The Overlap Between
Mechanical and Civil Engineering Graduate Education

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Abstract

This paper is a follow up to a previous paper on the overlap between civil and mechanical engineering fields. A very brief introduction on the overlap among various engineering fields is given followed by a short description of the common areas between the two specific branches of civil and mechanical engineering. The significance of this topic to the engineering education is outlined. The overlap between these two specific branches of engineering is larger and more conspicuous at the graduate level than the undergraduate programs. The focus of this paper is on the common graduate courses between the two fields. It gives some details on these common graduate courses. This is illustrated by practical examples from both engineering fields. Some recommendations based on the authors' experiences and opinions are provided at the conclusion of this paper.

Introduction

Engineering is essentially the use of scientific and mathematical tools in real life applications.[1] Over the years, the profession of engineering has been bifurcating itself into different fields based on society's needs and technological advances, and on how engineers apply science to solve technical problems. For instance, environmental engineering has started historically within the field of civil engineering until the time when it received sufficient universal recognition that it has the right to be a stand alone branch of the engineering profession. Many institutes of higher education like the University of Cincinnati; Stanford, Duke and Rice universities for instance still combine civil and environmental engineering in one department while few others like the Technical University of Crete in Greece have them as separate departments.

New engineering fields have been emerging constantly. For instance, the Massachusetts Institute of Technology (MIT) recognized the high complexity of engineering systems and established a new separate systems engineering program at the end of the last century.[2] This new field is on the overlap between many engineering fields. More recently, the field of sports engineering has emerged as a viable field of engineering. Sports engineering is a part of mechanical engineering at some institutes like the University of Sheffield in England, while it is an outright branch by itself at other institutes like Queen Mary University of London. Nanoengineering has just emerged, and it promises to attract the attention of those students who are looking into engineering as their professional careers.[3]

Each engineering discipline however has its own characteristics that distinguish it from other engineering fields. Nonetheless, different engineering fields overlap with each other in many and interesting ways. Examples include the above two sets of engineering fields: civil and environmental engineering [4], and mechanical and sports engineering. Sometimes, the overlap involves more than two engineering fields. For instance, fluid mechanics is a common part of chemical, mechanical, and civil engineering fields. It is not uncommon to see fluid mechanics as a civil engineering course in some universities while other colleges offer it as a mechanical or chemical engineering course. This is merely an example of an array of areas and courses that can be part of various engineering disciplines.

ABET recognizes the interdisciplinary nature of the engineering profession. Criterion 3C specifically states that engineering students should be able to work in multi-discipline environments.[5]

Mechanical Civil Engineering General Overlap

Civil and mechanical engineering fields are the two largest branches of engineering in the US.[6] They are also large fields around the world. Both branches deal with various aspects of solids and fluids in their design applications. Thus, their overlap is in the two huge areas of fluid and solid mechanics. More specific details on the overlap between these two fields can be found elsewhere in the literature.[7] This overlap manifests itself at both undergraduate and graduate levels of education.

The common areas between civil and mechanical engineering at the undergraduate level were outlined in a previous paper by the authors.[7] That study was limited in scope to the undergraduate level and was not expanded to the graduate level.

By nature, a student undertakes a graduate education to focus on a specific area of his/her engineering field. That is, it is fair to expect that engineering graduate programs do not overlap much within each other. Contrary to this intuitive expectation however, civil and mechanical engineering graduate programs overlap with each other. In fact, the overlap between these two distinct engineering fields at the graduate level is even larger and more tangible than its undergraduate counterpart.

The Importance of Outlining the Mechanical and Civil Engineering for Educators

The importance and relevance of outlining the overlap between civil and mechanical engineering were previously established.[7] It is nonetheless beneficial to briefly restate this significance with some modifications again here.

