

Online experimentation for study of stress and deformation in structural beams

Alamgir Choudhury, Jorge Rodriguez, Mitch Keil, Sam Ramrattan and Pavel Ikonomov

Department of Industrial and Manufacturing Engineering

Western Michigan University

Abstract

Analysis of stress and deformation of beam elements are utilized in a wide range of curriculum. In most engineering and engineering technology programs, analytical methods are often augmented with computer applications and laboratory experiments. In the lecture only classes, theoretical learning can be complemented by online experimentation in a remote laboratory. The laboratory consists of a hydraulically actuated beam loading mechanism, sensors, data acquisition system, and web based application programs for the data monitoring and control. Using this system, one can quickly create an experimental setup in a remote laboratory for a theoretical problem, apply the load, and monitor resulting deformation and stress. Close agreement between the analytical and the experimental results establishes the validity of the theoretical analysis without the use of a formal laboratory class. Among the students of the class, it also creates awareness on limitations of the theoretical methods predicting behavior of structural members in reality.

1. Introduction

Stress and deformation analysis [1,2] is taught in undergraduate level mechanical design courses in both engineering and engineering technology programs. The goal is to enable students to investigate different stress and deformation scenarios in design problems. They are expected to be familiar with the theory, formulation of problems, and use of efficient techniques for solution of the problems. The effectiveness of this learning depends on the depth of subject matter covered and the method of instruction. In the engineering technology programs, the emphasis is on mastering the routine techniques for the solution of a problem. After learning the theoretical foundations, students use both analytical and computer assisted solution methods for this purpose. They are also introduced to commercial computer assisted tools or customized packages for the

solution of specific design and analysis problem. An important aspect of their learning, students learn how to develop a problem based on the given criteria, gain proficiency in the use of solution methods or select the appropriate solution tools. In programs with laboratory classes students are able to verify their theoretical solutions with actual stress and deformation in a real system. The laboratory classes also make them aware of the limitations of theoretical methods and the importance of realistic analysis to predict actual behavior of a mechanical beam. To overcome this deficiency in a lecture-only class, we are presenting a method for online verification of the theoretical stresses and deformation in a beam element without relying on laboratory exercises. The aim is to let students compare their theoretical findings with actual results in a laboratory without leaving the classroom.

The technology to access remote laboratories has been utilized by researchers [3,4,5,6] in various fields. It has been used for remote monitoring and control of a variety of engineering systems and processes. Esche, et. al. [3] introduced an internet accessible laboratory for cost effectiveness and flexibility in an undergraduate dynamics class. Francisco, et.al. [4] utilized online robotic experiments to allow a large number of students to benefit from a physical laboratory in distance education courses. As it required no specific timetable for the laboratory, students could use this system to learn at their own schedule. Similarly, Rohrig [6] used an internet accessible laboratory for enhancing distance education in control engineering. Besides analytical computation, these systems require use of high level programming language to monitor, process and transmit various application data. In the area of automated measurement of quantitative data in engineering applications, LabVIEW [7] is a popular programming language. Krehbiel [5] used a LabVIEW tool to remotely access controllable laboratory equipment for online experiments in environmental and ecological science. His objective was to focus on pedagogical issues related to learning through a remote system rather than real time experimentation.

In the following, a new tool is presented for online experimental verification of theoretical results in a mechanics class. The goal is to create learning opportunities for students by using two different methods: computer aided analytical solution, and verification of these results by actual experimentation in a remote laboratory. The computer aided solution method was developed earlier and is already available to the students. The online experimentation is a new tool that the students will use along with the computer aided analysis tool. The method utilizes a hydraulic actuation system that can be accessed and controlled remotely through the web. The system can be used to load a simple beam element in a remote laboratory according to the specification of a theoretical problem under consideration and measure the resulting stress and deformation.

2. Computer aided analysis

At Western Michigan University the topics of stress analysis are taught in two sequential classes. In the first course, concepts of stress, axial and transverse forces, bending moment; normal, shear, and torsional stresses for statically determinate problems are taught. In the second course, students utilize states of stress, principal stresses, and deflections for the analysis of a variety of design problems. As a traditional method of

learning, students utilize manual solutions of the problems as well as Excel or other standard application packages (e.g., Matlab) to solve problems requiring extensive computation. Recently, a web based application package [8] has been developed to provide students with a structured guide to lead through the steps of problem formulation and solution method taught in the class.

The computer-aided analysis tool is available to the students for the solution of stress and deformation in a simply supported, over hanging and cantilever beam elements. To use this tool one starts with the selection of type of analysis - stress or deformation. In Figure 1 below, the steps followed in the stress analysis method are shown. The user specifies the type of beam, and the nature and number of the loads. In the next step, as the user enters magnitude and location of each load, the corresponding reaction forces, shear force, and bending moment distributions are displayed. After the last load is specified, the user can select a critical section of the beam to compute bending and shear stresses, determine the state of stress, and investigate stress transformation and the principal stresses.

