Infrastructure Education using the Impacts of Extreme Storms as Case Studies

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Introduction

In an effort to improve infrastructure education and meet the challenges faced by the poor state of infrastructure in the United States, our university joined the University of Wisconsin Platteville, the US Military Academy at West Point, and several other institutions on the project funded by the National Science Foundation. This collaboration has also resulted in the development of an infrastructure education community of practice,[1] the Center for Infrastructure Transformation and Education (CIT-E). In Spring 2015, Our University is offering a freshman level course titled "Introduction to Infrastructure" that will be required for all students in the Civil and Environmental Engineering program. In addition to the primary goals to enhance and improve the education and development of future engineers, given the current state of infrastructure in the US in particular, one of our goals for this course is to provide students with an early exposure to the practice of civil engineering and its importance to society. A common complaint from students over the years has been that they do not have a good understanding of what civil and environmental engineering *is*, and what civil engineers *do*. Our hope is that this will provide freshman with a solid context within which to continue their studies and motivate them to continue in the program.

Course Overview

Our course is a 2-credit lecture course consisting of two 75-minute periods per week of about 30-35 students per section. It includes sections on structural systems, foundations, transportation systems, water and environmental systems, sustainability, coastal resilience, as well as a general overview of economic and social considerations for infrastructure. The poor state of infrastructure in the US is stressed in order to highlight the importance of the civil engineering profession to the public welfare. Throughout the course, we emphasize how the quality of infrastructure directly affects the economy and security of the US, and that the next generation of civil and environmental engineers needs to be more skilled and more able to design and create sustainable infrastructure. The authors will team teach the course, with one section officially assigned to each faculty member. Most of the lectures will be based on course materials from the University of Wisconsin – Platteville and the U.S. Military Academy at West Point. These course materials consist of PowerPoint slide presentations and course notes.

One of our concerns when structuring the course is to maintain consistency across the course and across each section. We saw two challenges in maintaining consistency; one was the fact that the course is co-taught by two faculty members with different backgrounds and styles of teaching. The second challenge included maintaining consistency between the presentations of each civil engineering sector to the class. That is, we did not want each section and sector of civil infrastructure to be presented as separate and unrelated to other sectors.

In order to meet the second challenge, we took the approach that most of us, including our students, have an intuitive sense of what infrastructure is. We do not present an explicit definition of infrastructure, but as we present material and go over different sub-disciplines of civil engineering, the student's sense of the term should become more clear. Our pedagogical approach is based on a few key aspects that in define infrastructure. Star and Ruhleder[2] provide a list of defining features of infrastructure.

1. *Embeddedness*: Infrastructure is "sunk" into, inside of, other structures, social arrangements and technologies;
2. *Transparent* to use: It is not reinvented or reassembled each time, but invisibly supports tasks.
3. *Reach or scope*: Infrastructure goes beyond a single event or local practice.
4. *Learned as part of membership*: It is taken-for-granted. Outsiders encounter infrastructure as an object to be learned about, and new participants acquire a naturalized familiarity as they become members.
5. *Links with conventions of practice*: It shapes and is shaped by the conventions of the community of practice.
6. *Embodiment of standards*: It becomes transparent by fitting into other infrastructures and tools in a standardized fashion.
7. *Built on an installed base*: It inherits the strengths and limitations of its base.
8. *Becomes visible upon breakdown*: Working infrastructure becomes visible when it fails.
9. *Repaired modularly, not all at once:* It is layered and complex. Changes require time, negotiation, and adjustment with other aspects of the system[2,3]

It is beyond the scope of this paper to elaborate on each of these features of infrastructure, however an explicit description of these features helps to understand our approach. Features (1), (2), (4), (6), and (8) provide an indication as to why we all have an intuitive sense of infrastructure. Take (4); travel to a foreign country can make one more aware of infrastructure to the degree to which it is different from what one is accustomed. For example, take one accustomed to driving in the US who is traveling to the UK. Driving on the left side of the road will feel uncomfortable, and it will take time to become accustomed to using the UK's transportation infrastructure. But by far the clearest way to illustrate infrastructure's ubiquity, embeddedness, and visibility, as in (1) and (8), is through highlighting failures. In particular, our course will have an emphasis on the impacts of extreme storms on infrastructure.

The first half of the course is led by Dr. Daraio who presents lectures introducing infrastructure, on financing and economics, and on social impacts of infrastructure. These lectures serve to show the reach or scope of infrastructure, and to get them to frame the course from a broad perspective. Dr. Daraio then presents on the topics of water resources and environmental infrastructure. The course will include broad coverage in water resources and environmental infrastructure, including distribution systems, storm water, dams and levees, and water and wastewater treatment. Our University is located in southern New Jersey, and the majority of our students were born and raised in the state. In the first half of the semester, a significant emphasis will be placed on the impacts of what has been called "Superstorm" Sandy on New Jersey's water infrastructure as well as the impacts of storm surge and flooding on other civil infrastructure. (Sandy was not a hurricane when it made landfall, and the term "superstorm" is an invention of the media. Therefore we will refer to the storm as "Sandy.") Sandy hit New Jersey in October 2012 causing significant damage, on coastal counties in New Jersey in particular.

The storm resulted in 34 deaths across New Jersey (out of a total of 125 in the US), and losses were estimated at approximately $7.1 billion for the state GDP in just the final quarter of 2012, while the total economic cost was much higher than that.[4] The state's infrastructure was badly damaged by the storm, including roads, bridges, electrical and water infrastructure. State waterways were impacted and environmental impacts directly affected the fishing and aquaculture industries. Water and wastewater infrastructure sustained an estimated $2.7 billion in damages as a direct result of the storm.[4] Storm water sewer lines were blocked contributing to flooding, almost 100 wastewater treatment systems either failed or had significant interruptions in service, and the loss of electrical power caused many others to go offline.[4] Over 70% of New Jersey's water supply systems were impacted by the storm, mostly due to loss of power, and approximately 360,000 residents were under a boil water advisory, of which around 10,000 homes in Ocean County were still under a boil water advisory after one month.[4]

New Jersey's coastal counties are home to approximately 60% of the state's total population[5], and this is reflected in the student population at Rowan University. Many of our students were either directly affected by the storm or knew someone who was affected. This fact provides us an opportunity to stress the infrastructure crisis to a group of individuals with perhaps a better appreciation of its importance. Students will do a case study of the impacts of Sandy on their communities. The focus, of course, will be on the impacts to infrastructure, but will also include social and economic impacts. We use CATME (www.catme.org) to build teams of 4-5 students in each section. The primary factor in determining groups is the degree to which Sandy impacted a student and her community. As of this writing, the CATME survey has not been completed by students, however a preliminary survey indicated that approximately 30% of students in each section experienced significant impacts from Sandy. Additionally, almost all students experienced some impact, such as waiting on long lines to refuel their cars.

In the second half of the semester, after spring break, Dr. Dusseau gives lectures on geotechnical, structural, transportation, and construction infrastructure. Again, the impacts of an extreme event on infrastructure are used to introduce students to these areas of civil infrastructure. While a little less close to home for Rowan students, the importance of civil engineering infrastructure for the protection of lives and property was clearly demonstrated during Hurricane Katrina[6,7,8,9]. The storm struck on August 29, 2005. Two days later 80% of New Orleans was under flood water, and some parts of New Orleans were left under as much as 20 feet of water. The extensive flooding was caused by a combination of strong winds, heavy rainfall, and storm surge. Out of a total of 284 miles of federal levees and floodwalls in New Orleans, 169 miles were damaged. Many pumping stations in New Orleans were left either inaccessible or inoperable by the flooding. Bridges along interstate highway I-10 and along US highway 90 in Louisiana, Mississippi, and Alabama were extensively damaged or destroyed by storm surge, wind, and/or wave action. Many other federal, state, and local bridges in all three states were also severely damaged or destroyed by the storm. The transportation systems and subsequent relief and reconstruction efforts in Louisiana, Mississippi, and Alabama were severely disrupted by these bridge failures. Dr. Dusseau will discuss these impacts and how students and faculty from Rowan University helped to play a role in the relief effort for New Orleans. Teams of Rowan students, as part of their Junior/Senior Engineering Clinic courses, traveled to New Orleans in 2005, 2006, and 2007 to assist with relief, cleanup, and reconstruction. In addition, Rowan University played host to students from New Orleans who were displaced by the flooding. Students will have the opportunity to compare the impacts of Sandy and Katrina, and assess and critique recovery efforts in both areas.

The impacts of Hurricane Katrina will be addressed in two main areas: the impact on retaining walls in New Orleans and the impact on bridges in Louisiana, Mississippi, and Alabama. The discussion of retaining walls in New Orleans will come after the students are introduced to geotechnical engineering and specifically to retaining walls. Similarly, the discussion of bridges in Louisiana, Mississippi, and Alabama will come after the students are introduced to structural engineering and specifically to bridges.

The geotechnical engineering topics will begin with a lecture that covers an introduction to geotechnical engineering and failures, a lecture that discusses soil strength, and a general lecture on retaining walls. These three lectures are based on course materials provided to us by the University of Wisconsin – Platteville[1]. The geotechnical engineering topics will conclude with an entirely new lecture on the impact of Hurricane Katrina on retaining walls in New Orleans.

The structural engineering topics covered in the new Introduction to Infrastructure course will begin with a lecture that covers an introduction and history of structural engineering, a lecture that discusses materials and deflection, and a general lecture on bridges. These three lectures are based on course materials provided to us by the University of Wisconsin – Platteville[1]. The structural engineering topics will conclude with an entirely new lecture on the impact of Hurricane Katrina on bridges in Louisiana, Mississippi, and Alabama.

