Proceeding of the 2007 ASC Region III Conference

Downers Grove, Illinois

October 24-27, 2007

Edited by
Mohamed El-Gafy
Michigan State University
Reviewers Recognition

On behalf of the Associated Schools of Construction, the regional director would like to thank the following individuals who have contributed to the 2007 paper review process. Without their effort, the Annual Regional Proceedings would not be possible.

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A Study of Cold In-Place Recycled Asphalt Roads

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Cold In-Place Recycling (CIR) provides an economical rehabilitation method that mitigates crack reflection by pulverizing the asphalt pavement surface, thus destroying the old crack pattern in the recycled layer. However, recycled roads have inconsistent performance. This paper investigates how the changes in engineering properties of the CIR materials and other factors affect pavement performance. Twenty-four sample roads were selected to represent various ages, traffic volumes, and support conditions in a geographically balanced sampling in Iowa. Pavement Condition Index (PCI) ratings were collected. Engineering properties of CIR materials were examined through field and lab tests. Statistical analyses were conducted to describe the relationships between the pavement performance and the prominent factors.

Key Words: Cold In-Place, Asphalt, Recycling, Pavement Performance, Rehabilitation.

Introduction

Asphalt pavements deteriorate over time. Typically three to five years following construction, reflected cracks, one of the primary forms of distress in hot-mix asphalt overlays of flexible pavements, may be observed. Cold In-Place Recycling (CIR) has proved to be an effective rehabilitation method for reflected cracks. However, recycled roads have inconsistent performance. Several years after recycling, some roads are still in excellent condition with only a few minor cracks while extensive cracking and rutting were observed on other roads. These opposite behaviors can be observed on roads that were constructed in the same county, by the same contractor in the same construction season. Thus the difference in performance is probably not from such factors as weather, equipment, contractors’ experiences, and construction procedures. Rather, other factors become more prominent in affecting pavement performance, such as:

- Age of the recycled pavement,
- Cumulative traffic volume,
- Support conditions, and
- Aged engineering properties of the CIR materials.

In 2004, a study was conducted by researchers at Iowa State University and University of Iowa, attempting to answer the following questions concerning CIR performance:

- What effects do traffic, age, and support conditions have on pavement performance?
- How can these effects be explained by aged engineering properties of the CIR materials and other factors?

A comprehensive description of this investigation can be found in a recent research (Chen, 2006) and is summarized herein.
Method

Scope

This study provides a summary of the results of a comprehensive program of performing field distress surveys, field testing and laboratory testing for 24 cold in-placed recycled asphalt roads constructed from 1986 to 2004 at various locations throughout the state of Iowa (Figure 1). Of these 24 projects, 18 projects were selected from a sample of roads in a previous research project (Jahren, 1998). Six projects were selected from newly constructed CIR projects that were built after 1999.

Data Collection and Processing

In order to evaluate the pavement performance, the following data of each road were collected, processed and analyzed.

- Support conditions as inferred by pavement deflections.
- Engineering properties of CIR materials obtained by coring 4 inch diameter asphalt samples and conducting lab tests.

For the purpose of backcalculating Falling Weight Deflectometer (FWD) measurements (described in detail in the later section) to infer pavement support conditions, a three-layer pavement structure (Figure 2) was defined. The three layers are:

- HMA (hot mix asphalt) layer,
- CIR layer, and
- FND (foundation) layer.
The FND layer consists of all material layers beneath the CIR layer that provide structural support for the layers above.

Figure 2. Pavement structure

Surveys

In 1998, pavement distress surveys of 18 sample roads were conducted, and the present serviceability index (PSI) and pavement condition index (PCI) of each road were calculated and then evaluated (Jahren, 1998). In 2004, researchers obtained the same types of data from the 18 roads under new conditions. In order to find out whether or not factors other than those studied had significantly changed, the researchers sent out a questionnaire to all of the eight jurisdictions that maintained the roads. The survey inquired about the levels of traffic (including truck traffic), support condition, and other new changes that may have occurred since 1998. After reviewing the results, the researchers decided that none of the changes on these 18 roads were significant enough to invalidate the assumption that there were no important changes during the time of the longitudinal study. Additional information obtained from this survey indicated that the percentage of truck traffic has not changed for each CIR road. Therefore, it was decided that the traffic volume (AADT, Annual Average Daily Traffic) was used in this study.

Pavement Distress

The 2004 pavement distress survey for this study was conducted by researchers at University of Iowa (Lee, et.al, 2006). Then pavement condition index (PCI) was calculated using MicroPaver, a software package developed by the Construction Engineering Research Laboratory of the U. S. Army Corps of Engineers.

Support Condition

The Falling Weight Deflectometer (FWD) was chosen to evaluate the support condition, because it is the support condition measurement device that is commonly in use by the Department of Transportation (DOT). For this research project, a JILS-20, manufactured by Foundation Mechanics, Inc., was used to conduct the FWD tests on the 24 roads. The JILS-20 was operated over a 1,500 feet-long section of each test road. The loading plate was dropped every 100 feet, and
the deflections from 8 sensors were collected. Figure 3 shows the locations of FWD tests, and Figure 4 shows the sensor layout of the FWD equipment for this study.

![Figure 3. Locations of FWD tests](image)

BACKFAA (developed by the Federal Aviation Administration) was used to calculate moduli of the HMA, CIR, and FND layers. Several CIR roads had high HMA and CIR modulus values (larger than 6,000 ksi). Since the FWD tests were conducted in December 2004 and March 2005, the pavement structure that was hardened by the low temperature might caused the unusual high modulus values. In addition, the lack of information regarding the layer determination in BACKFAA might contribute to these high values.

**Laboratory Testing**

For each selected road, six cores (4” in diameter) were typically taken by the investigation crew. On several roads, more than six cores were taken. The laboratory testing effort was divided into three phases:
- Mixture properties testing,
- Asphalt binder properties testing, and
- Aggregate properties testing.
A total of 24 projects were selected and tested in this evaluation. The projects were sampled by coring the outside driving wheel path. Normally about 6 cores were obtained along the 1,500 ft sample project length of each road (Figure 5).

Figure 5. Locations of cores

Several lab tests were performed and identified by AASHTO and ASTM designations as appropriate and the number of replications of each test performed. The laboratory testing process is illustrated in Figure 6. The following parameters/products of the CIR materials were obtained from the various lab tests:

- Bulk specific gravity (Gmb);
- Indirect tensile (IDT) strength (wet and/or dry specimens, 40° C);
- Photograph broken faces of specimen after IDT test;
- Theoretical maximum specific gravity (Gmm);
- Penetration readings;
- Aggregate gradation;
- Complex Shear Modulus (G*) and phase angle obtained from dynamic shear rheometer (DSR) tests; and
- Flexural creep stiffness (S(t)) and m-value obtained from bending beam rheometer (BBR) tests.

Parameters that are directly related to the aged engineering properties of the CIR materials were used in this study.

Data Reconstruction

Twenty-four sample roads were divided into two groups according to traffic volume (AADT). As follows:

- Low traffic roads (AADT < 800), and
- High traffic roads (AADT > 800).

Most county roads were low traffic roads. All other State and U.S. Highways and some county roads with high traffic volume were in the high traffic roads category.
Figure 6. Flow chart of laboratory testing

1. Calibrate test equipment
2. Photograph all samples for each road
3. Prepare specimen (Cutting 4in. diameter x 2 in. height)
4. Determine bulk specific gravity ($G_{mb}$) of specimen following AASHTO T166-93
5. Condition for dry and wet @ 42 degree C for 24 hours
6. Conduct mixture performance test (IDT)
7. Photograph broken faces of specimen after IDT test
8. Combine and heat until material softens and is easy to break
9. Determine theoretical maximum specific gravity ($G_{mm}$) following ASTM D 6857-02 with Corelok™
10. Binder extraction following AASHTO T 164 (Quantitative extraction)
11. Ignition of binder following ASTM D 6307 (Ignition oven)
12. Penetration Test following AASHTO T49-96
13. Aggregate gradation analysis following AASHTO T27-93
14. Frequency sweep test using DSR following AASHTO T315-02 and Table 3
15. Flexural creep stiffness test using BBR following AASHTO T313-02 and Table 3
Results

Response Variable

Relative PCI, the difference between the observed PCI and the expected PCI, was considered as the response variable in the statistical analyses. It was used to represent which CIR pavements are performing especially well and which are performing especially poorly.

Relative PCI = Observed PCI – Expected PCI

The observed PCI was obtained from the pavement distress survey described in the previous section. The expected PCI was calculated based on a statistical relationship; this statistical relationship is between the observed PCI and age. Large positive values of relative PCI value indicate that the CIR road has performed better than expected.

