The positive effect of construction site visits in the adequate comprehension of structural engineering concepts for students.

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Abstract

The purpose of this paper is to evaluate, through on-line polls, questionnaires, and face-to-face interviews, how the civil engineering and architectural students feel the improvement of their comprehension of structural analysis topics by the construction site visits experience. There is a large number of structural systems that can be seen in construction sites, so, the more visits are made, more structural systems we can study directly from the source, not only by watching and feeling the structure but also by talking and even interviewing the site actors such as construction workers, architects and engineers who can explain directly the application of many theoretical concepts.

In the study of different topics in structural analysis and design, the students' approach to the contents is based on theoretical contents and mathematical equation demonstrations that describe the structural behavior of different structural elements that integrate a building for different purposes, housing, commercial, industrial or infrastructure.

To develop mathematical models that adequately represent the structural behavior of the elements (slabs, beams and girders, columns, and footings among others), is mandatory that the students understand how each structural element behaves to handle the loads and mechanical elements acting over it. Also, the connecting forms that allow the mechanical elements transmission between these elements. Beam-beam connection, beam-column connection and column-footing connection.

It begins with the solution of structural models from simply supported beams with single loads trough complex structural models and variable loads. In this journey from simple mathematical models to complex models to analyze and design the structural behavior, the student doesn't get the complete concept and idea until they get in touch with real structural elements, not only in pictures or videos but in construction site visits where they can watch and feel from every possible angle and touch and feel the structure and its components. Not only in fully functional structures but in structures under construction to see and feel the insights of the element, rebars, reinforcements distribution and requirements, etc., so they can observe in a better and more complete way the function and behavior of every element. With this, they start to develop their own *structural concept*.

The best way to interact with the structure and its components is at the construction site, although the labs are helpful, the real action field is where they live and understand the structural behavior. The construction site visits are a fundamental tool in the competencies development for the students.

Key words: Higher Education, Structural engineering basic concepts

1. Introduction

In the study of different topics in the Structural analysis and design, the approach of the students to the contents is based on theoretical contents and mathematical demonstration of equations that describe the structural behavior of a number of elements that shape a building or a structure in any area, residential, commercial, industrial or transportation infrastructure.

To be able to develop mathematical models that adequately represent a real structure and its behavior, is necessary that the student understands how every structural element works and their connections to interact between all of them in a complete structure, beam-column connections, beam-beam connections, column-footing connection, etcetera.

The structural analysis and design study begins with the solution of structural models from basic model of beams with simple load distributions through complex structural model geometries with variable loads. In this transition from simple to complex structural models to be analyzed and designed, the complete concept is not obtained until there is a direct contact with real structural elements, not only in pictures and videos but in site visits where you can see them from every angle, touch and feel the structure and its components. But not only already finished and functioning structures, but structures during their construction period to observe the element interiors, the steel bar location, the welded elements, so the behavior of the element can be received by the senses and having a better understanding of their participation in the complete structural behavior. In other words, they are developing their “structural concept”. The “structural concept” is how an engineer, or an engineering student, visualizes the structural elements needed to fulfill the behavior of a building creating the spaces and areas developed in an architecture project, that provides safety levels to the users according to the different codes appliable to the structure according to its location and use.

The best way to get related with the structure and its elements is at the construction site, even tough the laboratories are really helpful, is in the action field at the construction site where we can live and understand the structure and its behavior. The construction site visits are a fundamental tool in the development of the competencies that the university is trying to develop in the students.

It is also necessary that the students identify the reason why, the designs that come from a structural analysis, must be feasible to be constructed and adapted to the available systems, tools and procedures in the construction site.

2. Methodology

During the period of this paper, we took a group of students to several construction site visits, the number of participants in each visit varies from 15 to 25 students, depending on the space available and the access allowed by the construction company responsible at each construction site.

Before and after every visit we asked some questions to the participants regarding their experience in construction site visits previous to our activity and their perception and learning goals after the visit was concluded.

