DI04006071: Railway, Harbour & Tunnel Engineering

Lecture 2.9: Grade Compensation on Curves

GTU Course Instructor

Civil Engineering

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Introduction to Grade Compensation I

Grade compensation on curves is the reduction in the gradient of a track on a curve to compensate for the additional resistance offered by the curve. When a train traverses a curve, it encounters curve resistance in addition to the normal tractive resistance. To prevent the total resistance from exceeding the hauling capacity of the locomotive, the gradient must be appropriately reduced.

Key Points

- Reduces gradient on curves to offset curve resistance
- Prevents total resistance from exceeding locomotive capacity
- Maintains a uniform ruling gradient equivalent across the section

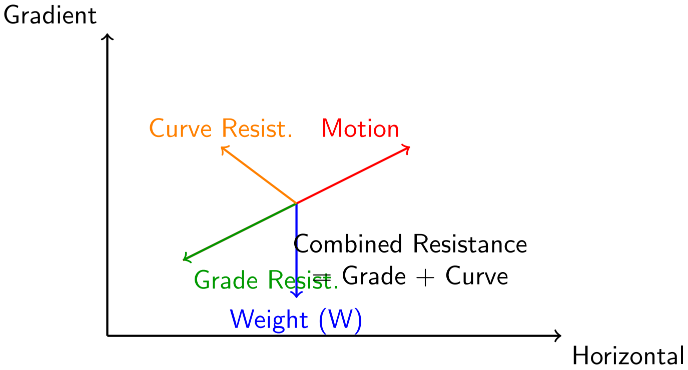
Mechanics of Curve Resistance I

When a railway vehicle moves along a curved track, it experiences additional resistance due to the rigidity of the wheelbase, centrifugal force pushing the flanges against the outer rail, and the longitudinal slip of the wheels. This curve resistance acts in the same manner as grade resistance, opposing the motion of the train and demanding extra tractive effort.

Key Points

- Flange friction against the outer rail due to centrifugal force
- Slipping and skidding of wheels caused by a rigid wheelbase
- Additional tractive effort required to overcome curve resistance

Forces Acting on a Train on a Curve I



Forces Acting on a Train on a Curve II

Key Points

- Visual representation of grade and curve resistances
- Both forces act opposite to the direction of motion
- Combined resistance dictates the required locomotive power

Why Grade Compensation is Essential I

The ruling gradient is the maximum gradient allowed on a particular section of track, dictating the maximum load a locomotive can haul. If a curve occurs on a ruling gradient, the effective resistance is higher than that of the straight ruling gradient. Without grade compensation, trains would stall or require assistant (banking) engines. Compensating the grade ensures smooth and continuous operations.

Key Points

- Preserves the hauling capacity defined by the ruling gradient
- Eliminates the need for banking engines on curved gradients
- Prevents train stalling and reduces mechanical wear

Standards for Compensation I

| Gauge Type | Rate of Compensation per Degree of Curve | |:—:|:—:| | Broad Gauge (BG) | 0.04% | | Meter Gauge (MG) | 0.03% | | Narrow Gauge (NG) | 0.02% |

Key Points

- Values specified by Indian Railways for uniform track design
- Given as a percentage reduction in gradient per degree of curve
- BG tracks require the highest absolute compensation per degree

Calculation of Compensated Gradient I

The compensated gradient is calculated by subtracting the required grade compensation from the ruling gradient. The compensation is a product of the specified rate of compensation and the degree of the curve. It is crucial for track engineers to ensure that the compensated gradient is accurately laid out during construction to prevent tractive failures.

Key Points

- Grade Compensation = Rate of Compensation × Degree of Curve
- Compensated Gradient = Ruling Gradient - Grade Compensation
- Must strictly align with locomotive tractive effort calculations

Curve Resistance Equivalent I

Curve resistance is often expressed as an equivalent gradient to simplify calculations. For instance, on a Broad Gauge track, a 1-degree curve offers resistance equivalent to a 0.04% up-gradient. This equivalence allows engineers to convert complex horizontal curvature mechanics into a simple vertical gradient equivalent, integrating it seamlessly into track profiling.

Key Points

- 1° curve on BG $\approx 0.04\%$ gradient resistance
- Simplifies complex friction and centrifugal force calculations
- Allows unified assessment of overall track geometry

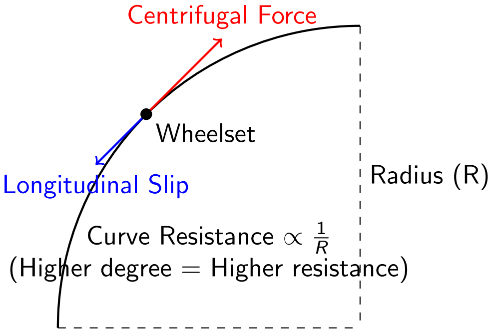
Example Problem: Broad Gauge Track I

Consider a Broad Gauge (BG) railway track designed with a ruling gradient of 1 in 200 (which equals 0.50%). If a 4-degree curve is introduced on this gradient, we must calculate the compensated gradient. The compensation required is $0.04\% \times 4 = 0.16\%$. Therefore, the maximum allowable gradient on the curve is 0.50% - 0.16% = 0.34%, or approximately 1 in 294.

Key Points

- Ruling Gradient = 1 in 200 (0.50%)
- Degree of Curve = 4° (BG Track)
- Calculated Grade Compensation = 0.16%
- Final Compensated Gradient = 0.34% (or 1 in 294)

Geometry of Curve Resistance I



Geometry of Curve Resistance II

Key Points

- Centrifugal force pushes wheel flanges against the outer rails
- Longitudinal friction arises from differing travel paths of wheels
- Curve resistance is inversely proportional to the curve radius

Economic & Operational Impacts I

Failing to properly compensate for gradients on curves leads to severe operational inefficiencies. Locomotives may be forced to carry lighter loads across an entire railway section just to negotiate a single uncompensated curve. Alternatively, the deployment of expensive banking engines would be required. Proper grade compensation optimizes payload capacity, reduces fuel consumption, and limits wear.

Key Points

- Maximizes the payload hauled by a single locomotive
- Eliminates the operational cost of localized banking engines
- Reduces fuel consumption and mechanical wear on wheel flanges

Summary & Conclusion I

Grade compensation on curves is a fundamental track design principle in railway engineering. By reducing the gradient on curved sections, engineers neutralize the added curve resistance, maintaining a uniform maximum tractive resistance throughout the ruling gradient section. Adhering to standards, such as those set by Indian Railways, ensures safe, efficient, and economically viable operations.

Key Points

- Grade compensation neutralizes additional curve resistance
- Standard compensation: BG = 0.04%, MG = 0.03%, NG = 0.02% per degree
- Ensures uniform tractive effort requirements across the section
- Optimizes locomotive payload, efficiency, and safety