Double Track Railway Planning of Terminal Petikemas Surabaya-Surabaya Pasar Turi

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Abstract. The National Railway Master Plan estimated that the potential for freight transport in Java Island in 2030 will reach 534 million tons/year. Therefore, the government is planning to develop a double-track railway line between Surabaya Pasar Turi-Kalimas/Tanjung Perak. This research aimed to add a new track next to existing track to increase the capacity of Surabaya Pasar Turi-Terminal Petikemas Surabaya railway. The method in this double track planning includes primary and secondary data collection. The analysis method follows the regulations related to railway track planning. The design of the new track plan is depicted using Autocad Civil 3D. The results in a new track following the existing trace with a new track on Surabaya Pasar Turi-Mesigit, Kalimas-Prapat Kurung, Prapat Kurung-Terminal Petikemas Surabaya, Mesigit-Kalimas, the reactivation of Kalimas-Prapat Kurung, and planning to add new side track on the Prapat Kurung and Terminal Petikemas Surabaya emplacements. Planning the new emplacement by implementing a double track operating pattern. The horizontal alignment geometry of the new track consist 15 curves and the new vertical alignment is adjusted to the existing vertical alignment. The railway construction planning with first class track of railway classification, using R54 rails, Pandrol E-Clip fasteners, TJM BJR 1067mm prestressed concrete sleepers, and 1:10 switches. The needs for R54 rail components are 510 rods, 10504 sleepers, 42016 fasteners, 4132,36 m^3 ballast, and 18154,28 m^3 subballast. The new track planning result was 15058,79 m^3 volume of embankment and 30179,05 m^3 volume of heap.

Keywords: Double Track, Trace Design, Railway Construction, Railway Freight.

1 Introduction

The Terminal Petikemas Surabaya-Kalimas-Surabaya Pasar Turi trace with a length of 6,685 kilometers is currently single track, which means that only one train can pass and other trains that will pass must wait to take turns passing through the line [1]. This has an effect on the small line capacity that makes the volume of goods that can be unloaded is still small. This small line capacity is a serious problem that has an impact on the lack of demand for railway freight transport [2]. Railway freight transport on Java

A. Pradipta et al. (eds.), *Proceedings of the 2nd International Conference on Railway and Transportation 2023 (ICORT 2023)*, Advances in Engineering Research 231,
https://doi.org/10.2991/978-94-6463-384-9_12

Island in 2022 was recorded at 12,27 million tonnes/year [3]. This figure is still far from the target, which targets freight transport in Java to reach 534 million tonnes/year [4]. As a solution, it is necessary to develop railway lines and services that were previously single track into double track [5]. The development of the track in the form of the construction of a double railway track between Surabaya Pasar Turi-Kalimas/Tanjung Perak is listed in the development programme [4].

The construction of a double track on this line is useful to increase line capacity, accelerate the delivery of goods, and reduce the operational costs of railway service users [2]. This is expected to have an impact on increasing the demand for logistic transport and the volume of goods that can be unloaded at the Terminal Petikemas Surabaya or Kalimas.

The construction of a double track on the Terminal Petikemas Surabaya-Surabaya Pasar Turi line requires geometry planning, new track construction, and calculation of the components needed so that the double track can be operated properly [6]. The existing rail conditions on the line are used as the basis for determining the new line trace on the double track planning by modifying the rail geometry and construction in accordance with the topography of the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace.

This study aimed to find out the new line location, geometry planning, new track construction, and calculation of the components needed for double track of Surabaya Pasar Turi-Terminal Petikemas Surabaya.

2 Research Methods

2.1 Data Collection Method

The data collected consisted of field observations at the double track planning location to find out the real conditions and the documentation of the existing track conditions and emplacements across Terminal Petikemas Surabaya-Surabaya Pasar Turi as a reference for double track planning. Also topographic map as a reference for double-track planning and technical data on railway facilities and infrastructure as data used for planning calculations.

2.2 Data Processing Method

The redrawing of the existing trace is carried out based on the topographic map of the area obtained using the help of Google Earth, GPS Visualizer, and AutoCAD Civil 3D [7]. The redrawing of the existing trace also follows the results of field observations and satellite images in AutoCAD Civil 3D. This redrawing of the existing trace is to serve as a reference in planning the new track in the planning of the Terminal Petikemas Surabaya-Surabaya Pasar Turi double track. The new trace to be planned was determined accordingly free space and built space, distance to existing track, destination station emplacements, and *Groondkart*.

2.3 Data Analysis Method

The emplacement changes were made as a result of the double-track operating pattern from the previous single-track. Railway geometry planning is carried out based on Ministerial Regulation Number 60 of 2012 and PJKA Service Regulation Number 10 of 1986. Planning analyses were carried out for rails, rail joints, rail ties, sleepers, ballast layers, sub-ballast layers and switches. In the rail planning for the new track, PJKA Service Regulation Number 10 of 1986 was used by modifying the Talbot dynamic influence factor equation with the AREMA (American Railway Engineering and Maintenance of Way Association) dynamic influence factor. The AREMA dynamic influence factor is used because this equation is applicable in the operation of freight trains running at low speeds so that it is in accordance with the designation of this line plan which is planned to serve freight trains. Calculation of railway components is carried out to determine the number of component requirements that will be used in planning. The analysis is carried out on the components of rails, sleepers, fasteners, ballast volume, and subballast volume. Volume calculation of excavation and heap volumes is carried out to determine the volume requirements of excavation and heap required in planning. The analysis is carried out from the design results assisted by AutoCAD Civil 3D.

