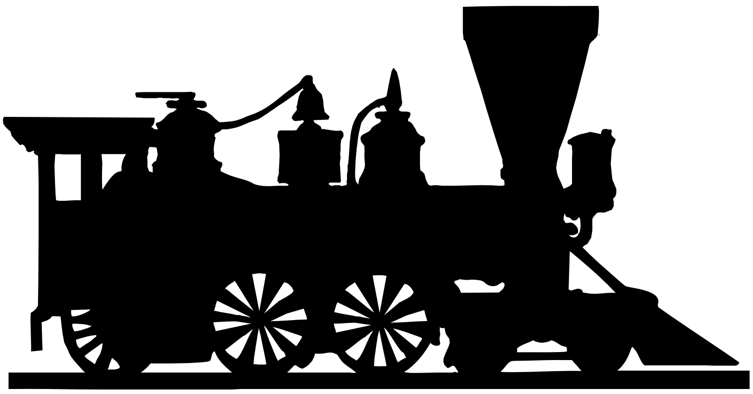
University of Technology
Department of Buildings &
Constructions Engineering

Branch of Bridges &
Highways Engineering
3rd. Stage

Railway Engineering



By

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Introduction

1.1 Definition:

Rail transport refers to the land transport of passengers and goods along railways or railroads. A railway (or railroad) track consists of two parallel rail tracks, formerly of iron but now of steel. Usually vehicles running on the rails are arranged in a train (a series of individual powered or unpowered vehicles linked together). The cars move with much less friction and the locomotive that pulls the train uses much less energy than is needed to pull wagons.

1.2 History:

1. Ruman were the first try running of animals drawn vehicles on stone line (parallel).
2. 15th century, wooden rail in Europe – good speed.
3. Wooden rail above were covered by iron at the next stage.
4. Using angle iron to prevent lateral movements.
5. The above were replaced with rised flange (Cast Iron C.I.).
6. It was observed that animals can draw vehicle on C.I. better than on roads.
7. 17th century, thinking of device to replace the animals was found.
8. In France, Nicolas Cugnot at 1771 constructed steam locomotive.
9. In Britain 1786, William Murdock prepared steam locomotive model.
10. 1797-1804 it was designed (steam locomotive).
11. First complete success 1781-1848 George Stephenson had got complete success.

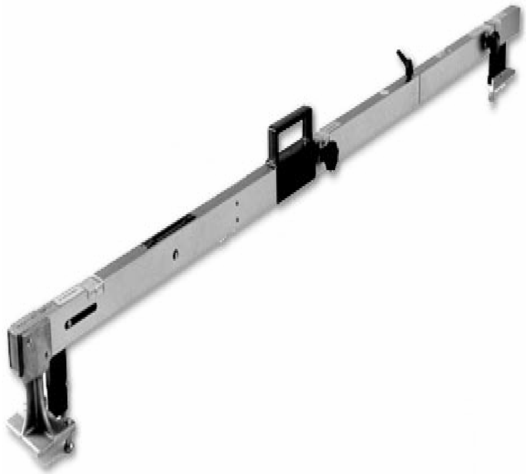
12. In 1825 on 27 September, the first running was successed between Stockton and Darlington.

1.3 Comparison between Roads and Railway:

1. In railway the concentrated load needs very strong track.
2. Road is suitable for different types of vehicles but the track is suitable for trains only.
3. The train wheels can only move on tracks, it needs an arrangement "Points and Crossing".
4. In track, there is no obstructions, so greater speed can obtained comparing with roads.
5. Movement in train is due to tractive force between steel rail and steel wheels. The friction in rail is about $(1/5)^{th}$ of that between rubber and road (vehicles-road).
6. Rails need more maintenance compared with roads.

1.4 Rail Gauge:

Rail gauge is the distance between the inner sides of the two parallel rails which make up a railway track as shown in Fig.1-1 (a and b). Sixty percent of the world's railways use a gauge of 1.435 m (4 ft 8½ in), which is known as the **standard** or **international gauge**. Rail gauges wider than standard gauge are called **broad gauge**, and rail gauges smaller than standard are called **narrow gauge**. Some stretches of track are built to a **dual gauge**: that is to say that three (or sometimes four) parallel running-rails are laid in place of the usual two, in order to allow trains of two different gauges to share the same route. The term **break-of-gauge** refers to the situation obtaining at a place where different gauges meet. In England, first track (1.524 m) from outside of wheel to outside.



(a) **(b)**

Figure (1-1) Rail Gauge.

1.5 Difficulties Due to Change of Gauge:

1. At every change of gauge, passengers have to change the train.
2. Missing the train in case of lating.
3. At junctions, goods must be unloaded and reloaded.
4. Any fault of labours leads to miss send of goods.
5. Extra cost.
6. Rolling stocks and old engine of one gauge cannot be used on branch gauges.
7. In case of needs, more transportation to one point it is impossible to use the train because of the difference of gauges.
8. Extra difficulties to army in war time.
9. Changing is very difficult, because it needs to change the tunnels, bridges…..etc.

1.6 Loading Gauge:

An instrument within which all railway vehicles must fit. It is dictated by the size of tunnels and height and width of bridges as shown in Fig.1-2 (a and b). It varies between different countries and may also vary on different lines within a country.

In more recent times, the term **loading gauge** has fallen out of use among railway professionals, since it is a purely static concept and ignores other factors affecting clearance. Factors such as suspension travel, overhang on curves (at both ends and middle), lateral motion on the track, etc. are just as important as the vehicle's static profile. All these factors must be considered in determining whether the moving rail vehicle will fit within allowed clearances.

(a)

(b)

Figure (1-2) Loading Gauge

1.7 Speed:

- Speed depends on gauge, on wider gauge it can present more speed compared with narrow one.
- Power of locomotive.

- Weight of train.
- Nature of formation under the track and the ground layers.

1.8 Train Resistances

a) Resistance due to speed (track and wind):

- Wind depends on direction.
- Side resistance depends on length of train.

b) Resistance due to gradient:

R. due to G. = (Weight of train / rate of grade)

- If 1 in 150 is provided, the resistance = (Weight of train / 150)
- If the direction is upward, this force is the resistance.
- If the direction is downward, the force is added to locomotive.

c) Resistance due to friction and wave action in moving:

Wave action between rail and wheel in moving (Creep), this can be equal to (0.0025 * weight of train).

d) Resistance due to curve:

It is increased with speed increasing.

- The curve resistance in wide gauge (Broad gauge B.G.) is = $4 * 10^{-4}$ * degree of curvature * weight of train
- The curve resistance in Metric gauge (M.G.) is = $3 * 10^{-4}$ * degree of curvature * weight of train
- The curve resistance in Narrow gauge (N.G.) is = $2 * 10^{-4}$ * degree of curvature * weight of train

Dynamic of Movement

2.1 Introduction:

How to transport any load between two points through known line at better economical case??. To solve that, there is the main elements:

1. ***Power :***

Weight (W) to be transferred from A to B

by sliding resistance = $W/40$

= $W/100$ (for tires)

= $W/400$ (for railways)

The railways is the cheaper.

2. ***Resistances:***

1) Internal resistance of locomotive (cylinders…..etc)
2) Resistance depends upon the load on axle can be defined as (journal friction + rolling friction + track resistance).
3) Resistance depends on the speed which caused a friction between the track and flange).
4) Air resistance $\alpha\ V^2$.
5) Resistance due to extra load on axles (Generators or A/C devices).
6) Resistance due to deflection of track.
7) Resistance due to curvature.
8) Resistance due to grade.
9) Resistance due to acceleration.
10) Starting.
11) Great winds.

From all resistances that mentioned above: Resistance = kg / ton.

- ❖ R_m = Resistance due to moving.

$R_m = R_{axle} + R_{flange} + R_{air}$ (additional load + track deflection).

- ❖ $R_{rolling + air}$ = (rolling and air resistances) depends upon:
    1. Friction between wheels and track depends on coefficient of friction.
    2. Track resistance: due to wave resistance. If the weight of track increases (*42-74 kg/ton*), it should be minimized $R_{rolling} = 0.20$ kg/ton from 2 kg/ton.
    3. Journal resistance: is the resistance between end of axle and the seats in axle box (lubrication).
    4. Wheel flange resistance.
    5. Air resistance.

2.2 W. J. Davis Equation:

$$R_{(r + air)} = 0.6 + \frac{13}{w} + AV + \frac{BCV^2}{nw}$$

Where:

$R(_{r + air})$ = Resistance due to rolling and air.

$[0.6 + \frac{13}{w}]$ = Resistance due to rolling, track, axle.

AV = Flange resistance.

$[\frac{BCV^2}{nw}]$ = Air resistance.

w = weight of axle (ton).

n = number of axles.

V = speed (km/hour).

The above equation valid to speed equal to and less than (***80 km/hour***).

$A = 0.0085$ for trains and passengers

$= 0.013$ for goods trains

$= 0.026$ for diesel trains

$B = 0.0045$ relative (diesel, electric, steam)

$= 0.0007$ passengers

$= 0.001$ goods

$= 0.0045$ diesel

$C = 9.75$ for train of *50* ton weight

$= 10.40$ for train of *70* ton weight

$= 11.20$ for train of *100* ton weight and more

$= 8.0\text{-}8.5$ for goods train

$= 11.00$ for passenger

$= 7.5\text{-}10$ diesel *2* motors

$= 6.5\text{-}7.0$ diesel *1* motor

2.3 Tuthill Equation:

For speed more than (***80 km/hour***), the resistance due to rolling and air in vehicles only:

$R_{(r+a)vehicle} = 0.90 + 0.0110\,V + 0.00088\,V^2$ (*20* ton)

$= 0.55 + 0.0057\,V + 0.00080\,V^2$ (*30* ton)

$= 0.50 + 0.0030\,V + 0.00068\,V^2$ (*40* ton)

$= 0.27 + 0.0028\,V + 0.00060\,V^2$ (*50* ton)

$= 0.20 + 0.0042\,V + 0.00054\,V^2$ (*60* ton)

$= 0.26 + 0.0006\,V + 0.00051\,V^2$ (*70* ton)

$= 0.24 + 0.0006\,V + 0.00050\,V^2$ (*75* ton)

Note: The resistance always decreases as the weight increases for the similar speed as shown in Fig. 2-1.

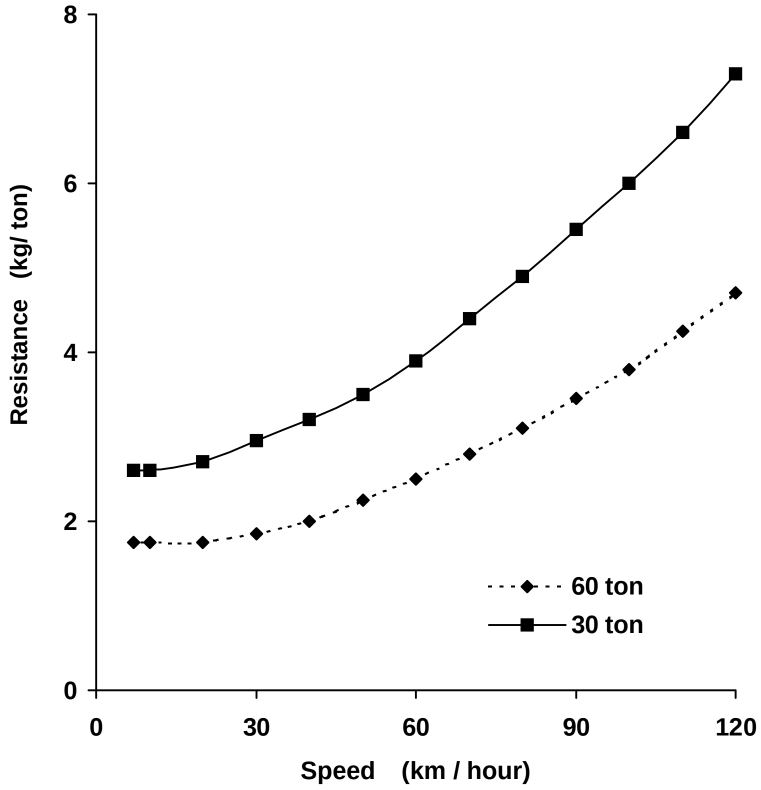


Figure (2-1) Resistance-Speed Relationship

For calculating of $R_{(r+a)}$ for ($V > 80\ km/hr$) speed:

$$R_{(r+a)} = \frac{R_{(r+a)}\ \text{Tuthill eq.}}{R_{(r+a)}\ \text{Davis eq.}} * R_{(r+a)\ \text{locomotive}}\ \text{Davis}$$

<u>**$R_{(r+a)}$ *Specific:***</u>

$$R_{(r+a)\ specific} = \frac{R_{(r+a)vehicle} * \text{weight of vehicles} + R_{(r+a)locomotive} * \text{weight of locomotive}}{\text{weight of vehicles and locomotive}}$$

where:

$R_{total} = R_{(r+a)\,specific}$ [*weight of vehicles* + *weight of locomotive*] *(kg/ton)*

2.4 Strahl Equations:

1) $R_{(r+a)\,vehicle} = 2.5 + \frac{(V + \Delta V)^2}{K}$ *(kg/ton)*

where:

V = Speed (km/hr)

ΔV = additional coefficient.

