Design of Analysis Railroad Structure Loads on Passenger Trains using Hand Method

Sunaryo[1], La Ode M Magribi[2], Minson Simatupang[3], Adris A Putra[4] and M Thahir Azikin[5]

ABSTRACT- The purpose of this study is to design a railroad type of passenger railroad to determine the transfer of forces up to the contact area and is influenced by overlapping forces and is useful for determining the improvement of subgrade conditions if they do not meet the requirements, using the philosophy of equilateral triangles and Pythagoras. This research method is not to use the equation used for railroad planning in general but will use the philosophy of the isosceles right triangle and Pythagoras will be used to plan the railroad and determine the force acting and transferred in the area of contact to the carrying capacity land, assuming moderate soft soil and hard soil/rock, this design uses the hand method or the manual method by utilizing the help of the goodness of Microsoft Excel. In this study, only looking for forces that occur in contact fields that are affected by overlapping forces, based on these forces, it will be useful to improve the condition of subgrade if it does not meet the requirements. What's new in this study is a railroad design using hand methods or manual methods and is only aided by the goodness of Microsoft Excel and uses the philosophy of the isosceles right triangle and Pythagoras. The results of the study are based on the transformation of the load that forms the trapezoid to widen the contact area, then the railroad can pass through the fields, agricultural fields with the carrying capacity of the subgrade must be greater than the load received by the contact area if no two ways are achieved: first, just add thickness to selected embankment; and the second to improve the subgrade so that the carrying capacity can increase. However, what happens in the field is to add the selected embankment thickness not to widen the contact area but to elevate the height so that it is not flooded. Others only occur in mountains with hard and rocky subgrade conditions, so the use of selected embankment is no longer needed, the reason being that the soil carrying capacity is very high and there is no flooding, just by making drainage on both sides of the rainwater road will not form rainwater inundation.

Keywords: Railroad. Loads. Force. Hand Method. Manual Method. Formula Text. Microsoft Excel.

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1 INTRODUCTION

Railroad modeling is still very much needed in-depth discussion, especially in fast trains and the condition of the infrastructure used which is related to the structure of the sleeper, ballast, sub-ballast construction, and reinforcement construction underneath [1], this is strongly influenced by speed conditions train height which causes vibrations and greatly affects the construction of the existing pavement structure, but in the study it is only dotted in the first layer above the subgrade, which still uses ordinary piles that are used as support and fit in contact with the contact area, not using selected embankment as the initial construction or the so-called contact area, It is possible the unavailability of selected embankment or deliberately not to use. All railroad construction structures, designed by anyone in general, still range not far from the basic soil conditions and the conditions of reinforcement in the contact area that will carry the burden on it.

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The dynamic response in a railroad design is strongly influenced by the level of interaction of the subgrade and the reinforcement conditions of the foundation soil above it and there is also a result of the vertical resonance response [2]. To determine these parameters, a capital system is used which involves finite element analysis and the use of SAP2000 software. However, what is used to complete the design of the railroad will ultimately lead to how the condition of the strengthening of the foundation structure, starting from the top to the bottom and then the subgrade is still the main study. All components in completing the railroad are the unity that cannot be separated from one another, the interrelationships of each component determine the treatment that must be done. The speed of the train greatly influences the dynamic response that will be used to design the bridge and the foundation structure of the bridge.

The design of a high-speed railroad, using a conventional trackbed ballast model with a thickness of 15 cm, is useful to be able to give up high sound [3][4][5] and most importantly can control vibration, because it can do high vibration attenuation. With the use of the trackbed in addition to the benefits as above, it will also continue to be useful to reduce the peak load received by the subgrade will be small and reduced, thus the foundation design can be designed more economical and inexpensive, for areas that experience material difficulties for railroad pavement.

The use of train vibration dampers by using ballasts with a mixture of aggregate and recycled used rubber tires, can reduce soil vibrations caused by the movement of trains can be damped [6], laboratory tests show that the use of an aggregate mixture with recycled used tire rubber can reduce vibrations caused by trains to 12 dB for frequencies above 31.5 Hz. Thus, it turns out that the harsh subgrade conditions in the railroad design do not necessarily guarantee that the structural construction will be strong, but instead the waste rubber tires whose hardness is not as hard as rock can be used as railroad construction, primarily functioning as a vibration damper, which over time if not addressed will damage other construction.

The use of the disc brake system on trains is very modern progress, compared to the use of the previous brake system [7], but all types of train braking systems also cause an added force called traction force, this force will arise when the train braking. It's just that in the disk system all parameters can be determined and measured and in this braking system does not cause slippage, it's just that the method and method of braking are not used suddenly. The added force when braking a train is very influential when designing a railroad design, but all can be overcome by the designer using a mathematical system.

Due to mechanical behavior that occurs on the railroad which has been overcome by a variety of methods but still exists and is a very serious problem that must be faced by planners and maintain periodic railroad [8], railroad design is the most work difficult compared to designing highways in general, and the most difficult is designing cableway. On trains of all sizes must be precise, this size will change due to excessive train loads, extreme hot and cold weather, the use of wheels that are not appropriate and the most important is irregular periodic maintenance and supervision. When designing a railroad, all parameters that can affect railroad construction have been taken into account, except for non-mathematical matters which are rather difficult to input unless it is noted in the description, such as periodic maintenance and supervision.

Railroad without a ballast is a very modern dream in the present and future [**9**], this is an extraordinary progress, but a deeper study is needed to solve it, a railroad without a ballast may be possible it can be made only that it is still limited to light-type trains that can pass while luxury passenger-type trains and container cars may still need to be reviewed. A train is a vehicle that is used to transport passengers or goods in bulk and the number of carriages is by the ability of the towing or driving locomotive, if you have to walk on the highway then the road will be seriously damaged, thus the train is the solution used to overcome this. Thus the need for more in-depth studies and research to design a better railroad and increase working capacity becomes larger and longer planning life.

In electric trains, it turns out to have an impact on traction power, this is strongly influenced by the interaction conditions between the catenary and pantograph [10], this is because along the electric railroad the distance conditions of the catenary and pantograph interactions have the same distance value, thus the conditions this is very influential on other systems, especially on high-speed electric trains. For this reason, a deeper study needs to be carried out and is an issue and a problem that must be considered by planners of the electric fast railroad tracks, especially those relating to wind forces, aerodynamics are made in such a way so as not to have an impact on the catenary and pantograph.

The speed of the train crossing the Yangtze river bridge according to the results of the study is limited to 200km/h [11], trains exceeding that speed will affect the condition of the railroad bridge and if not then it needs to be strengthened or redesigned cantilever decks. This is not possible, so it is best to only limit the speed so that it does not exceed specified conditions. Thus the need for additional criteria in the planning of the railroad bridge and include the speed factor as an additional that needs to be considered, if these criteria are met then the speed of the train crossing the river is no longer necessary to be limited.

Due to the size of Bogie trains produced by various industries which have many types and sizes, and the irregularity of the bogies will affect the increased force on loading and affect the strength of the subgrade, due to the increased force of the train itself [12][13], this is very possible because there is a difference in the size of the railroad bogie so that the rail is forced to change size and can be permanent or temporary, but the lateral force occurs on the rail. To overcome this, it is necessary to have a tolerance value when planning a railroad, this value will be useful to anticipate the possibility of differences in the size of the train bogie.

The operational safety of high-speed trains is strongly influenced by aerodynamic conditions that withstand wind loads [14], wind loads must be given special treatment to overcome them, wind loads are also very dangerous especially crosswind models and wind turbulence models, but to overcome this, train body structure models are made in such a way especially the front to overcome wind loads that can endanger train travel. In addition to the treatment of the train body design, it is also important to include the wind factor as a burden that must be taken into account.