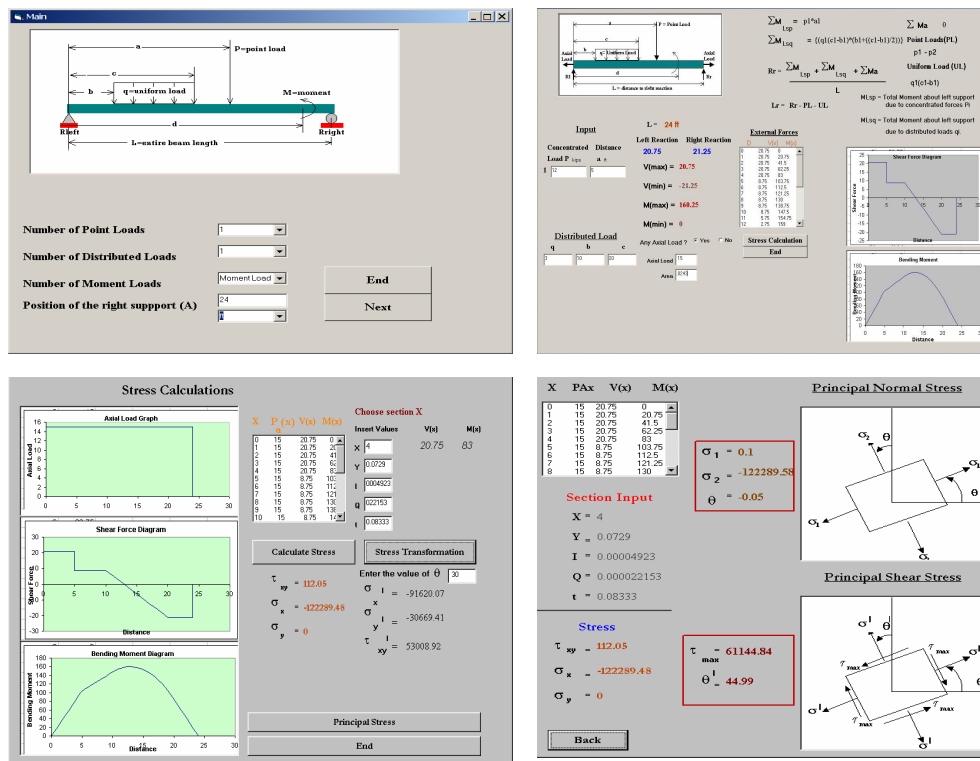


Figure 1. Computer aided stress analysis

The stress and deformation analysis tool has been developed in separate modules using Visual Basic and Excel with a graphical interface to visually display the result. Students can use each module for independent analysis of a subset of a problem or the whole package for complete analysis of a stress and deformation problem. Since the solution method utilizes the same theoretical equations taught in the class, students can also use this tool to check the accuracy of their specific homework solution.

3. Online experimentation tool

Due to lack of hands-on experimentation, in a lecture class, students do not see the effectiveness of the theory learned in real-life applications. Students also tend to overlook the limitations of the theoretical methods and the cause of variation between theoretical and actual behavior of mechanical bodies. Therefore, this new tool has been developed to show actual behavior of the beam elements within the limitations of a lecture course. It can be used to setup in a remote laboratory, the same beam problem that they have already analyzed theoretically. Using online input to specify the magnitudes and locations of the loads, students would apply the loads on a real beam element and see the resulting deformation and stresses.

4. Laboratory Setup

The experimental setup for the online stress and deformation analysis is composed of an aluminum beam-loading platform along with a simply supported beam element. The magnitude and location of the load on a beam element can be achieved by using a variety of technology, such as electric, hydraulic, or mechanical system. Considering the simplicity and flexibility requirement of the system to accommodate different types of beam specimen, a hydraulic system was the most logical choice. The platform is equipped with two hydraulically operated actuators that move on a grooved track to apply the loads on the beam underneath. The location of the beam support and the vertical loads are determined by the angular positions of three lead screws operated by their respective hydraulic motors. Two linear actuators attached to their lead screw driven platforms generate the loads on the beam element. A constant-pressure load-holding hydraulic circuit is utilized to control the magnitude and location of each load. The system is monitored by using a National Instrument (NI) data acquisition system, which includes a PXI 1000 data acquisition chassis, embedded PXI & VXI controllers, PXI multifunction input/output kit, shielded connector blocks, and terminal blocks. The user of the system specifies the locations of the loads and their magnitudes through the input in a Visual Basic application program. Strain gages are installed in critical locations of the beams and used as target elements for an analysis problem. These gages send signals to a LabVIEW application program through the PXI module. An LVDT sensor is installed for monitoring deflection of the beam at a specified location. Using the LabVIEW application program, real time stress and deformation data are acquired in a database in the server. Beyond the simply supported beam, this system can be adapted to measure stress and deformation in over hanging or cantilever beams as well. The configuration of the overall system is shown in Figure 2. The hydraulic circuit is equipped with a relief valve and limit switches to ensure its operation within specified limits. For safety purpose, the video image of the actual physical system in the laboratory is also shown along with the stress and deformation data. Therefore, in case of component or system malfunction, one will be able to see the system and take appropriate steps to shut down the system and trouble shoot. In case of emergency, the NI data socket writer transmits the user input signal to the PXI module which turns the pump power supply relay off.

