Paper ID #35748

The Development of a Hands-on Impact Testing Lab/Mini-Project in the Context of Machine Component Design

Dr. David C. Che, Indiana Wesleyan University

Dr. Che worked in the industry for over ten years, including eight years with General Motors in Michigan. He had taught at Geneva College in Pennsylvania, Anderson University in Indiana, Mount Vernon Nazarene University in Ohio, and Bryan College in Tennessee. He is currently Professor and Engineering Program Director at Indiana Wesleyan University in Marion, Indiana. His research interests include CAD/CAM/CAE, automotive engineering, manufacturing engineering, quality control, mechanical design, engineering mechanics and engineering education. He is a member of ASEE and ASME.

The Development of a Hands-on Impact Testing Lab/Mini-Project in the Context of Machine Component Design

David Che
Indiana Wesleyan University
david.che@indwes.edu

Abstract

Traditionally, engineering labs are conducted in such a way that students are given well-defined descriptions and/or procedures, which reduces a student’s role to mostly data collection and analysis. The new ABET student learning outcome “6” specifically calls for students to develop an *ability to develop and conduct appropriate experimentation*. A hands-on mini-lab/project activity was developed in the context of a Machine Component Design course to address this need. Students were given more freedom to come up with (aka *design*) and conduct an experiment that would verify the impact theory they just learned in class. Minimum directions and guidelines were given in the lab description, so that students could gain maximum exposure to experimental design. The lab/project is team-based. Students showed enthusiasm and reported with excitement what they've learned. Student teams presented their work in class and submitted a written report. Student learning outcome assessment results are shared.

Keywords: Bending impact testing; impact factor; design of experiment

Introduction

Inquiry-based learning emphasizing the method of discovery helps to develop the critical thinking skills necessary in learning the experimental process[1]. As it is eloquently said[2], “*One of the key elements in inquiry-based lab experimentation is to allow students to formulate their own lab experiments and exercise creative thought while developing their own ideas, applications, processes, and analysis techniques. A traditional lab setting often includes having the students follow step-by-step procedures as outlined in the lab manual. However, it is typically not the intention of the laboratory exercise to train the students to become lab technicians. Rather, the* *principal purpose in putting our students in the laboratory setting is to enhance and supplement their understanding of the concepts and principles being taught within the classroom."*

For engineering curriculum, impact analysis is typically first introduced in a physics or engineering dynamics course. More in-depth analysis and practical applications are typically covered in a mechanics of materials course for all engineering majors, and/or a machine component design course for mechanical engineering students. Impact testing labs normally involve the use of a *Charpy* or *Izod* testing equipment. These are costly to acquire; and the standard specimen required of these machines (square bars containing a V-, keyhole-, or U-shaped notch) are tedious to prepare[3, 4]. While these precise machinery/equipment and standard specimen are needed for standardized testing procedures as called for in ASTM standards[5], they are not ideal for facilitating student learning of impact theory.

Bending impact testing using a specially designed drop-weight system has been widely used for testing toughness and fracture strength of a variety of engineering materials[6, 7, 8]. However, limited use of this type of testing has been found in classroom teaching. Chris Carroll[9] reported using dropped weight impact test in a competition-based learning project in a Reinforced Concrete Design course. It was not clear from the paper whether the calculation of impact factors was involved in this activity. Some commercial dropped weight testing apparatus are available for testing plastics[10]. The procedures developed in this paper hopefully contribute to the project-based learning pedagogy in the area of impact testing, with an aim of bolstering student capability in designing and carrying out experiments on their own.

Inspiration and Background Knowledge

In spring of 2019, while teaching a machine component design course at Mount Vernon Nazarene University, a low-cost lab/project that encourages students to exercise their independent and critical thinking with regards to designing and performing an experiment was developed and implemented.

The idea originated from solving an example problem in the textbook[11]. Sample problem 7.3 states:

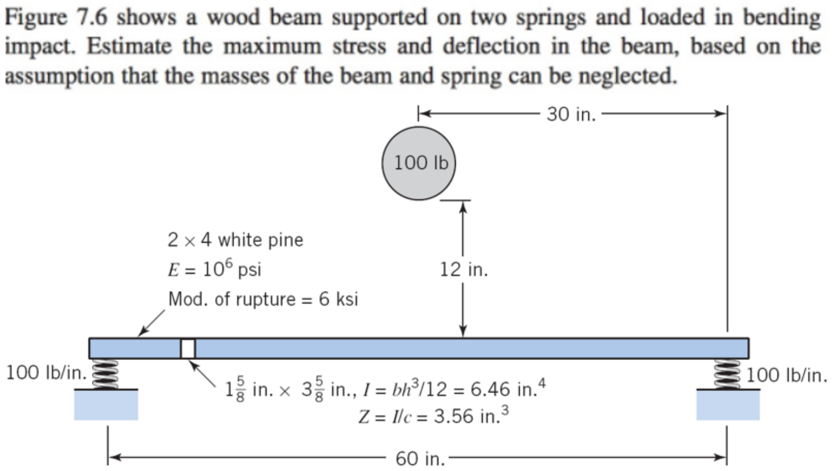


Figure 7.6 shows a wood beam supported on two springs and loaded in bending impact. Estimate the maximum stress and deflection in the beam, based on the assumption that the masses of the beam and spring can be neglected.

Figure 1 Drop Weight Bending Impact Test[11]

Students were asked to design their own experiments to verify the impact theory they just learned from the chapter. Here is a short summary of the impact theory. Fig. 2 shows an idealized version of a freely falling mass impacting a structure[11]. The structure is represented by a spring as all structures have some elasticity. Figure 2(a) shows the initial position where weight W is held still at height h above the spring with a spring constant of k. Figure 2(b) shows position of the weight W at the instant of maximum deflection after impact load is applied by the falling weight.

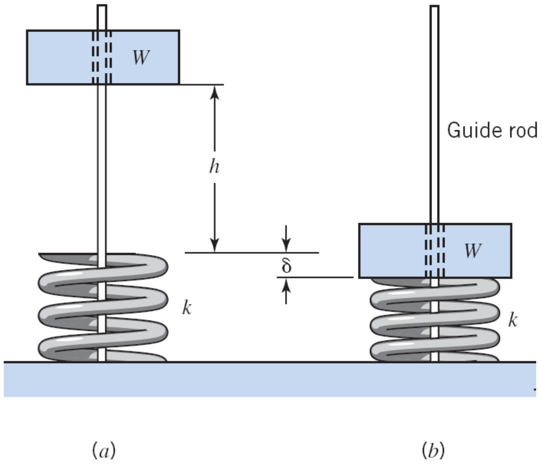


Figure 2 Idealized Representation of a Structure[11]

Equating the potential energy given up by the falling mass with the elastic energy absorbed by the spring (structure),

$$W(h+\delta)=\frac{1}{2}F_e\delta$$

Eq. (1)

where

$$F_e = k\delta \qquad \text{and} \qquad k = \frac{W}{\delta_{st}}$$

Eq. (2)

We then have

$$F_e = \frac{\delta}{\delta_{st}}W \quad or \quad \frac{\delta}{\delta_{st}} = \frac{F_e}{W}$$

Eq. (3)

Substituting Eq. (2) and (3) into Eq. (1), we have

$$W(h+\delta) = \frac{1}{2}\frac{\delta^2}{\delta_{st}}W$$

Eq. (4)

Solving the quadratic equation (4) above we have

$$\delta = \delta_{st}\left(1+\sqrt{1+\frac{2h}{\delta_{st}}}\right)$$

Eq. (5)

or

$$F_e = W\left(1+\sqrt{1+\frac{2h}{\delta_{st}}}\right)$$

Eq. (6)

The multiplier in the bracket in Eq. (5) and (6) is called the *impact factor*. It is the factor by which the load, stress or deflection caused by the dynamically applied weight, exceeds those caused by a slow, static application of the same weight[11].

This equivalent load $\mathbf{F_e}$ can then be used as **P** in the three-point bending stress analysis in Figure 3 to figure out the maximum bending stress based on the maximum bending moment at the center:

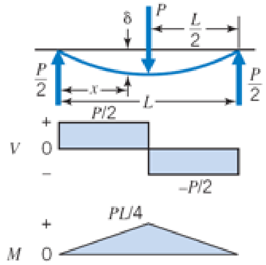


Figure 3 Shear and Bending Moment Diagram of a 3-point Bending Beam[11]

Design of Experiments

Students were asked to come up with an experimental set up similar to Figure 1. They need to choose a weight, a beam, and conduct several tests to figure out dropping at what height would the weight break the beam. At Mount Vernon Nazarene University, the engineering lab area has some stock wood pieces. Some students used plywood, some used regular wood, and some students went to a local art supply store and bought some balsa wood pieces. Figures 4 through 8 show the different experimental setups by the four student teams.

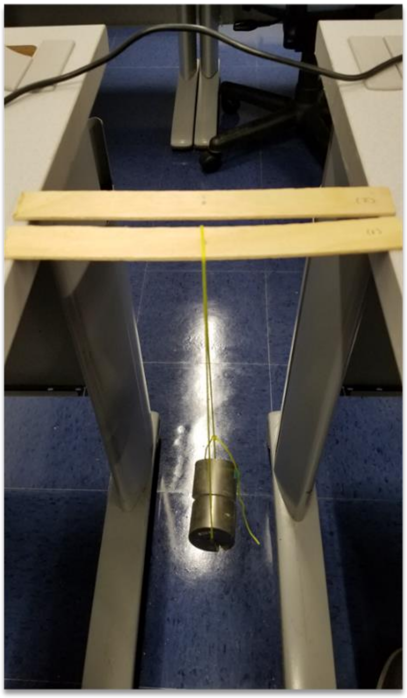


Figure 4 Static loads are being applied so that static deflection can be calculated

Figure 5 Dynamic loads being applied until failure

Figure 6 Loads applied to beam made of plywood

Figure 7 A second team used balsa wood

Figure 8 Measuring static deflection of a plywood beam

To relate material strength properties to impact factors, students need to apply the knowledge they learned in a prerequisite course – mechanics of materials. This is a standard three-point bending test. As a first step, students need to load some static weights on the center of the beam and measure the deflection using a ruler or tape measure. Using the standard deflection formula of

$$\delta_{st} = \frac{PL^3}{48EI} \qquad \text{Eq. (7)}$$

Young's Modulus **E** can be calculated. This **E** value is compared to handbook data for similar materials to see correlation. Balsa wood samples had good correlation with handbook data.

The flexure formula will be used in calculating the bending stress:

$$\sigma = \frac{M}{Z} = \frac{F_e L}{4Z} \qquad \text{Eq. (8)}$$

where **Z** is section modulus. Eq. (8) provides a basis for predicting failure in the wooden beams. Again, Balsa wood samples correlated well with handbook data on ultimate strength. Students also found that plywood beams are much harder to break and have poor correlation with handbook data. Some of the poor correlation could be caused by the bouncing of the wood pieces as they are not clamped down.

For the lab, various weights were provided to students, together with other tools such as tape measures, caliper gages, etc. This is a group project – students formed two to three-person teams. They were encouraged to take pictures and record videos and use them in reports and presentations. A group project report and a group presentation were required. The project report should include an introduction section (defining the objective of this activity), materials list, procedures which include steps taken, detailed documentation of equations used, detailed measurements of dimensions, etc. It should also include a section on results/conclusions and error analysis. How close were your experiment results match with the theory? What are probable causes of error or poor correlation? Students were also instructed to analytically predict the drop height that would break the beam before proceeding to the actual tests as only limited number of wood pieces were available. Some of the student groups obtained results that showed 10%-20% error. Even with this large error, students reported positive learning experience.

Outcome Assessment

EGR-3093 (Machine Component Design) can be taken either in students' junior year or the senior year. It is offered in the Spring semester every year and the only prerequisite is Mechanics of Materials which is typically taken by students in their fall semester of junior year. This is a required course for all students in the mechanical engineering concentration of the BSE program at Mount Vernon Nazarene University. The number of students who took this class was 15 (four are seniors and 11 are juniors, all MEs) in spring of 2019.

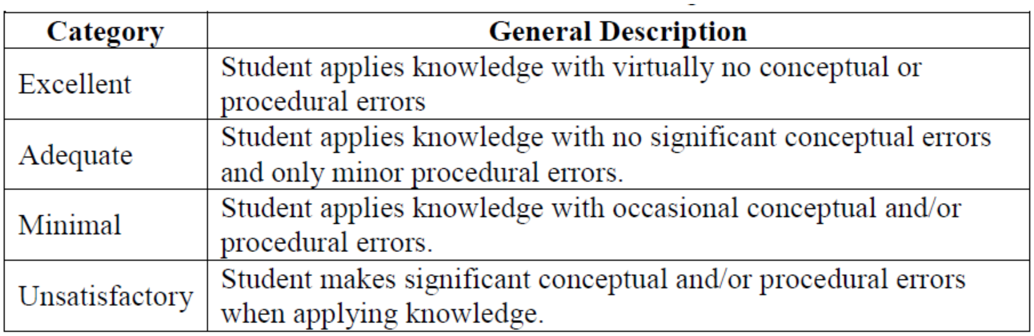
A mini-lab on the topic of impact analysis was introduced for the first time in this course in spring of 2019. Student feedback was positive. It provided a hands-on approach to the study of dynamic impact analysis, which has been a traditionally very theoretical study. The table below shows the relevant course learning outcomes and where they are assessed in the course.

Table 1 Faculty's Direct Assessment results on applicable (1-7) ABET Student Outcomes for this assessment period (on a scale of 1 to 4)

Student Outcomes per ABET	**Key Assignments**	**E**	**A**	**M**	**U**	**Average Score**
6. An ability to design and conduct an experiment	Impact mini-lab team presentations and reports	5	10	0	0	3.33
3. An ability to communicate effectively.	Impact mini-lab team presentations and reports	5	4	6	0	2.93

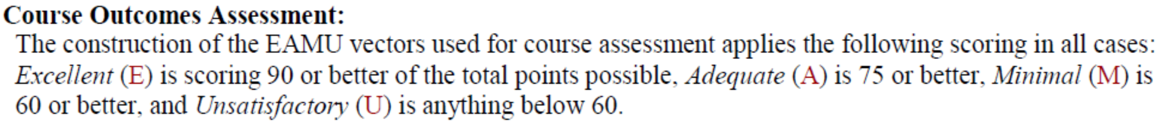
Since the outcomes achievement benchmark has been established at 2.67, as a minimum, any outcome with results below the benchmark will be given special attention/consideration for improvement action. Others will be considered as well, for sustainment and/or improvement, as time and resources allow.

Here is a sample rubric[12]:



Category	General Description
Excellent	Student applies knowledge with virtually no conceptual or procedural errors
Adequate	Student applies knowledge with no significant conceptual errors and only minor procedural errors.
Minimal	Student applies knowledge with occasional conceptual and/or procedural errors.
Unsatisfactory	Student makes significant conceptual and/or procedural errors when applying knowledge.

E=4; A=3; M=2; U=1



Course Outcomes Assessment:

The construction of the EAMU vectors used for course assessment applies the following scoring in all cases: *Excellent* (E) is scoring 90 or better of the total points possible, *Adequate* (A) is 75 or better, *Minimal* (M) is 60 or better, and *Unsatisfactory* (U) is anything below 60.

The following are some student feedback from the End of Course Survey:

- *Overall the class was very difficult but I enjoyed the first lab where we studied impact. It was also nice how we were able to do this with a partner.*
- *I liked the mini projects*
- *I liked learning about many of the subjects in engineering that are derived experimentally and that are very specific.*
- *The group lab was helpful.*

ABET Student Outcome “6” assessment – ability to design and conduct experiments:

This is a new outcome that was added to the assessment for this course this semester. This was done because the instructor for the first time implemented a mini lab on the topic of impact. This new project seems to have generated some excitement – the students showed great enthusiasm in the project and reported with excitement that they learned a lot from the hands-on lab and the subsequent calculations. The EAMU assessment vector gives an average score of 3.33 which is indicative of the outcome of this lab. All student teams were asked to present their work and submit a written report. This supported the assessment of outcome “3” (communication skills) as well.

ABET Student Outcome “3” assessment – effective communication:

The EMAU vector was constructed from student performance in the mini impact lab project presentations and written reports. Average score of 2.93 is above the threshold of 2.67 and satisfactory.

Acknowledgements

The author wishes to thank his former students at Mount Vernon Nazarene University for their contribution to the success of this lab in Spring of 2019 in the Machine Component Design course. Some of the lab setups as shown in the pictures in this paper were completed by Dustin Shenberger, Rodrigo Barauna, Yanni Patten, Connor Whitaker, Jeremy Grimm, Austin Miller, David Delahunty, Jevon Knox, Alex Short, Jake Sharpes, Dustin Troxell, and Alex Stefanuik.

Bibliography

1. *Civil Engineering Body of Knowledge for the 21st Century*, *Preparing the Civil Engineer for the Future,* Second Edition. American Society of Civil Engineers, Reston, Virginia, 2008
2. *Bringing Creativity into the Lab Environment*, Clifton B. Farnsworth, Ronald W. Welch, Michael J McGinnis, Geoff Wright, Annual American Society for Engineering Education (ASEE) conference, Atlanta, GA, 2013
3. *DeGarmo's Materials and Processes in Manufacturing,* J T. Black and Ronald A. Kohser, 10th edition, John Wiley & Sons, Inc., pages 42-43.
4. *Undergraduate Materials Research: Tensile Impact Toughness of Polymers,* Mir Atiqullah, ASEE 2008 Annual Conference
5. *ASTM D256 - Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics, https://www.document-center.com/standards/show/ASTM-D256*
6. *Experimental Study of Impact on Composite Plates with Fluid-Structure Interaction*, Kwon, Young Wook, Angela C. Owens, A. S. Kwon and Jarema M. Didoszak, *The International Journal of Multiphysics* 4 (2010): 259-271.
7. *Impact Bending Strength as a Function of Selected Factors: 2-layered Materials from Densified Lamellas*, Milan Gaff, Daniel Ruman, Tomas Svoboda, Adam Sikora, et al, BioResources.com 12(4), pages 7311-7324, 2017.
8. 7-*Subsystem Testing of Solder Joints Against Drop Impact*, E.-H. Wong and Y.-W. Mai, *Robust Design of Microelectronics Assemblies Against Mechanical Shock, Temperature and Moisture, Woodhead Publishing Series in Electronics and Optical Materials*, 2015, pages 221-260.
9. *Competition Based Learning in the Classroom*, Chris Carroll, 120th ASEE Annual Conference, Atlanta, June 23-26, 2013
10. https://www.zwickroell.com/products/products-for-impact-testing/drop-weight-testers-for-tests-on-plastics

11. *Fundamentals of Machine Component Design*, R.C. Juvinall and K.M. Marshek, 4th edition, John Wiley and Sons, 2006.
12. *Improving Upon Best Practices: FCAR 2.0*, John K. Estell, John-David S. Yoder, Briana B. Morrison, Fong K. Mak, ASEE Annual Conference, San Antonio, Texas, 2012 https://peer.asee.org/improving-upon-best-practices-fcar-2-0.pdf