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Transfer effects of challenge-based lessons in an undergraduate dynamics course

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Transfer effects of challenge-based lessons in an undergraduate dynamics course

Abstract

Challenge-based instruction, a method of instruction where course content is framed around and driven by a complex problem or set of problems, requires learners to continually evaluate posed challenges based on what they know and refine this understanding through a series of formal learning experiences. A version of challenge-based learning has been used in an introductory course of dynamics to teach kinetics and kinematics to sophomores in a civil engineering department at Rose-Hulman Institute of Technology. As an introduction to specific instructional sequences, students were posed a challenge to frame the remaining lectures for that topic. Once the challenge was introduced and before any formal instruction, students were asked to generate ideas about the immediate problems they needed to solve and to generate ideas about potential solutions. In addition, they were asked to generate questions about what more they needed to learn in order to better solve the problem. Next, students engaged in a series of lectures, discussions and problem solving exercises to explore the concepts associated with answering the challenge. At the end of the instructional sequence, students were asked to submit their solution to the initial challenge. An initial study of this approach compared exam question scores between students of challenge-based instruction and traditional lecture and homework problems sets. Results showed the challenge-based students outperformed the prior cohort of students on exam questions similar to those found in the textbook. Therefore, the exam questions were more focused on recall of basic concepts and did not require the same level of processing as the challenges required of students. In this second study, additional questions were added to the exams to better align with the challenges. Initial analysis of the data indicates that students increase their ability to generate ideas and questions using concepts and principles applied in the earlier challenges. The analysis of results also helps describe the limits of students' conceptual understanding of the governing principles and how these limits diminish with time. Therefore, students are on a learning progress that increases their potential for generalizing their knowledge which will increase their potential to use it in less familiar context. The results of this study will be interesting to instructors and researchers involved in the teaching and learning of dynamics. This paper provides an overview of the fundamental concepts covered by the modules, common challenges to learning dynamics and a qualitative analysis of students work on the challenge statements and exam questions.

Introduction

This investigation evaluated the second iteration of implementing challenge-based instruction to enrich a second year dynamics course. The mechanics course, offered primarily to civil engineering students, initially followed a traditional lecture and homework model of instruction.

Students were required to solve homework and exam problems that tested their ability to solve fundamental problems in kinetics and kinematics. The instructor noticed, however, that students tended to struggle transferring their skills to solve dynamics problems significantly different or more complex than the problems typically assigned on homework. In 2012, the course was enhanced by introducing a model of challenge-based instruction.[1] Challenge-based instruction is a problem based approach in which units of a course are framed around a challenge or set of challenges. For the course enhancement, the challenges were introduced and implemented following a proven learning cycle in which students are led through a meticulous problem solving approach. All other course activities for each unit were framed with the initially posed challenge in mind. Results from the initial implementation proved positive, as the challenge based students outperformed the prior cohort of students on exam questions similar to those found in the textbook.[1] However, the first iteration of challenge-based instruction did not provide information on how students improved in their ability to transfer their knowledge and solve new and complex problems. As such, a second iteration of the challenge-based course was implemented to investigate students' performance on exam questions requiring the same level of processing as the challenges required. This paper provides the results evaluating student performance during the second iteration of the challenge-based course compared to the students in the course following a traditional model of instruction. Additionally, this paper provides the results and discussion of student performance on challenge level term exam questions.

Background

Problem-based learning consists of a wide variety of methods and approaches proven to enable students to solve well-defined analytical problems as well as to equip students to solve more complex engineering problems.[2,3,4] Challenge-based instruction, one type of problem-based learning, engages students with a complex challenge that requires students to transfer knowledge and aggregate multiple concepts in order to develop a solution.[2,5,6] Instruction and other classroom activities are presented with the challenge serving as a unifying theme to the course content. The central learning theory looks to develop the students' ability to identify and implement key fundamentals within the complex problem. At the end of a particular unit, students are required to provide a solution to the initially posed challenge by making use of the fundamentals developed and practiced in the classroom setting. Challenge-based instruction has been successfully implemented in multiple engineering contexts providing students with high-level problem solving experience, system analysis, and a realization of the relevance of course material to their future profession.[3,7]

