EAN 2012
50th annual coference on experimental stress analysis

# Experimental methods for vehicle bodies stress assessment and calculation model verification

Jan Humplík, Zdeněk Malkovský, Jiří Navrátil; VÚKV a. s., Bucharova 1314/8, CZ-158 00 Praha 5, Czech Republic; humplik@vukv.cz, malkovsky@vukv.cz, navratil@vukv.cz

**Abstract:** Correct boundary conditions determination as a basic presumption for experiment performance in conformity with real vehicle service conditions and valid standards requirements for vehicle dimensioning. Substitutive tested vehicle body support during the test. Analysis of real vehicle body loads and methods of substitution of real loads by test loads. Means for test load forces applying and methods of introduction and distribution of loading forces into vehicle body. Methods for determination of test sample dead weight stress and its effect on the overall stress of vehicle body. Verification of computational model by comparing calculation and test results.

**Keywords:** boundary conditions, test load, stress, deformation

## 1. About VÚKV a. s. Company

The company deals with development and testing of railway vehicles, their parts and other components from the area of transport engineering. The company also offers advisory and consultancy services in these areas.

These activities are performed by a team of highly qualified and experienced in-house experts applying the most up-to-date methods, procedures and equipment.

The major customers of the company include domestic and foreign manufacturers of railway rolling stock and transport technology, repair plants, infrastructure administrators and operators.

One of the important activities of the testing lab for railway rolling stock is also the static strength tests of the car body structures.

## 2. Introduction

The static strength test is currently a common partial measure carried out during approval process of new railway vehicle type. It is an acquisition of real image about the state of stress of vehicle body structure acquired from experiment made on real test sample in 1:1 scale. Stress and deformation values obtained in that way and the general response of vehicle structure to the test load are consequently compared with the strength calculation outputs.

Because of the extensive range of static strength tests the attention will be paid entirely to passenger vehicles in following text. The great circumspection during determination of boundary conditions is necessary especially at this kind of vehicles because much more variables are usually acting here compared to e. g. freight wagons.

The whole strength test procedure can be generally divided into three following steps:

*2.1. Preparation*

Preparation of the test represents processing of all needed information about vehicle body structure under test. It means classification of the vehicle to relevant passenger rolling stock group (P1 till P5 according to relevant standard EN 12663-1) and thence following vehicle body structure strength requirements, definition of test loads, correct determination of all boundary conditions etc.

*2.2. Realization*

The most difficult part of the test realization is usually test sample preparation and it's adjusting into the testing bench. The test preparation can be divided from point of view of contents into preparation of all sensors and measuring equipment (stress, deformation and force measuring) and test bench preparation. Test bench preparation consists of preparation of both mechanic and hydraulic part. The load forces are generated by hydraulic part.

*2.3. Evaluation*

The evaluation of results means especially their critical analysis following by comparison with results obtained from calculation by means of finite elements method.

## 3. Boundary condition analysis in terms of test preparation

Correct boundary condition analysis is a key presumption of correct static strength test performance. It consists of determination of test loads to which the vehicle body structure is intended to withstand, general vehicle weight analysis, considerations about influence of particular loads to state of stress in vehicle body structure, detailed analyses of a vehicle body design spots important for force transmission, analyses of degrees of freedom (DOF) etc. The following documents are needed for the mentioned analysis:

*3.1. Valid technical standards*

Basic requirements to vehicle body structure strength are fixed in valid standards. For passenger vehicles, European Standards EN 12663-1 and EN 15227 are valid. The required kinds of load for the mentioned vehicle type, test loading force values, test performance conditions etc. are stated here. The standards prescribe minimum requirements which can be enlarged on the base of customer requirements.

*3.2. Type drawing*

Type drawing is a basic information source for static test performance. Except of directly mentioned values the expected general force effort of vehicle body structure parts respectively design spots can be presumed and also potential critical points can be estimated. If it is a type drawing of a whole multiple unit the force efforts on the particular cars of the unit can be analyzed in the basic way and the maximal loaded vehicle body structure can be chosen for the test.

*3.3. Weight analysis of the vehicle*

The first step is to assess the size of particular loads. During this assessment, the important single loads which are simulated as single forces during the test are chosen. All remaining loads are substituted during the test by surface loads uniformly distributed in particular length segments of vehicle body structure. This necessary simplification enables the practical test performance.

