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DETERMINATION OF TORSIONAL STIFFNESS OF WAGONS

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Abstract: *This paper presents the experimental methods and the finite element method for determination of torsional stiffness of the wagon body. The methods presented cover only static conditions for determination of torsional stiffness of the three-axle two-part car transport wagon, type DDam. The methodology of experimental determination of torsional stiffness of three-axle wagons described in this paper is not defined by the ORE and UIC regulations. Based on a mathematical model, the presented methodology of experimental determination of torsional stiffness represents a basis for running safety of this type of wagons on a distorted track.*

Key words*: wagon, railway, calculation, torsion, torsional stiffness, FEM*

INTRODUCTION

This paper presents two methods for determination of torsional stiffness of the three-axle car transport wagon, type DDam. One method is experimental, based on the UIC and ORE regulations [1], [8] and on the developed mathematical model [9], while the other method for determination of torsional stiffness is numerical, based on the finite element method-FEM. In both methods, torsional stiffness of the empty wagon was determined, where the boundary value of track distortion g^* was determined according to the ORE recommendations [1], [7].

Determination of torsional stiffness of wagons with the standard structure, two-axle and four-axle wagons, is defined by regulations [1], [7] and represents the basis for further modelling [2], [3], [6], [5] and experimental determination of wagon running safety.

As the car transport wagon, type DDam, is a three-axle wagon, the calculation of torsional stiffness is not defined by the existing regulations [1],[7].

EXPERIMENTAL DETERMINATION OF TORSIONAL STIFFNESS

The object of testing and the test stand

The car transport wagon, type DDam, is a three-axle, two-part wagon. Its dead weight is 27 t, with the carrying capacity of 20 t, and it is designed for speeds of up to 120 km/h in S and SS regimes.

Figure 1. DDam car transport wagon

Figures 2, 3 and 4 show a schematic presentation of the car transport wagon, type DDam, where the freedoms of wagon offsetting around the chosen axes are given.

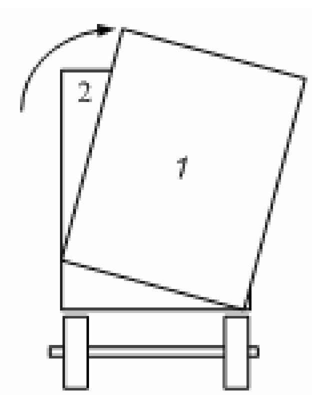

Figure 2. Wagon offsetting around the longitudinal axis

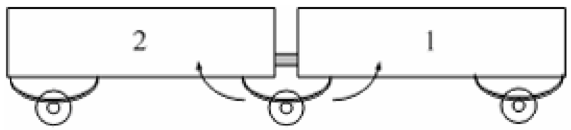

Figure 3. Wagon offsetting around the transverse axis

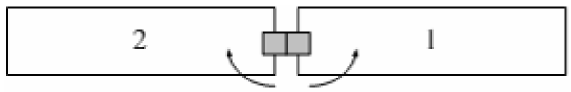

Figure 4. Wagon offsetting around the vertical axis

It is considered that the following assumptions hold during the exploitation of a three-axle wagon:

- the offset of one wagon unit in relation to the other one will not exceed 2^o,
- the mutual influence of wagons is transferred only by means of springs in the suspension system of the centre axle,
- the wagon units are symmetrical in relation to the plane which is normal to the longitudinal axis and passes throught the joint connection above the centre axle.

According to the ORE and UIC recommendations, it is necessary to decompose the wagon structure to the elements that have approximately linear characteristics of stiffness. In the mathematical model [9] and the described methodology of experimental testing, the following elements with approximately linear characteristics of stiffness were identified:

- the bodies of the first and second units of the wagon,
- the springs in the suspension system at the ends of the wagon,
- the springs connecting the wagon units.

The experiment was organized in such a way as to determine torsional stiffness of the wagon body (the first and second wagon units), and after that, taking into account the elastic elements in the suspension system of the wagon, according to the mathematical model for determination of torsional stiffness of three-axle wagons [9], the total torsional stiffness of the three-axle car transport wagon, type DDam, was determined.

Experimental determination of torsinal stiffness was performed on the static test stand of the Wagon Factory in Kraljevo. During the determination of torsional stiffness, the operation of all springs in the suspension system was blocked (Figure 5.).

