17th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2013, Istanbul, Turkey, 10-11 September 2013

EXPERIMENTAL ANALYSIS OF STEEL SPACE TRUSS STRUCTURE

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ABSTRACT
In the paper is presented experimental analysis of steel space truss structure. The space truss structure was loaded by spatial set of forces that simulate real condition of the structure with eight balanced member forces (4 chord and 4 diagonal members), up to structure failure. It was realized in a specially designed test facility. Tested space truss structure samples were made in real scale, according to the model originated after finite element analysis and optimization. Basic idea was to construct and test a space truss structure that can be made in average technology conditions, without special tools and requirements. Besides, results of a stress-strain finite element analysis are presented and comparison of the two analyses is given for the most critical regions of the space truss structure. Values of measured and calculated strains across model samples and characteristic measuring points are presented.
Keywords: Experimental analysis, structure, steel, space truss, finite element, optimization

1. INTRODUCTION
Space trusses, especially the steel ones, belong into cost-effective and wide used structures, with variety of advantages regarding other structural systems (plane trusses, beams and frames, plates and shells, etc.). The node joint figures as a dominant element in its assemblage, and features of the system mainly depend of it. There are many accepted and largely patented node joints ([2], [8], etc.). Aim of this research was to design as simple and cost-effective node joint as possible, fulfilling the conditions of bearing capacity and functionality. Optimization of mass and stress-strain state should be performed, so that manufacturing demands stay at minimum.

2. CHARACTERISTICS OF THE TESTED NODE JOINT
Dimensional drawing of the sample is presented in Fig. 1. Material used for the node joint was steel ISO 9001, Re=360 MPa, Rm=515-670 MPa, i.e., Re=250 MPa, Rm=360-460 MPa, all according to standards ISO.

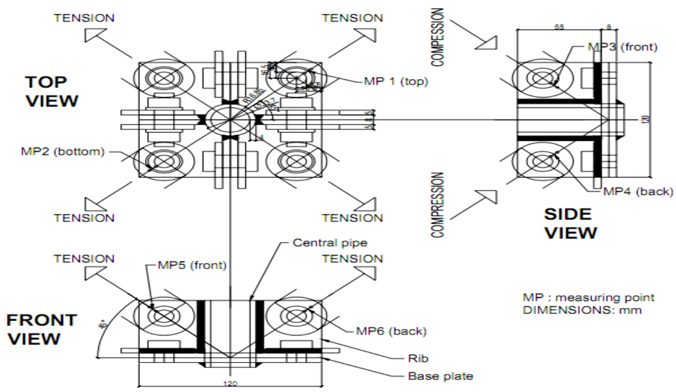

Figure 1. Geometry of the node joint and measuring point disposition

The samples were made using the simplest technology, feasible in average conditions, with no special demands. Joint elements are welded, and the connection of the joint with members was made using standard fitting bolts M14. Beside the node joint samples, appropriate member lugs were made in order to make real simulation of the node connection. The lugs were over designed, so the test procedure could be focused on the node joint.

3. EXPERIMENTAL SET-UP

The test facility and experimental procedure were aimed to represent as truly as possible the real conditions of loading and bolt connections of the node joint together with the members. However, in real conditions there are many factors that cannot be predicted with certainty, such are: imperfections in material and connections, imprecision of shape and dimensions, and uneven bearing in bolt connections. Practical test of behavior of such structure type may be done in real space trusses structure [3], [4], [5], [6], or, more often, using laboratory methods [5], [6], [7], [9]. Disposition of the test facility with appropriate auxiliary devices is presented in Fig. 2. The test facility was equipped with devices specially intended for application of tension forces (Fig. 2b). Load application was obtained using a hydraulic jack with capacity of 8x100 KN, and force application was registered by dynamometer (Fig. 2b, c). Four samples were tested, all with identical load constellation: all horizontal members tensioned, two diagonals tensioned, and two compressed. Thus the samples were subjected dominantly to tension forces, and that represents a more unfavorable case, according to the FE analysis.

