Using computer simulation to teach technical aspects of construction in a liberal arts setting

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Abstract

The general education curriculum at Liberal Arts colleges requires students to take courses in history, literature, civilization, social sciences, sciences, and cultural diversity. These courses comprise almost a third of the entire curriculum. All students, including engineering students, are required to take these courses to fulfill the general education component of their curriculum. In this day and age where technology plays an integral role in people's daily lives, it seems odd that, although engineering students are required to take almost a third of their courses on non-engineering topics, the liberal arts students are not required to take any engineering or technology-oriented courses. Engineering courses are deemed too technical for the non-engineers to take. At such colleges, the freshman-writing course is considered to be a venue to introduce young students to a mature level of analytical reading, thinking, discussion, and writing. A new experiment is being developed to make available to both engineering and non-engineering students a technical module on construction technology. The module is designed to introduce the liberal arts students in particular to highly technical aspects of the construction industry. It aims at allowing students to acquire appreciation for the complicated and carefully coordinated effort associated with the construction of sophisticated structures. Several types of structures and methods of construction techniques will be presented. The role played by different structural components in carrying and resisting expected loads will be discussed in detail. The structures covered in this module are suspension and cable-stayed bridges, towers, domes and shells, sea platforms, dams, tunnels and monuments. Each of these structures has its own special features, and their construction involves certain challenges that must be tackled in a well-planned manner. For non-engineering students, the module intends to make a meaningful contribution to their comprehension of the complicated nature of construction. This will be coupled with assigned technical readings on simple principles of load-supporting structural components. It is hoped that this module will serve as an eye opener for those who have never had any exposure to the building industry. It is also anticipated that the technical content planned for this course will help non-engineering students achieve a reasonable level of understanding of what could be a life-long useful knowledge.

I. Introduction

Colleges and universities design their General Education Curriculums to create in students a commitment to learning over the course of a lifetime. Union College, for instance, has "designed a general education curriculum that (1) seeks to open students' eyes and whet their appetites for more learning and (2) directs them toward acquiring the kinds of skills and knowledge appropriate for Americans living in the twenty-first century."

The following is a presentation of the components of the General Education Curriculum at Union College. These components are designed so that students would achieve the above two stated goals by the time they complete the requirements for their undergraduate education. "The aim of the General Education Curriculum is to ensure that every student graduates from Union with a liberal education and with the ability to write clearly and persuasively. Each of its elements makes a particular contribution to this end by providing:

1. An introduction to a mature level of analytical reading, discussion, and writing in the Freshman Preceptorial.

2. A comprehensive knowledge of one of three significant areas in Western civilization through four courses in the history, literature, art, and thought of Classical Antiquity, Europe, or America.

3. An introduction to the methods of the social or behavioral sciences through a course in anthropology, economics, political science, psychology, or sociology.

4. An understanding of the inherent beauty and poetry of mathematics through an appropriate course.

5. An experience in the natural sciences through two courses in basic or applied science, at least one of which must include laboratory work.

6. An exposure to other languages or cultures, by participating in the Terms Abroad program, or completing two or three courses in a foreign language, or three courses in one of the following -- Africana, East Asian, or Latin American Studies.

7. Significant writing experiences: (1) Freshman Preceptorial, (2) two to four courses that include intensive writing, and (3) a Senior Writing Experience such as a senior thesis, project, or seminar."

II. Observation

As can be seen in the above, the General Education Curriculum places considerable emphasis on providing the students with exposure to aspects in the humanities and social sciences, and with a lesser extent, to aspects in science and mathematics. This is probably the case in many colleges and universities. Engineering students are usually required to take courses that are not completely related to their majors. These courses are meant to provide engineering students with a background in history, the arts, and social or behavioral sciences. The liberal arts students, on the other hand, are not necessarily required to take courses in aspects related to engineering or technology. The recent technological advances of the information age have touched the society in a tangible way. The importance and vitality of engineering and technology to a smoothly functioning society cannot be overstated. Despite this major role played by engineering and technology in the daily lives of many people, the undergraduate education curriculums have not created a proportionate room to accommodate and represent these factors. It is argued that an exposure of the non-engineers to engineering and technology in undergraduate education can help create an even more advanced society. It can also lead to a greater degree of comprehension and appreciation of the important role played by engineering and technology.

III. Concerns

There exist many subjects related to engineering and technology that could be added and/or incorporated into a general education curriculum. Before incorporating any engineering or technology-related courses into the general education curriculum, one needs to be able to address three possible concerns: (1) the level of sophistication and technicality of the materials; (2) whether this topic is added as a new material or as a replacement of an existing material; and (3) who should teach this material.

Unfortunately, the above three concerns cannot be addressed to the full satisfaction of all interested parties. It is necessary to find a compromise that would be acceptable to all. The first concern is probably the easiest to address. The level of sophistication and technicality should not be too high. The goal is to make the material appeals to non-engineers with little technical background, thus a reasonable level of technicality would make the material attractive. Another aspect that could be of great help is that if the selected topics of study are intuitive, students will naturally like the material because they will sense that they do not need to tax their brains to understand what is being covered.

The second concern is probably the most controversial one to address. If technology or engineering-related topics are to be included in the general education curriculum, one will find many objecting voices to the replacement of traditional fields of study with the new materials. A compromise on this issue is hard to achieve. An unconventional way to solve this problem is to structure a technical section of freshman preceptorial that can be taken by those who desire it. As these technology and engineering-related topics gain acceptability and popularity, it can become a permanent fixture in the general education curriculum.

The third concern is somewhat problematic because it may involve “turf battles”. The conventional fields of general education are traditionally taught by liberal arts faculty. With the introduction of technology and engineering-related courses, faculty with technical or engineering background will be needed to teach these courses. To remedy the feeling of loss that traditional liberal arts faculty may feel, any faculty who feels capable of teaching a technology or engineering-related material should be given the opportunity to do so.

IV. Implementation

The construction area is a rich field of study that can be easily adapted to meet the above requirements. Construction is an area that has seen great advancements in materials and techniques yet the overall stability of structural components could be intuitively sensed and appreciated. Furthermore, the need to construct a given structure and the factors that affect its form and shape including cultural, environmental, historical, economical, social, and political factors are all subjects that can be a wealthy source of reading, writing, and discussion. Since these are the main components in a successful preceptorial, construction projects constitute a resource for all needed ingredients of success. With this in mind, a module on construction was developed to introduce the liberal arts students to a fascinating aspect of technology without overwhelming them with complicated or hard-to-understand materials.

V. Themes

Suspension Bridges
Suspension bridges are very sophisticated structures. Cables are used to suspend the bridge deck from bridge towers. The study of the stability of a suspension bridge is very complex. The stability of these bridges as they undergo construction is even more complex. The selected project addressed in this theme is the Brooklyn Bridge (Figure 1). The following are some of the major features of this bridge:

- Completed in 1883.
- Distance of roadbed above water: 135 feet.
- Height of Towers: 276 feet Tower Structure.
- Depth of Brooklyn caisson: 44 feet, bearing on bedrock.
- Depth of New York caisson: 78 feet, bearing on sand.
- Thickness of towers is about 100 feet.
- Thickness of concrete abutments is about 500 feet.
- Total masonry in towers: 85,159 cubic yards. Stone clad steel towers.
- Weight of suspended structure: 6,620 tons.
- Total weight of bridge: 14,680 tons.
- Suspension cables: four 15.75 inches diameter wire ropes.
- Steel cable wire strength: 160 ksi.
- Total length of steel wire cables: 15,000 miles. A total of 5434 cables were used.
- Dead weight of deck and suspenders: 13,240 kips - 3,410 kips per cable.
- Maximum load on single cable (live and dead load): 6,000 kips.
- Ultimate strength of cables: 24,600 kips. Cable factor of safety: 4.
- Maximum cable sag: 130 feet.
- Brooklyn Bridge East River span: 1595.5 feet. Supported land span: 930 feet. Total length end-to-end is 6,016 feet.
- Thickness of wooden walkway boards – 1.5 inches.

- World Record Status at time of completion fifty percent longer than any bridge ever built first use of pneumatic caisson.

The main factors stressed in this project are:
- Historical factors related to physical gap between Manhattan and Brooklyn.
- Political factors related to the responsibility of funding the project.
- Economical factors related to cost of the bridge.
- Design factors related to the nature of the adopted innovative design and the unprecedented length of the span. Of importance too is the enormous size of the towers and their foundations.
- Construction factors related to the expertise needed to execute such structure.
- Health factors related to the mysterious health condition that affected those workers who worked on the caissons of the foundation under very high pressure.

