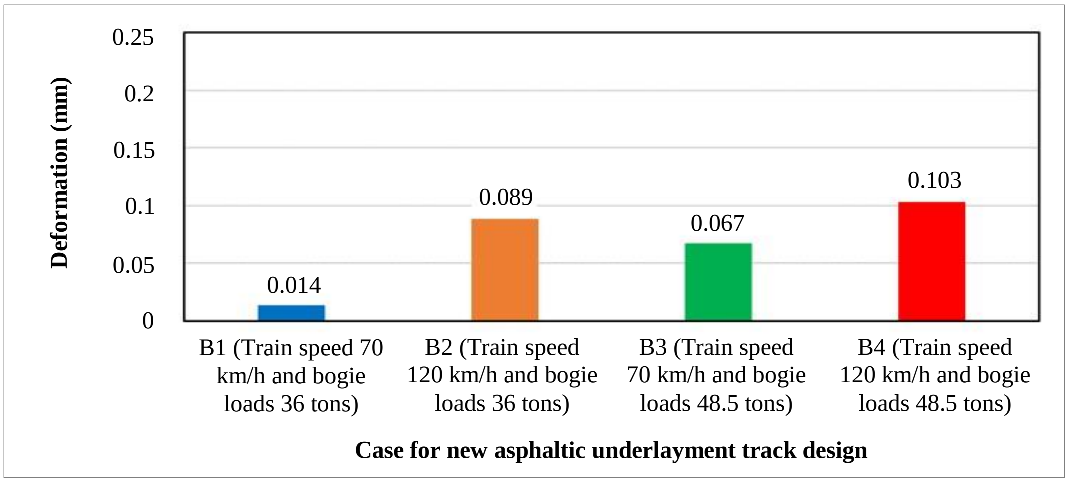


(c) Train speed 70 km/h and bogie loads 48,500 kg (d) Train speed 120 km/h and bogie loads 48,500 kg

Figure 10 (continued) Numerical simulation results of ballast and asphaltic layer’s deformation in new asphaltic underlayment track design



(a) Existing Indonesia’s conventional track



(b) New asphaltic underlayment track

Figure 11 Deformation

Figure 11a shows the calculation results of deformation in existing Indonesia's conventional track after forty thousand loading cycles. We can see that Case A4 has the highest deformation, which is 0.234 mm (more than two times higher than the baseline in Case A1 as the lowest), followed by Case A2 and Case A3. Again, the same pattern can be found in the four cases for the new asphaltic underlayment track design in Figure 11b. As expected, the new asphaltic underlayment track design produces significantly lower deformation compared to existing Indonesia's conventional track. For each loading condition, A1 vs. B1, A2 vs. B2, A3 vs. B3 and A4 vs. B4, the reduction of deformation magnitude due to the substitution of 40 cm sub-ballast layer with 20 cm asphalt layer is varied, 88%, 52%, 53%, and 56%, respectively. Therefore, we can conclude that if the new asphaltic underlayment track design is applied for the existing Babaranjang freight train operation (train speed of 70 km/h and bogie load of 36 tons in Case A1), we can reduce the magnitude of deformation up to 88% from 0.115 mm in (Case A1) to 0.014 mm (Case B1).

Surprisingly, the deformation in Case B4 is around 10.5% lower than the deformation in Case A1 (0.103 mm vs. 0.115 mm). It means that the new asphaltic underlayment track design shows an excellent performance in minimizing the deformation even though the structure was subjected to a significantly higher train speed, 120 km/h, and heavier bogie load, 48.5 tons.

4. Conclusions

Based on several numerical simulations performed through the ABAQUS software, we can conclude that the performance of the new asphaltic underlayment track design subjected to various Indonesia's Babaranjang freight train loading conditions is significantly superior to existing Indonesia's conventional track in all three parameters, horizontal strain, vertical stress, and deformation. The results indicate and confirm the potential and promising capability of the new asphaltic underlayment track design application for the Indonesian railway system in serving Babaranjang freight trains with the speed of 120 km/h and bogie load of 48.5 tons. In other words, the Babaranjang freight train set will be allowed to run with an operating speed 70% higher than the existing operating speed, 70 km/h, and every coal wagon in the Babaranjang freight train set will be permitted to operate with maximum payload up to 75 tons, or 50% higher than the existing maximum payload, 50 tons.

The findings of this research will help Indonesia's government to consider the new asphaltic underlayment track as the promising solution in providing a higher quality of rail track structure and in delivering the robust transportation system for Indonesia's freight train operation in general, especially for the Babaranjang freight trains so that it can transport the coal product with higher speed and heavier hauling capacity. The application of the asphaltic underlayment track in Indonesia's railway systems could be beneficial for optimizing the life cycle cost of the rail track since it could reduce the structure's height and maintenance needs.

However, it is known that asphalt is a viscoelastic material. Its responses vary with the temperature and loading time. Considering the asphalt concrete as a linear elastic material could yield unrealistic results in terms of the response and damage in the asphalt concrete track-bed. Therefore, future research should consider the linear viscoelastic constitutive behavior of asphalt material especially the 60/70 penetration grade as the main bitumen types in Indonesia, to predict the asphaltic underlayment track performance more accurately. In addition, the validation process of the asphaltic underlayment track design that has been developed in this study should be conducted in the next research work.

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