A linear regression analysis was performed to determine the expected PCI. The response in this analysis is observed PCI of all 24 CIR roads. The independent variable is age. Figure 7 shows the output of a polynomial regression of observed PCI versus age. The middle line represents the regression line, the lines next to the regression line represent 95 percent confidence interval, and the outside lines represent 95 percent prediction interval. The expected PCI can be calculated from the regression equations that were determined by the regression lines.

For all CIR roads, the regression equation is:

Expected PCI = 96.97 - 0.0067*Age^3

Figure 7. All 24 CIR roads: Observed PCI vs. Age
Independent Variables

Independent variables that were initially considered are:

- Cumulative traffic,
- Resilient modulus of the HMA layer (psi),
- Resilient modulus of the CIR layer (psi),
- Resilient modulus of the FND layer (psi),
- Indirect tensile strength of the mixture (wet samples) (psi),
- Air voids (Va,%),
- Complex shear modulus (G*, kPa),
- Flexural creep stiffness (S(t), MPa),
- m-value, and
- Types of aggregate.

Which material properties were associated with roads that performed “better than average” or “worse than average”? To answer this question, conceptual statistical analyses were conducted (Figure 8). The results showed that there were no strong associations between the performance and selected important material properties, such as air voids and the stiffness of the CIR layer for all traffic levels combined. However, further statistical analyses proved that such strong associations did exist for some traffic categories.

*Figure 8. Scatter plot of selected material properties vs. Relative PCI*
The regression model for high traffic roads is:

\[
\text{Relative PCI} = -12.23 - 1.59 \times \text{CIR modulus} + 1.73 \times \text{Va} - 0.00085 \times \text{Cumulative Traffic}
\]

- \(p\)-value = 0.023 (significant at 0.05 level)

The regression model for low traffic roads is:

\[
\text{Relative PCI} = -25.06 + 0.87 \times \text{IDTwet} + 1.73 \times \text{Va} - 1.02 \times \text{CIR modulus}
\]

- \(p\)-value = 0.052 (not significant at 0.05 level)

The regression model for all 24 CIR roads is:

\[
\text{Relative PCI} = -10.37 + 2.45 \times \text{Va} - 1.38 \times \text{CIR modulus} - 0.00026 \times \text{Cumulative Traffic}
\]

- \(p\)-value = 0.001 (significant at 0.05 level)

**Discussions**

*Modulus of the CIR layer (stiffness)*

In a typical flexible pavement structure, material layers are usually arranged in the order of descending load bearing capacity with the highest load bearing capacity material on the top and the lowest load bearing capacity material at the bottom. Therefore, the surface course (typically an HMA layer) is the stiffest (as measured by resilient modulus). The underlying layers are less stiff. Serving as the base of the HMA surface course, the CIR layer should not only be stiff enough to provide adequate pavement strength, but also be flexible enough to allow the total pavement structure to deflect under repeated traffic loading. This study showed that the stiffness of the CIR layer significantly affects performance of high traffic roads, and that a CIR road with a more viscoelastic CIR layer performs better. This finding agrees with a previous study (Halim, 1985, 1986) in that serving as a stress-relieving layer, the relatively less stiff CIR layer will reduce cracks in the HMA layer.

*Air voids (Va)*

The results showed that Va was associated with pavement performance for high traffic roads, but it was not significant for low traffic roads. Although performance improved within the range of Va in this study (6 ~ 12%), it seems that performance would deteriorate if Va increased much beyond those limits.
Conclusions

The study concluded that:

- The CIR layer acts as a stress-relieving layer. Therefore, within the range of the data analyzed, a lower stiffness CIR mix with higher air voids indicates that better performance is expected.

- Moisture sensitivity of the CIR mixture may affect performance of low traffic CIR roads (AADT<800).

- As expected, a higher amount of cumulative traffic is associated with lower relative pavement performance in the models for High traffic roads (AADT>800).

- Variables other than those selected, such as environmental factors, may affect performance of low traffic CIR roads.

Recommendations for Future Study

The following recommendations were made from this study:

- A larger sample size (about 50) is recommended for a future study. More cores and FWD tests on each road are also necessary to reduce the variance in the response variable, relative PCI.

- This study investigated the overall CIR pavement performance, which was affected by both the HMA and/or the CIR layer. A study with a larger sample size will contain sufficient information to distinguish these two effects. Therefore, a regression analysis between part of the response (relative PCI) that is affected solely by the CIR layer, and the independent variables might provide more conclusive findings.
References


The current sustainability practices are not complete in that: 1) the industry does not have complete sustainability rating systems that recognize the substructures’ contribution to overall sustainability of the built structures; and 2) the current project delivery/management approach is in itself not a sustainable one because sustainability-related information is not shared throughout the different phases of a project life cycle. In this paper, a new technology and new paradigm are presented to provide better sustainable management practices from the substructure’s perspective for new and existing buildings. The PDA (pile dynamic analyzer) non-destructive testing (NDT) is first presented via a case study as a way of enhancing the sustainability of the existing structure. Due to its limited applicability in foundation management, a more advanced sensing method via the wireless technology is introduced as a proactive monitoring system and its implication to a more sustainable project delivery/management system is discussed.

**Key Words:** Sustainability, Sensing and Monitoring, Non-Destructive Testing

**INTRODUCTION**

In the building construction community, the LEED (Leadership in Energy and Environmental Design) rating system of USGBC (U.S. Green Building Council) has attracted many building owners and helped them achieve different levels of sustainability for their facilities in various areas such as sustainable sites, water efficiency, energy & atmosphere, materials & resources, and indoor environmental quality (USGBC, 2005). The LEED rating system, however, mainly focuses on the environmental impacts and the energy efficiencies of the building features from the superstructure perspective. The rating system does not account for the impact of the substructure of the buildings to the sustainability. Specifically, recognition of a potential contribution of deep foundation design and construction to sustainability is almost negligible. This viewpoint is problematic as the structures are eventually to be under deteriorating conditions due to ageing, overuse, misuse, and lack of maintenance (Mirza, 2006). This is even more problematic when the structures are often confronted with nature’s disastrous forces such as hurricanes, earthquakes, and tsunami. In this paper, a new technology and new paradigm are presented to provide better sustainable management practices to the new and existing deep foundation areas.
Sustainability of built structures is enhanced with a maintenance and monitoring system as they are degraded over time or impaired in unfortunate occasions by nature (Wadia-Fascetti, 2003). This is even critically important for the deep foundation system, and it is very challenging for substructures to be monitored and diagnosed.

From the substructure’s perspective, non-destructive monitoring systems are presented in this section as a way of enhancing the sustainability of the existing structure. The case study presented here will demonstrate the monitoring systems’ economic, environmental, structural, and social benefits toward expanding the sustainability of the existing deep foundation structure.

A case study involves evaluation of the capacity and condition of existing timber piles that were installed circa 1930. The record of the exact lengths and diameters of these piles was not existent. These piles, located in the downtown of New Orleans, Louisiana, originally supported an old 6-story building, which was eventually demolished for a proposed 6-story modern research building. The owner of the building intended to reuse the existing timber piles to support the proposed building. Since the condition of the piles was not known, however, the feasibility of this reuse plan needed to be verified (SESI, 2006).

The soil profiles at the site consisted of generally very soft clays with organic matter and sand seams to approximate 36-foot depth, followed by very dense silty sands from 36 feet to 47 feet. These layers were underlain by loose clayey sands with gravel to the approximate depth of 62 to 72 feet. Based upon the review of the driving performance of the reaction piles installed for the static load test program as well as the soil conditions, the length of the piles was estimated to be as long as 36 to 38 feet. The foundation system consisted of 81 group piles that typically had 4 to 9 timber piles as shown in Figure 1.
Since only the partial information of the existing piles was available from the design drawings and soil investigation results, the key information such as capacity and integrity of the piles for the diagnosis of the piles had to be determined as non-destructively as possible to avoid undermining the unknown condition of the piles. To this end, PDA testing was performed on four existing timber piles at the locations as indicated by the arrows in the figure, and after being attached with the gages, the piles were re-struck and monitored with the PDA for 12 to 22 blows using a Vulcan 01 air hammer.

The PDA (Pile Driving Analyzer) technology, one of the NDT methods, is described as a monitoring tool for deep foundations. The PDA, schematically depicted in Figure 2, is based on electronic measurements of the stress waves occurring during pile driving. The measurements are made through the strain transducers and accelerometers attached to the pile top during pile driving (Figure 2 (a) & (b)), and the measured data are collected and analyzed in the PDA hardware (Figure 2 (c)). Based on the testing data and analysis on site and in office, the bearing capacity of the piles is calculated to estimate the capability of transferring the load from the superstructure. And the pile stresses and pile integrity are checked to determine the damage in the driven pile (Lim, 2005; McVay, Alvarez, Zhang, Perez, & Gibson, 2002).
With the PDA non-destructive testing, the overall pile wave speed (i.e., impact wave speed due to hammering) for each pile was measured to inspect pile integrity or damage. As a result, the PDA produces the BTA (Beta) value of a tested pile, which represents the percentage of the effective pile cross section compared to the full cross section of a pile. Such damage indicated by BTA values could be from cracks, fractures, or other discontinuities in the pile section. The typical ranges of damage by BTA values are presented in Table 1.

**Table 1. Typical Categories of Damage by BTA Values**

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<th>BTA Values</th>
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<tr>
<td>100 %</td>
<td>No Damage</td>
</tr>
<tr>
<td>80 to 99 %</td>
<td>Slight Damage</td>
</tr>
<tr>
<td>60 to 80 %</td>
<td>Damage</td>
</tr>
<tr>
<td>&lt; 60 %</td>
<td>Pile Broken</td>
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According to the PDA test results, all the timber piles at Test Piles No. 2, 3, and 4 showed 100% of BTA values, which signified that the piles were not in a structurally damaged condition. Note that
since the quality of the PDA data from Test Pile No. 1 was very poor, the analysis was not conducted.

When analyzing the PDA results for the capacity of an existing pile, the data is usually evaluated by CAPWAP (CAse Pile Wave Analysis Program) that is a signal matching process that extracts the resistance distribution and soil behavior such as damping and stiffness. The CAPWAP analysis should be performed especially on non-uniform piles such as the timber piles of this case study. In the CAPWAP analysis any type of pile shape can be emulated and the soil model can be used to improve the wave equation analysis results.

Since the piles were the existing ones, the same PDA test procedure as that used in the re-strike PDA test was used in this case. The CAPWAP analysis was performed on the collected PDA field data from the test piles to predict ultimate load capacities of the selected piles. Results of the CAPWAP analysis indicated that the ultimate pile capacities ranged from 70 to 77 Kips for Test Piles No. 2, 3, and 4. These values represented enough strength for timber piles used as the deep foundation system.

**IMPLICATION OF MONITORING SYSTEM IN SUSTAINABLE FOUNDATION MANAGEMENT**

An advanced sensing technology, the PDA non-destructive test, presented in the case study indicated potential impacts on expanding the sustainability of the existing structures as described in the following:

- Economically, the PDA non-destructive test allowed the existing deep foundation structure to maximize its useful life.
- Environmentally, therefore, it avoided a case where the deep foundation would have to be abandoned or replaced, which involves a long-term impact to the surroundings of the site. Also, the PDA did not make any negative environmental impacts to the site at the time of testing.
- Structurally, the non-destructive technique avoided further damage to the structure whose integrity was not known before the testing. Conventional excavation-based visual inspection would possibly damage the foundation.
- Socially, the fact that the existing foundation would be reused for the proposed building provided the community with the same confidence that their own deteriorated/damaged structures could be reusable.

**COMPLETE SUSTAINABLE DEEP FOUNDATION MANAGEMENT**

Even though the PDA non-destructive test in the case study provided several sustainability-related benefits, this technology worked in a limited way in that it was utilized to provide the condition of the deep foundation only at the time the testing was done. It was therefore a passive and casual way of using the technology for minimal sustainability gains. Recently, a wireless communication and
miniature sensor technology has emerged as an alternative to provide a more integrated and long-term sensing capability to substructures to improve the overall sustainability. One example in this category of technology is a wireless monitoring system (McVay, Alvarez, Zhang, Perez, & Gibson, 2002) as shown in Figure 3.

![Figure 3. Wireless Monitoring System](image)

This new cutting-edge system (Figure 3 (a)) consists of two major components: a non-recoverable unit embedded in the pile to transmit data through a wireless interface (Figure 3 (b)), and a receiver/data processing unit to recover and analyze the information from the transmitting unit (Figure 3 (c)). The non-recoverable unit is composed of accelerometers, strain transducers, and a sending unit with antenna. The receiver/data processing unit is equipped with a data acquisition card and data processing software.
Since the cost of the non-recoverable units is very low and their size is very small, they can be placed permanently in the pile. The receiver/data processing unit is portable and receives signals up to a few hundred feet away from the pile head where the transmitter antenna is installed. Some benefits of this wireless monitoring system technology are summarized as follows: 1) affordable system; 2) less skill required to interpret data; 3) safe to install, operate, and use; and 4) capable of monitoring long-term behavior.

The integration of this wireless monitoring technology with substructures certainly provides better sustainability practices in the deep foundation area and delivers a solution to the problem related to the temporary use of the PDA non-destructive testing technology. That is because more accessible, easier, and ongoing monitoring data collection will allow immediate and timely responses. However, the bigger problem of the current sustainability practices, especially in the deep foundation area, is not entirely related to what a monitoring technology can or can not deliver. Rather, it is more related to the fact that the industry in general has adopted an unsustainable and fragmented approach for built structures. The contemporary project delivery and management system has not helped the industry to realize sustainability to a maximum level. The design-bid-build-operate-maintenance approach is the most fragmented and detached one (left, Figure 4) in terms of the degree of interactions between functional components such as design, construction, operation, and maintenance. This signifies that sustainability features of projects are not passed along well through the different life cycles of the projects since they do not share much in common.

![Figure 4. Detached versus Integrated Approaches for Built Environment](Aktan, Ellingwood, & Kehoe, Year Unknown)

This approach influences sustainability-oriented industry entities to pick the “low hanging fruit” and eventually to hit a “green wall” where the sustainability benefits are only marginal, which makes them no longer continue with sustainability initiatives (De Bruijn, 1997). Therefore, the current approach of building-managing built structures is unsustainable in itself. The sustainability features of built structures should be shared and inherited throughout their life cycle (right, Figure 4).
In this approach, a monitoring system is only utilized in limited cases and special situations where the data is used for small operational gain and marginal maintenance improvement, as seen in the PDA case study. Therefore, this kind of approach itself, regardless of how advanced monitoring technologies are, is a bottleneck in sustainability practices.

This observation has led the authors to a sustainable approach presented in Figure 5. The main focus of this approach is to maximize the sustainability of future built structures, especially deep foundation systems, by integrating, utilizing, and engaging the monitoring function into each phase of their life cycle. Main functions of this integrated monitoring system approach include active anticipation and prediction in order to operate the built environment in an optimal condition and to mitigate possible negative outcomes in advance. The design phase is also enhanced through the comparing of actual responses with the predicted, and the active monitoring system also makes it possible to determine the degree of recycling and reusability of the structure.

CONCLUSION

The current sustainability practices do not consider the substructures’ contribution to the overall sustainability of built structures. The non-destructive PDA monitoring system was presented in this paper as a way of enhancing the sustainability of the existing structure in a case study from the substructure’s perspective. The case study demonstrated PDA’s economic, environmental, structural, and social benefits toward expanding the sustainability of the existing deep foundation structure.

However, these benefits were limited because the PDA system was merely used to provide the condition of the deep foundation at the time the testing was done. This limited and temporary use of the advanced sensing technique reflected the contemporary fragmented building/management approach where sustainability features, if any, are not fully appreciated throughout the life of built structures.

More advanced sensing methods such as the wireless monitoring system was introduced to propose a more comprehensive approach for better sustainability practices. By utilizing and engaging this monitoring system as an integral part of the project delivery/management practices, structures’
intended sustainability will be fully realized and enhanced because the monitored data on building condition and performance are constantly utilized and iteratively used in the building’s life cycle.

REFERENCES


Teaching Spanish for Construction: Lessons Learned

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A new course, *Spanish for Construction*, was developed and taught for the first time in Spring 2007 at Southern Illinois University Edwardsville (SIUE). It was taught once as a senior-level undergraduate elective and twice as a continuing education workshop for the local construction industry. The course goal was to teach job-specific Spanish to non-Spanish speaking construction management personnel. This course also addressed cultural issues that lead to potential conflicts between labor and management. This paper presents the challenges that were encountered in teaching the course for the first time, how those challenges were addressed, the results of the course evaluations, and the changes that will be implemented as a result of the first year assessment.

**Key words:** Spanish, Hispanic, foreign language, construction safety

Introduction

The Construction Department at Southern Illinois University Edwardsville developed a “Spanish for Construction” course in response to requests from local industry. The course was offered three times in 2007, once as a 3 credit senior-level undergraduate elective and twice as a 16-hour continuing education workshop for the local construction industry. The course goal was to teach job-specific Spanish to non-Spanish speaking construction management personnel, with the long-term goal of improving job-site safety. This course also addressed cultural issues such as the major Hispanic holidays that impact the construction industry, the role of religion in the work life of Hispanic workers, and other points of potential misunderstandings and conflict between Spanish and non-Spanish speakers (Lopez, 2006). This paper will address the attainment of the original course objectives, measures used to assess student performance, and changes to be implemented as a result of the first year assessment.

Course Content

The course was offered as an undergraduate elective for the first time in Spring 2007 with 15 students enrolled. The course had two main objectives. The first was to enable students to master a basic Spanish vocabulary of 50 phrases used in construction to be able to greet and compliment employees, give simple directions in Spanish, and address medical and safety situations. The second objective was to increase the understanding of Hispanic culture and its impact in the construction workplace. There were some unforeseen challenges that had to be addressed throughout the course. Teaching the course to undergraduate students who had no experience working with Spanish
speakers was challenging because it was often hard to decide which words/ phrases would be most needed on the jobsite. Ideally, students would learn all the words and phrases that potentially could be used on the jobsite. However, research indicated that an average person can memorize only around 50 phrases, after which the retention rate significantly decreases (Command Spanish 2007). The solution to this challenge was to select the 50 phrases that are most commonly used in the jobsite for the students to memorize and provide them with a list of additional phrases and an audio CD. This way students can go back and learn additional phrases as needed in their future jobs. A second challenge was measuring and evaluating student learning. On one hand, the instructor did not want to discourage or intimidate students, who were already feeling anxiety about having very strict oral vocabulary quizzes, given their lack of foreign language skills. On the other hand, since this was a for-credit course which required a final grade, there was a need to evaluate and differentiate “A” students from the rest of the class. The solution to this challenge was to quiz students informally at the beginning of each class, with no grades assigned. There were two exams during the semester and the final exam. For the first two exams, each student was scheduled a 10-minute period to take an oral exam in the instructor’s office. The process was time consuming, and it was hard to evaluate the students and compare their progress to that of their peers. Another problem was that there was no written proof of each student’s examination. To solve this challenge, for the final exam, the Construction department acquired headphones with microphones. Students were divided into three groups of five to come to the computer lab at a scheduled time. A PowerPoint exam was given, consisting of 20 questions to which the students recorded their answers orally and in written form. The questions were given in random order on each individual exam, and the students were spread out enough that they could not hear each other’s answers. Giving the final exam in an electronic format accomplished several objectives. It was less time consuming, easier to grade because the instructor was able to go back and listen to the answers, and it provided written documentation in case any questions or issues should ever arise.

Continuing education courses were offered to construction companies in March and August of 2007. The participants were construction professionals, many of whom had previously worked with Spanish-only speakers and experienced firsthand the language barrier. The first course had 8 students and the second course had 10 students. The continuing education courses were capped at a lower number because of its shorter duration to cover the material, and the need to provide one-on-one instruction in a limited amount of time.

Teaching Spanish for Construction to professionals was less challenging because the course was targeted to meet their language needs, which were often impacted by their job description. For example, a person working for human resources might need to know how to ask for proof of work authorization in the US, while a superintendent’s main language needs might be to enforce the use of personal protective equipment.

All students learned basic vocabulary/ phrases but by knowing their job descriptions and language needs, the instructor modified the courses to suit individual needs and maximize the course benefit. Since the courses were not graded, no formal exams were given. The students were quizzed informally throughout the course and most of the class time was spent mastering the vocabulary through role-playing and repetitive practice. At the end of the workshop, students were given a last informal quiz. If they answered the question correctly, they were given their certificate of completion. If they answered incorrectly, another question was given to them until they answered
correctly and the certificate was given to them. Even though there were no negative consequences for not learning the course content, there was never an issue of a workshop student not putting enough effort into it. One of the reasons for this might be that working professionals are more mature and they understand the importance of making the most out of the workshop.

Lillyman (1993) asserts that instruction should include intensive practice on recognition of vocabulary in class, through role-playing, one-on-one repetitive practice with a partner, and memorization of key phrases. In both the 3-credit course and the continuing education workshops, students spent a significant amount of class time practicing the vocabulary/phrases. One of the activities that proved to be most beneficial to students was to play a modified version of the children’s board game “Chutes and Ladders.” Participants were divided into teams of 2 or 3 people depending on the class size. A stack of questions was placed on the board, and the students would draw a card which gave a scenario and asked them to answer in Spanish. For example, if the question was, “Tell a worker that he should bring a hard hat”, and the team answered correctly (answer: debe traer casco), they would roll the dice and move their chip to the appropriate square. If they answered the question incorrectly, they would not roll the dice and it would be the next team’s turn. By having Chutes and Ladders in the game, it made the game less competitive, and balanced the different abilities in the classroom. Winning the game not only required knowledge of Spanish but also luck. The person who knew the most, probably because of taking Spanish in high school, was not the winner every time.

The course met the objectives. At the end of the course the student had a better understanding about the Hispanic culture and knew enough Spanish to be able to greet and compliment employees, give simple directions in Spanish such as to ask an employee to “get to the next jobsite” (vaya a la siguiente obra), and to address medical and safety situations such as “An ambulance is on its way” (ya viene la ambulancia).

As it can be seen in figures 1-7, the course evaluations were very positive. Thirteen students completed the evaluation for the 3 credit senior-level undergraduate elective and 8 participants completed the continuing education course offered in March of 2007. Figures 1-4 represent the results of the evaluation by students taking the 3 credit course. Figures 5-7 represent the results of the evaluation by participants in the continuing education course.
Figure 1: The objectives of the course were clear.

Figure 2: Please rate the textbooks/ manuals/ workbooks.

Figure 3: The tests were reliable measures of your knowledge to the material.
Figure 4: You were provided with a timely and helpful feedback about your performance.

Figure 5: The program objectives were consisted with the course as advertised.

Figure 6: Program material was up-to-date, well organized and presented in sufficient depth.
Figure 7: Audio-visual materials and handouts enhanced program content.

When asked what the best part of the program was, several students replied Chutes and Ladders was good learning tool, another student replied “jumped immediately into context we were looking for – did not spend time on info we would not use/need”. When asked how the program could be improved students answered “broken up more” and “more Chutes and Ladders”.

**Conclusions**

Teaching the language to the construction industry was very helpful in determining the content that should be included in future Spanish for construction courses for credit. The construction professional pointed out the vocabulary/ phrases that the construction students will need to know when they join the workforce. There were several jobsite scenarios that the workshop students described that will be helpful in the classroom to illustrate the need of knowing Spanish in the jobsite. The most effective way to test Spanish for Construction for credit courses was to record their answers in Powerpoint so that the instructor could listen to them after the test. In the future, all exams will be given in this format.

The Spanish for Construction will be offered in Spring of 2008, and enrollment for the course will start the second week of October. Several students have already expressed interest in taking the course, and a class size of about 15 students is expected for this course.

**References**


Design and Implementation of an In-class Exercise to Monitor Equipment Production

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This paper describes the design and implementation of an in-class exercise that provides hands-on experience in monitoring and measuring equipment production. The exercise is performed during discussion of earthwork and equipment production in a Construction Materials and Methods course that is provided to students early in the construction curriculum. The exercise demonstrates selected factors affecting equipment production as well as data gathering techniques and methods of interpreting equipment production. The exercise also provides experience in concepts, such as learning curves and method comparison, which students can draw from in later coursework and while on-site.

Objectives and context

The exercise described in this paper is intended to reinforce discussion of earthwork and equipment production through hands-on experience. Students achieve this by working with materials and measuring and experiencing the effects of varying exercise parameters on the quantity and methods of determining the production of an earthmoving operation.

Prior to this exercise, the class studies properties of soil and elements and methods to determine equipment production. This exercise directly follows discussion of loaders and haulers (e.g. identifying the match point of trucks to loaders and distinguishing loader-driven versus hauler-driven production) and directly precedes discussion of construction method comparison.

Selection of toy problem

Possible approaches to visualizing and measuring productivity of earthwork operations in a classroom setting range from toy- or computer-based simulation to photographic, videographic, or in-person exposure. Site visits are often difficult to coordinate in a full-class setting, so this course requires that students monitor construction operations individually for a separate assignment. Furthermore, site visits and photo- or video-based monitoring allows students to visualize operations, but not to experiment with different aspects of the operation, such as varying the number of haulers or loaders. Simulation tools, such as STROBOSCOPE (Martinez, 1996), can rapidly demonstrate an equipment operation and allow students to explore multiple scenarios affecting production, such as ground condition and travel distance. However, students may not as easily recognize the learning that occurs in operating a piece of equipment, and the variability of production with each bucket fill, for example. Philips, et al. note that selected examples of toy problems in engineering curricula have proven effective for student learning (Philips, et al., 2002). While toy problems provide an abstraction of real-world problems (and hence some factors in an earthmoving operation, such as the effect of elevation and ground conditions) would not be as easily demonstrated), they do provide a way to simulate real-world problems and provide students with a means to actively learn engineering concepts. The toy
based exercise, as defined below, meets the time constraints of a short class period, and addresses the desire to develop multiple equipment operation scenarios, and the intent to provide a hands-on learning environment.