Figure 1. The Brooklyn Bridge, New York City, New York.

Cable-Stayed Bridges
Cable-stayed bridges adopt an innovative technique to achieve stability. Cables are used to suspend the bridge deck from the main towers of the bridge. These cables transmit the loads to the towers that subsequently transmit it to the foundation. Bridge deck is usually made of segments. Each segment of the deck relies on at least a pair of cables to transmit its load to the tower. The operation of attaching the deck to bridge towers is a delicate one and requires balance because the loads on either side of the tower are usually almost identical. This is one of the major features of equilibrium in these bridges. The Sunshine Skyway Bridge, Tampa, Florida, is selected as an example of cable-stayed bridges (Figure 2). The following are some of the major features of this bridge:
- Completed in 1987.
- Length including approaches: 29,040 feet.
- Tendon capacity: 514,000 pounds of tension.
- Materials: steel and concrete.

- The bridge is 22,000 feet long, features a center span of 1200 feet; two 6,000-foot approach sections constructed of precast, pre-tensioned concrete beams with two 100-foot spans; two 4,000-foot high level approach sections of post-tensioned, segmental concrete construction; a 2,400-foot cable-stayed center section of post-tensioned, segmental concrete; and two 430-foot concrete towers to support the cable stays.
- The dolphins around each pier were designed to withstand the impact of an 87,000-ton ship sailing at ten knots.
- Steel cables support the roadway: 21. The cables are sheathed in steel pipes, 9 inches in diameter.
- Forty-foot-wide roadways run on either side of the cables. This design allows drivers to have unobstructed views of the water.
- Tampa is a busy shipping port. To ensure that navigation would not be blocked, engineers designed the bridge to soar 190 feet above the water.

The main factors addressed in this project are:

- Economical factors related to spanning the water body across Tampa Bay and its effect on the ease of transportation of people and goods.
- Political factors related to funding and the length of time it would take for the project to cover its cost.
- Environmental factors related to the effect of the construction of the bridge on the surrounding area.
- Construction factors related to the presence of the bridge in a humid area with high concentration of salts that has a negative impact as a result of corrosion on steel in structures.
- Design factors related to the many piers and caissons that are used to support the bridge. These foundation elements require special design and protection against navigation accidents from vessels traveling across the bay.

Figure 2. The Sunshine Skyway Bridge, Tampa, Florida.

Towers

Towers are lightweight, tall structures usually anchored to the ground to prevent overturning and the impact of severe wind. The degree of sophistication of the anchoring system depends on the height and the weight of the structure. The method used in the construction of the tower depends on the materials used in construction. The selected tower addressed in this theme is the CN Tower in Toronto, Canada (Figure 3). This tower is the world's tallest building and the highest freestanding tower in the world. The following are some of the major features of this tower:

- Completed in 1974, and the antenna was completed in 1975.
- Total height: 553.33 m (1,815 feet).
- At the base of the CN Tower: circumference - 109.1 m (358 feet); radius - 33.2 m (109.2 feet); diameter - 66.6 m (218.4 feet).
- Total weight of the Tower: 117,910 metric tonnes (130,000 tons).
- Volume of concrete: 40,523.8 cubic meters (53,000 cubic yards).
- Tensioned steel: 128.7 km (80 miles).
- Reinforcing steel: 4,535 metric tonnes (5,000 tons).
- Structural steel: 544.2 metric tonnes (600 tons).
- Number of elevators: 6.
- Speed of elevators: 6 meters/second (20 feet/second).
- Slow speed of elevators (in high winds): 1.5 meters/second (5 feet/second).
- Maximum sway in 190 km/h winds with 320 km/h gusts (120 mph winds with 200 mph gusts): antenna - 6 feet, 8 inch from center; sky pod - 3 feet, 4 inch from center; tower sphere - 1 feet, 7 inch from center.

Figure 3. The CN Tower, Toronto.

The main factors addressed in this project are:

- Commercial factors related to the purpose of constructing this tower to be a center for radio transmission.
- Economical factors related to the cost of construction and the return on the investment.
- Design factors related to the unprecedented height of the structure and safety concerns due to wind effect, earthquake motion, and thunder storms including lightning.

