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TESTING AND NUMERICAL MODELING - STEEL TRUSS OF THE SPORTS HALL

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Abstract: *The paper shows comparative analysis of data obtained by numerical simulation and by field testing of main girder of a gymnasium roof. Testing was conducted during construction as soon as the roof structure and the roof cover were erected. Total weight of applied load represented full design load of the truss. Obtained measurements were compared against three numerical models: classical plane model and two models in which the roof structure was modeled as a space frame and roof cover was represented by plate elements. Results obtained by numerical modeling verified findings from the field measurements in which thin corrugated roof cover significantly increased the stiffness of the main steel truss.*

Key words: *field testing, numerical modeling, steel truss, roof, stiffness.*

1. Introduction

This paper deals with issues related to the field testing of the sports hall (gymnasium) of the elementary school in town of Mol (Vojvodina, Serbia) [1]. Since the hall is to be used by school children and for public venues with greater number of spectators Serbian codes demand that main structural elements have to be subjected to tests by trial loads. Current domestic code that defines this procedure is SRPS_U.M1.047. Upon request made by the owner of the hall, the team of experts from the Faculty of Civil Engineering made a survey of the structure and prepared a testing program [2]. The program was aimed at testing of the main roof girder. At time of testing, Figure 1, major construction works at the hall were completed while works on the final surface finishing and installations were about to be started. Foundation works, bottom concrete layer of the floor, masonry works, concrete columns walls, upper layer of the roof cover and roof structure were completed. At this stage the roof structure was ready for testing since it carried only its self weight and the weight of thin corrugated roof cover, [3].

The structure of the hall covers the area of approx. 28×36 meters and it consists of reinforced concrete foundations, columns, beams, masonry walls and main roof girder - steel truss. RC columns have dimensions 40×53 cm. The columns are connected by horizontal RC beams (42×60 cm) within masonry walls. Steel trusses of main roof girders are positioned with spacing of 5.0 meters between every truss. The main span for all steel trusses is 27,88 m while the height of the truss in the middle of the span is 3,00 m. Roof cover is made by thin

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corrugated steel plates that rest on longitudinal beams made from cold formed steel beams, box size 140/80/3 (height/width/thickness [mm]). These beams rest on top of the main steel truss and are designed as simple span or continuous beams, depending on the construction conditions. All members of the main steel truss are made from cold formed steel box profiles as follows: upper members from two CFS110×110 with thicknesses of 5, 4 and 3 mm, vertical members from one CFS60×60 with thicknesses of 4 and 3 mm, diagonal members from one CFS60×60 with thicknesses of 3 mm, bottom members from two CFS110×110 with thicknesses of 5, 4 and 3 mm.

Fig. 1. *Photos of the sports hall prior to testing under trial loads*

2. Testing under trial loads

Testing program was based on main design project of the hall, control calculations and current state of the structure. The codes require that intensity of the trial load must amount to remaining design permanent and variable load of the structure excluding the load already placed on the structure prior to testing. In this case, remaining design load came from: installations, finishing surfaces, snow and wind load. In total the trial load was 16 tons. Since the contractor had enough cement bags on construction site it was decided that using these bags was the best and most precise way to apply the load, Figure 2. Testing/loading was conducted on one randomly chosen steel truss while neighboring trusses were monitored. Testing was divided into six stages of loading and five stages of unloading with three additional stages of measurements: initial stage prior to loading, four hours observation after maximum loading and final stage after unloading.

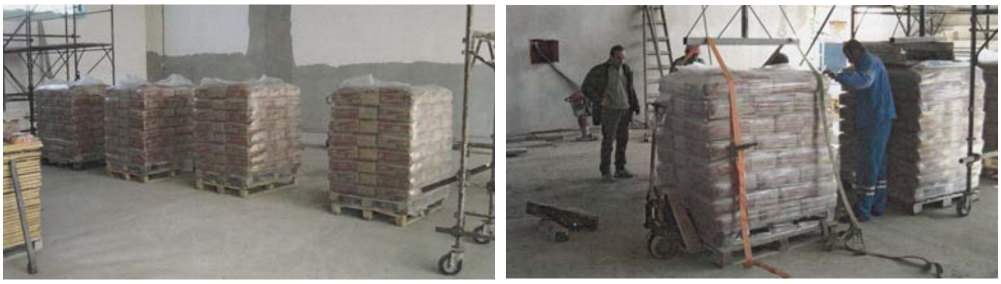

Fig. 2. *Cement bags as the 16 tons trial load*

Total load was divided into eight parts, each weighing 2 tons. Sequence of the loading was predefined in order to induce maximum strains and stresses within critical sections of the steel truss. Strain and stress measurements were conducted on three members near the support region and three members within the mid-span region. Deflections were measured on five locations of the loaded truss and in the middle of the neighboring trusses.

3. Results of testing

Detailed description of the testing and obtained results are given in the reference [2], while for the purpose of this paper, measured deflections were chosen as the main representative of the structural behavior. Since the main topic of the paper is related to comparison of the numerical and measured data without inclusion of the time dependant phenomena, measured results given in the Table 1 are for the loading stages only and for the deflections of the middle of the truss span.

Measured deflections [mm] Table 1

Stage	Left truss	**Loaded truss**	Right truss
1	0.95	**4.34**	0.98
2	1.35	**8.76**	1.52
3	2.45	**13.64**	2.57
4	3.38	**18.58**	3.42
5	4.83	**26.29**	5.03
6	6.11	**33.45**	6.28

Measured results revealed that, although only one truss was loaded and its connection to neighboring trusses was just by roof cover and rather soft joints with longitudinal roof beams, deflection of the neighboring trusses was noticeable. This showed that both loaded truss and neighboring trusses contribute to the load carrying capacity of the loaded truss. Based on measured results the ratio of load distribution among three observed trusses was: 13.33% - 72.97% - 13.70%.

4. Numerical verification of the testing results

Initial numerical verifications relied on numerical models used within the main design project [1], Figure 3.

Basic calculations Table 2

Stage	Mid-span deflections [mm]
1	8.93
2	17.86
3	27.18
4	36.50
5	52.95
6	67.36

Significant differences can be observed between measured and calculated results. There are number of reasons for these differences. This simulation is rather basic and it includes plane model for the truss where loads are defined by means of simple transfer from one element to the supporting elements without inclusion of possible composite actions of the two, e.g. roof cover transfers its load to longitudinal roof beams, the beams transfer the load to trusses... This model also could not account for the deflection of the neighboring trusses. These results motivated more precise numerical models to be developed that can give better prediction of structural behavior for this structure. For this purpose several additional numerical models were created. All models were defined as space frames with roof cover modeled with plate elements. Testing of the real structure confirmed linear elastic behavior of the trusses so numerical simulations took no nonlinearities into account.

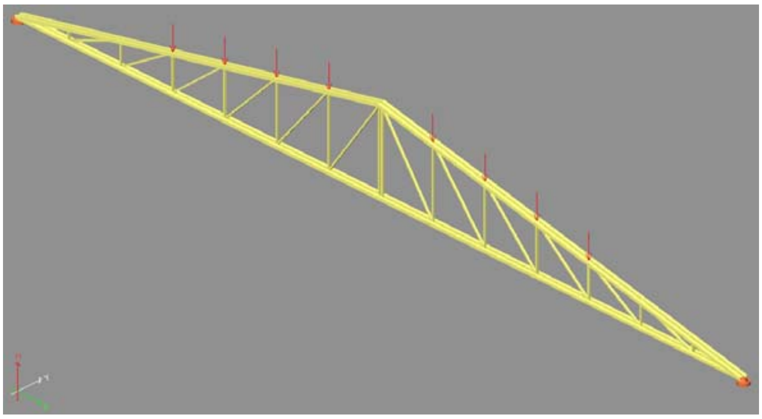

Fig. 3. *Model 1 -Basic numerical model - 2D plane truss*

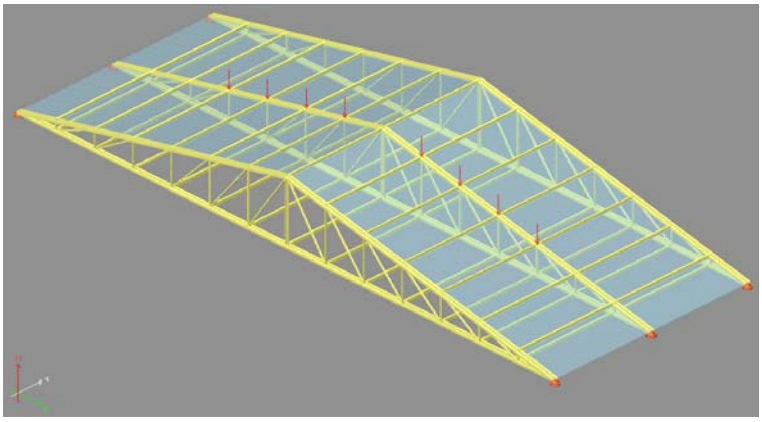

Fig. 4. *Model 2 - 3D model with loads only on the middle truss*

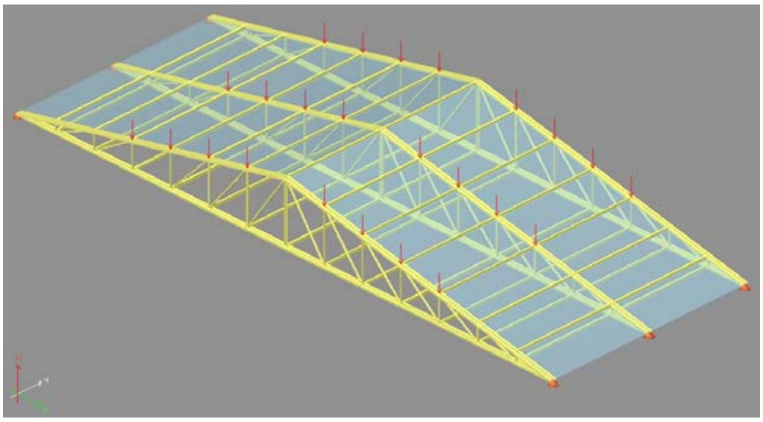

Fig. 5. *Model 3 - 3D model with loads on all trusses*

Out of number of 3D numerical models, for the purpose of this paper two models were chosen. Both models are based on the same geometry and boundary conditions while only the loads were different: one model has loads only on the middle truss, Figure 4; and one model has loads applied on all trusses, Figure 5. It is relatively easy to develop these 3D models from the basic one but still these two gave much better predictions of the structural behavior. First 3D model was used for verification of the testing results and for calibration. The second one represents possible situation in which full design load is applied on three trusses. The results of these simulations are given in Tables 3 and 4.

Model 2 - deflections [mm] Table 3

Stage	**Loaded/middle truss**	Left/Right truss
1	**4.87**	0.93
2	**9.69**	1.79
3	**14.78**	2.73
4	**19.84**	3.64
5	**28.71**	5.33
6	**36.43**	6.86

Model 3 - deflections [mm] Table 4

Stage	**Middle truss**	Left/Right truss
1	**6.66**	6.28
2	**13.32**	12.56
3	**20.25**	19.58
4	**27.17**	25.59
5	**39.50**	37.22
6	**50.34**	47.45

Comparisons of results obtained from testing and from the Model 2 show good agreement and point out to a conclusion that structural elements that were not taken into account by Model 1 significantly contribute to structural stiffness. Model 2 and similar models show composite action of the corrugated roof cover and the steel truss. This does not imply that practical design of similar strictures should be carried out by taking into account this joint action. It rather shows that evaluation of load bearing capacity based on significantly smaller stresses and deflections, when comparing testing results and results from Model 1, without considering the effect of the roof cover could lead to unsafe evaluations when, for instance, additional load is to be approved.

Testing vs. Model 1 Table 1

Stage	Testing	Model 2	**Difference [%]**
1	4.34	4.87	**12.2**
2	8.76	9.69	**10.6**
3	13.64	14.78	**8.4**
4	18.58	19.84	**6.8**
5	26.29	28.71	**9.2**
6	33.45	36.43	**8.9**

Comparison of results obtained from testing, from Model 1 and from Model 3 show that results obtained from loading one truss and monitoring neighboring two could be used for evaluation of the load bearing capacity. In this case, numerical results should be compared to testing results in a way that testing results from the loaded truss are increased by the portion of the load that was distributed on neighboring trusses, as opposed to comparison with directly measured results from the loaded truss only.

5. Conclusions

This paper shows results obtained by testing a 28 meters span steel truss roof girder of a sports hall (Figure 6) under trial testing loads. The total weight of the applied load was 16 tons and it was applied through six stages and then unloaded in five stages. Testing results showed that load is partially transferred from the loaded truss to neighboring trusses with distribution ratio of 13.3% - 73.0% - 13.7%. Initial numerical results, obtained from simple, plane, model of the structure that was used for the design purposes, showed significantly different behavior of the structure when compared to testing results. Measured results were approx. one half of the results obtained by the Model 1. Slightly improved numerical models in 3D that included joint action form neighboring trusses, longitudinal beams and corrugated roof cover showed much better agreement with the measurement results. The differences between results obtained by testing and by Model 2 were approx. 9.4%. Results obtained from 3D models (Model 2 and Model 3) verified findings from the field measurements in which thin corrugated roof cover significantly increased the stiffness of the main steel truss. This observation has significant effect on the evaluation of the load bearing capacity of the tested structure. It shows that evaluation of load bearing capacity based on significantly smaller stresses and deflections, when comparing testing results and results from simple plane truss models, without considering the effect of the roof cover could lead to unsafe evaluations when, for instance, additional load is to be approved. Since the design load can appear on all trusses at once, it can be concluded that either the measured results of the loaded truss have to be increased by the measure of load that was distributed on neighboring trusses or minimum three neighboring trusses have to be loaded by trial loads in order to asses the load bearing capacity of the roof structure. Application of the trial loads on three trusses at once can be, not only expensive but, very time consuming and difficult. Analysis given in this paper shows that it is possible to apply loads on one truss and, with slightly more sophisticated numerical models, obtain good insight into structural behavior and make good evaluation of the structural load carrying capacity.

Fig. 6. *Tested sports hall after completion*

References

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