DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

UDC 624.21.093.001.24

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THE EXPERIMENTAL CHECK OF RELIABILITY OF MATHEMATICAL MODELS OF FRICTION JOINTS

Problem statement. Up to now, there has been no model describing work of friction joints on high-strength bolts in elastic stage. All previous models describe the structure after macrodisplacement when bolt was subjected to shearing and crushing. There also has been no model of complex joint with gusset and linings.
Results and conclusions. The bolted joint model involving substitution of the friction rigidity for elastic links is presented. Stresses in complex joints of metal bridge are determined experimentally. The results obtained with the use of the model are compared with experimental results. Stresses at the points of joint beyond the reach of experiment are calculated. Experimental results supported the validity of the model.

Keywords: high-strength bolts, metal bridges, calculation of joints, mathematical model, friction joint.

Introduction

In modern calculation methods, bolted joints are taken to be absolutely rigid, i. e. mutual displacements of joint plates are assumed null. Besides, calculations of joints proper take into account the post-macrodisplacement stage when, the friction forces exhausted, all the rows of bolts are displaced. Actually for friction joints there is a preliminary displacement area characterized by the elastic interaction of the rough surfaces of the adjoining plates. Several models describing the behavior of these systems were suggested for the analysis of complex joints on high-strength bolts. These models continue and develop the line of the bolted joints studies [1—3] considering how the joints operate at the elastic stage. At this stage (before the macrodisplacement) the structures were assumed to be flexibly bonded plate joints imitating a preliminary bolt tension friction.

The experiments helped to establish the elasticity of these flexible bonds. It firstly depends on how a joint is processed. So, for sandblaster processing it is $3.39 \cdot 10^{-6}$ cm/kg on average; the upper limit (with a supply of 0.95) — $3.96 \cdot 10^{-6}$ cm/kg; the lower limit — $2.20 \cdot 10^{-6}$ cm/kg.

Not only the models for simple joints of two plates by a third one were obtained but also complex joints apart from gussets containing linings. The model allows to obtain the force distribution in joint plates between the rows. The models were tested in a natural experiment.

1. Experimental validity testing of the mathematical model for friction joints

The experiment was performed on an overbridge on branch 27 of the small circular ring of the Moscow railroad between the Zvenigorodskoe highway and the Moscow International Business Center ‘Moscow City’. The overbridge was designed for the railway load C14.

The project of all-metal upper-traffic overbridge span on a ballast was designed by Plc (OAO) ‘Gyprostrojmost Institute’. The overbridge span is located in a plan on a circular curve of radius of 329.565 m. The overbridge span includes two main box-section beams joined together by transverse beams of an orthotropic plate and lower cross linkings.

The distance between the main beams is 7.53 m, between the walls of the main beams — 1.23 m. According to the static scheme, the inner main overbridge beam is a continuous three-span beam with the calculated spans of 42.36+50.42+29.71 m. The external continuous main beam was designed with the calculated spans of 38.05+53.08+28.59 m.

Two knots where the main beams are linked together, transverse beams and a plate of roadway covering were tested. According to the research results, the plots of tension changes in the rows between the bolts were obtained (Fig. 1).

