STRENGTH ANALYSIS OF A FREIGHT BOGIE FRAME UNDER THE DEFINED LOAD CASES

This work presents results of strength analyses of a modified freight wagon bogie frame. It consists of two main parts. The first part is addressed to introduction of the structure of a freight wagon bogie frame. It is a modified frame structure, which reflects current requirements of modern railway transport means. The conditions for rail vehicles approval and the main load cases, which every bogie frame must meet for commissioning, are described. The next part deals with computer modelling and analyses of this bogie frame. Strength analyses were performed using the FE method and they were focused on the assessment of stresses in the frame structure. Loads definition and the method of calculation were based on valid norms and standards.

**Keywords:** freight wagon bogie frame, modified structure, strength analysis, finite element method

1. Introduction

The transport of goods by railways represents an important element of a transport service. It is the environmentally friendly kind of goods transport, which is mainly obvious in international and intermodal transport. Therefore, the railway transport is nowadays an inseparable part of the transport system.

The railway transport allows an efficient way to move large quantities of goods over longer distances [1], [2], [3]. Nowadays, the design of rail vehicles has to satisfy conflicting requirements. On one hand it is the rail vehicles weight reducing and on the other hand all the railway transport means must meet the strict safety criteria, standards and norms. Every new designed railway vehicles and also construction units, such as bogies must meet before commissioning satisfy the terms set out in codes [4], [5].

2. Modified structure of a freight wagon bogie

By reason that mainly in the region of the Central Europe (Slovak Republic, Czech Republic, Poland, Hungary, Baltic countries, etc.) the freight railway transport makes use of the same railway tracks as passenger railway transport, the question about the stronger depreciation of this infrastructure arises [6], [7], [8]. These negative outcomes strongly relate among other things with the much higher axle load of freight wagons and with different design of freight wagons bogies [9], [10].

The Y25 bogie is the most commonly used bogie for freight wagons. In comparison to bogies for passenger wagons, it features the relatively stiff structure. On one hand there are solutions allowing steering wheelsets in curves by releasing the wheelsets in guidance, but on the other hand such a design meets problems when a freight wagon passes straight sections of tracks [11], [12], [13], [14]. These facts have led engineers to the modification of the original Y25 bogie design. Basis of the modification of the bogie consists of removing the buffer beams and in partial modifications of some other parts (increasing thicknesses of same sheets in structure) [15], [16]. Such a modified bogie cannot any longer use standard block brake acting on both side of a wheel, but it is equipped with the integrated block brake unit acting on one side of a wheel or with a disc brake [17]. The decreasing of the bogie mass is another important advantage of such a technical solution. When one compares the original Y25 bogie, equipped with the standard block brake, to the modified Y25 bogie design, equipped with the block brake unit, it can save up to 250 kg [15] and as standard freight wagons use two bogies, the mass of wagons is not longer negligible. Both bogie designs are shown in Figure 1.

From the operation point of view, reducing of the wagon unloaded mass means increasing the wagon capacity weight, lower operating costs when a wagon is transported in an unloaded state by saving energy consumption [18], and from the production point of view, one can save in material costs and partly reduce the needed production time.

The bogie frame is the main carrying part of the bogie. Therefore it is not possible to perform such an essential modification of the frame without adequate analyses. They come out and rely on strict requirements embedded in relevant standards and regulations. In the European standard the considered analysed bogie is classified in the category B-V: bogies freight rolling stock with single-stage suspensions [4].

3. Prescribed loads for freight wagon bogies

Freight bogies are loaded in real operational conditions by a wide spectrum of loads, which depends on actual level of loading, quality of a track expressed by variations from its geometrically

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ideal position load or an eventual buckling of the track in the
given track section and various others factors. Therefore, for
the load of bogie frames the replacement load spectrum was
determined according to which new developed bogies are tested
[19]. In this work the modified bogie frame was tested using
virtual models.

Generally, various load cases of bogies frames can be divided
into external and internal. The external load of bogies represents
the load relevant to the bogie running on the track, when it has to
carry gravitational forces, as well as dynamic forces acting in the
vertical and lateral directions. The internal load is caused by the
presence and operation of the bogie equipment, such as the brake
system, system of suspension with dampers, anti-roll bars system,
traction motors and also by masses attached to the bogie frame
(inertia effects) etc. [4], [19].