**Layout**
The layout of the exercise, shown in Figure 1, is composed of an approximately five foot long haul road with two lanes (haul loaded and return empty), a gravel stockpile containing 180 lbs of gravel, an empty 2’ x 2’ x 4” box designed to match the height of the rear dump of the haulers, and a loading ramp that allows the loader to reach over the edge of haulers while loading. The entire workspace is level and elevated upon a table. The (toy) equipment consists of two loaders and four haulers, and a small bulldozer to push gravel into place once it is dumped.

![Figure 1: Exercise layout](image)

**Participation**
The participants in this exercise consisted of operators and recorders. (The exercise can be expanded to include timers as well, to ease the burden on recorders and increase the detail of data recording.) The equipment operators attended to their equipment at all times. The time-keepers recorded the stopwatch start time at the beginning of each action. Time-keepers for loaders recorded the stop-watch reading at the beginning of wait, load, travel (loaded), load and travel (empty) actions. Time-keepers for haulers recorded the stop-watch reading at the beginning of wait, load, travel (loaded), wait, dump, and travel (empty) actions.

**Exercise sequence**
The exercise is composed of four sequences, each placing a one inch lift of gravel in the destination site. The equipment that was used in each sequence follows: in the first sequence, one loader and one hauler; in the second sequence, one loader and two haulers; in the third sequence, one loader and three haulers; and in the fourth sequence, two loaders and four haulers. In the loading operation, the hauler spots up to the loading ramp while the loader fills its bucket with gravel and travels to the ramp. The rear of the hauler is open, so the hauler is considered ‘filled’ when gravel begins to spill from the rear of the hauler. The hauler operators move their loaded trucks across the haul road to the dump site, back up, dump the load over the edge of the fill site, and then return across the haul road and wait for the next load cycle. The dozer operator spreads each load across the fill site enclosure until the one inch lift is complete. In each sequence, the class first predicts whether the loader(s) or hauler(s) will limit the production of the operation.
Method of data analysis – cycle time data

The production of each operation is determined using the measured cycle time data and capacity information for loaders and haulers. Each lift corresponds to 0.33 CF of gravel; at maximum observed capacity, bucket capacity is 0.033 CF, and hauler capacity is 0.1 CF. By witnessing the operation, students can observe which type of equipment is limiting production. This assessment is reinforced by comparing the students’ observation of production to theoretical production as provided by the following equations, where the smaller of the two production amounts limits the production of the operation:

\[
\text{Production loader} = \left( \frac{\text{bucket volume}}{\text{loader cycle time}} \right) \times 100\% \text{ efficiency} \\
\text{Production hauler} = \left( \frac{\text{truck volume} \times \text{number of trucks}}{\text{truck cycle time}} \right) \times 100\% \text{ efficiency}
\]

Method of data analysis – student outcomes

To gauge the benefit of student outcomes, data from the in-class exercise and a follow-on homework assignment provide support for evaluation of the types of errors experienced in understanding cycle time data and in interpreting cycle time data. The data collected during the in-class exercise demonstrate numerous types of errors in recording cycle time data. These are useful in gauging the students’ understanding of cycle time data. During the exercise, the students are able to visually evaluate the operation and quickly judge whether the production of the operation is limited by the loader(s) or hauler(s). In the follow-on assignment, students are asked to interpret correctly recorded cycle time data for a loader and two haulers. Students must interpret the data to determine cycle times for each piece of equipment and then determine whether the operation is hauler- or loader-driven. The assignment then provides feedback on what types of errors exist in understanding the data and in understanding how to analyze the data to assess the operation.

Results

Students experienced numerous types of errors and deviations in cycle time records during the in-class exercise. Types of errors encountered during the exercise follow:

- Not maintaining a continuously running stopwatch (thus omitting the data needed to determine the duration of the final (travel empty) action.
- Recording the finish time instead of the start time of an action
- Recording the duration of an action
- Reduction in granularity of actions of recording (either omitting the ‘wait’ action or omitting multiple actions due to the speed of operation
- Reduction in significant digits of recording
- Mixing actions (such as lumping return and wait times because a queue backed up onto the road)

After the exercise and before the follow-on assignment, the class revisited the notation and process for interpreting cycle-time data. Types of errors encountered in a follow-on assignment using cycle-time data are more limited, and comprise the following:
- Incorrect interpretation of a complete cycle (stopping one action short of a complete cycle in cycle time calculation)
- Incorrect interpretation of a complete cycle (considering all cycles as one cycle)
- Interpretation of loader-driven vs. hauler-driven production

The majority of the errors in the follow-on assignment were related to interpretation of a complete cycle (primarily related to failure to include each action in a given cycle). Most students were able to correctly judge loader-driven vs. hauler-driven production and support their conclusions adequately based upon their calculations of cycle time. This implies that the exercise does provide exposure into how to interpret data about multiple cooperating pieces of equipment, but can improve to provide better insight into what constitutes a complete cycle.

**Improvements for upcoming design and implementation**

The loader operators noted a modest learning curve while operating their particular pieces of equipment. This learning curve effect was more pronounced for loaders than for haulers, because the loaders comprised more moving parts and were clumsier to operate with a given load. This behavior can be leveraged in upcoming discussion of learning curve effects, both by showing how the durations of each action trend over the course of each operation, and by demonstrating how over cycle times improve over the course of each operation. This improvement will also provide greater visibility to the difference in learning curve between loader and hauler operators, and will permit students to hypothesize why the learning curves are different for each piece of equipment and what effect this has on the operation as a whole.

Students may benefit by comparing actual performance to a theoretical baseline. The exercise can be formalized more by using bucket and truck capacity to estimate the number of bucket loads to fill a truck and number of truckloads to create a 1” lift, rather than rely on intuition to gauge the expected productivity of a given operation. This will provide a platform for students to hypothesize why differences occur, why variation occurs within observations, and what contributes to differences from the baseline and variations from other observations.

With small modifications, this exercise can provide a better platform for discussion of method comparison. In the current design, it is possible to compare different ratios of haulers and loaders. This operation can be enriched by adjusting the capacity of equipment (e.g. comparing results obtained with these “full-sized” haulers to operations that employ smaller haulers and loaders) or adjusting the methods used to excavate, load, haul, or dump. From this data and assumed cost information, students can determine the break-even point for selection of an operation with larger or smaller equipment.
This exercise can be improved to simulate additional factors related to equipment production. For example, the grade of the road used for haul and return was smooth and level. Students might view differences in haul and return times depending on the road condition, direction of the grade and the load. For the current dimensions of haul road, the difference between hauling loaded and empty is at most one second. Students were slightly more careful on the haul road so as not to spill their load. To simulate the effect of grade, students might be prompted to drive only as fast as possible without spilling material from the open back of the hauler. At grade, this will certainly create a noticeable difference between haul times and return times. With differences and variability in haul and return times, students can determine the effects of (simulated) factors, such as grade and road condition, on equipment production.

Conclusions
This paper presents the objectives, design, and results of an in-class exercise to measure and monitor equipment production. Students simulated a loading and hauling operation using toy equipment and a stockpile of gravel, and measured the times for each action in the operation for each piece of equipment. During this exercise, students observed modest learning curves in equipment operation, as well as loader-driven and hauler-driven operations. Student recording errors during the exercise related to incorrect start times, mixed actions, and reduced granularity of record-keeping. Given a correct cycle time record, the students exhibited a good sense of loader-driven versus hauler-driven production. Some students, however, erred in formulating a complete cycle from the presented actions. This exercise can be improved to better explore and convey the components and interpretation of a complete cycle and factors related to equipment production. Additionally, this exercise can grow to incorporate comparisons of different loading and hauling equipment, and thus introduce study of method comparisons.

References

Communication-Based Virtual Construction Environment

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The 3D virtual construction environment is a computer desktop graphical environment where, through the use of 3D graphical building models, users build their buildings without physically building them on a real construction site. In this graphical (virtual) environment, however, users have no constraints on what they can do and how they do the job. Students do not recognize the communication requirements involved with real construction projects, and therefore do not recognize the consequences of a poor communication in the project execution phase. This paper is to describe a proposed communication-based virtual construction environment (CB-VCE) in order to increase the realism in the simulation of construction management practices in such a way that the simulation closely emulates the real construction project. Therefore, the proposed simulation system enhances the educational experience and should result in the recognition of the need for better communication because student users immediately see the results of their collaborative outcomes. Student users get an opportunity to visually see how different project participants impact their own performance, and how project information and documents play a critical role in the success of construction projects. As a result, the proposed system becomes a true tool for learning and understanding real construction management processes.

