

## **AC 2009-1849: DEVELOPING A COMPUTER-BASED SIMULATED ENVIRONMENT TO LEARN ON STRUCTURAL FAILURES**

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# Developing a Computer-Based Simulated Environment to Learn on Structural Failures

## Abstract

The need to include topics of analysis and investigation of structural failures in Civil Engineering undergraduate courses has been nationally recognized for some time. Structural failures are taken here to an educational ground because important lessons can be learned from failures. The goal of this project is to create new learning materials for active learning in a simulated environment to improve students' awareness about the causes and effects of structural failures in engineering. To achieve this, the research develops a computer-based learning system, in which students learn on structural failures by performing in a simulated environment. In the completed version, several modules will be developed and tested, to prepare undergraduate civil engineering students to tackle problematic situations. The implementation of computer-based learning has proven to be effective in university courses in disciplines other than SMET. The idea of asking the student to perform in a simulated environment is not new and was originally developed for students of management schools, but its use in civil engineering will be a specific contribution of this project. This involves adapting a methodology to groups of engineering students. The approach can be seen as immersed in case-based reasoning, although reasoning in this proposal is made by the learner and not by the computer. Only the simulated cases that need to be solved by the learner are implemented in the computer.

## Introduction: The Engineering Education Needs

This paper reports on the development of a computer-based learning system, in which students learn about structural failures by performing in a simulated environment.

Petroski <sup>7</sup> has emphasized the importance of studying structural failures in engineering, by supporting the idea that there is much one can learn from the bad experiences that have occurred in the recent or distant past. The underlying assumptions are that failures associated with design errors have been repeated throughout the history of structural engineering; therefore learning about what happened in the past will decrease the risk of future constructions. A similar argument was advanced over thirty years ago by Sibly and Walker <sup>14</sup>, who investigated structural failures in bridges in order to understand patterns behind those failures. The status of a theory that may identify causes of structural failures has been recently reviewed <sup>6</sup>.

The importance of integrating lessons learned from case studies of structural failures into the civil engineering undergraduate education has been emphasized by several authors (see, for example, Rendon-Herrera <sup>9</sup>, Delatte and Rens <sup>2</sup>). The ASCE-TCFE (American Society of Civil Engineering, Technical Council on Forensic Engineering) encourages universities to include forensic engineering and failure case studies in Civil Engineering education because a gap was recognized within this area in the engineering education.

Teaching about structural failures can be done using traditional methodologies (including lectures and assignments), but it is not easy to get instructors with the required knowledge to

make quality presentations on the topic. This requires a specialist, not present in most universities. The results of a survey conducted ten years ago by the ASCE-TCFE to ABET-accredited Civil Engineering schools, supported an initiative to include failure studies in the curricula; however, many schools responded that they did not know how to do that, or that they did not have case-studies on which the teaching could be based. “The lack of instructional material was cited as a reason that failure analysis topics were not being taught”<sup>2</sup> (pp. 99). Further, they are not included because many instructors think that there are more pressing teaching needs related to analysis and design.

Thus, the research reported in this paper addresses a recognized need in Civil Engineering education. Structural failures are taken here to an educational ground because important lessons can be learned from failures: A structural failure is here seen as an opportunity to learn. This problem is not restricted to Civil Engineering, because failures and the possibility of learning from them can be seen as a learning opportunity in nearly all Engineering branches.

### **Ways to Teach Lessons Learned from Structural Failures**

Besides the traditional lecture/conference approach mentioned before, an educational alternative is to generate new material that can be shared by many instructors, and which includes the main topics in a didactic way. This could be done in the form of a booklet (passive approach), or using new information and communication technologies within the framework of an active approach. This research attempts to meet the need of integrating lessons learned from case studies of structural failures by developing new learning materials to be used as part of an existing course. Specifically, we attempt to create new learning materials for active learning in a simulated environment. The main goals are to improve students’ awareness about the causes and effects of structural failures in engineering, and to help them develop skills on conducting failure investigations.

To achieve this, the present research develops a computer-based learning system, in which students learn on structural failures by performing in a simulated environment. In the completed version, several modules will be developed and tested, to prepare undergraduate civil engineering students to tackle problematic situations. At present, a module for an advanced course has been developed and partially tested.

### **Learning by doing in a computer-based simulation**

As stated by Dede<sup>1</sup> and others, students may have significant differences in learning styles. This is the root of a “blended” approach, according to which different teaching strategies should account for the differences in student learning styles. Most teaching occurs at present in lecture format, which appeals to just one learning style, and it would be desirable to have other formats available in the same course.

This project is centered on the methodology known as “Learning by doing in a simulated environment”. The idea of asking the student to perform in a simulated environment is not new and was originally developed for students of management schools, its use in civil engineering will be a specific contribution of this project. This involves adapting a methodology to groups of

engineering students. This methodology has been successfully applied by Roger Schank and co-workers in a number of simulations in business administration<sup>12,13</sup>. It evolved from earlier work on case-based reasoning and case-based explanations<sup>10,11</sup>, which is somehow different from using case-based teaching<sup>8</sup>. Schank's approach is about active learning, and its main postulates may be stated as:

(1) Training that is carried out on a computer should involve some form of simulation, in which the learner plays a role in doing something. "Doing" in this project is some form of action on a situation related to a structural failure.

(2) The environment should be designed so that it can provide the learners with several ways to support their learning.

(3) Failure is an essential part of learning, so that a simulation should provide the learner with situations in which she can make mistakes and fail. This can be achieved by including information that may lead a novice to form premature erroneous conclusions.

(4) The learners should be able to ask questions to an expert when they need it more, that is, when they make mistakes. If a situation does not result as expected, then it brings questions to the people who attempt to understand the situation.

(5) A learning environment may be effective if it is related to the interests of the students. The current project will bring professional issues, which are of great interest to engineering students.

The simulations presented by Schank tell how a story (or parts of it) develops<sup>12</sup>, but not how the computer-based system is organized. An example of how this is presented in one of Schank's simulations is given in Figure 1.

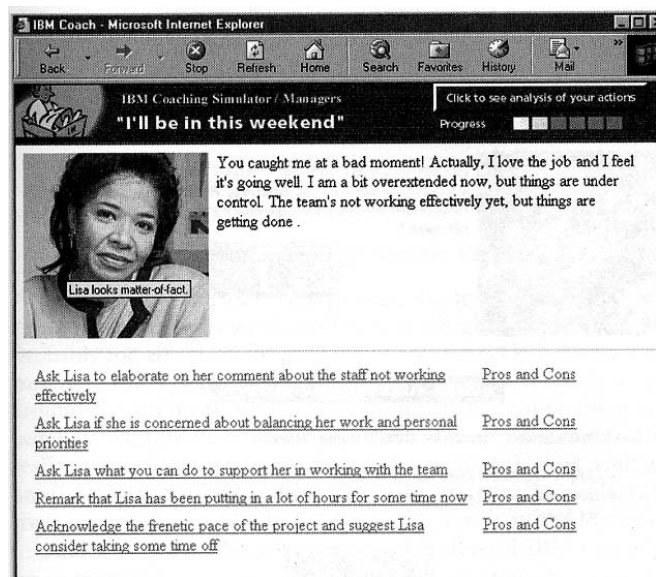


Figure 1. A typical screen in one of Schank's simulations.

### The organization of a learning module

An adaptation of Schank's approach to the field of engineering structural analysis has been implemented in this research. Some of the initial tasks carried out in this research included the

organization of a simulation in a systematic and effective way<sup>3</sup>. Rather than obscuring the methodology employed, this section attempts to fill details concerning the system architecture.

The opening screen of the environment is a welcoming address in which a task is assigned to the student. This is Level 1 in the navigation tree. The student is addressed by a member of a fictitious company involved in the oil industry, who requests his/her help in investigating the causes of failure of a storage tank. A photograph of the failed tank is shown to the student. To create a more realistic simulated environment, this company member speaks from a video. The student plays the role as an expert in the field. The video ends with a question: Will you be able to help us?

By tapping into the question, the student goes to the next screen (Level 2), in which there are three possible answers:

- Yes, and I want to start my investigation now.
- Yes, but first I need to prepare a strategy to do the job.
- No, I cannot do the job at the moment.

