Undergraduate Student Research in Blast Simulation of Wide Flange Steel Columns

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Abstract

It is generally a challenging task for undergraduate students to deliver meaningful results out of any independent research course within a time frame of one or two semesters. This is due to lack of knowledge, time management, and new learning experience, which is different from traditional lecture style courses. A new research project was proposed at Manhattan College to analyze and study behavior of steel structures subjected to close-range detonations. The study was motivated by the reality that many steel structures are exposed to public spaces and the protection of these structures against close-range blast effects is a major concern to engineers and facility owners, while no building code requirements or procedures are present at the moment. The blast analysis involves both highly non-linear finite element analysis based on solid mechanics and computational fluid dynamics. The theoretical backgrounds of the analysis are mathematically intense and require knowledges from several graduate level courses.

To engage undergraduate students in a highly technical and theoretical research project, a new pedagogy is needed; a guided learning component shall be more utilized than an independent learning component in the undergraduate research. In this work, discussions are provided about how a one-semester undergraduate-level independent study course at Manhattan College was used to successfully perform the research; and how undergraduate students were able to learn the fundamentals of highly technical theories to run finite element software and to perform various parametric studies of numerical simulations within a relatively short time period. Careful planning and multiple steps taken for this research course before, during, and after the semester are discussed. Some technical findings by students in collaboration with the instructors are included. This research course provided a new learning experience to undergraduate students, and opportunities for instructors to expand the research with the aid of the students.

Keywords

Undergraduate research, blast simulation, finite element, steel columns, parametric study

1. Introduction

In a typical private college, focusing on undergraduate education, full-time faculties are often tied up with teaching numerous courses during each academic semester. The college may offer masters' program through night classes for professionals who have full time jobs during daytime. Faculties in such colleges would have challenges to find full time research students to work on research projects. Undergraduate students are sometimes available for research, but they can participate on a part-time basis only due to their own curriculum. Even if faculties are fortunate enough to find qualified undergraduate students for research, undergraduate education is often not enough for students to understand or to digest research topics in competitive research fields. After spending many hours in educating undergraduate students for research, discontinuity of the research due to graduation or finding other jobs is another challenge to encounter by whom wish to produce significant outcomes in research. Undergraduate research is even more challenging due to lack of research funds, because faculties in such an environment may not necessarily have competitive records of past research accomplishments. To overcome all these challenges, creative strategies are needed for faculties, who wish to make most use of available resources and to result in any meaningful research outcomes. In this study, detailed planning and strategies are discussed for successful undergraduate research, followed by demonstration of some technical outcomes of the research.

2. Methodology

After September 11, blast effects caused by possible terrorist attacks have been considered increasingly in structural designs. Certain attempts to attack major transportation and government infrastructures have been discovered or prevented, but some others caused catastrophic results, leaving significant fatalities, damages and interruptions to the facilities [7].

Most available engineering approaches for blast resistant design were developed originally for military facilities, where a certain stand-off distance can be maintained [4]. However, such a distance is not practical in major cities. Instead, critical structural members of infrastructures are exposed to public without any protection. Currently, there are no building code requirements or procedures available for the protection of exposed structural members. Thus, it is an urgent matter to mitigate the risks in urban structures subjected to blast loading with a close-range detonation.

This research is to develop a novel simplified approach for use by general structural engineers to design protection of steel structures exposed to public. A series of numerical analyses were performed to suggest the approaches. The analysis is a detailed nonlinear explicit dynamic analysis for investigation of high-intensity and short-duration blast effects on structures using a fully coupled interaction technique between computational fluid and structural dynamics.

To engage undergraduate students in the research, the main strategies to overcome the challenges discussed in Section 1 are composed of the following steps:

- Summer research by faculty
- Undergraduate research course for credit
- Hiring undergraduate students for research
- Presenting and publishing research outcomes