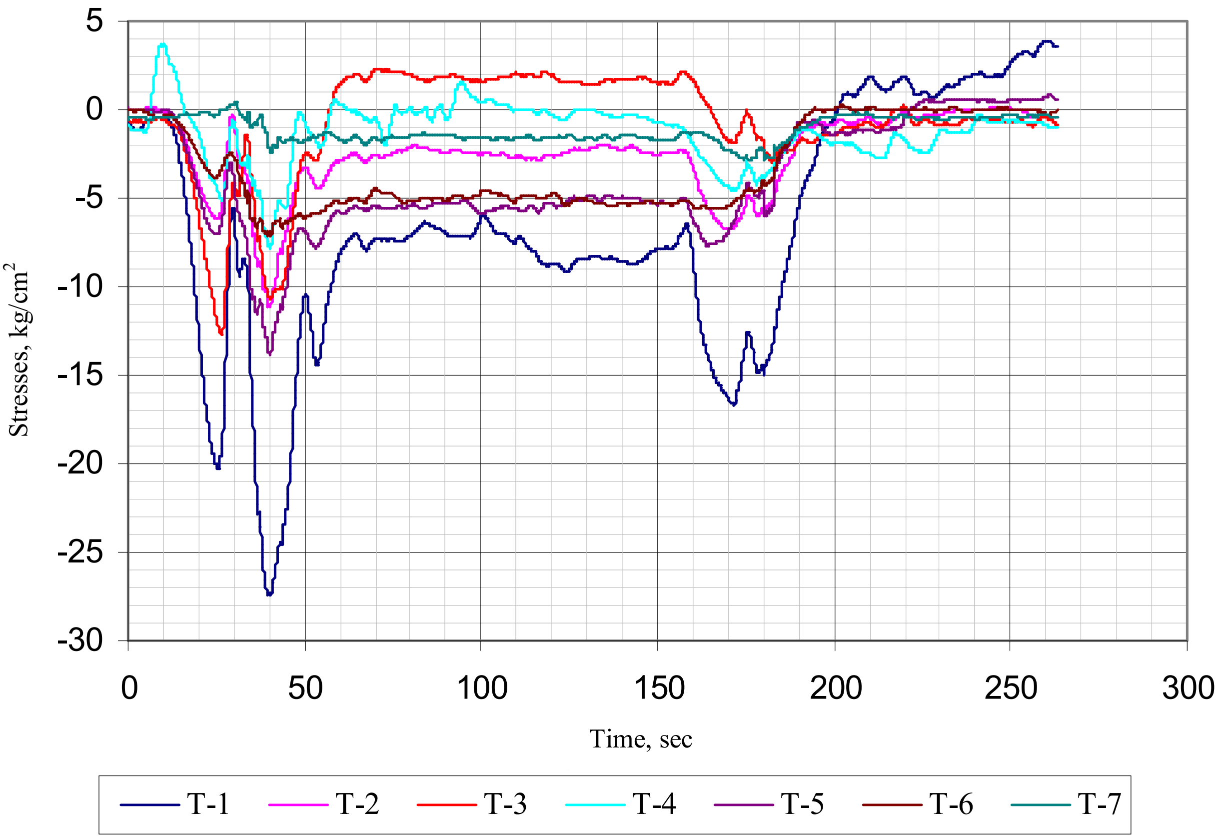

Fig. 1. Example of tension oscillogram in a knot

The changes in the relations of tensions along the rows depending on the time were plotted to be compared with the calculated values. Thus, in an example studied further

$$I = \frac{\sigma_3}{\sigma_1};\ II = \frac{\sigma_4}{\sigma_1};\ III = \frac{\sigma_5}{\sigma_1},$$

where $\sigma_{1\text{-}5}$ are tensions in the plates between the rows 1—5.

In an ideal joining model, these relations remain unchanged (provided the system does not leave the elastic stage). In actual knots this relation varies within some average values. This variation is caused by the peculiar features of preliminary tension. Even at the elastic stage there can be microdefects forming on the surfaces which in one way or another affect the joint rigidity, i. e. as joint forces vary, there can be microslippages causing the rigidity to change slightly. Thus, we have some range of force relations along the plates in time.

Let us consider one of the rows of a loaded knot as an example (Fig. 2).

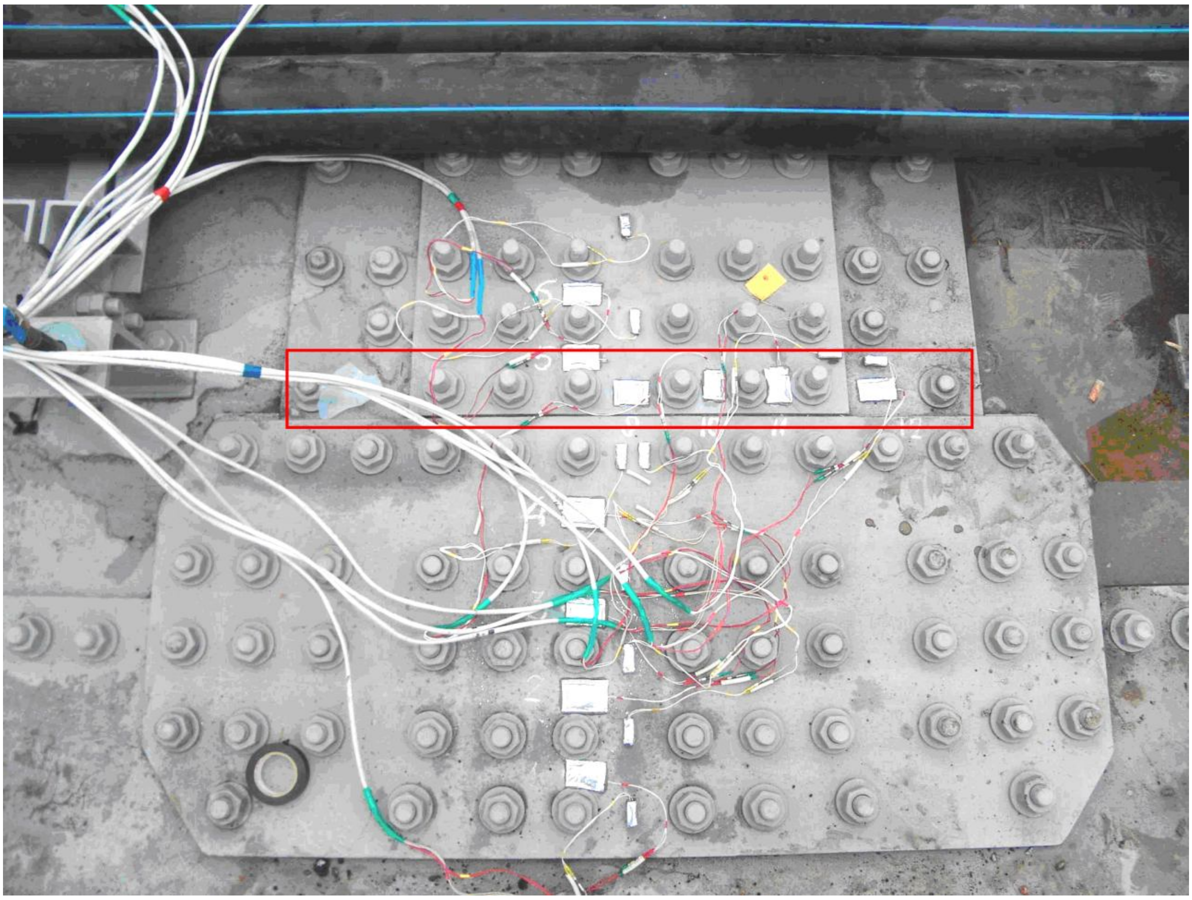

Fig. 2. Knot and a row of bolts being examined
(highlighted with a frame)

Let us accept the following five-row joint with a lining for the model (Fig. 3).

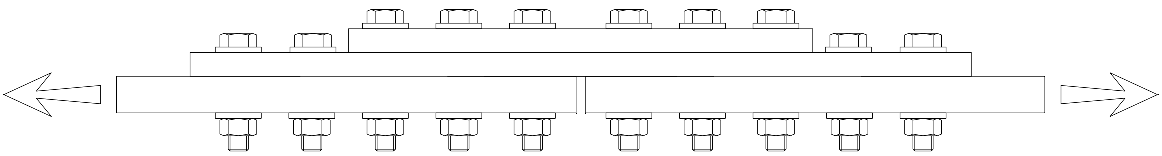

Fig. 3. Model of a five-row joint with a lining

Let us examine a three-row joint, i. e. the plate width will be assumed to be 8×3 = 24 cm.

Two end rows in an actual knot are not completely filled, which is to be considered in the model. Let us insert the upper and lower rigidity limits into the model and compare the actual values with the obtained range.

Fig.4 gives the force relations and ranges (all with the same color).

