A case for the inclusion of structural dynamics in undergraduate structural engineering programs

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Abstract

Undergraduate structural engineering programs at their core are generally limited to studying the linear elastic behavior of structural systems under static loads. This knowledge is essential, giving students a fundamental understanding of the field of structural engineering. However, to obtain a holistic and complete picture of the field, it is necessary that students are exposed to the inelastic behavior of structural systems under dynamic loads. This is even more relevant in small, rural, teaching-focused satellite campuses of major schools that have a significant population of lower income, first-generation students who do not intend to pursue graduate degrees, possibly due to financial reasons or due to a lack of exposure to the possibility of doing so. In this light, this paper presents a case for the inclusion of two basic structural dynamics courses as electives in an undergraduate structural engineering program. They have been recently included as novel and unique additions to the undergraduate program at Purdue University Northwest. The paper also describes the theoretical content of these courses, along with a description of a creative "project" component that requires students to apply their theoretical principles to a problem in the area of earthquake resistant design, using a state-of-the-art software. The course offers students an excellent opportunity to go beyond the minimum amount needed at the undergraduate level, thereby giving them an edge in a competitive employment market. It provides students with a passion for structural engineering an opportunity to advance their knowledge in this area, without having to incur the financial and time related costs of a master's degree. It also helps teaching-focused schools offer a unique program that differentiates itself from standard programs, helping them to stay competitive in a market with abundant educational choice. Finally, teaching more advanced material helps to motivate and challenge faculty in teaching-focused schools.

Keywords

Structural, Dynamics, Earthquake, Engineering, Education

Introduction

The goal of this paper is to present a case for introducing two nontraditional elective courses into an undergraduate civil engineering curriculum: 1) The fundamentals of structural dynamics (referred to as Structural Dynamics 1 in this paper), and 2) Applications of structural dynamics in earthquake engineering (referred to as Structural Dynamics 2 in this paper). These courses are offered in the 7th and 8th semesters during the senior year of the civil engineering degree program at the author's institution. They are very beneficial courses that expose civil engineering students that are interested in specializing in structural engineering, to more advanced applications of structural engineering principles (in the field of earthquake engineering). These courses assist students in obtaining a more complete picture and a broader perspective of the area of structural engineering, by going above and beyond the content covered in the relatively basic courses prior to it. They were introduced into the structural engineering program in the department of civil engineering at the author's institution in 2014. At the time, the civil engineering program was a new program and faculty were given the autonomy to think creatively and develop a unique curriculum. This paper: a) explains the motivation for including Structural Dynamics 1 and 2 as electives in the undergraduate civil (structural) engineering curriculum, b) presents a brief description of the existing content of these courses and their objectives, c) discusses the significant benefits accrued by the students, the professors, and the department of civil engineering at the university by including these courses in the plan of study, and d) provides an overview of a unique feature of Structural Dynamics 2 (the "project" component of the course) by discussing the motivation for including this component into the course, and the structure of the "project".

Background Information and Significance of this Paper

The undergraduate structural engineering curricula of a sample of 18 schools in the states of Michigan[1-16], Indiana[17-23], and Illinois[24-32] were investigated to obtain information regarding their treatment of structural dynamics and earthquake engineering. Some of them did not offer these courses at all, while some offered them as graduate courses available to undergraduates as electives. University of Detroit Mercy has a graduate program that offers earthquake engineering[4], but not structural dynamics. Additionally, it does not encourage its undergraduates to opt for this as an elective, since it is not mentioned in its list of technical electives for undergraduates[3]. Lawrence Technological University offers structural dynamics, but not earthquake engineering at the graduate level[6]. This course is available to undergraduates as a technical elective[5]. Michigan Tech offers both these courses at the graduate level[9,10] and they are available to undergraduates as electives if they have a GPA greater than 3.0[8]. The University of Michigan at Ann Arbor offers structural dynamics and its application to earthquake engineering as one course[11], offered at the graduate level and can also be taken by undergraduates as an elective[12]. Wayne State University offers structural dynamics at the graduate level[14], which undergraduates can opt for as an elective[13]. However, it does not offer earthquake engineering. The Rose-Hulman Institute of Technology offers structural dynamics and earthquake engineering combined into one course, at the graduate level, and is also available to undergraduates[20,21]. Purdue University at West Lafayette offers both structural dynamics and earthquake engineering as graduate level courses[22], which undergraduates can opt for as electives[23]. Southern Illinois University at Carbondale[17-18] offers a course at the undergraduate level on seismic design which is focused on seismology and on using building codes to design earthquake resistant structures. It does not discuss technical concepts in earthquake engineering such as the elastic and inelastic response spectrum, response spectrum analysis, etc. Graduate courses on structural dynamics and earthquake engineering are available. The course on structural dynamics focuses on single degree of freedom systems and does not cover multi degree of freedom systems. Bradley University offers both structural dynamics and seismic design as graduate courses available to undergraduates as electives. University of Illinois at Urbana-Champaign[21] offers both courses as graduate courses that can be completed by undergraduates as electives. The Illinois Institute of Technology offers both courses at the graduate level and they are available to undergraduates as electives.

