Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 7 (1964)

Artikel: Model tests on a box girder bridge

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DOI: https://doi.org/10.5169/seals-7825

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Model Tests on a Box Girder Bridge

Essais sur modèle réduit d'un pont à poutre en caisson

Modellversuche einer Brücke mit Kastenträger

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1. Spatial Deformation of the Box Girder

The bridge of prestressed concrete, which was represented by our model, is a continuous five-span bridge (68,25 + 115,50 + 115,50 + 115,50 + 68,25 = = 483,00 m). Its horizontal member is a box-girder with a highly variable cross-section (fig. 1). It is simply supported at both ends, whilst rigidly joined

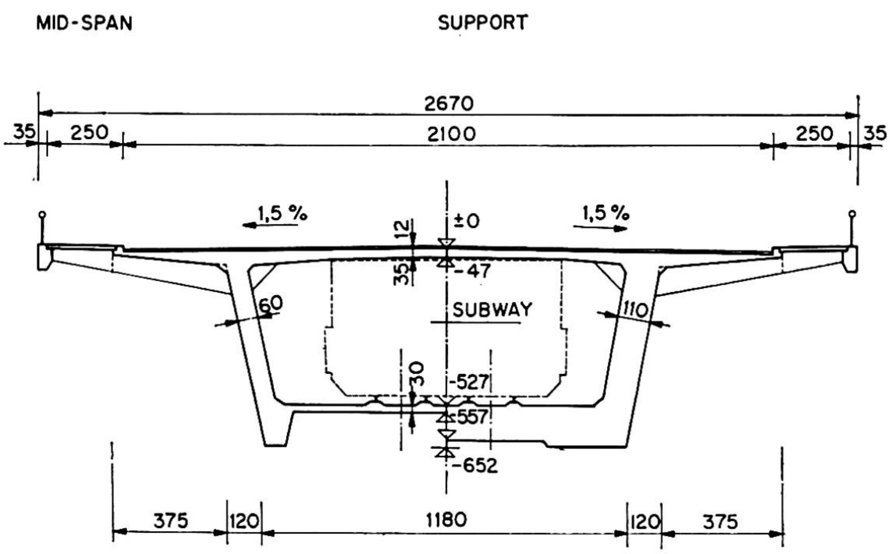

Fig. 1. Cross-section of the bridge.

to four intermediate pillars, each of which is divided into four oblique stanchions (see detail of model, fig. 4). As the interior of the box-girder must be left free for tram traffic, the entire length of the girder is without diaphragms or stiffening frames.

Mainly for this reason it was necessary to study thoroughly the spatial behavior of the bridge under a live load, especially if unsymmetrical with respect to the longitudinal axis of the bridge, or under the wind force. This spatial deformation and the corresponding pattern of stresses may be obtained by superposing two stages:

A. The box-girder is regarded as a system of plates of variable thickness, whose longitudinal nodal edges a, b, c, d (fig. 2) are, for this first stage, supported so that they are not displaced under load, and consequently the angles of all four plates remain unchanged. But from the deformation of the plates of which the girder is composed we may compute only their internal forces at this stage-bending moments m_{x0}, m_{y0}, twisting moments m_{xy0} and shear forces t_{x0}, t_{y0}.

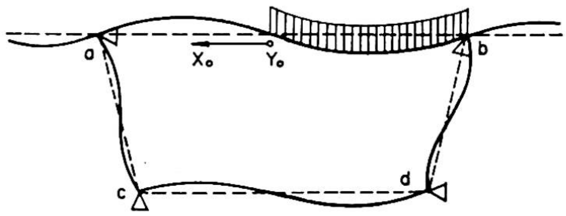

Fig. 2. Deformation of the cross-section at stage A.

B. Now let us remove the fictitious supports at the nodal edges, i. e., allow for their displacements under load, and replace the entire load by an equivalent system of reactive forces in the planes of the four plates forming the girder. We then come to the second stage, which was the main subject of our investigation, namely the spatial deformation of the box-girder behaving as a box-section beam with a deformable cross-section subjected to bending and torsion. We dealt theoretically with the problem by using the variational method derived by V. Z. VLASOV in his book Strojitěl'naja mechanika tonkostennych prostranstvennych sistem (Gosstrojizdat, Moscow, 1955) and also obtained some numerical results by the use of an ELLIOT 803 digital computer.

The principle of this method should be indicated here, because we used it for further interpretation of the experimental results.