Domes and Shells

Stadiums, houses of worship, sport and entertainment complexes are examples of structures constructed with a roof formed as a dome or as a shell. The design of domes and shells is one of the most complicated engineering tasks. Domes or shells are thin structures that cover large area with a considerable span. The segmental construction of these structural elements requires very extensive planning and sophisticated scaffolding systems. Every precaution is taken to ensure that these structures do not deform while they are under construction. Any deformation may compromise their safety. An excellent example of such structures is the Superdome, New Orleans, Louisiana (Figure 4). The following are some of the major features of this dome:

- Completed in 1975.
- Total land area: (building, garages, and grounds) 52 acres.
- Height: 273 feet (82.3 meters).
- Diameter of dome: 680 feet (210 meters).
- Area of roof: 9.7 acres.
- Interior space: 125,000,000 cubic feet.
- Total square footage: 269,000 sq. feet (82,342 sq. meters).
- Main arena: 166,180 sq. feet (50,685 sq. meters).
- Convention concourse: 27,084 sq. feet (8,261 sq. meters).
- Concrete: 169,000 cubic yards (131,820 cubic meters).
- Structural steel: 20,000 tons (18,200 metric tons).
- Air conditioning: 9,000 tons (8,190 metric tons).
- Electrical wiring: 400 miles (640 kilometers), including fiber optic lines.
- Anodized aluminum siding: more than 550,000 sq. feet.
- Escalators: 42.
- Elevators: 14, plus 1 for freight.
- Maximum seating capacity: football - 72,675; expanded football - 76,791; arena concerts - 24,500; basketball - 64,659; baseball - 63,525; festival concerts - 87,500.
- Artificial turf: 81,120 sq. feet, 26 panels for football; 127,520 sq. feet, 80 panels for baseball.

The main factors addressed in this theme include:

- Political factors related to issuing of bonds for public finance of the project.
- Design factors related to the size and the area covered by the roof since a roof that large was never constructed before.
- Drainage factors related to the fact that the city of New Orleans is under sea level that constituted a challenge to collect the water of rainfall and pumping it out of its environs.
- Construction factors related to a temporary scaffolding system that supported the roof during erection.
- Economical factors related to the management of the Superdome.

Figure 4. The Superdome, New Orleans, Louisiana.

Sea Platforms

Sea Platforms are used extensively in oil exploration and production. These platforms could be floating or anchored to the seabed. In either case, the construction of these structures constitute an unparalleled challenge due to factors that are extremely difficult to cope with such as water current and tide, in addition to strong winds. Engineers have been successful in devising innovative methods for offshore construction. The selected project addressed in this theme is the Statfjord B oil platform, Norway (Figure 5). The following are some of the main features of this platform:

- Completed in 1981.
- Height: 890 feet.
- Total weight: 824,000 tons of concrete and steel. The platform is gravity structure that rests on the seabed under the effect of its immense weight.
- The base consists of 24 cells made of reinforced concrete, built in a dry dock. Twenty of these cells are storage cells 75 feet wide by 210 feet high for crude oil. This weight helps stabilize the platform.
- The weight of the deck is 40,000 tons. The deck rests on four hollow legs rising from the base cells.
- Rate of oil production: 150,000 barrels a day.
- Maximum drill depth: 19,700 feet.
- Storage capacity in the cells: 2 million barrels.
- Constructed on the deck is a 7-storey, 200-bed hotel where workers live. There are also a refinery and a helicopter landing pad.
- The platform is the largest structure ever moved. It was towed 245 nautical miles.

The main factors addressed in this project include:

- Environmental factors related to detailed impact studies conducted on the pollution and contamination that may affect the environment due to small oil leaks or more serious spill resulting from an accident.
- Economical factors related to the fact that the North Sea oil can only be economical to produce if oil prices do not fall below a certain level. If oil prices are lower than the limits of an economical operation, the viability and feasibility of the project become questionable.
- Political factors related to the opposition of certain groups and interested parties to the idea of oil exploration in a virgin area such as the North Sea that is considered by many as an environmental treasure that should not be contaminated.

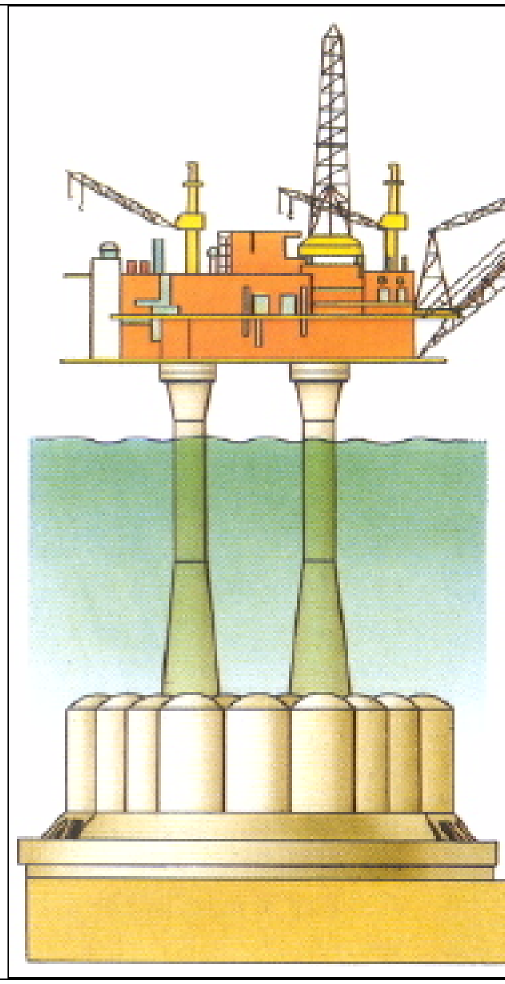

Figure 5. The Statfjord B Oil Platform, Norway.

Dams

Dams are huge structures that are built across rivers to basically block the waterway. They are used to regulate water and/or for power generation. In some cases a temporary structure must be built to protect the real structure while being constructed. In other cases the river will have to be diverted to make the construction of the dam possible. The stakes are usually high in projects of this nature because the amount of water held by the temporary structure could cause a very destructive damage to communities along the river path. Hoover Dam, Nevada, is covered in detail in this theme (Figure 6). The following are some of the main features of this structure:

- Completed in 1935.

Dam Dimensions

- Height: 726.4 feet (221.3 meters).
- Length at crest: 1,244 feet (379.2 meters).
- Width at top: 45 feet (13.7 meters).
- Width at base: 660 feet (201.2 meters).
- Weight: 6.6 million tons.

Reservoir Statistics

- Capacity: 28,537,000 acre-feet (35,200,000 cubic meters).
- Length: 110 miles (177 kilometers).
- Shoreline: 550 miles (885 kilometers).
- Maximum depth: 500 feet (152 meters).
- Surface area: 157,000 acres (63,900 hectares).

Quantities of Materials Used in Project

- Concrete: 4,440,000 cubic yards.
- Explosives: 6,500,000 pounds.
- Plate steel and outlet pipes: 88,000,000 pounds.
- Pipe and fittings: 6,700,00 pounds (840 miles).
- Reinforcement steel: 45,000,000 pounds.

The main factors addressed in this project include:

- Historical factors related to the inability to control or regulate water flow in the area where the dam is constructed.
- Economical factors related to the depressed economy at the time of dam construction and the difficulty associated with financing options.
- Geographical factors related to the selection of the most proper site for the construction of the dam along Colorado River.
- Design factors related to the unprecedented size of the structure and the enormous amount of concrete that would be used. This involves problems related to the cooling down of the concrete after the completion of the hydration process.
- Construction factors related to the development of new methods to transport enormous amounts of aggregates for concrete manufacture. The transportation of the mixed concrete and heavy structural elements also required innovations in the use of cableways and cranes.
- Logistical factors related to housing and feeding the thousands of workers who worked on the project and providing them and their families with health and social services.

