IMPACT OF RAILWAY INFRASTRUCTURE PARAMETERS ON SAFETY OF GOODS TRANSPORTATION BY RAILWAYS

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Abstract: *It is important to load and fix goods in railway wagons in well done way to reduce the number of accidents on the railway. The bad way of loading and fixing of the goods in the railway wagons can bring a very dangerous results as a damage of the transported goods or accident of the train. This paper deals with the analysis of the railway infrastructure parameters which affect the well done way of loading and fixing of goods in railway wagons.*

Keywords: LOAD, FIXING, GOODS, RAILWAY INFRASTRUCTURE, PARAMETERS, SAFETY

1. Introduction

The basic rules for loading and fixing of goods in railway transport are Regulations UIC. Their application ensures operational safety and avoids damaging of transported goods and wagons. Consigner of sent goods is responsible for the observance of the rules. If the provisions of regulation directives are not respected, railway operators are entitled to not accept the shipment for transportation. Rules of regulations are valid for international as well as for national transportation. They are the higher legal standard than the operator`s transport rules and the lower legal standard than laws. Operator`s transport rules have to accept loading and fixing rules of regulations. Therefore their knowledge and application is a prerequisite to make good contract of goods transportation and safety transport. Railway operators may also use their own, supplemented and modified rules (examples of loading), which in their entirety may or may not be mandatory for all railway undertakings.

2. Loading regulations

Loading regulations were issued by the International Union of Railways (UIC) and are applied since the 1st January 1999. They were issued in UIC official languages - French, German and English but there are also national translations. For example holder and the main responsibility of loading rules in Slovakia is Railway Cargo Company of Slovakia, Inc. About 20 changes were received till today and range of rules is about 350 pages.

Loading directions consist of three volumes:

- Volume 1: Principles - contains binding principles that must be followed by fixing and loading of goods.
- Volume 2: Goods - provides methods for loading different types of goods which correspond with principles of Volume 1 or which have been developed on the basis of practical tests.
- Volume 3: Line category - contains information about the railway lines of UIC stakeholders. They are currently published on the website of the UIC (LOCA).

3. Rules of loading and fixing of goods

Nature of the goods, the technical characteristics of the wagon and used railway line must be taken into account at the time of loading. The railway operations may not be endangered by:

- bad stowage of goods,
- bad location of goods gravity center,
- the effect of wind, ice and snow on the loading ramp or goods etc.

Therefore the goods must be stably stored and fixed against raising, falling, sliding, rolling off and overturning not only in the longitudinal as well as in transverse direction. At once the goods may not be damaged by its mounting and fixing. There are used walls, side walls, stanchions and integrated locking devices in wagons to fix goods. Side walls and stanchions are therefore fundamentally bring into the active position. If this is not possible, for example transported goods exceed the width of the wagon, the goods must be fixed with the consent of the sending railway undertaking by the special fixing devices. In this part of the direction there is loading and fixing of the goods dividing by the various kinds of goods:

- goods loaded freely and disordered,
- bulk goods,
- compact or rigid mounting,
- loading with mass displacement in the longitudinal direction,
- goods that can roll,
- goods that can be inverted,
- stacked goods,
- goods loaded on more than one vehicle,
- solid loading units,
- flexible loading units.

If a new way of goods loading is used it is necessary the security of loading proved:

- in the longitudinal direction of the wagon by the crash tests based on the corresponding table,
- in the transverse direction of wagon by the driving tests or by the tests on a test stand.

Safety of railway operation must be always guaranteed in each case.

4. Basic parameters

There are several parameters which could affect safety and quality of goods transportation by railway transport. They could be divided into two categories of parameters:

- track parameters,
- train parameters.

The basic track parameters are:

- number of the track lines,
- track speed limit,
- traffic signaling system,
- track leaning ratios,
- minimum curve radius,
- track resistance (slope, curvature, crossovers, tunnel).

The basic train parameters are:

- load capacity (per axle, per usual loading meter),
- maximum train weight,
- maximum train length (in meters, in number of the axles),
- train driver (driving style, driver skills),
- pull force of the locomotive engine (indicated, circumference of the drive wheels, at coupler, adhesion).

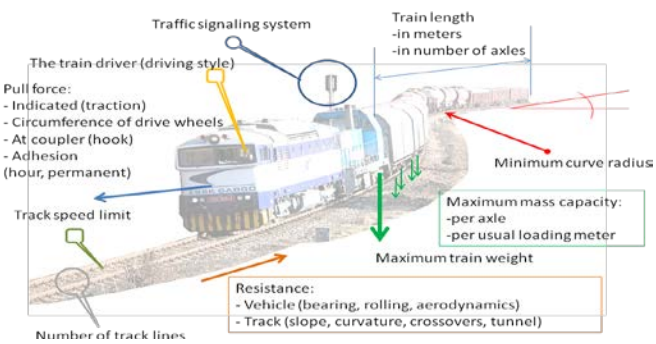

Fig. 1 *The track and train parameters*

5. Dependence of the observed indicators on changes of the railway infrastructure parameters

Description of the main parameters, which are necessary for the railway transportation:

- minimal transport time ($T_{\min}$):
  - maximum of the track speed limit ($V_{\max}$),
  - minimum of the track curve radius ($r_{\min}$),
- maximum capacity ($n_{\max}$):
  - number of the track rails (TR),
  - minimum of the track curve radius ($r_{\min}$),
  - maximum of the track speed limit ($V_{\max}$)
- maximum capacity of the transported wagon units per track relay (N^{T}_{wu}):
  - number of the track rails (TR),
  - minimum of the track curve radius ($r_{\min}$),
  - maximum of the track speed limit ($V_{\max}$),
  - maximum track mass capacity ($M^{\max}$)
  - maximum train length ($L^{\max}_{tr}$),
  - maximum number of axles ($N^{\max/tr}_{axle}$),
  - maximum train weight ($M^{\max}_{tr}$).

6. Relationship between transport time and infrastructure parameters

If we simplify the train drive just to a drive with a fixed speed and zero acceleration, then the travel time is proportional to the train passed distance and inversely proportional to its maximum speed.

$$T_{\min} = \frac{l}{V_{\max}} \qquad (1)$$

Than we can calculate the travel time for each track section and the total travel time on the passed track by adding the partial travel times.

$$T^{T}_{\min} = \Sigma T^{i}_{\min} \qquad (2)$$

In the curve ride with the radius *r* (*m*) by a fixed speed *v* ($m.s^{-1}$), we must add also the centripetal force to the tractive force acting in the same direction as the curve tangent (Majerčák, J. et al. 2008). The centripetal force is directed into the curve center and it makes the trajectory curvature. Then the dimension of the centripetal force is:

$$P = \frac{m.v^2}{r} \ [\mathrm{N}] \qquad (3)$$

This force causes the vehicle response, which is equal to the size of the centripetal force but has the opposite direction – centrifugal force. This force is reflected at the railway vehicle on its wheel flange and gives the vehicle curvilinear movement. The centrifugal force and the vehicle weight together make the resultant into three typical aspects:

- resultant cuts the drive plane in the middle of rails – the equivalence is stabilized,
- resultant cuts the tangent point between the vehicle wheel and head of the rail – the equivalence is labile,
- resultant cuts the drive plane in general out of the rail track – the turnover of the vehicle:
  - inside the curve – the track camber is abnormally high,
  - from the outside of the track – the camber is abnormally low.

For the smooth curve ride and also the stabilized vehicle ride position we must eliminate the negatives of the centrifugal force effect:

$$\sin\alpha = \frac{p}{s} \qquad (4)$$

The dimensions of the superelevation can be figured out of the resultant of the vehicle gravity and the centrifugal force which is perpendicular to the drive plane and axis of it. The pressure on the rails is the same.

The resultant R consists from centrifugal force *P* and the gravity force (*G*=*m.g*) which acts on the ride plane.

$$tg\alpha = \frac{v^2}{g.r} \qquad (5)$$

The angle α can be described also from the range of the liaison circles of the wheel set and the superelevation

$$\sin\alpha = \frac{p}{s} \qquad (6)$$

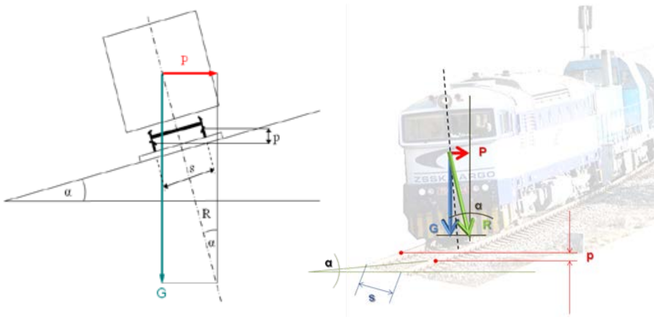

Fig. 2 *The superelevation of the track in the curve (left: ideal situation; right: common situation)*

Because the dimensions of angle α are too small, it can be written with the sufficient accuracy *sin α=tg α* and than

$$\frac{p}{s} = \frac{v^2}{g.r} \tag{7}$$

from this situation, the superelevation is

$$p_t = \frac{s.v^2}{g.r} \tag{8}$$

For the railway needs better suits the using of the superelevation in *mm* and the speed in $km.h^{-1}$.

We can describe this superelevation as theoretical and we mark it p_t . The theoretical superelevation is used for the ideal situation – all the trains travel at the same speed. Generally the trains don't ride at the same speed, however, so this equation must be transformed (slower trains can damage the lower rail in the curve superelevation). The transformation is made multiplying with $\frac{2}{3}$.

This superelevation can be denoted as normal and sign it p_n .

$$p_n = \frac{2}{3}.\frac{s.v^2}{g.r} = \frac{2}{3}.\frac{s.\frac{V^2}{3{,}6^2}}{9{,}81.r} = \frac{2.s.V^2}{381{,}41.r} \tag{9}$$

The superelevation of the curve rails can be stated by each country on its own decision. That's why we can count the maximum speed in the curve ride in the general conditions

$$p_n^{\max} = \frac{2.s.V^2}{381{,}41.r_{\min}} \Rightarrow V_{\max}^{T} = \sqrt{\frac{381{,}41.r_{\min}\cdot p_n^{\max}}{2.s}} = 13{,}81.\sqrt{\frac{r_{\min}\cdot p_n^{\max}}{s}} \tag{10}$$

Maximum (theoretical) volume of the capacity is proportional to the calculated time and inversely proportional to the occupation time of the track per one train.

$$n_{\max} = \frac{T}{t_{occ}} \tag{11}$$

The resulting track volume capacity is given by the volume of the capacity of the constraining section (it is the section with the lowest capacity)

$$n_{\max}^{T} = \min\left\{{}^{i}n_{\max}\right\} \tag{12}$$

7. Comparative indexes

The logistics performance index (publish by World Bank) is composed by 6 pillars. The second one is infrastructure. The infrastructure means in this case – quality of infrastructure based on evaluation of the quality of trade and transport related to infrastructure in country. The quality of infrastructure shows situation in each country in ports, airports, roads, rails, warehousing/ transloading facilities and telecommunications and IT. The global competitiveness index framework is based on three sub indexes – the basic requirements, the efficiency enhancers and the innovation and sophistication factors. Those three sub indexes can be split deeper into 12 pillars, 4 pillars are required for basic, 5 pillars for efficiency and 2 pillars for innovations. The second pillar in sub index basic requirements is infrastructure. The infrastructure pillar is calculate by ranking of quality of overall infrastructure, quality of roads, quality of railroad infrastructure, quality of port infrastructure, quality of air transport infrastructure, available airline seat kilometers, quality of electricity supply, mobile telephone subscriptions and fixed telephone lines. The Global innovation index is composed by two sub indexes (innovation input and innovation output). Innovation input is based on five indicators. The third one is infrastructure which consists from ICT, energy and general infrastructure. Three global comparative indexes which show competitiveness in different type cases use one very similar indicator – the infrastructure. This indicator is compiled three times but every time by different procedures. The result from this comparison is knowledge that infrastructure is very important for each country for own development and international competitiveness.