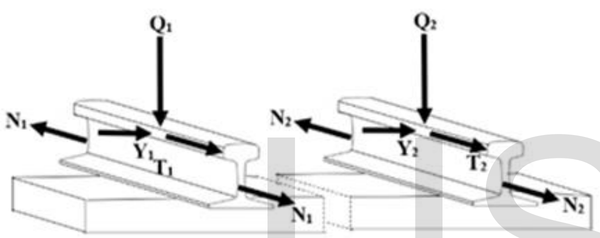
The Wuhan-Guangzhou China high-speed rail transportation, and carrying heavy loads or loads, it is necessary to have the reliability of the rail brake bracket both the disc system and the old system (clamp brake system) need to receive special attention especially to the material of the rail incubation system [15], the train in driving at high speed and then make an ideal braking or perfect is not sudden, then in addition to causing braking or traction forces that affect the loading plan, also very important is that the material or components must be made from the material that has been tested and get good characteristics. The use of railroad braking components that use materials that are not goodwill cause danger and high risk.

The use of clothoid curves is more beneficial than using Symmetrically Projected Transition Curve (SPTC) [16], this is very possible because the use of clothoid curves is smaller. This method is mostly used on railroad lines during horizontal alignment conditions, in this condition, there will be a transition or change from normal conditions to super-elevation conditions which are useful to hold or overcome the centrifugal force and overcome the risk of a train being rolled over. In this condition, the pie rail planner must include this factor as part of the geometric planning of the railroad at a predetermined speed, because the speed of the planned railroad determines the super-elevation slope of the railroad tracks.

The superior technical and economic capabilities that are produced by high-speed trains that use the electromagnetic hybrid compensation system (EHCS) [17] are the development of trains using the railway static power conditioners (RPC) and with Magnetic static var compensators (MSVC) if compared to traditional compensation methods. It has advantages according to the results of experiments based on the work of the digital signal processor (DSP).

2 LITERATURE REVIEW

Loads and forces on the railroad: Railroad roads are very complex construction of civil buildings or in other words not as simple as civil buildings in general, if in other civil buildings the size of the enlargement occurs will not be a problem, but if the building civilian railroad going enlargement then that is a problem. For that, we need very careful handling in planning and building a railroad. In railroad planning that must be considered is the load that will turn into force, the forces are vertical, transverse (lateral) and longitudinal forces [18][19]. Here is an illustration of Figure 1 about the forces on the railroad that occurred:



Information:
Q = vertical force
Y = lateral force
T = longitudinal force
N = Force due to temperature

Fig.1. The forces loading on rail

As a result of the forces that occur the force will be distributed up to the subgrade which will be transferred by ballast, sub-ballast and selected embankment, the meeting between the subgrade and the layer above it is called the contact plane, this contact area is the highlight of the value obtained from the load transfer and carrying capacity of the subgrade.

Vertical force is a burden that occurs very large on the railroad, the force needs to be planned because with this force will occur deflection or vertical deflection which is the best instrument or indicator for determining the quality of a material or even the behavior of railroad development, including in the depth and strength of the railroad. In general, the most influential is the large vertical force by loading by locomotives, trains and passenger cars [20][21]. a. The force due to the locomotive, model and type of locomotive will determine the load acting on the locomotive, this is largely determined by many bogies and axles that will carry the weight of the load by the axle on the rail. The more number of wheels in each bogie, the lighter the axle load and vice versa; b. Train style (car, coach), Characteristics of train carriage loads will determine the load acting on a train car, this is largely determined by many bogies and axles that will carry the weight of the load by the axle on the rail. Besides the load on the axle, the passenger comfort factor and speed (dynamic factor) affect the load that occurs on each axle; c. Carriage style (wagon), In principle, loading on the car is the same as the locomotive and train. It's just that the most important load capacity of each type of car must be considered in the planning process.

The mathematical model or calculation of the vertical force generated by the load that occurs on the axle by locomotives, trains, and carriages is a static load, whereas what happens is real, that the load that occurs on the railroad structure is a dynamic load that is influenced by aerodynamic factors (air resistance and wind load), including geometric conditions and speed of movement of the train circuit [20]. Therefore, there needs to be a transformation of static force into a dynamic force in more realistic load planning. Talbot equation in 1918 is a mathematical equation as a transformation of the force in the form of dynamic factor multiplier as follows:

$$I_p = 1 + 0.001\left(\frac{V}{1.609} - 5\right) \quad (1)$$

where, I_P = dynamic factor, V = Plan speed (km/h)

Transverse force (Lateral) is the force that occurs as a result of centrifugal force (when the train circuit is in horizontal curvature), snake motion coupled with the circuit (snake motion) and the railroad geometric unevenness at each elevation, so that at the same point with the force vertical [22]. In this force will cause nails or bolts pulled out, due to lift force (uplift force), shifting sleeper and allows the occurrence of derailment (drop or release of the train wheels from the rail). Thus there are conditions for limiting the amount of lateral force so that no drop occurs:

$$\frac{P_{lateral}}{P_{vertical}} < 0.75, \text{ for worn rails and wheels} \quad (2)$$

Thus mathematically the lateral force can be described in Figure 2 below:

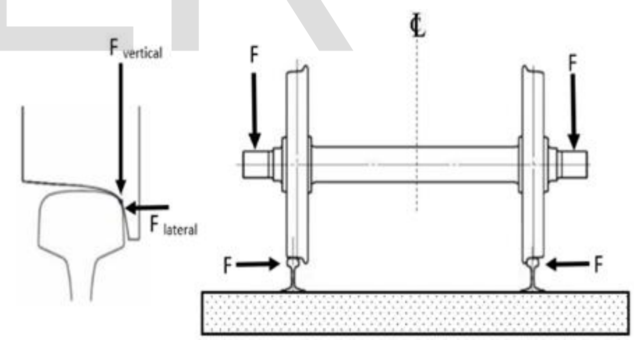


Fig.2. The vertical and lateral forces on rail

Longitudinal force is the force caused by changes in temperature on the rail (thermal stress). This force is very important in the analysis of forces, especially for railroad construction using long welded rails. The longitudinal force is also the adhesion force (due to wheel friction and headrails) and the force due to wheel braking on the rail.

The general model of vertical load distribution train transfer model is described as follows: 1. The dynamic load model between railroad wheel and rail interaction is a function of the characteristics of a railroad track, operating conditions, and its environment. The load force model on a track by railroad movement is a combination of static load and dynamic component given to static load. At the dynamic load received by the rail there will be contact stress between the railhead and the wheel, therefore, this is very influential by the choice of rail steel quality; 2. This loaded model is then distributed from the base of the rail to the sleeper. 3. The vertical load model of the bearing will be distributed to the ballast and sub-ballast layers and even selected embankment is distributed in the subgrade so what is called the contact area between the subgrade and the layer above it. Thus, it becomes smaller and wider. A load distribution model that widens and produces less pressure and is acceptable to the subsoil. The rail structure force distribution model basically aims to produce a reduction in the contact area that occurs between the rail and the wheel to a very small pressure on the subgrade (± 2 kg/cm^2).

