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Traffic Capacity Analysis of Existing Conditions With The Effect of Additional Coal Transportation Targets on The Tanjung Enim - Tarahan Railway Line

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Abstract: The production volume target from 24.8 million tons in 2020 to 29.5 million tons in 2021 underlies the optimization of transportation availability in distributing coal mining products carried out by PT Bukit Asam Persero in achieving the growing target until 2023. In 2021, the Company will increase investment in developing business diversification, downstream coal. The railway network in Sumatra has a strategic role in serving the distribution of coal transportation. The railway line, which is directly connected to the location of the mining plant to port access and the availability of locomotive facilities and wagons that are very adequate, is an attractive option for mining companies and freight forwarders to establish coal transportation cooperation by rail. To meet the Babaranjang train tonnage target of 52 tons / year in accordance with the target of PT Bukit Asam (Persero), the Loop rail line design at TLS T4 PT Bukit Asam Muara Enim used the most effective classification. From the calculation results, 55 train trips are required per day to transport the production target of 57 tons / year in 2023. It is necessary to pay attention to the adequacy of the rail track from the TLS loop to Tanjung Enim Baru here it is necessary to conduct a study regarding the traffic from TLS to Tanjung Enim Baru because the number of trains set per day is 55 sets.

Keywords: v*olume, track, train, mining, coal*

Introduction

PT Bukit Asam is expanding its coal transportation capacities project by establishing two new lines. The lines are through the North Line and South Line from Tanjung Enim. The development of the project is to expand coal transportation capacities in line with exploiting the high demand momentum in the country to fulfill the requirements of the energy sector. On the other hand, PTBA is also aiming to increase its production volume up from 24.8 million tons in 2020 to 29.5 million tons in 2021. The company is also aiming for an increase in sales from 26.1 million tons in 2020 to 30.7 tons in 2021. In 2021, the Company will be increasing investment in developing business diversification, downstream coal.The total investment planned in 2021 for the sector is Rp 3.8 trillion [1].

The railway line network in Sumatra has a strategically important task in serving the distribution of coal transportation. Railway lines that are directly interconnected to the location of the mining plant to port access and the availability of locomotive facilities and wagons are very sufficient, an attractive option for mining companies and freight forwarders to establish coal transportation cooperations by railway.

The most significant physical infrastructure in the transportation sector on the Sumatra Island is the railroad network. Railway transportation modes on the island of Sumatra are used as people transportation and logistics transportation. Furthermore, the logistics movement, especially coal in Muara Enim, is mostly served by the railroad network and a small part uses the existing road network. Specifically for the existing Railway Network, it can be seen from the large number of train stations, which go to the destination port, namely Tarahan (Lampung Province), which is 14 stations. This railway network currently fulfills the transportation of 25 million tons/year of coal from Tanjung Enim to Tarahan Port which is transported by the Babaranjang Railway. From the existing secondary data which is based on the Strategic Plan for the Railway sector for 2020-2024, including the Railway Network and Service Development Plan including in the context of preparation in the South Sumatra Region. The plan to develop railroad networks and services in the region is currently open for financing through not only the APBN but also KPBU.

The research will be used for decision making on the continuation of infrastructure development as well as other needs. The research also considered and compared and examined relevant previous studies and reviews if any, at least utilizing relevant data and recommendations as secondary data in the data collection methodology.

Method

In designing the Railroad geometry, it requires design criteria to determine the required parameters as below. Planning a new rail line, designed to assist and increase the capacity of traffic trains at the TLS T4 construction site. Therefore, it requires data on the traffic carrying capacity of the central Tanjung Karang station as a reference. To calculate the traffic-train carrying capacity received by the rail can use the following formula [2].

$$T = 360 \times S \times TE \quad \textbf{(1)}$$

$$TE = T_p + (K_b \times T_b) + (Ki \times Ti) \quad \textbf{(2)}$$

Description:

T = Freight capacity (tons/year)

T_E = Tonnage equivalent (tons/day)

T_p = Tonnage of daily passengers and trains

K_b = The Coefficient that depends on the axle load, with; K_b 1.5 axle load <18 tons and K_b 1.3 with axle load >18 tons.