*3.4. Detail drawings of particular design spots important from point of view of force load transmission*

Correct introduction of particular loads as significant single forces requires the knowledge not only about the values and application points of particular forces but also about load conditions – the sizes and forms of the loaded contact surfaces, stiffness of the real equipment which are intended to be substituted by test jigs etc.

## 4. Practical test performance

The attention was paid for the analytical test preparation hitherto. Now follows the part which deals with very realization of the test. As the first step a general inspection of vehicle body structure under test and possible production imperfections – e. g. inequalities, non-symmetric places, weld failures etc. – have to be marked to obtain information about the initial condition before the test. Important part of vehicle body structure preparation is a bonding of strain gauges, rosettes, setting of all deformation sensors etc. Adjustment of vehicle body structure into the test bench consists of preparation of all parts of loading device (mechanical parts, hydraulic circuits,…) responding to the analysis carried out in previous step. The correct performance of this step is important in the same way as the correct analysis.

*4.1. Substitutive test load in vertical direction*

Substitutive test load has to satisfy the following conditions:

4.1.1. Bending moment

Particular test forces must have such sizes and such points of application in order that resulting bending moment acting in particular cross sections of vehicle body structure corresponds to bending moment invoked by real service load.

4.1.2. Reaction forces in the supports

Particular substitutive test forces must have such sizes and such points of application in order that the reaction forces measured in the supports have the same size as the reaction forces of vehicle body structures loaded by real service load.

4.1.3. Position of mass center

Particular substitutive test forces must have such sizes and such points of application in order that the resulting mass center of the vehicle loaded by test loads and mass center of the vehicle loaded by service load has in case of projection to horizontal plane approximately the same position.

*4.2. Practical performance of boundary conditions*

Practical realization of boundary conditions can be divided into following areas:

4.2.1. Practical realization of supports – see Fig. 1

Vehicle body structure is supported by substitution test bogies during the test. The bogies are universal from point of view of their construction; substitution jigs for simulation of a real bogie–body interface can be located on them. This interface must correspond to parameters of a real car body support on the bogies. The contact surfaces position and size must be kept and the degrees of freedom of real system must be respected. This interface also includes the force transducers for verification measurement of reaction forces from the introduced vertical load.

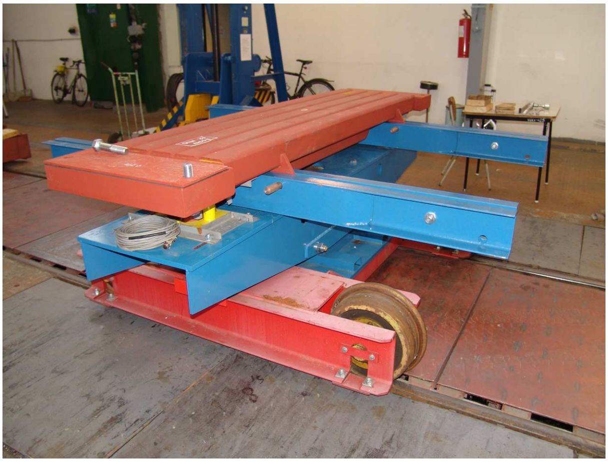

**Fig. 1.** Practical realization of supports - substitution test bogie

4.2.2. Practical realization of the vertical load

All vertical loads will be divided into two groups – surface loads and single force load – due to further description lucidity. This dividing is carried out on the base of ratio between loading force and size of area subjected by relevant force. This ratio is signally smaller in case of surface loads then in case of single force load.

4.2.2.1. Equable (surface) load – see Fig. 2

The load simulating passenger weight or dead weight of vehicle body structure can be stated as a typical example. Two pairs of wooden planks are located symmetrically in the direction of longitudinal vehicle axis on explicit length vehicle body segment. Their mutual distance and position against sidewall is set geometrically. The longitudinal planks are consequently connected by short cross planks. Respective loading force acts to these cross planks by means of special steel frames. The loading force reaction is captured to testing hall body by means of transversely oriented girders and poles.

**Fig. 2.** Practical realization of equable (surface) load

4.2.2.2. Single forces – see Fig. 3

The loading by single forces do not vary by a way of capturing the reaction forces from the uniform load. The main difference is in the fact that the loading forces are introduced into excessive smaller vehicle body area – e. g. pads, aggregate consoles, bogie hangings etc. Special jigs as devices for load introducing are usually produced as substitution for real devices. If available, also the original parts (e. g. carrying frame for motor-generator) can be used. The parameters of the jigs (size, form of contact surfaces, stiffness,…) must be of such kind in order to the loads introduced by means of them correspond to the loads invoked by the real devices. For the realization of this condition is necessary that the positions of mass centers of real devices and substitution loads are the same during projection to horizontal plane. Also number of degrees of freedom of real and substitution systems must be the same.