Basically, the railroad is a road consisting of rails, sleepers, ballasts, sub-ballasts, and selected embankments and does not miss the subgrade where all structural construction will stand [20]. During its development, the railroad experienced many models and ways to plan. Euler-Bernoulli-beam model, this theory is considered normal even this theory is considered conventional beam theory or commonly referred to as the Rayleigh-Timoshenko beam. The Rayleigh-Timoshenko theory is principally about the cross-section of the material itself, namely the rotational inertia of a beam-shaped cross-section and the deformation of the beam due to the sheer force. So for the design of the railroad was formulated using the concept of the "beam-on-elastic-foundation model" with the assumption that each railroad will behave as a continuous beam placed on an elastic pedestal by Winkler in 1867 and is still used for calculations and ways of reflection which is easy and fast. The railroad foundation modulus (as support), k, is defined as the bearing force per unit rail length per rail deflection unit. The railroad foundation modulus here includes the effects of fastening, sleeper, ballast, sub-ballast and subgrade. And the results show the load patterns and reactions produced by Winkler's theory. The model can be written in general terms as follows:

$F(x) = -k.y(x)$

$EI\frac{d^4y}{dx^4} + k.y = 0$ ....(3)

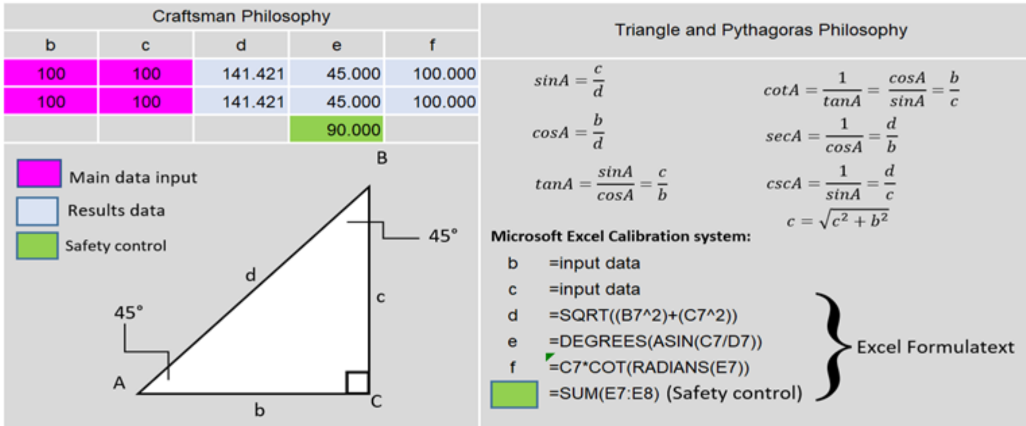
where,

Fx= Reaction evenly per unit length; of the steel making up the rail;
k = Modulus of railroad elasticity;
y = Deflection due to load on the rail;
E = Modulus of elasticity
I = Moment of rail inertia.

The use of Microsoft Excel must really be able to perform operations as in table 1, if the software is not used frequently so it needs to calibrate or try it out if it has produced such a value then the software is declared good.

The use of certain formulas in Microsoft Excel must be the user who will input, this is because not all the formulas we need are available and available in Microsoft Excel, however, this research will be guided and explained in detail. It's just that, the ways and explanations are formulated in tabular tables so that they are easier to understand and appear clearer.

Table 1 Calibration table before using Microsoft Excel



3 RESEARCH OBJECTIVES

This research method is not to use the equation used for railroad planning in general but will use the philosophy of the isosceles right triangle and Pythagoras will be used to plan the railroad and determine the force acting and transferred in the area of contact to the carrying capacity land, assuming moderate soft soil and hard soil/rock, this design uses the hand method or the manual method by utilizing the help of the goodness of Microsoft Excel. In this study, only looking for forces that occur in contact fields that are affected by overlapping forces, based on these forces, it will be useful to improve the condition of subgrade if it does not meet the requirements. What's new in this research is a railroad design using hand methods or manual methods and is only aided by the goodness of Microsoft Excel and uses the philosophy of the isosceles right triangle and Pythagoras.

4 RESEARCH METHODS

Based on the explanation and reference above, starting from equation 1 to equation 12, then it is a mandatory standard used for railroad planning, both planning work projects or other tasks related to railroad planning, and that has been used for decades and all use the equation so that it has become a common good. However, in this study do not use equations and methods, because if you use these equations, then in this study there is nothing new. So to create new things in this research, the Research Team used a hand method in calculating the loading in planning railroad tracks, using the hand-method was certainly a new thing in this study, this is because everyone must have a way and each method, to check the truth of the hand-method, just make it using the method using the above equation, then the results are relatively the same, if not the same then it is a new thing that needs attention and study and that is the result of this research.

5 RESULTS

4.1 The size and amount needed in research

Size and magnitude in this study, taken from references and other data held by researchers, if there are size and quantity that is not appropriate it is only an assumption and can be corrected under other Research Teams, because all teams have different assumptions, including methods -his. The dimensions and loads can be clearly seen from the following figure:

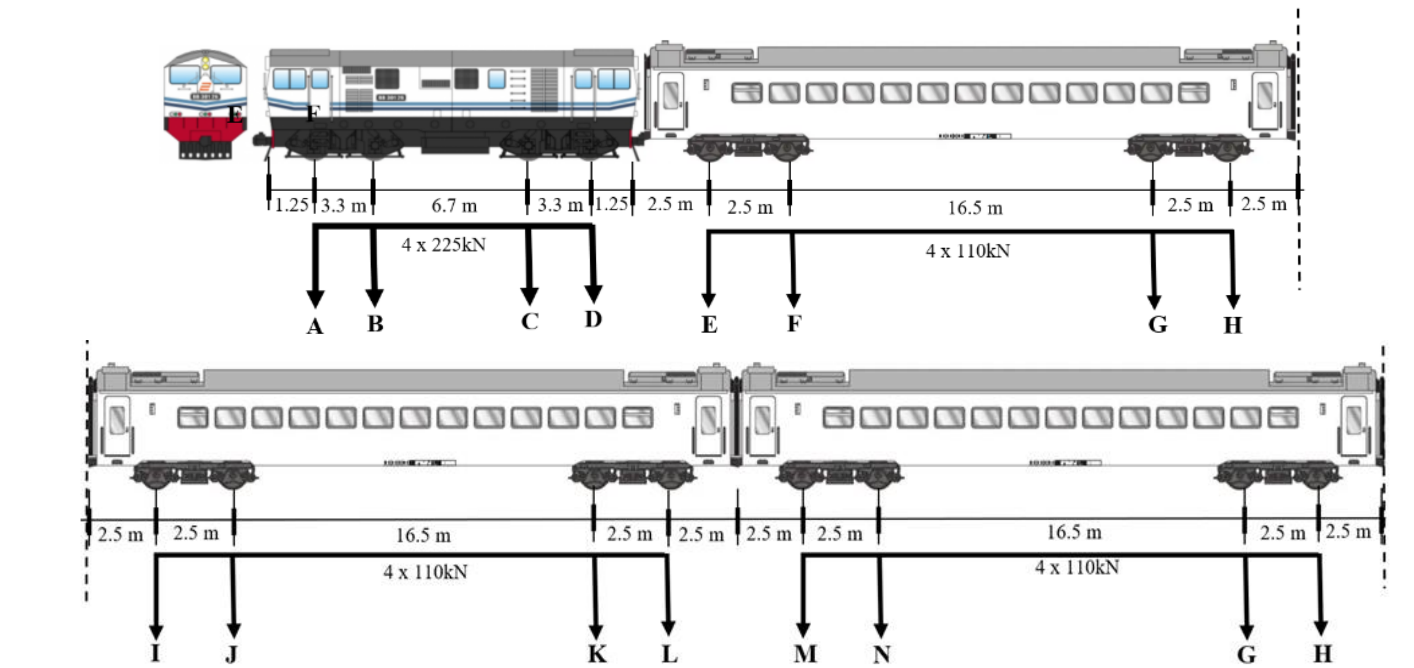


Fig.3. Dimensions, loads on Locomotives and passenger trains

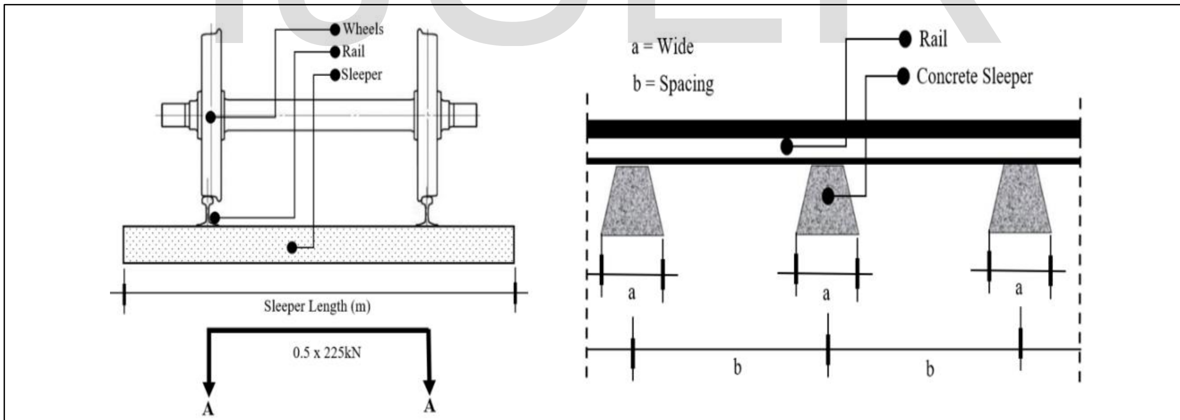


Fig. 4. Identification of dimensions and loads on rails and sleepers

Based on Figures 3 and 4, then the size and quantity are needed for railroad planning, the rest, if there are sizes and quantities sourced from other references, can also be used to be complete.