Key Words: BIM, Virtual Construction, 4D Scheduling

Multi-Dimensional Capabilities of 3d virtual CONstruction

Virtual construction technology has gained recognition as an effective management tool (Schwegler 2003) mainly because it allows users to present construction information in an easy-to-understand 3D graphical format. This 3D virtual construction technology has evolved as a multi-dimensional simulation environment (Park and Wakefield 2003). A 3D graphical environment has now been transformed into a hub of a project database in which project information is generated, stored, retrieved and maintained as shown in Figure 1. Three-dimensional models serve as a visual interface to a project database by providing efficient access to construction project data that is easily integrated into the project work plan. Building information modeling (BIM) has become a common focus for attempts to integrate project data in a 3D environment.
Specifically, a four-dimensional (4D) scheduling (3D graphical models combined with the construction time) technique has also emerged as a construction process visualization tool by presenting 3D models in a time-lapsed fashion (Haymaker and Fischer 2001; Alianza 2003) as shown in Figure 2. This advancement allows users to build their buildings without physically building them on sites. Some of the reported applications of the 4D technique include: construction schedule verification, alternative schedule comparison, trade coordination, temporary structure design, and active hazard anticipation and safety improvements (Brawn and Sloan 2003; Ray and Reed 2003).

### DRAWBACK OF THE CURRENT 3D VIRTUAL CONSTRUCTION

As much as the existing 3D virtual construction technology provides substantial features for better managing construction projects, there is, however, a critical drawback in the technology in that it is not a complete educational tool in construction-related disciplines. The drawback is that there are “no constraints” in the 3D virtual environment with respect to project resources and information. The current state of the art in this area has not shown any dealing with such an issue in the virtual environment. In the 3D virtual environment, it is assumed that all the materials, equipment and workers required to perform construction work are always readily available. In other words, users can complete any work even without asking themselves if there are appropriate sets of resources and permissions for the work to be performed. For example, precast...
concrete construction is done in the virtual construction site even without acquiring and using a feasible set of resources such as machines, workers, and materials, and/or without generating and reviewing sets of information such as permits, inspections, purchase orders, submittals, and so on. In the 3D virtual environment users have no restrictions and regulations on how they build the project. Therefore, student users are not given an opportunity to learn the building is the outcome of exchanges and communications of the project information data. This must be generated, transmitted, reviewed, and approved, through various communication routes with parties involved in the project.

DEVELOPMENT of the new SIMULATION ENVIRONMENT

In order to address this “unconstrained” simulation in the 3D virtual environment, which results from the lack of communication components in the simulation, the authors propose a Communication-Based 3D Virtual Construction Environment (CB-VCE) by integrating a web-based project collaboration environment (PCE) with the 3D virtual construction environment (VCE) as depicted in Figure 3. The web-based project collaboration environment (PCE) (such as Autodesk’s Constructware and Meridian’s Prolog) has been widely used in the construction industry as a managerial solution for multiple project participants to generate and exchange construction-related information in real-time in order to increase communication and information sharing for construction projects via an online project collaboration website (Leung, Chan et al. 2003). In this paper, the 3D virtual construction environment (VCE) is defined as an existing and commercially available 3D graphical environment in the computer desktop where users can interactively assemble 3D graphical building components for construction process visualization.

Figure 3. Framework of Communication-Based Virtual Construction Environment (CB-VCE)
In this integrated Communication-Based 3D Virtual Construction Environment (CB-VCE) in Figure 3, students assume roles of owners, architects/engineers, agencies, contractors, and suppliers, and they interact with each other in a web-based project collaboration environment (PCE, Layer I) to simulate real construction management processes and business operation situations. Through a series of interactions, students generate key essential construction documents and information such as purchase orders, change orders, permit acquisition, inspections and so on, which are all essential project information the project managers should deal with in managing the project.

Such information and data communicating activities will affect the resulting construction operations in a 3D virtual construction environment (VCE, Layer III) either positively or negatively depending on how the role-playing students have managed the communication process with other role-players. For example, if a contractor role-player has not acquired panels for pre-cast concrete wall construction through purchase orders and delivery confirmation with a vendor (another role-player) in the web-based project collaboration environment (PCE, Layer I) or has not secured an approval of the pre-cast panel submittal from the architect (another role-player), he or she can not perform this work in the Communication-Based 3D Virtual Construction Environment (CB-VCE) simply because the contractor role-player did not meet the communication requirements for the panel construction to be performed. For this reason any information, data, and documents in the communication process amongst project parties becomes a constraint condition for physical construction operations to be executed in the field or in the 3D virtual site.

Internally, as depicted in the framework in Figure 3, these constraint conditions are captured in another layer, called the Constraint Management Layer (CME, Layer II). The communication information and data in the web-based project collaboration environment (PCE, Layer I) are processed into this new layer to provide constraining conditions on visual construction operations in the 3D virtual construction environment (VCE, Layer III). This CML layer is an essential element in this integrated simulation learning environment because it functions to link two communication and visual learning environments (Layer I & III) in a way that only the construction operations with completed communication processes can be completed in the 3D virtual site.

Based on this conceptual frame work, an example of the pre-cast concrete wall construction is presented in Figure 4. Students assume roles as different parties such as a contractor, an architect, and a vendor. The contractor role-playing student identifies appropriate resources and document requirements necessary to execute the job. Once determined, the student initiates the communication process in the web-based PCE before he or she can put up the precast concrete wall panels in the VCE as depicted in Figure 4. As one of the communication requirements for the precast wall construction, a submittal process should be simulated properly for the precast panels to be available in the VCE. Only when all the precast submittal communication and approval process have been properly done, then the construction simulation is allowed to take place in the virtual environment.
Figure 4. Implementation of CB-VCE Using the Precast Wall Construction Submittal Process

**Conclusion**

The proposed simulation system (CB-VCE) enhances the educational experience and results in the recognition of the need for better communication because student role-players immediately see the results of their collaborative outcomes. Specifically, each student gets an opportunity to visually see how different project participants impact their own performance and how project information and documents play a critical role in the success of construction projects. As a result, the communication-based 3D virtual construction environment (CB-VCE) becomes a tool for better learning and understanding of real construction management processes.
References


A Case Study in Student Service Learning Using the AISC Structural Steel Teaching Sculpture

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Student service learning has been receiving much attention. Universities have used many different methods to engage students in this activity. From mandatory to voluntary, community service to university service, several methods to engage students in the concept of service without financial gain have been presented. This paper describes the case in which student service learning became the vehicle through which a construction management program built their own Structural Steel Teaching Sculpture—a teaching tool promoted by the American Institute of Steel Construction. As an incentive and guide to others who may wish to attempt a similar project, details of the process, potential obstacles, associated costs, and recommendations are presented.

**Key Words:** AISC, Steel Teaching Aid, Structural Steel Teaching Sculpture, Service Learning

**Introduction**

Depending on the type of program, to varying degrees construction students receive basic training in statics and structures. Unlike engineering programs, they also receive instruction in plan reading. While engineering students receive much more detail of structural steel design, construction students, with their limited design exposure, will be required to visualize these details and make them into reality.

It was recognized that construction students could benefit from a model showing structural steel elements and related connections as they learn about the basic concepts of steel design and construction. The American Institute of Steel Construction (AISC) promotes such a model in the form of a Structural Steel Teaching Sculpture (hereafter referred to as the SSTS or simply, the structure). Such a model, usually donated by an industry partner, was not available to this institution due to a lack of interested fabricators.
How does one obtain one of these models with no fabricator and limited funds? Make it a service learning project and involve as many students as possible from across campus. How does one convince a potentially reluctant university administration of the merits of such an approach? Get students, faculty, and staff from across campus, as well as the local community, involved in the process.

The following describes the approach one program took to become the first university to fabricate their own SSTS, placing it in a prominent position on campus in affirmation of the efforts of all those involved, and providing an additional tool for the effective teaching of structural concepts.

**Student Service Learning**

Just what is meant by *service learning*? Furthermore, what is different about *student service* learning versus other service learning? Perhaps this needs no explanation. However, the term has become quite popular of late among academics. What is it that has caught the collective eye of these academics?