= *zero* (horizontal line and quit weather)

= *12* at (lateral wind , medium intensity)

= *20* at (lateral wind , strong intensity)

= *30* at (strong wind , high intensity , long duration)

K = Constant coefficient depends upon the type of train.

= *4000* (high speed and goods train, homogeneous complete)

= *3000* (medium speed, non homogeneous train)

= *2000* (different types of vehicles)

= *1000* (empty vehicles)

2) $R_{(r+a)\,locomotive} = \frac{250}{w}\left[\frac{V + \Delta V}{100}\right]^2$ *(kg/ton)*

where:

w = weight of axle (*ton*).

V = Speed (*km/hr*)

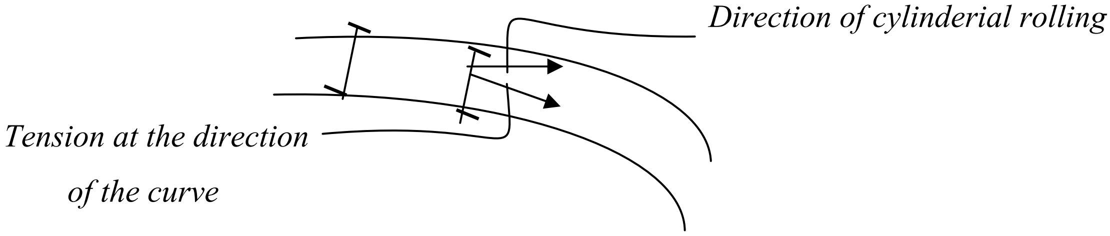
ΔV = additional coefficient as above.

3) $R_{(r+a)\,train} = 2.2 + 3\left[\frac{V + \Delta V}{100}\right]^2$ *(kg/ton)*

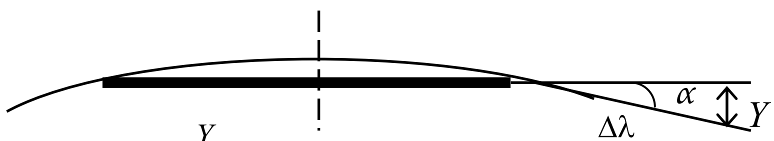
2.5 Curve Resistance:

It caused by:

1. increasing of tension (direction of tangent of the curvature (see Fig. 2-2a)).
2. resistance due to friction between flange and crown of track.
3. lateral sliding for wheel from the crown of track (see Fig. 2-2b).
4. increasing of pressure on the internal track or external one.
5. bad maintenance for example: corrosive parts.



(a)



$$Sin\ \alpha = \frac{Y}{\Delta\lambda}$$

$Y = \Delta\lambda * Sin\ \alpha$ *where Y: Pressure at track.*

(b)

Figure (2-2) Cylinderical Rolling Movement.

Resistance due to curvature: depends on the radius of curvature. The radius may increase at high speeds, see the Table 2-1 below.

Table (2-1) Radius of Curvature according to Type of Terrain.

Terrain	Flat area	Mountain area
Radius , r	*500 m*	*300 m*

Rockel Equation:

$$R_{(c)} = \frac{650}{r - 55} \quad \text{at radius} > 500 \text{ m \& normal gauge } (1.435 \text{ m})$$

$$= \frac{400}{r - 20} \quad \text{at M.G. } (1.00 \text{ m})$$

$$= \frac{200}{r - 5} \quad \text{at N.G. } (0.60 \text{ m})$$

$$= \frac{500}{r - 30} \quad \text{at radius} < 500 \text{ m \& normal gauge } (1.435 \text{ m})$$

where:

$R_{(c)}$: Resistance due to curvature *(kg/ton)*

r : radius of curvature *(m)*

In **U.S.A.**, the resistance due to curvature would be calculated according to the central angle (degree of curvature) which makes an arc of *(30.5 m = 1000 ft),* as shown in Fig.2-3 below, that is to be *(0.36 kg/ton)* for every central angle.

$$R_{(c)} = 0.36 * \alpha \quad (kg/ton)$$

$$\frac{\alpha}{360} = \frac{30.5}{2\pi r} \longrightarrow \alpha = \frac{1746}{r}$$

$$R_{(c)} = 0.36 * \frac{1746}{r} = \frac{630}{r} \quad (kg/ton)$$

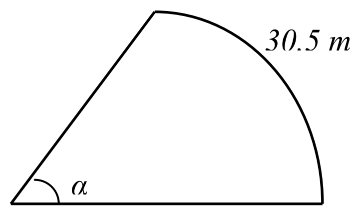


Figure (2-3) Degree of Curvature.

However in **Europe**, there are famous equations to require $R_{(c)}$:

$$R_{(c)} = \frac{233.2 + 103.4 * A}{r} \quad (kg/ton) \quad \text{where}$$

A: is the distance between the fixed axle in vehicle.

Mutzner Equation:

$$R_{(c)} = \frac{800 - 0.4 * r}{r - 40} \quad (kg/ton)$$

2.6 Grade Resistance:

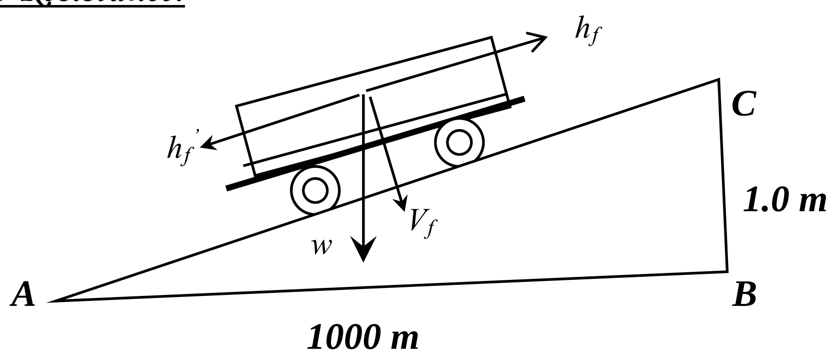


Figure (2-4) Determination of Grade Resistance.

As shown in Fig.2-4 above:

$$\frac{h_{f'}}{w} = \frac{AB}{BC} \approx \frac{AB}{AC} \qquad \text{(for small angle)}$$

assuming that slope = S %

$$\frac{h_{f'}}{w} = \frac{h_f}{w} = \frac{S}{1000} \qquad \text{then} \qquad h_f = \frac{w*S}{1000}(ton) = \frac{1000*w*S}{1000}(kg)$$

Therefore, the resistance due to grade:

$$R_g = \frac{1000*S}{1000} = S \qquad \textit{(kg/ton)} \qquad \textit{(for unit force of w)}$$

i.e. when the grade = *5 %,* the R_g = *5 kg/ton*

Using of Momentum for Upgrade:

If a body fallen from (*h*) height at a speed of *v* (*m/sec*) then:

$$h = \frac{v^2}{2g} \quad (m) \qquad \left[\frac{m^2/\sec^2}{m/\sec^2}\right] = m \qquad g = 9.81\ m/sec^2$$

$$h = \frac{v^2 * 1000 * 1000 (km/hr)}{2*9.81*3600*3600} = \frac{v^2 * (km/hr)}{2*9.81*3.6*3.6} = 0.00394 * v^2 \quad (m)$$

v = speed in *(km/hr)*

For the result of rotating energy it may be added the sum of 6%:

$h = 1.06 * 0.00394 * v^2 = 0.0042 * v^2$

i.e. when a train flows at speed of *v (km/hr)* it can be pass a height of *h (m)* from the momentum energy without any increasing of mechanical work. Therefore, the max. grade can the train climbed:

$$S_{\max} = S + \frac{0.0042 * (v_1^{\;2} - v_2^{\;2})}{\lambda} * 0.7$$

where

S = grade that the train can clime without any increasing of energy.

v_1 = the speed at the beginning of the grade *(km/hr)*.

v_1 = the speed at the ending of the grade *(km/hr)*.

λ = horizontal distance of the grade.

h = had been decreased by an amount of *30%* for increasing the factor of safety.

The S_{max} must be used carefully because of the probability of train to stop at the slope then *energy = 0* .

__Example 2-1:__ Calculate the max S that the train can be climbed using the momentum of energy, if the initial velocity is 60 km/hr and the final velocity is 30 km/hr and then calculate the max slope that can be climbed by using of locomotive alone which is 6% and the horizontal distance a) 300 m and b) 3000 m.

__Solution:__

$$S_{\max} = S + \frac{0.0042 * (v_1{}^2 - v_2{}^2)}{\lambda} * 0.7$$

in case a λ = *300 m*

$$S_{\max} = 0.006 + \frac{0.0042 * (60^2 - 30^2)}{300} * 0.7 = 0.032 = 32\%$$

in case b λ = *3000 m*

$$S_{\max} = 0.006 + \frac{0.0042 * (60^2 - 30^2)}{3000} * 0.7 = 0.0086 = 8.6\%$$

__2.7 Acceleration Resistance:__

It is related to:

- Mass of train.
- Acceleration needed.

Additional force needed

$$R_{ac} = \text{Mass of train} * \text{Acceleration} = M * ac$$

$$= \frac{1000\,(w_l + w_v)}{g} * ac \qquad (kg) \longrightarrow \qquad M = \frac{1000(w_l + w_v)}{g}$$

Specific R_{ac} $= \dfrac{1000}{g} * ac$ *(kg/ton)* where:

ac: acceleration resistance *(m/sec^2)*.

g : acceleration due to gravity *(m/sec^2)*.

To calculate R_{ac} for train to be accelerated from v_1 to v_2 *(km/hr)* at time t_1 to t_2 *(sec)*:

$$R_{ac} = \frac{1000}{9.81} * \frac{(v_2 - v_1)}{(t_2 - t_1)} * \frac{1000}{60*60} = 28.3 * \frac{(v_2 - v_1)}{(t_2 - t_1)}$$

For a train accelerated from v_1 = 20 *km/hr* to v_2 = *70 km/hr* at time of *2 sec:*

$$R_{ac} = 28.3 * \frac{(v_2 - v_1)}{(t_2 - t_1)} = 28.3 * \frac{(70-20)}{(2*60-0)} = 11.79 \quad (kg/ton)$$

2.8 Resistance due to Starting:

From the equation of ***Strahl*** the first term = *2.5* it means the self resistance of vehicles resulting from friction at Journal box and resistance between track and wheels and it equal grade of *2.5%.* It means that the stations (track) must be horizontal or not more than *2.5%* grade to prevent the train from going down.