There are differences in size and size issued by railroad producers, but in this study, it does not refer to where the producers are referred to, but in general in this study will only look for how the burdens that are received by the subgrade, both soft subgrade, are and hard or rock, all will be described in this study according to the version that is owned by the Research Team.

4.2 Load distribution on Locomotive

Locomotive loading is adjusted to Locomotive conditions, each manufacturer has different characteristics, but that is not an obstacle for planners to do their job, in this study Locomotive uses only 2x4 wheels and the working load is 4x225kN, this load will be distributed on the railroad and continued to the subgrade. In more detail, it will be described in the following table:

TABLE 2
Distribution of loading at Locomotive

No.	Description	Loads kN	Segmen (m)																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u
	Percentage			100.0	88.9	77.8	66.7	55.6	44.4	33.3	22.2	11.1	0.0						
1	Wheels A	225	66.67	75	66.67	58.33	50	41.67	33.33	25	16.67	8.333	0	0	0	0	0	0	0
2	Wheels B	225	58.33	66.67	75	66.67	58.33	50	41.67	33.33	25	16.67	8.333	0	0	0	0	0	0
3	Wheels C	225	0	0	8.333	16.67	25	33.33	41.67	50	58.33	66.67	75	66.67	58.33	50	41.67	33.33	25
4	Wheels D	225	0	0	0	8.333	16.67	25	33.33	41.67	50	58.33	66.67	75	66.67	58.33	50	41.67	33.33
5	Wheels E	110	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52
6	Wheels F	110	0	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59
	Total		125	141.7	150	150	150	150	154.1	162.2	170.4	178.5	186.7	186.5	178	169.4	160.9	144.3	119.4

Legenda: Formula Text : f1 =($D$12/3)*(F11/100) g2 =($D$13/3)*(F11/100)
Main data input g1 =($D$12/3)*(G11/100) h2 =($D$13/3)*(G11/100)
Results data h1 =($D$12/3)*(H11/100) i2 =($D$13/3)*(H11/100)
Wheel loads i1 =($D$12/3)*(I11/100) j2 =($D$13/3)*(I11/100)

Based on table 2, column d is an input data, the value is directly input in that column, in the processed data column or the results 6 cells are colored blue is a sign that the cell is the starting point for the calculation, calculation or formula must start at that point or cell, then copy to the left and right, but don't forget to adjust the percentage, the farther from the wheel the percentage will be smaller and the farthest will be zero (0). Data processing using hand method which is assisted by using Microsoft Excel with stacking formula as shown in the formula text in the table. In the bottom row of the table there is a total of the results of the load distribution, then all the columns will be added up and this value reflects the load distribution in each segment of the length of the railroad.

At the bottom, a row is the largest total value is in column o with a value of 186.7kN and the smallest value is in column u equal to 119.4kN, overall the load distribution can be seen in chart on Figures 5.

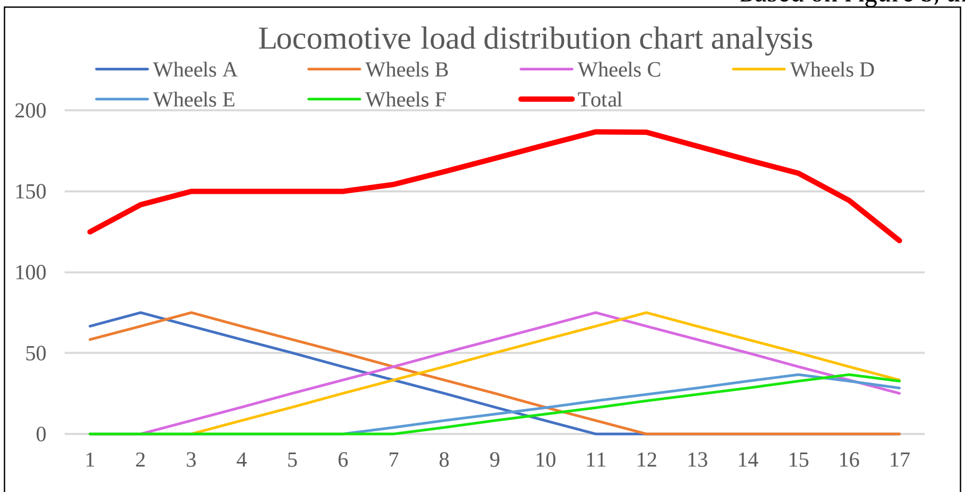


Fig. 5. Locomotive load distribution chart

Based on Figure 5, the wheels A, B, C and D initially get the same load, but after distribution, the load is not the same, this is due to the addition of loads from wheels E and F which are very significant and zero (0) before arriving on wheels A and B. If you look at the chart's style and the trip, you can see that the change in the line is very linear even if it is sloping up or sloping down, this indicates that the calculation done by hand method is correct, if it is incorrect then the chart line occurs inconsistently or disheveled.

Wheel load distribution A and B will be zero (0) if it reaches the wheels C and D and vice versa, the zero value will apply to the left and right direction. In the total load distribution in each segment is depicted on the red line, the lowest value is in wheels A and B followed by wheels E and F then the highest is C and D. Why are the A and B wheels lowest when the load value is equal to C and D are 225kN while the E and F wheels are only 110kN. This is because the E and F wheels get extra weight from the C and D wheels which are so significant that logically this will be and mathematically correct.

Based on Figure 5, that the main and most important thing in the chart is that the total value is depicted in thick red lines, it turns out that the highest force is located on the wheels C and D then followed by wheels A and B then E and F, this logically it makes sense. Thus, the results obtained from the hand-method or the manual method are correct, because the chart line is not random or inconsequential.

4.3 Load distribution on passenger trains

The loading on passenger trains is adjusted according to conditions such as model, size and size, each passenger train manufacturer has different characteristics, but this does not become an obstacle for planners to do their job, in this study Locomotive uses only 2x4 wheels and loads work is equal to 4x110kN, this load will be distributed on the railroad and continued to the subgrade. In more detail, it will be described in the following table:

TABLE 3
Distribution of loading at passenger trains

No.	Description	Loads kN	Segmen (m)																				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y
	Percentage							100.0	88.9	77.8	66.7	55.6	44.4	33.3	22.2	11.1	0.0						
1	Wheels C	110	50	41.67	33.33	25	0	0	0	0	0	0	0	Wheels M		0	4.074	8.148	12.22	16.3	20.37	24.44	28.52
2	Wheels D	110	58.33	50	41.67	33.33	0	0	0	0	0	0	0	0	Wheels N		0	4.074	8.148	12.22	16.3	20.37	24.44
3	Wheels E	110	32.59	36.67	32.59	28.52	24.44	20.37	16.3	12.22	8.148	4.074	0	0	0	0	0	Wheels O		0	4.074	8.148	12.22
4	Wheels F	110	28.52	32.59	36.67	32.59	28.52	24.44	20.37	16.3	12.22	8.148	4.074	0	0	0	0	0	Wheels P		0	4.074	8.148
5	Wheels G	110	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52	24.44	20.37	16.3	12.22	8.148	4.074	0	0	0	0	0	0	0
6	Wheels H	110	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52	24.44	20.37	16.3	12.22	8.148	4.074	0	0	0	0	0	0
7	Wheels I	110	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52	24.44	20.37	16.3	12.22
8	Wheels J	110	0	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52	24.44	20.37	16.3
9	Wheels K	110	0	0	0	0	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59	28.52
10	Wheels L	110	0	0	0	0	0	0	0	0	0	0	0	4.074	8.148	12.22	16.3	20.37	24.44	28.52	32.59	36.67	32.59
	Total		198	197.6	189.1	172.4	114.1	114.1	110	101.9	93.7	85.56	81.48	85.56	93.7	101.9	114.1	126.3	134.4	142.6	154.8	163	163

Legenda:
- Main data input
- Results data
- Wheel loads
- Previous data
- Next data

Formula Text :
k4 =($D$16/3)*(J10/100)
l4 =($D$16/3)*(K10/100)
m4 =($D$16/3)*(M10/100)
n4 =($D$16/3)*(M10/100)
s5 =($D$17/3)*(J10/100)
t5 =($D$17/3)*(K10/100)
u5 =($D$17/3)*(M10/100)
v5 =($D$17/3)*(M10/100)
t6 =($D$18/3)*(J10/100)
u6 =($D$18/3)*(K10/100)
v6 =($D$18/3)*(L10/100)
w6 =($D$18/3)*(M10/100)

Based on table 3, column d is an input data, the value is directly input in that column, in the processed data column or the results 8 cells are colored blue is a sign that the cell is the starting point for the calculation, calculation or formula must start at that point or cell, then copy to the left and right, but don't forget to adjust the percentage, the farther from the wheel the percentage will be smaller and the farthest will be zero (0). Data processing using hand method which is assisted by using Microsoft Excel with stacking formula as shown in the formula text in the table. In the bottom row of the table there is a total of the results of the load distribution, then all the columns will be added up and this value reflects the load distribution in each segment of the length of the railroad. At the bottom, a row is the largest total value is in column e with a value of 198kN and the smallest value is in column o 81.48kN, overall the load distribution can be seen in chart on Figures 6.

Based on Figure 6, the wheels G, H, I, J, K, and L initially have the same load, but after distribution, the load is not the same, this is due to the additional load of the C, D, and M, N wheels which are very significant and zero (0) before arriving at the wheels G, H and I,

If you look at the chart and chart, you can see that the line changes very linearly even if the pitch is up or down, this indicates that the calculation is done by hand- method is true, if not true then the chart line occurs inconsistent or disheveled.

Wheel load distribution I and J will be zero (0) if it reaches the wheels K and L and vice versa, the zero value will apply to the left and right direction. In the total load distribution in each segment is depicted on the red line, the lowest value is in the G and H wheels followed by the wheels I and J then the highest is E and F. Why are the G and H wheels lowest when the load values are the same with I up to N which is 110kN. The highest value of the E and F wheels, is because the wheel gets extra weight from the C and D wheels which is very significant so logically this will be and mathematically correct.

Based on Figure 6, that the main and most important thing in the chart is that the total value is drawn in a thick red line, it turns out that the highest force is located on the wheels E and F then followed by the wheels K and L then I and J then followed by G and H, this makes very logical sense. Thus, the results obtained from the hand-method or the manual method are correct, because the chart line is not random or inconsequential.

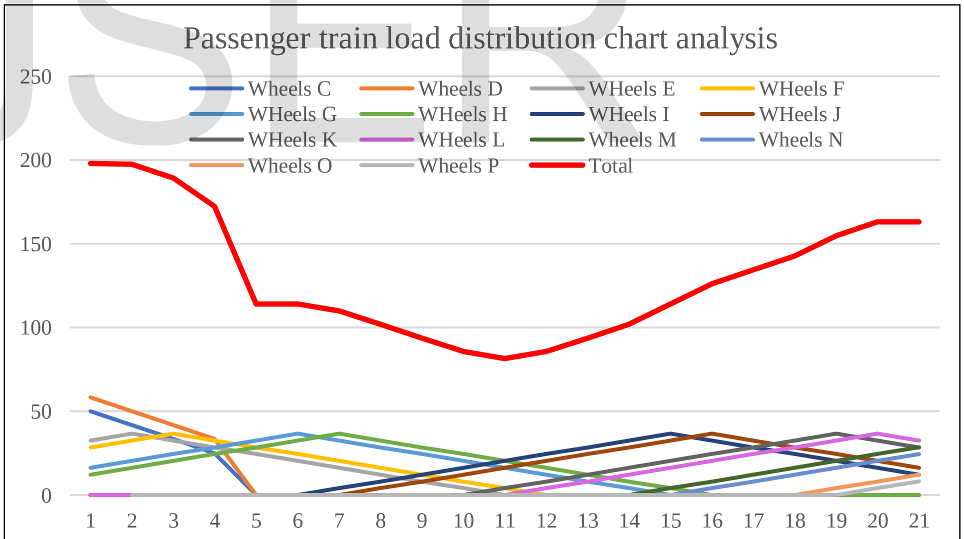


Fig. 6. Passenger train load distribution chart

4.4 Sleeper load distribution to subgrade type soft soil on passenger trains

All loads that have been received by the sleeper will be

transformed up to the subgrade, to transform the load many ways and conditions that must be done, especially the main requirement is about how the condition of the subgrade itself, soft soil, medium soil or rock hard soil/rock, these conditions will be considered technically to take action.

To prove that a passenger train is lighter than a locomotive, it helps us try it and can be seen in the explanation in table 4.

TABLE 4
Distribution of sleepers to soft soil on passenger trains

No.	Description	Segmen Length	Sleeper (m)					Ballast (m)		Sub Ballast (m)		SE (m)		Force kN	SF	LCA kN/cm²	LCA kg/cm²
			Wide	Thick	Length	Spacing	BA m²	Thick	BA m²	Thick	BA m²	Thick	BA m²				
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
1	WHeels G & N	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	2	219.97	197.59	3	2.6948	0.2747
2	WHeels H & M	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	2	219.97	189.07	3	2.5786	0.2629
3	WHeels I & L	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	2	166.64	114.07	3	2.0536	0.2093
4	WHeels J & K	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	2	166.64	110	3	1.9803	0.2019
5	Segmen 1 &26.5	1.25	25	20	2.75	40	1.3221	20	2.5567	40	11.014	2	83.322	114.07	3	4.1072	0.4187
6	Segmen 8 & 20	2.75	25	20	2.75	40	2.9087	20	3.4798	40	24.232	2	183.31	101.85	3	1.6669	0.1699
7	Segmen 10 &18	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	2	133.32	93.7	3	2.1086	0.2149
8	Segmen 12 & 16	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	2	133.32	85.556	3	1.9253	0.1963
9	Segmen 14	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	2	133.32	81.481	3	1.8336	0.1869

Legenda: Formula Text : i =(E11/100*G11)*(D11/(H11/100+E11/100)) r =(P11/O11)*Q11 s =R11/9.81
Previous data k =(E11/100+2*J11/100)*G11+(2*J11/100)*(D11/(H11/100+E11/100))
Main data input m =(G11+(2*J11/100)+(2*L11/100))*(((E11/100)+(2*J11/100))+(2*L11/100))*((D11/(H11/100+E11/100)))
Results data o =(G11+(2*J11/100)+(2*L11/100)+(2*N11))*(((E11/100)+(2*J11/100))+(2*L11/100)+(2*N11))*((D11/(H11/100+E11/100)))

Based on table 4, we obtain the highest load stress against the surface area with a value of 4.1072kN/cm² or 0.4187kg/cm² and the smallest value of 1.6669kN/cm² or 0.1699kg/cm², the value if later is stated to be the largest will be used, and if it turns out to be the smallest then it is not used.

In column q is SF (Safety Factor), in this section, there is an increase in the load from the actual, in this study intentionally SF was given a value of 3, this means that the actual load was increased to 3 times, it is possible to anticipate the safety factor arising from earthquake forces, vibration forces, traction forces, moment forces and other forces that may occur.