3.1 Combinations of individual loads

In reality, loads described above do not occur individually,
but they act concurrently in various combinations and in various
intensities. For needs of the strength and dynamic design of
a bogie frame, the European standards submit several selected
load combinations. They are compiled in such a manner, that
the designed bogie frame will withstand the possible combined
operational loads. In the European standard two combinations of
loads are defined, the static load combination and the dynamic
load combination. Based on the static load combination and the
removal of the static load, the permanent deformations must not
occur in the frame structure. In exceptional cases and based on
agreement with the vehicle operator, the permanent deformations
are compared to the permissible values [4], [19].

Bogie structures are loaded by the very high number of the
varying dynamic loads. Effects of such a load are concentrated
in critical locations of the analysed bogie frame (e.g. points of
action forces, geometry changes, welded joints etc.). The objective
of the fatigue tests is verification, if a bogie frame has sufficient
fatigue strength, i.e. if a cyclic operational load does not result
in initiation of fatigue cracks or fractures. Fatigue stresses are
possible to be determined by the two methods, i.e. the fatigue
resistance, if the fatigue lifetime is known (stress value, in which
under load by determined number of cycles the fatigue damage
not occur) and the cumulative damage, if the stress is constantly
under the fatigue lifetime level for all the determined load
combinations [4], [19].

In this work, only the static load combinations are considered.

4. Stress analyses of a modified bogie frame

Ride properties of rail vehicles significantly influence their
dynamic behaviour [20]. One can theoretically predict the
movement of the wheelset on a track by means of the wheelset
and track geometrical characteristics analysis. Geometrical
characteristics define the rail/wheel profiles contact couple
géometrical relationship. The shape of the contact couple crucially
influences the size of the contact patch and contact stress between
the wheel and rail value. This creates loading and excitation forces
acting inside the vehicle and track systems [21], [22], [23]. The
analysis of the mechanical systems dynamics may be conducted
using various methods [24].

4.1 Determination of the loads

Formulations for determination of the loads are prescribed
in the European standard [4]. For these calculations the freight
wagon bogie parameters were as follows: the total weight of the
bogie was \( M = 4.25 \) t, wheelbase \( b = 1.8 \) m and the total weight of
the wagon \( M_w = 90 \) t, (Figure 2).

The bogie is loaded in the vertical direction by the force:

\[
F_Z = \left( \frac{M_w}{2} - m \right) g
\]

where \( g \) represents the gravitational acceleration of 9.81 m.s\(^{-2}\). For
the vertical direction the value of the exceptional load is given by
following formulas:

- if vertical forces act only in the centre pivot:
  \[
  F_{Z_{\text{max}}} = 2 \cdot F_Z
  \]

- if vertical forces act in the centre pivot and on one side-bearer:
  \[
  F_{Z_{\text{max}}} (\text{or } F_{Z_{\text{max}}}) = 1.5 \cdot F_Z \cdot \alpha
  \]
  \[
  F_{Z_{\text{p}}} = 1.5 \cdot F_Z \left( 1 - \alpha \right)
  \]

where \( F_Z \) is the total vertical load on a bogie, \( F_{Z_{\text{p}}} \) is the vertical
force acting in the centre pivot, \( F_{Z_{\text{p}}} \) and \( F_{Z_{\text{p}}} \) are vertical forces act
on side-bearers, \( \alpha \) is coefficient for the body swinging. In this case,
the value \( \alpha = 0.3 \) was considered.

For the lateral force of the exceptional load, acting on every
wheelset, the following formulation is applied:

**Figure 1** The original Y25 bogie (left) and the modified Y25 bogie (right)
The structure of a bogie frame is acceptable, when it withstands required loads without deflecting to an extent that would impair functionality under the application of the loads or without suffering permanent deformation after removal of the loads [19]. It practically means that for all the load cases, stresses in the whole structure have to be under the yield strength of used material.

Figure 3, Figure 4, Figure 5 and Figure 6 show results from strength analyses of the modified freight wagon bogie frame under prescribed four load cases. Stresses were evaluated according to the HMH hypothesis.

