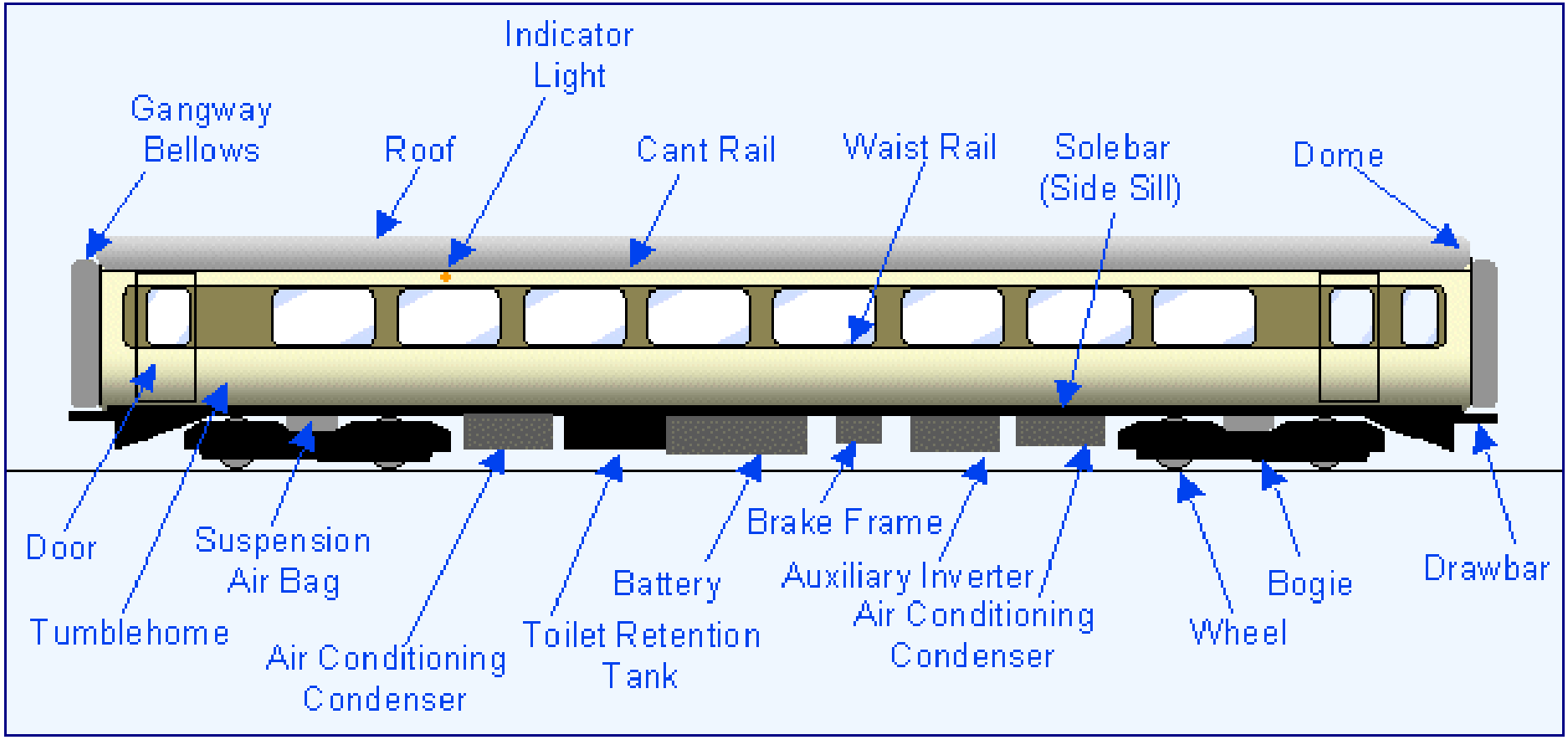
RAILWAYS

Rolling stock & kinematics

Jarosław Zwolski, PhD CE

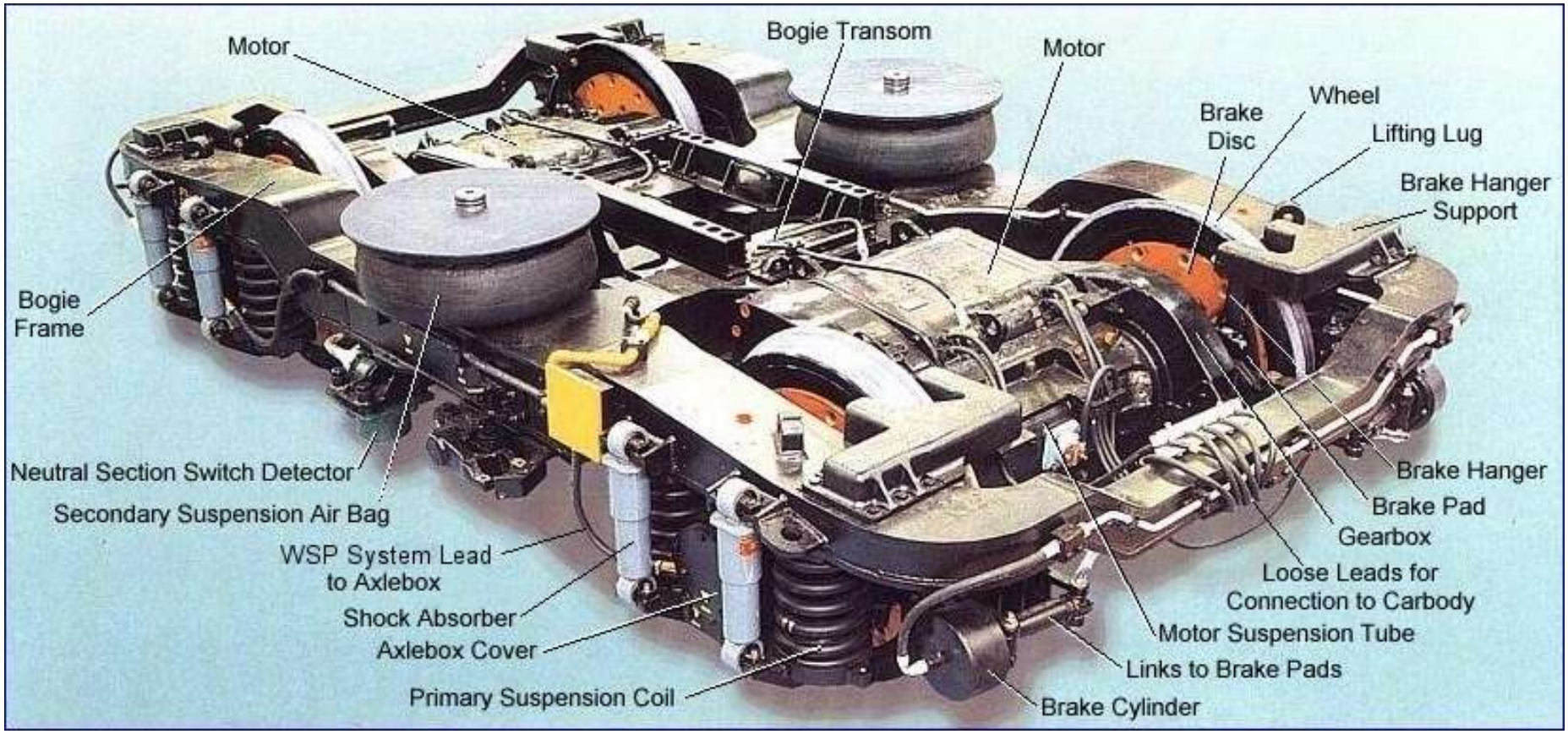
HUMAN CAPITAL
HUMAN – BEST INVESTMENT!
Wrocław University of Technology
EUROPEAN SOCIAL FUND
Project co-financed from the EU European Social Fund

Construction of a carriage



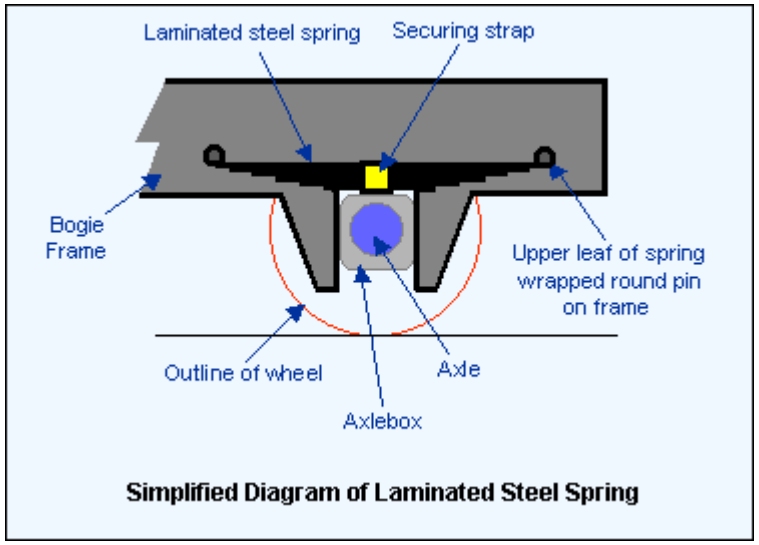
source: http://www.railway-technical.com