One of the most interesting and complete site visit was to a cable-stayed bridge in Pachuca, Hgo. We had the opportunity to make three visits there in different stages of the construction.

Figure 1. Cable-stayed bridge visit (foundation and column casting).

Figure 2. Drilling and casting pile foundations.

Figure 3. Drilling and bar reinforcement location in pile foundations.

Figure 4. Cable-stayed bridge pylon assembling.

Figure 5. Cable-stayed bridge set of pylons.

Figure 6. Box girders.

Figure 7. Box girder supported before the prestressed tendons are placed.

In these visits, we were at the foundation pile drilling, in site column casting, structural steel girders mounting and cable tensioning.

A cable-stayed bridge is one of the most complex structural behavior elements there is, so its mathematical model, analysis and design is challenging to everyone involved in the process. The students find it really attractive and interesting, so they were very excited on these visits.

In the classroom sessions, the student gets, using mathematical models and theoretical developments, a general basic description of the structural behavior of a cable-stayed bridge. The concepts of general equilibrium so that the structures hold the performance requirements stablished in codes and state or federal laws, the characterization of the materials to evaluate their behavior during construction processes and the operation of the structure (during short and long term in the useful life of it), are the main topics of the lectures to give the students a complete comprehension of the structure's behavior.

The structural elements that are fundamental in a cable-stayed bridge like the mast or pylon, the torpedo tube, the prestressed cable tendons, steel decks, girders and slabs, can be studied using mathematical models, drawings, diagrams and blueprints, complemented by pictures and videos, but the students cannot feel or appreciate their dimensions and proportions neither their behavior and interaction. Due the location of these bridges, a lot of them in highways far from the cities with university campus, it is hard to have access to site visits, because of this geographical situation, it is very important for students and professors, when there is an opportunity close to our location, to be there and take all the knowledge and experience we can.

When students visit a bridge construction site, they can appreciate every element and their interaction with every other element in the structure. This is even better when they can visit in different stages of the construction process.

In the classroom, we study the general concepts of the bridge analysis and design in different kind of structural system: simply supported bridges, continuous beam bridge, precast elements in bridges, reinforced concrete bridges, structural steel bridges, suspension and cable-stayed bridges.

The total perception of the student regarding the elements that assemble a bridge and the behavior of these to handle the mechanical elements to be supported in all the stages of the bridge's life is usually incomplete with only theoretical concepts. Taking it to the analysis and design process, some of these missing concepts are completed using pictures and videos, drawings and blueprints, but there are missing points regarding the complete structural performance between the loads and the structural elements.

The possibility of having construction site visits at a cable-stayed bridge, are not frequent, mainly because these infrastructure developments are not common in our country (Mexico). Also, the access to these sites is often restricted due to logistic and safety matters and distances and location.

In 2020 and 2021, we had the chance to have access to the construction site of the cable-stayed bridge “Miguel Hidalgo” in Pachuca, Hgo. Mexico. The students had the opportunity to be there and not only watch and feel the structure but also to talk and have interaction with structural engineers, construction workers, construction administrators, government officers, supply company people and many more involved in the process. Due to the pandemic situation in these years, some of the visits where virtual using Zoom Meetings [1]. In these visits, we had approximately 120 students from both, Civil Engineering and Architecture Majors.

The construction site visited has a hybrid structure with approach ramps in reinforced concrete with prestressed box girders and the cable-stayed zone with structural steel box girders and a post tensioned slab supported by prestressed tendons on 4 pylons. This structural system combinations, made this project a complete tool for many topics in the structural design and analysis area, to be explained to the students on site and later at the classroom.

We watched complete construction processes like pile drillings, rebaring and location of reinforced steel bars, concrete casting of piles, prestressed box girder fabrication, compression slab rebaring and concrete casting.

When we studied deep foundations with concrete piles casted in-situ, the students did not comprehend every step of the process, the concrete casting using “treamie” pipes and so on, but watching it done at the construction site they fully understood all the process. This is only a short example of what happened at the site visits.