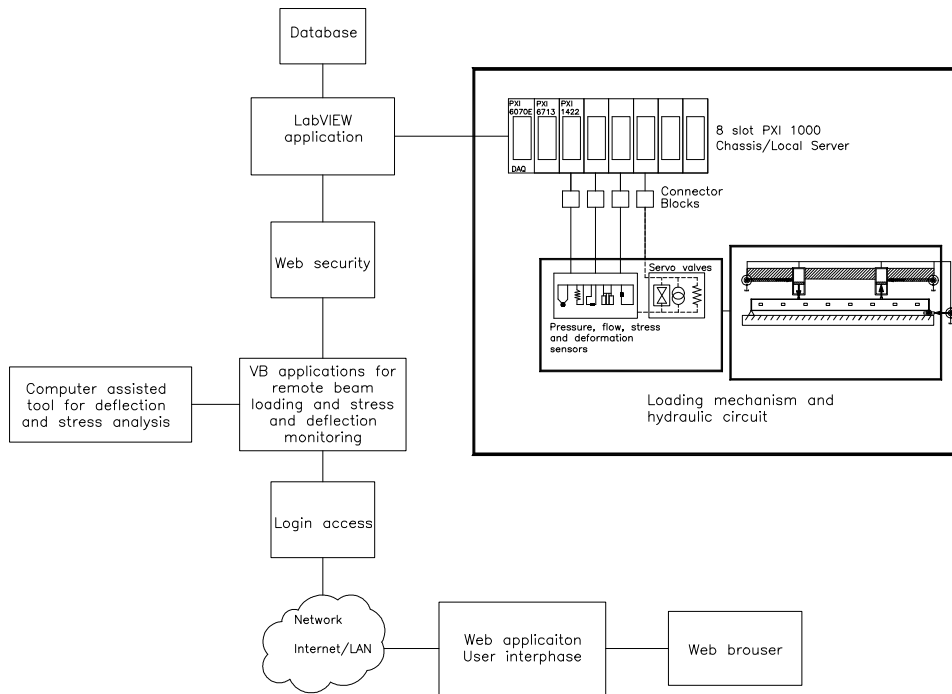


Figure 2. Configuration of online experimentation system

5. Implementation method

Appropriate data base architecture and web applications have been developed to integrate the use of a computer-aided analysis and online experimentation tool. After the initial login process, the user may choose the stress and deformation analysis or online experimentation. For the experimentation module, a second web security system is developed to prevent unauthorized break in from the internet and to limit access to the physical laboratory equipment to only one authorized user at a time. After gaining this access, the user goes through a step-by-step procedure for the initial system check and specifies the magnitudes and locations of the load. Based on the user input, signals are transmitted to the actuators of pressure and flow control valves through the NI data socket server reader and writer. Once the loads are applied, on board strain gages and deflection transducers send stress and deflection signals to the PXI data acquisition system. Using a LabVIEW application program, this data is displayed in both tabular and visual form and posted in the web through the LabVIEW web publishing tools. This experimental result is compared with the analytical result obtained earlier to verify the effectiveness of the theoretical analysis. The combined use of the analytical and experimental tools for specification of a problem, system setup and comparison of the results are shown in Figure 3.

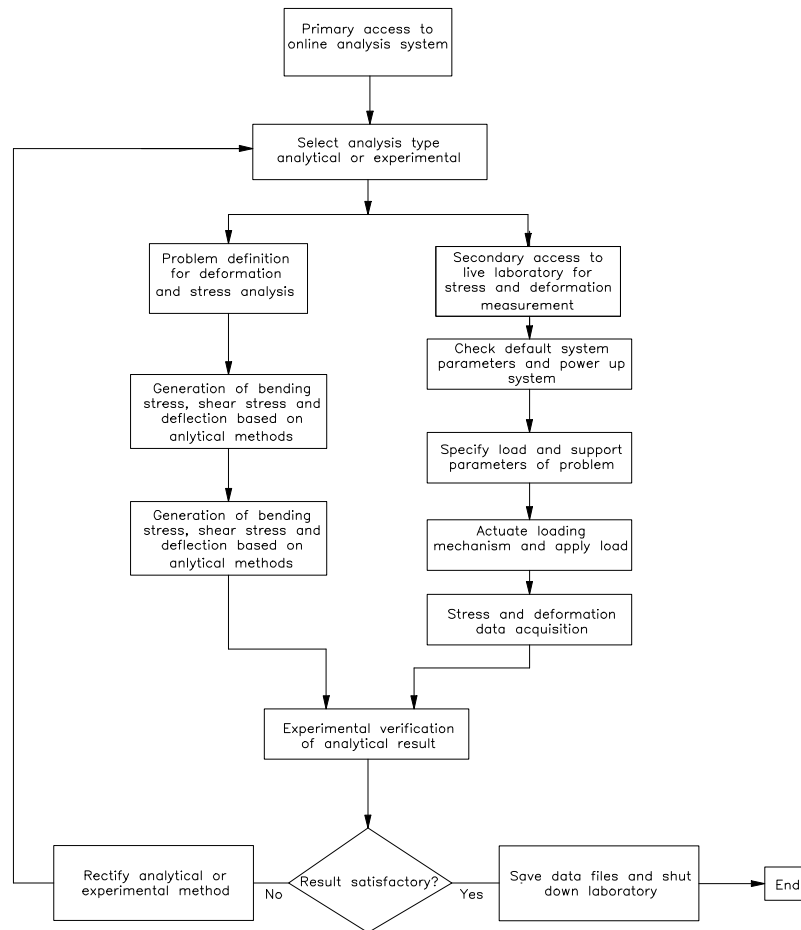


Figure 3. Online analysis methodology

Initially, the system will be used to demonstrate solutions of example problems already addressed in the lecture class. Later the system will be available to students enrolled in the class to solve other problems out side the class at their own schedule.

6. Conclusions

The stress and deformation analysis tool presented here leads students through a step-by-step learning process taught in the class and allows them to compare the theoretical solution with actual laboratory results. Combined use of the computer-aided solution and the laboratory experimentation will maximize the students' learning of the subject taught in a lecture class. The web based tool may also be used for distance education and for promotion of engineering education to potential future students.

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ALAMGIR CHOUDHURY

Alamgir A. Choudhury is an assistant professor of industrial and manufacturing engineering at Western Michigan University, Kalamazoo, Michigan. He earned his MS and PhD from NMSU and BS in mechanical engineering from BUET (Dhaka). His interest includes computer applications in curriculum, MCAE, instrumentation & control, fluid power and mechanics. He is also a Registered Professional Engineer in the State of Ohio and affiliated with **ASME**, **ASEE**, **SME** and **TAP**.

PAVEL IKONOMOV

Dr. Ikonov is an assistant professor in the Department of Industrial and Manufacturing Engineering at Western Michigan University. He received his Ph.D. in Mechanical Engineering from Hokkaido University, Japan; his M. Eng. from Muroran Institute of Technology, Muroran, Japan and M. Sc. from Technical University of Varna, Bulgaria. His research is in the field of Virtual Reality simulation, Nanotechnology, CAM, Tolerance modeling and inspection.

MITCHEL J. KEIL

Dr. Keil is an associate professor in the Industrial and Manufacturing Department at Western Michigan University. He received his Ph.D. from Virginia Polytechnic Institute (VPI&SU), his MS from Florida Atlantic University, and his BSME from VPI&SU. His areas of expertise are mechanisms, computer graphics, CAD/CAM/CAE, and vibrations. He is a registered professional engineer in the State of Florida. He has had industrial work experience at Litton Poly-Scientific, Motorola, and Bethlehem Steel Corp.

SAM RAMRATTAN

Sam Ramrattan is a professor of IME department at Western Michigan University. He has BS in manufacturing engineering, MS in management technology and PhD in industrial technology. His areas of research and publications are metal casting, plastic process, materials and manufacturing process improvement. He is a professionally active member of EIT, TAPI, SME, SPE, AFS and Key Professor of Foundry Education Foundation.

JORGE RODRIGUEZ

Jorge Rodriguez is an Associate Professor in the Department of Industrial and Manufacturing Engineering and a Research Associate of the Human Performance Institute at Western Michigan University. He received his Ph.D. in Mechanical Engineering from University of Wisconsin-Madison and his M.B.A. from Rutgers University in Piscataway, NJ. Dr. Rodriguez teaches courses in Computer-Aided Design and Manufacturing, Mechanical Design, Biomechanics and Finite Element Analysis. His research is in the field of computers in engineering, particularly in machine design, systems modeling, and biomechanics.

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