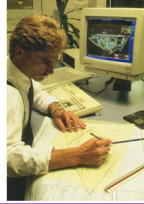
If the student chooses the second option, then the next screen (Level 3) helps him/her to prepare a research strategy. This help is in the form of written texts provided (as in a library), in which successful strategies followed by experts in this field are described. There is a chance of writing a mail to the instructor to verify if the proposed strategy looks coherent.

If the student chooses the first option, then the next screen (Level 3) offers five possibilities:

- Meet the engineer(s) in charge of the plant to request information and documentation on the tank.
- Visit the failed structure.
- Identify possible scenarios that could explain the failure.
- Carry out structural computations.
- Read technical literature on the failure of this class of structures.

Associated with each option, there is a link to seek for expert advice. In each expert advice link, a pop-up opens in which a short explanation is given regarding advantages and disadvantages (pros and cons) of following the path, and regarding when would be the best moment to take that action.

Meeting personnel at the plant includes two main engineers (Level 4): Alex Stadopoulos, who deals with the documents, and John Berger, who is in charge of operation of the facility. The student can ask the first one for plans and documents about the design and construction of the tank, as shown in Figure 2. The choice of one of the documents leads to plans such as that illustrated in figure 3 (Level 5). In another screen, the student may also ask for the company that designed the tank, when was it designed and fabricated, and if it was a special design or if those tanks are a standard structural model.



Well, I'm here to help you in your investigation.  
 In this office we keep all documents of each tank that we operate in the plant.  
 What exactly are you looking for?

You may ask for the following documents

- Plans showing the shell thickness and the roof
- Plans of the construction of the cylinder
- Plans of the construction of the roof
- Welding details
- Support system of the roof
- Structure foundation
- Memory of calculations

Figure 2. A typical screen in Level 4 of the present simulation.

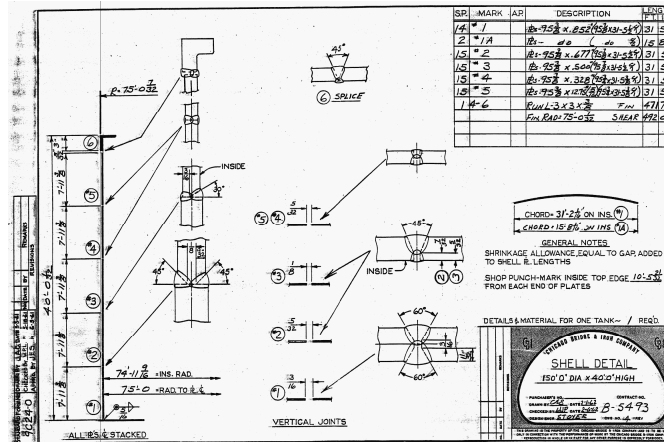


Figure 3. A typical screen in Level 5 of the present simulation.

The student may ask John Berger information concerning the operation of the structure, and on the environmental and general conditions prevailing on the day of the collapse. In the first case, there is a set of possible questions in Level 4, including:

- What types of products were stored in the tank?
- Did the tank have any major damage during its service life?
- Was there any significant corrosion?
- When was the last time that maintenance was performed on this tank?
- For how long was oil stored each time?
- Where does the stored oil come from?
- Where does the stored oil go to when it leaves the plant?

There are answers for each question in Level 5. For example, the answer to sixth question is “Oil is transported by sea and is pumped through a pipeline from a port which is three miles away from this plant. Once the oil reaches the plant, it is assigned to different tanks depending on the storage availability”.

Returning to Level 2, there is a chance of visiting the structure. This has been implemented in the simulation by providing five views of the failed structure, seen from different perspectives. Details are also shown in pictures.

Another possible action in Level 2 is to identify possible scenarios that could help in explaining the failure. Eleven such scenarios have been implemented:

- Localized foundation settlement.
- High stresses due to gravity load with the tank full of liquid.
- Buckling due to internal vacuum (tank is emptied).
- Wind buckling.
- Seismic load with a full tank.
- Impact of a vehicle or object with the structure.
- Loads due to sabotage.
- Material or joint failures.
- Deficient shell thickness or deficient shell geometry with respect to the as-designed configuration.
- Dynamic failure.
- Thermal effects.