Based on data analysis, the researcher then designs the drawing stage that carried out with the help of AutoCAD Civil 3D. The depiction of all plans that have been calculated includes new emplacement drawings, profile plans, cross sections, and cut & fill.

3 Result

3.1 Existing Line Condition

Fig. 1. Track Existing's Condition

Horizontal alignment is obtained from remote sensing from Google Earth and observation of existing trajectories assisted by GPS tracker applications so that reference points are obtained to obtain horizontal alignment conditions. Existing vertical alignment data from Surabaya Pasar Turi-Terminal Petikemas Surabaya is obtained from topographic maps processed by GPS Visualizer and the results of field measurement surveys with the help of the Altimeter application on a Smartphone. The existing emplacement of Surabaya Pasar Turi is as follows.

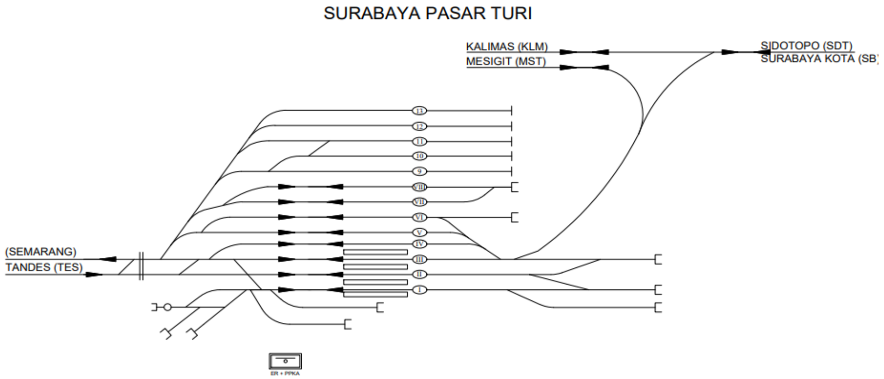

Fig. 2. Emplacement of Surabaya Pasar Turi's Station

3.2 Determination of The New Track Line

3.2.1 Selecting Location for The New Line

The condition of the existing trace is then used as a reference for determining the location of the new line or second line. Determining the location of this new line also uses several considerations that affect the location of the new line against the existing line. In planning the Terminal Petikemas Surabaya-Surabaya Pasar Turi double track, the author uses four considerations to determine the location of the new line or second line, namely:

1. Based on Free Space and Built Space

The space allocation for double track construction is obtained at a minimum distance of 7,95 metres with details of 4,2 metres distance between rail axles added 3,75 metres for new track building space [8]. This distance becomes the author's reference in laying a new line with the consideration that the new line will be free from obstacles on the right and left sides of the railway line.

2. Based on Survey Results of Existing Line Conditions

Measurements were made by measuring the nearest obstacle to the existing track axle. After the measurement, it was found that there was hardly enough free space to allow for the laying of a new track as there were mostly residential areas on either side of the railway. The track is surrounded by residential areas that are close to the railway, making it dangerous for train operations as well as for residents living around the railway. The following is an example of obstacles in the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace.

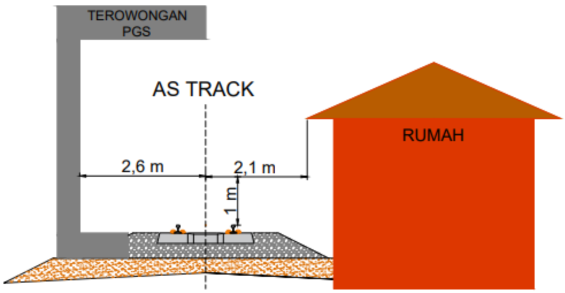

Fig. 3. Distance Between The Obstacle and As Track

3. Based on The Destination Emplacement

Alternatives for laying the new line were then made based on the destination emplacement. The selection of the location of the new line based on the destination emplacement is based on the following operating considerations.

4. Based on *Groondkart*

Grooondkart is data on legal land ownership by the railway company during the Dutch colonial era. In this consideration, the author does not get complete data, so the consideration of laying a new line only reaches the consideration of existing station emplacements as an option for laying a new line.

3.2.2 Reactivation of Non-Active Line KM 4+540 to 5+360

At KM 4+540 to KM 5+360 there is a line that has changed its function to become a residential area. For this double track planning, the old track trace is used with a planning land requirement of 7,95 m to the left of the existing track axle which is currently still usable. The illustration is as follows.

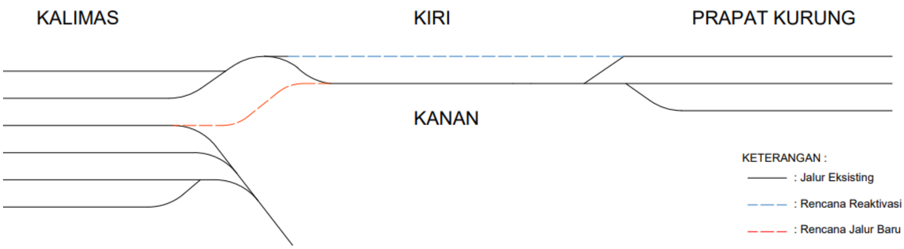

Fig. 4. Reactivation Line Layout

3.2.3 Addition of Track at Emplacements

The purpose of this additional track is to provide a sidetrack and increase the capacity of trains that can be in an emplacement. This is necessary considering the process of loading and unloading goods that require time. The addition of the line was carried out on line III of Prapat Kurung Emplacement and a new storage track at the Terminal Petikemas Surabaya Emplacement. The land requirement for the addition of lines at the

Terminal Petikemas Surabaya Emplacement is 5 metres so that it can facilitate the mobilization of loading and unloading that occurs.