Significance of the study

11 of the 18 schools in the sample offer either structural dynamics, or earthquake engineering, or both, as electives to undergraduates. In some cases, the courses are combined into one course, since they are offered at the graduate level. This paper presents a case to offer both these courses at the undergraduate level as two separate elective courses. Additionally, all the courses referenced in the background search focus on the theoretical principles of these subject areas. This paper presents a case to augment the sequence of courses on structural dynamics and earthquake engineering with an application-based project component. Finally, all the schools that offered these courses had an established graduate program that offered them. This paper presents a case for offering these courses as undergraduate electives for schools whose primary focus lies in providing students with a high-quality undergraduate education. Even though the Rose-Hulman Institute of Technology, whose mission is to provide their students with the “world's best undergraduate science, engineering, and mathematics education in an environment of individual attention and support”, offers the course material, it is combined into one course and is offered as a graduate level course available to undergraduates as an elective. Being a graduate level course, it is possible to combine the material into one course since students are more capable of absorbing material faster.

Motivation for including Structural Dynamics 1 and 2 in the Undergraduate Curriculum

Motivation for including structural dynamics and earthquake engineering into the undergraduate structural engineering curriculum: Structural Dynamics 1 and 2 were included in the undergraduate plan of study for the following reasons:

1) The author’s institution is one that is primarily focused on teaching. Consequently, in order for the institution’s structural engineering curriculum to be competitive on the market and to assert its uniqueness, it is essential that the curriculum offers more than just the standard course of study. Since structural dynamics and its applications to earthquake engineering are not generally covered in most undergraduate structural engineering programs, their inclusion into the program enabled the program to differentiate itself from other structural engineering programs. Additionally, being a teaching focused school, the professors are expected to focus more on teaching rather than the acquisition of research funds. Including Structural Dynamics 1 and 2 serves to challenge professors, by providing them with an opportunity to teach advanced courses.

2) These courses offer students an excellent opportunity to learn more, thereby giving them an edge in a competitive employment market. The feedback of employers at the college career fair was positive regarding the inclusion of these courses at the undergraduate level. Knowledge of structural dynamics opens up another category of jobs to students (for example, assessment of the performance and safety of nuclear reactors under blast loadings).

Earthquake engineering is an extremely significant component of structural engineering, and learning about serves to give students a holistic perspective of structural engineering. In addition to the standard linear static structural behavior taught at the undergraduate level, this course exposes students to the inelastic behavior of structural systems subjected to dynamic loads, providing students with a complete picture of the field by exposing them to the overall spectrum of structural behavior. The principles mastered in these courses can be applied to other fields that involve nonlinear dynamic systems as well. Additionally, pushing the students to venture out of their comfort zone by challenging them with more advanced material is very beneficial for their intellectual growth and development.

3) To provide students with an interest in earthquake engineering an opportunity to advance their knowledge in this area if it is one that they are interested in pursuing, without having to incur the financial and time related costs of a master's degree to do so. This benefit is even more pronounced in institutions such as those in which the author teaches, comprising students from relatively modest economic backgrounds. Their passion to learn is reflected by the fact that, in many cases, they are the first-generation college students.

Description of the Courses

Structural Dynamics 1: Structural Dynamics 1 is an introductory elective course in structural dynamics that is offered in the fall semester of senior year and gives students interested in majoring in structural engineering an opportunity to learn more about this field by teaching them the fundamental concepts of structural dynamics in the context of structural engineering.

The course starts by studying the general equation of motion of a single degree of freedom system subjected to a time-varying force. Here, basic concepts of a "single degree of freedom system"(SDOF), the components of the equations of motion of such a system (the stiffness component, the damping component, the inertia component) are introduced and their significance is explained, and the representation of an earthquake excitation as a ground motion displayed as ground acceleration versus time, are explained to the students.

This is followed by a study of the free vibration response of a single degree of freedom system. The free vibration response of both undamped, as well as viscously damped single degree of freedom systems is obtained. Subsequently, the elastic response of a single degree of freedom system to different external excitations is studied: a general periodic excitation, a harmonic excitation, a unit impulse, a step force, a ramp force, a rectangular pulse, a half-cycle sine pulse, and a triangular pulse.

At this stage, numerical methods that are commonly used to solve the equation of motion of a dynamic system are studied. Initially, the solution of the equation of motion for linear systems using common time-stepping methods such as methods based upon interpolation of the excitation, the central difference method, and Newmark's method for linear systems are studied. Following this, the concept of nonlinear structural response is introduced and the Newton-Raphson method of iteration for the analysis of a nonlinear single degree of freedom system is presented. Finally, the application of Newmark's method to linear systems is now extended to nonlinear systems.

The course concludes with a study of the earthquake response of both elastic and inelastic SDOF's. Important earthquake engineering related concepts such as modeling an earthquake excitation, the system equation of motion under the effect of an earthquake excitation, the response quantities that characterize the system's response, the "response history" concept, and the elastic and inelastic design response spectrum are studied thoroughly.