2.1 Summer Research by Faculty

Summer break is typically the best time to make most significant progress in research. There is no interruption by teaching assignments, but continuous and significant amount of time to focus on research. During this time, the computer software, Ansys/Autodyn [2,3], was used to perform numerical simulations for blast analysis on steel columns. Several tutorials on similar explicit simulations, provided by the software company, were carefully selected so that undergraduate students could learn how to build the models needed for the research. Literatures by other researchers were also reviewed to look for any testing data to verify numerical simulations in this study. Material properties were investigated to account for strain rate effect as well as temperature changes during detonation [5,6]. Throughout the initial runs of numerical parametric studies, technical challenges and practical solutions were sought. Tasks that can be performed by undergraduate students were identified. Parametric studies were progressed nearly up to the final research goal, but relatively coarse finite element mesh sizes were used in the computer models to speed up the analysis. This is to predict as many obstacles as possible prior to students' research. Mesh refinements were made during the students' research in the following semester. During this time, communications with prospective students who were planned to take over the summer research were arranged so that the students could register and get ready to begin the research as soon as the fall semester began. Also the research course was designed and scheduled carefully, so that the students can follow and make progress during the subsequent semester.

2.2 Undergraduate Research Course for Credit

Manhattan College offers an independent research course (CIVL415 *Civil Engineering Projects*) for credits for undergraduate seniors in the Civil and Environmental Engineering department. Through this course, students experience completely different type of coursework from traditional lecture style classes. Rather than learning wide but shallow knowledges in a well-structured and fixed format, as is the case of traditional lectures, they learn very narrow but deep knowledges in amorphous and unestablished formats. Also the students have opportunities to closely interact with individual faculty members and to forecast if they are suitable for graduate research or academia for their future.

Typical research in a college is composed of a guided learning component as well as an independent learning component. Each component has its own educational benefit. However, in this research course, a guided learning component was more emphasized so that students could avoid losing orientations, or major obstacles during the research. Twice weekly meetings were scheduled similar to traditional lectures, detailed schedules were given to follow throughout the entire semester. Syllabus with clear research goals were identified and given to students. In the beginning of the semester, theoretical overview was given at the students' viewpoint so that they could understand the background of how the computer software runs. Only closely related topics to the research were discussed during this time. In the first couple of weeks, students began to learn the graphic user interface of the software. Simultaneously, students mimicked the tutorials selected earlier by the faculty advisor. Students learned what parts or procedures of the tutorials must be added or subtracted to build the model meeting the research goal. Once practiced, students began to write their own tutorial to build the pilot model. This was for students to use their own tutorial, when they forget certain steps or they diagnose their own models. The faculty gave clear directions to students about what range of each parameter should be varied, based on the faculty's own experience during the summer research. Students' outputs from parametric studies were reviewed by the faculty and compared to the faculty's own model. Once the faculty gained confidence in students' models, the students were asked to extend parameters beyond what were tested by the faculty. Through this process, the faculty was able to maintain quality control. From time to time, the students were asked to write an intermediate report for a parametric study, with an expectation that a comprehensive final report shall be put together at the end of the semester. The faculty reviewed the students' intermediate reports so that comments at the final report could be minimized. Students' tutorials, intermediate reports, and final reports were the grading basis for the research course.

Through this research course which emphasized the guided learning components, the students lost opportunities to learn how to overcome unexpected issues during research. However, they experienced a complete cycle of a research project from theoretical reviews, to parametric studies, to writing a research report, within a relatively short time period. Simultaneously, the faculty was able to expand the research beyond what he had accomplished during the previous summer with more refined models during a busy academic semester.

In Manhattan College during fall 2015 semester, two undergraduate students participated in the independent research course. After successful completion of the research, another undergraduate student participated in the same course in fall 2016. In 2016, parameters were changed to expand the research beyond what the two former students accomplished.

2.3 Hiring Undergraduate Students for Research

Right after the fall 2016 semester, the undergraduate student, who performed the blast analysis research for credit in fall 2016, was hired to continue the research in spring 2017 semester. The student did not need to spend extra time to learn the software or the basic theories for the analysis. The research goal remained unchanged, but more analysis has been performed to explore various parameters that were not explored in the past. It is an ideal combination to train a student through the research course for credit, and to hire the student to continue the same research for an efficient use of the research funds.

2.4 Presenting and Publishing Research Outcomes

Two students participated in the independent research course in fall 2015 semester and the faculty advisor put together a conference presentation abstract for presentation in Engineering Mechanics Institute (EMI) conference in May 2016 at Vanderbilt University, Nashville, TN. The students also participated in the student poster competition during the same conference. Their conference participation should have been beneficial to the students to expand their academic experience limited within a college.