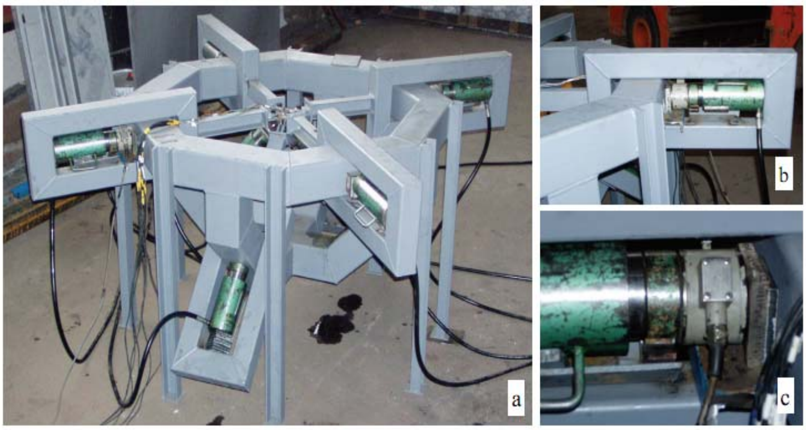

Figure 2. a) Disposition of the test facility b) auxiliary device and operating cylinder of the hydraulic jack; c) detail of the position of the jack cylinder and the dynamometer.

The testing regime had static character, which was in accordance with exploiting conditions for the STS. Load increment was 8 KN, and maximum values of the applied forces across samples were 66, 45, 35, 60 KN. Measuring of strains in characteristic points was obtained using strain gages with base length of 3 mm (type: HBM LY 3/120), using an adequate adhesive (Z-70). The data were registered by measuring and acquisition system HBM SPIDER 9, along with use of a PC computer and CATMAN software. The results were processed by MS EXCELL software, which gave the force-strain correlation.

4. FINITE ELEMENT ANALYSIS RESULTS

Beside the experimental, a FE analysis of the node joint was performed, where the governing parameter was von Misses stress, as a generally accepted value in FE analysis of spatial stress states, especially for metal structures. The FE analysis was done using the ANSYS software and appropriate literature [1]. After the nonlinear FE analysis with application of contact elements in bolt connections, a stress contour given in Fig. 3, was obtained. Expected stress concentrations occurred in bolt holes, which was entirely in accordance with the behavior of the joint during the experiment. Calculation load was P=35 KN per member, which represents the threshold of plasticization in the joint.

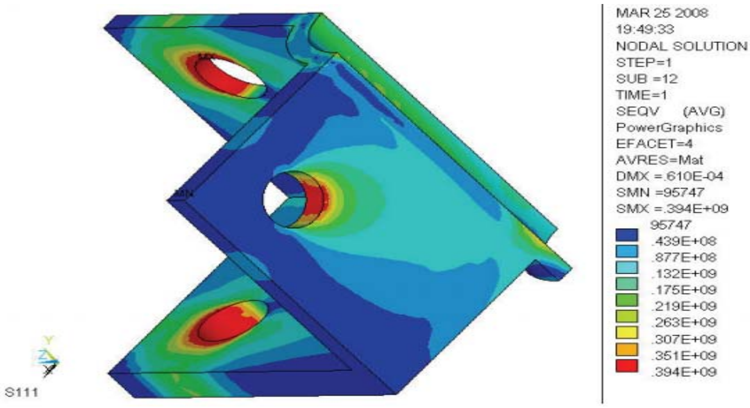

Figure 3. Joint model after nonlinear FE analysis; load: P=30 KN; on Misses stress contours.

5. EXPERIMENTAL ANALYSIS RESULTS

In contrast to the FE analysis where the governing value was von misses stress, in the performed experimental analyses were measured strains, using strain gages. Strain gages record the strains of material in chosen points in the structure, namely on the structure surface, and only in given direction. It is known that the experimental values of the stress state in measuring points may be obtained indirectly using the σ-ε diagram for the used material, that is, the diagram of the real modulus of elasticity in elastic and plastic range. However, these derived values have limited reach in the meaning of qualitative validation of the structure. FE analysis, on the other hand, may give all stress and strain values as an output and among them the strains, Experimental Analysis of an Original Type of Steel Space Truss Node Joint 49 too. It is significant that strains in the FE analysis may be tracked continuously, from the elastic domain up to the full plasticization, and across the whole volume of the structure, also. Due to the cited reasons, strain as a common and governing value was established for the comparative analysis of calculated and experimental, that is, measured parameters in Fig. 4.

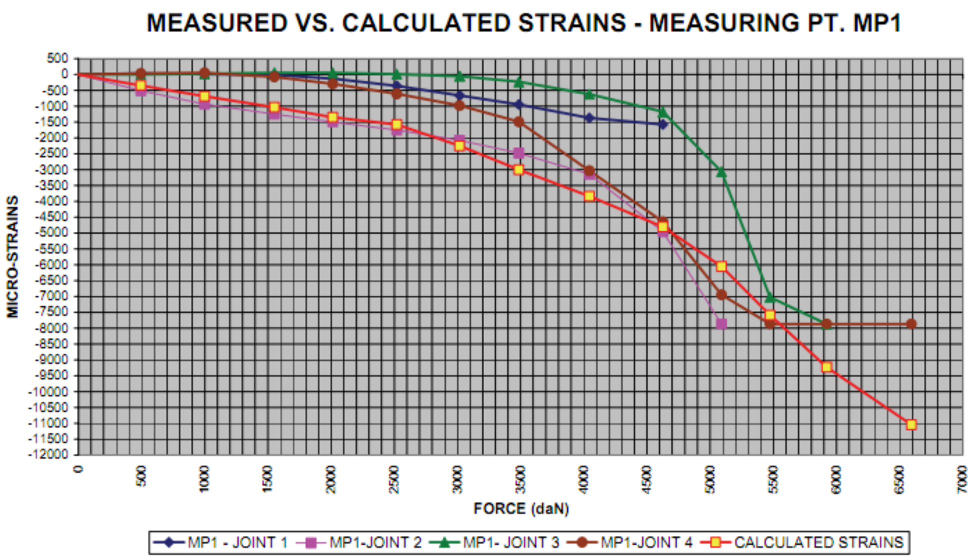

Figure 4. Comparative presentation of the force-strain diagram of the calculated.

Comparing the results from the diagrams we conclude that the shape of the experimental curves is globally very similar to the calculated one. Quantitatively, measured values deviated more or less from the calculated (strains of the joint No. 2 are almost identical to the calculated). Further, one may notice that measured values of strains are almost always lower than the calculated ones, considering the absolute value. This has a favorable conclusion as a consequence: numerical method gives greater values of strains, that is, deformations, thus the FE analysis of the structure is on the safe side. In other words, the real structure shows greater bearing capacity than the calculated one.

6. CONCLUSIONS OF THE EXPERIMENTAL ANALYSIS

Based on the performed investigations in experimental and numerical domain certain conclusions were made, which are given in the following text. Although the number of the tested samples was not large (4), it afforded essential data about the behavior of the suggested node joint, and enabled comparisons with the theoretical results. The test facility and devices were conceived in such a way to enable testing of an isolated truss node, as in the elastic domain (calculating force of 30 KN per member), so in the plastic domain, up to rupture (maximum force of 76 KN). Since the load transfer from the test facility, auxiliary devices and lugs to the node joint itself was not ideal, some deviations in sample deformations occurred (i.e., asymmetry), in which case occurrence of adaptation of connections was registered, especially pronounced in plastic domain. Of course, even in real conditions such irregularities in loading are possible, and thus the result dissipation too, as across the measuring points, as well as across the different samples. Maximal measured strains of 8000 micro-strains represent extremely high values for the used material (steel ISO 9001), which gives stress value in measuring points σ=1680 MPa for nominal modulus of elasticity for steel E=2.1E11 MPa. At the same time it means that ultimate strength (Rm=510-680 MPa) in the measuring points of the sample would be significantly exceeded, which would consequently lead to failure. These phenomena, however, occur in a very small volume of material, so their influence has strictly local character. Besides, at such high stressing local plasticization occurs, whereby the modulus of elasticity significantly decreases, so the stresses are practically substantially lower, too, and there is no failure. Global deformations of the samples were not visually registered, while the local ones, in the bolt holes, were strongly pronounced in all samples. Regularity of local deformations was noticed, in such a way that tensioned holes underwent significantly greater than the compressed ones, which was in agreement with the behavior of the numerical model. Comparison of the measured and calculated strains shows good agreement for the most of the valid measuring points. As a very important observation we emphasize that strains obtained by FE analysis in most cases had greater values than the experimental ones, which indicated that samples generally show greater bearing capacity than the calculated model. Therefore, the calculation stays on the safe side (η = calk/ means > 1), which represents one of the basic parameters in quality evaluation of the structure. Practically, the FE analysis gives the upper bound of results regarding the strains, i.e., stresses. For further investigations it would be significant to examine the behavior of the suggested node joint and a space truss structure (STS) in real structural assemblage (in situ). In that way, one could make consideration of this structural element in a broader way, with varying of parameters that are essential for an STS (span, construction depth, restraint conditions, load, etc.).

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