First, generally speaking, an educator at the college level who teaches a common civil mechanical engineering course has only one background. This educator is usually familiar with the applications of such a course in his/her own field of engineering. An instructor with a civil engineering background uses civil engineering applications in his/her class. Such an educator might be aware of the applications of the common course in the mechanical engineering field, but his/her knowledge is superficial. This educator is nonetheless teaching students who belong to both engineering fields. Similarly, an instructor with a mechanical engineering education feels comfortable using and tends to use mechanical engineering examples in his/her class despite the fact that this class may consist of civil and mechanical engineering students.

Second, almost all common civil mechanical engineering courses contain parts that are only useful to one group but useless to the other group. Examples include the Nondestructive Testing course. Certain applications are suitable to mechanical engineering applications but are not appropriate in civil engineering applications. Other examples include open and close channel flows in advanced fluid mechanics courses. Civil engineers design, construct, and maintain open channel conduits while mechanical engineers deal with closed channel flow.

Many civil and mechanical undergraduate students opt to take graduate courses especially in their senior year. At some institutes of higher education, graduate courses are required in the engineering curricula. The arguments used to support this study for the undergraduate case can therefore be carried over to the graduate case.

Consequently, knowing and learning about the overlap between these two different engineering disciplines can add a new dimension to the engineering education process. Increasing the efficiency of the engineering education process is beneficial to our students.

Specific Mechanical Civil Engineering Graduate Overlap

As stated earlier, the common areas between civil and mechanical engineering encompasses the two areas of solid and fluid mechanics. At the undergraduate level, several common courses exist in both of these two areas. This was detailed in a different paper.[7] At the graduate level, almost all of the common courses are in the area of solid mechanics. Currently, based on the authors' knowledge and investigations, very little overlap exists in the fluid mechanics area at the graduate level. Both fields have their own outright courses when it comes to fluid mechanics. Perhaps, this is due to the fact that mechanical engineering deals exclusively with closed channel flow while open channel flow is the only concern for civil engineers. This may however change in the future if more applications using fluid mechanics concepts are created in both of these fields.

Common civil and mechanical engineering graduate courses include:

1. Advanced Mechanics of Solids
2. Elasticity
3. Plasticity
4. Fracture Mechanics
5. Advanced Dynamics
6. Plates and Shells
7. Non-Destructive Testing
8. Experimental Stress and Strain Analysis
9. Finite Element Methods
10. Numerical Engineering Analysis

The subject of mechanics of solids by virtue of its broad definition relates externally applied loads (all kinds of forces and moments) to internal stresses and strains.[8] Engineering students learn the basic concepts of this topic in the undergraduate level.[9] One and even two advanced graduate courses are needed to deeply understand the concepts of mechanics of solids.[10] Deep understanding is required to solve complex technical problems. That is, the framework of this course is the same for both undergraduate and graduate levels. Graduate courses however have an extended scope as they use more advanced techniques to solve more complicated engineering problems. Examples from the fields of civil and mechanical engineering are as follows.

In civil engineering applications, most bridges use straight beams. Concepts from the undergraduate strength of materials course along with senior design courses are sufficient to handle such straight bridge stringers. These concepts are not enough however to deal with the more complex kind of curved beams appearing in many large transportation projects. Concepts from advanced mechanics of solids courses are needed to calculate and analyze circumferential and radial stresses and their associated strains.[10] On the other side, mechanical engineering applications include the design of vessels under internal pressure. Mechanical engineers learn how to deal with thin cylinders in their undergraduate strength of material course.[9] In the graduate course of advanced mechanics of solids, mechanical engineering students understand how to deal with the more complicated and challenging case of thick vessels.[10] They also learn how to use materials more efficiently and how to determine the effect of holes on stresses in spinning disks.[10]

Elasticity is a branch of engineering mechanics.[11] The theory of elasticity started more than 350 years ago when Hooke established a theory stating that a force is linearly related to the elongation it causes. His famous law of $F=kx$ is still being used nowadays in a very wide variety of applications. Since then, many advances have made elasticity a big field of study. Currently, the theory of elasticity is a graduate course offered to both civil and mechanical graduate engineering students.[12] It is also suitable for aerospace engineering.[11] This course simply deals with stress and strain, but in very advanced and complex ways. Examples from civil and mechanical engineering are as follows.

Often, civil engineers have to drill or accept the presence of undesirable holes in structural steel elements. Examples include holes to allow ventilation ducts in buildings and drainage pipes in bridges. Stresses due to these holes have to be calculated using elasticity techniques like the technique introduced by Kirsch in Germany back in 1898 using Airy stress function ϕ and its associated three partial differential equations in two variables.[10] Mechanical engineers use the torsion theory within this course to calculate shearing stresses and angles of twist for rotating shafts with a general cross sectional area including irregular and unsymmetrical cases.

It is interesting to note that even biomedical engineering students take this course at several institutes like Duke University. Elasticity theories can be employed to study the behavior of bones and other structural body components.

Not all engineering materials are elastic. Further, many elastic materials change their behavior from elastic to plastic at higher states of stress. This is more or less how far engineering students learn about plasticity in their undergraduate education and in graduate courses in advanced strength of materials and in elasticity courses. A graduate course on plasticity is needed for advanced analysis. Similar to elasticity, the theory of plasticity is a graduate course offered to both civil and mechanical graduate engineering students.[12] Plasticity is a major engineering area because it has many applications.[13]

Most structural applications in civil engineering are performed using elastic analysis. It is well established that the elastic load limits in steel structures are lower than actual plastic load limits as explained next.[14] Upon reaching the elastic limit, the stresses in a structural member redistribute themselves and the result will be a larger load capacity. Civil engineering students are taught how to conduct the much easier elastic analysis in their undergraduate classes as plastic analysis is very complex and it requires an advanced course in plasticity. If a plasticity course is taken, and as explained above, a plastic analysis will result in bigger capacities and this in turn leads to better use of our engineering materials. The theory of plasticity can be employed when inelastic deformation is present in mechanical engineering applications like ballistic penetration.[15]

Failure in solid structural components is broadly one of two types. One type involves general yielding while the other involves fracture.[16] The general yielding failure is within the scope of the above described plasticity course, but failure by fracture is the main subject of a fracture mechanics course which is a graduate course undertaken by both civil and mechanical engineering students.

In mechanical engineering applications, concepts from linear elastic fracture mechanics (LEFM) are used to predict and therefore guard against the detrimental stress corrosion cracking (SCC) in metals and metallic alloys used in all kinds of machines and devices. Examples include steam boilers and ships. Stress corrosion cracking is the simultaneous presence of mechanical stresses and environmental attacks. This is actually the conditions facing many structural components. It has been well established that cracks in hostile environments (i.e. corrosion) propagate faster as the mechanical stress levels due to applied loads increases.[17-19] It is worth noting here that many stress corrosion cracking accidents during the era of World War II were mistakenly attributed to other sources.[20]

Fracture mechanics concepts have been established primarily for metals. Its use in civil engineering applications includes predicting fatigue of steel and other metallic structural components. Fatigue refers to failure due to load repetitions.[19] Fracture mechanics concepts have been also introduced and used extensively as well in concrete structural elements.[21-22]

An advanced dynamics course is an extension to the basic dynamics course in engineering mechanics. Mechanical engineers employ vibration concepts and models when they design and construct a soil compactor, which is incidentally used by civil engineering professionals. The natural frequency of the motor operating the compactor must be different from the natural frequency of the unit to avoid a destructive state of resonance.[23] This state of resonance was and is the cause of many dramatic and sometimes fatal accidents like the infamous failure of the Tacoma Narrow Bridge in 1940. In that accident, the frequency of the wind matched the natural frequency of the bridge causing it to collapse after only a few months from its construction. Luckily, no one was killed in this accident, but the financial cost was huge. Other theories and concepts from advanced dynamics are utilized to properly design various structures like tall buildings and monorails against the massive and destructive power of earthquakes.[24]

In the plates and shells course, the student learns how to derive and apply the relationships between stress and strain for plate and shell structural components.[25] Many civil and mechanical engineering projects involve plate and shell elements. Two-way and flat plate reinforced concrete slabs, and dome stadiums like the home field of the 2007 Super Bowl bound NFL Indianapolis team, otherwise known as the Dome, make prime civil engineering respective examples. Mechanical engineers designing offshore oil refineries employ various types of plates and shells as well.

Nondestructive testing (NDT) has emerged as an important subject in recent years for various fields including civil and mechanical engineering. As its title implies, nondestructive testing is to evaluate the properties of existing components without destroying or distorting them. In this graduate course, students learn the theoretical background and applications of various techniques. There are many techniques in this regard. More information is available elsewhere in the NDT literature. This course has a wide array of applications in civil and mechanical engineering. Mechanical engineers for instance use nondestructive tests to detect and arrest cracks in the wings of a fighter jet while similar techniques are used by civil engineers to detect and fix cracks in concrete bridge decks.

Global competitiveness stipulates teaching engineering students practical aspects of the theoretical background which they have gained in their courses.[26] A graduate course on strain measurements and stress analysis suits this purpose. Mechanical and civil engineering graduate and undergraduate students use this course to augment their strength of materials and other advanced courses.

Finally, the courses of finite element methods (FEM) and numerical analysis are on finding exact enough instead of un-necessary extremely exact solutions to difficult differential and partial differential equations governing various engineering applications. The basic concepts and techniques of these courses are essentially the same for all fields including civil and mechanical engineering. It is the application part that differs from discipline to another.

How Do Universities Offer these Common Graduate Courses

Institutes of Higher education differ on the ways by which they teach common civil mechanical engineering courses: undergraduate and graduate. A fairly detailed analysis of this topic was presented at the 9th International Journal of Modern Engineer-INTERTECH Conference in October 2006 at Kean University by one of authors. It is also published in the conference's proceedings.[12] There are five categories in this regard. Some institutes offer these courses by the Civil Engineering Department while several other institutes offer them as mechanical engineering courses for the two groups of students. Yet many institutes have departments or divisions other than civil or mechanical engineering to offer such common courses.

Recommendations and Conclusion

Civil engineering students benefit more if their courses are taught by civil engineering professors at either level of their studies undergraduate or graduate. Instructors with civil engineering background understand the ins and outs of the profession of civil engineering and choose and teach relevant topics and applications. That is, instructors and students will be speaking the same language. This holds true also for the mechanical engineering case. This argument is especially true and stronger at the graduate level because students focus more on their own field at this high stage of their education.

Students do not benefit much if they have to listen and perform analysis from outside their own field. A mechanical engineering student for instance will end up wasting his/her time if he/she sits in a finite element course where the civil engineering professor performs the analysis on a bridge. Similarly, a civil engineering student will not like performing a finite element analysis on a complicated unsteady flow in a U tube when he/she sits in a class taught by a mechanical engineering professor.

Accordingly, we recommend that all graduate courses need to be taught by civil engineering professors for civil engineering students and by mechanical engineering professors for mechanical engineering students.

Unfortunately, we recognize that this option cannot be made available all the time at many places.[12] In this case, we strongly suggest the following. Instructors should make sincere efforts to be inclusive rather than exclusive in their treatment of the above common courses. That is, instructors need to be aware of applications outside their fields. They need to learn and explore these outside field applications, and use them equally with their own field applications in their classrooms. This is an extra huge burden, but it is needed for the sake of the students.

University administrations need to be made aware of this situation and they should be asked to facilitate the job of the instructors in any way they can. It is the duty of the institute to provide the best education to the students including those in their graduate programs.

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Biography

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