However, prior research illustrates that poor guidance or the lack of a solid instructional framework can produced negative results when implementing problem-based learning.[8] A great deal of research has been conducted to develop instructional models to guide these learning activities. One such model to guide instructional design is the STAR.Legacy learning cycle.[9] STAR stands for Software Technology for Action and Reflection. Central to the instructional method is the focus on having students take action on what they know and reflect and refine that understanding through exploration of the challenge. The learning cycle, shown in Figure 1, is a framework that guides the instructional approach. An entire course or unit within a course is started with the introduction of a challenge problem. The challenge is usually rich in context and contains many concepts that will be covered during the duration of the course. Students are asked to immediately generate ideas and questions about how the challenge might be solved. Their initial ideas can then be compared to opinions of experts on how they might solve the challenge through a variety of media: articles, videos, or short lectures. The remainder of the unit or course engages students in a variety of different activities (Research and Revise and Test Your Mettle) where students learn to apply new concepts within context (e.g. dynamic systems). These activities can take the form of lectures, homework, quizzes, demonstrations, or in-class activities. The cycle is then brought full circle when students are required to aggregate and synthesize the content learned and asked to *Go Public* requiring students submit a final solution to the initially posed challenge. The *Go Public* phase is often an exam, final report, or presentation. Overall, the learning cycle provides a solid framework that enables instructors to effectively implement challenge-based instruction while being able to maintain their style and delivery of course material.

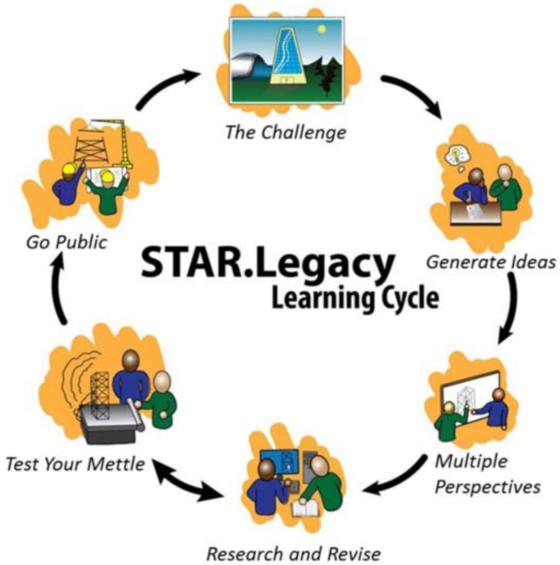

Figure 1: STAR Legacy Learning Cycle

Challenge-Based Instruction in a Civil Engineering Dynamics Course

For this investigation, challenge-based instruction following an adaptation of the STAR.Legacy learning cycle was used to enhance a second year dynamics course for civil engineering majors. Topics for the course, selected partially based on the sequence recommended by the course textbook[10] included particle and rigid body kinematics, the equation of motion, the principle of work and energy, and the principle of impulse and momentum. During the fall 2012 and fall 2013 quarters, selected topics were modified to follow a challenge-based approach and the objectives of the course were expanded. A higher level collection of objectives were included to capture the intent of the challenge problems: to engage students in areas that the instructor felt required enduring understanding. Specifically, the objectives emphasized students modeling and problem solving ability that would be important during their undergraduate career and beyond. The previous list of objective were not deleted but included in the category of important to know. Table 1 shows a comparison of the course objectives between the fall 2011 quarter and the fall 2012 and 2013 quarters. The enhanced Challenge-Based Instructional (CBI) implementation was framed in terms of a working backward framework promoted by Wiggins and McTighe.[11]

Table 1: Comparison of Course Objectives between the Traditional and Enhanced CBI Implementation

Traditional Objectives	**Enhanced Challenge-Based Objectives.**
1. Describe, analytically and numerically, the motion of particles and rigid bodies. 2. Apply the equation of motion to analyze particle and rigid body dynamic motion. 3. Apply the principle of work and energy to analyze particle and rigid body dynamic motion. 4. Apply the principle of impulse and momentum to analyze particle and rigid body dynamic motion.	Enduring Understandings 1. Develop simplified, conceptual models to represent the dynamic behavior of complex structural systems. 2. Consider multiple approaches to solving a dynamic system and justify the selection of the optimum method. 3. Create and solve equations based on the models from Objective 1. 4. Provide a logical justification that the results of an analysis are reasonable. 5. Generate written reports that describe problem solving strategy, assumptions, and solution. Important to Know 6. Describe, analytically and numerically, the motion of particles and rigid bodies. 7. Apply the equation of motion to analyze particle and rigid body dynamic motion. 8. Apply the principle of work and energy to analyze particle and rigid body dynamic motion. 9. Apply the principle of impulse and momentum to analyze particle and rigid body dynamic motion.

