# Geometric Design of the track

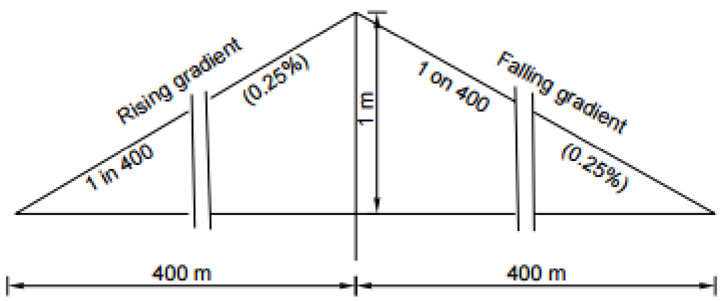
## Gradient and Grade Compensation

**A: Gradient:** any departure of the track from the level is known as grade or gradient. Gradient is measured either

A gradient is normally represented by:

- The distance travelled for a rise or fall of one unit.
- The gradient is indicated as per cent rise or fall.

For example, if there is a rise of 1 m in 400 m, the gradient is 1 in 400 or 0.25%, as shown in the Figure.




Gradient are provided on the tracks due to the following reasons:-

i- To provide a uniform rate of rise or fall as far as possible.

ii- To reach the various stations at different elevations, and

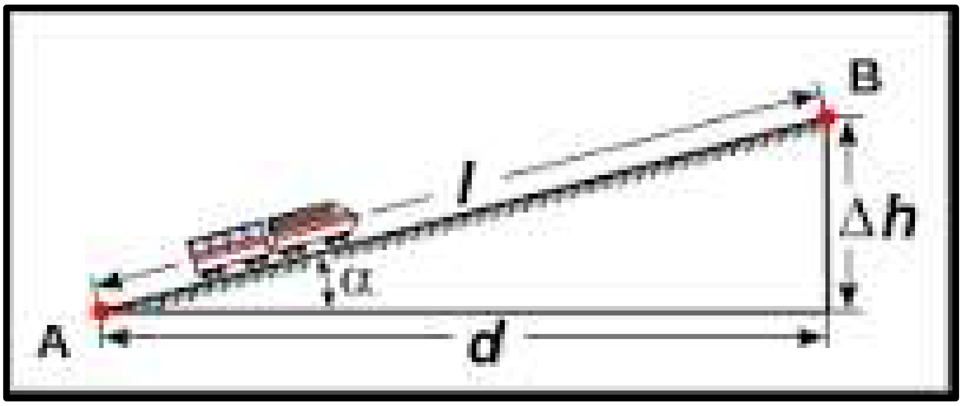
iii- To reduce the cost of earth work.

Various gradients used on railway tracks can be classified under the following heads:

1- **Ruling gradient**.

**It is the maximum gradient allowed on the track section.** It determines the maximum load that can be hauled by a locomotive on that section. Steep gradients necessitate more powerful locomotives, smaller train load, lower speed and costly haulage.

While deciding the ruling gradient of a section, it is not only the amount of gradient that will come into play but also the length of the gradients and its position. For example (a train is able to climb a rising gradient more easily if this rising gradient follows a falling gradient).




The extra pull force required by the locomotive to climb a grade:

**P = W* Sinα**

**= W* tanα (approximately, as α is very small)**

**= W × gradient**

Example: - if a train weighing 500 tons travels a slope of rising 1 m in 100 m, the additional force required is 1/100 * 500 = 5 tones. If the same height 1 m is a lined in 200 m, the additional force required is 1/200*500= 2.5 ton.

Once a ruling gradient is specified for a section, then all other gradients provided in that section should be flatter than the ruling gradients.

## 2- Momentum gradient.

The momentum gradient is steeper than the ruling gradient and can be overcome by a train because of the momentum it gathers while running on the section. For example, in valleys a falling gradient is usually followed by a rising gradient. A train while coming down falling gradients acquires sufficient momentum. This momentum gives additional kinetic energy to the moving train which would enable the train to overcome a steeper rising gradient than the ruling gradient. The rising gradient is called as momentum gradient.

**Note: -**

**In sections with momentum gradients there are no obstacles provided in the form of signals, etc., trains must be not stopped where it acquires the momentum; otherwise this gradient is changed to be the ruling gradients.**

## 3- Pusher or helper gradient.

If the ruling gradient is sever the train for a large portion of its journey will have unused capacity for carrying higher loads. But if the grade is concentrated in a specific section such as mountainous section, instead of limiting the train load, it may be more economical to run the train on the basis of load that the engine can carry on other section and use another or assisting engine for the portion where the gradient is severe. Such gradient is known as pusher or helper gradient.

**4- Gradients at station yards.**

The gradients in station yards are quite flat due to the following reasons.

(a) To prevent standing vehicles from rolling and moving away from the yard due to the combined effect of gravity and strong winds.

(b) To reduce the additional resistive forces required to start a locomotive to the extent possible.

It may be mentioned here that generally, yards are not leveled completely and certain flat gradients are provided in order to ensure good drainage. The maximum gradient prescribed in station yards on Railways is 1 in 400, while the recommended gradient is 1 in 1000.

