Integrated Educational Project of Theoretical, Experimental, and Computational Analyses

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Abstract

This research demonstrates how to design an integrated capstone project by including theoretical, experimental and computational analyses of a truss bridge. The project mainly focused on leading students to approach engineering problems with various methods and to understand the advantages and disadvantages of each method. The students applied three methods to acquire the values of stresses and deflections of members in the given truss bridge. First, they calculated the stresses and deformations theoretically. Second, they actually conducted an experiment of the truss bridge with electronic measuring equipment. Lastly, they built two simulation models with Autodesk Inventor and Dassault Systèmes SolidWorks. From the comparisons of above three methods, students were guided to the validation of assumptions of theories.

1. Introduction

In engineering education, educators found that some students learn sequentially, mastering a material more or less as it is presented. This group of students are the sequential learners. The other group shows a different pattern. They may have some difficulties to solve relatively simple problems until they understand all related topics completely. Then, they might be able to apply the contents to the problem which is more comprehensive and advanced. The second group of students are the global learners [1]. For both of them, it is important to teach the related topics with different approaches. However, to review all contents in a short time duration would be helpful to both.

This study is the application of integrated structural analysis education including mechanics, an experiment, and computational simulations. Students, who are sequential learners, might understand the underneath theories and contents step by step. A global learner can find the relation and physical phenomenon all at once. For both types of learners, the project focuses on increasing the students' ability to understand how to apply the theoretical contents of structure analysis to computational modeling and simulation. In addition, the instructor leads them to confirm the validation of assumptions of theoretical truss analysis by comparing the stresses and deformations from the theory to those of actual experiment. As a result of the comparison and analysis of different approaches, the students found the advantages and disadvantages of each method, and understood the reason why the results show reasonably acceptable differences.

2. Planning an Integrated Project

There are many ways of approaching design education that appear to offer both systematic payoffs and a framework for continuous quality enhancement. Faculty members at the university help to manage the contextualization of engineering design theory and practice. This would not only bring invaluable experience into design classrooms and studios, but would also help to alleviate the burden of faculties who want to teach design because they are comfortable with their own design experiences [2].

This educational project started with guiding students to have a question about the joints of truss structures. The theoretical truss analysis assumes all joints are pin connections, so that any moment cannot exist at the joint. However, truss structures in reality are connected by gusset plates which can cause moment at the tips of members. Therefore, the problem from the difference arises and the students need to set up the procedure to confirm that this difference can be negligible. In the project, they set up four analyses to compare each other: a theoretical method using pin joints, an experimental method using gusset plates, a computational method using pin joints and an additional computational method using gusset plates. For the educational purpose, the computational model with pin joints was developed by Dassault Systèmes SolidWorks and the other computational model with gusset plates was built by Autodesk Inventor Professional. Above two user-friendly computer aided design (CAD) software with finite element method (FEM) enabled the students to approach the structural analysis even though some of them did not have strong theoretical background such as the students in engineering technology.

3. Procedure of the Project

3.1 Analytical Method

To analyze the truss bridge theoretically, the method of joints taught in the statics class was used. Because this method assumes that all joints are connected by pins, the students began with the free body diagram as in Fig. 1 with tensions and compressions only. Once the students found all forces on the members, they could calculate the deformation of each member by using the theory in the strength of materials class. Then, they could specify the displacement of each joint geometrically. All required dimensions and material properties in this procedure was measured and calculated with the members which were actually used in the experiment.

3.2 Experimental Method

From the beginning of engineering education, laboratories have had a central role in the education of engineers. While there has been an ebb and flow in the perceived importance of laboratory study versus more theoretical classroom work, it has never been suggested that laboratories can be foregone completely. Certainly the main purpose of engineering is still to modify nature ethically and economically for the benefit of humankind, but engineers do this increasingly from a computer terminal and not from the workshop floor or a field truck. Nonetheless, most engineering educators agree that students must have some contact with nature [3].

In listening to those students who had acquired a deep understanding of the complementary nature of theory and experiment in engineering, the professors were particularly impressed by their allusions to just one or two key experiments in their past laboratory work as being instrumental in developing understanding. This suggests that a significant change in students' understanding could be achieved by just a few well-designed experiments. Although course provisions in the junior and senior years offers opportunities for experimentation, there is an urgent need for students in their first two formative years of study to have some engagement with genuine experimentation. This should be designed to provide experience in testing the limits of theory, and through this develop students' appreciation of the essential role of experimentation and empirical validation in such situation [4].

For the experiment of truss structure, the experiment kit by PASCO was used. As shown in Fig. 2, load cells were installed on the eight truss members to estimate tensions and compressions. The voltage from the load cells was amplified and recorded by the PASCO software. Then, the students could measure the average in thirty seconds. The kit includes joint which can transfer moments. Figure 3 shows the joint in the experimental kit and it can be compatible to the gusset plate in the actual truss structures. The displacements were compared to those from the theoretical calculation. Furthermore, the students were encouraged to discuss the sources of differences on the results.