Table 2 shows a summary of the selected enhanced topics and associated challenge problems with a brief description for the fall 2013 quarter. For the second iteration, two of the challenge problems from the fall 2012 quarter were used and two additional challenges were developed. Also, one fewer challenge problem was implemented based upon results from the initial investigation to lighten the load of the instructor. A detailed description of the challenge problem implementation can be found in Lovell et al.[1]

For reference, a sample of one challenge problem statement has been included as an appendix to this paper. The "Post-Earthquake analysis of the Ibis Hotel, Christchurch, New Zealand," handed out on the first day of class, asked students to determine estimations of interstory drift of a ten story building during and aftershock of the 2011 Christchurch earthquake. Students were given filtered acceleration records from three stories in the structure along with associated meta-data. This exercise required students to perform numerical integration of the data, relative motion analysis to calculate differential displacement between sensor locations, and finally interpolation between stories to calculate maximum interstroy drift. As the final submittal, students were required to submit a maximum two page report documenting their findings and interpretations (albeit at a sophomore level) of the performance of the structure.

Table 2: Summary of challenges used in the fall 2013 dynamics course

Topic Area	**Details**
Particle Kinematics	**Title:** *Post-Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand*
	Fundamental Principles: Rectilinear Motion, Relative Motion
	Description of Problem Context: Given a 10-story building that has recently experienced an earthquake, determine its inter-story drift by evaluating its response to an aftershock.
Equation of Motion for a Particle	**Title:** *Analysis and Modification of an Amusement Park Ride*
	Fundamental Principles: Curvilinear Motion of a Particle, Newton's Second Law for Particles
	Description of Problem Context: Given the current specifications of a spinning amusement ride, determine the change in the structural performance of the system if the rotational speed is increased.
Principle of Impulse and Momentum (Impact)	**Title:** *Analysis of a Jersey Barrier Rail and Moment Slab Connection*
	Fundamental Principles: Principle of Impulse and Momentum (Impact)
	Description of Problem Context: Students are required to determine the force in a barrier rail connection based on an impact Level 6 test as identified by NCHRP 350.
Principle of Work and Energy	**Title:** *Aircraft Impact Analysis*
	Fundamental Principles: Conservation of Energy and the Work of a Force
	Description of Problem Context: Students are required to determine and compare the magnitude of two aircraft impacts on high-rise structures: The Empire State Building and the World Trade Center Towers.

<u>Assessing impact for using challenges</u>

Assessments were also increased for this study to achieve a stronger balance between the focus on increased knowledge. A shortcoming of the fall 2012 version of the course was that the only tool to evaluate students' higher level problem solving skills were the challenge problem solutions themselves. Additionally, students indicated they felt their performance on these higher level questions had little to do with their preparation for exams or the final grade for the course. To increase the importance of this fundamental learning outcome, the fall 2013 course added challenge level questions on two of the three term exams. Both of the questions focused at evaluating students against the higher level objectives as stated in Table 1. Specifically, students were to be evaluated based on their ability to develop a simplified model of a complex problem and their ability to make predictions based on their model.

The first challenge level exam question, given at the middle point of the course, provided students with an image of the Gosport Millennium Bridge, Gosport, Hampshire, England. The unique architecture of this cantilever and counterbalanced structure make it a very interesting bridge to analyze. For the exam, students were required to develop a model (free body and kinetic diagram) of the system and determine which is heavier: the bridge deck or the counterweight.

The second challenge level exam question was given at the end of the term and provided students with a vehicle collision report shown as a schematic of the scene. Students were given information about the final resting place of two vehicles and skid marks left on the pavement. Students were again asked to develop models to help analyze the problem. Additionally, students were asked to describe how they would determine the initial velocities of each of the vehicles.

Research questions and instruments

Multiple studies are planned to investigate these questions. The primary research question builds off the initial study's conjecture that the implementation of challenge-based instruction improves students' ability to solve a wide range of dynamics problems and that these skills will develop throughout the course. This improved student ability would therefore lead to improved test scores and overall problem solving ability. As such, the basic research questions are:

1. How can a series of challenge-based learning cycles improve students' ability to analyze the behavior of dynamic (physical) systems?
2. How do students' abilities to define problems and generate solutions improve across a sequence of challenges during a term?