Construction of a carriage bogie



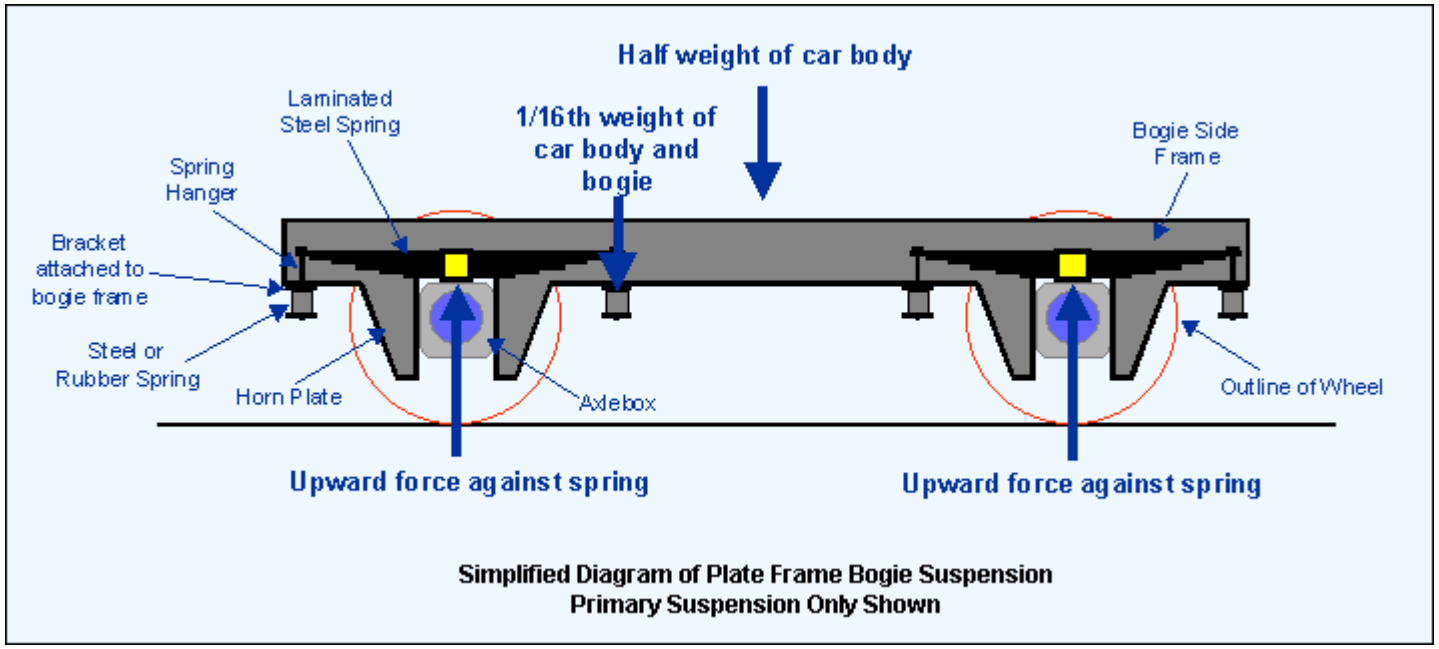
source: http://www.railway-technical.com

Construction of a carriage bogie suspension



Simplified Diagram of Laminated Steel Spring

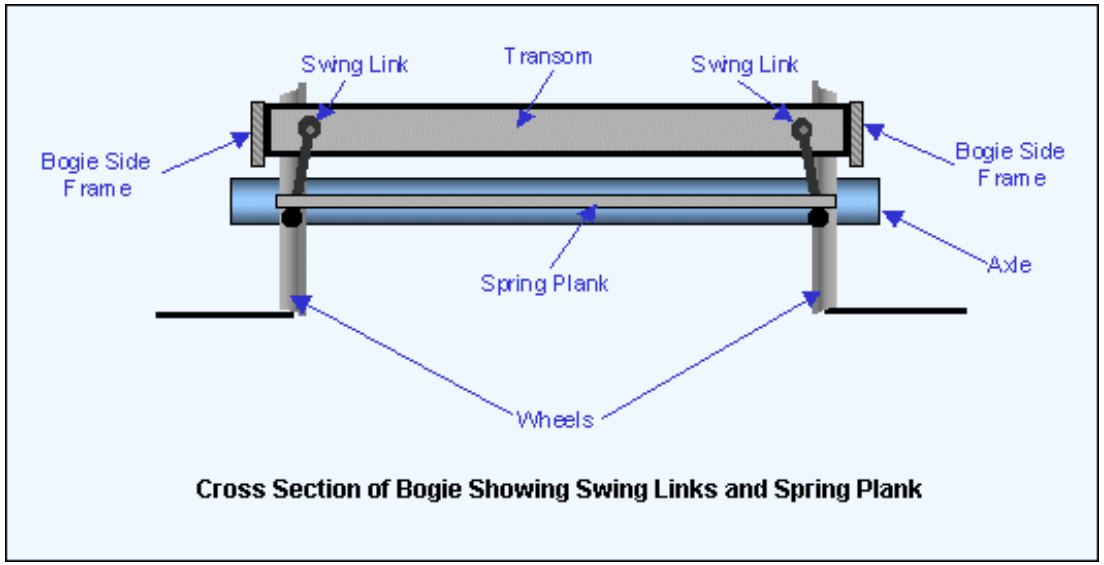
It was recognized very early in the development of railways that the interface between vehicle body and wheel needed some sort of cushion system to reduce the vibration felt as the train moved along the line. This was already part of road coach design and took the form of leaf (laminated) steel springs mounted on the axles, upon which the vehicle body rested.



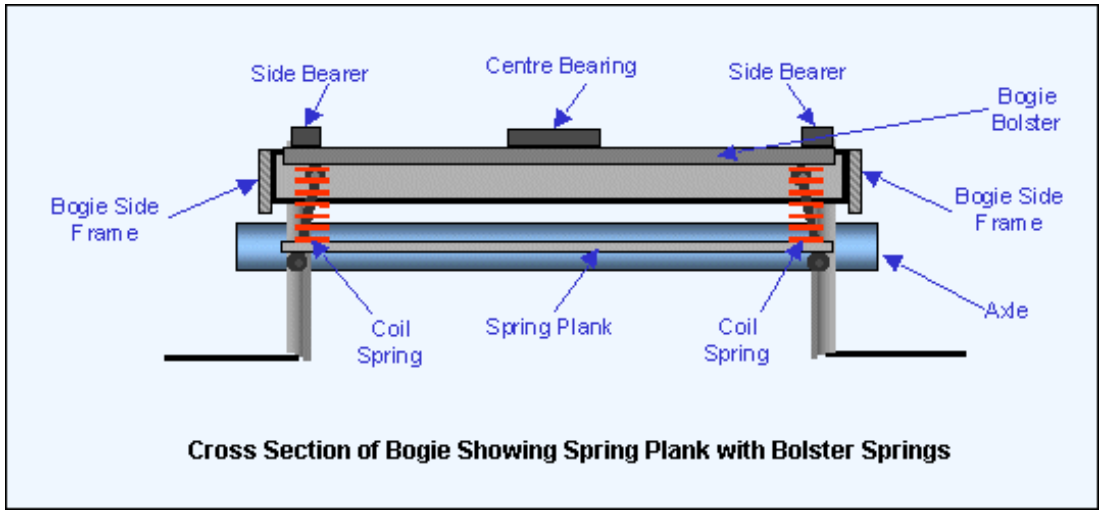
Simplified Diagram of Plate Frame Bogie Suspension
Primary Suspension Only Shown

source: http://www.railway-technical.com

Secondary bogie suspension



Cross Section of Bogie Showing Swing Links and Spring Plank

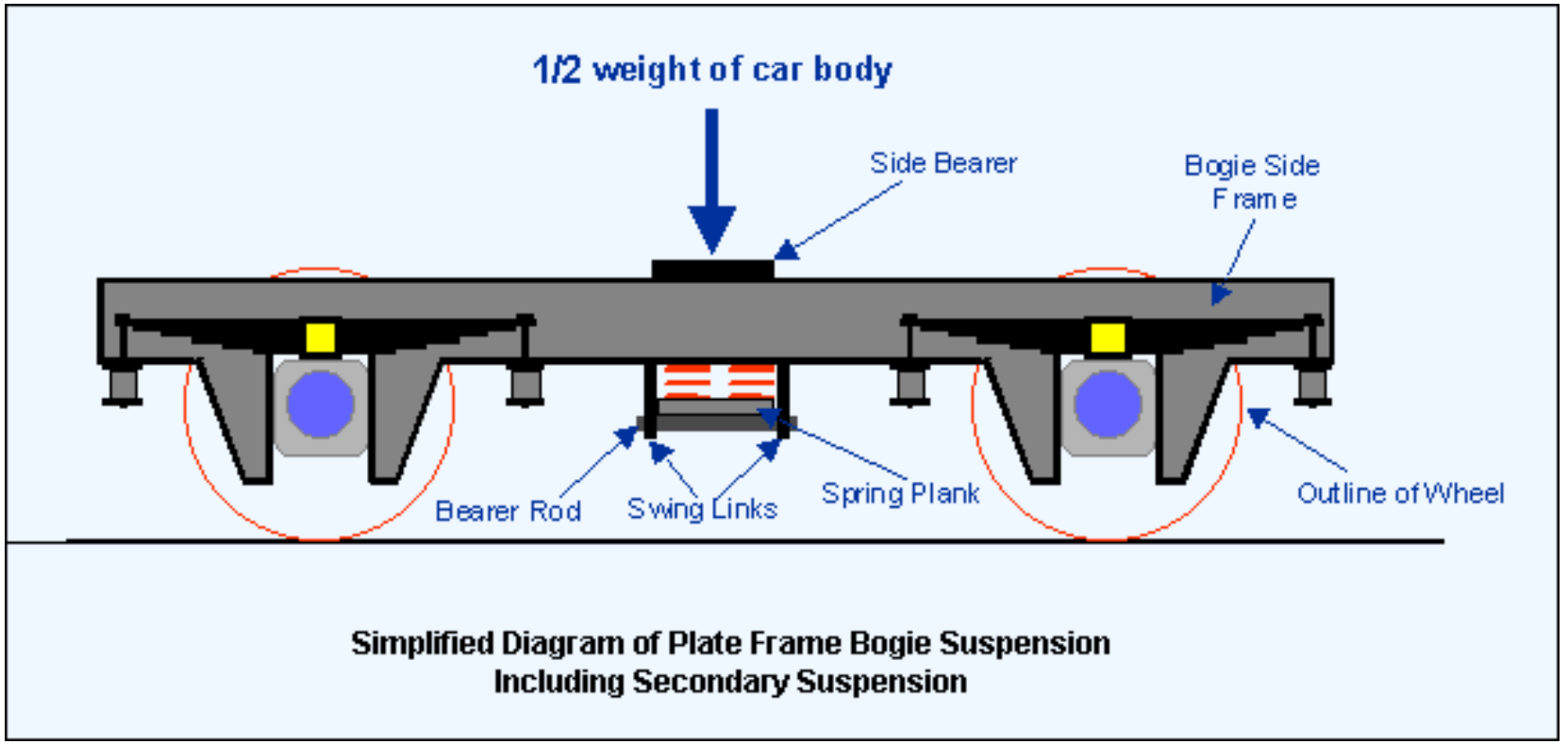


Cross Section of Bogie Showing Spring Plank with Bolster Springs

The bogie has a pair of transverse members called "transoms". They are riveted or welded to the bogie side frames. A steel "swing link" is hung from each end of each transom and a spring plank is laid across the bogie between them. A side view of the bogie below shows the way the spring plank is supported by the swing links. The spring plank rests on bearer rods suspended between the swing links. This arrangement allows the spring plank to rock from side to side and it will act in opposition to sideways movement of the bogie frame.