8. Decisive infrastructure parameters

Every infrastructure is a system of components – energy supply network, communication network, system of safety devices and tracks (paths, roads, waterways, pipelines, airways). Each parameter from those main systems influences final product of transporters/ carriers (Gogola, M. 2005). Carrier can offer services just in size which enable the infrastructure parameters in each country. Carrier's services are different for example in provided feeder systems, payment system possibilities, the highest measure/ volume/ size of one package (consignment), 24 day services, distribution system, delivery system, time of delivery etc. The resulted quality of performed service is directly depended on the real time situation on infrastructure, its current operation parameters and limits for different type of reasons.

The railway infrastructure parameters which are directly connected to quality of provided services are:

- Type of locomotive (pull forces of locomotive engine – indicated, circumference of the drive wheels, at coupler, max. adhesion forces), type and system of driving, driving style, drivers experiences;
- Number of track lines, track speed limits, traffic safety system, track leaning ratios, minimum curve radius, track resistance (slope, curvature, crossovers, tunnels);
- Loading capacity (per axle, per usual loading meter), maximum train weight, and maximum train length (in meters, in number of the axles).

More about infrastructure parameters can be found in (Kendra, M., Babin, M. 2012) and (Kendra, M., Babin, M., Barta, D. 2012).

9. Dependence between railway infrastructure parameters and quality of provided services

Dependence between railway infrastructure parameters and quality of provided services can be explained with following example. Consignee and also consignor expected high quality service – compliance of delivery time (on right time), right volume (mass/ pieces/ etc.), right place (door2door/ freight village/ etc.) and fair prices (Nedeliaková, E. et al. 2013). Fair prices depends on many factors – especially energy consumption, volume efficiency - unit costs. Delivery time is depending on traffic schedule, real time traffic management, train ride, operational problems, working (building) shutdowns and others. Right volume (mass…) is close depending to efficiency (economic, energetic) – but shipper requirements are usually not in conformity with carriers requirements (unit parameters) – feeder and delivery system problem. The efficiency problem is also closely connected to vehicle and track path (route) parameters (loading capacity – track/ vehicle, minimum curve radius, track leaning ratios, track speed limits etc.). Most of these parameters depend on right type locomotive (carrier's ownership) with well experienced driver. Conclusion for this part is knowledge that quality of transportation services is closely depended to infrastructure parameters, which means direct impact to country competitiveness in global market.

Fig. 3 *Stress analysis*

10. Conclusion

Loading of goods onto railway freight wagons and its fixing is a very important issue, which is directly related to protection of the transported goods, saving lives endangered by accidents, safety of operations and also the economic and commercial interests of the carriers. The proposed solution and additional information is useful for railway transportation and elsewhere as well. One of the most important areas of implementation is the transportation of dangerous goods (inflammable, explosive etc.) and prevention of danger by clear information how to load and fix the goods. The result of LOADFIX project will be a powerful information tool based on universal international data warehouse. It will allow a structured approach to complex data on goods loading. It will provide structured and up-to-date info for managers, staff and the professional public. It is especially intended for the employees of the carriers who deal with the issue of how to load and secure the cargo safely and economically. The info will also be useful to the professionals who deal with the method of storage and fixing (safeguarding) of cargo in the vehicle as a part of their job, particularly the specialists and institutes dealing with transportation such as sales agents, staff of non-standard shipment services and security advisors. Furthermore, the data is especially to be used by the operations staff who carries out the activities connected with handover of shipments and cars from the carriers and the inspections of the vehicles and goods during transport – wagon master, transport workers, transport warehousemen. It mainly covers inspection of storage and securing of goods during loading and the subsequent care of the transported goods during transport.

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