During the new Introduction to Infrastructure course, students will be divided into teams of 4 or 5 students and asked to prepare a report dealing with one of the following: 1) the failure of a specific retaining wall in New Orleans or 2) the failure of a specific bridge in Louisiana, Mississippi, or Alabama. As part of this report, the student teams will be asked to do one of the following: 1) a detailed assessment of the impact of the retaining wall failure on specific areas of New Orleans or 2) a detailed assessment of the impact of the bridge failure on the regional transportation network in Louisiana, Mississippi, and/or Alabama.

Assessment of the Course

The effectiveness of the course will be assessed using a pre- and post-course survey, shown in Figure 1. The last three questions are unique to the Rowan University survey form, while the first eight questions in the survey are based on a similar survey conducted at the University of Wisconsin – Platteville. These eight similar survey questions will allow us to compare our student responses to those of some of the other universities who are collaborating in the NSF project. In addition to the pre- and post-course surveys of students enrolled in the course, we will include several of the questions from the survey in the exit interview that Rowan University conducts on our graduating seniors. Rowan University conducts exit interviews every year for the purpose of assessing several aspects of our program. The fact that the 2014-2015 freshman class is the first to take the Introduction to Infrastructure course allows us the opportunity to collect three years of data from graduating seniors who have not taken the course and assess the effectiveness of the course for students going through our program. The exit interview will include questions 1, 4, and 8 shown in Figure 1.

1. Which is the most appropriate definition of "sustainability" as used by engineers (circle one).
   a. Constructing infrastructure systems to ensure maximum durability with minimal need for maintenance and/or rehabilitation.
   b. Meeting the needs of the present without compromising the ability of future generations to meet their own needs.
   c. Designing structures and other components of infrastructure so that they can sustain expected loading over the entire lifecycle.
   d. Constructing infrastructure systems that can be reused and/or recycled.

2. If you were to characterize the state of the nation's infrastructure (roads, bridges, sewers, water supply, etc.) using a typical grade scale, what grades do you think would be most appropriate (circle one)?

   a. mostly A's and B's
   b. mostly B's and C's
   c. mostly C's and D's
   d. mostly D's and F's

3. Explain the basis for your answer to question 2. That is, specifically, what factors led you to select the answer you chose?

4. Select an example of an infrastructure project that civil engineers would work on. State at least two subdisciplines of civil engineering that would be involved. Explain how the subdisciplines would work together on the project.

5. Choose an example of a project that civil engineers would work on (it could be the same example as question 5 or you could choose a different example). Explain how civil engineering professionals would interact with *non-civil engineering professionals*? List at least two examples of interactions.

6. Choose one of the considerations listed below (circle one) and *using a single infrastructure example* (a road, bridge, water treatment plant, retaining wall, etc.) state why the this consideration is important and explain how engineers would incorporate this consideration in the design of that example.

   Constructability   Risk
   Aesthetics   Economy
   Sustainability

7. Select one of the infrastructure components below (circle one) and list the considerations that would be necessary to conduct a field assessment of the component:
   a) Stormwater drainage system for a city block.
   b) Road pavement for a stretch of county highway.
   c) Substructure of a bridge crossing a small creek.
   d) Retaining wall along a highway cut.

8. The following is a recent quote from the Transportation Secretary in regard to the $50 billion infrastructure investment plan proposed in September 2010: "We know that upgrading our nation's infrastructure is vital to our economy and our future competitiveness." Explain briefly why you think this statement is true or not true (circle one). Cite any examples that you can think of to support your argument.

   True   False

9. Which area of civil engineering are you most interested in working in (circle one)?
   a. Environmental Engineering
   b. Water Resources Engineering
   c. Geotechnical Engineering
   d. Structural Engineering
   e. Transportation Engineering
   f. Other – Explain:______________________________

10. What is your current level of interest in pursuing a career in civil engineering (circle one)?
    a. Very High
    b. High
    c. Moderate
    d. Low
    e. Very Low

11. What grade do you expect to receive in this course (circle one)?
    A   A-   B+   B   B-   C+   C   C-   D+   D   D-   F

Figure 1 Pre- and post-class survey.

Conclusion

We believe the emphasis on the impacts of extreme events on civil infrastructure will provide a strong point of interest with students. It is likely this interest will be even greater at Rowan because a majority of our students were either directly or indirectly affected by Sandy. Additionally, as the impacts of climate change have become measurable and as climate change projections suggest increased frequency and intensity of extreme events, the need to account for climate change in design for infrastructure is becoming more clearly recognized.[10] This is a fact that is vital for civil engineering students to understand in order to increase reliability and decrease the nation's risk and vulnerability to the failure of infrastructure in the future. Finally, we are hoping that the emphasis on extreme storms will help us highlight the connection of all civil infrastructure by providing students with a unifying context.

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