T_b = Tonnage of goods and daily wagons

Ki = A coefficient equal to 1.4

Ti = Tonnage 1 locomotive 1 daily 2

S = 1.1 for crossings with trains with a maximum speed of 120 km/h

To comply with the Babaranjang train tonnage target of 52 tons / year in accordance with the target of PT Bukit Asam (Persero), the Loop rail line design at TLS T4 PT Bukit Asam Muara Enim used the following design criteria (**Table 1).**

Table 1. Design Criteria [3]

Parameters	Requirement
Railroad Class	I
Number of Tracks	Single Lane
Track Width	1067 mm
Maximum Speed	40 km/h
Horizontal Curve Radius	2370 m (without LS)
	780 m (with LS)
Maximum Ramps	2‰

Design of Horizontal Alignments

Determination of Points *Point of intersection* (PI)

In the planning of horizontal railroad alignment, the first thing that is needed is to determine the PI point. This PI point then becomes the basis for the horizontal alignment planning process based on the applicable railroad regulations in Indonesia.

Minimum Radius of Horizontal Curvature

While designing the horizontal curvature, first determine the smallest radius of the circular arch to be used. The smallest radius of curvature in horizontal arch planning is the smallest radius allowed to be used in planning according to the rail elevation criteria [4]. When viewed from the centrifugal force balanced by the weight and bearing force of the rail components and in accordance with the rules, the maximum rail elevation is 110 mm with the minimum radius formula as follows:

$$R_{min} = 0{,}054 \times V^2 \quad \textbf{(3)}$$

Description:

R_{min} = minimum radius of horizontal curvature

V = maximum velocity

After the calculations are obtained the minimum radius, according to PM Transportation No. 60 of 2012 in accordance with the maximum planned speed, the horizontal alignment used adjusts the minimum radius (**Table 2)**.

Table 2. The Minimum Radius of Curvature [3]

Plan Speed (Km/h)	minimum radius of circular arch without intermediate curves (m)	minimum permitted radius of circular curvature with intermediate curvature (m)
120	2370	780
110	1990	660
100	1650	550
90	1330	440
80	1050	350
70	810	270
60	600	200

Rail Elevation

The centrifugal force that occurs in the train on the bend can be offset by elevating the outer rail so that it becomes higher than the inner rail. To determine the elevation used, the

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minimum rail elevation (h_{min}), normal elevation (h_{normal}) and maximum elevation (h_{max}) are calculated with the following formula:

$$V_{elevation\ plan} = 1.25 \times average\ operating\ speed \quad (4)$$

a. Minimum rail height minimum elevation is 55 mm
b. Normal rail elevation

$$H_{normal} = 5.95 \times \left(\frac{V^2}{R}\right) \quad \textbf{(5)}$$

Transitional Curve

Transitional curves are curvatures with regularly changing radius. Transitional arches are used in changes between straight segments and circular sections as well as changes between two unequal radius circles. The minimum arch length can be determined using the following equation [4].

$$L_n = 0.01 \times h \times V \quad \textbf{(6)}$$

Description:

L_n = Minimum length of curve (m)
H = The Relative height between 2 connected parts (mm)
V = Plan speed for the intermediate curves (km/h)

Results And Discussion

Starting and Ending Points

This railroad planning has a starting point located at the planning of the new rail crossing TLS T4 (535851.47; 9408379.799; 0), and ends at a point located at the final crossing TLS T4 (523111.23; 9429305.58; 0) (**Figure 1**).

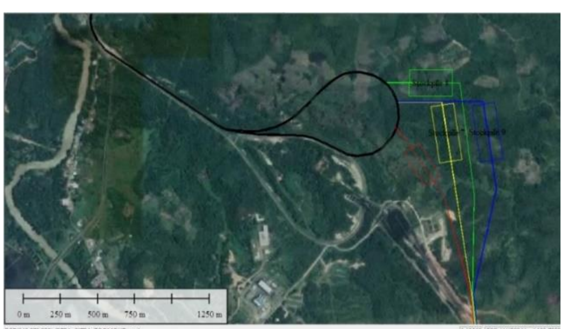

Figure 1. TLS T4 Design Plan

To calculate the traffic-train carrying capacity received by the railroad can use the following formula:

$$T = 360 \times S \times TE \quad \textbf{(7)}$$

$$TE = T_p + (K_b \times T_b) + (Ki \times Ti) \quad \textbf{(8)}$$

The operations in the mine area in charging the TLS to the circuit must pay attention to the cycle of the entire circuit so that the loading time and departure time can be arranged and achieved for a capacity of 52 million tons per year.