Structural Dynamics 2: Structural Dynamics 2 builds upon the content of Structural Dynamics 1, and is offered in the spring semester of the senior year. Structural Dynamics 2 exposes students to the application of the concepts taught in Structural Dynamics 1 to earthquake engineering. In this course, the principles of structural dynamics are studied in the context of multi degree of freedom (MDOF) systems. The free vibration of MDOF systems, damping in MDOF systems, modal analysis of linear MDOF systems, and the earthquake analysis of linear MDOF systems using the response history analysis method, and the response spectrum analysis approach are studied. Finally, building codes used for seismic design of structures are introduced.

The dynamic analysis and response of linear systems, and the earthquake analysis of linear systems, is done in a less theory-intensive manner and only the most significant areas are emphasized and covered. These topics, albeit significant in the context of earthquake engineering, are specialized and would be better addressed in detail in a more advanced course on structural dynamics. Since the purpose of this course is to provide the student with an introductory understanding of the principles of structural dynamics applied to the area of earthquake engineering, it is reasonable to truncate the theoretical component of this course by providing the students a general understanding of these topics.

Motivation for including the “project” component into Structural Dynamics 2:

1) Structural Dynamics 2 is focused on the theoretical aspects of the application of the basic principles of structural dynamics to the field of earthquake engineering. While these theoretical concepts are essential for an in-depth understanding of the subject, it would serve the students better to focus on a combination of theory and practice.

2) Most structural analysis and design in the industry is performed using software packages. It would benefit the students to be exposed to a structural engineering software package that is commonly used in the industry so as to complete the set of tools that they need (theoretical understanding, ability to solve problems by hand, and mastery of a state-of–the-art software tool) to perform confidently in their future roles as structural engineers. Since Structural Dynamics 2 is offered in the final semester, this is an opportune time to teach the students how to use a software package by means of having them develop a structural design with the assistance of a software tool. The solution to the structural design problem implements the application of a broad set of structural engineering principles that the students have studied over all the structural engineering courses in their program, culminating in earthquake engineering.

3) All the relevant theoretical concepts in Structural Dynamics 2 that need to be discussed in the classroom are covered by the time spring break is reached, which generally occurs in the middle of the semester. Also, from the author’s personal experience, the motivation and focus of the students in order to absorb new theoretical material recedes after spring break during the final year of their degree program. They are now aware that graduation is around the corner, and are in the process of preparing for the transition to the real world. This change, combined with the fact that they are actively involved in completing their senior design/capstone project, creates an application-oriented mindset among the students, making this an opportune time to introduce a structural engineering focused project component into the course.

This project 1) imparts not only a strong theoretical foundation of the application of structural dynamics principles to earthquake engineering problems, but also incorporates their application to develop an earthquake resistant design. This will crystallize the students' understanding of the theoretical principles and they can graduate with a clearer picture of the field of structural engineering, and 2) familiarizes students with a state-of-the-art structural analysis and design software package that is commonly used in the industry.

This project requires students to complete the earthquake resistant design of a standard medium – rise box building, using the appropriate design codes to compute the seismic loads on a building in an earthquake prone region of the US. The design codes are founded upon the earthquake engineering principles explained in the classroom in both Structural Dynamics 1 and 2. The code provisions recommend the implementation of the "Equivalent Static Load Method" to design an earthquake resistant building, which is extensively used in the industry. By absorbing the theoretical principles upon which this approach is based, and then understanding the steps involved in applying it, the students obtain a thorough understanding of this method. Additionally, it is an excellent way for them to see the real-world relevance of their classroom knowledge, helping them internalize this knowledge, and enabling them to filter out the most significant parts. A lot of the abstract theory in the earthquake engineering field can appear to be very daunting and complex, and completing an earthquake resistant building design using a concrete set of fairly easily applicable rules laid out by the building design codes gives them the clarity that they need to develop a sense of confidence in their understanding of the material.

The earthquake resistant building is designed using a state-of-the-art software package named "RISA 3D". It was selected after consulting with design engineers and heads of structural engineering departments in the industry, and senior structural engineering faculty members at universities. It was unanimously decided that RISA 3D is the ideal software package to use for the purpose of structural design and is an excellent tool for the students to know. It is extensively being used in the industry and will be growing even more popular in the future, according to the industry experts consulted. This exercise familiarizes the students with this tool, which will be of help to them in their future careers in the industry. Additionally, it gives them a foundation to learn how to use other software tools in the future.

Conclusions

Based upon the above discussion, it can be seen that Structural Dynamics 1 and 2 are beneficial components of a structural engineering curriculum, benefitting not only the students, but also the professors. A practical "project" component assists students in visualizing and understanding the complex theoretical content in these courses better. This can potentially make it easier to attract students to this course and retain them upon enrollment in the future. This is important, since these courses are crucial to obtaining a deeper understanding of the field of structural engineering. The project also exposes students to the use of a state-of-the-art structural analysis and design software tool that they will be using in the industry after they graduate. Since these courses were introduced into the curriculum very recently, it will be beneficial to track the enrollment and retention numbers in these courses over the next five years and obtain student feedback regarding the courses' contents. This will constitute the content of a follow-up study.

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