3.2.4 Land Acquisition Requirements

The construction of the new Terminal Petikemas Surabaya-Surabaya Pasar Turi railway line is located on land that is densely populated with residential areas. The procedure for determining the railway trace, land acquisition is required so that the land can be used for railway construction and operation [9]. An illustration of the minimum land requirement according to the allocation of free space and built space for the construction of a new line is as follows.

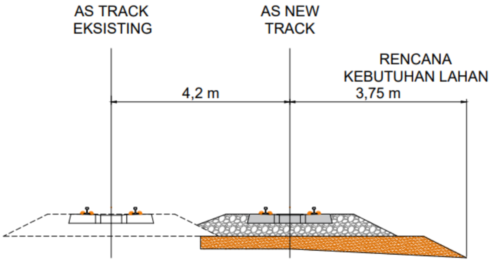

Fig. 5. Land Acquisition Requirements

On the Surabaya Pasar Turi-Mesigit section, the new line is laid on the right side of the existing railway. On the Mesigit-Kalimas section, the new line is laid on the left side of the existing railway. On the Kalimas-Prapat Kurung section, the new line is placed on the right side of the existing railway and reactivation of the line that has been converted into a residential area on the left side of the existing railway is also planned. In the Prapat Kurung emplacement, a new line is planned so that the Prapat Kurung emplacement has 3 lines. In the Prapat Kurung-Terminal Petikemas Surabaya section, the new line is placed on the right side of the existing railway. At the Terminal Petikemas emplacement, 2 new lines are planned so that the Terminal Petikemas emplacement has 5 lines.

3.3 Change of Emplacement

The laying of a new line results in each emplacement undergoing changes for the purposes of double track operation. Double track operations can only serve one direction on each line and should not interfere with each other except in certain circumstances that result in one line being unusable. To serve these conditions, a switch is needed so that trains can operate with one line that can still be used [10]. Changes include the location of tracks, switches, and operating patterns at each emplacement. In the Surabaya Pasar Turi emplacement, changes were made in the form of dismantling the train storage line on line III including the switch connecting line II to line III and dismantling the switch connecting line II and line I. The construction of double-slip switches 1A and 1B, crossover 2A and 2B, standard switches 1C, 3A, 4A, 5A, 6A, and new diamond crossings P1, P2, and P3 were carried out. A new line from Mesigit to

Sidotopo/Surabaya Kota was also constructed to support the double-track operation, but this was not planned by the author. The following is the new emplacement and operating pattern of the double track Surabaya Pasar Turi Station.

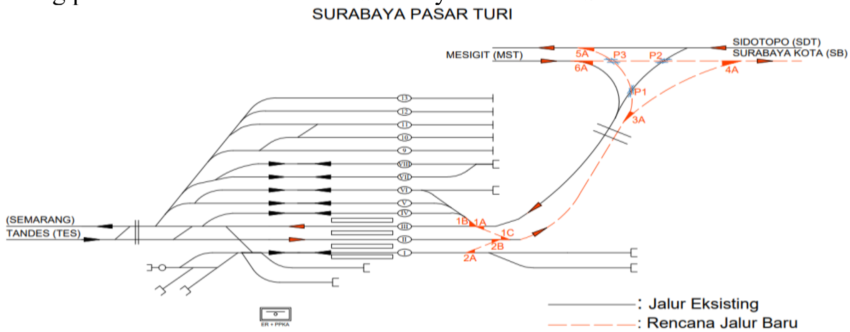

Fig. 6. Layout of Station Surabaya Pasar Turi's New Emplacement

Table. 1. Station Surabaya Pasar Turi's New Switch

Switch Number	Type of Switch	Angle of Switch	Type of Switch Blade	Sleeper Type
1A & 1B	Double-slip	1:10	Spring	Concrete
1C	Standard/Right	1:10	Spring	Concrete
2A	Standard/Left	1:10	Spring	Concrete
2B	Standard/Left	1:10	Spring	Concrete
3A	Standard/Right	1:10	Spring	Concrete
4A	Standard/Left	1:10	Spring	Concrete
5A	Standard/Right	1:10	Spring	Concrete
6A	Standard/Right	1:10	Spring	Concrete

Table. 2. Station Surabaya Pasar Turi's New Crossing

Diamond Crossing Number	Sleeper Type
P1	Concrete
P2	Concrete
P3	Concrete

3.4 Construction of New Railway Geometry Design

3.4.1 Horizontal Curve Geometry Planning

The planning of the horizontal curve of the new line is based on the existing line. Then identification of the horizontal curve on the existing line with Spiral-Curve-Spiral

(SCS) curve parameters is carried out. Before calculating the new curve, an angle correction is made on the existing line which will be used as a reference in making the curve on the new line. For horizontal curves that have a radius of a circular curve without a transition below 600 metres and a circular curve with a transition below 250 metres, inside forced rails are added to the rails in the curve which function to withstand the centrifugal force of the train which results in the outer side rails on the curve not wearing out/damaging quickly [10]. The construction of the inside forced rails are as follows.

Fig. 7. Inside Forced Rails

In horizontal curve planning, it is carried out based on the stages and formulas [11]. The results of the new curve planning on curve 1 are as follows.

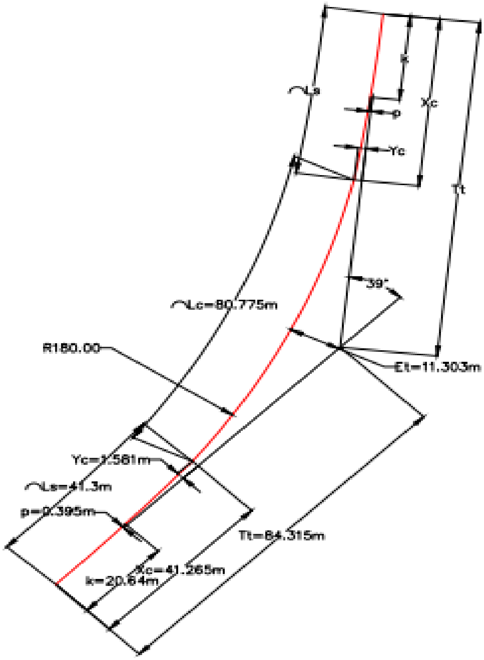

Fig. 8. Horizontal Curved Sketch

3.4.2 Widening Track

Planning for the widening of the new track adapts to the horizontal curve radius of the new track with a maximum widening of 20 mm [8].

3.4.3 Superelevation

The superelevation of the new track adjusts to the design radius and plan speed at the new horizontal curve with the largest railway superelevation of 107,10 mm. The results of this calculation are then rounded off by a multiple of 5 mm. Then for the superelevation of 107,10 mm a superelevation of 110 mm will be used [8].

3.4.4 Vertical Curve Geometry Planning

In the calculation of the vertical curve is influenced by the line plan speed. The scheme of the vertical curve at KM 0+000 to 0+435 is shown in the following figure.

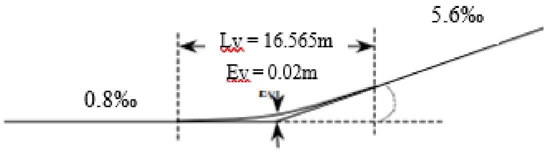

Fig. 9. Vertical Curved Sketch

The vertical alignment of the new line matches the existing line with a design speed of up to 100 km/h and a minimum vertical curve plan radius of 7000 metres [8].

3.5 New Track Upperstructure Construction

3.5.1 Rail Planning

The planning of the new line of the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace is planned using type R54 rail. The planned load is CC 206 load with a ready weight of 90 tonnes. The maximum speed (Vmax) is 80 km/h (PPCW wagon). The calculation of rail tension is as follows [11]. Rail characteristics R54 and CC 206:

a. Theoretical Rail Weight (W) = 54,43 kg/m
b. Moment of Inertia (Ix) = 2346 cm^4
c. Modulus of Elasticity (E) = $2{,}1 \times 10^6$ kg/cm^2
d. Cross-sectional Area (A) = 69,34 cm^2
e. R54 Class 1 Rail Allowable Voltage (σ) = 1325 kg/cm^2
f. Bottom Edge to Neutral Line Distance (Yb) = 76,2 mm
g. Railway modulus of elasticity (k) = 180 kg/cm^2
h. Rail expansion coefficient (α) = $1{,}2 \times 10^{-5}$
i. CC 206 weight = 90 tonnes
   CC 206 axle weight (Pg) = 90 tonnes/6 axles = 15 tonnes
   Wheel weight per axle (Ps) = 15 tonnes/2 wheels = 7,5 tonnes
j. CC 206 wheel diameter (d) = 0,914 m

The calculation flow is as follows:

1. Plan speed

$$Vplan = 1{,}25 \times Vmax \quad (1)$$

$$Vplan = 100 \text{ km/h}$$

2. Dynamic load with AREMA factor [12]

$$Pd = Ps\,\Phi = Ps\,(1 + \frac{0{,}0052\ Vplan}{d}) \quad (2)$$

$$Pd = 11{,}753 \text{ ton} = 11753 \text{ kg}$$

3. Reduction factor

$$\lambda = \sqrt[4]{\frac{K}{4\,E\,I}} = \sqrt[4]{\frac{180 \text{ kg/cm}^2}{4\,.\ 2{,}1\text{x}10^6 \text{ kg/cm}^2\,.\ 2346 \text{ cm}^4}} \quad (3)$$

$$\lambda = 0{,}00978$$

4._Maximum moment

$$Ma = \frac{Pd}{4\,\lambda} = \frac{11753 \text{ kg}}{4\,.\ 0{,}00978} \quad (4)$$

$$Ma = 255470{,}835 \text{ kgcm}$$

5. Analysis of rail stress against clearance stress

$$\sigma' = \frac{Mx\,.Yb}{I} = \frac{0{,}85\ .\ 255470{,}835 \text{ kg.cm}\ .\ 76{,}2 \text{ mm}}{2346 \text{ cm}^4} \quad (5)$$

$$\sigma' = 705{,}322 \text{ kg/cm}^2$$

$$\sigma' < \sigma_{clearance}$$

$$705{,}322 \text{ kg/cm}^4 < 1325 \text{ kg/cm}^4$$

6. Determination of minimum rail length

$$\ell = \frac{E \times A \times \alpha \times \Delta T}{r} \quad (6)$$

$$\ell = \frac{2{,}1\text{x}10^6 \text{ kg/cm}^2 \times 69{,}34 \text{ cm}^2 \times 1{,}2 \text{ x } 10^{-5} \times 30°\text{C}}{450 \text{ kg/m}}$$

$$\ell = 116{,}491 \text{ m}$$

$$L \geq 2 \times \ell \quad (7)$$

$$L \geq 2 \times 116{,}491 \text{ m}$$

$$L \geq 232{,}982 \text{ m}$$

$$L \approx 250 \text{ m}$$

(rounded up as the fabrication length of the R54 rail is 25 m)

The calculation results show that the R54 type rail with a permit stress of 1325 kg/cm^4 is able to withstand a stress of 705,322 kg/cm^4 due to the CC 206 load. Then the rail installation is planned with a rail length of 250 m at an installation temperature of 30°C [11].

3.5.2 Rail Joint Planning

Calculations in planning the joint plate are carried out as follows.

1. Bolt strength (No)

$No = 0{,}75 \times Ac \times \sigma$ (8)
$No = 0{,}75 \times 4{,}52cm^2 \times 11000\ kg/cm^2$
$No = 37303{,}2\ kg$

2. Bolt strength due to alternating load (T)
$T = 0{,}5 \times No$ (9)
$T = 0{,}5 \times 37303{,}2\ kg$
$T = 18651{,}6\ kg$

3. Lateral force at the center of the joining plate (H)
$H = Q \times \tan \propto$ (10)
$H = 7500\ kg \times \tan 19{,}98^\circ$
$H = 2726{,}8\ kg$

4. Inner bolt tensile force (T")
$T'' = T - H$ (11)
$T'' = 18651{,}6\ kg - 2726{,}8\ kg$
$T'' = 15924{,}8\ kg$

5. Analysis of bolt tensile force against bolt strength due to alternating load
$T'' \leq T$ (12)
$15924{,}8\ kg \leq 18651{,}6\ kg$

The results of the analysis show that the amount of tensile force that occurs due to the planned railway load can be resisted by the planned bolts.

6. Lateral moment at the connecting plate (M)
$M = Q \times a + m \times Q \times h$ (13)
$M = 7500\ kg \times 8\ cm + 0{,}03 \times 7500\ kg \times 6{,}96\ cm$
$M = 61566\ kgcm$

7. Stress occurring in the connecting plate(σ)
$$\sigma = \frac{M}{W} = \frac{M}{\frac{1}{6} \times b \times h^2} \quad (14)$$
$$\sigma = \frac{61566\ kgcm}{\frac{1}{6} \times 2{,}8\ cm \times (6{,}3\ cm)^2}$$
$\sigma = 2723{,}427\ kg/cm^2$

8. Gap width on long rail (G)
$$G = \frac{E \times A \times \alpha \times (50-t)^2}{2 \times r} + 2 \quad (15)$$
$$G = \frac{2{,}1 \text{ x } 106\ kg/cm^2 \times 69{,}34\ cm^2 \times 1{,}2 \text{ x } 10^{-5} \times (50-30)^2}{2 \times 450\ kg/m} + 2$$
$G = 9{,}766\ mm$

9. Analyse the stresses that occur with the permit stress of the joint plate

$$\sigma < \sigma' \tag{16}$$
$$2723{,}427 \text{ kg/cm}^2 < 7000 \text{ kg/cm}^2$$

The analysis results show that the stress that occurs on the joint plate of 2723,427 kg/cm^2 can still be withstood by the planned joint plate clearance stress of 7000 kg/cm^2. Calculation of the rail gap at 30˚C installation temperature shows that the gap that must be available is 9,766 mm, but the rail gap at 30˚C installation temperature must be 11 mm so that 11 mm rail gap planning is used for installation at 30˚C [10].

3.5.3 Fastener Planning

The new line is planned to use double elastic fasteners with Pandrol E-Clip type with details of 2 railpads, 4 insulators, and 4 clip fasteners for each sleeper. The calculation of the clamping force strength to be able to withstand the creep force that occurs on the rail is carried out as follows.

1. Creep force occurring on the rail (F)

$$F = E \times A \times \lambda \times \Delta t \tag{17}$$
$$F = 2{,}1 \times 10^6 \text{ kg/cm}^2 \times 69{,}34 \text{ cm}^2 \times 1{,}2 \times 10^{-5} \times 10°C$$
$$F = 17473{,}68 \text{ kg}$$

2. Total of the fastener

$$n = \frac{\text{rail length}}{\text{distance between sleepers}} \tag{18}$$
$$n = \frac{25\ m}{0{,}6\ m}$$
$$n = 41{,}67 \approx 42 \text{ pairs}$$

3. Creep force received by each pair of fasteners (Fp)

$$Fp = \frac{F}{n} \tag{19}$$
$$Fp = \frac{17473{,}68 \text{ kg}}{42 \text{ pairs}}$$
$$Fp = 416{,}04 \text{ kg/pair}$$

4. Analysis of the creep force received by each pair of fasteners with the clamping force of each rail fasteners

$$Fp < F' \tag{20}$$
$$416{,}04 \text{ kg/pair} < 1631{,}52 \text{ kg/pair}$$

The results of the fastener strength calculation show that the clamping force of the planned Pandrol E-Clip fastening is able to withstand the creep force of 416,04 kg/pair that occurs on the rail.

3.5.4 Sleeper Planning

The rail sleepers used are pre-stressed concrete sleepers for a rail width of 1067 mm with type TJM BJR 1067 mm. The calculation is based on the Railway Engineering book with the concept of "Beam on Elastic Foundation".

1. The moment that occurs at the pedestal area of the rail/edge of the concrete rail pad is calculated as follows.

$$M = \frac{Q}{4\lambda} \cdot \frac{1}{\sin\lambda L + \sinh\lambda L}\left[2\cosh^2\lambda a\,(\cos 2\lambda c + \cosh\lambda L) - 2\cos^2\lambda a\,(\cosh 2\lambda c + \cos\lambda L) - \sinh 2\lambda a\,(\sinh 2\lambda c + \sinh\lambda L) - \sin 2\lambda a\,(\sinh 2\lambda c + \sinh\lambda L)\right] \quad (21)$$

M = -319,071 kgm

2. The moment occurring at the center of the concrete rail sleeper is calculated as follows.

$$M = -\frac{Q}{2\lambda} \cdot \frac{1}{\sin\lambda L + \sinh\lambda L}\left[\sinh\lambda c\,\left(\sin\lambda c + \sin\lambda(L-c)\right) + \sin\lambda c\,(\sinh\lambda c + \sinh\lambda(L-c)) + \cosh\lambda c \times \cos\lambda(L-c) - \cos\lambda c \times \cosh\lambda(L-c)\right] \quad (22)$$

M = -546,354 kgm

From the calculation results, it is known that the moment that occurs at the rail pedestal of -319,071 kgm is still within the tolerance of the TJM BJR 1067mm bearing plan moment at the rail pedestal with a maximum moment of 1500 kgm and a minimum of -750 kgm.

The moment that occurs at the centre of the bearing of -546,354 kgm is also still within the tolerance of the plan moment of the TJM BJR 1067mm bearing at the center of the bearing with a maximum moment of 660 kgm and a minimum of -765 kgm.

3.5.5 Ballast Planning

Ballast planning includes the thickness of the ballast layer (d_1) for class 1 railways is 30 cm with the distance from the axle of the track / railroad axis to the top edge / shoulder of the ballast (b) is 150 cm [8]. The distance from the track to the shoulder of the ballast (b) needs to be taken into account [11].

The calculation is as follows.

b > ½ L + x (23)

b > ½ 200 cm + 50 cm

b > 150 cm

It is found that the distance from the track axle to the shoulder (b) must be greater than 150 cm, so the planned distance from the track axle to the shoulder is 160 cm.

3.5.6 Subballast Planning

The minimum thickness of the subballast layer is calculated as follows.

1. Reduction factor (λ)

$$\lambda = \sqrt[4]{\frac{k}{4\,E\,I}} = \sqrt[4]{\frac{25\text{ cm} \times 8\text{ kg/cm}^3}{4\,.\;143108{,}351\text{ kg/cm}^2\;.\;15549{,}375\text{ cm}^4}} \quad (24)$$

$\lambda = 0{,}0122$

2. Pressure on ballast and subballast surfaces σ_1 is calculated using the concept of "Beam on Elastic Foundation" with the equation.

$$\sigma_1 = \frac{60\%Pd\,\lambda}{2b}\frac{1}{(\text{Sinh}\,\lambda L+\text{Sin}\,\lambda L)}\,[\,2\,\text{Cosh}^2\,\lambda a\,(\text{Cos}\,2\lambda c+\text{Cosh}\,\lambda L)-2\,\text{Cos}^2\,\lambda a\,(\text{Cosh}\,2\lambda c+\text{Cos}\,\lambda L)+\text{Sinh}\,2\lambda a\,(\text{Sin}\,2\lambda c-\text{Sinh}\,\lambda L)-\text{Sin}\,2\lambda a\,(\text{Sinh}\,2\lambda c-\text{Sin}\,\lambda L) \quad (25)$$

$$\sigma_1 = 7{,}363\ \text{kg/cm}^2$$

3. Minimum thickness of ballast & subballast layer (d)

$$d = \sqrt[1{,}35]{\frac{58\,\sigma_1}{\sigma_t}-10} = \sqrt[1{,}35]{\frac{58\ .\ 7{,}363\ \text{kg/cm}^2}{1{,}2\ \text{kg/cm}^2}-10} \quad (26)$$

$$d = 75{,}979\ \text{cm}$$

4. Smallest size of subballast

$$d_2 = 75{,}979\ \text{cm} - 30\ \text{cm} > 15 \quad (27)$$

$$d_2 = 45{,}979\ \text{cm} > 15$$

5. Distance from the railway axis to the top edge of the subballast layer

The value of the distance from the railway axis to the top edge of the subballast layer (k1) is 265 cm [8]. Calculations were carried out on the plan to determine the distance from the railway axis to the top edge of the subballast layer (k1) planned [11]. The calculation is done as follows.

a. On the straight

$$k_1 > b + 2d_1 + m \quad (28)$$

$$k_1 > 150\ \text{cm} + 2\ .30\ \text{cm} + 40\ \text{cm}$$

$$k_1 > 250\ \text{cm}$$

b. On curve

$$k_{1d} = k_1$$

$$k_{1d} = b + 2d_1 + m + 2e \quad (29)$$

Dengan:

$$e = (b + 0{,}5) \times \frac{h}{L} + t \quad (26)$$

$$e = (150\ \text{cm} + 0{,}5) \times \frac{11\ \text{cm}}{114{,}4\ \text{cm}} + 21{,}7\ \text{cm}$$

$$e = 16{,}64\ \text{cm}$$

Then the value of k_{1d} is,

$$k_{1d} = 150\ \text{cm} + 2\ .30\ \text{cm} + 60\ \text{cm} + 2\ .16{,}64\ \text{cm}$$

$$k_{1d} = 303{,}28\ \text{cm}$$

Based on the results of the subballast calculation, the subballast thickness (d_2) is 45,979 cm with the distance from the railway axis to the top edge of the subballast layer on the straight (k_1) must be greater than 250 cm and on the curve (k_{1d}) 303,28 cm. These values are used by the author as a reference in planning the subballast with a subballast thickness of (d_2) 50 cm with a distance from the railway axis to the top edge of the subballast layer at the straight (k_1) 265 cm and at the curve (k_{1d}) 305 cm.

3.5.7 Switch Planning

In the planning of the Terminal Petikemas Surabaya-Surabaya Pasar Turi double track, several types of switches are used, namely, standard right switches, standard left switches, and double-slip switches to support the double track operation pattern. Switch needs to be calculated in order to determine the feasibility of using the planned switches [11]. In this double track planning, the planned switches are 1:10 switches with a permit speed on the straight line of 120 km/h and on the turning line of 35 km/h. The calculation of the switch that will be used on the track line is as follows.

1. Calculation of the frog length of the 1:10 switch

$$P = \frac{(B+C)}{2\ \mathrm{tg}\left(\frac{\alpha}{2}\right)} - d \quad (30)$$

With the angle of intersection of the 1:10 switch equal to 5,71°, then the frog length is:

P = (140 mm + 72,2 mm) 2 tg (5,71° 2) − 10 mm

P = 2,12 m

From the calculation results, the planned 1:10 switch has a frog length of 2,12 metres.

2. Calculation of spring type switch blade (switch tongue)

The tongue of the switch must be smaller than the track to reduce the risk of derailment of the rolling stock. The length of the railway tongue is calculated as follows.

$$t > B \cot g\ \beta \quad (31)$$

$$t > 0{,}0722\ \mathrm{m} \,.\, \mathrm{cotg}\ (0{,}955°)$$

$$t > 4{,}33\ \mathrm{m}$$

The calculations show that the length of the tongue of the switch must be more than 4,33 metres, so a length of 4,5 metres is planned.

3. Calculation of the switch curve radius

The length of the outer curve radius of the switch (Ru) must be greater than the length of the inner curve radius (R). The following describes the calculation of the outer curve radius of the 1:10 switch.

$$Ru = \frac{W - t\sin\beta - P\sin\alpha}{\cos\beta - \cos\alpha} \quad (32)$$

$$Ru = \frac{1{,}067\ \mathrm{m} - 4{,}5\ \mathrm{m} \,.\, \sin(0{,}955°) - 2{,}12\ \mathrm{m} \,.\, \sin(5{,}71°)}{\cos(0{,}955°) - \cos(5{,}71°)}$$

$$Ru = 162{,}003\ \mathrm{m}$$

The following describes the calculation of the inner curve radius of the 1:10 switch.

$$R = \frac{V^2}{7{,}8} = \frac{(35\ \mathrm{km/h})^2}{7{,}8} \quad (30)$$

$$R = 157{,}051\ \mathrm{m}$$

It is known that the value of the outer curve radius of the switch (Ru) which is 162,003 m is greater than the value inner curve radius (R) which is 157,051 m so that it meets the requirements. From the calculation of the switch planning, it can be concluded that the 1:10 switch can be used in the planning of the Terminal Petikemas Surabaya-Surabaya Pasar Turi double track.

3.6 New Track Component Requirements

3.6.1 Rail

The calculation of rail requirements is as follows.

Surabaya Pasar Turi-Mesigit section

$$\text{Total of the rail rod} = \frac{\text{Length of the new track}}{\text{Length of rail rod}} \tag{33}$$

= 1040 meter / 25 meter

= 41,6 rail rods

≈ 42 rail rods

= 42 rail rods x 2

= 84 rail rods

On the Surabaya Pasar Turi-Mesigit section, 84 new R54 rail rods are required.

From the calculation results, the requirements of rail rod along the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace as a whole is 510 R54 rail rods.

3.6.2 Sleeper

Calculation of sleeper requirements as follows.

Surabaya Pasar Turi-Mesigit section

$$\text{Total of the sleeper} = \frac{\text{Length of the new track}}{\text{Distance between sleepers}} \tag{34}$$

= 1040 meter / 0,6 meter

= 1733,3 sleepers

≈ 1734 sleepers

On the Surabaya Pasar Turi-Mesigit section, 1734 new pads are required.

From the calculation results, the requirements of sleeper along the Terminal Petikemas Surabaya -Surabaya Pasar Turi trace as a whole are 10504 sleepers.

3.6.3 Fastener

The calculation of fastener requirements as follows.

Surabaya Pasar Turi-Mesigit section

Total of the fastener = Total of the sleeper x 4 (35)

= 1734 sleepers x 4

= 6936-unit fasteners

In the Surabaya Pasar Turi-Mesigit section, 6936 unit fasteners are required.

From the calculation results, the requirements of fastener along the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace are 42016 unit fasteners.

3.6.4 Volume of Balas and Subbalas

The planning of ballast and subballast volumes was carried out with the help of Auto-CAD Civil 3D.

Balas			
Station	Area	Volume	Cumulative Volume
0+050.00	0.72	0.00	0.00
0+075.00	0.72	18.12	18.12
0+100.00	0.72	18.01	36.13
0+150.00	0.72	35.80	71.93
0+200.00	0.72	35.80	107.73
0+250.00	0.72	35.80	143.53

Subbalas			
Station	Area	Volume	Cumulative Volume
0+050.00	3.17	0.00	0.00
0+075.00	3.17	79.34	79.34
0+100.00	3.15	79.05	158.39
0+150.00	3.15	157.50	315.89
0+200.00	3.15	157.50	473.39
0+250.00	3.15	157.50	630.89

Fig. 10. Result of Balas and Subbalas Calculation in Civil 3D for Kalimas-Prapat Kurung Section

From the results of the calculation of ballast and subballast volumes in AutoCAD Civil 3D, the new line is planned to require a total ballast volume of 4132,36 m^3 and sub-ballast volume of 17366,8 m^3.

3.7 Excavation and Heap Volume

Calculation of excavation and heap is determined with the help of AutoCAD Civil 3D.

Cut and Fill						
Station	Fill Area	Cut Area	Fill Volume	Cut Volume	Cumulative Fill Vol	Cumulative Cut Vol
0+050.00	0.00	2.90	0.00	0.00	0.00	0.00
0+075.00	0.01	2.46	0.18	66.37	0.18	66.37
0+100.00	0.07	2.02	1.11	55.49	1.29	121.86
0+125.00	0.00	2.05	0.95	50.22	2.24	172.08
0+150.00	0.00	1.70	0.02	46.72	2.26	218.81
0+200.00	0.00	1.89	0.00	89.77	2.26	308.58
0+250.00	0.00	4.08	0.00	148.83	2.26	457.42
0+275.00	0.00	5.57	0.00	119.57	2.26	576.99
0+300.00	0.00	6.83	0.00	154.02	2.26	731.01
0+325.00	0.00	5.15	0.00	148.83	2.26	879.84
0+350.00	0.00	3.24	0.00	104.04	2.26	983.88
0+375.00	0.15	0.00	1.90	40.16	4.16	1024.04
0+400.00	1.39	0.17	19.48	2.14	23.64	1026.18
0+425.00	2.27	0.01	46.25	2.23	69.89	1028.41
0+450.00	2.38	0.00	58.65	0.11	128.53	1028.52
0+500.00	2.63	0.00	125.46	0.02	253.99	1028.54

Fig. 11. Result of Excavation and Heap Calculation in Civil 3D for The Surabaya Pasar Turi-Mesigit Section

From the calculation results in AutoCAD Civil 3D, it is known that the total excavation volume of 15058,79 m^3 and the heap volume of 30179,05 m^3.

4. CONCLUSIONS

Based on the results of the planning and analysis of the new line on the Terminal Petikemas Surabaya-Surabaya Pasar Turi trace, it can be concluded that:

1. The new railway track follows the existing trace with the layout of the new line on the Surabaya Pasar Turi-Mesigit section placed on the right side of the existing track, on the Mesigit-Kalimas section placed on the left side of the existing track, on the Kalimas-Prapat Kurung section placed on the right side of the existing track and then it is also planned to reactivate the line that has turned into a settlement on the left side of the existing track, in the Prapat Kurung emplacement, the addition of a new line is planned so that the Prapat Kurung emplacement has 3 lines, in the Prapat Kurung-Terminal Petikemas Surabaya section, the new line is placed on the right side of the existing track, in the Terminal Petikemas emplacement, the addition of 2 new lines is planned so that the Terminal Petikemas emplacement has 5 lines.
2. The changes to the emplacements in the double track planning include rearrangement of the emplacements as well as construction of new standard switch, coupled switch and crossover at an angle of 1:10. On the Surabaya Pasar Turi-Mesigit section, a new crossing is planned. In the Prapat Kurung and Terminal Petikemas Surabaya emplacements, new tracks are planned. Changes to the emplacements are planned with a double track operating pattern.
3. Railway geometry planning for the horizontal alignment of the new railway planned 15 curves with different radius and plan speeds so that the widening and superelevation of the rails are also different with a maximum widening of 20 mm and a maximum superelevation of 110 mm, for a radius of less than 250 m added inside forced rails to increase the level of safety. Railway geometry planning for the vertical alignment of the new line is adjusted to the existing vertical alignment so that the height of the new line is not much different from the existing trace with a planned speed of up to 100 km/h and a minimum planned radius of 7000 m.
4. After analyzing the plan load and adjusting to PM No. 60 of 2012 and PD PJKA No. 10 of 1986, the construction planning of the upper-structure of the new track uses:
   a. Rail type R54 with a planned rail installation length of 250 m at an installation temperature of 30°C. For the installation of the R54 rail joint plate at a temperature of 30°C is done by providing a gap between rails of 11 mm.
   b. Pandrol manufacturer's fastener E-Clip type with a clamping force of >1631,52 kg each pair.
   c. Prestressed concrete sleeper TJM BJR type 1067 mm with K-500 kg/cm^2.
   d. The ballast layer is 30 cm thick with a distance from the axis of track to the ballast shoulder of 160 cm with a maximum slope of 1:2.
   e. The subballast layer is 50 cm thick with a distance from the axis of track to the top edge of the subballast of 265 cm on straights and 305 cm on curves with a maximum slope of 1:1,5.

f. Right and left standard switches, coupled switches, double-slip switch and crossing. Each switch has an angle of 1:10 with a straight line speed of 120 km/h and a turning line speed of 35 km/h.

5. From the results of planning a new line with a new line length of 7,23 km, the following number of railway component requirements were obtained.
   a. Rails : 510 R54 rail rods (R54 rail rod unit 25m)
   b. Sleepers : 10504 TJM concrete sleeper 1067mm
   c. Fasteners : 42016 pieces of Pandrol E-Clip fastener
   d. Ballast Volume : 4132,36 m^3
   e. Subballast Volume : 18154,28 m^3
6. Double-track planning design drawings include site plan, new track plan and profile, new track cross section, and new emplacement layout.
7. Based on the topography of the area and vertical alignment planning on the new line, the planned excavation volume of 15058,79 m^3 and heap volume of 30179,05 m^3 were obtained.

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