Achieving the coal transportation target of 52 million tons per year must be taken into account:

1. Readiness of locomotive and wagon fleet,
2. If in 1 year there are 340 operating days, coal transportation per day must reach: 152,941 tons,
3. Each train must carry 3000 tons,
4. Then 55 trains must be run every day,
5. This means that there is traffic of 104 trains every day with the condition that the train departs filled and returns empty.

Development of Mining Area to meet the capacity of 52 million tons/yr, assuming: TLS 1,2,3,4 is already in operation, TLS 5 is under construction, Total capacity of TLS 1,2,3,4,5 = 30 million tons/yr, additional capacity of 22 million tons/yr must be sought from TLS-T4 and TLS-T5.

Regarding the basic Loop design, each new TLS (TLS-T4 and TLS-T5) must be able to load enough trains to achieve total coal transportation of 52 million tons per year together with TLS 1, 2, 3, 4 and 5.

PT KAI must also consider the adequacy of the rail track from the TLS loop to Tanjung Enim Baru where a study needs to be carried out regarding the circuit traffic from TLS to Tanjung Enim Baru because the number of circuits per day is 55 circuits.

Design of Horizontal Alignments

Determination of Points *Point of Intersection* (PI)

In the planning of horizontal railroad alignment, the first thing that is needed is to determine the PI point. This PI point then becomes the basis for the horizontal alignment planning process based on the applicable railroad regulations in Indonesia.

Drainage La = 2 m
Lb = 1 m
T = 1 m
On the right and left side

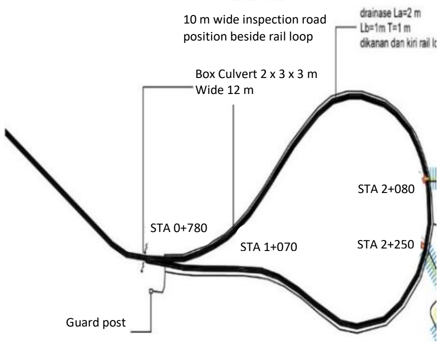

Figure 2. Point of Intersection

From the point of intersection in **Figure 2**, the coordinates are obtained in **Table 3**.

Table 3. Trase Coordinate Points

Point	X Coordinate	Y Coordinate
Start	535796	9408520
A	533929	9415068
B	525319	9416934
C	524323	9420219
D	525162	9421968
End	523270	9429353

To find the distance between PI points, the simple quadratic formula is used as below:

$$d_{AB} = \sqrt{(X_b - X_a)^2 + (Y_b - Y_a)^2} \quad \textbf{(9)}$$

$$d_{AB} = \sqrt{(525319 - 533929)^2 + (9416934 - 9415068)^2}$$

$$d_{AB} = 8809.88$$

After finding the distance between the PI points, then find the azimuth angle of the two lines. To find the azimuth angle, you can use the formula below:

$$\alpha_{ab} = \tan^{-1}\left(\frac{x_b - x_a}{y_b - y_a}\right) \quad \textbf{(10)}$$

Description:

α_{ab} = azimuth between point A and point B
x_b = x coordinate at point B
x_a = x coordinate at point A
y_b = y coordinate at point B
y_a = y coordinate at point A

to find the value of azimuth is influenced by the position of the quadrant α contained in the **Table 4**.

Table 4. Azimuth Quadrant

Quadrant	△X	△Y	Azimuth Φ
I	+	+	α
II	+	-	180 - α
III	-	-	180 +α
IV	-	+	360 -α

With an example calculation on the azimuth at point PI-A as below:

$$\alpha_{0a} = \tan^{-1}\left(\frac{x_a - x_0}{y_a - y_0}\right) = \tan^{-1}\left(\frac{-1867}{6548}\right) = -15.91$$

$$\alpha_{0a} = \tan^{-1}\left(\frac{x_b - a}{y_b - y_a}\right) = \tan^{-1}\left(\frac{-8610}{1866}\right) = -77.77$$

$$Azimuth\ (\Phi_{0a}) = 360 - (-15.91) = 375.91$$

$$Azimuth\ (\Phi_{ab}) = 360 - (-77.77) = 437.77$$

$$\Delta^{\circ}\ \mathrm{PI} - \mathrm{A} = 437.77 - 375.91 = 62^{\circ}$$

From the above calculations, the results of each PI point on the trajectory are shown in the **Table 5**.