Since there is a joint connection between the wagon units, since the mutual influence between the wagon units in exploitation is reduced to the action of springs in the suspension system on the centre axle and the torsional stiffnesses of the wagon body are much bigger than the influence of the other parameters, during the determination of torsional stiffness of the wagon body the three-axle wagon can be observed as two two-axle wagons with elastic connection. The wagon units are symmetrical in relation to the point of connection.

Measurement of wheel load was carried out on the horizontal track, on a straight railway line without distortion. During measurement, a horizontal device with high stiffness was placed and it leaned against the track placed on a concrete base. The hydrocylinder with force transducers (DTI Figure 5) were placed under each wheel, at the transverse distance of $2b_z$ = 2000 mm symmetrically to the longitudinal axis of the track. Wheel lifting up to the boundary distortion was performed by means of hydrocylinders, while displacements were registered by displacements transducers.

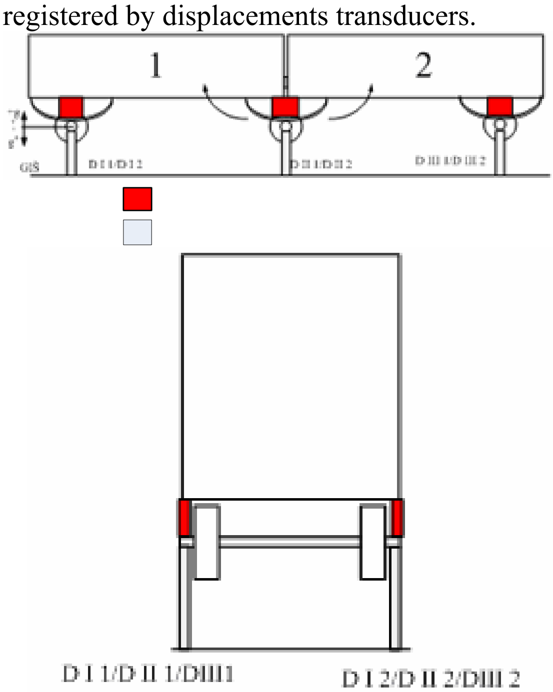

Figure 5. Distribution of measurement points

The experiment is performed by introducing distortion on axle I on wheel I1, and loads and unloads on the wheels II1 and II2 on axle II are read. Then distortion is introduced on axle II on wheel 1, and the loads and unloads are registered on wheels I1, I2, III1, and III2. Thus, the forces mesured on the wheelsets contain differences in wheel load originating from distortion and displacement of the gravitational centre.

During lifting, the wheel load was registered at each 3 mm with dynamometers manufactured by the Wagon Factory Kraljevo. The error in measuring by the DTI dynamometers is $\Delta Q = 0,5kN$.

Vertical lifting and lowering was measured by using inductive converters made by «Hottinger», whose measurement error is Δh = 0.5 mm.

Measuring instruments:

- The measuring system for dynamic measurement HBM MGC Plus (16 channels),
- A PC computer,

Software:

- the software package for acquisition and on-line data procession «Catman» (manufactured by HBM),
- the software package for data procession and presentation «Origin» (manufactured by MicroCal).

The measurement was carried out by the measurement system HBM MGC Plus, where all measurement results were directly entered and saved in the memory of the PC computer.

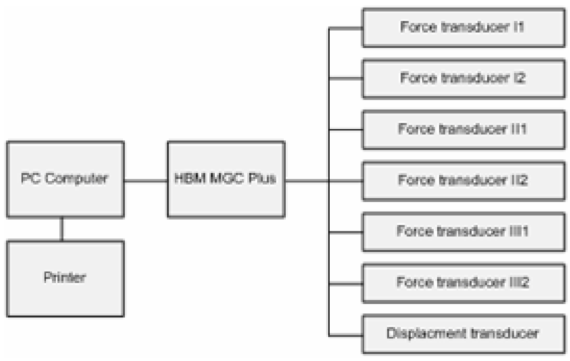

Figure 6. Block diagram of the measuring instruments

Measurement results

Figures 7 and 8 present characteristic diagrams of variations of wheel load for determination of torsional stiffness of wagons. Loads of two wheels (denoted by 1 and 2) on one axle (denoted by III) during lifting of the adjacent axle on the wagon are presented here.