3.3 Computational Method

Although details vary, computational science and engineering education tends to focus on a common tool set of subjects that have proven themselves useful in solving problems in a number of disciplines. While many of these subjects may get coverage in courses taught by traditional departments, professors have described the need for separate science and engineering classes that (1) put the tools together, (2) develop an appropriate problem solving viewpoint, (3) glue the multiple disciplinary classes together, and (4) develop a sense of belonging to a computational community [5].

To make a computational truss model with pin joints, the students used Dassault Systèmes SolidWorks which can implement structural analysis by FEM. The pin joint modeling is depicted in Fig. 4. For the computational truss model with gusset plates, the students used Autodesk Inventor Professional which is able to apply FEM to the given structures as well. The gusset plate modeling of experimental kit is shown in Fig. 5. The simulation results with pin joints from the computational analyses are shown in Figs. 6 and 7. Fig. 6 displays Von-Mises stress and Fig. 7 shows the displacement. Likewise, the simulation results with gusset plates are shown in Figs. 8 and 9. Von- Mises stress is shown in Fig. 8 and the deformation is depicted in the Fig. 9.

3.4 Comparison

Based on the deformed lengths of members calculated theoretically, geometrically the students could find the maximum vertical displacement, which was 0.2305 mm. These results were compared to the calculated results from the theoretical method. The error range was from 0.5 to 28.1% and the average error was 11.2%. During the experiment, they were guided to find the differences from the theories such as different assumptions for joints and bending, warping, and friction that exist in members and joints in the experiment. Furthermore, they had the opportunity to discuss these differences and to find their effect on the results. The position of maximum displacement obtained from the FEM analysis of the truss model with pin joints was same as the position in the theoretical method and the maximum displacement was 0.2020 mm (Fig. 6). This result showed 12.4% less deformation than the theoretical calculation. The students were encouraged to find the possible sources of difference and they suggested that the friction at the supports might cause tensions and bring the point upward. In the static analysis of the truss model with gusset plate connections, the maximum displacement existed at the same position as the theoretical method and the computational model with pin joints. In this case, the maximum displacement was calculated as 0.1944 mm (Fig. 8). The analysis result showed 15.7% less deformation than the result from the theoretical method. Likewise, the students had the chance to discuss the causes of differences and finally they decided that the deformation of gusset plates could hold the energy so that it caused less deformation on the members.

4. Summary

In order to perform this integrated capstone project including theoretical, experimental and computational analyses of the truss structure, the students were guided to approach engineering problems with various methods and to understand the advantages and disadvantages of them. By the above three methods, they could calculate or measure the stress and deflection of components in the given truss bridge. They calculated the stress and deformation based on the information from statics and strength of materials classes. The actual experiment was performed with PASCO kit and load cells. In addition, two computational simulation models were built by Autodesk Inventor and Dassault Systèmes SolidWorks. From the comparison of the results from various methods used in the project, students were encouraged to found the differences in the results and their causes.

Through overall progress in three month, the students had opportunities to apply the theories to the given model, to estimate forces on members by using electronic devices, and to build two computational FEM models with different connection types using Dassault Systèmes SolidWorks and Autodesk Inventor. For this project, they reviewed and applied the contents of several classes: physics I, statics, strength of materials, and computer aided drafting and design classes. Most importantly, as a result of the procedures to compare three analyses and one experiment, they increased their ability to analyze the differences and to find the causes and effects. For the logically fair comparison, they should have also built a computational model with gusset plates using SolidWorks and a computational model with pin joints using Inventor so the variable of different analysis programs could be eliminated in the comparisons between computational simulation results. However, due to the insufficient time, those two models could not be developed. It will be one candidate of future works. In addition, this type of integrated educational project will be applied to other subjects as well.

Acknowledgement

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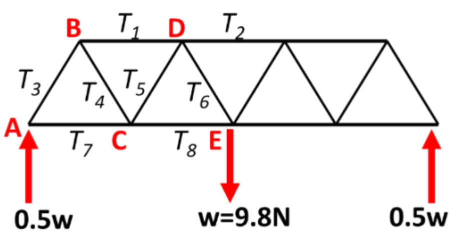

Fig. 1 Free Body Diagram

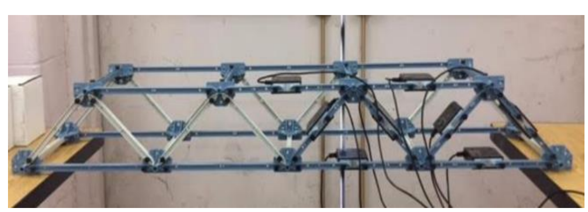

Fig. 2 Truss Bridge Experiment

Fig. 3 Gusset Plate in the Experiment

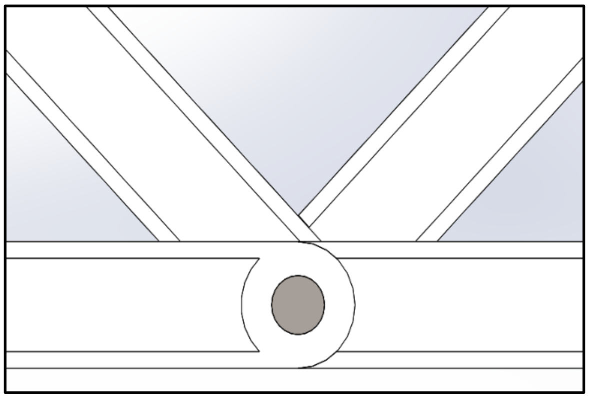

Fig. 4 Pin Joint in Simulation

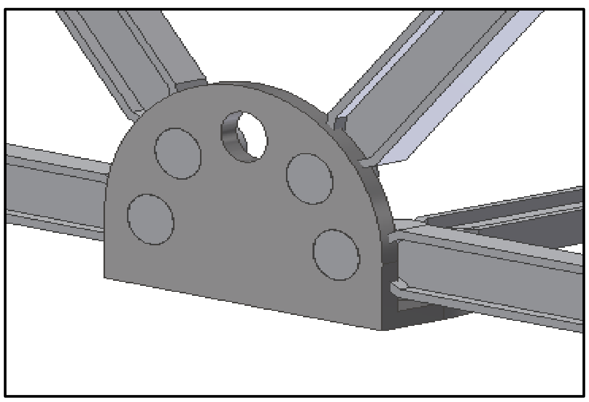

Fig. 5 Gusset Plate in Simulation

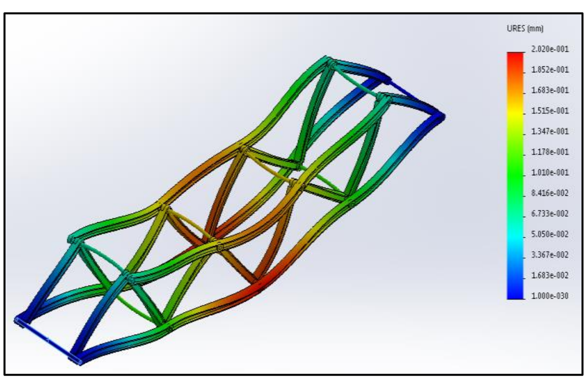

Fig. 6 Displacement of Pin-Jointed Truss

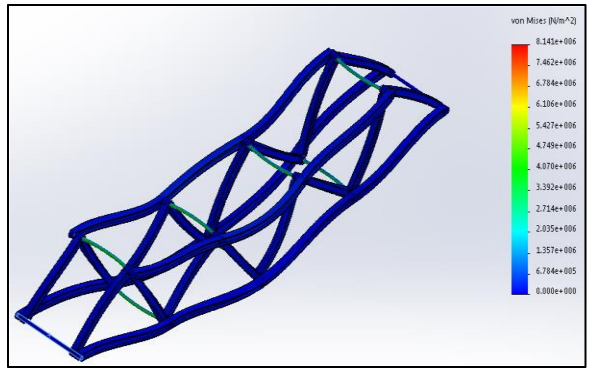

Fig. 7 Stress of Pin-Jointed Truss

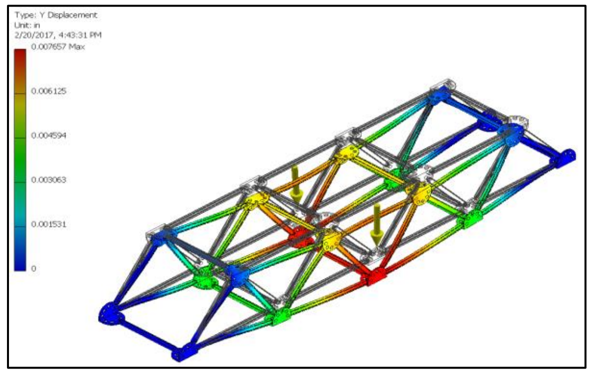

Fig. 8 Displacement of Gusset-Plated Truss

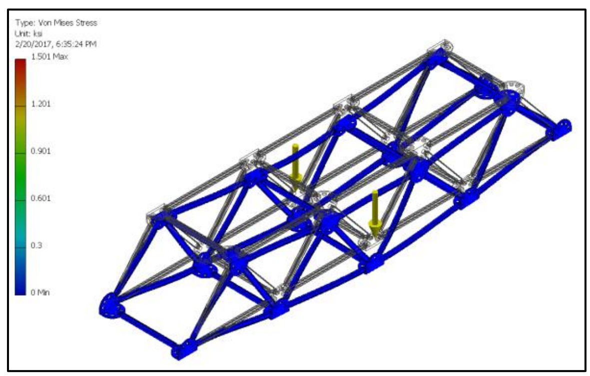

Fig. 9 Stress of Gusset-Plated Truss