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EXPERIMENTAL SHAKEDOWN ANALYSIS OF DOUBLE BUTT, PRESTRESSED, BOLTED CONNECTIONS

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Abstract. This paper deals with the description of an experiment on double-butt prestressed bolted connections. The goal of the experiment is to verify a 3D computational model of the connection. The connections are loaded cyclically according to a load program based on load variability observed in engineering practice.

1. Introduction

The connections are an integral part of each steel structure therefore the correct design of the connections and the elements cross-sections determines the structural safety. The element cross-sections and the connections influence also the deformability of the structure. The deformability is always limited, so the connections design should meet the relevant requirements [1]. Regarding the deformability the best connections are the prefabricated welded ones. Considering the connections made "on site" a variety of the bolted joints is dominating. One of their types is a butt-friction connection. However, this type of joints has a disadvantage caused by the necessity of a special treatment of the sticking surfaces in order to achieve assumed load carrying capacity. In conclusion, it seems to be useful to find a connection in which the load capacity remaining after first slip could be purchased even using elements without previous treating. The butt connection with high resistance bolts has this type of features. The considered connection characterises low deformability (especially at the beginning of loading process the deformability is comparable with welded joints) and higher load capacity than the butt-friction one. The higher load capacity is achieved due to exploiting the remaining load capacity after the first slip. The deformability of such a connection after

the first slip significantly increases, however, knowing its behaviour it is possible to estimate the maximum load adequately to certain limited deformations. However, due to the fact that the elastic-plastic behaviour of the joint is relatively complicated it is necessary to verify some modelling assumptions.

2. Experiments equipment.

The goals of the experiment are as follows:
- identification of the behaviour of the joint till the first slip
- identification of the behaviour of the joint after first slip
- investigation of the initiation and development of the plastic zone
- recognition of the shape of the sticking surfaces and their interdependence.

Additionally, stress distribution due to prestressing w.r.t. butts thickness and prestressing force variation during the loading process are also investigated. The investigated connections are divided into four groups distinguished by the particular plates thickness (butts and midplates) and some of the samples are covered by the elastooptic layer and some of them are not prestressed. The contact phenomena between the pin of the bolt and the openings are important, so there is no screw in the butts and midplate zones. The element groups are presented in Fig. 1.

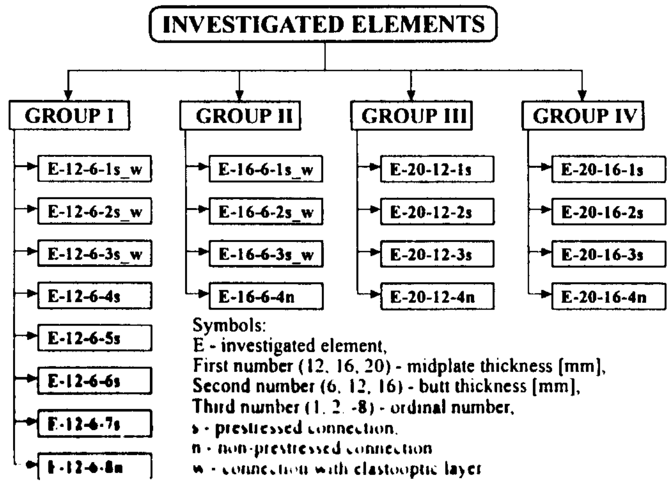

Fig. 1 Tree of the investigated elements

Sample element is given in Fig. 2. All the plates are made of St3S steel [6]. The bolts are of type M20, class 10.9(10) [5].

The following quantities are measured: relative displacements of the plates (inductive sensors C1, C2), strains in the regions of the expected plastic zones (tensometers T1, T2, T3). The range and development of the plastic zones using the elastooptic layer is observed. The experiment is conducted in the laboratory belonging to Steel Structures Department at the Warsaw University of Technology. The central control unit is a PC

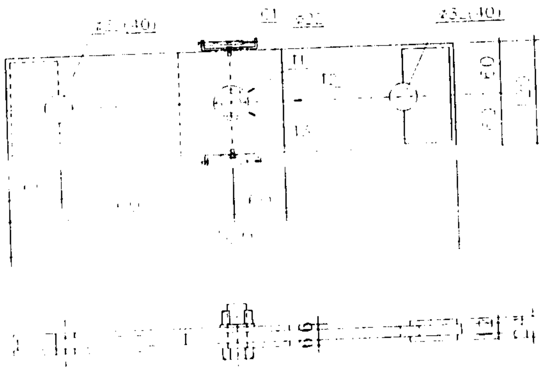

Fig. 2. Scheme of a sample element

computer. The most important part of the employed measurement system is the analogue-numeral converter card type PCL812PG (Advantech) collecting the data from all of the installed gauges and sending them to the central unit steering the experiment. A computer program GENIE (Advantech) is used to control the experiment and all data are stored on the disk. Usually, during the experiment the researchers tend to realise a load program similar to occurring in the engineering practice. The loading of steel frame structures consist of the dead and live loads. An analysis of typical projects points out that the amplitude of live loads may be assumed as: $\Delta P = P_{max} - P_{min} = 0.4\ P_{max}$ The load program is given in Fig. 3. The load is applied incrementally assuming the