A review of the available literature contains a multitude of resources describing the topic and offering advice. Choosing one web resource for discussion, *The Big Dummy's Guide to Service-Learning* (Cooper, 2006) provides a basic overview of the goals of such activities. This particular resource allows readers to submit suggestions for goals. At the time of this writing, the website listed nineteen goals. Eliminating redundancy and entries irrelevant to the project at hand leaves the following ten goals (provided verbatim):

1. To enhance student learning by joining theory with experience and thought with action.
2. To fill unmet needs in the community through direct service which is meaningful and necessary.
3. To enable students to help others, give of themselves, and enter into caring relationships with others.
4. To assist students to see the relevance of the academic subject to the real world.
5. To enhance the self-esteem and self-confidence of your students.
6. To develop an environment of collegial participation among students, faculty, and the community.
7. To develop a richer context for student learning.
8. To better prepare students for their careers / continuing education.
9. To help students know how to get things done.
10. To do something. Anything.

The process described herein supports all of these goals, and more. In particular, while it may seem trite, the last item in the list says so much more. From the standpoint of the faculty and students that wish to see the outcome, when faced with limited funds and a lack of sponsorship, doing *something* is a much better way to channel frustration. In addition, doing *something* is an opportunity to engage students.
Learn and Serve America is a program of the Corporation for National and Community Service, an independent federal agency. Their website states “Service-learning engages students in the educational process, using what they learn in the classroom to solve real-life problems.” It continues, “Service-learning can be applied across all subjects and grade levels; it can involve a single student or group of students, a classroom or an entire school. Students build character and become active participants as they work with others in their school and community to create service projects in areas like education, public safety, and the environment.” (Learn and Serve America, 2006)

These goals and ideals of student service learning always directed the project development.

The AISC SSTS

Perhaps more familiar to schools of structural engineering, the AISC’s SSTS has been around since 1986. The original design by Dr. Duane Ellifritt, a University of Florida Professor of Structural Design at that time, was intended to help students visualize the three-dimensional reality of a two-dimensional drawing. It was later adopted by the AISC as part of their university programs. The intent of the program is to partner a steel fabricator with an interested university, having the fabricator donate the completed structure to the school for final placement. To date, the structure is located or being placed at 135 schools throughout the United States and Mexico. AISC also provides universities many other tools and opportunities to assist in the teaching and understanding of the use of steel in construction. To view the complete list of these schools and available materials, visit the AISC website at http://www.aisc.org, click on Learning Opportunities, then University Programs (American Institute of Steel Construction, 2006).

Basic Approach

The desire to acquire the structure was first met with resistance in lower level administration. Concerns centered on need, cost, and placement. The program was not an engineering program. Funds for such an effort were not available. If acquired, where would it be placed? Little discussion took place for one year while efforts to gain a fabrication sponsor moved slowly.

In the meantime, a series of changes in all levels of university administration opened the door for new initiatives. A casual conversation in July between a Construction Management professor and a Welding Engineering Technology professor ignited a slow flame. The idea of having students fabricate, assemble, and erect the structure themselves was born. The next six months were spent submitting requests and negotiating with university administration.

The basic approach was to have Sigma Lambda Chi (SLC), the construction honor students, carry out the role of project managers while a group of welding students completed the fabrication of the steel components as one of the class projects in the two-year welding technology capstone lab.
Who Else Can Be Included?

There is much more to placing a SSTS on a campus than merely cutting and welding some steel. It is understood—perhaps universally known—that little is done in most academic institutions without involving some campus politics. Anticipating potential reactions encouraged a review of the goals of student service learning. To enhance the service learning aspects of the project a concerted effort to involve as many people as possible from across campus was sustained.

To increase the number of students involved and incorporate a cross-college experience, a landscape design competition of the SSTS’s foundation setting was introduced. The design competition was presented as a request for proposals (RFP). Teams were to be composed of one student each from SLC, Architectural Technology, and Ornamental Horticulture. Since the number of Ornamental Horticulture students was significantly smaller than those of the other two programs, these students were allowed to serve on more than one team. The students submitting the winning entry would receive $100 each and would provide the construction management oversight of the foundation and landscape construction. The contest provided approximately one month for completion of proposals.

Once again, with an eye on campus-wide acceptance and the goals of service learning, a panel of judges was assembled. Professors from the Colleges of Technology, Arts and Sciences, and Business—representing diverse programs in Architectural Technology and Facility Management, Humanities, Biology, and Music Industry Management—joined the Dean of the College of Technology to serve as judges. Final award for the selected design would follow approval of the faculty of Construction Management. Ultimately, implementation of the design would be coordinated with the University’s Superintendent of Grounds.

Four of the seven teams submitted their proposals for review. Each team provided a formal presentation with a question and answer period. The union of differing views provided by three students with such diverse backgrounds was quite evident and encouraging. The most interesting observation was the unique and completely different perspectives offered by the panel of judges—extending the service learning aspects to this room of professionals. In closed deliberations, the judges declared a tie and students from both teams received awards. It was decided that, with the guidance of the Superintendent of Grounds, the two proposals would be combined—a fusion of their best features.

Fabrication

As a final component of the two-year degree program in Welding Engineering Technology, students complete a project of their choice. Everything from kennels to wood burning stoves can be seen at various stages of completion on their shop floor. From this class of students, four volunteered to work on the fabrication of the SSTS.

SLC members shared the responsibility of visiting the welding students during their nine lab-hours per week, answering questions and interpreting drawings. For the construction students, the relationship emphasized the importance of providing clear construction documents,
developing simple instructions, problem solving, critical thinking, and dealing with issues related to the welding trades. The welding students experienced much the same, as well as exercising a depth of plan reading skills that exceeded their normal instruction. Most importantly, the learning took place between and among the students, with guidance from their professors.

Fabrication began with the winter semester, culminating with the structure’s unveiling 15 weeks later on the last day of classes. The original set of drawings was obtained from the AISC’s Director of University Relations, Mr. Fromy Rosenberg. After the start of fabrication, a CAD file was found in the Teaching Aids section of the AISC website (American Institute of Steel Construction, 2006). After downloading and reviewing the file, it was discovered that the file contained some significant changes to the design that would have voided some of the work already accomplished. It was decided to move forward using the original set of drawings.

Landscaping

The landscape competition was discussed earlier. As the project progressed into the spring, efforts to acquire donations of materials got underway. National home improvement retailers and local landscape professionals were contacted to assist the anticipated student labor force by providing in-kind materials and equipment. However, as paperwork and contacts were being processed, the location changed—effectively eliminating the need for any landscape preparation.

Steel Preparation and Painting

Questions regarding the sequence of priming, finish coat painting, and sandblasting arose early in the project. Several options existed.

1. Question of Assembly and Placement versus Erection: Perform final assembly of the structure prior to placement on-site versus erecting the structure on the foundation. The former allows controlled conditions for all steps through assembly but risks damage to the coating during placement. The latter avoids some of the anticipated damage involved in moving the entire structure and, regardless of order of painting processes, requires final coating of connection bolts and welds.
2. Question of Process: Individually sandblast, prime coat and final coat each piece, then assemble and touch up the whole structure. This provides the protection of a controlled environment during all painting.

3. Question of Process: Individually sandblast and prime coat each piece then assemble and final coat the whole structure. This provides the protection of a controlled environment through priming and, if done off-site, through final coat. It also avoids potential damage to the final coat during assembly.

4. Question of Process: Completely assemble the structure, then sandblast, prime, and final coat the entire assembly. The reduced time and simplicity of this suggestion was very compelling. The argument was made that mill scale between pieces would be sealed by the paint, sealing the joints from water infiltration and potential rust stains.

Industrial coatings sales representatives provided conflicting opinions. After careful deliberation of the fourth option, the potential for paint cracks developing at the joints and around connections due to thermal movement seemed great. The concern for a lifetime of rust stain maintenance removed the option from consideration.

Original plans called for the use of the Auto Body program’s facility and student labor for sandblasting and painting. It became obvious that the program’s equipment was inadequate for structural steel. Efforts to locate a sufficiently large paint booth and a satisfactory sandblasting unit required two locations. Combined with time constraints, student labor was ruled out. Arrangements were made to use the paint booth and technician of the Heavy Equipment Technology department. Sandblasting services, necessary to remove mill scale and clean the steel surfaces prior to prime coating, was to be donated by a nearby manufacturer.

The limited size of this paint booth, the need to move the structure off-site for sandblasting, and the desire to obtain the best possible prime coat lead to the selection of the third option, and the decision to erect the structure on its foundation. Therefore, to protect the final painting process from the April elements, a temporary enclosure needed to be built around the erected structure.

Students disassembled the structure, transported the pieces to the sandblasting facility, and returned the prepared pieces to the Heavy Equipment program’s painting booth across campus for priming by the program’s technician and university painters using air sprayers. In the meantime, students prefabricated plastic-sheeted stud panels for the on-site paint booth. Following prime painting, the pieces were moved to the foundation and erected, the paint booth was assembled around the SSTs, and final painting performed by university painters.