Methods

This study focuses on a replicating the first study with enhanced summative assessments used to evaluate the performance of the students during fall 2013 implementation of the course. These assessments included: challenge level questions on two term exams and a common final exam to the prior implementation of the course containing questions based on fundamental concept questions related to topic areas in Table 2.

Participants

Three separate groups of second year engineering students participated in a dynamics course during the 2011 fall quarter (43 students), the 2012 fall quarter (38 students), and the 2013 fall quarter (47 students). Each group of students were compared based on their SAT scores and their GPA's upon entering the course, and it was found that the three groups of students statistically equivalent with a 95% confidence. Students in all three classes provided their consent to have their course materials used in the study. The instructor had no knowledge of their consent before final grades were delivered; therefore, their participation had no bearing on their grade.

Results

Comparison of Final Exam Scores

A common final exam was used for the three iterations of the dynamics course: fall 2011, fall 2012, and fall 2013. The final exam consisted of textbook style questions focused at testing the students' ability to solve basic concept questions. For the 2012 and 2013 years, an additional question was added to cover the topic of vibrations. All three tests were graded using a similar rubric, and Table 3 shows the comparison of scores between the three years on each of the final exam questions. The results of the second implementation of the challenge-based method of instruction proved to be very positive. Comparing students' performance of the Fall 2013 cohort with the Fall 2011 cohort indicates the enhanced version of the course improved their test scores on every test question. Three of the five similar questions showed significant improvement in performance. These results are very similar to the performance of the 2012 group of students. It is also interesting to note that the average scores between the two enhanced versions of the course are very similar as well.

The new assessments on exams 1 and 2 were ill-defined problem statements; that is, the problems were missing some information required to determine a numerical solution. Students were therefore required to have a firm understanding of the fundamental concepts for each of the problems and identify the missing information needed. Student solutions were evaluated for two key components: (1) students could develop a correct model or set of models to represent the problem and (2) students could correctly interpret their model to develop a solution to the problem being asked. A simple rubric was developed to easily evaluate student responses. Table 4 shows the aggregate results of student performance on the two challenge level exam questions.

3 Points – Correct model and correct interpretation of the model
2 Points – Minor errors associated with the model but correctly interpreted
1 Point – Incorrect Model, but interpretation of model is adequate
0 Points – Model and interpretation are significantly lacking

Overall, the assessment showed improvement through the quarter between the two higher level questions. However, students performed below what the instructor would have anticipated. Most of the students made very common errors when developing their models. Specifically, students often drew internal forces on their free body diagrams and used them to make incorrect interpretations about the problem. It is important, though, to not make reaching conclusions regarding the challenge level questions. There were only two exam questions, and the problems themselves were very different. It may be that students were still gaining familiarity with the different question format. For future iterations, it would be important to vary and increase the number of the potential higher level questions.

Table 3: Final Exam Scores for fall 2011, 2012, and 2013

Final Exam Scores										
Topics	**2013 (n = 47)**		**2012 (n = 38)**		**2011 (n = 43)**		**Improvement over 2011**		**Stat. Sig. (α = 0.05)**	
	AVG	**STD**	**AVG**	**STD**	**AVG**	**STD**	**2013**	**2012**	**2013**	**2012**
P1 - 2D Rigid Body Kinetics (Dependent Motion) *^	82.4%	16.5%	81.8%	19.4%	75.0%	19.6%	X	X	X	
P2 - Particle Kinematics (Variable Acceleration) *^	80.9%	18.0%	79.2%	17.2%	77.2%	21.1%	X	X		
P3 - Principle of Impulse and Momentum (Impact) ^	81.3%	20.9%	70.2%	24.0%	78.0%	22.0%	X			X
P4 - Conservation of Energy	60.1%	15.7%	59.5%	21.8%	76.3%	14.2%	NA - Different Problems		X	X
P5 - Principle of Impulse and Momentum*^	80.1%	13.9%	74.9%	12.4%	64.1%	15.4%	X	X	X	X
P6 - 2D Equation of Motion for a Rigid Body*^	77.0%	12.8%	80.5%	14.5%	69.5%	15.9%	X	X	X	X
P7 - Vibration	71.6%	12.8%	63.7%	14.5%	-	-	NA	NA		NA