4.5 Distribution of Sleeper load to locomotives of soft soils at the locomotive

The load will be transferred to subgrade type medium soil, but what differs from the type of soft soil is only the thickness of the selected embankment, all layers above it remain the same, for more details can be seen in the description in table 5.

TABLE 5
Distribution of sleepers to soft soil on locomotive

No.	Description	Segmen Length	Sleeper (m)					Ballast (m)		Sub Ballast (m)		SE (m)		Force kN	SF	LCA kN/cm²	LCA kg/cm²
			Wide	Thick	Length	Spacing	BA m²	Thick	BA m²	Thick	BA m²	Thick	BA m²				
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
1	Wheels A & D	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	2	219.97	177.96	3	2.4271	0.247
2	Wheels B & C	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	2	219.97	186.48	3	2.5433	0.259
3	Wheels E	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	2	166.64	160.93	3	2.8971	0.295
4	Wheels F	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	2	166.64	144.26	3	2.597	0.265
5	Segmen 8 & 20	2.75	25	20	2.75	40	2.9087	20	3.4798	40	24.232	2	183.31	178.52	3	2.9216	0.298
6	Segmen 10 &18	2.75	25	20	2.75	40	2.9087	20	3.4798	40	24.232	2	183.31	170.37	3	2.7883	0.284
7	Segmen 12 & 16	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	2	133.32	162.2	3	3.6505	0.372
8	Segmen 14	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	2	133.32	154.07	3	3.4671	0.353
9	Segmen 1	1.25	25	20	2.75	40	1.3221	20	2.5567	40	11.014	2	83.322	169.44	3	6.1008	0.622
10	Segmen 15.8	1.25	25	20	2.75	40	1.3221	20	2.5567	40	11.014	2	83.322	119.44	3	4.3006	0.438

Legenda: Formula Text : i =(E11/100*G11)*(D11/(H11/100+E11/100)) r =(P11/O11)*Q11 s =R11/9.81
Previous data k =(E11/100+2*J11/100)*G11+(2*J11/100)*(D11/(H11/100+E11/100))
Main data input m =(G11+(2*J11/100)+(2*L11/100))*(((E11/100)+(2*J11/100))+(2*L11/100))*((D11/(H11/100+E11/100)))
Results data o =(G11+(2*J11/100)+(2*L11/100)+(2*N11))*(((E11/100)+(2*J11/100))+(2*L11/100)+(2*N11))*((D11/(H11/100+E11/100)))

Based on table 5, the load stress is obtained from the largest surface area with a value of 6.1008kN/cm^2 or 0.622kg/cm^2 and the smallest value is 2.4271kN/cm^2 or 0.247kg/cm^2, and it turns out that this value is the largest, then this value will be used up to the condition of hard soil types, for LCA is Loading contact area.

Based on the picture 7, the railroad design is obtained with conditions on soft soil/ agricultural soil (rice fields), in these conditions so that the load from the sleeper is transferred to the subgrade and so that the load can be reduced, the contact surface area is expanded, by way of increasing the thickness of the selected embankment, taking into account cheaper and technically eligible, with the addition to expanding the contact area can also be used to avoid flooding in agricultural areas and river banks or swamps.

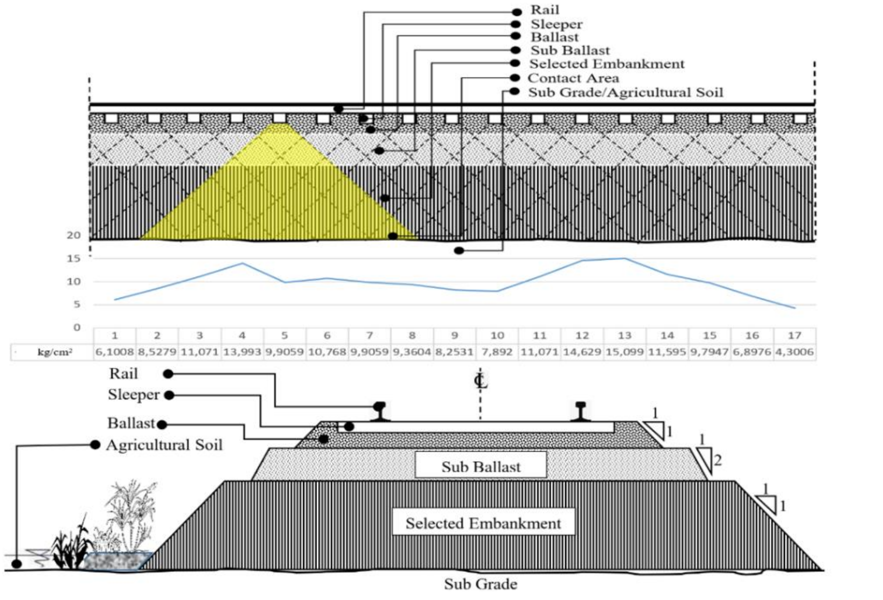


Fig. 7. Distribution of overlapping loads on soft soils/agricultural

The slope of the selected embankment is recommended enough to make a ratio of 1:1, this is to keep it stable. As for the slope of the ballast and sub-ballast, a ratio of 1:1 and 1:2 is sufficient.

4.6 Distribution of the Sleeper load to the subgrade of medium soil type at locomotive

Furthermore, it will use the load on the locomotive that turns out to have the greatest value, and what changes is only the thickness of the selected embankment which is changed in thickness, as detailed in Table 6.

TABLE 6
Distribution of sleepers to medium soil on locomotive

No.	Description	Segmen Lengh	Sleeper (m)					Ballast (m)		Sub Ballast (m)		SE (m)		Force kN	SF	LCA kN/cm^2	LCA kg/cm^2
			Wide	Thick	Length	Spacing	BA m^2	Thick	BA m^2	Thick	BA m^2	Thick	BA m^2				
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
1	Wheels A & D	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	1	104.22	177.96	3	5.1229	0.5222
2	Wheels B & C	3.3	25	20	2.75	40	3.4904	20	3.8183	40	29.078	1	104.22	186.48	3	5.3681	0.5472
3	Wheels E	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	1	78.952	160.93	3	6.1148	0.6233
4	Wheels F	2.5	25	20	2.75	40	2.6442	20	3.326	40	22.029	1	78.952	144.26	3	5.4815	0.5588
5	Segmen 8 & 20	2.75	25	20	2.75	40	2.9087	20	3.4798	40	24.232	1	86.847	178.52	3	6.1666	0.6286
6	Segmen 10 &18	2.75	25	20	2.75	40	2.9087	20	3.4798	40	24.232	1	86.847	170.37	3	5.8852	0.5999
7	Segmen 12 & 16	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	1	63.162	162.2	3	7.7051	0.7854
8	Segmen 14	2	25	20	2.75	40	2.1154	20	3.0183	40	17.623	1	63.162	154.07	3	7.3181	0.746
9	Semen 1	1.25	25	20	2.75	40	1.3221	20	2.5567	40	11.014	1	39.476	169.44	3	12.877	1.3126
10	Segmen 15.8	1.25	25	20	2.75	40	1.3221	20	2.5567	40	11.014	1	39.476	119.44	3	9.0773	0.9253

Legenda: Previous data; Main data input; Results data

Formula Text : i =(E11/100*G11)*(D11/(H11/100+E11/100)) r =(P11/O11)*Q11 s =R11/9.81

k =(E11/100+2*J11/100)*G11+(2*J11/100)*(D11/(H11/100+E11/100))

m =(G11+(2*J11/100)+(2*L11/100))*(((E11/100)+(2*J11/100))+(2*L11/100))*((D11/(H11/100+E11/100)))

o =(G11+(2*J11/100)+(2*L11/100)+(2*N11))*(((E11/100)+(2*J11/100))+(2*L11/100)+(2*N11))*((D11/(H11/100+E11/100)))

Based on table 6, we obtain the highest load stress on the ground surface area with a value of 9.0773kN/cm^2 or 0.9253kg/cm^2 and the smallest value of 5.1229kN/cm^2 or 0.5222kg/cm^2, and it turns out that this value is the largest, then this value will be used up to the condition of hard soil types.