The general displacement of the cross-section of the box girder may be represented by four components:

1. Translation in the direction of the axis of symmetry Y (fig. 3a);
2. or in direction of the other principal axis X (fig. 3b);
3. rotation (fig. 3c) and
4. distortion of the cross-section (fig. 3d), when the angles of the four component plates change, whereas for the preceeding three components of the general displacement the cross-section remains undistorted.

Analogically we have four components of the general longitudinal displacement in the direction of the bridge axis Z and consequently a similar pattern for the resulting normal stress (which, at this stage, is constant through the entire thickness of the plates):

1. Bending in the plane of symmetry YZ, when the cross-section rotates around the axis X and the normal stresses result in the bending moment M_x (fig. 3e).

2. Bending in the other principal plane XZ, when the cross-section rotates around the axis Y and the normal stresses result in the bending moment M_y (fig. 3f).
3. Torsion, when the cross-section warps out of the plane and the normal stresses result in a warping moment-bimoment (fig. 3g).
4. Axial deformation, when the cross-section is simply translated along the bridge axis Z and the corresponding normal stresses result in the axial force N (fig. 3h).

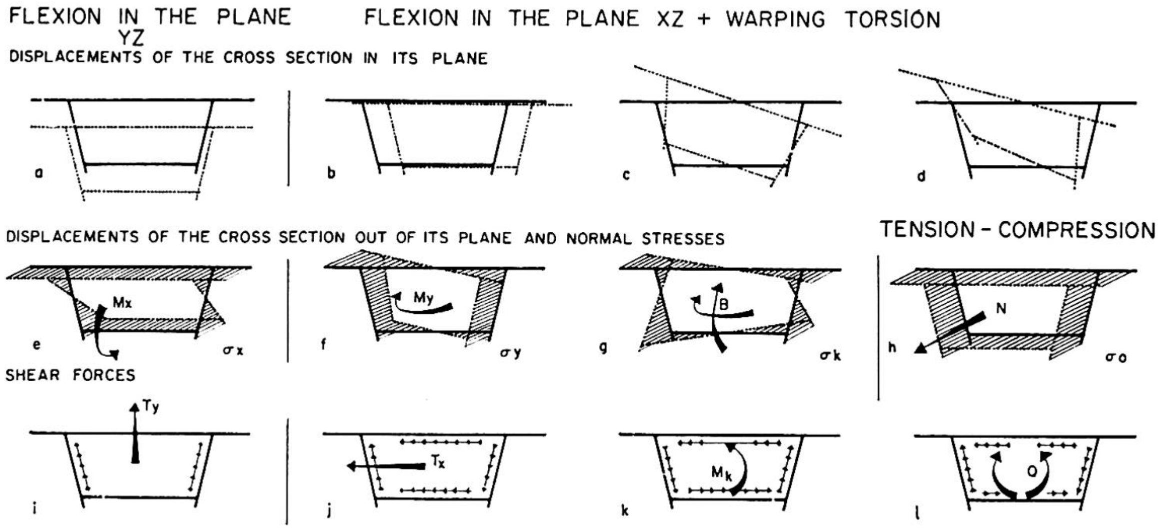

Fig. 3. Displacements and internal forces of the cross-section at stage B.

For the three components given under 1, 2 and 4 the cross-section remains plane.

Finally, the shear flow, in general, may also be obtained by superposing the following four components:

1. Shear flow resulting in the shearing force T_y corresponding to the bending in the plane YZ (fig. 3i).
2. Shear flow resulting in the shearing force T_x corresponding to the bending in the plane XZ (fig. 3j).
3. Shear flow giving a torsional moment M_k (fig. 3k).
4. Shear flow causing distortion of the cross-section and giving a transverse distorting moment Q (fig. 3l).

As the cross-section of the bridge has one axis of the symmetry — the vertical axis Y, only the bending in this vertical plane can occur independently (in addition, of course, to the axial deformation caused by force N, see fig. 3h), while the bending in the other principal plane XZ and the torsion accompanied by the distortion of the cross-section occur only simultaneously. This interaction is strongly influenced by the variability of the cross-section, whose centre of gravity, but especially its centre of torsion, changes its position considerably in different sections of the bridge.

2. Model Tests

The model was designed on the scale 1 : 50 and represents the prototype in all details. The bearings of the piers were arranged so that they had the same elasticity as the base, for which this value was obtained from the tests in the field.

The model was constructed of PVC-N plastic (hard polyvinyl-chloride) with a modulus of elasticity $E = 34850$ kg/cm² — the deviation of this value was 4.8 p. c. —, a Poisson's ratio $\nu = 0.365$ and a tensile strength of about 620 kg/cm². The greatest specific elongation observed during the tests on the model was about $1.5\,^0/_{00}$ for the stress 52 kg/cm², i. e., less than $^1/_{10}$ of the tensile strength and less than $^1/_5$ of the proportional limit. The creep and non-homogeneity of the material were studied during the preliminary tests, which had shown that it was possible to neglect them during the testing.