When we studied structural steel elements in compression, the general buckling and local buckling concepts are not clear enough in their real-life application, watching the interior of the pylons prior to their installation the students realize exactly how this phenomena is prevented and how useful is to know the basis of buckling to calculate their restrictions.

Figure 8. Interior reinforcement of the pylons to prevent buckling.

The structural steel box girders are another example of the construction site visits need, in the classroom we calculated the inertia moment and other cross section geometrical and mechanical properties, but the buckling revisions and their meaning got meaning at the site, because we can see and feel them, specially if they are at their final position.

Results

We found that using Google Polls applied to students participating in the construction site visits, was a good way to evaluate the positive effect of construction site visits in the adequate comprehension of structural engineering concepts for students.

We asked them their perception before and after the visit of the structural concepts and the understanding of the behavior of the different elements in a structure.

The period of this paper was from February 2020 to December 2022. In the first two years, the social distance restrictions limited the access to the construction sites so some of the visits were hybrid, having a small group physically at the site and a large group via zoom meetings in a live streaming broadcast. So, another question was if there is an extra possibility in the future to continue with these activities in the hybrid model.

We asked 127 students if they had the opportunity to be at a construction site visit previously, and we found that 77% haven't. In the second question, we asked the students about their understanding of a cable-stayed bridge being '1' I don´t understand anything and '5' I completely understand everything.

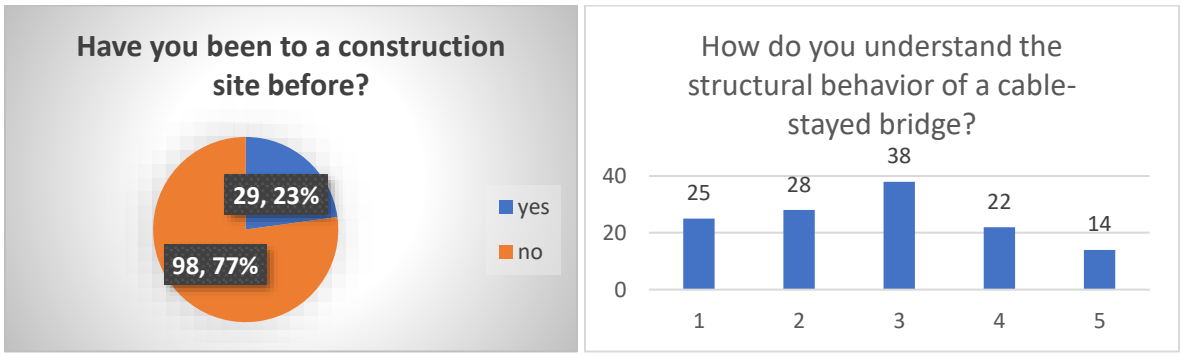

Figure 9. Poll answers about previous situation to the construction site visit.

After the visit, we asked the students about they structural understanding and the theoretical concepts understanding being '1' it did not improve at all and '5' I improved a lot.

