Enhancing Students' Understanding of Structural Behavior Using Small Scale Models

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Abstract

This paper describes the use of a computer-aided structural laboratory (the ANEX lab) in a structural analysis class to give students a hands-on method of developing a better understanding of structural behavior by observing the actual deflected shapes of a small scale model structure under load.

The ANEX[1] lab, developed at the University of Missouri-Rolla, is a computer-aided structural laboratory that includes a structural analysis module using M-STRUDL, and a computer-aided experiment module. The models can be made of either aluminum or plastic, and rigid and pinned connections can be modeled. Horizontal and vertical displacements are measured using linear variable displacement transducers (LVDTs).

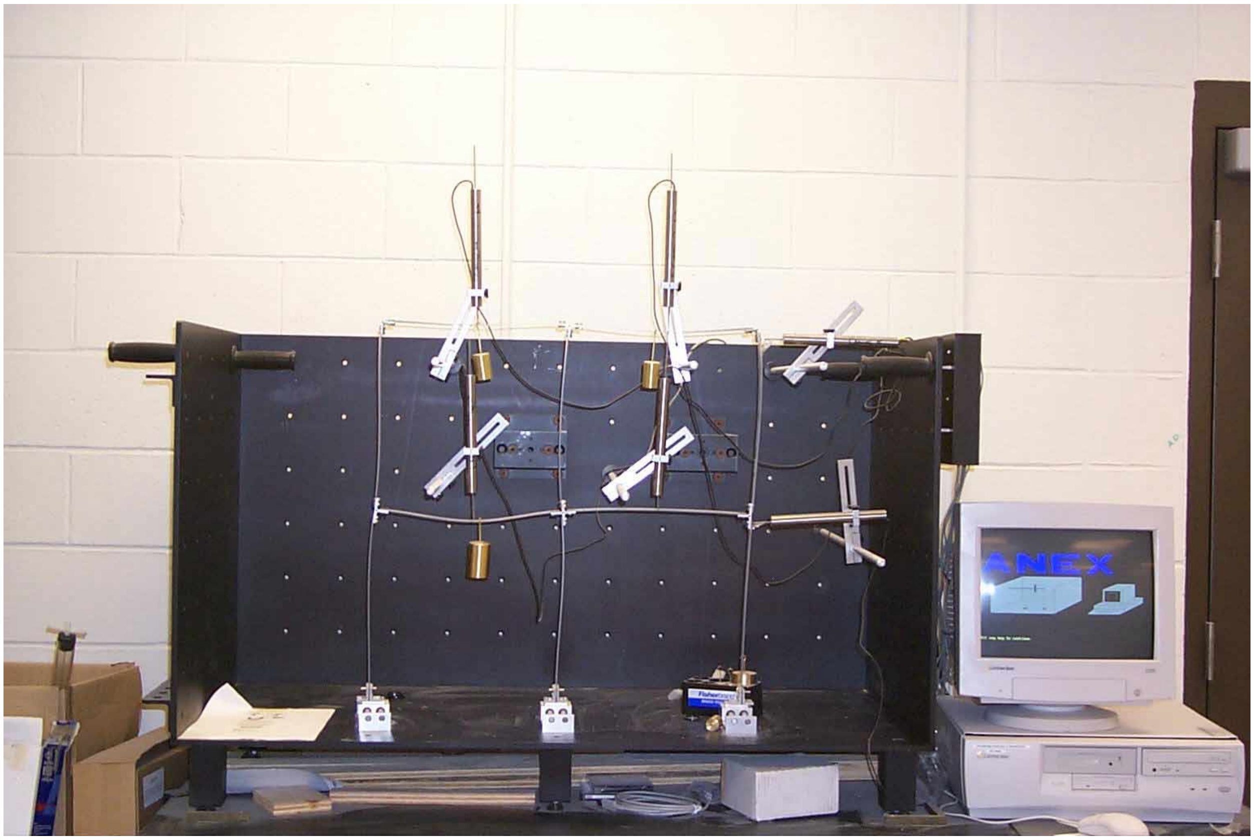
In the structural analysis class, students were instructed to form groups of 3 or 4 students to work on a quarter-long ANEX lab project that involved a two-story, two-bay frame made of plastic. The frame was subjected to various vertical load combinations. For each load combination, each team was required to compare and discuss the analytical and experimental displacements and draw the actual observed deflected shapes of the frame indicating the tension and compression sides of each member at the joints and at the mid-lengths of the members. Students were required to note any experimental observations and difficulties encountered, and also to submit a mid-quarter progress report.

1. Introduction

Civil Engineering Technology students need to develop the ability to visualize structural behavior but this skill cannot be acquired solely through the theoretical concepts that are taught in the classroom. These students need hands-on structural analysis experiments to complement and reinforce the theoretical concepts that are taught in class. To achieve this goal at minimal cost, several structural analysis mini-labs[1,2] have been developed. In this paper, the use of one such mini-lab -the ANEX lab[1]- is described and the students' feed back is discussed.