source: http://www.railway-technical.com

Secondary bogie suspension



Simplified Diagram of Plate Frame Bogie Suspension Including Secondary Suspension

A pair of steel coil springs (shown in red) rest on each end of the spring plank. On top of them sits the bogie bolster. The bolster carries the vehicle body. The body is located by a centre bearing, using a pin fitted to the underframe of the body and steadied by two side bearers. The side bearers are flat to allow the body to slide on the bearer so that the bogie can turn about the centre pin.

source: http://www.railway-technical.com

Air bogie suspension (passenger vehicles)

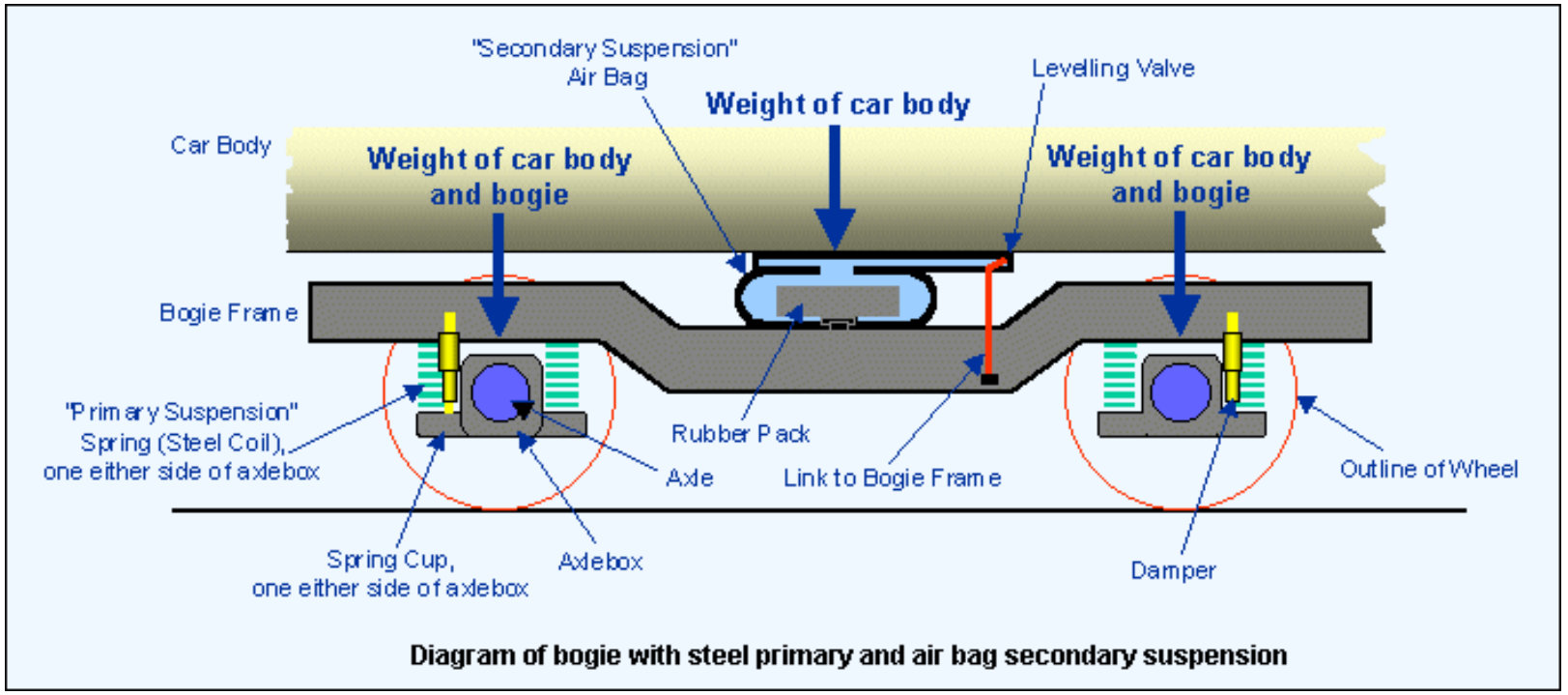
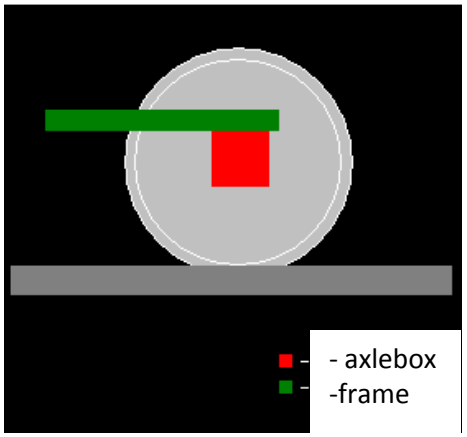


Diagram of bogie with steel primary and air bag secondary suspension

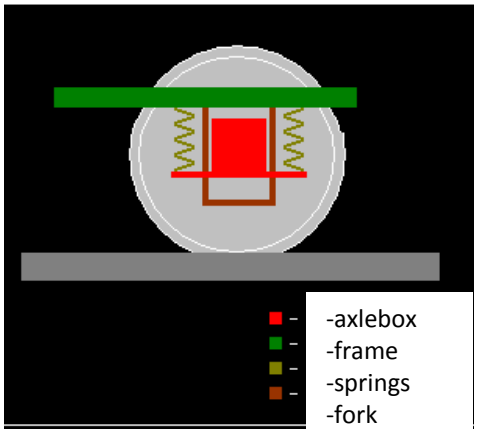
The weight of the half of car body rests on the air bag, which is mounted on the top of the bogie frame. Compressed air is fed into the air bag through a leveling valve attached to the underside of the car body. The valve is operated by a lever attached to one end of a link, whose other end is fixed to the bogie frame. Any vertical movement between the car body and the bogie is detected by the lever which adjusts the leveling valve accordingly. When the load on the car is changed at a station by passengers boarding and alighting the levelling valve adjusts the air pressure in the air bags to match. The effect is that the car body maintains almost a constant height from rail level, regardless of load.