Table 5. PI and Bend Angle

Point	X (m)	Y (m)	△X	△Y	d (m)	Quadrant	α°	Azimuth°	Δ°
Start	535796	9408520				IV	-15.91	375.91	
			-1867	6548	6808.96				
A	533929	9415068				IV	-77.77	437.77	62
			-8610	1866	8809.88				
B	525319	9416934				IV	-16.87	376.87	61
			-996	3285	3432.67				
C	524323	9420219				I	25.63	25.63	42
			839	1749	1939.83				
D	525162	9421968				IV	-14.37	374.37	40
			-1892	7385	7623.51				
End	523270	9429353							

Minimum Radius of Horizontal Curvature

In designing a horizontal arch (**Figure 3-7)**, first determine the smallest radius of the circular arch to be used. The smallest radius of curvature in horizontal arch planning is the smallest radius allowed to be used in planning according to the rail elevation criteria. when viewed from the centrifugal force balanced by the weight and bearing force of the rail components and in accordance with the rules, the maximum

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rail elevation is 110 mm with the minimum radius formula as follows in the **Table 6** [5].

Table 6. Minimum Radius of Curvature [3]

Plan Speed (Km/h)	minimum radius of circular arch without intermediate curves (m)	minimum permitted radius of circular curvature with intermediate curvature (m)
120	2370	780
110	1990	660
100	1650	550
90	1330	440
80	1050	350
70	810	270
60	600	200

Planning of Circle Curved Components

Calculation of the circular curved component as follows:

$$\theta s = \frac{360\ x\ ls}{(2R\ X\ 2\pi)} = \frac{360\ x\ 90}{((2\ x\ 800) X\ 2\pi)} = 3.22°$$

$$\Delta c = \Delta - 2\theta s = 62° - (2 \times 3.22°) = 55.557°$$

$$Lc = \frac{\Delta c}{360} 2\pi R = \frac{55.557°}{360} 2\pi\ \times 800 = 776.03°$$

$$Yc = \frac{LS^2}{6R} = \frac{90^2}{6\ X\ 800} = 1.688\ m$$

$$Xc = \ \mathrm{Ls} - \frac{LS^3}{40 \times R2} = 90 - \frac{90^3}{40\ X 800^2} = 89.972\ m$$

$$P = \ \mathrm{Yc} - R(1 - \cos\theta s) = 1.688 - 800\ (1 - \cos 3.22°)$$

$$= 0.423\ m$$

$$k = \ \mathrm{Xc} - R \sin\theta s = 89.972 - 800 \sin 3.22° = 45.013\ m$$

$$Ts = (\mathrm{R} + \mathrm{p}) \tan\frac{\Delta}{2} + k = (800 + 0.423) \tan\frac{62°}{2} + 45.013$$

$$= 529.96\ m$$

$$Es = \frac{(R + p)}{cos\frac{\Delta}{2}} - \mathrm{R} = \frac{(800 + 0.423)}{cos\frac{62°}{2}} - 800 = 133.80\ m$$

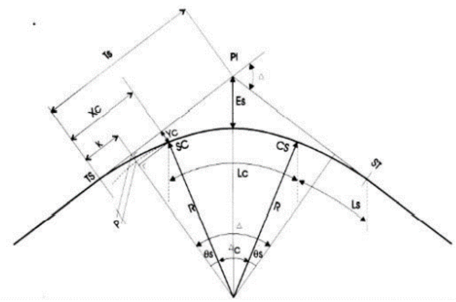

Figure 3. SCS Type Horizontal Arch Components

Table 7. Horizontal Alignment Calculation Results

Curvature	Speed km/h	Bend Angle	Rmin1 (m)	Rmin2 (m)	Selected R (m)	Hmin (mm)	Hnormal (mm)	Hmax (mm)	transitional arch	Ts (m)	Es (m)	Curvature Length (Lc,M)
PI-A	120	62°	1152	777,6	800	55	75	110	90	525,96	133,80	776,03
PI-B	120	61°	1152	777,6	800	55	75	110	90	516,50	128,96	762,06
PI-C	120	42°	1152	777,6	800	55	75	110	90	352,27	57,37	496,67
PI-D	120	40°	1152	777,6	800	55	75	110	90	336,34	51,79	468,73