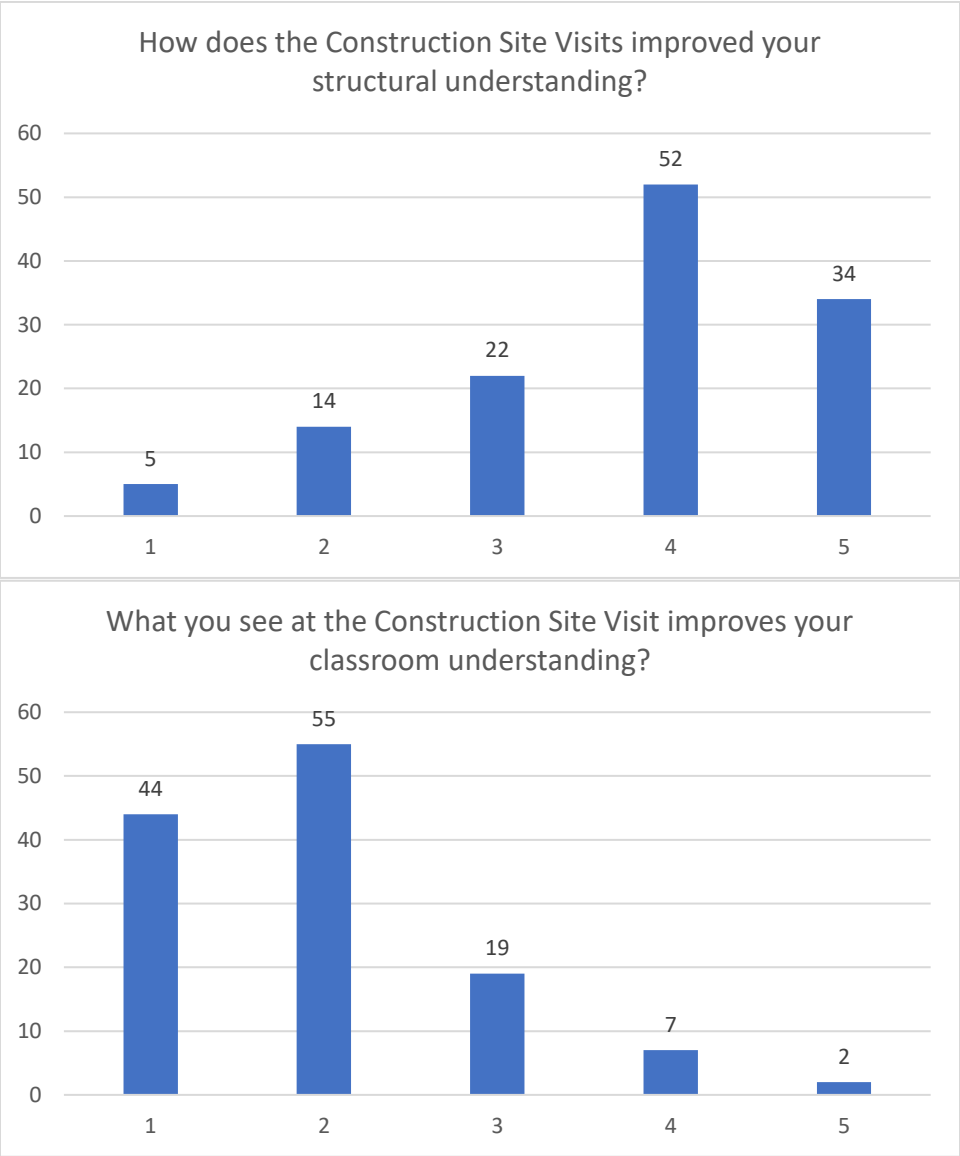

Figure 10. Poll answers about improvement after the construction site visit.

We can observe that the perception of the students, regarding their own improvement in the structural elements' behaviour understanding is high because in the first question about structural understanding 86 out of 127 answered in the top improvement answers and in the second question about understanding theoretical concepts in the classroom 99 out of 127 answered in the top improvement answers.

During these visits, we had the opportunity to talk and interact with professionals involved in the design and construction. We talk to the structural engineers design team and asked questions as; a)what software you used to make the bridge model, b) how do you evaluate the tension in the cables in the different stages of the bridge, construction, release of formwork, cable tensioning and short and long time use behaviour, c) how do you evaluate the mobile loads (trucks and vehicles) acting over the bridge, and a lot more of these type

of questions. We also talk to construction workers such as welders, we asked them a) how can you perform a quality job 180 ft above ground, b)how can you assure the quality in your welded connections, c)what is the most difficult part of your job, etc.

After the visit, in the classroom, we talked and have a discussion about what we have learned in these visits and in these opportunities to talk with the people directly involved in the construction job.

Conclusions

Construction site visits are fundamental in the development of competencies for the civil engineering students, to improve their understanding of the use and behavior of every structural element. If it is not possible to have construction site visits with a physical presence, virtual visits are a feasible option to continue with these activities. These construction site visits are not to be suspended and we have to find alternatives to keep going with them and with their participation in the competencies' development for the students.

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