source: http://www.railway-technical.com

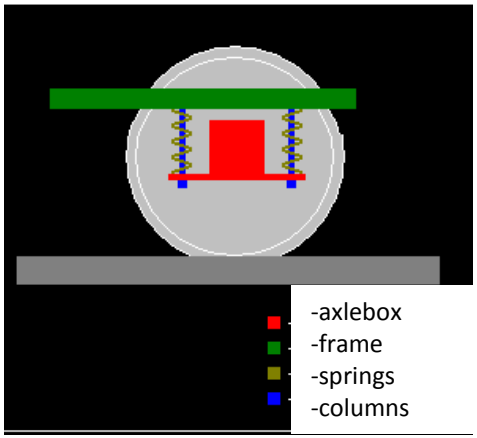
Various systems of bogie suspension



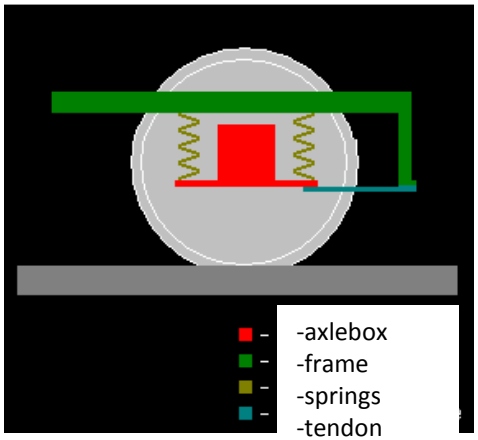
Stiff suspension



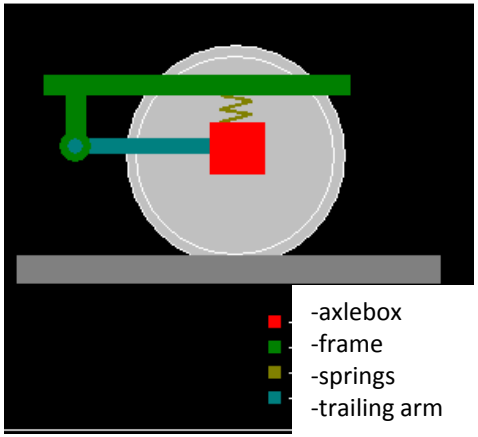
Fork suspension



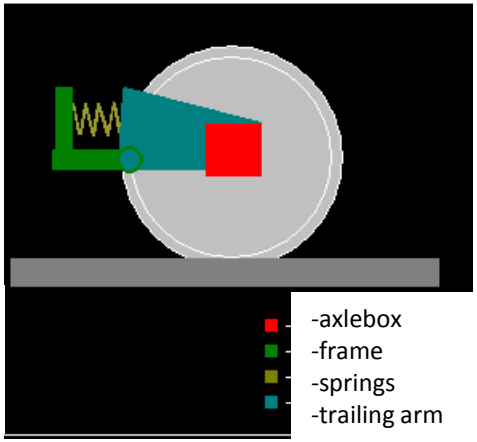
Column suspension



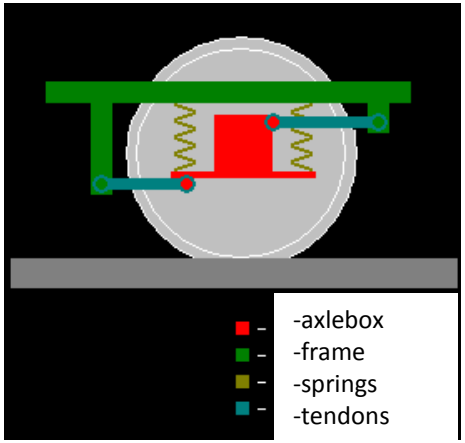
Tendon suspension



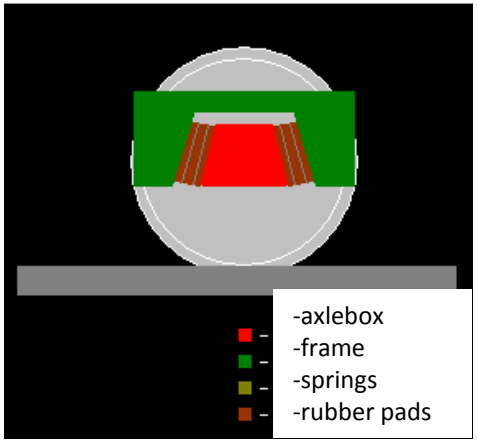
Suspension with trailing arm



Suspension with tilted trailing arm



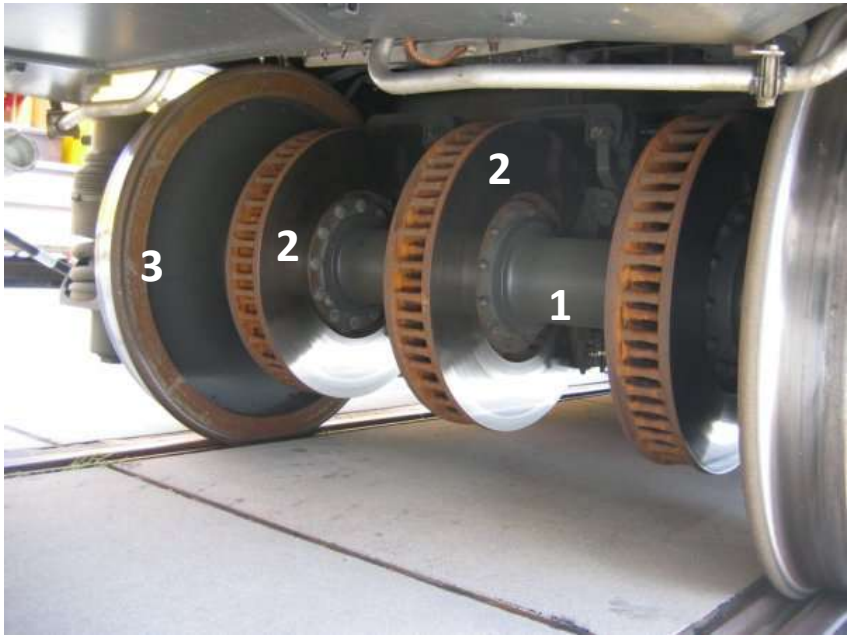
Alstom suspension (lemniscata suspension)



Rubber suspension

source: http://www.transportszynowy.pl

Wheelset



1. Axle
2. Breaking disc
3. Wheel

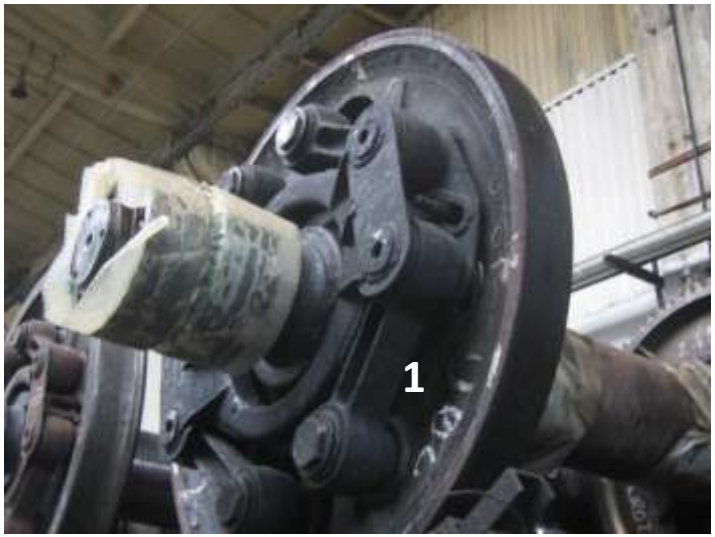


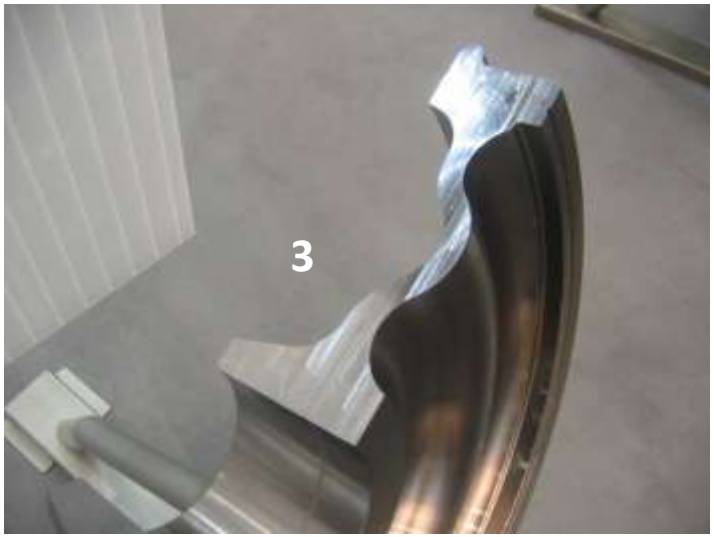
1. Internal breaking disc
2. The bracket with breaking pads
3. Double side lever
4. Breaking cylinder (jack)

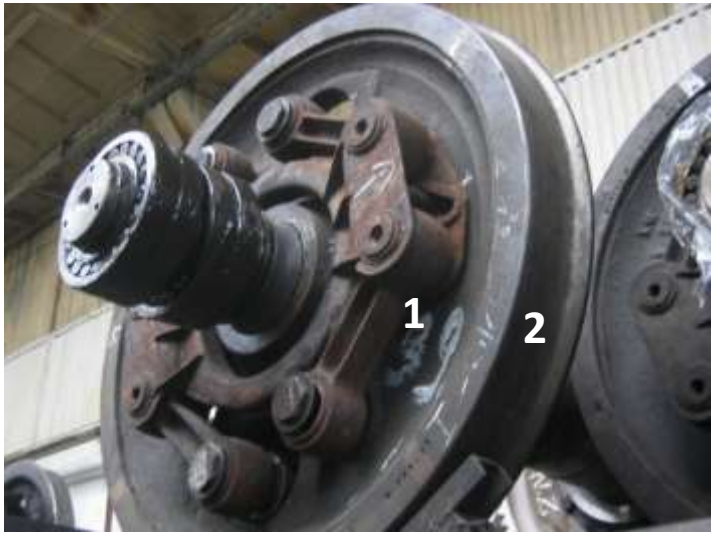
source: http:// www.transportszynowy.pl

Wheels

There are two kind of wheels: rimmed and monoblock.







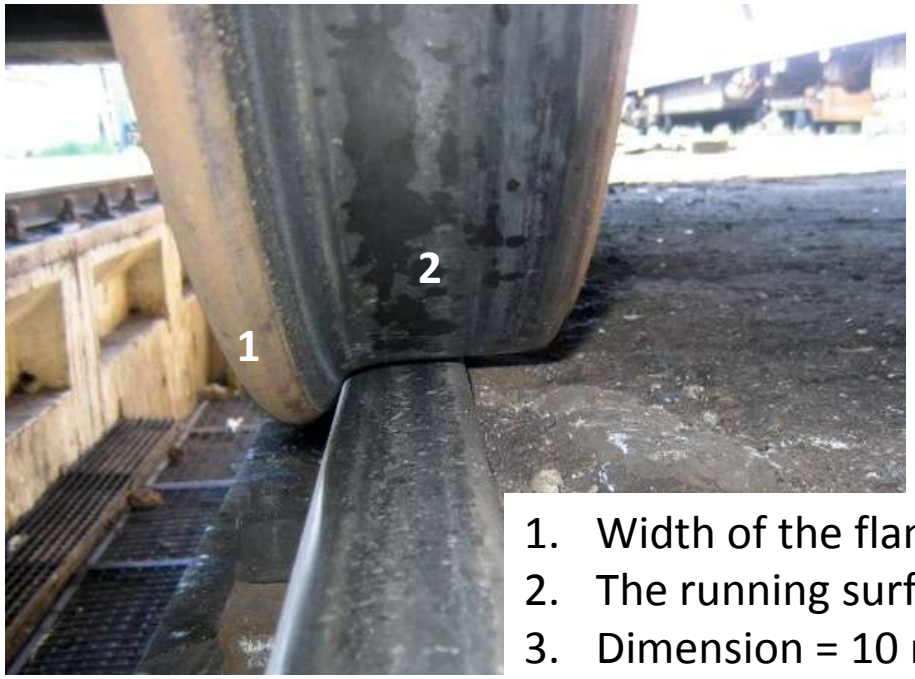
1. Wheel base
2. Rim
3. Monoblock wheel cross section

Safety (loosening of the rim)
vs
Economy (worn wheel has to be replaced)

source: http:// www.transportszynowy.pl

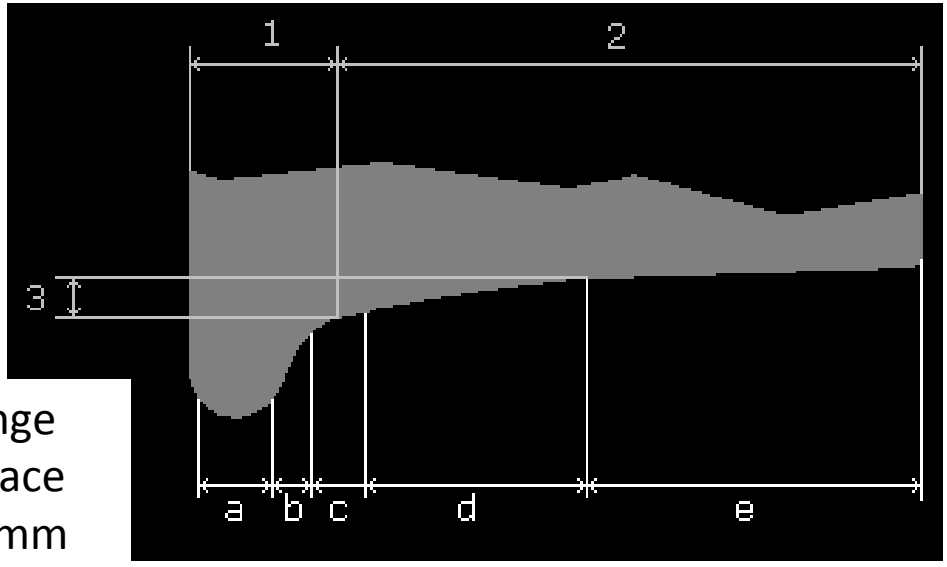
Running surface of the wheel

The running surface of the wheel is not cyllindrical.



1. Width of the flange
2. The running surface
3. Dimension = 10 mm

AOC profile

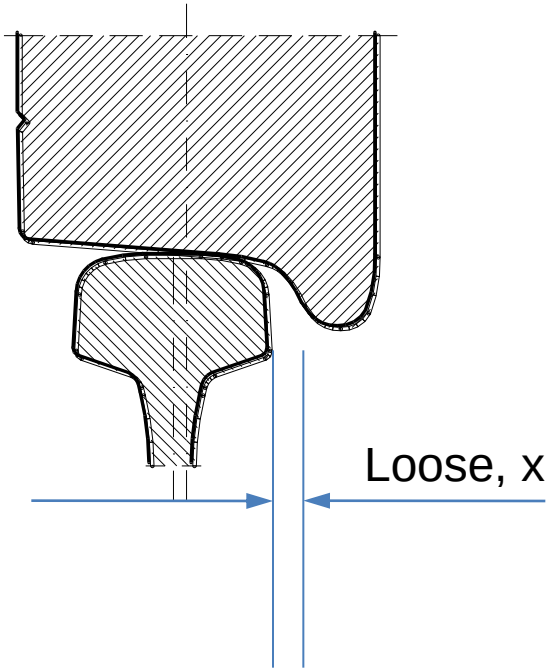


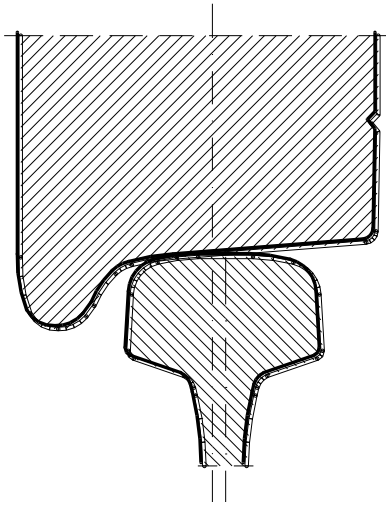
AOC wheel profile (so called „self centering”) enables wheelsets easier passing of curved sections of track (less wheel and rail wear). This solution is an equivalent of the differential mechanism in cars.

a) The tip of the flange
b) The side of the flange
c) The base of the flange
d) The internal running surface
e) The external running surface

source: http:// www.transportszynowy.pl

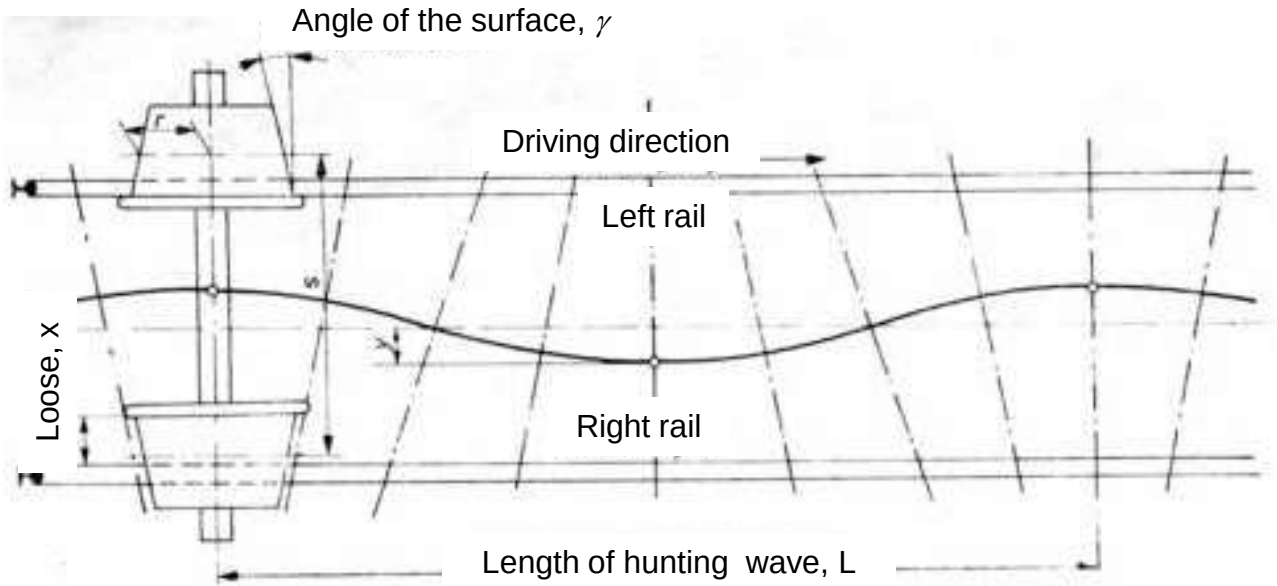
How it works on straight sections?





Hunting (but not for witches ☺)

The sideways motion of a bogie at a speed caused by side irregularities in the track and sinusoid movement of wheelsets (due to the loose between wheels and rails), referred also to as "boxing".

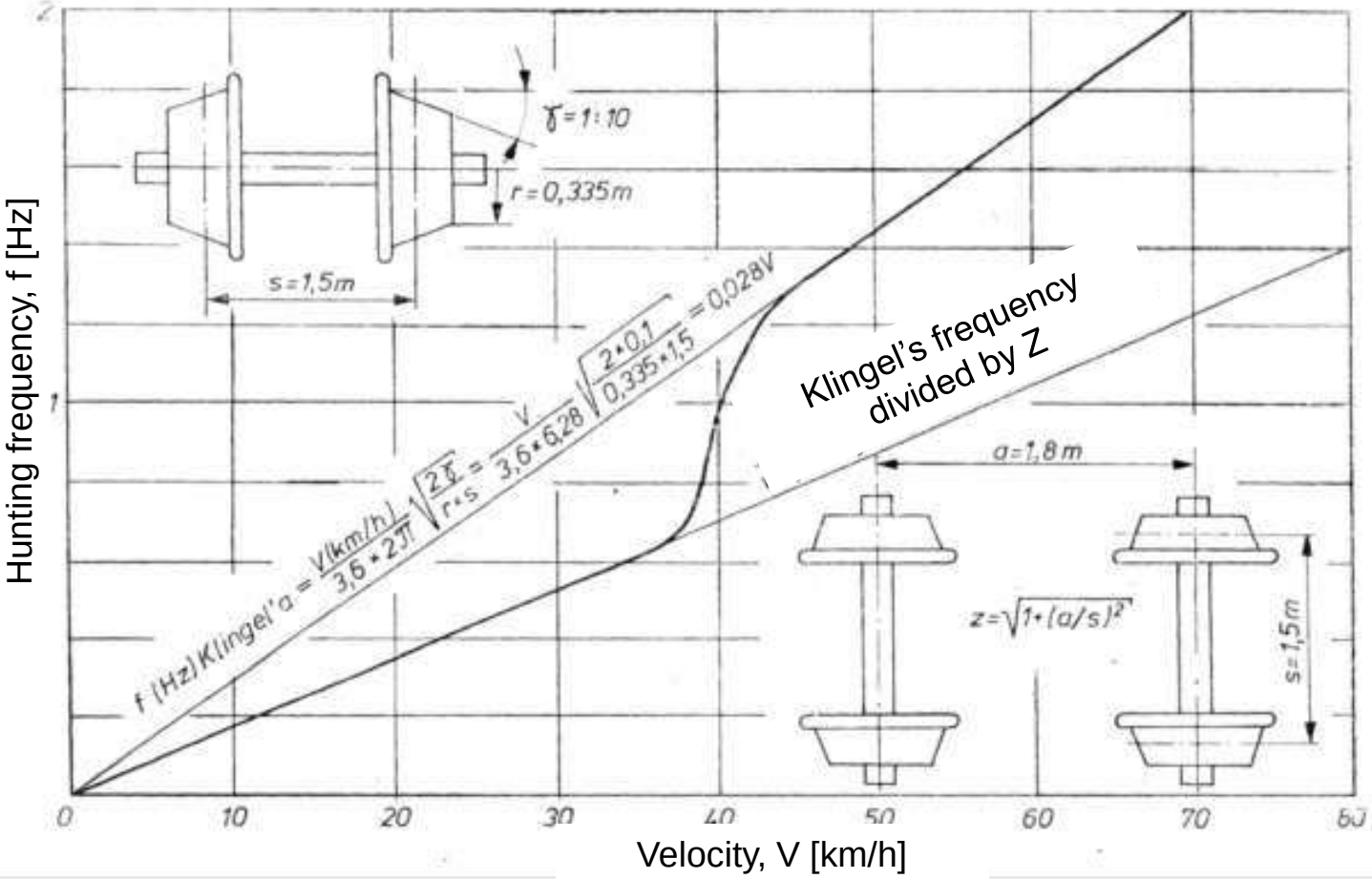


Klingel's formula for a single wheelset:

$$L = 2\pi \sqrt{\frac{r \cdot s}{2 \cdot \gamma}} \text{ (m)},$$

where:
r – wheel radius [m]
s – distance between rails = 1.5 m
γ – angle of the conical surface of the rail (for 1:20 γ=0.05)