In each case, the student reflects on the possibility of such mechanism being the cause of failure. As the student clicks on one of the options, then five questions appear in Level 4:

- Is there evidence of similar structures that failed due to this scenario?
- Which is the typical failure mechanism in this scenario?
- Were there conditions to justify these loads on the day in which the collapse occurred?
- What type of computational or experimental analysis would be necessary to investigate this scenario?
- What other aspect or scenario could have coupled with this one in order to contribute to trigger this failure?

Such questions are present in each scenario, and there are short answers and references to the literature in each case.

Another possibility in Level 2 is to carry out structural computations. This leads to two alternatives:

- Carry out computational analysis. At present there is no link so that the student performs the computations, but there are results obtained using structural analysis codes. Following this path, leads to the data used for the computations, and the stress and buckling response under various loading conditions.
- Carry out experiments on small scale models. This part of virtual experiments has not been implemented at present.

The final option in Level 2 is to study technical literature on the topic. Level 3 leads to a selected set of publications on the structural behavior of tanks (several of which have been generated by research of the PI in this field), including introductions to aboveground steel tanks, a primer on buckling of tanks, wind and earthquake loads, extracts of codes of practice, and photographs of tanks. This constitutes the “library dimension” of the simulation.

At the end of the “navigation dimension”, the student must provide an answer about the identified cause of the structural failure. There are four possible causes, and the student should choose the one that he/she finds adequate according with the evidence obtained during the navigation. For example, the first one reads: “The tank has failed due to localized settlement of the foundation. This tank was placed on a ground of removed soil that was substituted by soil filling and a layer of sand. A vertical settlement on a 30 degree arc around the circumference led to out-of –plane deflections that are seen in the photographs provided”. Feed-back is given to the student concerning the suitability of the explanation provided. In case this is not a correct explanation, indications are provided about what readings should be completed before attempting a new solution to the problem.

### **Assessment of the activity**

A small group of students in an Advanced Structural Analysis course took this module. A questionnaire was given to each participant after the simulation was completed. One of the responses was investigated in depth, and complemented with a personal interview. The main aspects are included in this section.

The navigation stage took more than three hours. Two hours were invested in the section on analysis of the causes of failure. “This section represents the best account of practical aspects of buckling failure that I have read. I took advantage of these readings to learn on the topic.” Considerable time was given to the study of documents provided by the simulation. The problem statement given at the beginning of the simulation, was it clear to establish the scenario in which you would work? “Yes, it was very clear. The presentation is a good simulation of what would happen in a real case, I could believe that this was an almost-real situation”.

The information provided about the main features of the structure and the operating conditions were they adequate? “They were adequate for the needs of the simulation. The most useful information was obtained from the interviews with the engineer in charge of the plant. The plans provided were also excellent; however, I had to save them and open them again with another software in order to read the details”.

In the “navigation dimension”, possible scenarios that could explain the failure are discussed. Did they provide adequate help in the study? “This was the most useful part, since this represents a summary of practical aspects of buckling failure. Putting together all possibilities in one single document was an excellent contribution”.

What other documents would have been useful to solve the task? “More photographs of the site and the localization of the structure with respect to the other neighboring structures. Another set of pictures could provide views of the site before the site is cleaned after the collapse. This would help in appreciating objects located close to the structure that could have impacted”.



Other comments on your experience in solving this activity. “This is an excellent effort and represents a novelty in the learning methodology to which I have been exposed since I entered university studies”.

## Conclusions

This paper reports on the first implementation in structural engineering carried out within the framework of learning-by-doing in a simulated environment. A computer module was developed for an advanced undergraduate course on structural analysis, in which a steel tank was taken as the object of study. The theme structure was chosen because of extensive research carried out in this field<sup>4</sup>. The specific structure investigated is a real structure that failed during a hurricane<sup>5</sup>, but other structures of the same type under different conditions could also be implemented with easy to illustrate other failure modes. The software is not case-specific at most levels, and the specific information is provided at the opening screen and in Level 5.

The preliminary assessment carried out was encouraging because the students showed great interest and satisfaction with the learning approach. The next stage in the project is the identification of differences between experts and novices concerning the analysis of structural failures, and the development of new modules for the standard Structural Analysis undergraduate course.

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