*Challenge-based instruction was used for the content for these questions during fall 2012
^Challenge-based instruction was used for the content for these questions during fall 2013

Table 4: Student Scores on Challenge Level Term Exam Questions

Term Exam Question	**Average Rubric Score**
Term Exam 2: Analysis of Gosport Bridge	1.59
Term Exam 3: Analysis of Accident Report	1.96

Limits of the Study

This study demonstrates a higher performance of students as part of a later implementation of the course that utilized challenge-based instruction. All other factors were controlled for include location of room, classroom learning resources and supplemental homework. However, familiarity and ease of the same instructor implementation the course could not be controlled. This kind of instructor bias cannot be controlled for and should merely be considered as part of the implementation.

Conclusions

Students' participating in second year dynamics course using challenge-based learning experiences outperforms prior cohorts on well-defined problems. All engineering faculty want their students to demonstrate the ability to apply constitutive properties of target domain to micro analysis task for larger context problems. As an example, engineers must size a part needed in a larger design or must evaluate factors that could have caused a failure. The replication of prior studies reinforces the benefits of challenge-based instruction to improve students' ability to solve well-defined problems. One premise is challenge-based instruction provides a context for how and when to use these constitutive properties. Therefore, students better comprehend how the constitutive properties apply to a particular context.

The challenge level term exam questions indicate students improved in their ability to model and make use of models of complex systems. This ability is at a higher level of comprehension of the domain compared to solving the well-defined problems. This would indicated that the practice and repetition of the generating ideas and challenge exercises helped to develop the students' problem solving abilities. However, scores are below what the instructor would have anticipated. Preliminary analysis of students' work indicates they make very common errors in developing their models. Specifically in constructing their free body diagrams which impacted their ability to make correct interpretations. The next iteration of the course will focus more on developing these skills and will begin with a more careful analysis of these students work. The two exam questions did work well for highlighting students weaknesses which illustrates their role as a diagnostics tool of student learning. Additional questions will be used in the future to better substantiate claims in students' potential for transferring what they learned in the course to future problem solving contexts

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Dynamics

Challenge Problem #1: Post Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand

Appendix

Challenge: In the last century, our understanding of how to properly design against the risk of earthquakes has improved significantly. Some of the largest advancements in our knowledge of seismic structural design results from observations of how structures perform in actual earthquakes. Essentially, a structure becomes a full-scale, real world experiment. Seeing how structures behave allows engineers to see if our current approach to design is acceptable or if adjustments are necessary. For this reason, research teams comprised of engineers and scientists quickly respond after a major earthquake by traveling to the impacted cities to inspect the post-earthquake status of its structures. They may also instrument the structure to measure the structure's behavior to any potential aftershocks. One such research group is the NEES@UCLA Mobile Laboratory. (www.nees.ucla.edu).

The NEES@UCLA team recently finished a field monitoring program in Christchurch, New Zealand following the 2011 earthquake. The team was able to set-up instruments on several structures and measured several aftershocks. They have requested that you help them with data analysis since they are overwhelmed with the amount of data.

They need your assistance to analyze the Ibis Hotel in Christchurch, New Zealand. It is a nine-story, reinforced concrete building. The research team placed accelerometers on three levels: the basement, the 3rd floor and the 9th floor as illustrated in Figure 1. The sensors captured an aftershock on 9/1/11 and the measured acceleration for the basement tri-axial accelerometer is shown in Figure 2.