3. Course Survey

Student surveys were performed to evaluate the teaching outcomes and student performance. The three students, who took CIVL415 course, were asked to fill out a survey with the following eight questions. It was intended to evaluate what the student knew or how much the student had done was changed, before and after taking the course.

- Understanding overall research process
- Attempting to find solutions when obstacles are encountered in difficult problems similar to CIVL415
- Learning and using complex numerical simulation software
- Learning how to put together complicated analysis results in simple graphs or charts
- Learning new knowledge independently
- Writing research reports
- Reading and understanding difficult research literature and articles beyond your knowledge
- Having interests in research and graduate studies

The survey was formulated to consider a scale of 0 through 4: 0-Nothing, 1-Little, 2-Satisfactory, 3-Fair amount, and 4 Substantial amount: the more the score, the more the research skill. The survey results from three student self-evaluations were consistent. The average scale before taking CIVL415 course was 1.9, but it was increased to 3.3 after taking the course. This is a rather small statistical sample to make any definitive conclusions but it motivates further study and shows an overall improvement of students' research skills after taking the research course.

4. Demonstration of Technical Outcomes

4.1 Problem Description and Finite Element Analysis

In the AISC Steel Manual [1], out of the most popular steel columns used for building constructions, W14 sections were chosen for the research. The W14 sections are wide-flange shaped steel members with a nominal depth of fourteen inches. To model the steel member, Lagrangian meshes were used for a solid mechanics analysis. To model air domain around the column, Eulerian meshes were used for computational fluid dynamic analysis. See Figure 1 for an overall model view.

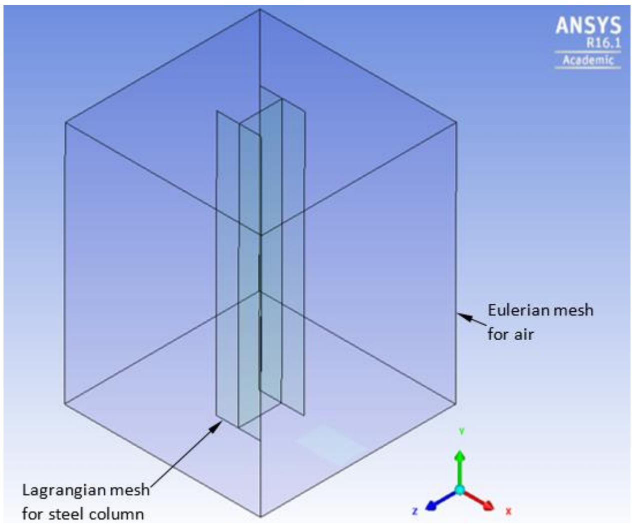

Figure 1. Overall Model Geometry for Blast Analysis of a Steel Member

The two meshes were solved independently via corresponding solvers, and simultaneously they interacted each other through complete coupling. During the coupling, Eulerian meshes applied pressure from detonation to the Lagrangian meshes to deform the steel member, while the Lagrangian meshes blocked flows from the Eulerian meshes. To simulate a standard column in a typical building, fixed boundary conditions were added at the bottom, while roller boundary conditions were applied at the top of the column. Column length is set to approximately eight feet to simulate a typical room height. TNT was assumed to be detonated at the base of the column.

4.2 Parametric Study

There are numerous parameters that affect the sensitivity of the analysis. It is very important to identify which parameters affect the analysis most in building a successful model. One of the important parameters is the erosion strain. Erosion strain is not a mathematical formulation in the theory of explicit dynamic analysis. However, in order to demonstrate actual fracture of a steel member beyond the percent elongation, and to avoid numerical problems for highly distorted elements during blast analysis, erosion was considered in the analysis. Once any element strain reaches a set value of the erosion strain, the element will be removed from the analysis. For further details, see Autodyn User's and Theory Manuals [2, 3]. For five possible erosion strain values, a series of blast analyses were performed, of which overall deformed shapes are presented in Figure 2.

In addition to the qualitative comparison of the deformed shapes, the out-of-plane displacements of the flanges adjacent to the detonation center for various erosion strain values are shown in Figure 3 for a quantitative comparison. As a result of this sensitivity analysis, the research team was able to conclude that the erosion strain did not affect the analysis large enough to change the damage level to the steel member.