التجارب أثبتت أن الوقوف لمدة طويلة يزيد من الاحتكاك نظرا لانخفاض درجة الزيوت. أن سرعة البدء يمكن التلاعب بها كما يلي: يتحرك القطار حركة خفيفة إلى الخلف ولوجود فراغ بيت عربات البضائع فهناك مسافة بينها وعند التحرك لا تتحرك كل العربات دفعة واحدة بل بالتدريج وهذا يساعد على الحركة. وتظهر المشكلة عند التوقف على الانحدار فلا يوجد خلوص وبذلك نحتاج إلى قاطرة مساعدة للتغلب على الانحدار.

2.9 Air Resistance:

Max. magnitude of air resistance at lateral with angle of 60^o between the direction of wind and direction of train at wind speed more than *35 km/hr*.

2.10 Resistance due to Extra Load :

$$R_{15\ kwatt} = \frac{68}{V} \quad (kg/ton)$$

$$R_{4\ kwatt} = \frac{47}{V} \quad (kg/ton)$$

Changeable

$R_{15\ kwatt}$: Resistance in (*kg/ton*) for generator (*15 kwatt*)

$R_{4\ kwatt}$: Resistance in (*kg/ton*) for generator (*4 kwatt*)

2.11 Total Resistance:

It is the sum of all resistances multiplied by the total weight of train:

$$R_T = (w_l + w_v) * \lfloor R_{(a+r)specific} + R_c + R_g + R_{ac} \rfloor + (w'_v) * R_{kwatt}$$ where

R_T: Total resistance

w_l: weight of train (ton)

w_v: weight of vehicles (ton)

w'_v: weight of vehicles which have mounted generators or A.C.

If there is no terms that mentioned above, the relation will be valid. When the total resistance is less than the tractive force then the train will be in state of acceleration. When its equal other, the speed will regular. When the resistance will be greater than tractive force then they are decreasing the acceleration rate of the train and the train will stop.

Tractive Force

3-1 Types of Locomotives:

1. *Steam Locomotive:*

A three numbers are used to define the locomotive:

Firstly: number of wheels at the front.

Secondly: number of tractive wheels, and

Thirdly: number of rear wheels.

For example: *4-6-4* the locomotive has *4* front wheels, *6* tractive wheels, and *4* rear wheels.

0-6-0 all wheels of locomotive is tractive and they are *6*.

2. *Diesel and Electric Locomotives:*

They are included numbers and letters. They can be described as:

A: one axle contains tractive wheels at the system of load.

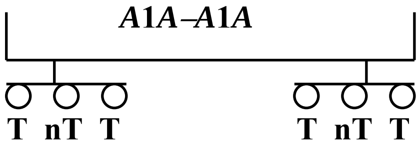
B: two axles contain tractive wheels at the system of load.

C: three axles contain tractive wheels at the system of load.

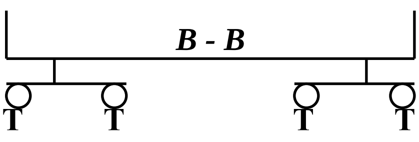
1: one axle contains non-tractive wheels.

For example: Fig. 3-1 below shows the type of diesel and electric locomotives

Locomotive A1A – A1A



Locomotive B - B



Locomotive C - C

Locomotive B – A1A

Locomotive B-B – B-B

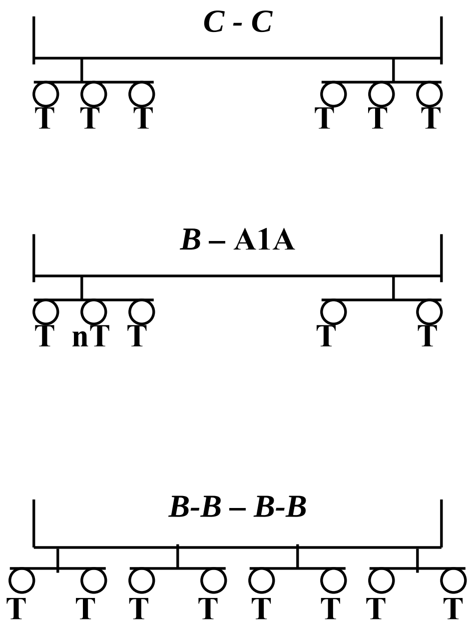


Figure (3-1) Types of Diesel and Electric Locomotives.

3-2 Types of Vehicles:

1. Box cars.عربات صندوقية
2. Gondola cars.عربات كشف
3. Flat cars.عربات سطحية
4. Hopper cars.عربات مخروطية
5. Tank cars.عربات صهاريج
6. Refrigerator cars.عربات ثلاجات
7. Caboose cars.سبنسات

The last type of vehicles are cars to be **added** at the end of the train to help in braking in case of using good cars with brake system.

Passenger cars:

Length = *l = 18.3-26.85 m* at average = *22 m*

Weight = *w = 45-50 tons*

3-3 Comparison between Diesel and Steam Locomotives:

1. In case of diesel locomotive, it can be found the total power from the beginning and even before the movement of the train it leads to get high acceleration.
2. Clean locomotive (diesel).
3. Dynamic effect of steam locomotive on track.
4. For the same power, the diesel locomotive is longer than the steam locomotive.
5. There is no need to stop for supplying water and coal in case of diesel locomotive.
6. There is accurate timing (diesel)..
7. Double cost (diesel than steam).
8. Cost of operation for diesel less than steam locomotive.
9. Steam locomotive going not to be used since *1963*.

3-4 Transmission of Power:

1) *Mechanical Transmission:* it is similar to cars (gear box), for many hundreds of *hp.*

2) Hydraulic Transmission: for *200-800 hp.*

3) Electric Transmission: the engine will rotate the generator and then there is electrical motors on the axles.

3-5 Calculation of Tractive Force:

A. Diesel Locomotive:

$$Power = T_e * v \qquad (watt)$$

$$Power * 75 = T_e * \frac{v}{3.6} \qquad (horses)$$

$$T_e = \frac{270 * Power_{(hp)}}{v} \qquad \text{where}$$

T_e = Tractive effort *(kg)*

v = Speed *(km/hr)*

An efficiency factor of *(80-85%)* was added, then:

$$T_e = \frac{0.82 * 270 * Power_{(hp)}}{v}$$

$$T_e = \frac{220 * Power_{(hp)}}{v} \qquad (kg)$$

B. Electrical Locomotive:

The electrical locomotive receives the current either from the third rail or from overhead wires. In case of using the current, voltage of *600 volts* was used by the third rail, while the current of overhead were *1500-300 volts*.

Tractive Force can be divided to :

a. *Force needed for acceleration (against acceleration resistance):*

$$F_{ac} = mass * a_c'$$

$$= \frac{1000(w_\lambda + w_v)}{9.81} * \frac{1000}{60 * 60} a_c$$

$$= 28.3(w_\lambda + w_v) * a_c \qquad (kg) \qquad \text{where:}$$

a_c' : acceleration *(m/sec²)*

a_c : acceleration *(km/hr/sec)*

For the purpose of rotation, the above sum must increase by *8-12%* :

$$F_{ac} = 31(w_\lambda + w_v) * a_c \qquad (kg)$$

b. Force needed for $R_{r+a} + R_g + R_c$:

Tension force needed for other resistances that is equal to:

$$T_F = (w_\lambda + w_v) * (R_{r+a} + R_g + R_c) \qquad (kg)$$

Then the total force needed to move the train will be:

$$= (w_\lambda + w_v) * (31 * a_c + R_{r+a} + R_g + R_c) \qquad (kg)$$

<u>Example 3-1:</u> Calculate the tension force to insure a velocity from break state to (90 km/hr) at a time of (3 minutes) knowing that the weight of train equal to (400 tons), the grade was 5%, suppose the rate of acceleration is constant and the resistance due to rolling and air was (6 kg/ton).

<u>Solution:</u>

$$T_F = (w_\lambda + w_v) * (R_{r+a} + R_g + R_c)$$

$$= 400\left(31 * \frac{90\, km / hr}{180 \sec} + 6 + 5\right) = 10{,}600 \ \ kg$$

❖ *<u>Tension force of train at the beginning of movement :</u>*

Work on the wheel = work from motor

π D T = Tourge moment * 2 π * 30.5 * No. of motors * efficiency * $(\frac{A}{B})$

$$\boldsymbol{\pi}\ \mathbf{D}\ \mathbf{T} = \boldsymbol{T_m} * 2\pi * 30.5 * N * \zeta * (\frac{A}{B})$$

$$\mathbf{T} = \frac{61 * T_m * N * \zeta}{D} * \frac{A}{B} \qquad \text{where}$$

T = Tension force for locomotive (kg)

D = Diameter of tracking wheel (cm)

T_m = Tourge moment for one motor (*kg.cm*) to be taken as *90%* of designed magnitude.

N = Number of motors.

ζ = Efficiency of gear working = *0.96*

$\frac{A}{B}$ = Gear ratio.

<u>Example 3-2:</u> Calculate the tension force for locomotive contains six motors knowing that the tourge moment at the beginning of movement equal to (310 kg.cm). The ratio of gear = (62/15), diameter of tracking wheel (1 m).

<u>Solution:</u>

$$\mathbf{T} = \frac{61 * T_m * N * \zeta}{D} * \frac{A}{B} = \frac{61 * 310 * 0.9 * 6 * 0.96}{100} * \frac{62}{15} = 4050 \quad kg$$

❖ <u>*Tension force at any speed :*</u>

When the tension force is known at any speed, it possible to find the tension force at other known speeds according to:

a) <u>*Continuous Current:*</u>

$$\frac{T_1}{T_2} = \left[\frac{v_2}{v_1}\right]^3$$

b) <u>*At Single Phase Motor:*</u>

$$\frac{T_1}{T_2} = \left[\frac{v_2}{v_1}\right]^{5/3}$$

3-6 Net Tractive Effort or Drawbar Pull :

It can be found by subtracting the resistances on locomotive from the tractive effort, i.e.:

$$Net\ T_F = T_F - [R_{(r+a)locomotive} * wt.\ of\ locomotive]$$

3-7 Coefficient of Adhesion between Tracking Wheel & Track :

It depends on the materials of track and wheels and if it is dry or not. If it is greased, the coefficient is equal to *0.15* for wet track & *0.30* for dry clean track.

$$F_{ad} = C_{ad} * wt.\ on\ tracking\ wheels = 1000\ \mu * w$$ where

F_{ad} = Adhesion force measured in *(kg)*

$C_{ad} = \mu$ = Coefficient of adhesion

$$C_{ad} = \mu = \frac{1}{1000} * \left[\frac{9000}{42 - v} + 116 \right]$$

w = Weight on tracking wheels *(ton)*

v = Speed *(km/hr)*

Note: ***F_{ad} must be greater than the resistances.***

F_{ad} can be increased by:

1. increasing of load on tracking wheels.
2. increasing of coefficient of adhesion μ , but it is not easy because it depends on the type of materials. Coefficient of adhesion can be increased by adding sand in front of tractive wheels in some cases.

3-8 Equivalent Straight Line :

If the resistances of line due to curvature and grade ($R_g + R_c$) is equal to the resistance of straight line due to grade only R_g (no curvature), the last line is named as *Equivalent Straight Line.*

For example: a line of grade *(5%)* and in same time has a curve of radius *r* equals *(500 m),* then:

$$R_c = \frac{630}{r} = 1.26\ kg/ton = 1.26\% \qquad and \qquad R_g = S = 5\ kg/ton$$

Hence, the grade of Equivalent Straight Line is = *5% + 1.3% = 6.3%*

3-9 Ruling Grade :

- It is defined as the max grade which the weight of train can be decided for locomotive (known type) can tract it at known speed.
- This grade is the max grade can be used except in some cases which are allowed to use supported locomotive at grades that are greater than the ruling grade as found in USA.
- When the curve lays at this ruling grade, the grade must be decreased at the same magnitude of curve resistance.
- Always the ruling grade has to be taken as:

  5% in flat areas.