**Fig. 3.** Practical realization of single forces

4.2.3. Practical realization of longitudinal loads

The valid standards prescribe specific longitudinal loads for relevant vehicle type to which the vehicle body has to withstand. These are the exceptional – extreme loads in all cases which can happen during the service (these loads simulate the collision with other vehicles or with various subjects). That is why most of such loads are verified not only with numeric calculation but also with the static test. These are the following loads:

- Compression force to buffers (if the vehicle is equipped by buffers)
- Compression and tension forces in mounting area of automatic coupler or joint
- Compression force to lower window ring bar of driver's cab
- Compression force to obstacle deflector – plough (operates symmetrical and asymmetrical)
- Compression force to upper ring bar of wagon front part (in gangway area)

Similar principles as in case of the loading by vertical single forces are valid in case of loading by longitudinal forces. The test force can be introduced respectively caught by substitution jigs or original parts to be tested. The same rules are valid using substitutive jigs as in case of introducing single forces in vertical direction:

- Identical size of contact surface
- Identical stiffness
- Keeping of degrees of freedom number

Typical example for such jig is automatic coupler substitution – see Fig. 4. To keep the same technologic process as in case of real equipment – except of requirements for relevant jig – is necessary – e. g. tightening torque of the screws.

**Fig. 4.** Automatic coupler substitution

An example for using of original part can be joint connecting two vehicle bodies. The joint can be partially modified – e. g. rubber-metal chuck can be substituted by a steel one.

Another example is testing load of obstacle deflector (plough). For such case special jigs from plywood with a "negative form" of the middle and transversal part of a plough are prepared. In case of both symmetric and asymmetric loads the required distance and parallelism of acting force with top of rail plane are checked. To keep the constant geometry during loading the plough shock absorbers are usually substituted by stiff rods.

## 5. Comparison of test and calculation results

All obtained values from static strength tests are to be substantial analyzed in very critical way. First phase is a basic estimation of measured values from point of view of size and polarity; next phase is a comparison of values with values from other loads, comparison with allowed values etc. Some important effects follow the whole process:

### *5.1. Linearity of measured values*

It is checked that the measured values of stress and deformations increase proportionally with increasing load. Eventual significant divergence from this presumption shows change of load flow. This change could be caused by plastic deformations of certain part of vehicle body.

### *5.2. Verification of residual values*

Downward tendency of state of stress and deformations to zero after loads subside is checked. Possible measured residual stresses and deformations show local plastic vehicle body transformation. Then not only their presence and immediate size but also the tendency of their further development is important. Residual stress and deformation values in case of sizable welded parts (e. g. vehicle bodies) are common after the first loading cycle but they should fall in limit way to zero after repeated loading cycles.

### *5.3. Verification of symmetric points*

The same measured values at symmetrically located sensors (strain gauges, potentiometers for deformation measurements) are checked. Potential great differences could be caused by vehicle body non-symmetry when production technology was violated, loads did not introduced symmetrically or a mistake has occurred in measuring chain; both last reasons have to be removed immediately.

### *5.4. Comparison with allowed values*

Obtained stress and deformation values are compared with allowed values which are defined in relevant standards. Eventually overrun of allowed values is to review not only from point of view of size but also from point of view of strain gauge position on vehicle body (design spots) and kind of loading (service, exceptional) in which the overrun has occurred.

### *5.5. General behavior of tested vehicle body*

A part of evaluation of static strength test is also general inspection of vehicle body similar as before the test aimed especially to most endangered parts. It is observed whether any permanent deformations occur that could be caused e. g. when construction stability was lost.

Quick preliminary analysis according to above described five steps during particular test loads is carried out in the praxis. Substantial analysis of all measured values is carried out at the end of the test.

## 6. Conclusion

On assumption that in case of elected kinds of load the measured stresses and deformation comply with allowed values and sufficient conformity between calculation and experiment was achieved in the same time it can be supposed that the strength calculation is correct also for load cases which were not experimentally verified. The general sufficient strength and resistance of vehicle body against both service and exceptional loads has been validated by this verification of strength calculation and by suitable measured values. Thereby also the main goal of the static strength test is fulfilled.