The selected paint system, donated by a national industrial coatings manufacturer, was a fast-dry, single coat, polyurethane formulated for accelerated maintenance painting of bridges. The use of an air sprayer with this fast-dry paint inside the enclosure caused a swirling effect difficult for the painters to control—drying on the backside of pieces and resulting in an unintended but visually interesting dimpled surface texture. This may have been avoided by using an airless sprayer.
Foundation

The SSTS plans do not provide direction for foundation design. Foundation design is dependent upon actual location and exposure to wind or seismic conditions. Other loads that must be considered are not necessarily obvious to a typical engineer. However, to a professor, such loads may seem ordinary. Consider, for example, the number of bodies that may be stacked upon one arm of the structure or a chain wrapped around the structure’s base with the other end attached to a pickup truck. Such unforeseen loadings may be significant.

Basic foundation design became a class problem. It was then beefed up to mitigate affects of unforeseen forces. After removing a select area of paving stones from the site, an electrical contractor bored a 30-inch diameter hole beyond the frost depth of 48 inches. This approach achieved penetration through glacial till that included very large boulders while minimizing disturbance to the pre-landscaped area. A standard forming tube was used to support the hole and provide a 6-inch above-grade reveal to protect the structure from the blade of snow clearing equipment. Longitudinal and hoop reinforcement was fabricated by construction students using ingenious methods for jigs and bending of the No. 3 reinforcing bars. Anchorage was provided with ¾-inch galvanized threaded bars extending a minimum of 3-feet into the foundation. As an added teaching feature, the leveling nuts were left exposed after erection of the SSTS.

Assembly

Assembly was done twice. The first occurred in the welding lab while being fabricated and was performed by welding students. Final assembly took place on the foundation, prior to final painting, and about five days prior to the unveiling. The process joined the construction and welding students with university grounds personnel and their backhoe to assist in placement. This gave the welding students the opportunity to supervise the careful erection of their work while construction students learned a little more about steel construction and related tools.

Location, Location, Location

The original proposal for the project was submitted in late summer. Approval from the highest levels of administration came in the form of an acceptance of concept. But, being a new administration, the exact method of approval was yet to be determined.

It is important to note that there are really two pieces to the approval being sought for a project of this nature. The first piece of this approval is the permission to locate the structure on
campus. Throughout this project, there were no less than five times that approval was considered final by the project team. Obviously, frustration mounted with each resurrection of the proposal. It would be difficult to explain the hierarchy of those that provided final approval. In fact, many of those involved in the approval of the project and its location are unknown to the project team.

The second piece of this approval is the agreement on the specific location. It is this second piece that is the most difficult. Three separate approvals were received—each thought to be final—each identifying the chosen location. No indication of any problem with the selection of the site was made evident to the project team. Two weeks prior to site work, the administration began second-guessing their location decision—resulting in six more iterations of the approval process. As the time came to break ground, and with no commitment on a site for modification to the winning landscape designs, the approved and final location was identified.

The location chosen by the administration was within 100 yards of all of the other locations. Surprisingly, it placed the structure in the most prominent of all locations, as the centerpiece of the adjacent quad. Since this location was already landscaped and required minimal effort for foundation construction, the pressure to break ground was relieved. The student landscape design competition became a mute point, albeit a learning experience for the students who competed.

**A Rose by Any Other Name . . .**

What is in a name? The title block of Dr. Ellifritt’s plans contain the phrase, *Structural Steel Teaching Sculpture*. Indeed, these four words have been combined in various ways to name like structures at other universities. Some schools have a *Steel Structure* or a *Teaching Sculpture*, while others have a *Structural Teaching Tool*.

After the fine arts community of this campus took exception to the use of the word *sculpture* in the title of the structure, it was discovered to be a common problem on many campuses. Objection was so strong that invitations to the representative of that community to participate on the panel of judges for the landscape design competition were rejected. In respect to Dr. Ellifritt’s original design, the name of the structure was not modified. However, it is now referred to as *the structure* or, more affectionately, the *SSTS*.

**A Union Shop or Not?**

Throughout this report, students, faculty administrators, staff, and university personnel are referred to often. This university is, in fact, a union environment. Understanding that the SSTS was to be a service-learning adventure, the unions enthusiastically embraced the project and engaged the students—working side-by-side with the students and faculty where needed. Their dedication to the university’s teaching mission was extraordinary.

**The Unveiling**

Having all site construction, painting, and erection completed within the 12 days leading up to the unveiling ceremony was indeed cutting it close. The ceremony occurred on the last day of
classes, taking advantage of concurrent advisory board meetings, student awards banquet, Sigma Lambda Chi inductions, and an alumni golf outing. A cross-section of the entire campus was on hand to witness the students uncovering their work (of art) with great pride.

**Show Me the Money!**

Original plans to acquire 100% material donations were modified by the uncertainty and timing of approvals. Outstanding support from the Dean provided a cushion of funding to see the project through. With two departments handling the process, the flow of money was somewhat buffered. Materials came in a combination of donated, wholesale, and retail pricing. Most services provided by other than students or faculty were graciously absorbed by various university administrative departments or provided in-kind by outside vendors. As the project neared completion, a grant was secured through the university’s Foundation to offset most of the costs incurred by the department and college. Table 1 provides a brief summary of the associated costs, materials, and labor.

Table 1

**Brief summary of associated costs, materials, and labor**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Steel and Miscellaneous Pieces</td>
<td>$3,000</td>
</tr>
<tr>
<td>Student Awards</td>
<td>500</td>
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<tr>
<td>Miscellaneous Equipment and Supplies Related to Onsite Construction</td>
<td>600</td>
</tr>
<tr>
<td>Miscellaneous Pieces and Supplies Related to Onsite Construction</td>
<td></td>
</tr>
<tr>
<td>and Erection</td>
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</tr>
<tr>
<td>Copies and Postage: Plans and Invitations</td>
<td>150</td>
</tr>
<tr>
<td>Unveiling Ceremony</td>
<td>500</td>
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<tr>
<td>Brass Plaque and Signage (estimated)</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$5,750</strong></td>
</tr>
</tbody>
</table>

**In-Kind Donations of Materials, Equipment, and Labor:**

- University union painters, Heavy Equipment department technician, and grounds personnel assisting with foundation drilling and steel erection, backhoe, and painting equipment.
- Industry facility, blasting sand, sandblaster, and operator.
- Industrial coatings (primer and paint).

**Materials Re-Used by Construction Department:**

- Temporary painting enclosure: wood framing and plastic sheeting ($400)

**Hours: (not including hours yet to be devoted for web design and introductory material)**

- Welding students: approximately 550 hours
- Other students: approximately 450 hours
- Faculty, staff, and industry partners: untabulated

**Recommendations**

The following provides advice for those who may wish to duplicate such an effort.

1. Receive, in writing, a description of the approval process prior to committing resources or involving others. This does not guarantee there will not be changes. But it does provide the roadmap excluding detours.
2. Do not fast-track the planning and fabrication. Take a semester to secure the donations of materials and services. Perhaps overlap this effort with the semester necessary for university approval. While students completed the fabrication in three months, it took the university nine months for approvals.
3. Consider the union environment. Get union agreements in place early.
4. Budget for all of the items discussed, then modify it for the program’s unique approach.
5. Consider the set of drawings to be used. While this project used the original hand-drawn set, a very detailed CAD file exists that provides bills of materials and the ability to more easily produce prints. It differs from the original. Select one and stick with it.
6. Do it. While it would be difficult for a school that has no welding program, the students’ pride will last for generations. At the unveiling, proud students voiced their desire to bring their yet unborn children back to campus in the decades ahead. For those lacking welding expertise, partner with a local vocational school or find another institution if needed. Across the spectrum of participants—students, faculty staff, and local industrial partners—a general sense of accomplishment and understanding was shared.

Finale

One year after the unveiling, a few touch-ups, signage, and minor tasks remain. A web-based photo journal is under development. Of course, it is expected that one or more students in the College of Business and the College of Arts and Sciences will assist in this effort.

The SSTS serves the campus community as a teaching tool for Architectural Technology and Construction Management students, a model for art students to use for sketching, a conversation piece for community members walking their dogs, and a point of pride for more than 1,000 student hours of service learning.

While the acquisition of a SSTS was the goal, student service learning provided an effective vehicle and the focus for the project. This paper described one program’s experience in that effort. However, it is not limited only to the acquisition of a SSTS. Student service learning offers valuable hands-on exposure to project management while providing a means of achieving any desired outcome. A program’s desire to reach any goal and a commitment to involve students in that effort are all that is necessary to get the ball rolling.

References