Based on the Figure 8, the railroad design is obtained with conditions on medium soil/agricultural soil (fields and plantations), in these conditions so that the load from the sleeper is transferred to the subgrade and so that the load can be reduced, the contact surface area is expanded, how to simply adjust the thickness of the selected embankment, taking into account cheaper and technically eligible, with the addition to expanding the contact area can also be used to avoid flooding in agricultural areas (fields and plantations).

The slope of the selected embankment is recommended enough to make a ratio of 1:1, this is to keep it stable. As for the slope of the ballast and sub-ballast, a ratio of 1:1 and 1:2 is sufficient.

4.7 Distribution of Sleeper load to locomotives of hard soil/rock types in locomotives

Furthermore, it will use the load on the locomotive that turns out to have the greatest value, and the only change is the thickness of the selected embankment which is changed in thickness, as detailed in Table 7.

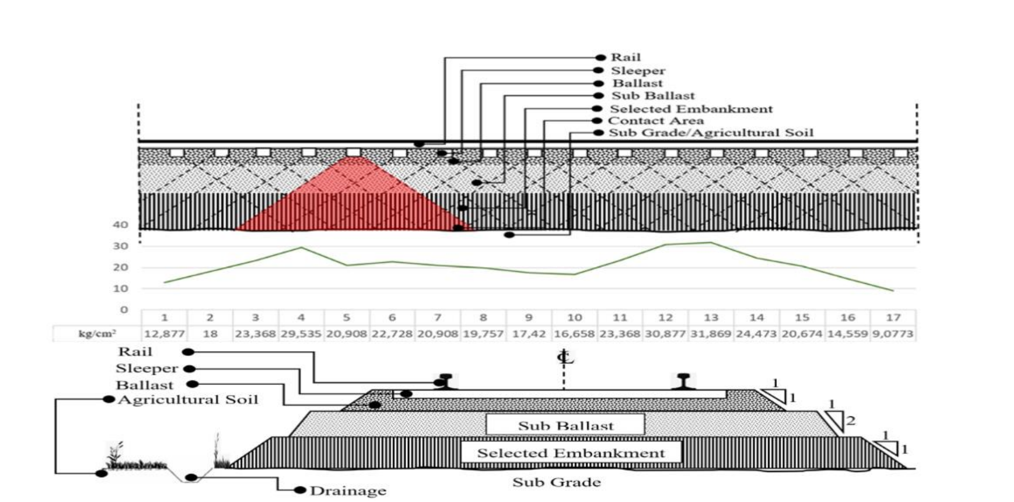


Fig. 8. Distribution of overlapping loads on medium soils

TABLE 7
Distribution of sleepers to hard soil/rock on locomotive

No.	Description	Segmen Lengh	Sleeper (m)					Ballast (m)		Sub Ballast (m)		SE (m)		Force kN	SF	LCA kN/cm²	LCA kg/cm²
			Wide	Thick	Length	Spacing	BA m²	Thick	BA m²	Thick	BA m²	Thick	BA m²				
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
1	Wheels A & D	3.3	25	20	2.75	40	3.4904	20	3.8183	30	23.798	0	23.798	177.96	3	22.434	2.2869
2	Wheels B & C	3.3	25	20	2.75	40	3.4904	20	3.8183	30	23.798	0	23.798	186.48	3	23.508	2.3963
3	Wheels E	2.5	25	20	2.75	40	2.6442	20	3.326	30	18.029	0	18.029	160.93	3	26.778	2.7297
4	Wheels F	2.5	25	20	2.75	40	2.6442	20	3.326	30	18.029	0	18.029	144.26	3	24.005	2.447
5	Segmen 8 & 20	2.75	25	20	2.75	40	2.9087	20	3.4798	30	19.832	0	19.832	178.52	3	27.005	2.7528
6	Segmen 10 &18	2.75	25	20	2.75	40	2.9087	20	3.4798	30	19.832	0	19.832	170.37	3	25.772	2.6272
7	Segmen 12 & 16	2	25	20	2.75	40	2.1154	20	3.0183	30	14.423	0	14.423	162.2	3	33.742	3.4396
8	Segmen 14	2	25	20	2.75	40	2	20	3.0183	30	14.423	0	14.423	154.07	3	32.047	3.2668
9	Semen 1	1.25	25	20	2.75	40	1.3221	20	2.5567	30	9.0144	0	9.0144	169.44	3	56.391	5.7483
10	Segmen 15.8	1.25	25	20	2.75	40	1.3221	20	2.5567	30	9.0144	0	9.0144	119.44	3	39.751	4.0521

Legenda:
Previous data
Main data input
Results data

Formula Text : i =(E11/100*G11)*(D11/(H11/100+E11/100)) r =(P11/O11)*Q11 s =R11/9.81
k =(E11/100+2*J11/100)*G11+(2*J11/100)*(D11/(H11/100+E11/100))
m =(G11+(2*J11/100)+(2*L11/100))*(((E11/100)+(2*J11/100))+(2*L11/100))*((D11/(H11/100+E11/100)))
o =(G11+(2*J11/100)+(2*L11/100)+(2*N11))*(((E11/100)+(2*J11/100))+(2*L11/100)+(2*N11))*((D11/(H11/100+E11/100)))

Based on table 7, we obtain the highest load stress against the surface area with a value of 56.391kN/cm² or 5.7483kg/cm² and the smallest value of 22.434kN/cm² or 2.2869kg/cm², and it turns out that this value is the largest, then this value will be used up to the condition of hard soil types.

In column q is SF (Safety Factor), in this section, there is an increase in the load from the actual, in this study intentionally SF was given a value of 3, this means that the actual load was increased to 3 times, it is possible to anticipate the safety factor arising from earthquake forces, vibration forces, traction forces, moment forces and other forces that may occur.

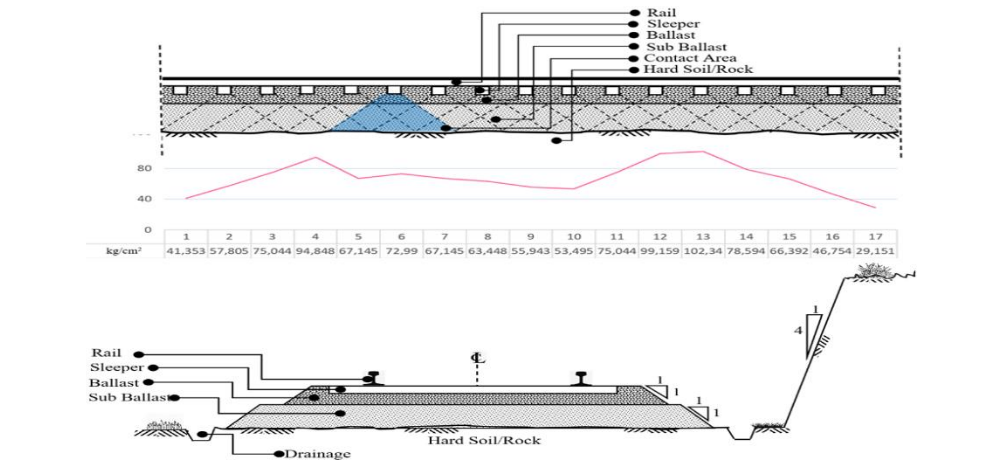


Fig. 9. Distribution of overlapping loads on hard soils/Rock

Based on Figure 9, the trapezoidal contact area, which originally or as if it only came from one sleeper, was not, in 1 (one) contact area, it was loaded with 5 (five) sleepers. This means that the load transferred by the sleeper will be lighter, but it will increase in weight. If seen on the chart line the lowest value is far from the wheel and the highest value is the closest to the wheel.

Thus using this hand-method is correct, because the result is logically very rational.