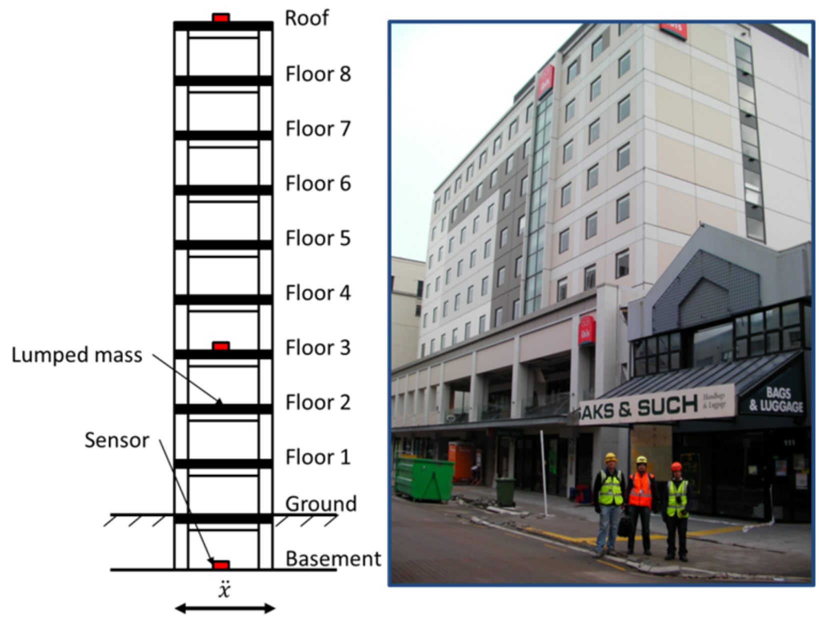

Figure 2: Simplified frame used to represent the Ibis Hotel with sensor locations.

A schematic of the Ibis Hotel and corresponding sensor locations is provided in an excel sheet: *IbisHotel_metadata.xlsx*. The building dimensions will need to be estimated based on the approximate length of the building obtained from Google Maps. Filtered acceleration records for the aftershock are provided in a second excel file: *Ibis_Aftershock_Filtered Data.xlsx*. Both files can be found on the EM202 course Moodle page.

The researchers need to characterize the current properties of the building using the aftershocks as the input force to the building (basement acceleration) and the 3rd floor and roof acceleration as the response to this applied force. The researchers at NEES@UCLA need a model of this data that estimates the maximum displacement between each floor. Therefore, they need you to provide a transformation of the data that will provide this information based on the measurements from the accelerometers.