Bend Detail

From the results of the above calculations, the following bend details are obtained:

a) PI A bend
R = 800m
Δ = 62°

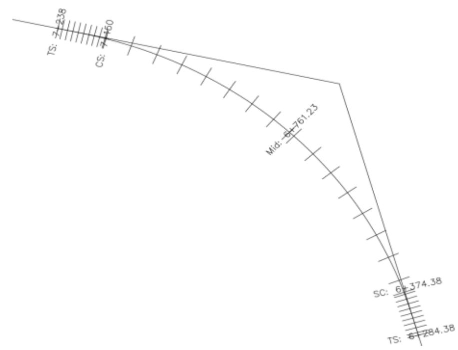

Figure 4. PI-A Bend Detail

b) PI B bend
R = 800m
Δ = 61°

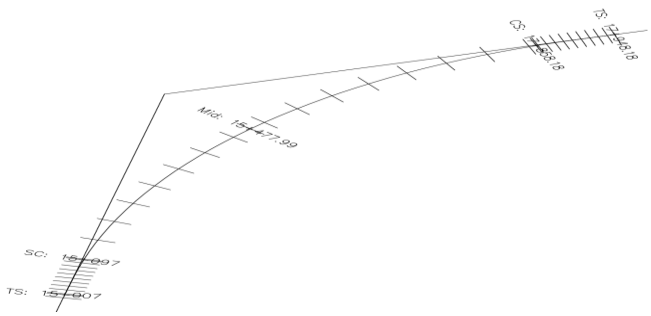

Figure 5. PI-B Bend Detail

c) PI C bend
R = 800m
Δ = 42°

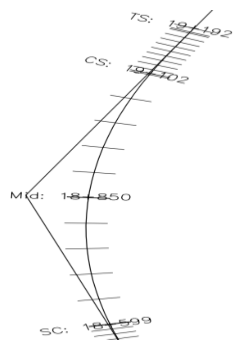

Figure 6. PI-C Bend Detail

d) PI D bend
R = 800m
Δ = 40°

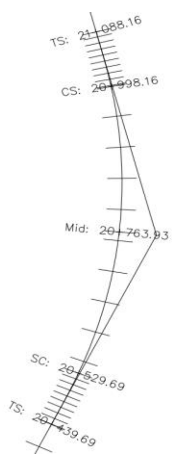

Figure 7. PI-D Bend Detail

Stationing

Stationing is a very important point obtained from utilizing the results of bend calculations. The significant point obtained from the calculation is in the form of the starting point of the curve, the end of the curve, the transition curve, and the roundabout curve and the end of the stationing. The calculation results are in the **Table 8**.

Table 8. Stationing

No	PI	Δ (°)	R	TS	SC	Mid	TS	CS
1	PI A	62	800	STA 6+284,38	STA 6+374,38	STA 6+761,23	STA 7+238	STA 7+150
2	PI B	61	800	STA 15+007	STA 15+097	STA 15+477,99	STA 15+948,18	STA 15+858,18
3	PI C	42	800	STA 18+609	STA 18+599	STA 18+850	STA 19+192	STA 19+102
4	PI D	40	800	STA 20+439,69	STA 20+529,69	STA 20+763,93	STA 21+088,16	STA 20+998,16

Railroad Structure Planning

The railroad structure is a flexible structure that is able to stem the weight of the train that must be passed onto the subgrade. Broadly speaking, there are 2 parts in planning the railroad structure, as shown in the **Figure 8**.