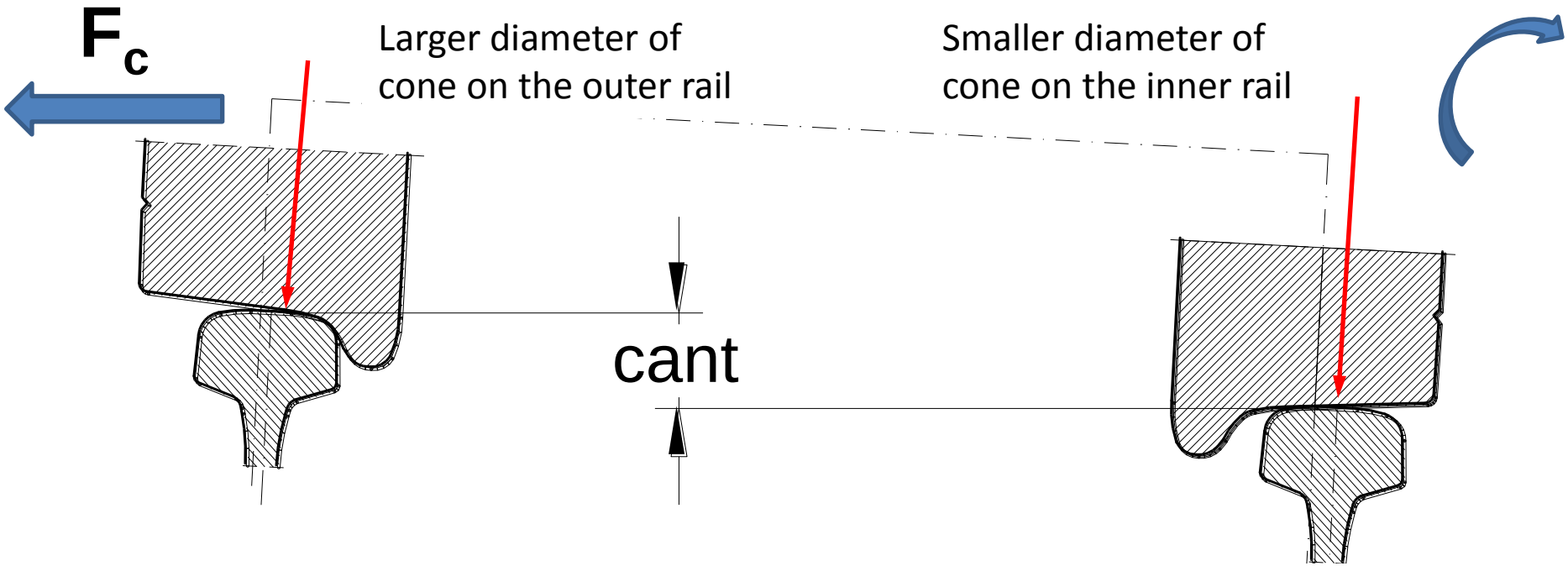
Hunting frequency



For a bogie with axles gauge *a* [m] Heumann gave the formule for multiplayer Z:

$$Z = \sqrt{1 + (a/s)^2},$$

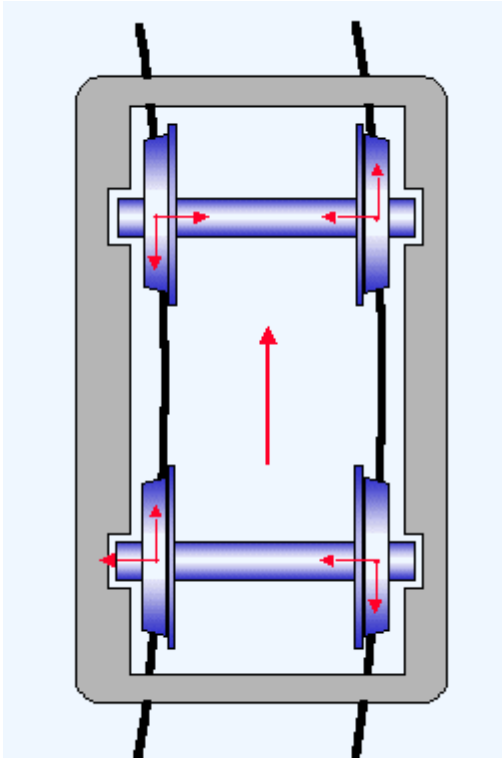
How it works on curved sections?



On curved track, the outer wheel has a greater distance to travel than the inner wheel. To compensate for this, the wheelset moves sideways in relation to the track so that the larger tyre radius on the inner edge of the wheel is used on the outer rail of the curve.

How it works on curved sections?

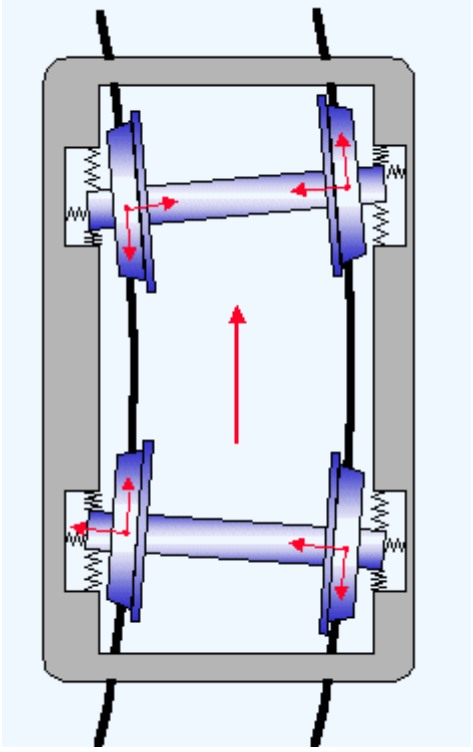
Many operators use flange or rail greasing to ease the passage of wheels on curves. Devices can be mounted on the track or the train. It is important to ensure that the amount of lubricant applied is exactly right. Too much will cause the rims to become contaminated and will lead to skidding and flatted wheels.



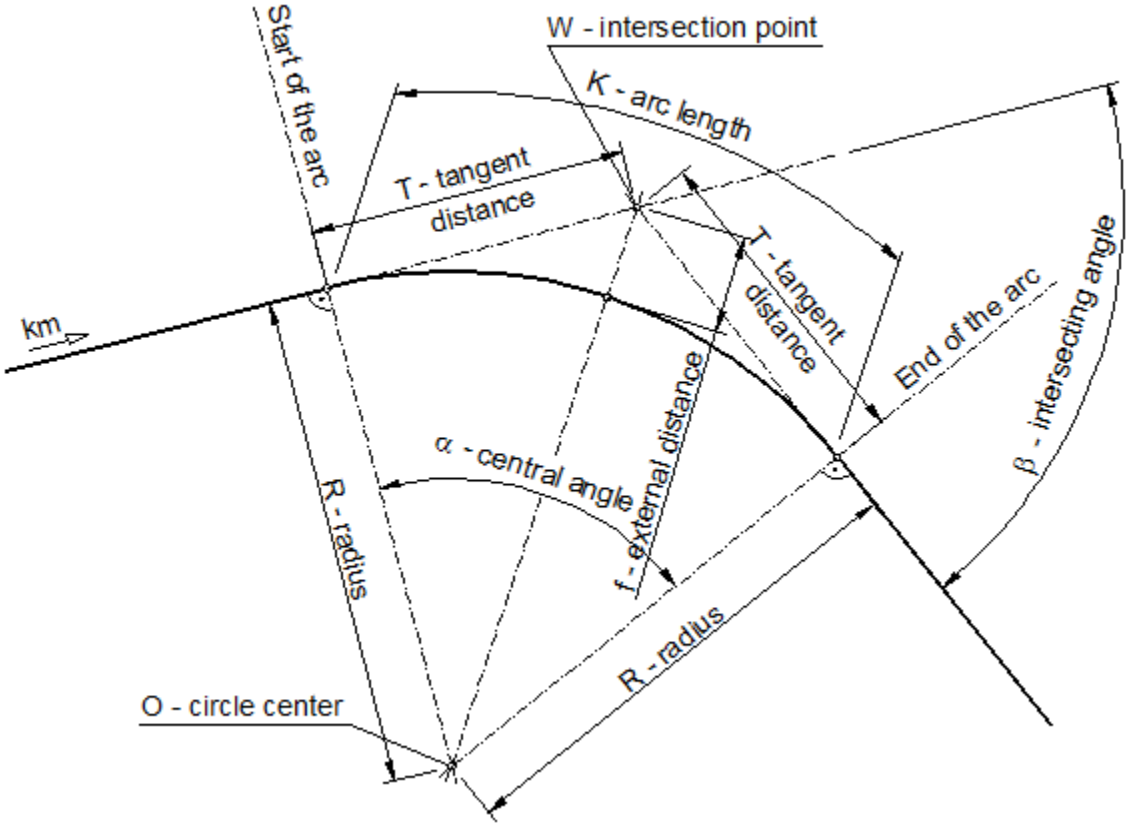
Rigid frame with wheelsets (simple structure)

vs

Rigid frame with radially steering wheelsets (less wheel and rail wear, less force required to pass the curve, less stresses in the frame)



Basic nomenclature&formulae for arc



$$K = \frac{\pi R \alpha}{180^o}$$

$$T = R\, tg \frac{\alpha}{2}$$

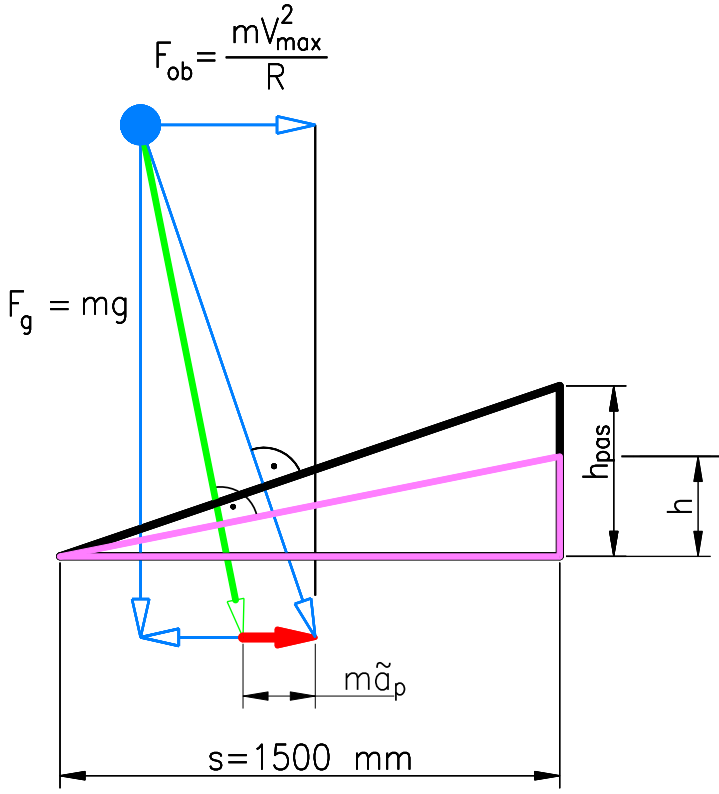
$$f = R \frac{1 - \cos \frac{\alpha}{2}}{\cos \frac{\alpha}{2}}$$

Cant

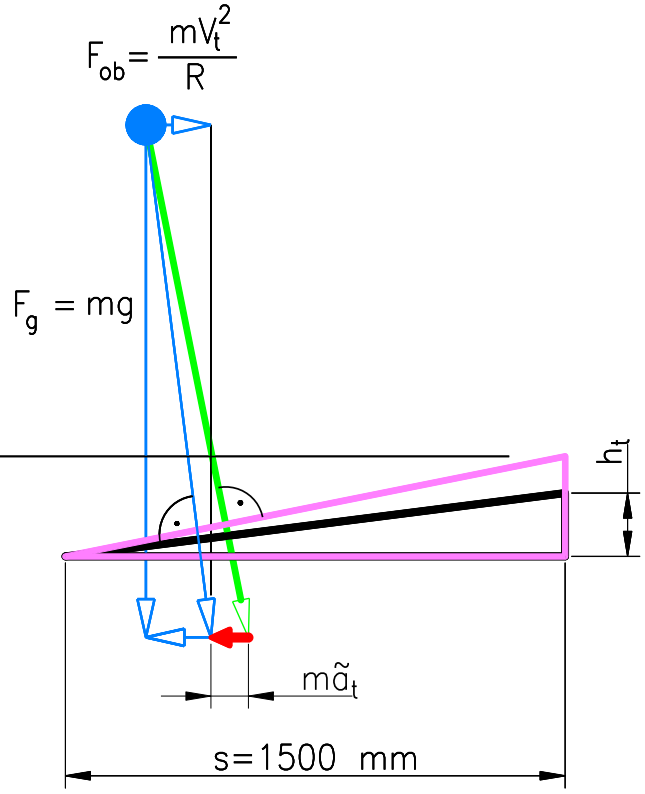


What is the cant?

Passenger trains



Freight trains



$$h_{\min} = \frac{11.8\,V_{\max}^2}{R} - \frac{s}{g}a_{dop} \le h \le \frac{11.8\,V_t^2}{R} + \frac{s}{g}a_t = h_{\max}$$

How to design the cant?

$$\frac{11.8 \cdot v_t^2}{R} + \frac{s}{g} a_t \geq h \geq \frac{11.8 \cdot v_{\max}^2}{R} - \frac{s}{g} a_{dop}$$

h_{max} (freight trains) h_{min} (passenger trains)

v_t – speed of freight trains [km/h]

R – radius of the curve [m]

s – distance between rails = 1500 [mm]

g – gravity constant = 9.81 [m/s^2]

a_t – allowable unbalanced acceleration of freight trains [m/s^2]

a_{dop} – allowable unbalanced acceleration of passenger trains [m/s^2]

Unbalanced accelerations

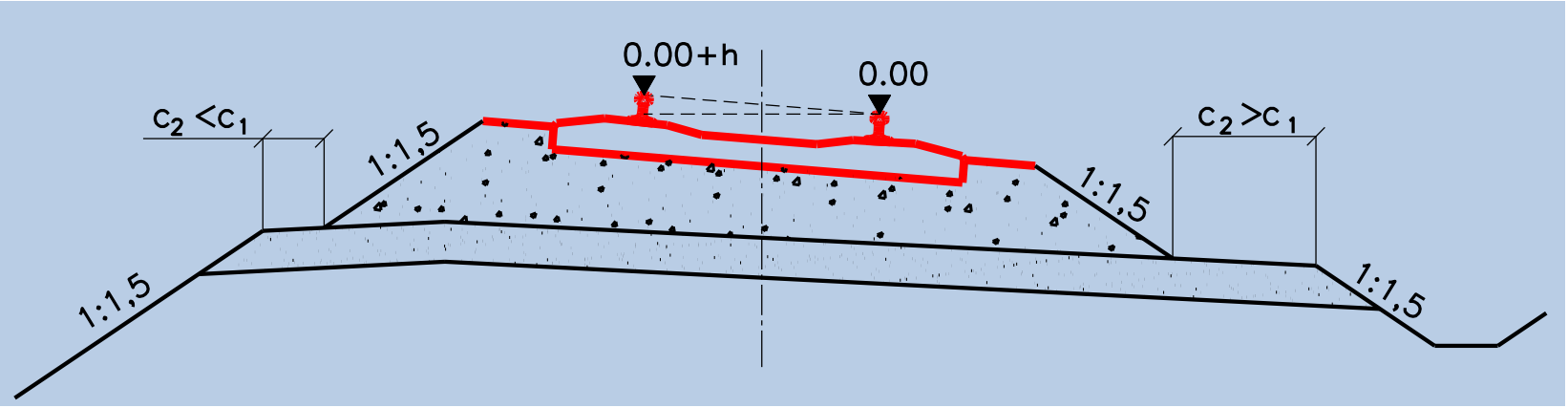
a_{dop} – allowable unbalanced acceleration of passenger trains [m/s^2]

Track type	a_{dop} [m/s^2]
Single circular arches or transition curves for tracks with speed < 160 km/h	0.8
Single circular arches or transition curves for tracks with speed ≥ 160 km/h	0.6
Side track in simple turnouts	0.65
Sidings on stations (v ≤ 40 km/h)	0.65
Circular arches with radius 200 m < R ≤ 250 m	0.5
Circular arches with radius R ≤ 200 m	0.45
Broadening of the gap between tracks (difficult conditions)	0.45
Broadening of the gap between tracks (favourable conditions)	0.3

a_t – allowable unbalanced acceleration of freight trains [m/s^2]

Intensity of traffic T [Tg/year]	a_t [m/s^2]
T < 5	0.6
5 ≤ T < 10	0.5
10 ≤ T < 15	0.4
15 ≤ T < 20	0.3
T ≥ 20	0.2

How to aply the cant?



1. The designed cant should fall into range from 20 to 150 mm -> safety.
2. The cant amount should be rounded to 5 mm -> technical limitations.
3. Analysis of the cant should take into account the true traffic structure and the real speeds of the passenger and freight trains.
4. The applied cant should allow shape the slopes of the ballast to save at least 60 cm of the cess on the trackway.

Remarks

1. The cant is NOT applied:
   - in curves of side tracks on stations (low speed),
   - in curves of turnouts if the main track is straight,
   - in curves if the speed is lower than 30 km/h,
   - on sidings shorter than 1 km.
2. If the maximum calculated cant < 20 mm then h=0 mm is applied.
3. If the minimum calculated cant > 150 mm then h=150 mm is applied and the maximum speed should be delimited.
4. At the end of calculation it should be checked if the eccentric accelerations are smaller than allowable ones:

$$\tilde{a}_p = \frac{\mathrm{v}_{\max}^2}{12.96\,\mathrm{R}} - \frac{h}{153} \le a_{dop}$$

$$\tilde{a}_t = \frac{h}{153} - \frac{\mathrm{v}_{\mathrm{t}}^2}{12.96\,\mathrm{R}} \le a_t$$

Tilting train technology



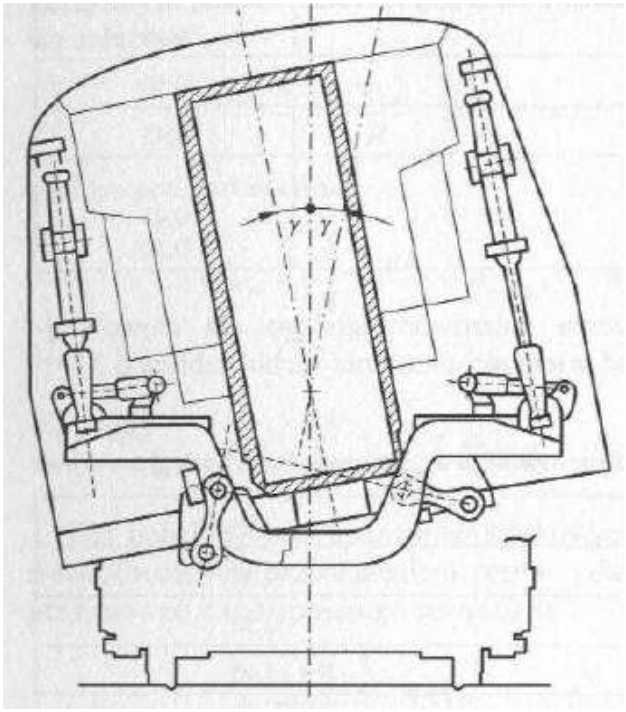
Hokkaido train (JR)

ICE train (DB)



Tilting train and cant

1. Passive system enables 2.8 – 3.5° of tilt.
2. Active system enables 6 – 10° of tilt.
3. Maximum speed on the curve of a radius *R* for a carriage with the tilting system can be calculated using the following formula:



$$v_{max} = \sqrt{\frac{R(h_{max} + \Delta h)}{11.8}}$$

where:

h_{max} - maximum cant = 150 mm,

Δh - maximum cant deficiency = 92 mm,

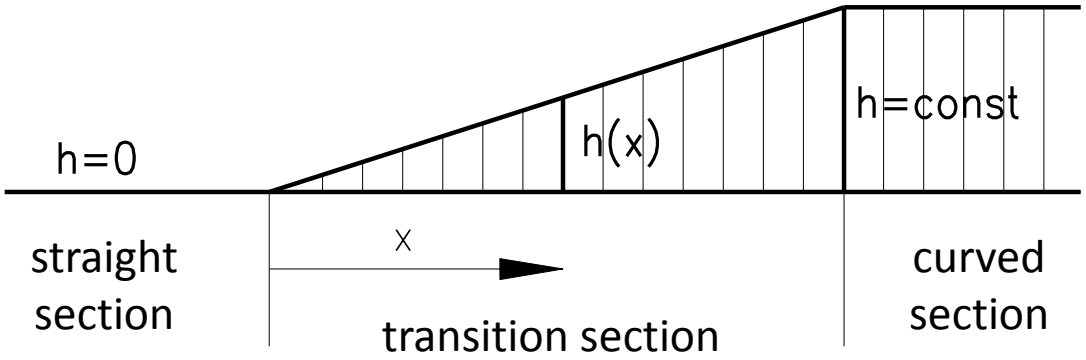
$v_{max} = 5.4\sqrt{R}$ - passive system, $\gamma = 3°$,

$v_{max} = 6.2\sqrt{R}$ - active system, $\gamma = 8°$.

The wheelsets will experience unbalanced acceleration of 2.0 m/s², but the passengers will experience less than 0.6 m/s².

Superelevation ramp

Between the straight section without cant and the curved section with a cant a superelevation ramp has to be applied, usually of linear function:



$$h_x = h\frac{x}{l}$$

Speed [km/h]	Ramp inclication [‰]	Lengt of the ramp [m]	
1	2	3	4
40 < v <200	$\frac{100}{v}$	zasadnicza	$\frac{h \cdot v}{100}$
40 ≤ v <200	$\frac{125}{v}$	dopuszczalna	$\frac{h \cdot v}{125}$
v < 40	2,5	minimalna	$\frac{h}{2,5}$

Units (sic!)
l [m]
h [mm]
V [km/h]

Superelevation ramp

The formulas for the basic and the permissible length of the ramp are constructed taking into account that the vertical speed of the wheel on the ramp is less than 28 mm/s or 35 mm/s, respectively for the basic and permissible conditions. The vertical speed of the wheel is calculated using the formula:

$$f = \frac{v_{\max} h}{3.6 l} \le f_{dop} \quad \text{so for example} \quad l \ge \frac{v_{\max} h}{3.6 \cdot 28} \approx \frac{v_{\max} h}{100}$$

In case of difficult local conditions or at railway line modernization a parabolic superelevation ramp can be applied:

$$h_x = h\left(\frac{3x^2}{l^2} - \frac{2x^3}{l^3}\right) \quad \text{or cosinusoid:} \quad h_x = \frac{h}{2}\left(l - \cos\left(\frac{\pi x}{l}\right)\right)$$

Transition curve

Transition curve is applied between straight section and circular arc section of the track for alleviate effects of impulsive acting of centrifugal force at the beginning of the curve. Usually a 3° parabolic curve is used, for which the curvature as well as the transversal acceleration is linear:

$$y = \frac{x^3}{6Rl}$$

what is the first approximation of clotoid: $$y = \frac{x^3}{6Rl} - \frac{x^7}{336R^3l^3} + \frac{x^{11}}{42240R^5l^5} - \dots$$

Minimum length of transition curve:

a) for arcs with a cant:

$$l \geq \frac{v_{\max} \cdot \max(\tilde{a}_p, \tilde{a}_t)}{3.6\psi_{dop}}$$

$$l \geq \frac{v_{\max} \cdot h}{3.6\, f_{dop}}$$

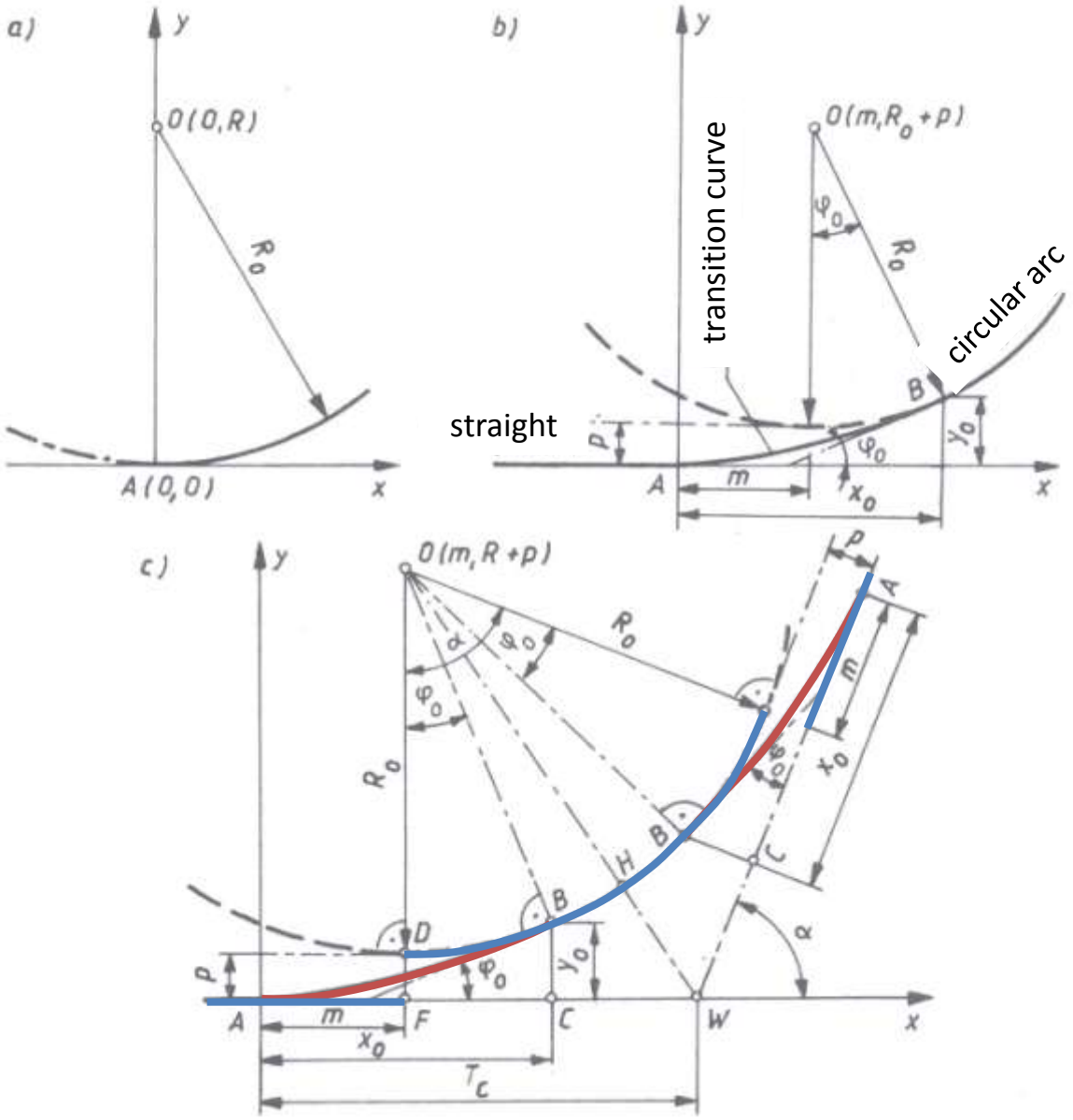
b) for arcs without a cant:

$$l \geq 0.0214 \frac{v_{\max}^3}{\psi_{dop} R}$$

$$l \geq 0.7\sqrt{R}$$

a) straight section and circular arc

b), c) straight section, circular arc and transition curves



Transition curve

Transition curve is NOT required:
1) in side tracks on stations,
2) in segmental (basket) arcs, under the condition that the growth of side acceleration is less than the permissible values (b=20 m for a rigid frame of carriage):

$$\psi = \frac{0.0214 \cdot v_{\max}^3}{bR} \leq \psi_{dop}$$

Tracks arrangement	ψ_{dop} [m/s^3]
Separate transition curves and widening of tracks distance by means of transition curves in difficult conditions	0.5
Widening of tracks distance by means of transition curves in difficult conditions	0.3
In between the arcs of turnouts	1.0

3) in other tracks where the speed is less than 30 km/h.

Transition curve, cant, superelevation ramp