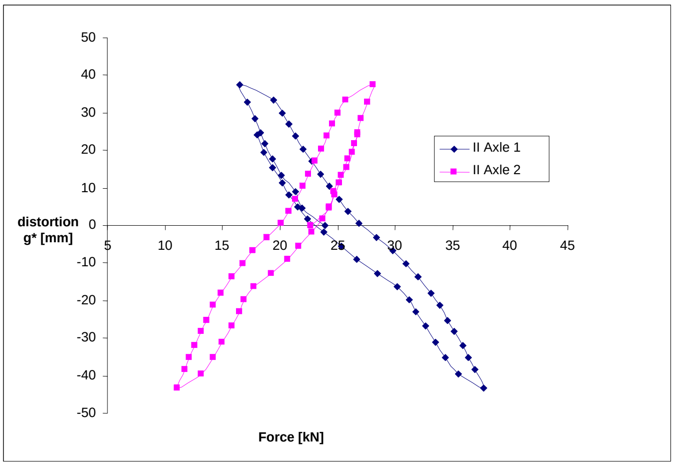

Figure 7. Wheel load on axle II during lifting and lowering on axle III

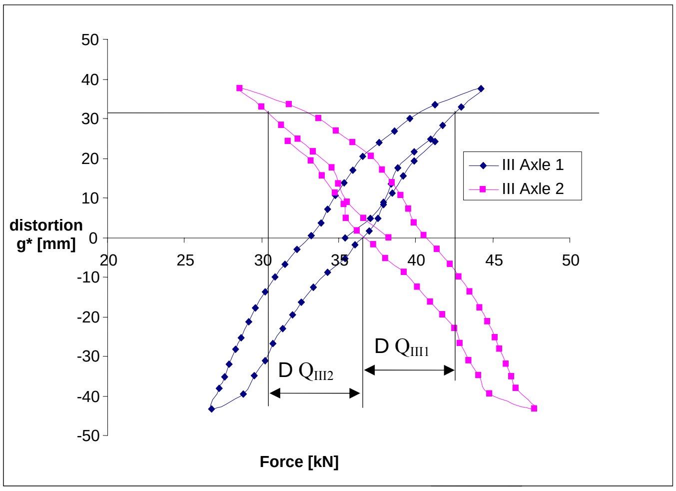

Figure 8. Wheel load on axle III during lifting and lowering on axle III

The value of variation of wheel load can be determined from the diagrams in Figures 7 and 8 for the boundary value of distortion g^* determined according to the equation according to [1]. For the wheels 1 and 2 on axle III, the load variation is:

$$\Delta Q_{III1} \approx 8,5kN,$$

$$\Delta Q_{III2} \approx 8,5kN,$$

According to the same methodology, the variation of wheel load on axles I and II for the boundary value of distortion, the variation of wheel load is:

$$\Delta Q_{I1} \approx 9kN,$$

$$\Delta Q_{I2} \approx 9kN,$$

$\Delta Q_{II1} \approx 8kN,$

$\Delta Q_{II2} \approx 7kN,$

DETERMINATION OF TORSIONAL STIFFNESS BY THE FINITE ELEMENT METHOD

For determination of torsional stiffness of wagons by FEM, a model of wagon body was formed by using line elements and thin-plate type of elements.

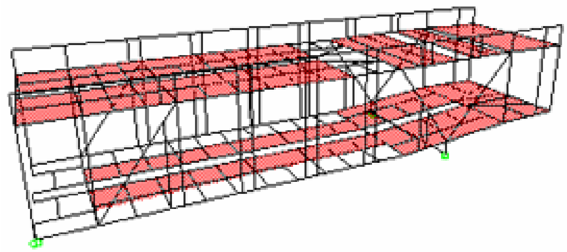

Figure 9. A model of wagon body

The wagon type DDam presented in Figure 1 has the covered upper platform. The influence of the roof structure in the model was taken through uniform load, as presented in Figure 10.

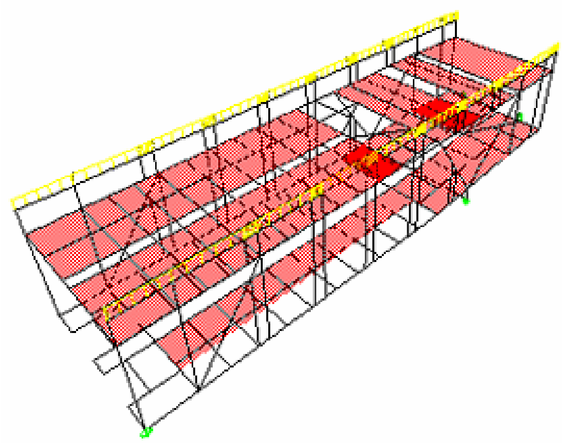

Figure 10. Influence of roof in the wagon body model

While forming the model, it was taken that the wagon was symmetrical by the vertical plane in the transverse direction in the middle of the wagon. In the FEM, the wagon unit was observed as an independent unit without the influence of another wagon unit and without the influence of suspension in the suspension system, as well as without the influence of the wheelsets.