Consider now Figure 3. For the first load case the highest value of the exceptional load \( F_{ZP_{\text{max}}} = 799.520 \text{kN} \) acts only in the centre pivot. Under this load the highest values of the stresses arise in the middle part of the frame. The maximum calculated stress is 596 MPa. It is located in the area of the centre pivot and the cross girder connection. This value is else over the yield strength of the material, but it occurs only locally. One has to consider important facts related to the numerical properties of the FE mesh, so this value can be neglected. Other values are safely below the yield strength. Therefore, the structure complies with given limits for the first load case.

In the second exceptional load case (Figure 4) the frame was loaded by forces acting in the centre pivot and on one side-bearer \( F_{ZP} = 419.750 \text{kN} \) and \( F_{Z1_{\text{max}}} = 179.892 \text{kN} \). Such the load model simulates a wagon body swinging. From results (Figure 4) one can see, that the maximum stress is 327.34 MPa. In the structure there are no stresses, which could be dangerous for the operation under these analysed load conditions.

The longitudinal force straining bogie frame is given by:

\[
F_{X_{\text{max}}} = \frac{F_{Z_{\text{max}}}}{2} = \frac{F_x + m \cdot g}{6} \tag{5}
\]

The load involved in the case of the wagon impact can be substituted by the static longitudinal forces acting in places where the equipment is connected to the bogie. Its value is determined from the mass of individual elements and maximum acceleration acting on them during wagon impact.

\[
F_{X_{\text{max}}} = 0.1(F_x + m \cdot g) \tag{6}
\]

### Table 1 Values of the calculated loads

<table>
<thead>
<tr>
<th>Load</th>
<th>Value [kN]</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_x )</td>
<td>399.760</td>
<td>(1)</td>
</tr>
<tr>
<td>( F_{Z_{\text{max}}} )</td>
<td>799.520</td>
<td>(2)</td>
</tr>
<tr>
<td>( F_{Z1_{\text{max}}} )</td>
<td>179.892</td>
<td>(3)</td>
</tr>
<tr>
<td>( F_{ZP} )</td>
<td>419.750</td>
<td>(4)</td>
</tr>
<tr>
<td>( F_{Y1_{\text{max}}} )</td>
<td>100.074</td>
<td>(5)</td>
</tr>
<tr>
<td>( F_f )</td>
<td>44.145</td>
<td>(6)</td>
</tr>
</tbody>
</table>

\( F_{Z_{\text{max}}} = F_{Z_{\text{max}}} = \frac{F_{Z_{\max}}}{2} = \frac{F_x + m \cdot g}{6} \tag{5} \)

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In the third load case (Figure 5) the exceptional load is formed by two vertical forces ($F_{ZP} = 419.750 \text{ kN}$ and $F_{Z1\text{max}} = 179.892 \text{ kN}$) and one lateral force ($F_{Y1\text{max}} = 100.0774 \text{ kN}$). As one can see in Figure 2, the vertical forces act in the centre pivot and the lateral force acts on the side-bearer. The maximum equivalent stress is 415.10 MPa in the area of the axle guide and the bogie solebar connection (Figure 5). This stress is identified only locally again. In this area two different types of FE mesh are used. The connection of these meshes causes calculation errors. In reality, the calculated stresses do not appear in the structure and the frame structure meets the prescribed criterion.

Finally, the fourth load case (Figure 6), was evaluated. In comparison to the previous case, vertical loads are the same ($F_{ZP} = 419.750 \text{ kN}$ and $F_{Z1\text{max}} = 179.892 \text{ kN}$), but instead of the lateral force, the longitudinal force acts in the centre pivot ($F_{X1\text{max}} = 44.145 \text{ kN}$). This force simulates the dynamic effects caused by traction and braking forces, etc. The maximum stress value (Figure 6) is slightly smaller in comparison to the third load case and it is of 405.1 MPa. It is calculated in the bogie solebar, specifically in the area of the longitudinal girder flange with the upper sheet. This local concentrator is formed due to the reasons described above. The frame structure is able to withstand the fourth load case, as well.

The future research will be focused on investigation of mechanical properties and dynamic behaviour of the entire modified bogie. A mechanical system of the modified bogie in a multibody software will be created and this just analysed FE model will serve as an important input for setting up a multibody system with a flexible body [28], [29] in order to study its dynamic properties and to compare to the original bogie for the detection of possible problems in terms of long-term operation.

References