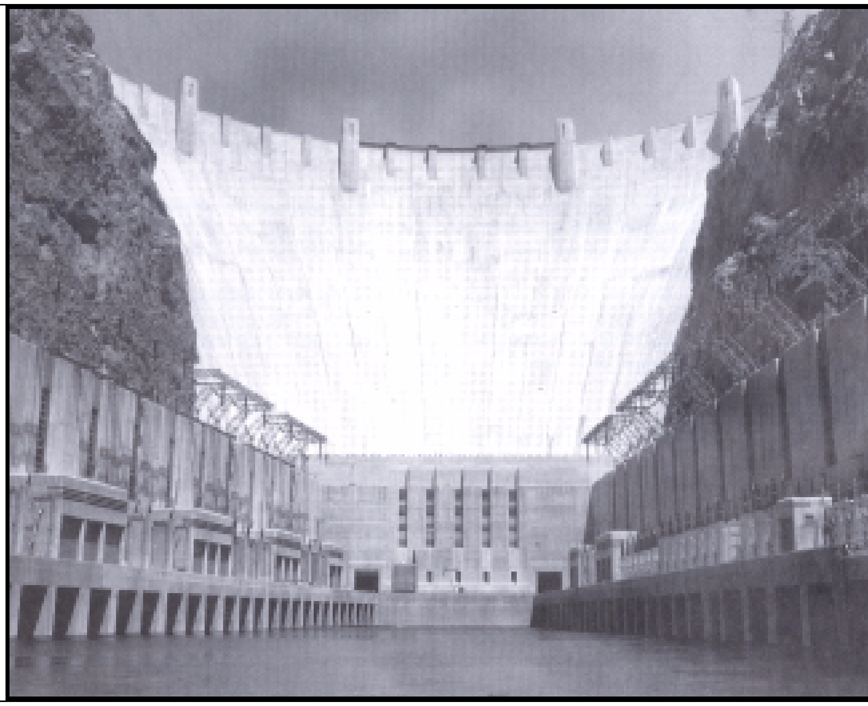

Figure 6. The Hoover Dam, Nevada.

Tunnels

Tunnels are structures that require high engineering skill in design and construction. There are many great examples of underground and under water tunnels. The Channel Tunnel that connects France and England is probably the most famous example of tunnels. The tunnel's conceptual idea emerged several centuries ago. There were always problems that prevented these ideas from being executed. The history and factors that affected the design and construction of the Channel Tunnel are selected as the subject of this theme (Figure 7). The following are some of the main features of the Channel Tunnel:

- Completed in 1994.
- Consists of three tunnels, each 50.45 km long, and are 30 meters apart (length undersea is 38 km or 24 miles). They were bored in the rock strata under the Channel at an average depth of 45 meters below the seabed.
- The two large tunnels (7.6 meters diameter) each contain a single-track railway line.
- The smaller service tunnel (4.8 meters diameter) is located between the two rail tunnels.
- All three tunnels are connected every 375 meters by a cross-passage that gives access to the service tunnel in case of emergency. The cross-passages are also used for ventilation and maintenance service access.
- Every 200 meters, piston relief ducts link the two rail tunnels.
- All three tunnels are lined with concrete linings.
- A circular access shaft, 70 meters deep and 55 meters in diameter was excavated and lined with concrete.
- Soil removed during building: 8 million cubic meters at a rate of 2400 tonnes/hour.
- 12 tunnels were excavated: 6 undersea, 6 underland.
- 11 tunnel boring machines (TBM): 6 undersea, 5 underland.

- Rate of advance of TBM (England side): best day - 75.5 m.
- Rate of advance of TBM (France side): best day – 56 m.

The main factors addressed in this project include:

- Political factors related to the easy access the tunnel creates between two countries with different cultures, languages, laws, and policies.
- Economical factors related to the enormous cost of the project and the rate of return on the investment.
- Social factors related to the mind set created by the physical presence of the tunnel that makes it easier for the English and French societies to blend and work in harmony.
- Commercial factors related to the opportunity the tunnel created in making it easy to transport people and goods.
- Environmental factors related to the effect of tunnel building on the environment and on the natural soil formation in the sea bed that. Of concern too was the disposal of the spoil resulted from the excavation of the three tunnels of the project.
- Design factors related to and associated with the difficulty, complexity, and sophistication of different control systems. There were many advanced features in this project including energy supply, ventilation, cooling system, control of air pressure, safety against drainage, pumping, alarm, fire hazard, remote control in case of emergency, and escape plans.
- Construction factors related to bringing to reality what engineers envisioned and the expedient and accurate execution of the plans.

Figure 7. The Channel Tunnel, England-France.

VI. Teaching Aids

A comprehensive set of animated figures and detailed movies were created for each and every project in this construction module. The aim is to make visual aids an integral component of the learning process since the learners will be students with little technical background. These teaching aids should be helpful especially that the themes covered in this module address structures with sophisticated nature and high level of technicality.

V. Conclusion

A construction module with themes on sophisticated structures has been developed and is intended for non-engineering students with little technical background. It is hoped that this module will serve as an eye opener for those who have never had any exposure to the building industry. It is also expected that the technical content planned for this course will help non-engineering students achieve a reasonable level of understanding of what could be a life-long useful knowledge.

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