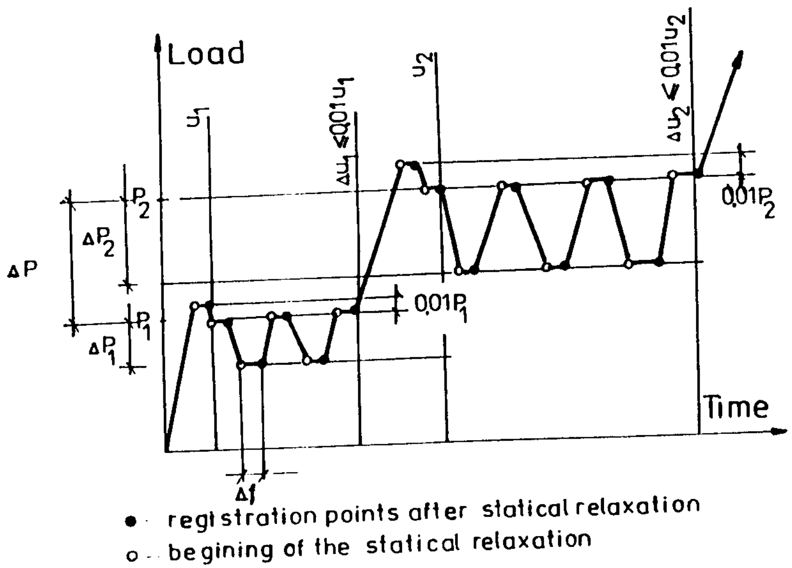

Fig.3.Load program

load increment as ΔP=10 kN. Passing to the new load increment the "overloading" of 5% of the total load P_i (at particular load step) is assumed and then, the loading amplitude Delta P_i is applied cyclically in the range of P_i and $0.4P_i$ till the stabilisation of the structural response (shakedown). As a shakedown condition the following one is assumed: considering two respective load cycles the condition $\Delta u_i = |u_{i,j} - u_{i,j-1}| \leq$ 0,01 where u_i is the displacement "u" at the beginning of the cycling "j" at the increment "i".At each new load level "overloading" 1.05 P_i, and the load levels P_i and ($P_i - \Delta P$) the results are registered and saved.

3. Experimental results

The dependence force-displacement measured with the two gauges placed in the mid--zone of the element is the most important. The curve for the element E-12-6-2s_w is given in Fig.4.

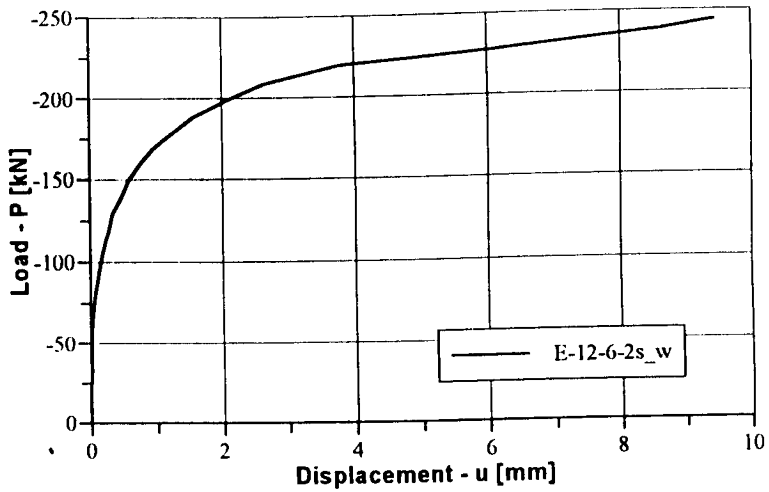

Fig. 4. E-12-6-2s_w - force-displacement curve.

The first slip takes place at the load level of 75 kN and the significant displacement due to the initial slacks in the connection is noticed. At the load level not higher than 120 kN the displacements are very small and not exceed 0.2 mm (neglecting the displacement arising from the initial slackening). The form of the load-displacement curve is quantitatively and qualitatively consistent with the Authors' expectations. The next important element of the experiment is the monitoring of development of the plastic zones by means of the observation of the isochromes arrangement in the elastooptic layer during the loading process. The pictures of the isochromes in the polarized light at the end of each load cycle are taken. The plastic zones in the sample E-12-6-2s_w are given in Fig.5. The plastic strains in the region of the photooptic layer appear in the butt material in the compression zone at the load level 140 kN. However, the butts are observed (because of their visibility) only out of the head of the bolt, so it is necessary to state that the plastic strains appear under the head at significantly lower load level. The plastic strains in the tension zone appear at the load level 190 kN.