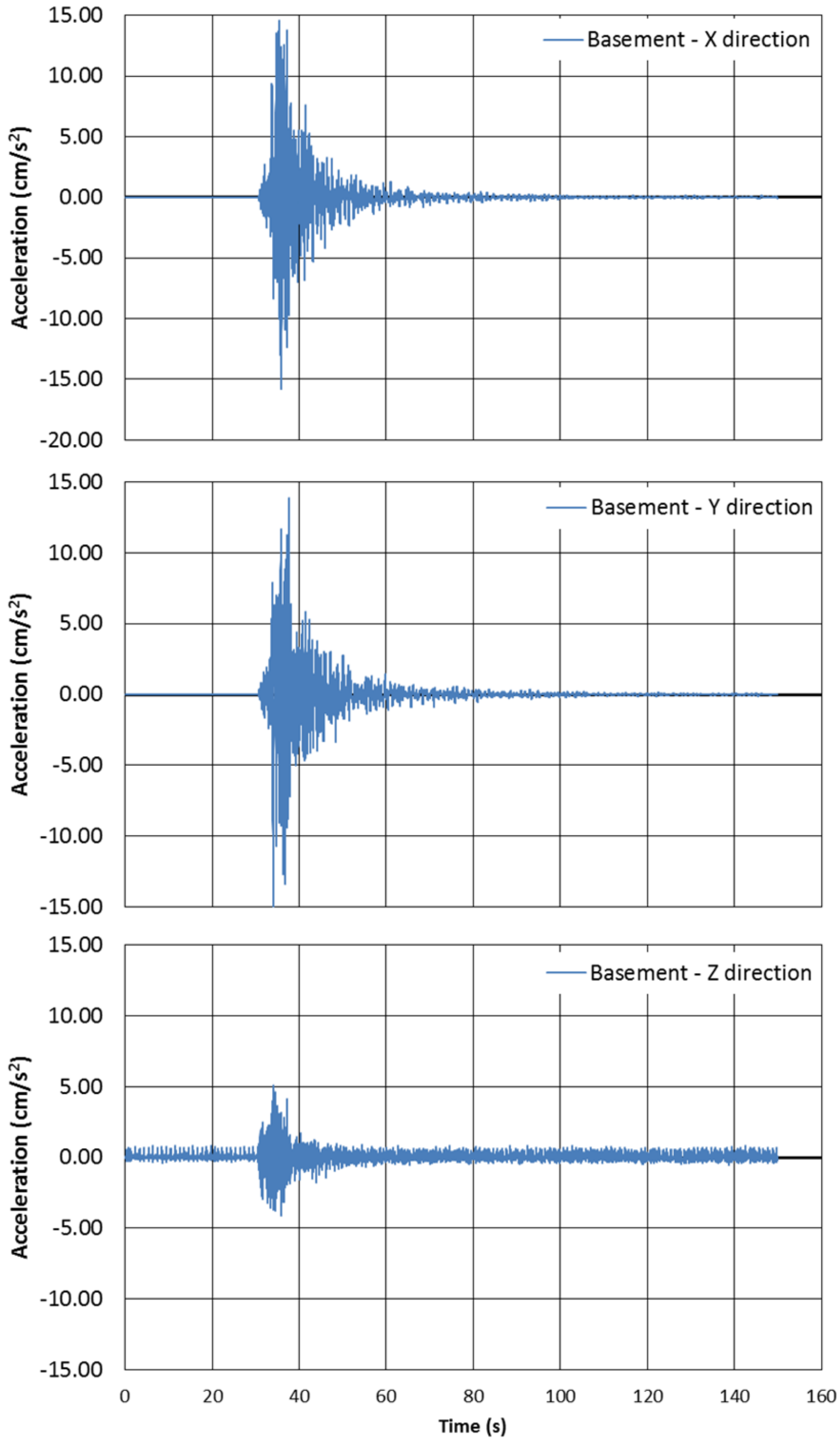

Figure 3: Filtered acceleration of a tri-axial accelerometer from the basement level of the Ibis Hotel from an aftershock of the Christchurch earthquake on 9/1/2011

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Dynamics

Challenge Problem #1: Post Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand

Generate Ideas: *An exercise to help you think about and plan your approach to the problem.*

Respond to the following items to the best of your ability. The reflection exercise will help you articulate your initial thoughts about the challenge and how you might solve it.

1. List in your own words what is the ***goal*** of this challenge (what is the research team asking for):

2. List in your own words the relevant ***given*** information for this challenge problem:

3. List in your own words the ***major sub-problems*** you will need to solve to achieve this goal (i.e. the intermediate steps/concepts to achieve the goal of the challenge.)

4. At this time, what additional ***questions*** do you need to answer to solve this problem (what are you unsure about?):

5. Briefly explain how you plan to approach and solve this problem:

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Dynamics

Challenge Problem #1: Post Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand

Research and Resources: ***<u>Background and supplemental information to aid in the problem solution.</u>***

These resources provide additional information that may guide your approach to the Challenge.

- Structural Engineering Education Module from NEES@UCLA (http://nees.ucla.edu/edumodule.html)
- Earthquake Response of Linear Systems (Chopra, A. K., 2001, *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, 2nd Ed., Prentice Hall, NJ, pgs. 197-203.) (Available on Moodle)
- How to use Calculus in Kinematics: Displacement, Velocity and Acceleration (http://www.youtube.com/watch?v=WABpcU0mHMU)
  (*Note: How does the method change if you have erratic data?*)

Deliverables by 9/13/2013:

- Your final goal for this challenge is to provide the research team with a short report of your analysis methods and findings. The "Required Homework Format" provides a good method for organizing your analysis methods in a short and concise way to your audience of technical experts. Therefore, the structure of your report will consist of these major sections.
  1. Cover Page – Reference example report for an example cover page.
  2. Problem solution report of challenge problem results (two page maximum):
     a. Discussion of problem approach including major sub-problems you had to solve, models you generated, assumptions you made and final conclusions you derived based on your computations. The details of your calculations from your model are to be included in an Appendix of the report.
  3. Appendix of calculations – Formatted as indicated in the "Homework Format" document.

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Dynamics

Challenge Problem #1: Post Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand

Solution Reflection: *An exercise to help you reflect about your plan and approach to the problem.*

Respond to the following items to the best of your ability. The reflection exercise will help you evaluate your problem solving approach and how you might improve it in the future.

1. List in your own words the ***major sub-problems*** you used to achieve the project goal: (*i.e. the intermediate steps/concepts to achieve the goal of the challenge.*)

2. Circle which answer best describes how confident you are about your solution that you provided to your client. Briefly describe below why you selected that score.

   1 – Not Confident 2 – Slightly Confident 3 – Very Confident

3. What questions do you wish you had asked before starting the Challenge Problem?

4. At this time, what additional ***questions*** do you have with regards to this problem? (*What are you still unsure about?*)

5. Any additional comments: