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Geometric Design Project for First Year Civil Engineering Students

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Abstract

Transportation engineering is an important sub-discipline of most Civil Engineering programs. Road design is a significant section of transportation engineering. One major aspect of road design is the geometric design that focuses on locating the road on a topographic map. Introduction to Engineering Design is a laboratory-based course for first-year students at the authors' university. In this course, students work on a civil engineering-related project during the semester. In the Spring 2019 and 2020 semesters, students were introduced to geometric design by working on a road design project. Three main sections were implemented in this project. The first piece was understanding of topographic map. In this piece, students were asked to select a non-flat site located in the United States. The topographic map of the selected site was printed and provided to the students. Students were asked to draft the topographic map in SOLID WORKS or AutoCAD – Civil 3D and print their files using a 3D-printer. In the next section of the project, students were asked to design a road between two points of their topographic map. In this part of the project, students were introduced to geometric design including horizontal and vertical curves. Students designed three roads between the selected points, using a ruler and compass, and drew a vertical profile of each option on a grid paper. In the last section of the project, students learned the concept of earthwork in road design. Students calculated the volume of soil that needed to be cut and filled for all three options. Finally, students picked their final design by studying steps two and three. This module was used to teach the concepts of geometric design to first-year civil engineering students.

Introduction

Visualization of the problem and its solution can play an essential role in the education of first-year engineering students. Therefore, the laboratory modules that contain an engineering problem and solution to that, might be a very useful tool for engineering education [1]. Recently many universities switched the introduction to engineering design course from lecture-based course to laboratory-based one [2]. To develop an appropriate laboratory module for the firstyear engineering students, it is very important to understand the students' view of an engineering problems. A couple of factors that should be considered in designing these types of modules are the students' level of engineering knowledge, the scale of the knowledge and topics which are covered, and the format of the presentation of these topics [3].

This paper describes a civil engineering module which was developed for the Introduction to Engineering course for first year civil engineering students. Introduction to Engineering Design is a course that is offered to all civil engineering students during their second semester at the authors' University. This course is a project-based course in which students meet in the laboratory twice a week and each time they spend two hours of their time working on civil engineering-related projects and modules. A semester-long project is mainly designed by the instructor of the course and students work on the project in groups of four to five students during

the laboratory period. In addition to the semester long project, some other aspects of design process are taught in this course.

In Spring 2018, the authors defined a structural-based project for students for Introduction to Engineering Design course. This project contained the design of an elevated water tank for a selected high school in the United States. The main purpose of this project was to introduce students to some structural and earthquake engineering concepts such as load, basics of column design, buckling, and resonance frequency. An alternative project introduced to students of the other sections of the same course was an environmental engineering-related project. In this project, students were introduced to wastewater treatment techniques and learned about solid wastes and different types of filters to remove the wastes. Authors concluded that, the elevated water tank project includes complex concepts of structural engineering which can make the project too sophisticated for a first-year civil engineering student. The wastewater treatment project is an environmental based project, that might not be an interesting concept for students who choose their major for other aspects of civil engineering such as structural, geotechnical or transportation engineering.

Authors decided to develop a new project that includes variety of engineering concepts and is not complex for first year civil engineering students. Therefore, a road design project was developed and assigned to students for this course in Spring 2019 and 2020 semesters. The main purpose of the project was to introduce students to multiple concepts of geometric road design. This paper describes the steps of the project from the beginning to the end. In addition to the content of the project, some of the students' work in the format of a poster is presented in this paper. It should be noted that for this project no specific handouts were distributed. At the beginning of each lab, the instructor introduced the specific task of the project for that session to students. Students worked on the task during the two-hour lab under the instructor supervisory. Students meet twice a week in the laboratory for this course. In the Spring 2020 semester moving to the online education format the students were able to finish the project and submit their final posters.

The goals and objectives of this course are:

1. To develop a basic understanding of the various steps in the design process typically encountered in the field of engineering.
2. To become familiar with several computer-related skills necessary to function as a practical engineer.
3. To develop an understanding of how to attack and solve a poorly defined problem - from the basic literature search, through planning, and to a finished and tested prototype.
4. To develop an awareness of (a) analytical thinking, (b) decision-making skills, (c) communication skills, and (d) the design process.
5. To gain an awareness of team-building skills and general business acumen.

Goals number four and five were applied and practiced by introducing the project presented in this paper. However, it should be noted that the goal of this paper is to describe the project that was introduced to students to the colleagues who are involved in the first-year civil

engineering education. This paper does not focus on the assessment of the goals and objective of the course as well as other components of the course.

Content

The Geometric Design Project contains multiple steps including, Topographic Map which includes basic understanding of a topographic map and 3-D printing, Geometric Design which includes teaching the vertical profile of the road, and the Earthwork, which includes the construction aspect of the project.

1. Topographic Map

The first part of the project is focused on teaching the concepts of the topographic map. Civil engineering students at the authors' university are introduced to the concepts of the topographic map during the Introduction to Geomatics course in their sophomore year in details. The topographic map is a tool that presents the changes in elevation of the ground in a two-dimensional map by using elevation contours. A civil engineer must understand the changes in the elevation of the work site by looking at the topographic map. For the first step of the project, students are asked to pick two points that are approximately four miles apart on a topographic map of a non-flat area. The final goal of the project is to design a road between the two points. It was suggested to students to define their project in the New England area. Mytopo.com is the website that students were asked to use to have access to the topographic map of various locations in the United States. Figure 1 presents one of the projects' topographic maps and selected locations in the East Haven Mountain range in Vermont.

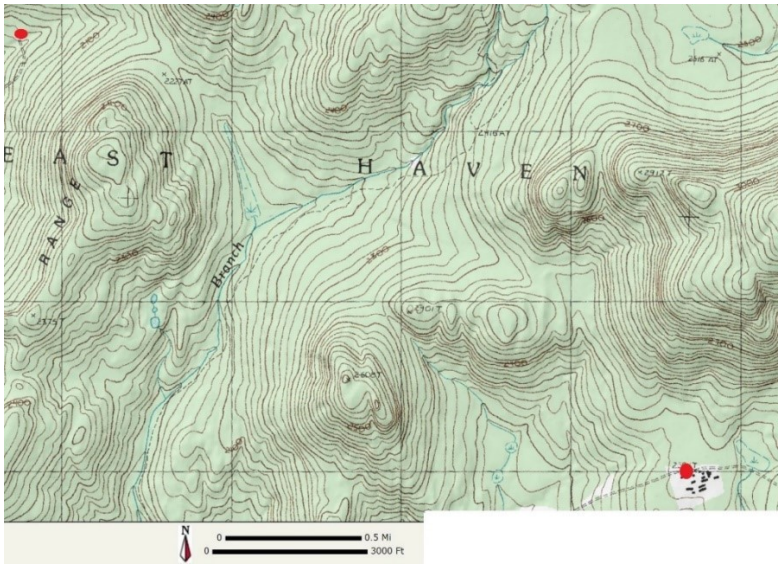

Figure 1: Topographic map and selected points of one of the projects

After defining the location, students were asked to prepare a 3-D model of their project. Students could either use cardboard and scissors or available 3D printers on campus to prepare

their models. Almost all group decided to draft the topographic map using SOLID WORKS or AutoCAD – Civil 3D and 3-D printed the drawing. Some of the printed models are shown in Figure 2.

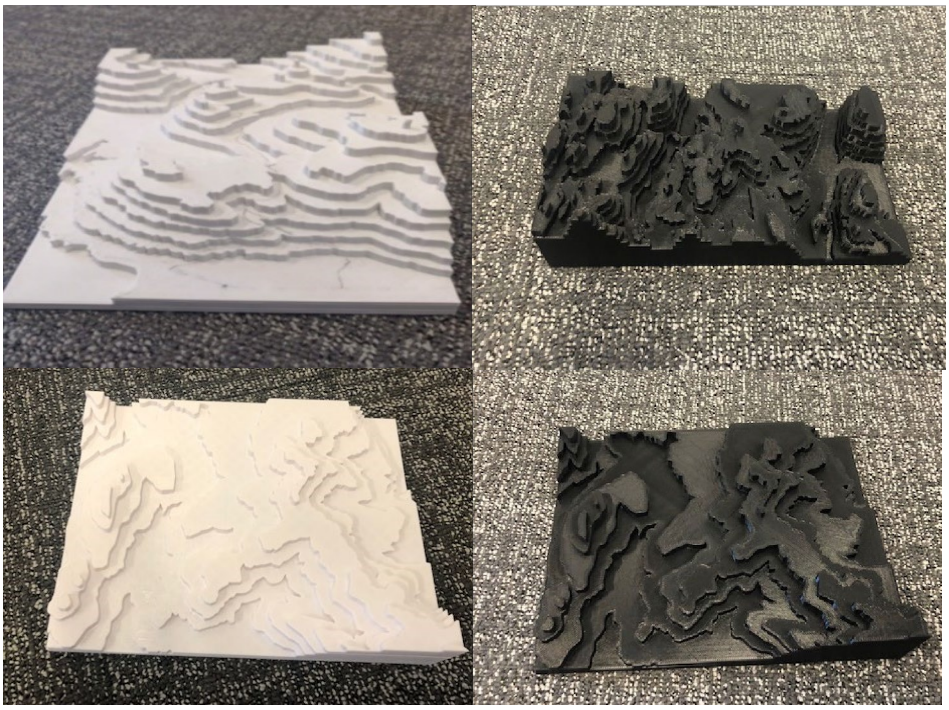

Figure 2: 3-Dimension print of topographic map

Comparing the 2-D map and 3-D model helps students to understand the meaning of elevation contours and visualize the topographic map. This part of the project can prepare students for the Introduction to Geomatics course in their sophomore year.

2. Geometric Design

The next step in the project is to define a road between the two selected points. Each group was asked to start their design by drawing the shortest road which is a straight line between the two points. The dashed line in Figure 3a shows the fastest road between the two selected points for one of the projects. Although this option is the fastest road, it is not the most economical option. Students were asked to draw the vertical profile of this option and compare the slope with the road's allowable slope (8% for this project). To draw the vertical profile, students identified the locations where the road intersects the contour line. Knowing the elevation of the contour line and the distance of the intersect from the starting point, students can plot the elevation vs distance of the road. The vertical profile of this road is shown in Figure 3b. It can be observed that to achieve the allowable slope excessive amount of earthwork needs to be done.

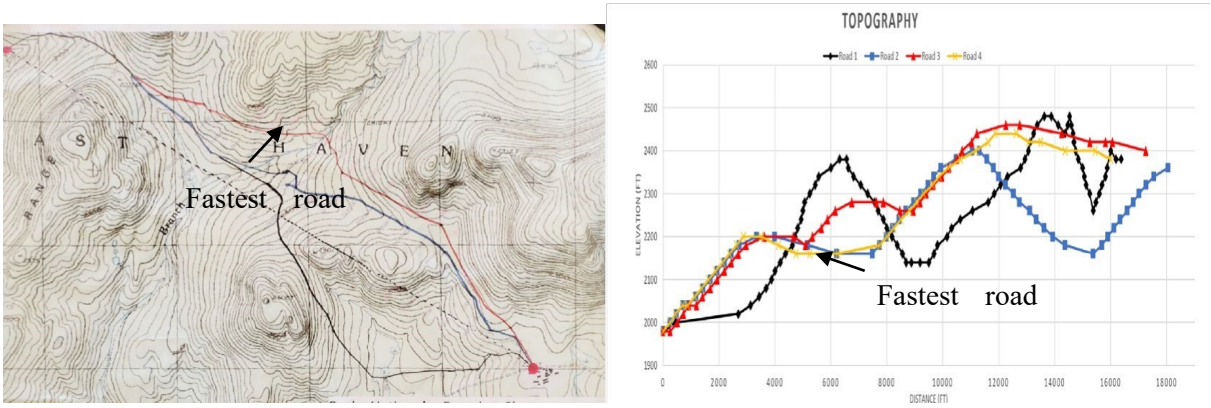

Figure 3: a) Fastest route between the selected points b) Vertical profile of the fastest route.

The next step is designing other road options that fulfill the required vertical curve slope (8% for this project) with the least amount of earthwork. Knowing the elevation difference between two contours, the scale of the topo map, and the distance of route between every two contours to satisfy the allowable slope can be calculated. For instance, if the elevation difference between two contours is 20 feet, to achieve an 8% slope the route should be at least 250 feet long between any two contours as shown in Figure 4.

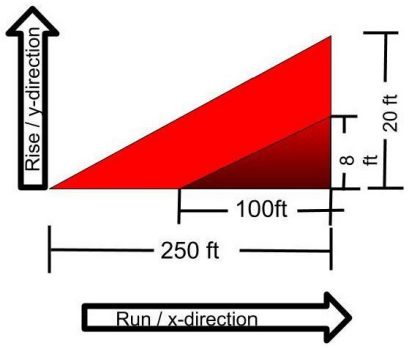

Figure 4: Horizontal distance between two contours to fulfill 8% slopes.

Figure 3a presents four road options designed for one of the projects. It should be noted that students were asked to avoid sudden horizontal curves. The concept of the horizontal curve was not taught in detail in this project. Also, for each proposed route, a vertical profile was generated, and the options were compared. Students are asked to decide for their choice of road by considering three criteria: first, slope of the road, second length of the road and third the amount of earthwork needed which can be observed by the number of sudden rise and drops in the vertical profile. Considering the criteria given and using their engineering judgment, each group decided for their option of the road. In this section of the project students were introduced to the concept of vertical curves and geometric design in an engaged project.