All the tests were carried out in a fully air-conditioned room with a constant temperature of 24° C and a relative humidity of 65 p. c. The strains were measured by means of strain gauges (120 Ohm, product of Mikrotechna ČSSR), either simple (500 pcs) or 45° strain rosettes (200 pcs). In all the cross-sections of type A 8 simple strain gauges and 16 rosettes were fixed, in cross-sections of type B 5 simple strain gauges and 9 rosettes were applied. The arrangement of the cross-sections investigated and of the position of loading on the model is evident from fig. 4a. The specific elongations were recorded by an automatic Baldwin apparatus. The displacement of the model was measured by means of the usual mechanical dial gauges.

3. Test Results

Thirty-six different positions of uniformly distributed load and concentrated load applied to the roadway were studied. The values of the loads were determined by the Čs. Standard 73 6202. The analysis was made only for the static loads.

We show in this paper the deformations of the construction and its stresses due to the uniformly distributed load on one longitudinal half of the roadway in all spans of the bridge (load 1) or due to the uniformly distributed load on one longitudinal half of the roadway in the spans 1, 3, 5, and on the other half in the spans 2, 4 (load 2). All other data correspond to the actual construction.

In the fig. 4b may be seen the vertical deflections v and horizontal deflections u due to the loads (1) and (2). The deflections are defined by the following relationships using the notation in fig. 6.

$$v = \frac{v(A) + v(D)}{2}, \qquad u = \frac{u(A) + u(B)}{2}.$$

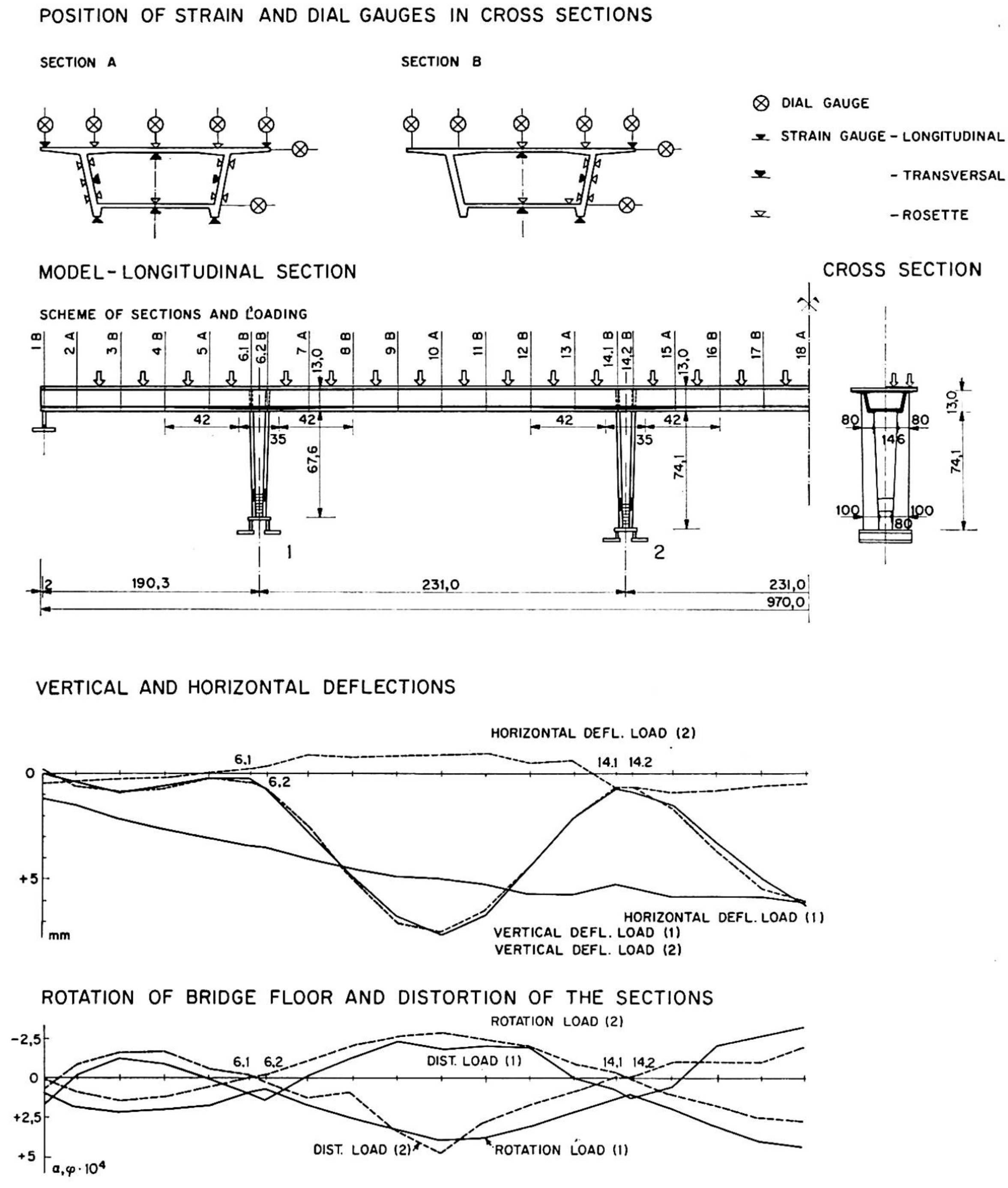

Fig. 4. Diagram of model and deformations of the box girder.

The vertical deflections in the plane YZ are nearly the same for both cases of loading, but the horizontal deflections u and also the rotation α of the bridge deck and the distortion γ_{xy} of the sections caused by warping torsion are quite different. The following formula define these deformations:

$$\alpha = \frac{v(A)+v(D)}{a}, \qquad \beta = \frac{u(A)+u(B)}{h}, \qquad \gamma_{xy} = \alpha+\beta.$$