  10% in rolling areas.

  25% -30% in mountain areas.

To ensure rolling, it should be that the tractive force or the adhesion force (the minimum one of them) must be grater than the total resistances. i.e.:

$$T_F \geq (w_\lambda + w_v) * (R_{r+a} + R_g + R_c)$$

When $(R_g + R_c)$ is the max, it named R_{rg} where:

R_{rg} : Resistance due to Ruling Grade.

Then $T_F \geq (w_\lambda + w_v) * (R_{r+a} + R_{rg})$

In maximum cases, we find that: $R_{rg} = \dfrac{T_F}{(w_\lambda + w_v)} - R_{(a+r)}$

It means that:

$$T_F = (w_\lambda + w_v) * R_{r+a} + (w_\lambda + w_v) * R_{rg}$$

Then: $$R_{rg} = \frac{T_F - (w_\lambda + w_v) * R_{(a+r)}}{(w_\lambda + w_v)} = \frac{T_F}{(w_\lambda + w_v)} - R_{(a+r)}$$

At the smaller speeds and at T_F greater than adhesion force:

$$R_{rg} = \frac{1000 \quad \mu w_1}{(w_\lambda + w_v)} - R_{(a+r)\,specific}$$

It is obvious that the ruling grade will be decreased with increasing the weight of the train. Minimum speed will be allowed on the ruling grade is (*15-25 km/hr*) or taken the mean speed between entrance and exist speed.

Example 3-3: ***Calculate the ruling grade for the locomotive type of A1A - A1A, weight of (120 ton) with energy of (2000 hp). The number of vehicles are (40 veh) each one of (20 ton) weight, the weight of added vehicles is (30 ton) and the speed at ruling grade is (50 km/hr). Using the Strahl Equation given that K=3000, ΔV =12 km/hr. Prove that if the locomotive can tract the train while it stopped at the ruling grade.***

Solution:

$$R_{(r+a)\ vehicle} = 2.5 + \frac{(V + \Delta V)^2}{K} \quad \text{--------------------------------}(1)$$

$$= 2.5 + \frac{(50 + 12)^2}{3000} = 3.78 \ kg/ton$$

$$R_{(r+a)\ locomotive} = \frac{250}{w}\left[\frac{V + \Delta V}{100}\right]^2 \quad \text{-----------------------------}(2)$$

$$= \frac{250}{120}\left[\frac{50 + 12}{100}\right]^2 = 0.8 \ kg/ton$$

$$R_{(r+a)\ specific} = \frac{R_{(r+a)vehicle} * \text{weight of vehicles} + R_{(r+a)locomotive} * \text{weight of locomotive}}{\text{weight of vehicles and locomotive}}$$

$$= \frac{3.78 * (40 * 20 + 30) + 0.8 * 120}{(40 * 20 + 30) + 120} = 3.4 \ kg/ton$$

Adhesion force $= F_{ad} = 1000\,\mu * w_1$

where:

$\mu = 0.214$ *at range of (0.15-0.30)*

$w_1 = 120 * (4/6) = 80$ *ton* *(4/6)= no. of tractive wheels of locomotive type of A1A - A1A*

Then $F_{ad} = 1000 * 0.214 * 80$

$= 17120$ *kg*

Hence $T_F = \frac{220 * Power_{(hp)}}{v}$

$= \frac{220 * 2000}{50} = 8800$ *kg*

Verifying:

When the train stopped on the ruling grade, it must be sure that the tension force of locomotive (which means the adhesion force) is greater than the sum of resistances on the grade. It is always equal to resistances of starting and ruling grade.

$\mu = 0.33$ *at* $v=0$

Then $F_{ad})_{v=0} = 1000 * 0.33 * 80 = 26400$ *kg*

$\sum$ *resistances* $= 950\ (12.8 + 5.85) = 17718$ *kg*

$T_F = Fad)_{v=0} = 26400 > 17718$ *kg*

Therefore, the locomotive can tract the train where it stopped on the ruling grade.

Example 3-4: ***If the ruling grade for track equal to 5%. Calculate the max number of vehicles can be tracted at a speed of (100 km/hr). given that the weight of vehicle = (45 ton), the locomotive of diesel type C-C of (132 ton) weight and energy (of 2200 hp).***

Solution:

Weight of train = 40 n+ 132 ton

$$R_{(r+a)\ vehicle} = 2.5 + \frac{(V + \Delta V)^2}{K} \quad \text{--------------------------------(1)}$$

$$= 2.5 + \frac{(100 + 12)^2}{4000} = 5.65 \ kg/ton$$

$$R_{(r+a)\ locomotive} = \frac{250}{w}\left[\frac{V + \Delta V}{100}\right]^2 \quad \text{-----------------------------(2)}$$

$$= \frac{250}{132}\left[\frac{100 + 12}{100}\right]^2 = 2.38 \ kg/ton$$

$$R_{(r+a)\ specific} = \frac{R_{(r+a)vehicle} * \text{weight of vehicles} + R_{(r+a)locomotive} * \text{weight of locomotive}}{\text{weight of vehicles and locomotive}}$$

$$= \frac{45 * n * (5.65) + 2.38 * 132}{45 * n + 132} = \frac{255 * n + 315}{45 * n + 132} \quad kg/ton$$

$$T_F = \frac{220 * Power_{(hp)}}{v} = \frac{220 * 2200}{100} = 4840 \quad kg$$

$$4840 = (45 * n + 132)\left[\frac{255 * n + 315}{45 * n + 132} + 5\right]$$

$$4840 = 255 * n + 315 + 255 * n + 660$$

$$4840 = 480 * n + 975$$

$$n = 8 \ vehicles$$

<u>Example 3-5:</u> It is needed to calculate the number of good vehicles which diesel locomotive type of A1A - A1A can tract. Knowing that the weight of one vehicle = (40 ton) (4 axles), speed of (50 km/hr), energy of (2500 hp) and (132 ton) weight. The added vehicles of (25 ton) weight. The grade lines and radius are presented the following table:

Grade %	*5*	*0*	*6*	*4*	*7.2*
Radius (m)	*800*	*1500*	*500*	*900*	∞

Verifying if the locomotive can tract the train if it needed to stopping on the ruling grade. Use Davis Equation to solve this example.

<u>Solution:</u>

$$R_{(r\,+\,air)} = 0.6 + \frac{13}{w} + AV + \frac{BCV^2}{nw} \quad \text{----------------} \quad \textbf{Davis Equation}$$

$$R_{(r\,+\,air)locomotive} = 0.6 + \frac{13}{22} + 0.0085 * 50 + \frac{0.0045 * 11.2 * 50^2}{132} = 2.54 \quad kg/ton$$

$$R_{(r\,+\,air)vehicles} = 0.6 + \frac{13}{10} + 0.013 * 50 + \frac{0.001 * 8 * 50^2}{40} = 3.05 \quad kg/ton$$

$$R_{(r\,+\,a)\ specific} = \frac{2.54 * 132 + 3.05 * (40 * n + 25)}{132 + 40 * n + 25} = \frac{411.53 + 122 * n}{157 + 40 * n}$$

Grade %	**5**	**0**	**6**	**4**	**7.2**
Radius (m)	**800**	**1500**	**500**	**900**	∞
R_c	*0.788*	*0.42*	*1.26*	*0.7*	*0*
R_{cg}	*5.788*	*0.42*	*<u>7.26</u>*	*4.700*	*7.2*

The max ruling grade to be taken is 7.26%.

$$T_F = \frac{220 * Energy}{v} = \frac{220 * 2500}{50} = 11000 \quad kg$$

$F_f = 1000\, \mu * w_1$

$w_1 = 132*(4/6) = 88$ *ton*

$$\mu = \frac{1}{1000}\left[\frac{9000}{42+50} + 116\right] = 0.2137$$

$F_f = 1000 * 0.2137 * 88 = 18816.7$ *kg*

Then:

$T_F = [\, R_{(r+a)} + R_{(rg)} \,] \, ((132+25)+ 40* n)$

$11000 = [\, 411.53 + 122 * n + 7.26 * 157 + 7.26 * 40 * n \,]$

$n = 22.91$ *vehicles*

Hence: 22 vehicles to be taken

$$\mu = \frac{1}{1000}\left[\frac{9000}{42+zero} + 116\right] = 0.33$$

$F_f = 1000 * 0.33 * 88 = 29065.14$ *kg*

$Resistance = [\, R_{st} + R_{cg} \,] \, (w_\lambda + w_v + 25)$

$= [12.8 + 7.26]\,(132 + 40 * 22 + 25)$

$= 20802.22$ *kg/ton*

$F_f >$ *Resistance* *So the train could tract the vehicles if it needed to stopping on the ruling grade.*

3-10 Virtual Length :

When it is needed to make a comparison between many lines to connect two points, the comparison usually depends on the work which the locomotive insure it. Then can be regarded by the work can cover the resistances at the line.

$$L_v \; (R_{(r+a)}) = (R_{(r+a)} + R_{(g)}) \; l$$

$$L_v = \frac{R_{(a+r)} + R_{(g)}}{R_{(a+r)}} * l = \left(1 + \frac{R_{(g)}}{R_{(a+r)}} \right) * l$$

When $l = 1\ km$ and $R_{(r+a)} = 2.5\ kg/ton$ at smaller speeds:

$$L_v = 1 + 0.4 * R_g$$

In the case of grade = *2.5% :*

$$L_v = 1 + 0.4 * 2.5 = 2\ km$$

It means that *1 km* at grade line of $R_g = 2.5\%$ equals (from point of tractive force) two kilometers on the straight line.

In case of existence of curvatures:

$$L_v = \left(1 + \frac{R_{(c)}}{R_{(a+r)}} \right) * l$$

In case of existence of curvature and grade:

$$L_v = \left(1 + \frac{R_{(g)}}{R_{(a+r)}} + \frac{R_{(c)}}{R_{(a+r)}} \right) * l$$

Example 3-6 : ***Calculate the virtual length of a line of (20 km) length with upgrade = 5%, the line will contain a curve of (800 m) length at radius of (500 m). Assume that $R_{(r+a)}$ = 4 kg/ton*** .

Solution:

$$L_v = \left(1 + \frac{R_{(g)}}{R_{(a+r)}} + \frac{R_{(c)}}{R_{(a+r)}}\right) * l$$

$$= l + l_1 * \frac{R_g}{R_{a+r}} + l_2 * \frac{R_c}{R_{a+r}} \qquad R_c = \frac{630}{r} = \frac{630}{500} = 1.26 \quad kg/ton$$

$$= 20 + 2 * \frac{5}{4} + 0.8 * \frac{1.26}{4}$$

$$= 22.752 \quad m$$

3-11 Mean Virtual Length :

It can be defined as the ratio of L_v of two directions of grades.

$$L_v = \frac{L_v(upgrade) * A + L_v(downgrade) * B}{A + B}$$

Where:

A= volume of transporting at upgrade direction.

B= volume of transporting at downgrade direction.

3-12 Breaks :

The purpose of breaks is to help the train to stopping or decrease its velocity at min time and min distance. The break action is take place by the pressure of break discs on the wheels. It makes very high resistance to be added to the known resistances. If the breaking force is very high, it causes the stopping of wheels but it is sliding on the rail.

Points must be considered in breaking :

1) ***Continuity :*** to achieve high breaking force, the breaking system should be provided with all vehicles.
2) ***Automatic :*** when any fault happened in the connection of break, the breaking system must work automatically.
3) ***Ability of Calibration :*** it means the controlling of breaking force when it is needed such as the needing of high breaking force at downgrade direction.