Figure 1. ANEX Lab Setup (without Loads)

Figure 2. ANEX Lab Setup (with Loads)



The ANEX lab is a mobile mini-laboratory (see figures 1 and 2) that includes an M-STRUDL analysis module, an Experiment module, and a Compare module. It consists of a desktop computer and a test bed that is 48 inches wide by 22 inches deep by 26 inches high. The test bed has threaded holes on a 4-inch grid necessary for mounting equipment or supports for the structural models, and is attached to a table that is set up on four wheels. This makes the lab completely mobile and thus allows it to be wheeled to class or any location on campus for demonstrations of structural behavior.
The data acquisition system includes an analog to digital board that converts analog or voltage signals into digital inputs. The ANEX lab has several measuring devices, including linear variable differential transducers (LVDTs) for measuring displacements, rotation sensors, load cells or force sensors, and strain gages for determining member stresses. The lab comes with several fixtures for attaching these measuring devices to the test bed.

To simplify the construction of the small-scale models, the ANEX lab comes with an Erector set that enables different types of structures of Plexiglas or aluminum with various support and joint conditions to be tested. A metric weight set with weights varying from 10 grams to 1000 grams is also included. The weights have a hook system with which they are attached to the model.

The data generated by the ANEX Compare module, which includes statistical comparisons between the analysis and experiment has to be interpreted and analyzed.

2. The ANEX Lab Project

The ANEX software guides the users with several on-line instructions as they proceed through the M-STRUDL analysis module, the Experiment module which involves the set-up of the structural model and sensors as well as the data acquisition, and the Compare module which compares the M-STRUDL analysis with the experimental results.

As part of the Structural Analysis class that is offered to fourth year Civil Engineering Technology students at the Rochester Institute of Technology, a laboratory project is assigned. The project consists of a two-story two-bay Plexiglas frame with fixed column supports set up on the ANEX test bed. Displacement measuring devices or linear variable displacement transducers (LVDTs) were located at six points on the frame; vertical displacements were measured at the mid-span of the beams and lateral or horizontal displacements were measured at the roof and 2nd floor levels. Only static loads are applied and four different load cases shown in Table 1 were investigated, with the concentrated vertical loads located as shown in Figure 3. The project was completed in groups of three or four students, and a mid-quarter progress report, as well as a final report, was required.

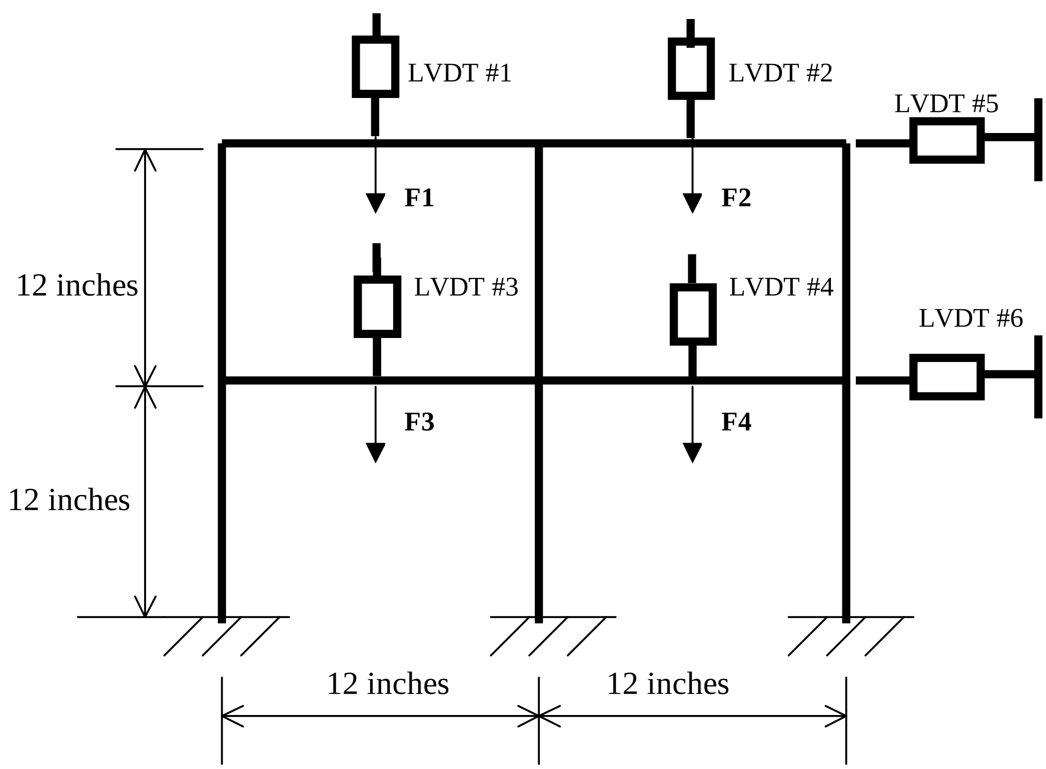
The lab involves measurements and calculations of the sectional properties of the frame members, labeling the nodes or joints for the M-STRUDL analysis and the Experiment module, and measuring the vertical and lateral displacements at the LVDT locations. For each load case, displacement readings were taken five times and the average value was calculated internally by the ANEX software. Students were required to submit a final report that includes the following:

- A description of the structural model
- A sketch of the experimentally observed and analytical deflected shapes for each load case.
- On sketches of the experimentally observed deflected shapes, show the flexural tension (T) and compression (C) sides at the mid-lengths and at the ends of all the members of the frame.
- Comparisons of the analytical results from M-STRUDL with the ANEX experimental results.
- Discussion of experimental observations, difficulties encountered, and recommendations.

Table 1 Load Cases

Load Cases	LOADS			
	F1	**F2**	**F3**	**F4**
1	0.2 kg	0	0.3 kg	0
2	0.2 kg	0	0	0.2 kg
3	0.2 kg	0.5 kg	0.2 kg	0.2 kg
4	0.2 kg	0	0.5 kg	0.2 kg

Figure 3 Structural Model with LVDT and Load Locations



3. Students' Experiences

In the ANEX lab final reports[3], submitted by the students in the Structural Analysis class, most of the groups observed that the M-STRUDL analysis yielded displacements that were different than the experimentally obtained deflections, although the deflected shapes were similar. Some of the reasons advanced by the students for the differences are as follows:

- Some error is introduced into the analysis by assuming perfectly rigid joints; since the joints are not perfectly rigid, this implies that the structural model is actually not as stiff as the M-STRUDL analysis assumes.

- The vertical deflections in the M-STRUDL analysis were calculated at the mid-span of the beams. However, as the frame deflected laterally during the experiment, the LVDT locations shifted somewhat from the original location at the mid-span of the beams; thus, the experimentally measured vertical deflections would be less than the actual value at the mid-span of the beams.

- The M-STRUDL analysis did not account for the initial imperfections or deflections of the structure, which the experiment is able to account for, which results in experimental displacements being larger than the analytical displacements.

- The modulus of elasticity assumed in the analysis did not account for the permanent distortions that have taken place in the structural model from repeated use. This would make the analytical model stiffer than the actual structure.

- The accuracy of the horizontal displacements (LVDT # 5 and #6) was not as good as the vertical displacement readings (LVDT #'s 1 through 4) because LVDT #'s 5 and 6 had to be physically attached to the frame. Without this attachment, the frame could move away from the LVDT's under some loading conditions.

The following are additional comments from the students' final reports regarding some of the benefits gained from the ANEX lab project:

"The experiment was a great hands-on and visual model of what a real structure will do under certain loading condition. It was a great opportunity to see how loads acting on one part of the frame can affect the whole structure."

"During the course of this lab, we were able to see actual bending and deformation of real framing members."

"This experiment firmed up principles learned in class; as such, we feel that hands-on learning should never be underestimated as an aid to learning."

"With what we have seen from this experiment, we will hopefully be better able to visualize bending and displacement of frames in future analyses."

By observing the deflected shapes of the small-scale structural model under various loading conditions, students were able to differentiate between single and double curvature bending of flexural members; they were also better able to grasp the meaning of "point of inflection" when it was taught in class.

The students encountered some difficulties in the course of the lab project. One of them is the fact that the current version of ANEX is DOS-based. ANEX could also not handle more than one load case at a time; if multiple load cases were done at once, the ANEX Compare module would have the results for the last load case only. Another problem was the fact that once you entered information into ANEX and left a particular screen or module, it was not possible to go back and change or fix any errors discovered in the input; you would have to start the load case all over. A Windows version of ANEX, which is presently under development, would solve most of these problems.

4. Concluding Remarks

It is very important for students to develop an intuitive "feel" for structural behavior and to be able to visualize the action of a structure under load. This important skill which will enable them discern errors in the output from computerized structural analyses can hardly be developed solely through the abstract and theoretical concepts that are taught in the classroom. The use of hands-on physical experiments such as the ANEX lab helps students to develop the ability to visualize the response of structures under load thereby fostering a better understanding of the structural concepts that are taught in class. It also helps to reinforce the importance of independent verification of computerized analyses or experimental data.

A side benefit of the lab is in satisfying the Accreditation Board for Engineering and Technology (ABET) criteria which states that "graduates of engineering programs should have an ability to design and conduct experiments as well as to analyze and interpret data".

The ANEX lab also hones the students' problem solving and trouble-shooting skills since this lab project is an open-ended problem with no unique answer. Each group had unique analytical and experimental results, and were required as part of the project to explain the reasons for the similarities and differences between the analytical and experimental results.

Furthermore, the benefits from the hands-on experience of the ANEX lab are achieved without the constraints of the large space and equipment requirements that are necessary for a standard full-scale structural engineering laboratory, plus the ANEX lab is completely mobile.

5. Acknowledgments

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