3. Earthwork

The main purpose of this section is to introduce students to the concept of earthwork, and specifically the concept of cut and fill. In this part of the project, students were asked to define stations, one thousand feet apart on the selected road. At each station, students read the elevation of the ground ten feet to the right and ten feet to the left of the station (It is assumed that the width of the road is 20 feet). They drew the cross-section of the profiles and calculated the amount of soil needed to be cut and fill. This process was completed for all stations and the total amount of soil needed to be cut and fill was calculated.

Figure 5 shows the method students used to calculate the amount of cut and fill between two stations.

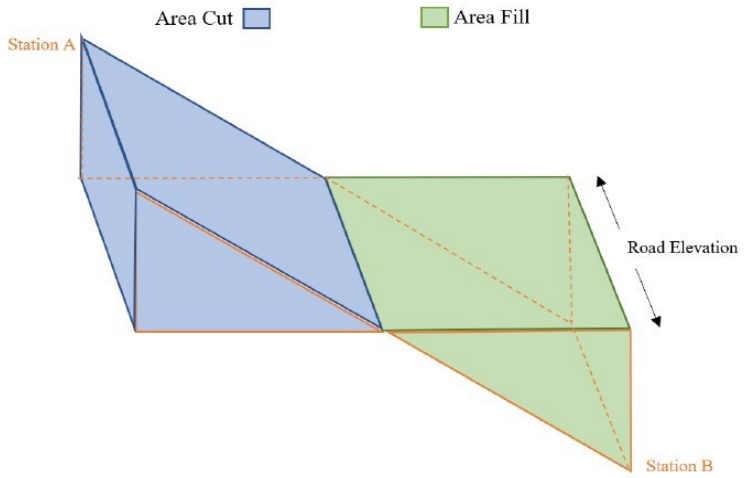

Figure 5: The cut and fill concept demonstration by one of the groups

Discussion and Assessment

A road design project was assigned to first-year students in Spring 2019 and 2020. The project included multiple civil engineering aspects, such as practicing SOLID WORKS or AutoCAD – Civil 3D, understanding the concepts of a topographic map, geometric design, and earthwork. Students presented their projects in the format of a poster in the first-year student showcase at the end of the semester.

38 out of 48 (79%) students who worked on this project in the Spring 2019 and 2020 semesters participated in the end-of-semester course evaluation. This evaluation included 18 questions, but not all the questions were related to the project and could be used as an assessment tool for the effectiveness of the project. The results of the evaluation for questions that were

related to the project is explained as follows (It should be noted that the results represents both Spring 2019 and 2020 semesters):

- More than 94% of students agreed or strongly agreed that the course was able to integrate theory and application.
- 93% of students agreed or strongly agreed that they gained conceptual understandings by taking this course.
- More than 87% of students agreed or strongly agreed that the course helped them to gain understanding traits of leadership.
- More than 90% of students agreed or strongly agreed that they were able to improve their teaming skills by taking this course.

One of student's comments about the project when they passed the Introduction to Geomatics course in the Sophomore year of their education is presented below:

"The road map project was a great project to center our class around. It was engaging and got everyone involved. It definitely did help me in Geomatics class and I am sure it will help in the future when I deal with topography maps. It was fun to do something hands on and take a break from our difficult classes. I always looked forward to it an hope I can do something similar in the future."

In Fall 2020, the students learned about surveying in the Introduction to Geomatics course. Students who worked on this project in their first year of college education agreed that the 3-D printing of the topographic map and working on the map helped them to understand sections of the Introduction to Geomatics course better in Sophomore year. One of the students' comments is presented below:

"The introduction to engineering design project we completed was a great insight to future classes. More specifically introduction to geomatics. It was very helpful to recognize topographic maps, as well as understand how they work. It helped transition to a more advanced class and understand the topics at hand in geomatics."

Students who worked on this project will learn about geometric design in Summer 2021 and 2022 when they take the Highway Design course. The authors will run a survey about the effect of this project on their learning of geometric design at the end of (the) Summer 2021 semester.

Conclusion

This project helped students to learn multiple aspects of civil engineering, such as topographic map, geometric design of roads, and earthwork. Students appreciated an important aspect of civil engineering and they moved on to the sophomore excited to learn more. The main purpose of this paper is to share this interactive project with other first-year civil engineering instructors. Colleagues are welcome to reach out to authors to learn more about this

project. All colleagues who are involved in teaching first year engineering education are welcome to use or modify this module and idea for their classes.

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