Geometry Design Study of the Railway Between PT Inka Workshop – Tanjung Wangi Port Banyuwangi

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ARTICLE INFO

Article Information

Article Received: 2021-03-05

Article Revised: 2022-10-11

Article Accepted:

Keywords

Banyuwangi, Dual Gauge, Railway geometry, PT INKA Workshop.

ABSTRACT

PT Industri Kereta Api (Persero), abbreviated as PT INKA, is a State-Owned Enterprise (BUMN) engaged in the railway infrastructure industry. In 2014, PT INKA officially signed a procurement contract for 150 passenger trains ordered by the State of Bangladesh which then in 2017, Bangladesh added an order for 200 Passenger Trains. This shows that the number of railway carriage export requests is increasing. To fulfil the demand, PT INKA built a new factory located in Banyuwangi Regency. PT INKA uses sea transportation mode for the export activities. The closest port to the railway workshop in Banyuwangi Regency is Tanjung Wangi Port. To facilitate the export process of railway facilities, PT INKA plans to build a railway connecting PT INKA's workshop - Tanjung Wangi Port Banyuwangi. In this study, a railway line with high traffic priority is planned by planning a minimum of three alternative trajectories and then selecting the one that better meets the requirements. In planning the selected trajectory, several trajectory selection criteria will be used. The planned rail road connects PT INKA Workshop with Tanjung Wangi Port in Banyuwangi with a distance of approximately 2 km and intersects with the ring road. In writing this study, several analysis results were obtained, namely: produced railway geometry planning drawings, rail construction, and the required budget estimate plan (RAB) of IDR 122.218.142.000.

INTRODUCTION

PT Industri Kereta Api (Persero) which is abbreviated as PT INKA is a State-Owned Enterprise (BUMN) engaged in the railway infrastructure industry. Before the establishment of PT INKA, Balai Yasa Kereta Api Jawatan Company (PJKA) became the predecessor of PT INKA. PT INKA's head office and railway factory are located in Yos Sudarso Street, Madiun, East Java. So far in Indonesia, all domestic railway facilities are produced by PT INKA, both trains from the Ministry of Transportation, PT Kereta Api Indonesia (Persero), local governments, and also private parties.

Over time, PT INKA not only produces domestic demand for train carriages and locomotives, but PT INKA receives orders from abroad as well. Such as in Bangladesh, the Philippines, Malaysia, Thailand, Singapore and Australia. In 2014, PT INKA officially signed a procurement contract for 150 passenger trains (100 MG (Meter Gauge) and 50 BG (Broad Gauge)) for Bangladesh Railway, in Dhaka, Bangladesh. Later in 2017, Bangladesh added an order for 250 more Passenger Trains to fulfil the transport needs of its people. This shows that the demand for railway carriage exports is increasing.

Currently, the entire production of railway facilities is produced at the PT INKA factory located in Madiun. As reported in the news column on www.inka.co.id, the production capacity is 1.5 units per day. When compared to the demand to be met, it would be less effective to stick with a production capacity of 1.5 units per day. The export of railway rolling stock produced by PT INKA is by sea. Departures are made from Tanjung Perak Port, Surabaya. The distance between PT INKA's factory and Tanjung Perak Port is 167 km, which requires a travel time of approximately 3 hours. Furthermore, the access from PT INKA's factory in Madiun to Tanjung Perak Port in Surabaya is by large trucks. The disadvantage of lorry transport is that it uses up road capacity and can disrupt the traffic flow.

To optimise production capacity, in early 2019, PT INKA built a new workshop located in Tanjung Wangi Village, Kalipuro District, Banyuwangi Regency, East Java. The workshop is built on a land area of 83.49 ha with the contractor PT Adhi Karya (Persero). The workshop will be used to develop PT INKA's production capacity as the only manufacturer of railway facilities in Southeast Asia. The factory will make carriages and locomotives orientated for overseas export. The factory, which is planned to be completed and ready to operate by the end of 2020, can produce 3-4 units per day. Thus, it can accelerate the train production. Also the new factory is less than 5 km away from Tanjung Wangi Port, making export train shipments faster.

To facilitate the export process of railway facilities, PT

INKA plans to build a railway that connects the PT INKA workshop - Tanjung Wangi Port Banyuwangi. Therefore, in this design study, a railway line that has high priority traffic will be planned by planning at least two alternative trajectories and then selecting one that meets the requirements.

The railway will be planned using not only one track for one rail width, but will be planned using one track for two rail widths (1067 mm and 1435 mm). The planning of one track for two rail widths is applied because not only one type of rail width will be exported by PT INKA, there are various requests for rail width types from consumers that adjust to the width of the rail in the consumer area.

METODOLOGY

Figure 1. The flowchart for this design study.

RESULT AND DISCUSSION

A. Railway Track Analysis

I. Railway Track Alternative

In this study, there are 3 alternative railway track that will be selected as the most efficient one. The following are the specifications of each alternative railway track:

a) Railway Track 1 Alternative
   Specification:
   1. Length of the planned railway track 2.78 km
   2. Crossing one river
   3. Crossing the existing track 820 m
   4. Six level crossings

b) Railway Track 2 Alternative
   Specification:
   1. Length of the planned railway track 3.26 km
   2. Crossing one river
   3. Crossing the existing track 1560 m
   4. Three level crossings

c) Railway Track 3 Alternative
   Specification:
   1. Length of the planned railway track 4.7 km
   2. Crossing one river
   3. Crossing the existing track 3000 m
   4. Eight level crossings

II. The Determination of Railway Track Alternative

In determining the selected railway track, 5 criteria are multiplying the value in the railway track 1 by the railway track length criterion. Therefore, 3 x 0.25 = 0.75. The values in the other columns and rows are calculated in the same way. From the results of the above calculations, the alternative railway track 2 is obtained with the greatest value compared to other alternatives.

B. The Railway Geometry

I. The Horizontal Alignment

The Horizontal alignment planning in this study used the Spiral-Circle-Spiral (S-C-S). To calculate the horizontal alignment, azimuth angles and bend angles are required at each Point Intersection (PI) in the railway track plan. The following is an example of calculations on PI 1 and PI 2. Can be seen in Figure 2.

a) Angle ϕ PI 1 $= \tan^{-1} \times$ coordinate ΔX (PI 1) / coordinate ΔY (PI 1)

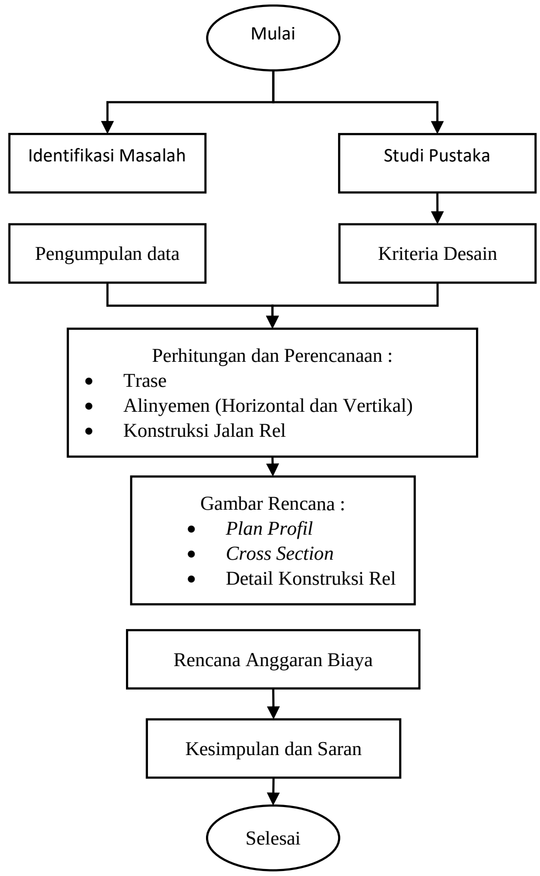

Figure 1. The flow Chart

used and each criterion is given its respective weight as presented in Table 1.

After determining the weight on each criterion, proceed with giving the value of each criterion to each alternative railway track. Can be seen in Table 2.

Description :

A = The length of railway track
B = The bridge construction
C = The Acquisition of residential land and paddy fields or gardens
D = The land acquisition of the existing railway
E = Level crossing

Followed by the calculation of the selected alternative railway track with an example of the calculation that will be presented in Table 3.

The value in (column trase 1-row A) is obtained by

$= \tan^{-1} \times 13.7980 / 182.0760$
$= 4.3337°$ (Quadrant 1)

b) Angle ϕ PI 2 $= \tan^{-1} \times$ coordinate ΔX (PI 2) / coordinate ΔY (PI 2)
$= \tan^{-1} \times 129.778 / 63.1140$

$= 64.0653°$ (Quadrant 1)

c) Bend angle (Δ) PI 1 = Angle ϕ PI 2 - Angle ϕ PI 1
$= 64.0653° - 4.3337°$
$= 59.7316°$

After the bend angle is found (Δ), followed by horizontal alignment calculation. With the required parameters:

a) Δ PI 1 = 59.7316°
b) R plan = 150 m
c) V plan = 30 km/hour

Table 1. The Weighting of Each Railway Track Criteria

No	Criteria	Weight
1	Length of railway track	0,25
2	Bridge constuction	0,30
3	Acquisition of residential land and paddy fields or gardens	0,175
4	Land acquisition of the existing railway	0,175
5	Level crossing	0,1
	∑Weight	1,00

Table 2. Railway Track Alternative Values Based on the Criteria

	RAILWAY TRACK 1	RAILWAY TRACK 2	RAILWAY TRACK 3
A	3	2	1
B	3	3	3
C	1	3	2
D	3	2	1
E	2	3	1

Table 3. Calculation of the Selected Railway Track Alternative

	RAILWAY TRACK 1	RAILWAY TRACK 2	RAILWAY TRACK 3
A	0,75	0,5	0,25
B	0,9	0,9	0,9
C	0,175	0,535	0,35
D	0,535	0,35	0,175
E	0,2	0,3	0,1
∑	2,55	2,575	1,775

II. Vertical Alignment

Vertical alignment is the projection of the railway axis in the vertical plane. Planning the minimum radius of the vertical curve is 6000 m and the straightness between the two curves is 20 m. The following is an example of PPV 1 calculation at STA 0+360.00.

a) Vplan = 60 km/hour
b) Curvature type = convex
c) Rplan = 6000 m
d) Elevation PVI = +21.335 m (Elevation plan)
e) G1 = 0.00 %
f) G2 = -1.8 %

C. Railway Construction

I. Rail Profile Dimension

Rail dimensioning is based on the allowable stress of the rail. This stress must not exceed the allowable stress value that has been determined in accordance with the road class. If a rail dimension with a given axle load results in σ < σ allowable, then the plan rail dimension is considered usable. In this study it is planned to use rail type R54 with the following rail planning characteristics data:

a) Velocity (V) = 1.25 x Vmax
= 1.25 x 60 km/hour
= 75 km/hour
b) The rail type = R54
c) The rail weight per metre (W) = 54.43 kg/m
d) The moment of inertia of the x-axis (Ix) = 2346 cm^4
e) The modulus of elasticity (E) = $2.1 x 10^6$ kg/cm^2
f) The cross-sectional area (A)= 69.34 cm^2
g) The Bottom edge to neutral line distance (Yb) = 76.2 cm
h) The axle load = 22.5 tons
i) The Rail allowable stress (σ allowable) = 1843 kg/cm^2

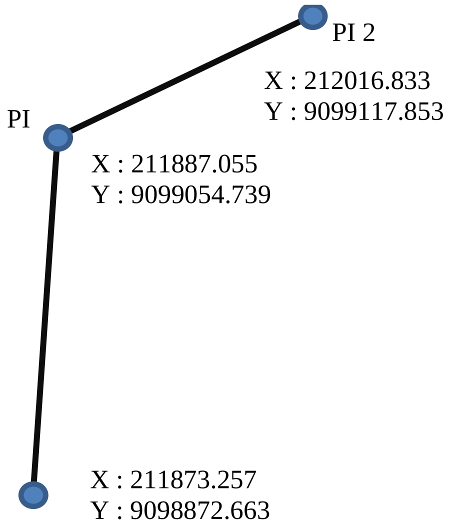

Figure 2. Example of a Bend at Point A, PI 1, and PI 2

j) The modulus of elasticity of the railway (K) = 180 kg/cm^2

The calculation of the rail dimension plan is as follows:

a. Wheel dynamic load (Pd) = 15931.44 kg
b. Dumping factor (λ) = 0.011 cm^1
c. Maximum momen (Ma) = 302668.0182 kg.cm
d. Check against Rail Permit Voltage (σ_{permit}) = 1514.445526 kg/cm^2 < 1843 kg/cm^4 (OK)

From the results of the above calculations, it can be concluded that the rail profile type R54 can be used in this study because the stresses that occur are smaller than the permissible stresses.

II. The Rail Sleeper

In the planning of rail sleepers using a dual gauge system, dual gauge is a combination of two track widths that will allow two types of train widths to pass on this line. The track widths used in this study are 1067 and 1435 mm.

In planning the sleeper, it is necessary to calculate the strength of the sleeper structure to be used. This calculation uses the basis of PD 10 PJKA 1986. The data that needs to be determined as follows:

a. Train width : 1067 dan 1435 mm
b. Sleeper width : 2440 mm
c. Concrete quality : 500 kg/cm^2 : 41.5 mpa
d. Compressive allowable stress : 200 kg/cm^2
e. Tensile allowable pressure : 35 kg/cm^2
f. k : 180 kg/cm^2
g. PC Wire : 8 Ø 9mm
h. Breaking stress σ : 16000 kg/cm^2
i. P initial (Transfer 70 %) : 8 x 2270.24 kg : 18161.92 kg
j. P initial (Efektif 55 %) : 8 x 1783.76 kg : 14270.08 kg
k. e (at the bottom of the rail) : 0.5 cm
j. e (in the centre of the sleeper) : 0.26 cm

The sleepers that will be used in this study have two different widths of train, namely 1067 and 1435 mm. then the calculation is needed on each width of the train.

Table 4. Horizontal Alignment Calculation

	Calculation	Result
A	Rail elevation (h)	49 mm
B	Switching Curve/Spiral (Lh)	14,58 m
C	Transitional/spiral curve angle (Ɵs)	2,7846^{o}
D	Curved circle length (Lc)	141,797 m
E	Distance from the circular arc is displaced with respect to the tangent angle (P)	0,0591 m
F	Distance from point Ts to point P (k)	7,2894 m
G	Distance from point TS to point PI (Ts)	93,4581 m
H	Total external distance from PI to centre Lc (E)	23,0398 m
I	Distance from TS point to the centre projection point Ys (Xs)	14,5766 m
J	Distance from point SC to projection line TS (Ys)	0,2362 m

Table 5. Horizontal Alignment Calculation

	Calculation	Result
A	Xm	32,4 m
B	Ym	0,087 m
C	L	64,989 m
D	Elv PLV	21,335 m
E	Elv PTV	20,984 m

i. Train width of 1435 mm

a) Sleeper dimension

a. At the bottom of the rail:

A1 = 55000 mm^2 = 550 cm^2
Ix = 29903.5 cm^4
Y1(a) = 10.5 cm
Y1(b) = 11.5 cm
W1(a) = 2847.952 cm^3
W1(b) = 2600.304 cm^3

b. At the centre of the sleeper:

A1 = 42692.4 mm^2 = 426.924 cm^2
Ix = 17375.77 cm^4
Y1(a) = 9.79 cm
Y1(b) = 10.31 cm
W1(a) = 1774.849 cm^3
W1(b) = 1685.332 cm^3

Description:

Y1 (a) = Neutral line position from the top section
Y1 (b) = Neutral line position from the bottom section
W1 (a) = Top-section resistance moment
W1 (b) = Bottom-section resistance moment

b) The calculation of modulus of elasticity based on *fcu* value.

E = 6400 x $\sqrt{fcu}$ = 156767.3 kg/cm^2

c) The calculation of λ concrete sleepers at the bottom of the rail and the centre of the sleepers

a. Bottom of the rail: λx = 0.009898 cm^{1}
b. Bottom of the rail: λt = 0.011337 cm^{1}

d) Calculation of Moments at Points C and D, exactly below the foot of the rail (C and D) and the centre of the sleeper (O):

Given:

a. V plan = 75 km/hour
b. Axle load = 22.5 tons = 22500 kg
c. Ps = 11.5 tons = 11250 kg
d. Pd = 15931.44 kg
Q = 60 % x Pd = 9558.864 kg
1. $M_{C/D}$ (1435 mm) = 3121.088 kg.cm.
2. M_{O} (1435 mm) = -8441.78 kg.cm

e) Stress analysis of the initial prestressing stage.

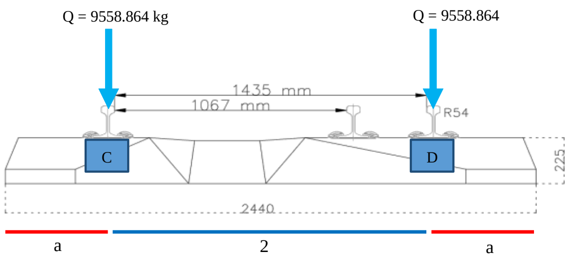

Figure 2: Loads Occurring on a 1435 mm Track Width.

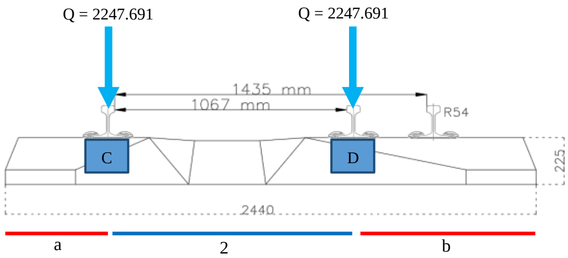

Figure 3: Loads Occurring on a 1067 mm Track Width.

(a). At the bottom section of the rail sleeper.

1. The top-section σ = 29.833 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).
2. The bottom section σ = 36.210 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

(b). The centre section of the rail sleeper.

1. At the top section: σ = 45.201 kg/cm^2 <200 kg/cm^2 (K-500 concrete allowable compressive stress)
2. At the bottom section: σ = 39.881 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

f) Stress analysis of the effective prestress stage

a. At the bottom section of the rail sleeper.

1. At the top section: σ = 24.53618 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).
2. At the bottom section: σ = 27.355 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).

b. At the centre section of the rail sleeper.

1. At the top section: σ = 40.272 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).
2. At the bottom section: σ = 26.579 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

ii. Train width of 1067 mm

The sleeper design is the same as point a-c. for the calculation of the moment on the 1067 track width is different. Here are the calculations from point a-c for a train width of 1067 mm.

a) Calculation of Moments at Points C and D, exactly at the bottom of the rail foot (C and D) and the centre of the sleeper (O):

Given:

a. V plan = 75 km/hour
b. Axle load = 18 ton = 18000 kg
c. Ps = 9 ton = 9000 k

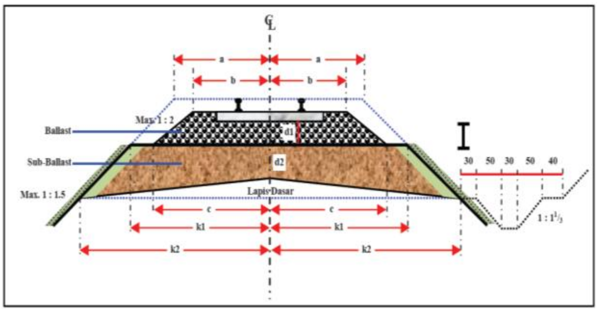

Figure 4. Railway Cross Section on a Straight Section.

d. Pd = 3746.152 kg
e. Q = 60 % x Pd = 2247.691 kg
1. $M_{C/D}$ (1067 mm = 1585.148 kg.cm.
2. M_O (1067 mm) = -1985.02 kg.cm.

b) Stress analysis of initial prestressing stage.

(a). At the bottom section of the rail sleeper.
1. At the top section: σ = 29.833 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)
2. At the bottom section: σ = 36.210 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

(b). At the centre section of the rail sleeper.
1. At the top section: σ = 45.201 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)
2. At the bottom section: σ = 39.881 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

c) Stress analysis of the effective prestress stage

(a). At the bottom section of the rail sleeper.
1. At the top section: σ = 23.999 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).
2. At the bottom section: σ = 27.894 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress)

(c). At the centre section of the rail sleeper
1. At the top section: σ = 36.634 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).
2. At the bottom section: σ = 30.217 kg/cm^2 < 200 kg/cm^2 (K-500 concrete allowable compressive stress).

From the results of the above calculations, it is obtained that the sleeper strength can accommodate the load that occurs on the sleeper. The compressive allowable stress is below 200 kg/cm2 with a concrete strength of K-500.

III. Rail Fastening

E-Clip Rail Fastening will be used in planning for rail fastening in this study, which is manufactured by PT Pindad (Persero) Beton.

IV. Ballast and Sub-ballast

In planning the dimensions of the ballast and sub-ballast, the author uses the references found in[1]. The dimensions quantity can be seen in Figure 3 and Table 6. The author uses the railway class V in the planning.

Table 6. The table of the Railway Transverse Dimension..

Road Class	V Max (km/hour)	dl (cm)	b (cm)	c (cm)	k1 (cm)	d2 (cm)	e (cm)	k2 (cm)
I	120	30	150	235	265	15-50	25	375
II	110	30	150	235	265	15-50	25	375
III	100	30	140	235	240	15-35	22	325
IV	90	25	140	215	240	15-35	20	300
V	80	25	135	210	240	15-35	20	300

D. The Budget Estimate Plan.

In planning the budget estimation for this study, the author uses the following guidelines [2]. The stages carried out are as follows:

I. The Budge Estimate Plan Recapitulation

In planning the budget estimate plan, price conversion from 2014 to 2020 using the US Dollar reference is required. In addition to converting from 2014 to 2020, it also needs to be multiplied by the costliness rate in each region that exists in [2]. The calculation example is as follows:

a) 1 USD in 2014= IDR 12.378
b) 1 USD in 2020= IDR 14.719
c) The conversion index = USD 2014/USD 2020
= IDR 14.719/ IDR 12.378
= 1.1891291

g) The costliness index of Banyuwangi Regency = 0.7320

In its application to the project board price as follows:

a. The conversion index = 1.1891291
b. The costliness index of Banyuwangi Regency = 0.7320
c. The unit price of the project board (2014) = IDR 1.400.000
d. The project board volume = 1

Thus:

The unit price in 2020
= The unit price in 2014 x The Conersion Index
= IDR 1.400.000 x 1.1891291
= IDR 1.664.780,74

The Amount
= The unit price in 2020 x Volume
= Rp 1.664.780,74 x 1
= Rp 1.664.780,74

The Amount x The costliness index
= Rp 1.664.780,74 x 0.7320
= Rp 1.218.620

CONCLUSIONS AND SUGGESTIONS

A. Conclusions

From the results of the planning carried out by the author, the following conclusions can be concluded:

1) The selected railway track and railway geometry.
a. The alternative railway track 2 was selected in this study with a total length of 4,555 km.
b. The horizontal alignment planning with a plan speed of 60 km/h, a minimum radius of 80 m, and designed using Spiral-Circle-Spiral (SCS) bends; a total of 13 horizontal alignments were

c. obtained.
d. The vertical alignment planning with a maximum slope used of 25‰ and a vertical alignment radius of 6000 m; a total of 13 vertical alignments were obtained..

2) The rail construction used uses type R.54 rails with dual gauge custom concrete sleepers that have a width of 1067 mm and 1435 mm, which are installed with a distance of 60 cm and connected with thermite welding. For ballast dimensions, the thickness (d1) is 250 mm and the sub-ballast thickness (d2) is 350 mm.
3) The Budget Estimate Plan (RAB) required for the construction of the railway line PT INKA Workshop - Tanjung Wangi Port is Rp 122,218,142,000.

B. Suggestions

Suggestions in planning the railway geometry between PT INKA Workshop - Tanjung Wangi Port Banyuwangi as follows:

1. The design of horizontal and vertical alignments is a suggestion from the authors and needs to be reviewed and adjusted to the applicable limits and parameters.
2. In determining the railway track, consideration should be given to the terrain conditions in the field.
3. It is recommended to use a Dual Gauge rail system. Because it can save the land used and cheaper construction costs.

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