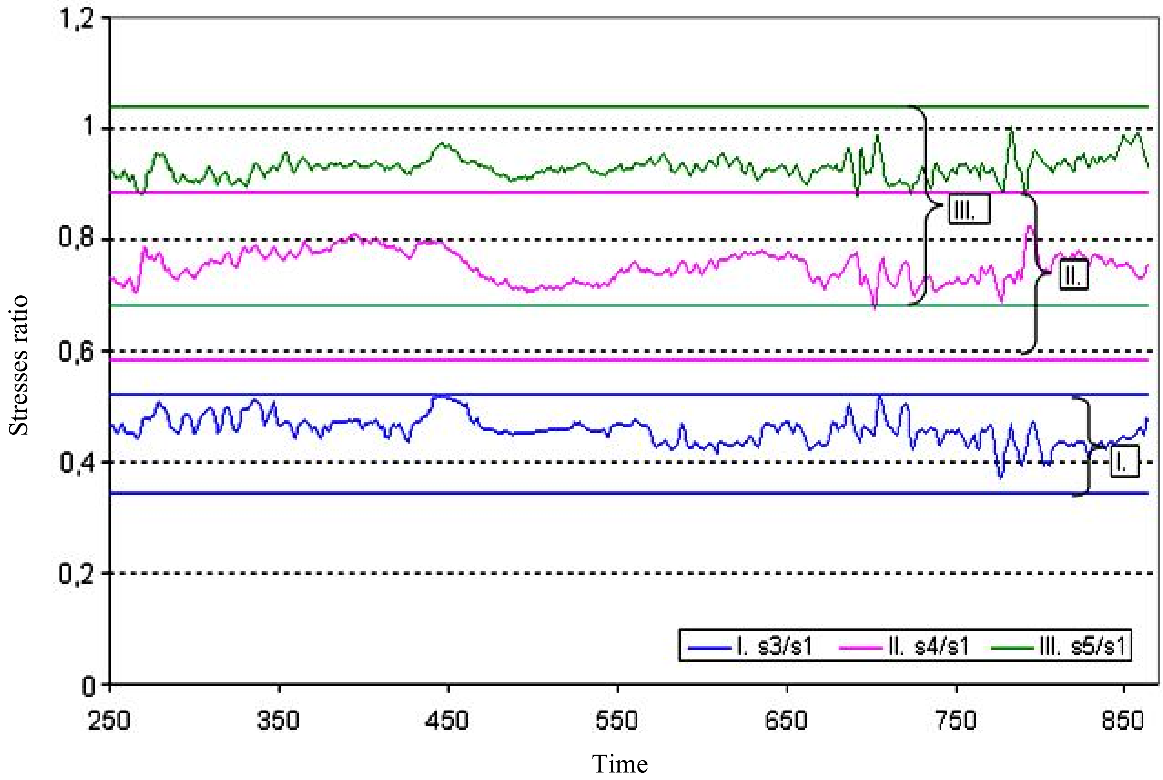

Fig. 4. Change in tension relations in the plates and ranges obtained with the mathematical model

As the Figure suggests, the model fairly well describes the behavior of the system. Most of the data is within the preliminary calculated range. The tension distribution between the bolt rows is generally in accordance with our models. The data out of the range can be related to the complexity of the knot. The same gusset, however, operates in it in two directions — back and forward. It should also be noted that too many different gussets are closely located and mutually influence the way they operate.

The experiment results bring us to the conclusion that the model fairly well describes the behavior even of a system of such a complexity.

2. Application of a model for determining tensions in other areas of the system

In the course of the experiment the sensors were installed at points 1, 3, 4 and 5 (Fig. 5). Point 2 lacked the space enough for putting in a sensor, while the other points were within the box and were not available.

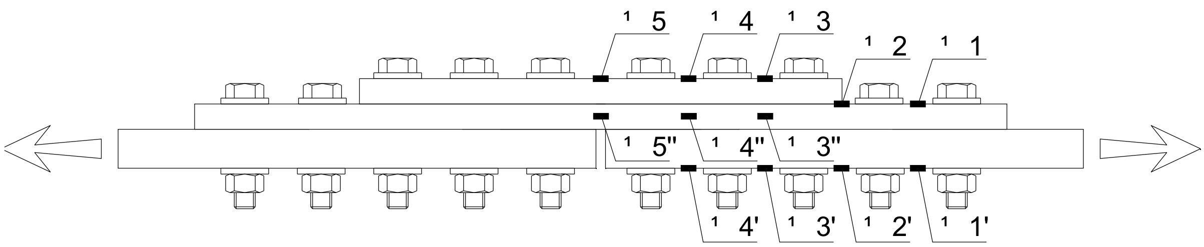

Fig. 5. Points of determining the tensions in the system

Since the results obtained with the model are in good agreement with the experiment results, it can be concluded that at the other points the system's behavior is in accordance with the model.

Thus, we can determine the state of stress at the other non-available joining points as well. We get the force relation coefficient at point 1 to the forces at the other points (Table 1).

Table 1

Force relation coefficient at point 1
to the forces at the other points

$C = 4.4e^{-6}$ cm/kg		$C = 7.92e^{-6}$ cm/kg	
$n_{2/1}$	1.94	$n_{2/1}$	1.97
$n_{1'/1}$	5.63	$n_{1'/1}$	5.62
$n_{2'/1}$	4.69	$n_{2'/1}$	4.65
$n_{3'/1}$	3.27	$n_{3'/1}$	3.19
$n_{4'/1}$	1.75	$n_{4'/1}$	1.66
$n_{3''/1}$	2.84	$n_{3''/1}$	3.08

End of table 1

$C = 4.4e^{-6}$ cm/kg		$C = 7.92e^{-6}$ cm/kg	
$n_{4''/1}$	4.00	$n_{4''/1}$	4.37
$n_{5''/1}$	5.59	$n_{5''/1}$	5.93

The plot of tension changes helps to find the maximum force value at point 1 (in Fig. 6. — sensor S12).

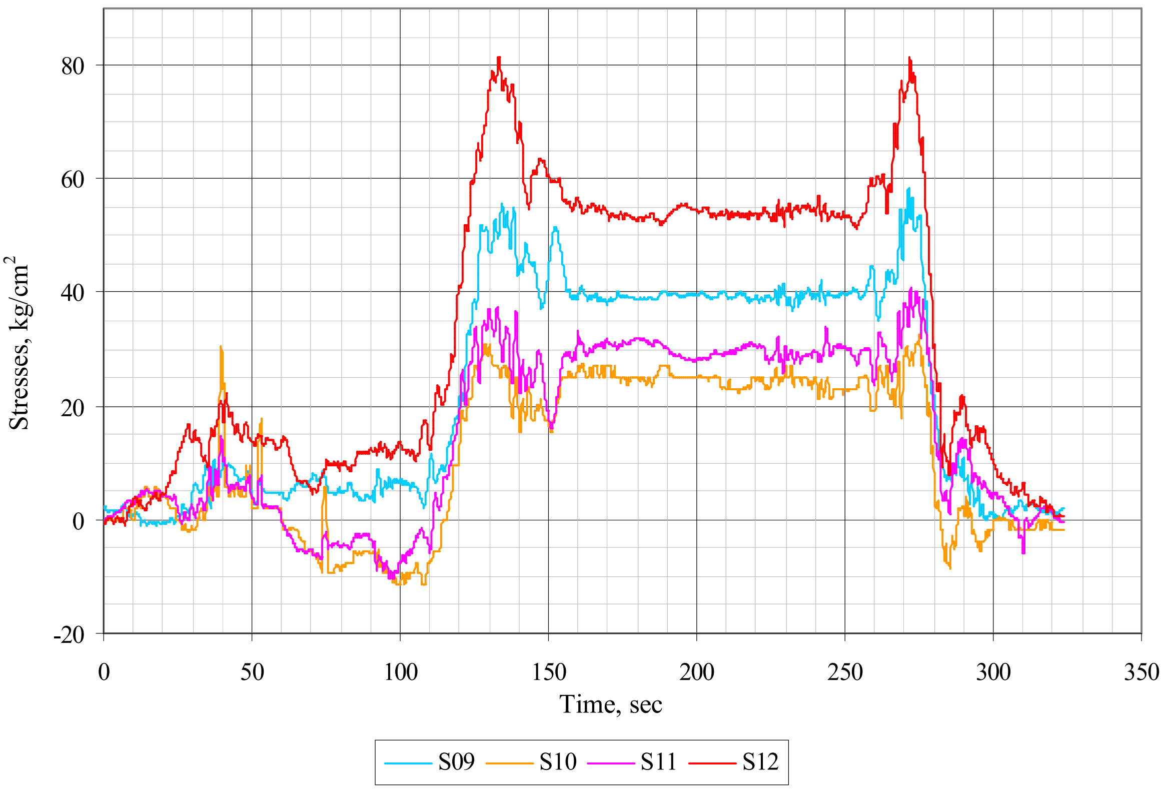

Fig. 6. Changes in tensions registered by the sensors

At point 1 the maximum tension was 82 kg/cm^2 (see Fig. 6.). Then using Table 1 we can determine the most 'unsuitable' coefficient for each area as well as maximum possible tensions at the other points.

$$\sigma_i = \sigma_1 \cdot n_{i\_\max} A_1 / A_2 ,$$

where A_1 and A_2 are the area of a gusset and blocking plate (to shift from forces to tensions).

Let us summarize the obtained results in Table 2.

Table 2

Tensions at points examined, kg/cm^2

σ_2	$\sigma_{1'}$	$\sigma_{2'}$	$\sigma_{3'}$	$\sigma_{4'}$	$\sigma_{3''}$	$\sigma_{4''}$	$\sigma_{5''}$
64.4	184.8	154	107.2	57.2	101.2	143.2	194.4

As Table 2 suggests, the values of tensions in non-available joint areas found are higher than those that can be measured. This proves it necessary to use our mathematical models in testing complex knots in order to get a clearer picture of force distributions within a structure.

Conclusions

The performed experiment showed that the suggested model of a friction-bond as a flexible joint is in good agreement with the experiment.

Thus, using the model we can obtain the force distribution along all the bolt rows between the lining, gusset and plates joined together. The result of this kind for was obtained for complex joints with linings for the first time.

Due to variations in data on friction joint rigidity, it is reasonable to use a range of rigidity parameters in calculations, which is also a new approach to calculation of high-strength bolt joints. The model allows to determine a state of stress at points non-available to sensors and to detect the most loaded areas of the system.

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