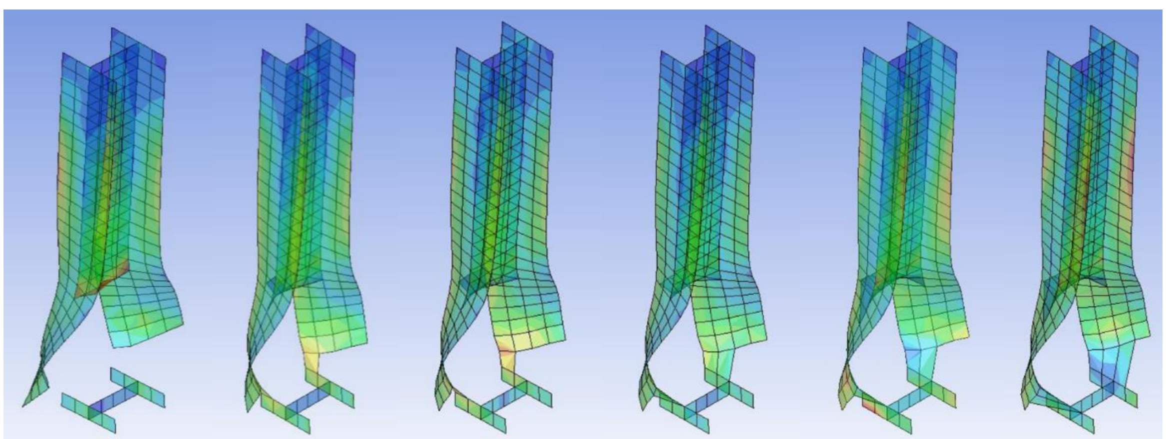

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Figure 2: Overall deformed shapes of steel member models with various erosion strains.

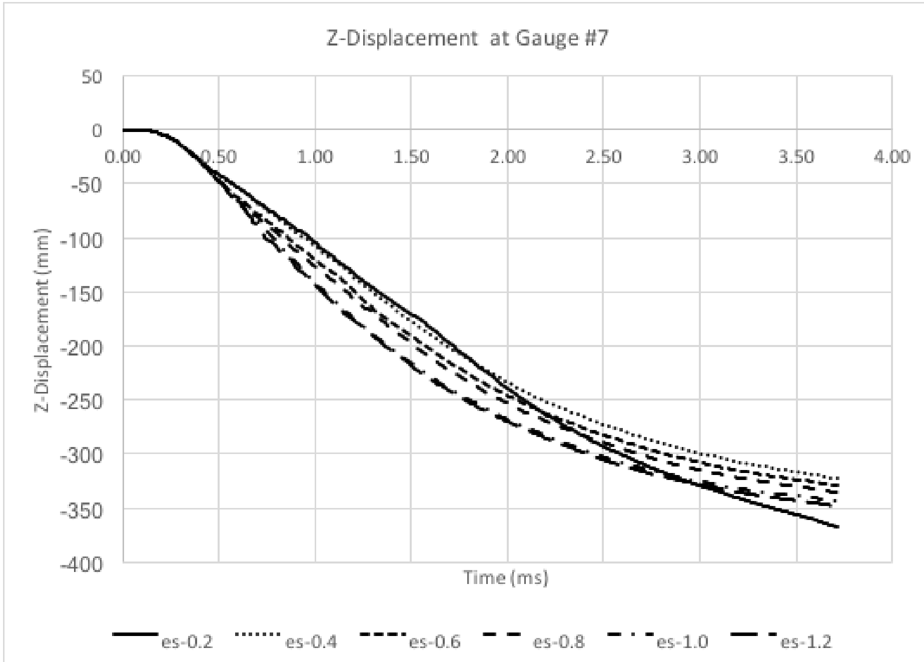

Figure 3: Out-of-plane displacements of flanges from various erosion strain models.

5. Conclusion

It is a daunting task for a faculty member in a private college with an emphasis on undergraduate education to make progress in research due to demanding circumstances. This paper presents a potential method to overcome typical challenges in use of undergraduate research. For the specific research project, careful research planning during summer was exemplified in details. In the subsequent fall semester, it was discussed how the independent research course was used to train undergraduate students to produce meaningful research outcomes. As an option, the undergraduate research student could be hired to produce further in the subsequent spring semester. Research outcomes were either already presented in an international conference or more presentations will be made in this coming year with the expectation to be published as a peer reviewed journal paper.

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