The obtained values of deviations of forces in the supports during registration of distortion in one support are not considered to be a sufficient indicator for determination of torsional stiffness of the wagon body.

All connections in the wagon unit structure are considered to have been performed by welding. This assumption being taken into account, a model was formed in FEM so that all connections between the elements of the structure were performed as undetachable.

In this model, no friction between the elements or inside the structure itself was considered, so that linear change of loads depending on the value of introduced distortion is expected.

The points of support of the wagon body were modelled so that they could accept only vertical forces from the weight of the structure itself and the wagon roof.

As the load for the given model, the boundary value of distortion obtained according to the ORE recommendations was introduced, i.e. the value for the observed DDam wagon is $g^* = 32mm$. On one end of the wagon, the displacement of the support by the value of boundary distortion was given, while in the other supports the difference of loads was calculated before and after registration of displacements.

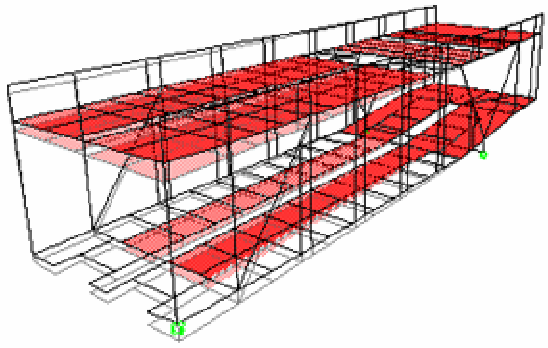

Figure 11. Presentation of the deformed wagon structure due to the distortion introduced at one end of the wagon

The results obtained by the finite element method are presented in the following table:

Height of wagon lifting [mm]	ΔQ [kN]
5	2.29
10	2.94
15	3.76
20	4.82
25	6.17
32	7.8

As it can be seen from the Table, distortion was gradually introduced on one support registering the displacement of 5 mm. Differences of forces in the supports are presented for each value of distortion. For the distortion value of $g^{*}=32mm$, the value of load difference $\Delta Q=7,8\left[kN\right]$ was obtained.

The following table presents the comparative presentation of variation of wheel load due to the distortion calculated by FEM and determined experimentally.

FEM	Experimental values	
7.8 kN	Variation of load on axle I	9 kN
	Variation of load on axle II	7.5 kN
	Variation of load on axle III	8.5 kN

CONCLUSION

In addition to the presented experimental method for determination of torsional stiffness, the finite element method can be very successfully used for determination of torsional stiffness in the design process.

The results obtained by the presented methods for determination of torsional stiffness of the wagon body, obtained experimentally and by FEM, agree to a considerable extent. On the basis of the obtained results, it can be considered that the proposed experimental method can be used for determination of torsional stiffness of one wagon body excluding the influence of the other one, which represents the basis for further determination of the total torsional stiffness of the three-axle wagon.

This paper proposes the methodology of experimental determination of torsional stiffness of three-axle wagons, which is not defined in regulations [1][7]. The proposed methodology takes into account only vertical forces for determination of torsional stiffness of wagons. Due to the lack of knowledge of horizontal forces on the wheels, at present it is not possible to define the boundary values of torsional stiffness for three-axle wagons. In order to define the boundary values of torsional stiffness, it is necessary to perform a series of tests of this type of wagons by pushing through the S-curve.

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ОПРЕДЕЛЯНЕ НА ТОРЗИОННАТА КОРАВИНА НА ВАГОНИ

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Резюме: *Докладът представя експерименталните методи и метода на крайните елементи за определяне на торзионната коравина на коша на вагона. Представеният метод включва само статичните условия за определяне на торзионната коравина на триосен товарен вагон от две части от типа DDam. Методологията на експерименталното определяне на торзионната коравина на триосни вагони не е определена от предписанията на ORE и UIC. Базирана на математически модел, представената методология за експериментално определяне на торзионната коравина представлява основа за безопасност на движение на този тип вагони в кривини.*

Ключови думи*: вагон, железница, изчисление, усукване, коравина на усукване, метод на крайните елементи.*