**B: Grade Compensation on Curve:**

If a curve lies on a ruling gradient, the resistance due to gradient is increased by that due to curvature. In order to avoid resistance beyond the allowable limits, the gradients are reduced on curves and this reduction in gradients is known as grade compensation for curves. The curve resistance is expressed as a percentage per degree of the curve.

Note: - the curve resistance is greater at lower speed.

**Compensation for curvature:**

**B.G. =0.04% per degree of curve**

**M.G. =0.03%**

**N.G. =0.02%**

**Example 1**

If the ruling gradient is 1 in 150 on a particular section of broad gauge and at the same time a curve of 4 degrees is situated on this ruling gradient, what should be the allowable ruling gradient?

Solution:

Grade compensation of B.G. = 0.04 percent per degree of curve.

Then compensation for 4 $^{o}$ curve = 0.04 *4 = 0.16 percent

Ruling gradient 1 in 150 = 1/150*100 = 0.67 percent

So allowable gradient or actual gradient to be provided

**= Ruling gradient – grade compensation**

= 0.67-0.16= 0.51 percent

=0.51/100 =1/100/0.51= 1 in 196.

**Example 2**

What should be the actual ruling gradient If the ruling gradient is 1 in 200 on a M.G. A curve of 3$^{o}$ is superimposed on the above track section of B.G.

Solution:

Assume grade compensation on M.G. = 0.03 percent per degree of curve.

Then compensation for 3 $^{o}$ curve = 0.03 *3 = 0.09 percent

Ruling gradient 1 in 200 = 1/200*100 = 0.5percent

So allowable gradient or actual gradient to be provided

**= Ruling gradient – grade compensation**

= 0.5-0.09= 0.41 percent

=0.41/100 =1/100/0.41= 1 in 244.

**1- Speed of the train.**

The speed of the train depends upon the strength of the track and the power of the locomotive.

**Safe speed:** for all practical purpose means a speed which is safe from the danger of overturning and derailment with a certain margin of safety. This speed; to negotiate curve safely, depends upon the following factors:

i- The gauge of the track.

ii- The radius of the curve.

iii- The distance at which the resultant of the weight of vehicle and its centrifuged force acts from the center of the track.

iv- Amount of superelevation provided.

v- The existence or absence of transition curves at the ends of the circular curve.

The following formula may be used for the safe speed on curve:-

**a- Where transition curves exist.**

1- For B.G. & M.G the safe speed V in kmph is given:

$\mathbf{V = 4.4\sqrt{R - 70}}$ ................ **A** R= m

2- For N.G. the safe speed V in kmph is given:

$\mathbf{V = 3.65\sqrt{R - 6}}$ ................ **B** R=m

**b- Where transition curves are absent.**

1- For B.G. & M.G. V= 4/5 th of speed calculated in A above.

2- For N.G. V=4/5 th of speed calculated in B above.

c- For high speeds:-

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

Where:-

V = speed in (kmph)., R = radius of the curve in (m).

**2- Radius or degree of the curve.**

Curves on the railway are generally circular i.e. each curve should have the same radius on every portion of it.

Degree of curvature is defined as the angle subtended at the center by an arc of 30 m length

$$\frac{D}{30} = \frac{360}{2\pi R} \quad \Longrightarrow \quad D = \frac{1720}{R}$$

Where:

R: radius of curve in meters.

D: degree of curvature. ; it is also may be defined as the angle subtended at the centre by a chord of 100 feet or 30.48 meter.

Note: normally curves on railway are not recommended as they may cause speed reduction, no heavy locomotive and limitation on train length. Moreover derailment and accident may occur.

**3- Superelevation or cant.**

When a train moves round a curve, it is subjected to a centrifugal force acting horizontally at the centre of gravity of each vehicle radially away from the centre of the curve. This increases weight on outer rail.

To counteract the effect of centrifugal force, the level of the outer rail is raised above the inner rail by a certain amount to introduce the centripetal force. This raised elevation of outer rail above the inner rail at a horizontal curve is called " superelevation " .

$$e = \frac{GV^2}{1.27R}$$

Where:
e = cant (superelevation) in (cm)
G =gauge of the track (m)
R = radius of the curve (m)
V= speed (kmph)

**G for B.G. = 1.676m**

**M.G. = 1.000m**

**N.G. = 0.762m**

$\mathbf{e = 1.315\,\frac{V^2}{R}}$**………………….. for B.G.**

$\mathbf{e = 0.8\,\frac{V^2}{R}}$**…………………… for M.G.**

$\mathbf{e = 0.6\,\frac{V^2}{R}}$**…………………… for N.G.**

**<u>Limits of superelevation &cant deficiency.</u>**

There are limits to the amount of superelevation which may be provided safely. Normally, the maximum value of superelevation, according to the railway Board is $1/10^{th}$ of gauge to $1/12^{th}$ of gauge.

- Maximum superelevation for B.G.= 1/10*1.676=0.167m=16.7cm
- Maximum superelevation for M.G.= 1/10*1.000=0.1 m=10 cm
- Maximum superelevation for N.G. = 1/10*0.762=0.0762m=7.62cm