Two types of braking system are as following :

a) *Compressed Air braking System .*
b) *Vacuum Air braking System .*

For the first type : Compressed Air braking System :

1. ***Westinghouse (direct breaking):***

It was designed on 1869. it contains a piston, air reservoir as shown in Fig.3-2:

i. Direct-Continuous: connected with all train connections.
ii. Controlling ability.

iii. Non-automatic when a break of tubes: there is no ability to breaking system to be worked.

2. Automatic Westinghouse breaking:

i. Continuous : for all vehicles.

ii. Automatic to stopping when error happened.

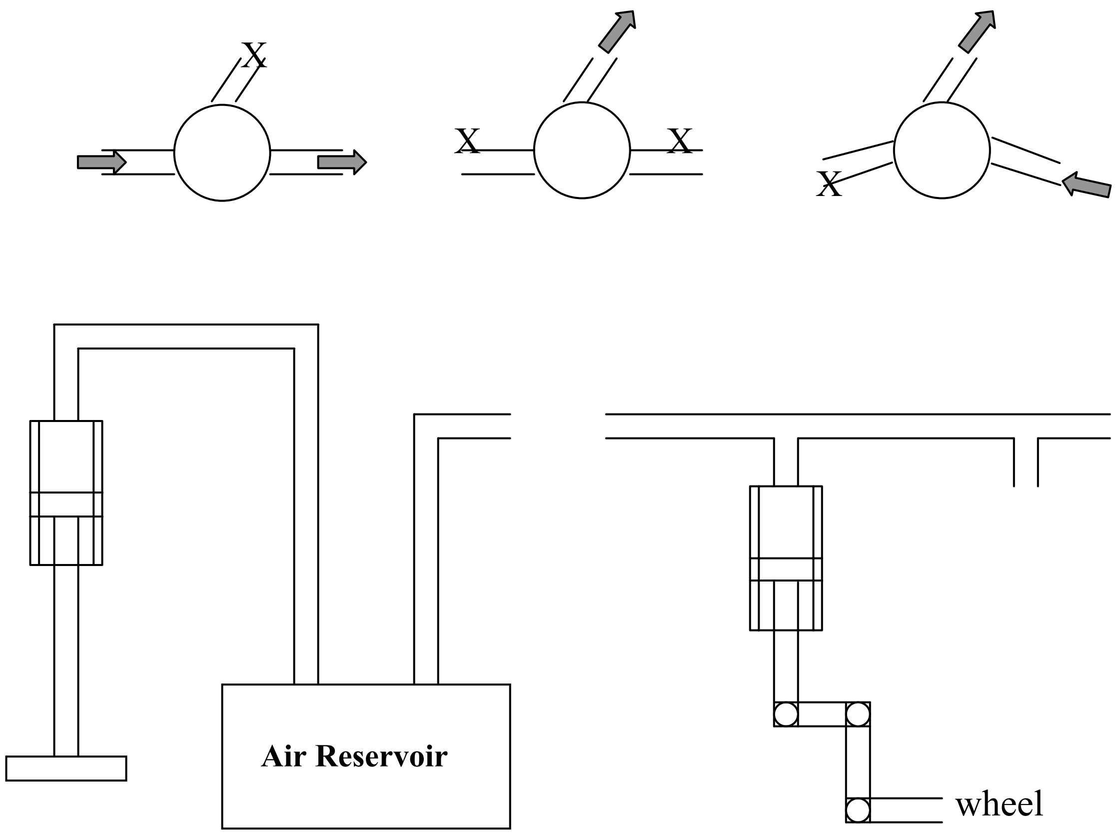


Figure (3-2) Westinghouse (direct breaking)

The Track

4.1 Definetion :

A railway track consists of two parallel rail tracks, formerly made of iron but now of steel, generally mounted upon cross beams termed "sleepers" or "railroad ties" which are sometimes made of timber, concrete or steel as shown in Fig.4-1.

Figure (4-1) Rial Tracks.

4-2 Track : Fig.4-2 gave an imagation of track embackment which is consisted of:

First : Infrastructure **البناء التحتي**

And it is named as subgrade.

Second : Superstructure **البناء الفوقي**

1. Ballast section.
2. Sleepers.
3. Rail and its fastening.

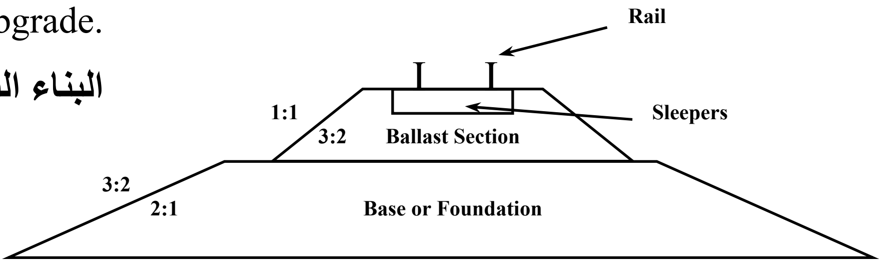


Figure (4-2) Track Embankment

4-2-1 Subgrade :

It is needed to decide the right of way, which its width depends on:

- Number of tracks.
- Height of subgrade and ballast and inelination.
- Requirments of drainage.

يجب أن تزال الحشائش والنباتات الضارة القريبة من السكة بطرق معينة للاسباب التالية:

1. تحسين الرؤية ليتمكن السائق من التحقق من مدلول الاشارات.
2. تحسين صرف المياه: وذلك بعمل مبازل جانبية لابعاد المياه عن السكة.
3. تقليل احتمال نشوب الحرائق: بازالة الحشائش والنباتات وقلعها من جذورها لان وجودها يتسبب بتكاثر البكتريا التي تؤدي فيما بعد الى وجود فراغات في التربة يخزن فيها الماء مما يضعف من طبقة التربة المقام عليها السكة.
4. منع وجود بخار الماء الذي يسبب الصدأ للسكة.
5. سهولة تحرك عمال الصيانة.
6. تقليل قيمة معامل التماسك بين السكة والعجلة.
7. تقليل تكاليف الصيانة بالمحافظة على Ballast section .

4-2-2 Purpose of Track Foundation :

1) To make regular bed to put the ballast section.
2) To support the load coming for ballast and train.
3) To privide good drainage.

4-2-3 Side Slope :

It was taken the *angle of repose*. The side slope (H:V) is considered according to the type of soil:

3:2 to 2:1 for cohesion & noncohesin soil foundation (clay or sand)

1:5 to 1:10 for rock soil foundation

However, in cohesion soil, the height of the slope should be not more than that causes the shear failure.

Hence,

$$\gamma h = 2.57\, q_u \qquad \text{where:}$$

γ: density of soil *(ton/m³)*.

h: height *(m)*.

q_u: unconfined compressive strength *(ton/m²)*.

For example, assume that $q_u = 1\ kg/cm^2$ and $\gamma = 1.8\ ton/m^3$ then:

$$max\ h = \frac{2.57 * 1kg / cm^2 * 100 * 100\, cm^2 / m^2}{1000\, kg / ton * 1.8} = 14.5\ m$$

4-2-4 Steps for Construction of Track Foundation :

1. Preparing of natural ground surface by releasing of trees….etc.
2. Adding a layer of soil of *(15-20) cm*.
3. Compaction of layers according to the type of soil:
    a. Sheep foot raller for cohesion soil (clay or silty-clay).
    b. Vibrating compactor for cohesinless or small cohesion soil.
4. Compaction at OMC to prevent swelling at degree of compaction ≥ 90%:

$$\frac{density.of.soil}{\max.density} * 100 \geq 90\%$$

5. The soil of good properties to be put at the top and slopes while the soil of low properties to be put at the middle.
6. Finishing: it must be compact (well) for the surface soil and gently finished without any excavation to prevent bad drainage. The top soil may be of L.L. = 20-35.

4-2-5 The Good Properties of Soil to Be Used in Construction :

1. high shear strenth (C & φ).
2. high permeability.
3. low compressibility.
4. low capillary tube property.
5. low change of volume at increasing of water content.
6. low elasticity (ability of soil to return to its heiht after releasing the load).

4-2-6 Disadvantages of Track Foundation :

1. unstable foundationleads to increaseing of maintenance cost.
2. low speed of train.
3. may cause accidents.
4. may find soft spots filled with water which are at last caused sliding or failure as shown in Fig.4-3.
    - These spots increase by increasing the movement.
    - Sliding will happen as a result of rain. It is dangerous type of unstable soil.

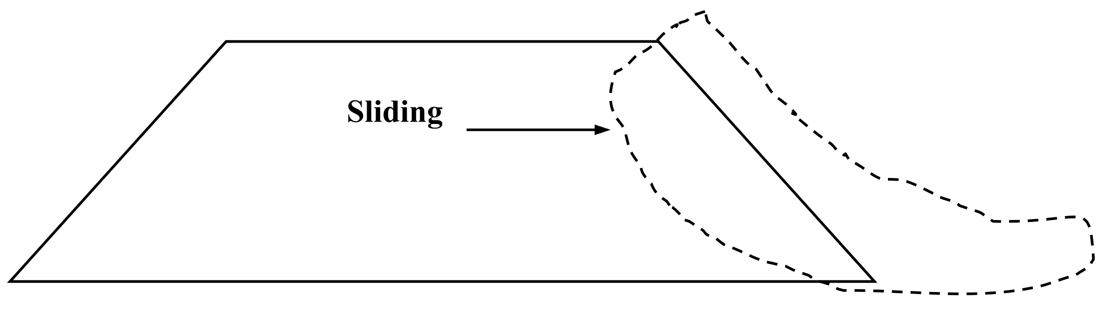


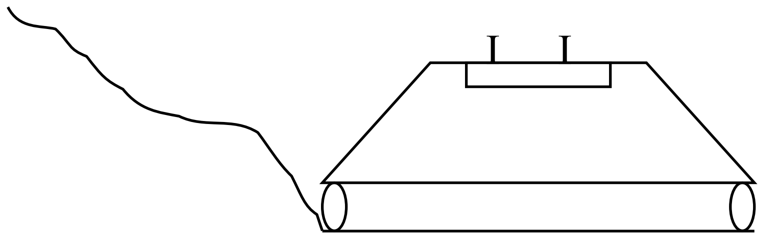
Figure (4-3) Sliding Failure.

5. settelment as a result of compressed soil and natural soil as shown in Fig.4-4.

Figure (4-4) Settlement of Soil.

4-2-7 Treatment of Track Foundation (Roadbed Stabilization):

1. *Drainage of water*: must be far away from the track embankment as shown in Fig. 4-5.



Galvanized Pipe with (8-10 inch) Diameter.

Figure (4-5) Drainage of Water.

2. *Pressure grouting*: Fig.4-6 bellow shows the pressing of soft cement-sand mortor at ballast section:

   Cement-sand 1:1 to 1:6 for rich mix

   1:12 for lean mix

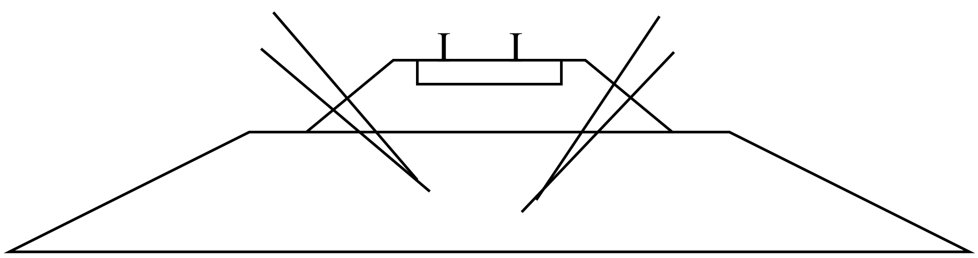


Figure (4-6) Pressure Grouting.

3. *Piling*: to support the ballast section as shown in Fig.4-7 below:

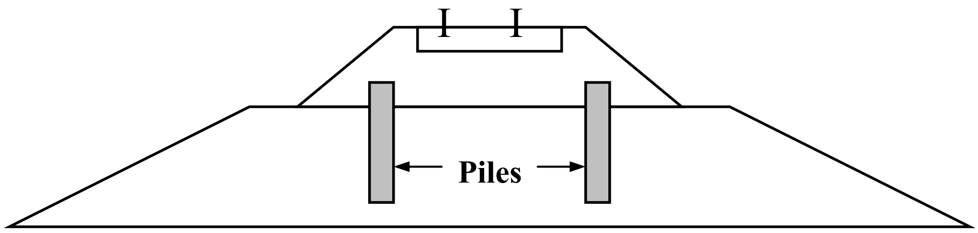


Figure (4-7) Piling.

4. *Sand piles*: halls to be excavated between rails and filled with sand to help in vertical drainage.
5. *Sand filled with blast holes*: it is modified for the previous way. Halls can be made by exclusive materials as shown in Fig. 4-8.

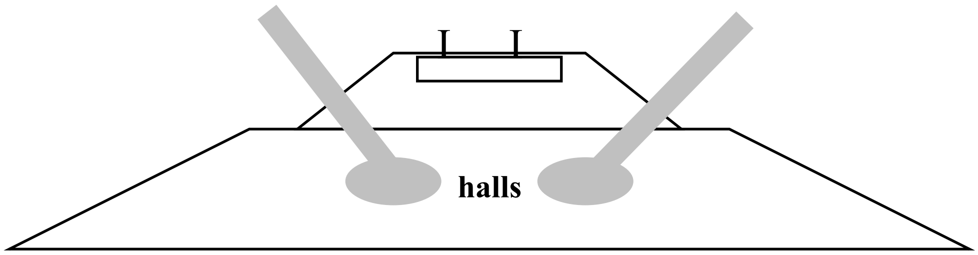


Figure (4-8) Sand Filled with Blast Holes.

6. *Mats*: to put pannels of reinforced concrete on the roadbed.
7. *Retaining walls*: it made of used sleepers and rails and put to prevent the sliding of slopes.
8. *Chemical materials*: to be mixed with soil to improve its properties.
9. *Neoprene sheet*.
10. *Bitumen coating*: to prevent the soil from water table.
11. *Releasing of trees*: by
    - Burning.
    - Mechanically or manually.
    - Chemically.

4-3 Ballast Section :

The ballast section is important for the track. It means, in case of no ballast section, the sleepers will implent in the foundation.

4-3-1 Purposes of Ballast Section :

1) Transfer the load of train to the roadbed.
2) Stability of sleepers at its positions.
3) Allowing of water to drain.
4) To provide easy operation and maintenance.
5) Prevent growing of herbs.
6) Absorbtion of impacts.

4-3-2 Properties of Good Ballast Section :

1) High elastic (ability of particles to move between them).
2) High resistance against erosion.
3) High resistance against crushing.
4) Ability of drainage.
5) Clean section (no organic materials).

4-3-3 Types of Ballast Section Materials :

A. *Natural Materials :*

1. ***Crushed Stone:*** such as granite, basalt,…..etc. it is high cost and grained to size *(2-6 cm).*

2. ***Gravel:*** natural materials to be cleaned by washing, releasing of fine material (clay) and then crashing of oversize particles.
    - Crashed stone more elastic.
    - Crashed stone more stable.
    - Crashed stone needs min maintenance.

3. ***Sand:*** not stable material especially if the particles are rounded or fines. It is effected by wind and rains.

B. *Side Results of Manufacturing :*

1. *Side results from manufacture of steel.*
2. *Carbon ashes and Clinker from the manufacture of cement.*

4-3-4 Tests May be Applicated on Ballast Materials :

a. *Sieve analysis*: for particles passing sieve *No.10*.

b. *Percentage of materials passing sieve No.200*: should not be greater than *1%.*

c. *Determination of percentage of soft particles*:

Releasing of particles passing sieve of opening *3/8 inch.* Then taken a sample of *1 kg* of ballast material ≥ *3/8 inch.* Each particles is rendered by a rod of copper of known dimensions and specification. The percentage of soft material is calculated, which has signed after rendering, must not be greater than *5%* (as weight).

d. *The percentage of clay lumps*: should not be greater than *0.5%.*

e. *Abrasion test*:

A sample of *5 kg* of material subjected to impact and erosion in a cylinder contains a spherical parts (cast iron). The cylinder may be rotated as *500 rph (30-33 rpm).* The fine materials passing sieve *No.12* may be calculated. Then the percentage of the last materials (finer than *No.12*) should not be greater than *40%* (as weight).

f. *Sound test*:

A sample of materials was sieved and weighted. The retained sample is submerged *16-18 hours* in sodium sulphate solution at 25^0C, then dried at $115\text{-}125^0C$, and finally cooled at 15^0C. The treated sample is weighted again and submerged in sodium sulphate solution. The sample is weighted to 5 times then to be sieved on the real sieve. The percentage of lossing in weight of sample should not be greater than *10%.*

g. *Density*:

A sample of materials of *2-4 inch* size is put at three layers in a specific mould of $1ft^3$ volume and compacted each layer by a tamping rod, of *1 inch* diameter and *24 inch* length, by a number of tamping = *25 blows* distributed on the surface of each layer. The sample is weighted after compaction to compute the density. The required density should be greater than $70\ Ib/ft^3$.

4-3-5 Choosing of Ballast Materials :

The choosing of materials depends on the following:

1) Requirement of transportation, the weight on axles, speeds, volume of transport. Heavy axles and high speed of train provide good ballast materials and thick section.

2) In the case of bad stability of embankment, the ballast section materials may punch in the embankment. In this case, it is possible to use cheaper materials to provide the stabilization. For example using of asphalt material.

3) Cost of instruction of ballast section related to the quality of materials.

The Purpose of Using of Asphalt Material for Stabilization of Ballast Section:

a) Isolated materials and prevented the water.
b) Increasing of stability of ballast section.
c) Increasing of ability of ballast section to minimize the effect of impacts.
d) Decreasing of maintenance cost.

4-3-6 Design of Ballast Section :

Thickness of ballast section must be adequate under the sleepers to distribute the pressure on the foundation as shown in Fig. 4-9 below. There are two factors must be considered the following:

1. The bearing capacity on the foundation is less than the allowable pressure at least.
2. Regular pressure distribution.

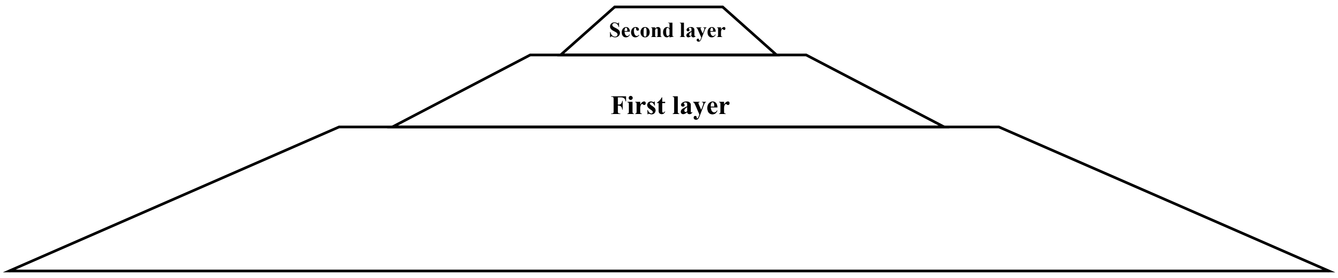


Figure (4-9) Ballast Section Design.

There are many equations to calculate the thickness of ballast section. In most countries, there is a use of two layers:

i. Low quality layer (first layer).

ii. High quality layer (second layer).

4-4 Talbot Equations :

By using pressure cells under the ballast layer shown in Fig.4-10 and to be compared with the bearing capacity of foundation. From this test, there are following relationships:

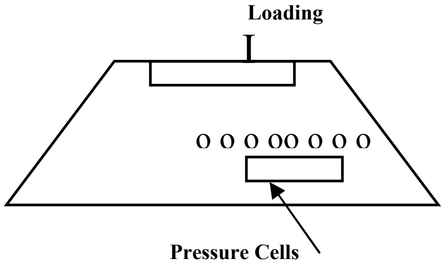


Figure (4-10) Pressure Cells.

a) Probability Equation :

$$\left(\frac{1}{2}+\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^n, n\left(\frac{1}{2}\right)^n, \frac{n(n-1)}{1*2}\left(\frac{1}{2}\right)^n$$

As shown in Fig.4-11

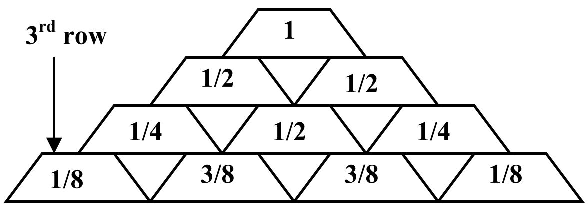


Figure (4-11) Ballast Section Rows.

where:

n = is the number of rows.

<u>*For example*</u>: the pressure at third row is:

$$\left(\frac{1}{2}+\frac{1}{2}\right)^3 = \left(\frac{1}{2}\right)^3, 3\left(\frac{1}{2}\right)^3, \frac{3*2}{1*2}\left(\frac{1}{2}\right)^3, \frac{3*2*1}{1*2*3}\left(\frac{1}{2}\right)^3 = \frac{1}{8}, \frac{3}{8}, \frac{3}{8}, \frac{1}{8}$$

when n go to be greater sum:

$$p = \frac{kP_o e^{-k^2b^2}}{\sqrt{\pi}} = \frac{kP_o e^{-k\ b^2}}{\sqrt{\pi}} \text{ -----------(1)}$$

where:

p = the vertical pressure at any point in the ballast section per unit area.

P_o = the pressure on the sleeper surface (down) at the surface of contact between the sleeper and the ballast section per unit length of sleeper.

k = coefficient depends on the depth.

b = horizontal distance from the center line of the sleeper to the point needed, as shown in Fig.4-12

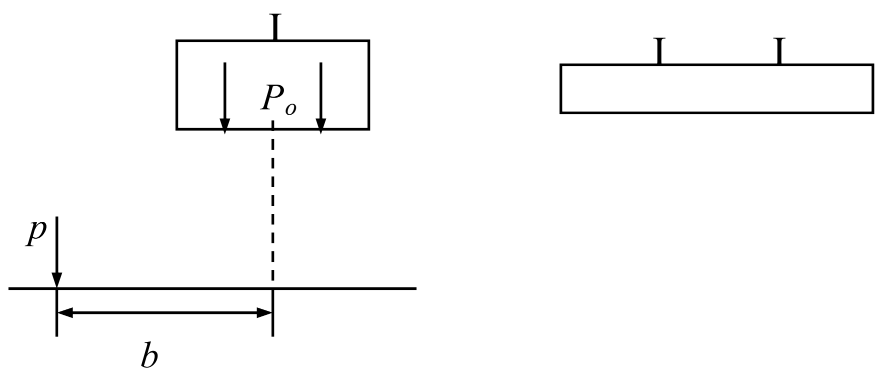
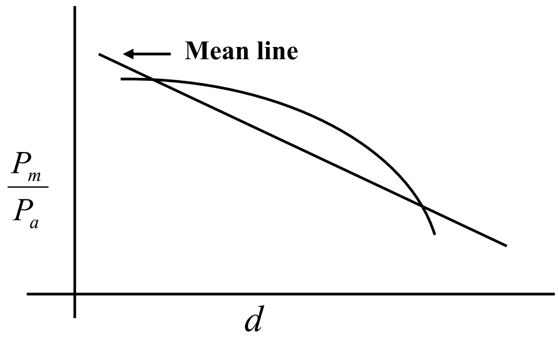


Figure (4-12) Vertical Pressure Distribution at any Point in The Ballast Section.

6) Another equation had been found practically :



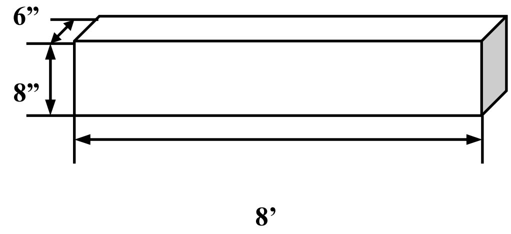


Figure (4-13) Pressure at any Depth in The Ballast Section.

As shown in Fig.4-13

where:

d = depth of ballast section.

$\frac{P_m}{P_a}$ = ratio of (P_m: pressure at any depth) to

(P_a: contact pressure between the sleeper and ballast section).

It was found that:

$$P_m = \frac{16.8 P_a}{d^{1.25}} \text{------------}(2)$$

where

P_m and P_a are pressures measured in *(Ib/in^2)*.

d is the depth measured in *(inches)*.

From equation 1 & 2, it can be found that:

$$P_o = 8\, P_a$$

Then $$p = \frac{8 k P_o e^{-k\ b^2}}{\sqrt{\pi}}$$

When $b = 0$

$$p = P_m$$

Then $$P_m = \frac{8kP_a}{\sqrt{\pi}} = \frac{16.8P_a}{d^{1.25}}$$

And $$k = \frac{2.1\sqrt{\pi}}{d^{1.25}}$$

$$p = \frac{16.8P_a}{d^{1.25}} e^{-13.9\left(\frac{b^2}{d^{2.5}}\right)} = \frac{16.8P_a}{d^{1.25}} (10)^{-6.05\left(\frac{b^2}{d^{2.5}}\right)}$$

In case of sleeper of width *10 inches*, it can be found that:

$$p = \frac{16.8P_a}{d^{1.25}} (10)^{-3.86\left(\frac{b^2}{d^{2.5}}\right)}$$

where

P_a measured in kg/cm^2.

b,d measured in inches.

Then p measured in kg/cm^2.

Now it can be found the vertical pressures at any point at the axes of sleeper and at any point at the right or left sides. To find the pressure under the set of sleepers, the pressure may be calculated at the needed point from the effect of every sleeper, then the sum of these pressures gives the total pressure as shown in Fig.4-14.

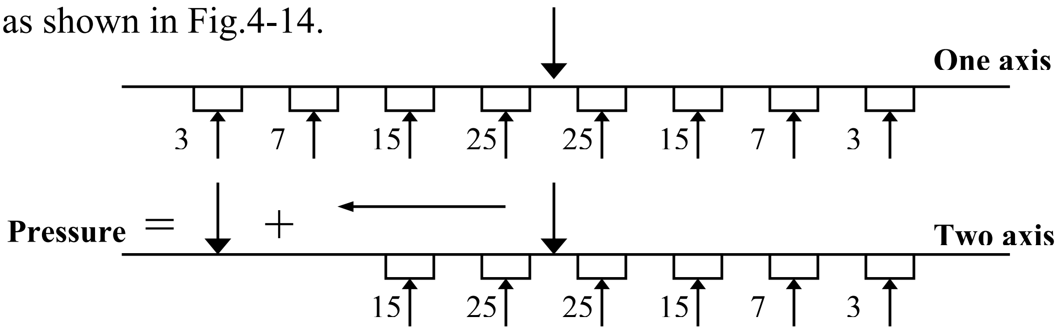


Figure (4-14) Vertical Pressure Distribution at any Point at The Axis of Sleeper.

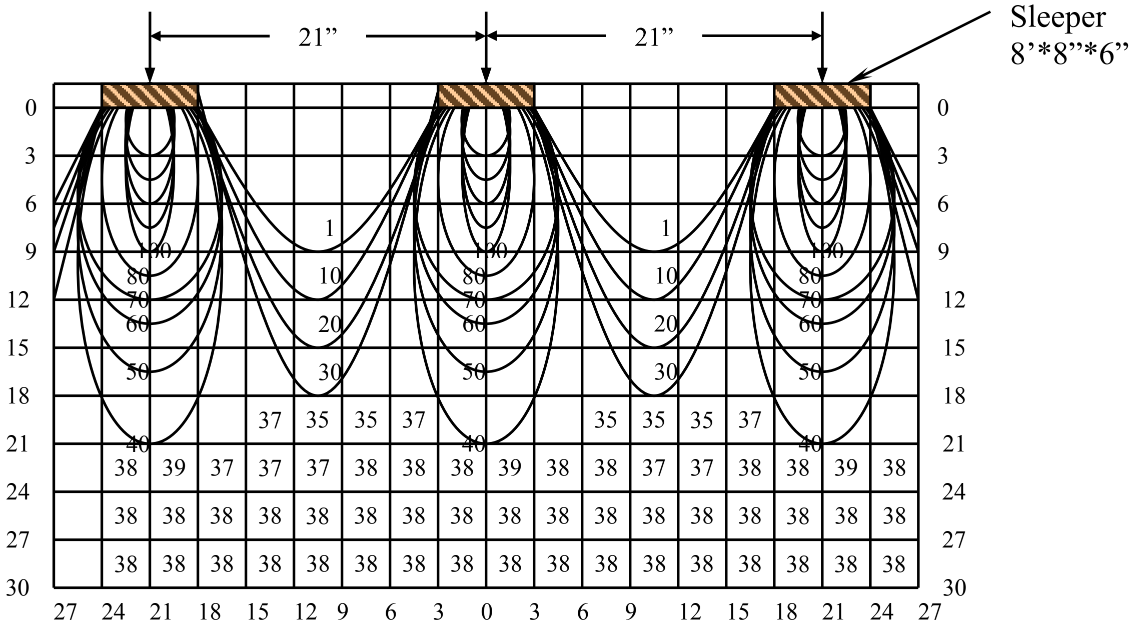


Figure (4-15) Pressure Distribution lines.

Fig.4-15 shows the pressure lines under three sleepers which are loaded. The values on these pressure lines represent the value of pressure as a percent of P_a.

Then the dynamic coefficient may be taken into account:

$$C_d = (v-5) * 0.6 \%$$

The dynamic coefficient effects after a speed of (*5 km/hr*). The load of axle was found practically to be distributed on three sleepers.

<u>Example 4-1:</u> ***A diesel locomotive type of A1A - A1A of weight = (132 ton) tract a passenger train of velocity of (105 km/hr). it is needed to calculate the max pressure under the axis of sleeper at the depth of (20 cm). Use Talbot Equations, knowing that sleepers is wooden of (15*25*260 cm) with a space of (49 cm).***

Solution:

Determine the dynamic coefficient C_d,

$$C_d = (v\text{-}s) * 0.6\ \% = (105\text{-}5) * 0.006 = 0.6$$

The total dynamic coefficient $= 0.6 + 1 = 1.6$

The total load on sleepers = $\frac{132 * 1.6}{6} = 35.2\ ton$

Where

The total load on sleepers = $\frac{wt.of.locomotive * dynamic.coeff.}{no.of.axles}$

Load on one sleeper = $\frac{35.2}{3} = 11.75\ ton$

$$P_a = \frac{11750}{260 * 25} = 1.8\ kg/cm^2$$

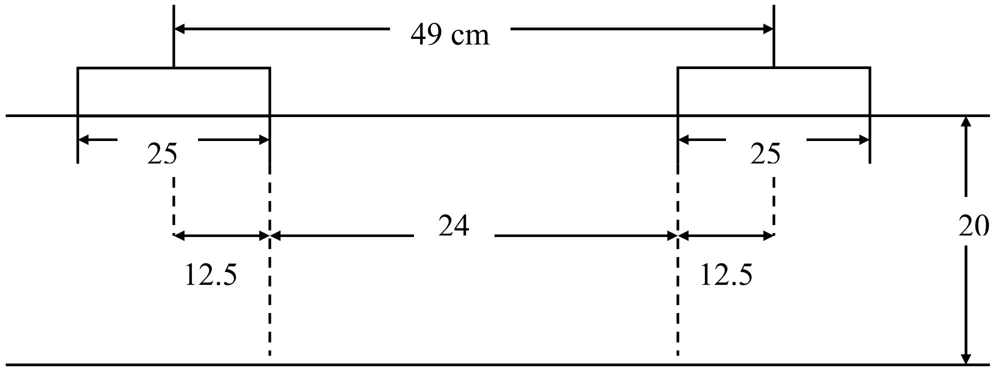
1) *Pressure under the sleeper directly (b= 0):*

$$p = P_m = \frac{16.8 P_a}{d^{1.25}} = \frac{16.8 * 1.8}{20^{1.25}} = 0.715\ \ kg/cm^2$$

2) *The effect of the next sleeper (spaced at 60 cm),(b= 24 cm):*

$$p = \frac{16.8 P_a}{d^{1.25}} (10)^{-3.86\left(\frac{b^2}{d^{2.5}}\right)} = 0.715 * (10)^{-3.86\left(\frac{24^2}{20^{2.5}}\right)} = 0.043\ \ kg/cm^2$$

Hence, the total pressures = 0.715 + 2*(0.043) = 0.801 kg/cm^2



Note:

If the axle will be directly on the sleeper, then, the sleeper will support (40-60%) of the axle load depending on:

1. ***degree of compaction under the sleeper.***
2. ***type of sleeper.***
3. ***weight of rail and inertia.***
4. ***maintenance.***

Sleepers

5.1 Definetion :

The term means the girders which the rail support on. It transfers the load to the ballast section and then to the foundation.

5.2 Purposes of Sleeper :

They are as following:

1. keeping of rails at constant distance.
2. insure elastic layer between the rail and the ballast section.
3. distribute and transfer the load on layer area of the ballast section.
4. to resist the extension of rail due to change of temperature.

5.3 Types of Sleeper :

1) Two parts (one under every rail) connected by steel rod.
2) Long sleeper for both rails.
3) Long sleeper along the rail.
4) Compound sleeper consists of longitudinal and lateral types.

To choose the sleepers, it must be at suitable dimensions and materials and must be provided the following points:

1. The dimensions at length and width should be suitable and adequate to support the rail and transfer the load to the ballast section to distribute the load at the capacity of the ballast section.
2. Thickness of sleeper is adequate to be elastic (within accepted magnitude).

3. Resist the creep.
4. High resistance to the climatic variations.
5. Adequate length (the long sleepers may be deflected at the middle section).

5.4 Treatment of Wooden Sleepers :

the erosion of sleepers comes from the bacteria which fed on the wooden tissues. The humidity and temperature will increase the erosion.

The treatment will be made by injection of sleepers by chemical materials such as Zinc Chloride and Capper Sulphate.

5.5 Stresses Under The Vertical Loading :

Suppose that the pressure will be regular as shown in Fig. 5-1.

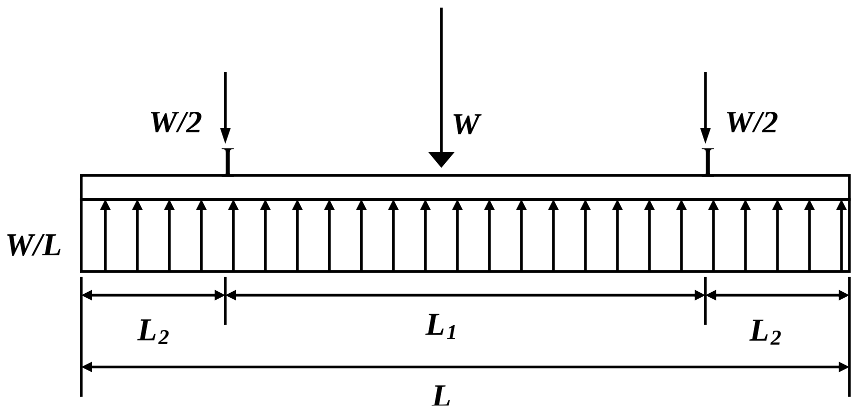


Fig. (5-1) Load Distribution Under Vertical Loading.

where:

load on sleeper = *W*

length of sleeper = *L*

load on one longitudinal unit = *(W/L)*

Therefore, the moment at the middle of sleeper:

$$M_m = \frac{W}{2}.\frac{L_1}{2} - \frac{W}{L}.\frac{L}{2}.\frac{L}{4}$$

$$= \frac{WL_1}{4} - \frac{WL}{8}$$

$$= \frac{W}{8}\left[2L_1 - (L_1 + 2L_2)\right]$$

$$= \frac{W}{8}\left[2L_1 - L_1 - 2L_2\right]$$

$$= \frac{W}{8}\left[L_1 - 2L_2\right]$$

While the moment under the rail:

$$M_r = \frac{W}{L}.L_2.\frac{L_2}{2} = \frac{WL_2^{\ 2}}{2L}$$

Then, it can be found that the length of sleeper at assumption of :

$$M_m = M_r$$

Then at $L_1 = 1.435$,

The length of sleeper $L = 2.56\ m$

$$M_m = M_r$$

$$\frac{W}{8}\left[L_1 - 2L_2\right] = \frac{WL_2^{\ 2}}{2L}$$

$$\frac{1}{8}\left[1.435 - 2\left(\frac{L - L_1}{2}\right)\right] = \frac{(L - L_1)^2}{2L}$$

To be solved.

The pressure really under the sleeper will not be uniformly distributed as shown in Fig 5-2.

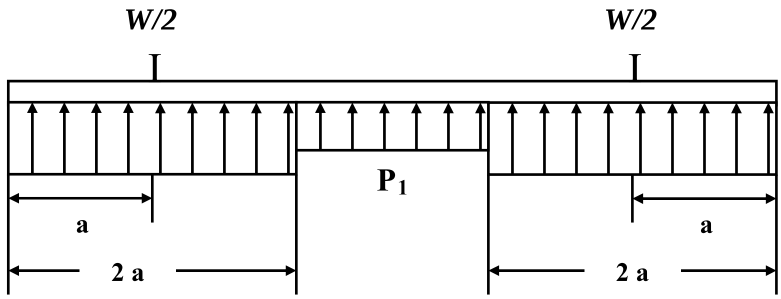


Fig. (5-2) Load Distribution Under The Sleeper.

To calculate the dynamic coefficient, it could be used ***Schramm Equation:***

1) In case of speed < 140 km/hr.

C_d = Dynamic coefficient

$$C_d = 1 + \frac{4.5v^2}{10^5} + \frac{1.5v^3}{10^7}$$

2) In case of speed > 140 km/hr.

$$C_d = 1.27 + \frac{0.75\,v^3}{10^7}$$

where:

v : speed measured in *(km/hr)*.

Railway Alignment & Survey

6.1 Factors Affact in Selection of Good Alignment :

1) Controlling Points :

i. Points the track must pass through:
   a) Important town and cities.
   b) Major bridges or river crossing.
   c) Site of tunnels.

ii. Points the track must not pass through:
   a) Acquisition of costly land.
   b) Religious places.
   c) Areas liable to flooding.

2) Traffic, its Position, Nature and Amount :

a) Traffic α $(\text{pop.})^2$.
b) Freight normally earns more than passengers.
c) New lines attracts passengers within (*15 km*) from sides while old one within (*25 km*) from sides.

3) Gauge Selection :

Increases in gauge width α initial cost α train speed α load carrying capacity.

4) Geometric Standards :

Relate to the min construction cost and min operation cost. These are included the following:

1. Less gradient.
2. Locomotive performance.
3. Rolling gradient.
4. Lesser curves radius lead to increase the operation cost.
5. Avoid curve at bridges and stations.
6. All bridges should be located at (90^o) and straight portion after and before of (*30 m*).

5) *Topography of The Country :*

The reduction of superelevation leads to decrease the operation cost.

6) *Other Considerations :*

The alignment should pass through good soil (not marshy), free of slips or slides and near quarries for construction materials, villages for labors.

6.2 Surveying :

1) *Traffic Survey :*

a. Census of population, locality and their density.
b. General resource of production. Such as agricultural and industrial goods, their weights and their origin and destination.
c. The general character of lands.
d. General information of fairs and recreation centers.
e. The nature and volume of exported and imported activities and their origin and destination.
f. Future possibility of development of trade centers, industries, and agricultural should be investigated.

2) Reconnaissance Survey :

a. To have information about existing rivers, roads, valleys,….etc.
b. To collect geological information about surface, formation, hill slopes,….etc.
c. To collect data about the available resources (materials and labors).
d. To locate the possible control points.
e. To decide the max gradient and curves.
f. To decide the rough economical estimates of the good alignments.

3) Preliminary Survey :

In this stage detail of different alternative as found as drawn in stage to its studied moreover economics of each alternative is prepared.

4) Final Survey :

Objective of refitting the final location from paper to the ground and all data required to the construction engineer. Such as levels, bench marks, measurement of center line of the track, water way, channels and bridges.

Geometric Design of The Track

7.1 Gradients :

1) Ruling Gradient :

It is the max gradient allowed on the track section. Steep gradient provides powerful locomotive, smaller train loads,….etc. the extra pull force required by the locomotive to clime the grade is equal to:

$$w.\sin\ \theta = w.\tan\ \theta = w.gradient$$

For example: if the train weighting (*500 tons*) travels over a slope of rising (*1/100 m*), then the additional force required is: (*1/100*) * *500 = 5 tons.*

2) Momentum Gradient :

Those gradients on a section with values higher than the ruling gradients. Normally, trains need to enough momentum to climb the momentum grade.

For example, in valleys a fulling gradient is usually followed by a rising gradient. A train while coming down acquires sufficient momentum which enable the train to over come a steeper rising gradient than the ruling gradient. The rising gradient is called the momentum gradient.

3) Pusher or Helper Gradient :

If the ruling gradient is sever than the train for a large portion of its journey, it will have non-used capacity for carrying loads. But if the grade is constructed in a specific section, for example in mountains, in stade of limited the train load it will be very economical to run the train on this basis of load that the engine can carry on other sections and use another one assisting engine (pusher) for the portion were the gradient is sever.

4) Gradient in Stations & Yards :

Normally, low gradient is preferable at station to prevent the movement of standing vehicle and to prevent additional resistance due to grade on the starting vehicle, gradient of (*1/1000 m*) is recommended for this case.

Grade Compensation on Curves :

If the ruling gradient is (*1/150 m*) on a particular section of broad gauge (*1.676 m*) and at the same time a curve of (4^o) is situated on this ruling gradient, then the allowable ruling gradient to be provided:

Grade compensation of B.G. = $\frac{0.04\%}{\deg ree.of.curve}$

Then the compensation for (4^o) curve = $\frac{0.04}{100} * 4 = 0.16\%$

Now, ruling gradient (*1/150 m*) = $\frac{1}{150} * 100 = 0.67\%$

So the allowable (actual) ruling gradient = 0.67- 0.16 = 0.51% or (*1/196 m*).

7.2 Speed of The Train :

Safe speed on the curve is safe from the danger of over turning and derailment with a certain manger of safety.

The following formula may be used for the speed on curves:

A. Where transition curves exist:

i. For B.G. and M.G.:

$$V = 4.4\sqrt{R - 70} \quad \text{..........(1)}$$

V: safe speed (*m/hr*), R: radius (*m*)

ii. For N.G.:

$$V = 3.65\sqrt{R - 60} \quad ....(2)$$

B. Where no transition curves exist:

i. For B.G. and M.G.:

$$V = \frac{4}{5} \text{ of Eq.(1)}$$

V: safe speed (m/hr), R: radius (m)

ii. For N.G.:

$$V = \frac{4}{5} \text{ of Eq.(2)}$$

C. For high speed:

$$V = 4.58\sqrt{R}$$

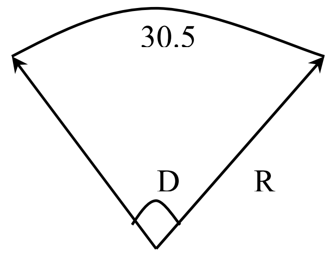


Figure (7-1) Degree of Curvature

As shown in Fig.7-1:

$$\frac{D}{30.5} = \frac{360}{2\pi R} \quad \text{then} \quad D = \frac{1746}{R} \quad \text{or} \quad R = \frac{1746}{D}$$

7.3 Superelevation :

A train is forced radially outward by centrifuge force when it moves in a circular path. The level of the outer rail is raised above the inner rail by a certain amount to introduce the centripetal force. This rise at the horizontal curve is called the superelevation or cant as shown in Fig.7-2.

In addition, the superelevated section of railway affects the tendency of the train to side outward.

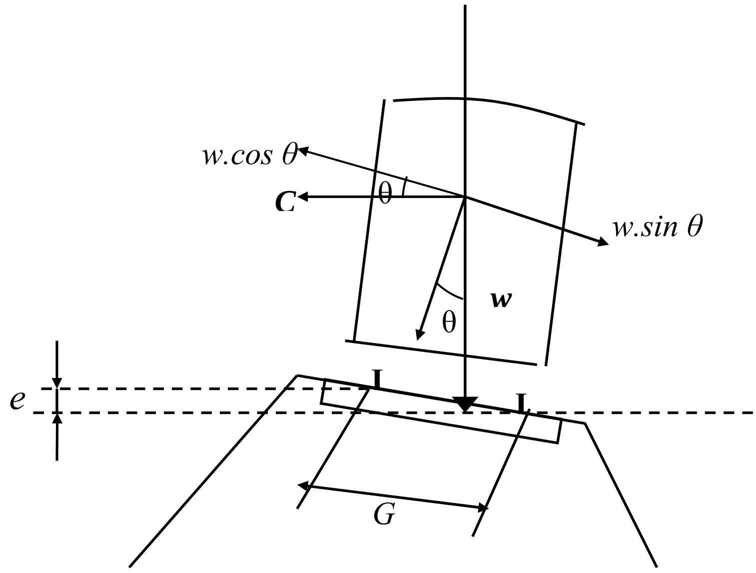


Figure (7-2) Superelevation

Where:

θ : angle of section slope.

e: superelevation measured in (*mm*).

G: gauge of the track (*cm*) where:

B.G. = *1.676 m = 167.6 cm*

M.G. = *1.00 m = 100.0 cm*

N.G. = *0.762 m = 76.20 cm*

R: radius of curve (*m*).

v: speed of train (*m/sec*).

V: speed of train (*km/hr*).

C: centrifuge force.

w: weight of the train.

As shown in Fig.7-2:

$w.\sin\theta = C.\cos\theta$ since θ is small then $\sin\theta = \tan\theta = \frac{e}{G}$

Therefore $$w.\frac{e}{G} = \frac{mv^2}{R} = \frac{wv^2}{gR}$$

Then $e = \dfrac{Gv^2}{gR}$

The speed will transfer from (*m/sec*) to (*km/hr*) and ($g = 9.81\ m/sec^2$)

Then $$e = \frac{GV^2}{127\ R}$$

Limits of superelevation: Normally the max value of the superelevation at the range of (*1/10 – 1/12*) from the gauge values. For example, max *e* for board gauge is (*1/10 * 1.676 *100 = 16.76 cm*)

<u>Example (7-1) :</u> Calculate the superelevation of the curve of (8^o) degree of curvature and board gauge track. What would be the permissible speed on this curve knowing that the average speed of different trains is (50 kph)?

$$R = \frac{1746}{D} = \frac{1746}{8} = 218.25\ m$$

$$e = \frac{GV^2}{127\ R} = \frac{1.676 * 100 * 50^2}{127 * 218.25} = 15\ mm$$

$$V_{\max} = 4.4\sqrt{R - 70} = 4.4\sqrt{218.25 - 70} = 53.57\ kph$$

Therefore, the permissible speed on this curve is (*50 kph*).