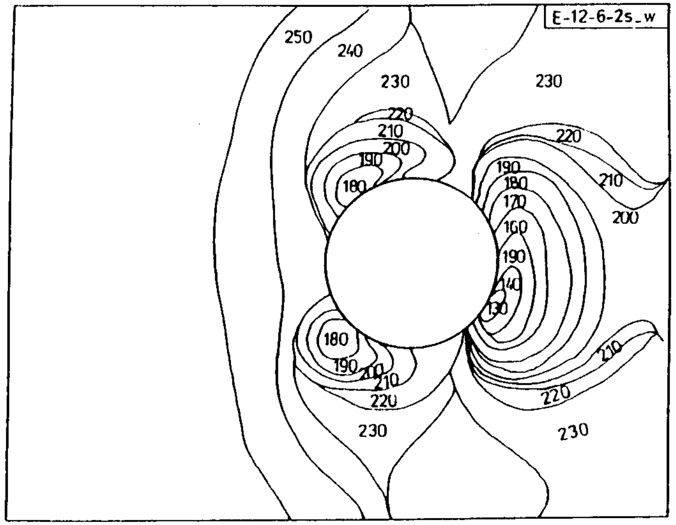

Fig. 5. E-12-6-2s_w - elastooptic layer

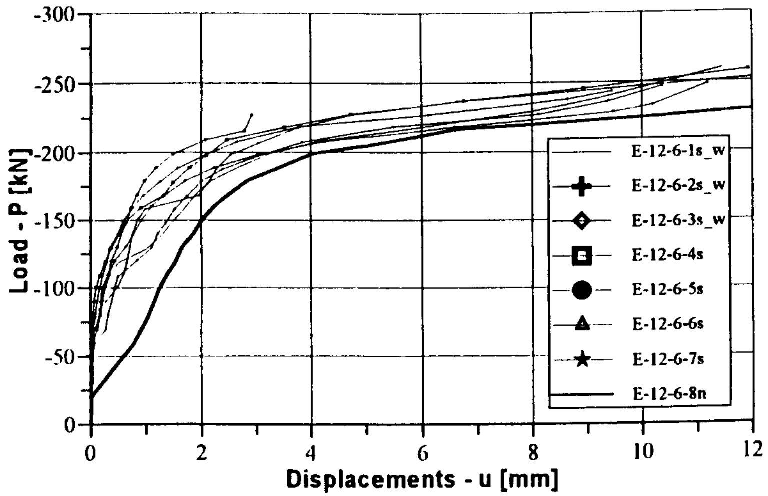

Fig.6. Curves force-displacements for elements in group I

The curves force-displacement for investigated samples in group I are given in Fig.6. The curves for all prestressed connections are close and the ultimate load for all of them tend to the value 250kN not exceeding it in any case and the similar situation is in the case of the non-prestressed connection. The deformability of the prestressed connections is much less than the nonprestressed ones, for example, the 1mm axial displacement in case of the prestressed sample is achieved at the load level 150kN but in the case of the non-prestressed one at the load level about 60kN. At the higher load levels the differences of the deformability are smaller and smaller.

4. Conclusions.

The conclusions are as follows:

- prestressing causes decreasing of the connection deformability,
- the ultimate load is not increased due to prestressing,
- shakedown appears very fast at the total load level of 80% of the ultimate load,
- the applied methodology allows to verify the being conducted numerical study of the connection shakedown behaviour.

The results prove the usefulness of the conducted research and correctness of the methodology and show that this type of connection may be used in the civil engineering structures.

References

1. Karczewski J.A., Karpezo Z., Lietz J., Michalski B., Experimental Analysis of the Deformability of the Prestressed Bolted Connections, (in Polish), Arch. of Civ. Eng. 33, 3, 1987, Warsaw, 373-380,
2. Karczewski J.A., Postek E., Wierzbicki S., Modelling of the Prestressed Double Plated Bolted Connections, (in Polish), Proc. Conf. „Badania nośności granicznej konstrukcji metalowych", 1998, Szklarska Poreba, 169-176,
3. Ramm E., Matzenmiller A., Consistent linearization in elasto-plastic shell analysis, Engineering Computations, 5(4), 289-299, 1988,
4. Gabryszewski Z., Gronostajski J. Mechanic of Plastic Treatment Process. (in Polish) PWN, Warsaw 1991,
5. PN-85/M-82101. The Bolts with Hexagonal Head. (Polish Code of Practice),
6. PN-88/H-84020. Low Carbon Steel. (Polish Code of Practice),