Measurement of displacements in steel arch bridge

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Abstract

Measurement of deformations are applied in artificial structures such as dams, tunnels, bridges, and large scale buildings, in which big threats can be caused by deformations, and in landslide regions. The structures that are subjected to huge loadings and vibrations and that are not laid on a strong ground are exposed to a continuous change. It is very important to prevent big hazards with a continuous observation of these changes by using various measurement methods and with analyzing the scales of these changes by using various analysis techniques. In this study a steel arch bridge, designed by the Civil Engineering students at Firat University and entitled to participate in "Design and Construct" competition by Bogazici University in 2010, was used. The purpose of this study is to determine the behavior of the steel arch bridge under external load by using finite element methods and comparators. The results obtained from different measurement methods are agreed in terms of detecting displacements.

Introduction

Prediction of the behavior of a structural system has an important role in design. In a design process, structural systems are idealized by making some assumptions to obtain accuracy. Although the observations on adverse effects of extreme loadings on structures are important, it is usually almost impossible to record the behavior of an actual structure under extreme loadings. Hence, different measurement techniques were developed to overcome the problems in deformations measurements. In addition, construction of small scale structures is not so common due to financial reasons.

The importance of the idealization and making assumptions are to be realized in “Design and Construct” type competitions by motivating students to construct small scale structures, hence these competitions guide students to realize the difference in between the idealized and actual performance of the structural systems. A group of students at Civil Engineering Department of the Firat University participated to “Design and Construct” competition held by Bogazici University in 2010. A steel arch truss bridge was designed and constructed for this competition. The performance of the structure and the correlation in between the measurement techniques was discussed in this study.

Numerical analysis

The numerical analysis for the idealized steel truss arch bridge was conducted by using Finite Element Method (FEM). By using SAP2000 structural analysis [1] software the bridge was modeled. The model was a three dimensional model (3D) with the actual sizes of the small scale steel bridge (Figure 1). The cross-sections of the members for the structural system were determined by an optimization step. The model of the bridge was updated by means of connection tools in accordance with the built structure since students faced with some problems while obtaining the applicable connection method for the member of the bridge during the construction process.

The bridge was designed to carry gravitational loads through a slab at an elevation of z=120 cm. Diagonally placed horizontal load carrying members (h2) were connected to the truss system (Figure 2). These connections were fixed boundary conditions for gravitational loads and were pinned boundary conditions for horizontal loads. The gravitational loads were transferred to the ground respectively through diagonal horizontal members (h2), diagonal and vertical members of the truss (v1, v2, h1), upper and lower flange members (b1) of the truss, and the column abutments (Figure 3).

The upper and lower flange members of the truss were rigidly connected to each other. However, the vertical and diagonal members of the truss were connected by using pinned connection.

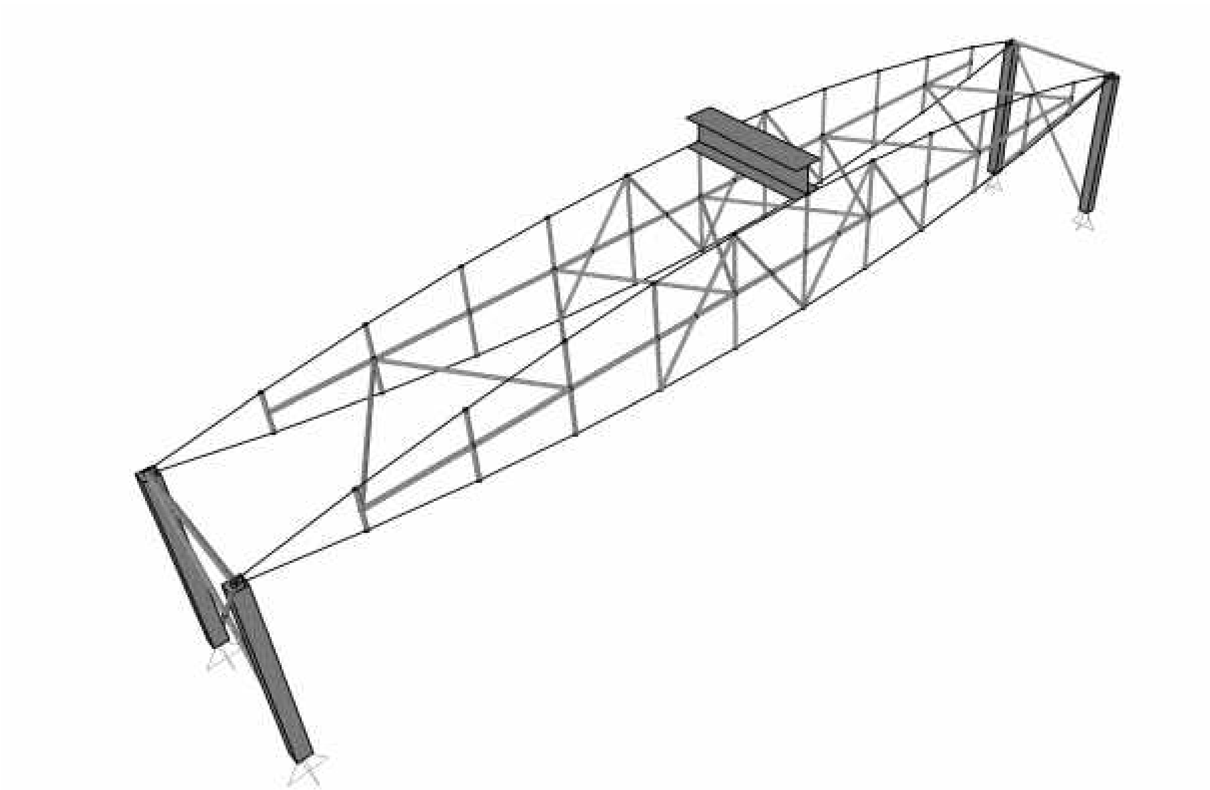

Figure 1 Three dimensional view of the finite element model

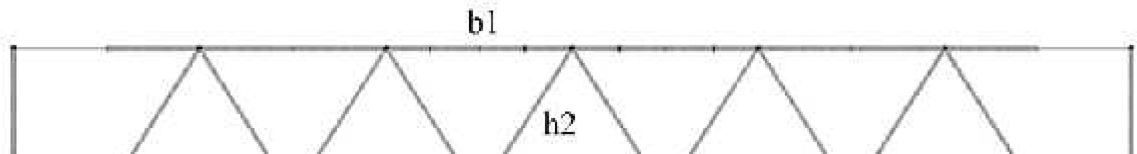

Figure 2 Top view of the finite element model

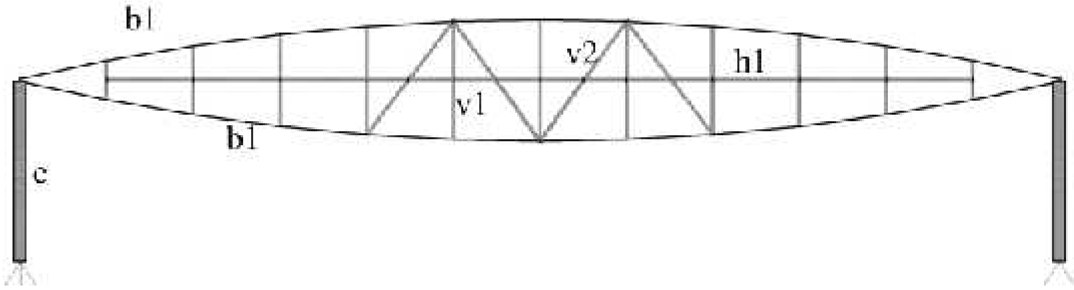

Figure 3 Longitudinal section view of the finite element model

The elevations of the upper and the lower bounds of the truss, which have a total span length of 690 cm and a width of 90 cm, were 160 cm and 80 cm, respectively. The views of the model are presented in Figure 1-3. The structural members of the bridge were S270 grade and material characteristic are presented in Table 1. All of the members that build the bridge are shown in Figure 1 and their section properties are listed in Table 2.

Table 1 Material characteristic properties

Unit Weight	γ_s	7.697x10-5	N/mm^3
Young's Modulus	E_s	200000	N/mm^2
Poisson's Ratio	υ	0.3	
Yield Strength	f_y	235	N/mm^2
Tensile Strength	f_u	340	N/mm^2
Effective Yield Strength	f_{ye}	352.5	N/mm^2
Effective Tensile Strength	f_{yu}	374	N/mm^2

Table 2 Section properties

Member	Section	ϕ or a (mm)	t (mm)
b1	Pipe Section	30	3
h1	Pipe Section	30	3
h2	Pipe Section	25	2
v1	Pipe Section	25	2
v2	Pipe Section	25	2
c	Square Box Section	80	3

Experimental program

The experimental part of the presented study was based on investigating the behavior of the bridge under extreme gravitational load. The load was applied incrementally by using a hydraulic jack. At each load step, the deflection of the bridge was measured at two locations, which were located on upper and lower flange of the mid-span. The deflections of these two points were measured by using dial gauges and theodolite without reflector. The load-deformation behavior of the bridge was compared with the numerical model. The applied load was limited to provide an elastic behavior for the structure by preventing the plastic deformations on structural members of the bridge.

Since the existing laboratory conditions were not appropriate to apply the load on horizontal slab diagonals, the load was applied on upper flange of the bridge. A stiff wide flanged (I-beam) was laid between the hydraulic jack and the upper flange of the bridge to apply the load symmetrically on both of the trusses of the bridge. A digital load cell was used to measure the resistance of the bridge to the applied deflection. The experimental setup is presented in Figure 4.

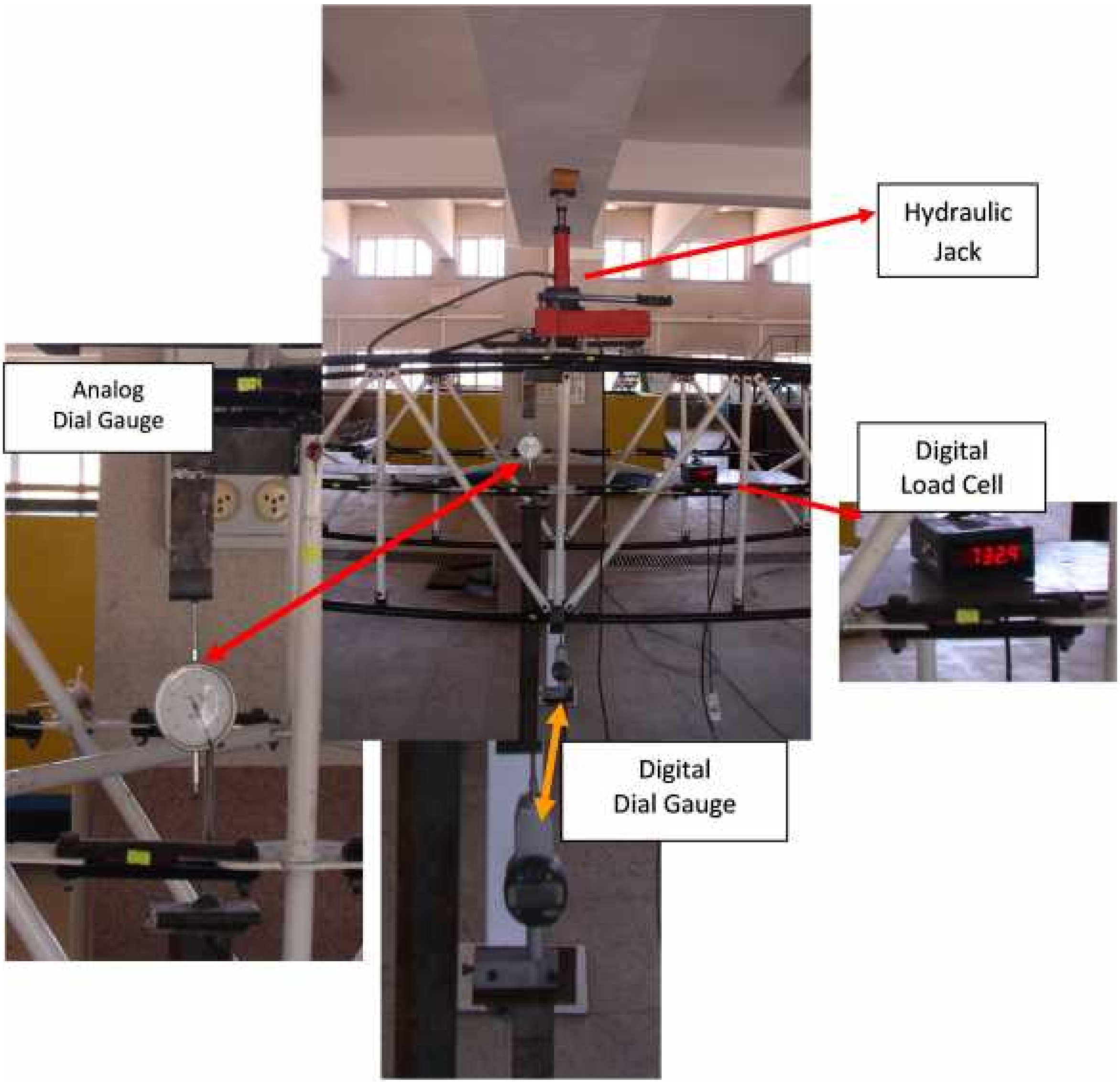

Figure 4 Experimental setup and instrumentation

Results

The bridge that was designed and optimized by using Finite Element Analysis, presented the expected behavior under gravitational load. The measured and expected deflections of the bridge were in an acceptable range when compared to each other. The deflections of the joints, which were on upper and lower flange, at mid-span of the bridge are presented in Figure 5 and Figure 6, respectively.