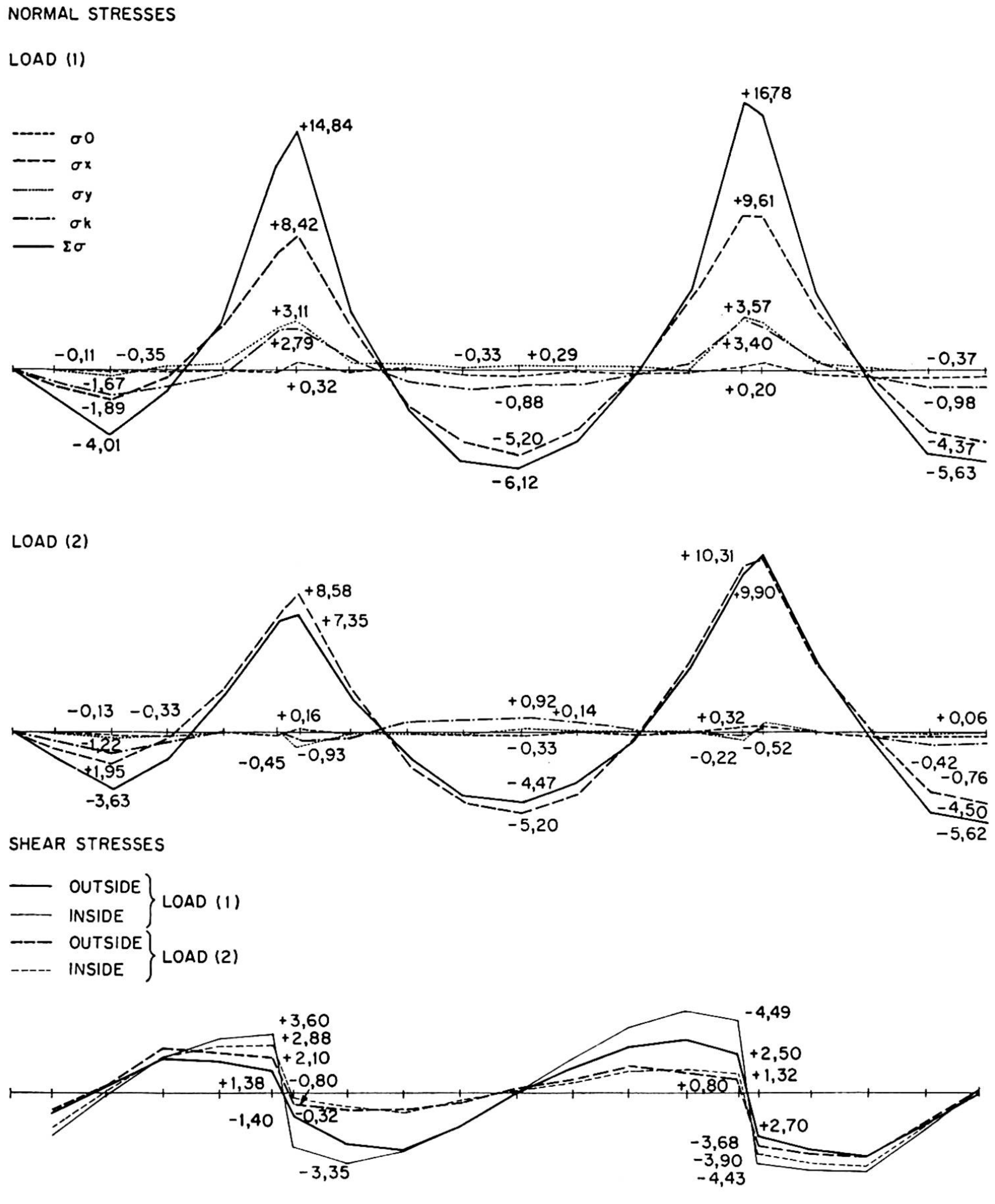

Fig. 5. Normal and shear stresses.

The box girder itself is deformed transversely, due to such loadings, over its entire length. Its deformations are influenced by the elastic supports.

The course of normal stresses in point A (corner of the box girder, see Fig. 6) due to loads (1) and (2) is shown in the Fig. 5, in which the stresses due to the above mentioned four components of the internal forces are also specified. While the courses of the stresses σ_0 due to the tension (compression) and σ_x due to the moment M_x in the plane YZ are again nearly the same in both cases of loading, the effects of the moment M_y and of the warping moment B are different. In the case of load (1) the stresses σ_k due to the warping torsion are high near the supports, which is caused by the greater rigidity of the box girder in these parts. The stresses σ_k attain 88 p.c. of the stresses in section 3 and 33 p.c. of those in section 6.2. Shear stresses in the upper part of the oblique plates below the bridge deck are illustrated in fig. 5 in both cases of loading. The stresses on the external and internal surface are different, owing to the transverse stresses in the box girder. This difference my be considerable.

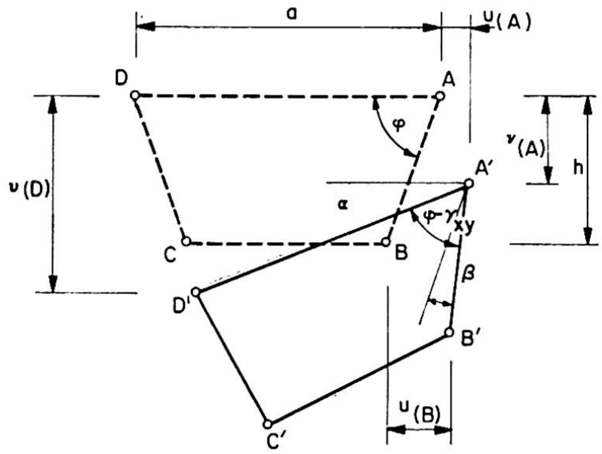

Fig. 6. Rotation and distortion of the cross-section.

Summary

A model representing a five-span bridge, with a 483 m long box-girder, to a scale of 1:50 was constructed of PVC-N plastic (hard polyvinylchloride). Its spatial behavior was investigated under 36 different loadings, i.e., bending in both principal planes, torsion and distortion of the cross-section. From the experimental results all the displacements and internal forces, both normal and shearing, were analysed by resolution into four components according to Vlasov's general method for similar problems.

Résumé

Le modèle examiné, fait en matière plastique PVC-N (chlorure polyvinylique dur) était une réduction 1:50 d'un pont à cinq travées de 483 m de longueur, avec une poutre en caisson. On a étudié son comportement sous 36 cas de chargement, c'est-à-dire la flexion dans les deux plans principaux, la torsion et le gauchissement de la section, qui n'était pas raidie. Tous les déplacements, ainsi que les forces internes (normales et de cisaillement) étaient analysés en quatre composantes selon la méthode de Vlasov, la plus appropriée pour résoudre un tel problème en général.

Zusammenfassung

Zur Untersuchung einer Brücke mit 483 m langem Kastenträger wurde ein Modell aus Kunststoff PVC-N (Polyvinylchlorid hart) im Maßstab 1:50 gebaut. Seine räumliche Deformation, d. h. Biegung in beiden Hauptebenen, Drillbiegung, Querschnittswölbung und Verformung wurde untersucht, besonders deshalb, weil der Querschnitt des Kastenträgers unversteift war. Alle gemessenen Verschiebungen und inneren Kräfte (Normal- und Schubkräfte) wurden in vier Komponente zerlegt, der Idee einer Methode von Vlasov folgend.