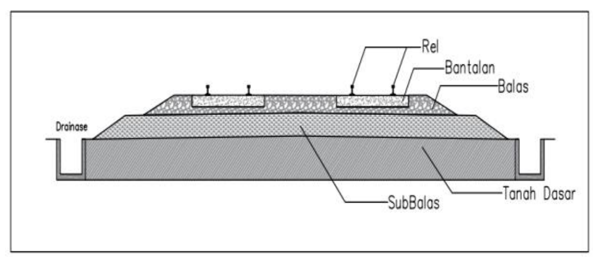

Figure 8. Railroad Structure

In planning the railroad structure, it must support safety, comfort, life and geometry requirements or provisions contained in the regulations (PD 10). There are 5 aspects that must be realized in designing [6], namely:

1. Stiffness, aimed at maintaining vertical deformation. Vertical deformation is a key indicator of the life, stiffness and quality of a railroad. Excessive vertical deformation can lead to poor railroad geometry and high wear and tear on the structural parts of the railroad.
2. Elasticity (Resilience), needed to keep trains comfortable on the track, prevent axles, wheels, shock absorption, impact, and vertical vibration. Rubber pads are used at the foot of the tracks if the railroad crossing or railroad is very rigid such as using concrete pads.
3. Resilience to fixed deformation, extreme vertical deformation will cause fixed deformation of the railroad and may cause the railroad geometry (vertical

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and horizontal unevenness, punter) to be unfavourable, which may cause inconvenience and safety problems.

4. Stability, i.e. the ability of a railroad track not to shift from its initial vertical or horizontal position during or after a force from a train. This requires a ballast of sufficient quality and density, bearings with tethers that never come loose, and very adequate drainage.
5. *Adjustability,* i.e. the railroad is easy to maintain such as changing the original position or the correct geometry position if the geometry has shifted when receiving loads and forces.

Structure of the Upper Building

The upper railroad building structure has the following structure:

1. Rail
   The use of rail types in this planning must be wear-resistant rails similar to UIC-WRA. The composition of the rail type is listed in the **Table 9.** Since this planning uses a width of 1067 mm with a railroad class I, the type of rail that can be used has 2 types, namely R-60 and R54, but in this planning the R-54 railroad type is used with a perimeter weight of not less than 54 kg / m (**Figure 9 and Table 10**).

Table 9. Chemical Composition of Rails [3]

C	0,60% - 0,80%
Si	0,15% - 0,35%
Ma	0,90% - 1,10%
P	Max 0,035%
Si	Max 0,025%

In addition, some mechanical properties and rail characteristics must be met such as:
Minimum tensile strength : 90 kg/mm
Minimum elongation : 10%
Minimum rail head hardness : 240 Brinell

Table 10. Rail-Cross Section Dimension [3]

Rail Geometry	Rail Type			
	R42	R50	R54	R60
H	138,00	153,00	159,00	172,00
B	110,00	127,00	140,00	150,00
C	68,50	65,00	70,00	74,30
D	13,50	15,00	16,00	16,50
E	40,50	49,00	49,40	51,00
F	23,50	30,00	30,20	31,50
G	72,00	76,00	74,79	80,95
R	320,00	500,00	508,00	120,00
A	54,26	64,20	69,34	76,86
W	42,59	50,40	54,43	60,34
I_x	1369	1960	2346	3055
Y_b	68,50	71,60	76,20	80,95

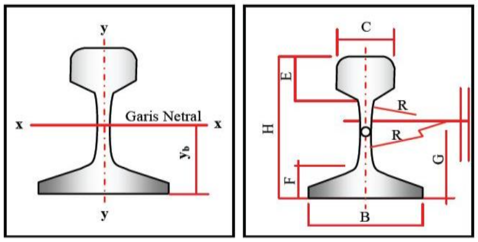

Figure 9. Rail Diameter [3]

Description:
A = Cross-sectional area
W = Rail weight per meter
Y_b = Moment of inertia about the X axis
I_x = Distance of the bottom edge of the rail to the neutral line

2. Sleeper
   Sleepers are one of the structural components of the upper building of the railroad track that plays a role in continuing the train load and the load of the railroad construction from the railroad tracks and maintaining the width of the sepur and stability towards the outside of the railroad body. In the design of the TLS T4 rail line using prestressed concrete type sleepers.

   Concrete sleepers are used to the extent of the railroad. There are some considerations that must be observed in the use of concrete sleepers such as durability factors, workability factors, and economic factors in maintaining railways. One of the reasons concretes is chosen as a bearing material is that concrete is more resistant to weather than wooden sleepers and has other advantages, namely:

a. Stability is good because the self-weight of one bearing block is up to 160 - 200 kg, so resistance to vertical, longitudinal and lateral forces is better,
b. Trains with heavy tonnage and considerable speed are more suitable for concrete sleepers.
c. Long construction period
d. Low maintenance budgets
e. Easier control of material quality
f. Its form and manufacturing process are free and easy.