Figure 5 presents the behavior of the joint that is on the upper flange under gravitational load. The behavior of the joint on lower flange is presented in Figure 6. As it is presented by

Figure 5 and Figure 6, there is slight difference in between the predicted deflections by using the finite element model and the measured deflections by using dial gauge and theodolite. This slight difference in between the predicted and measured behavior of the bridge is due to the assumptions that were made while modeling (such as the establishment of the joints of the trusses)

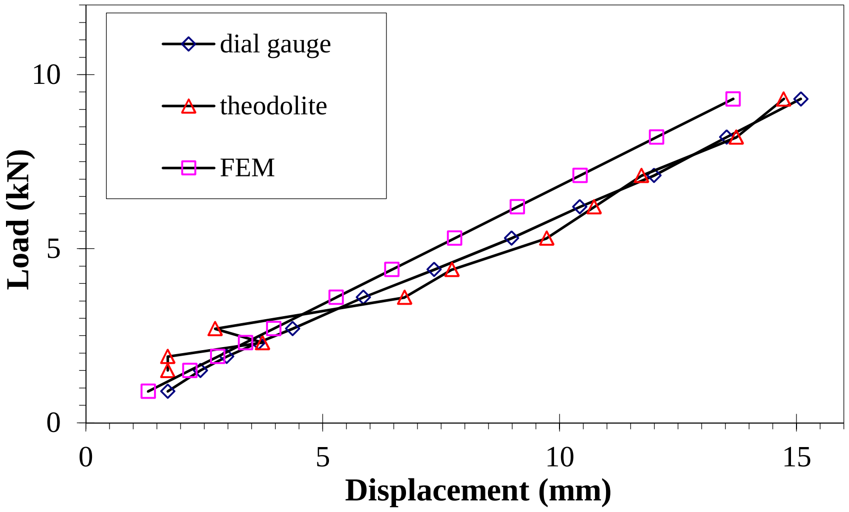

Figure 5 Deflection of the mid-span joint on upper flange

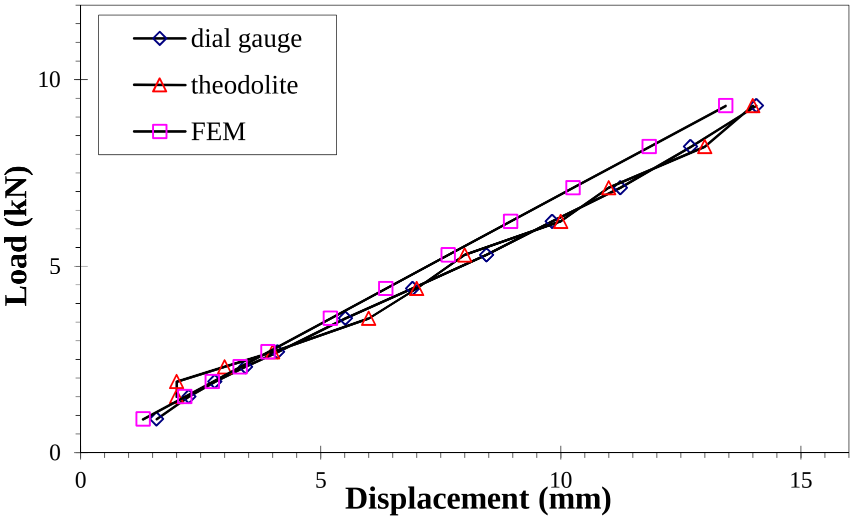

Figure 6 Deflection of the mid-span joint on lower flange

Conclusions

The presented study showed that the importance of the assumptions made during the design of a structural system. Due to the assumptions that are made during the design, there can be differences in between the actual and desired behavior of the structure. Due to the some possible handicaps related to the region of the structure, it is possible that the desired behavior for the structure may not be observed. The student group faced with some problems while constructing the bridge by means of purchasing the desired structural members, constructing the joints etc. Even after the design was updated by taking these handicaps into the consideration, there was a slight difference in the designed and constructed structure. The study presented that different measurement techniques can also be used effectively.

References

[16] Computers and Structures, Inc. (1976-2005) SAP2000. *Computers and Structures Inc.*, Berkeley, CA, USA.