Still based on Figure 9, the railroad design is obtained with conditions on hard soil/rock, does not require a selected embankment and enough to use sub-ballast and ballast then sleeper and railroad tracks. It does not need to be high because the subgrade is very hard it can be directly placed into the sleeper and the rails only need to be given over sub ballasts and ballasts which are useful as vibration dampers so that the sleeper and rail conditions will remain stable. Also, it does not need to be high because of sufficient rainwater and can be handled by using the left and right drainage of the road because the condition of hard soil/rock is certainly located in the mountains and altitude.

The slope of the sub-ballast and ballast is enough to make a ratio of 1:1, this is to keep it stable. As for the slope excavation of the mountain slope with a ratio of 1:4, why is that this is because the rocky excavation conditions are very stable and unlikely to be a landslide, and this is proven that at the time of work will experience difficulties due to hard.

4.8 Summary of research results

The results of the railroad design in this summary will be displayed in detail, ranging from soft soil design, medium soil design, and hard soil design. But the most important thing in this summary is the final result obtained, namely the value of the load strength of soil to the contact area. Based on this value, the condition of the subgrade must be able to support, if it is not able to support the need for repair or stabilization of the subgrade until it gets a carrying capacity value of land that is greater than the load strength or at least equal to the load strength. A complete summary of the load strength values can be seen and described in table 8.

TABLE 8
Summary of research results

No.	Description	Segmen (m)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
b	c	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u
1	Soft soil/agricultural soil	6.1008	2.4271	2.5433	2.9216	2.7883	3.6505	3.4671	3.6505	2.7883	2.9216	2.5433	2.4271	6.1008	6.1008	2.8971	2.597	4.3006
a	kN/cm²	6.1008	8.5279	11.071	13.993	9.9059	10.768	9.9059	9.3604	8.2531	7.892	11.071	14.629	15.099	11.595	9.7947	6.8976	4.3006
b	kg/cm²	0.6219	0.8693	1.1286	1.4264	1.0098	1.0977	1.0098	0.9542	0.8413	0.8045	1.1286	1.4912	1.5391	1.1819	0.9984	0.7031	0.4384
2	Medium soil	12.877	5.1229	5.3681	6.1666	5.8852	7.7051	7.3181	7.7051	5.8852	6.1666	5.3681	5.1229	12.877	12.877	6.1148	5.4815	9.0773
a	kN/cm²	12.877	18	23.368	29.535	20.908	22.728	20.908	19.757	17.42	16.658	23.368	30.877	31.869	24.473	20.674	14.559	9.0773
b	kg/cm²	1.3126	1.8349	2.3821	3.0107	2.1313	2.3169	2.1313	2.014	1.7757	1.698	2.3821	3.1475	3.2486	2.4947	2.1074	1.4841	0.9253
3	Hard soil/rock	56.391	22.434	23.508	27.005	25.772	33.742	32.047	33.742	25.772	27.005	23.508	22.434	56.391	56.391	26.778	24.005	39.751
a	kN/cm²	56.391	78.825	102.33	129.34	91.562	99.532	91.562	86.52	76.285	72.947	102.33	135.22	139.56	107.17	90.534	63.756	39.751
b	kg/cm²	5.7483	8.0352	10.432	13.184	9.3335	10.146	9.3335	8.8195	7.7763	7.436	10.432	13.784	14.226	10.925	9.2287	6.4991	4.0521

Legenda:
Previous data
Results data

Formula Text : e1a =D11; f1a =D12+E11; g1a =E12+F11; i1a =H11+I11+J11; j1a =I11+J11+K11; k1a =J11+K11+L11; m1a =L11+M11+N11; n1a =M11+N11+O11; o1a =N11+O11+P11; d1b =D12/9.81; d2b =D15/9.81; d3b =D18/9.81

Based on table 8, then 2 load press indicators occur by using kN/cm² and kg/cm², this unit is deliberately made of 2 (two) types, so that it can be easily used or adjusts to the condition of the tool used to determine the strength of the subgrade, if the tool uses the kN unit, then the same unit is immediately taken and if using kg, a tool that uses kg can be used, and no conversion is needed. For the formula text calculation operations on rows starting from row 11 and for columns as a whole starting from column b.

Graphically the research summary can be displayed, to clarify and provide an overview of the stress conditions that occur, in full presented and illustrated in figure 10.

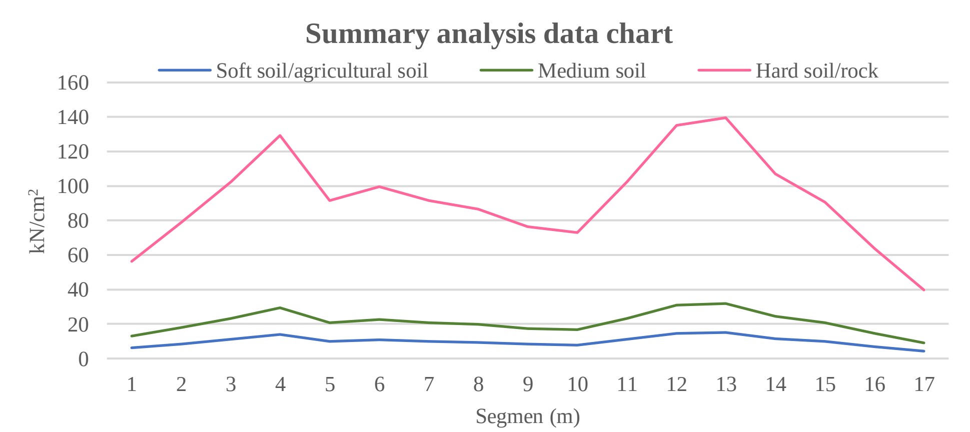


Fig. 10. The summary analysis data chart

6 CONCLUSION

Based on the Figure 10, then there are 3 (three) lines at the bottom of the chart is the value of the load stress on soft soil, the middle part is the value of the load stress on medium soil and at the top is the load threshold value on hard soil/rock. However, in depicting this chart using values derived from units of kN/cm² and for kg/cm² it is not possible to display but graphically the same or similar and identical, only the units used are different.

The load is transformed downward through a rod of concrete and steel material, then the amount of downward pressure will be adjusted by starting from the closest distance to the farthest distance, the closer the greater and the smaller and even equal to zero (0). This is caused by a rigid stem and given a centralized load, the load will propagate along the stem to form a value of zero (0), and the stem is supported evenly or sporadically, but still, up to the subgrade, the burden will overlap.

The load is transformed downward through a rod, as mentioned above and through several layers of material such as ballasts, sub-ballasts, and selected embankments, the thicker the layer, the smaller the value of the load received by the subgrade and vice versa the thinner the layer, then the greater the value of the load received by the subgrade. This is because the contact area, if the layer is getting thicker then the width of the pedestal or sleeper will be tethered to be twice (2x) the thickness of the layer, thus the contact area is not only as wide as the sleeper but becomes 3 fields (sleeper width, height left and right height) This happens because there is a load propagation through the material layer at an angle of 45°.

The load acting on the sleeper when transforming into a subgrade is trapezoidal at an angle of 45°. In the contact area of the subgrade, the area of the contact area is not only suppressed by the sleeper itself but is still burdened by 8 (eight) other sleepers with different load positions according to distance. Thus the contact area on the side of the trapezoid base is pressed by 9 (nine) trapezoid.

Based on the transformation of the load that forms the trapezoid to widen the contact area, then the railroad can pass through the rice fields, agricultural fields with the carrying capacity of the subgrade must be greater than the load received by the contact area, if not achieved there are two ways to overcome them: the first, simply add to the thickness of the selected embankment; and the second to improve the subgrade so that the carrying capacity can increase. However, what happens in the field is to add the selected embankment thickness not to widen the contact area but to elevate the height so that it is not flooded. Others only occur in mountains with hard and rocky subgrade conditions, so the use of selected embankment is no longer needed, the reason being that the carrying capacity of the soil is very high and there is no flooding, simply by making drainage on both sides of the rainwater road will not form rainwater puddles.

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