Besides the above advantages, concrete pads also have some disadvantages, such as:

a. Lack of elastic properties when equated with wood and iron sleepers
b. The installation process without the help of tools is more difficult due to the weight of the sleepers.

The use of concrete sleepers in this design refers to PM No. 60 of 2012, with the following concrete dimensions:

Length = 2000 mm
Maximum width = 260 mm
Maximum height = 220 mm

And the characteristic compressive strength of the concrete sleepers should not be below 500 kg/cm2, having a prestressed steel grade with a minimum tensile strength of 16,876 kg/cm2 (1.655 MPa). The concrete sleepers used must be able to withstand a minimum moment of +1500 kg m at the rail seat and -930 kg m at the centre of the sleeper.

3. Fastening

Rail fastening is a component that binds the rail to the bearing in such a way that the rail position remains strong and does not move. The fastener has a function that is a component that connects the rail and the bearing that can block the weight of the train and the weather load.

In this design, the tether used is a double elastic tether (pandrol, **Figure 10**). The type of fastening is chosen because it has a large pinch force so that it can block creep resistance well. The selection of this type of tether also refers to PD 10 Year 1993 which states that the appropriate tether for class I railroad is a double elastic tether.

Figure 10. An Example of a Pandrol Fastening

Bottom Building Structure

Ballast dan Sub Ballast

The ballast and sub-ballast are generally a continuation of the subgrade located in the area of greatest stress concentration from rail traffic on the railbed. Because of this, the material forming the ballast and sub ballast must be highly selected. The function of the ballast layer and sub ballast is to distribute and divide the bearing load to the subgrade, strengthen the position of the bearing, and pass water so that there is no inundation of water in the rail bearing area. The ballast layer is planned from crushed rock that is strong and has sharp corners and measures 2.5-6 cm. if the stone size is not appropriate it can cause uneven load transmission to the sub-grade and reduced drainage capabilities. The design of ballast and subbase refers to PM No.60 Year 2012 as in **Figure 11 and Table 11**.

Table 11. Railroad Cross Section [3]

Railway Class	V Max (Km/h)	d1 (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	225	240	15-50	22	325
IV	90	25	140	215	240	15-35	20	300
V	80	25	135	210	240	15-35	20	300

From the table above, according to the design of the maximum speed of 110 km / h, the road class II is obtained according to the PM 60 2012.

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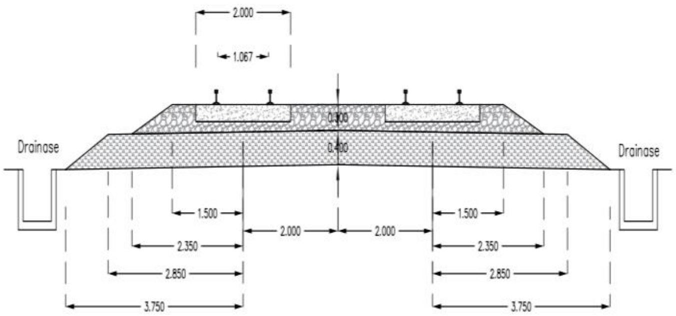

Figure 11. Railroad Cross-Section Dimensions (mm)

Conclusions

Achieving the coal transportation target of 52 million tons per year, must take into account:

1. Readiness of the fleet of locomotives and wagons,
2. If in 1 year there are 340 operating days, coal transportation per day must reach: 152,941 tons,
3. Each train must carry 3000 tons,
4. Then 55 trains must run every day,
5. This means that there is traffic of 104 trains every day with the condition that the train departs filled and returns empty.

Mine Area Development to meet the capacity of 52 million tons/year, assuming: TLS 1,2,3,4 is already in operation, TLS 5 is under construction, Total capacity of TLS 1,2,3,4,5 = 30 million tons/yr, additional capacity of 22 million tons/yr must be sought from TLS-T4 and TLS-T5.

Regarding the basic Loop design, each new TLS (TLS-T4 and TLS-T5) must be able to load enough trains to achieve total coal transportation of 52 million tons per year together with TLS 1, 2, 3, 4 and 5.

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