Awareness of Landscape and Ability to Think

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ABSTRACT

The foundation for appropriate engineering solutions is an examination of landscape – nature. Scientifically based engineering theory provides an acceptable project solution only when formulated with an awareness of landscape. Landscape is a defining aspect of most engineering problems; as such it frames the issues to which engineers apply their technical knowledge. Many engineers, however, take the wrong approach and seek to dominate nature with theory. When engineers fail to appreciate the landscape of a problem and lack the ability to synthesize and evaluate technical fundamentals the result is often a disaster. Conversely, superior technical solutions are the consequence of engineers trained to understand the landscape surrounding a project. The ASCE Policy Statement 465, *Academic Prerequisites for Licensure and Professional Practice* makes a strong case to adopt a new educational model. The suggested model seeks to strengthen the cognitive ability of engineers and encourages practices that work in cooperation and harmony with the landscape –nature– for the benefit of society.

Keywords: education, engineering, environment, knowledge, nature

RESUMEN

La base para una solución de ingeniería adecuada es un examen del paisaje - la naturaleza. La teoría de ingeniería con base científica proporciona una solución de proyecto aceptable sólo cuando se formula con conocimiento del paisaje. El paisaje es un aspecto determinante de la mayoría de los problemas de ingeniería, como tal, enmarca los temas en los que los ingenieros aplican sus conocimientos técnicos. Muchos ingenieros, sin embargo, siguen el enfoque equivocado y tratan de dominar a la naturaleza con la teoría. Cuando los ingenieros no toman en cuenta el paisaje de un problema y carecen de la capacidad para sintetizar y evaluar los fundamentos técnicos, el resultado es frecuentemente un desastre. Por el contrario, las mejores soluciones técnicas son consecuencia de ingenieros capacitados para entender el paisaje que rodea a un proyecto. La Declaración Política del ASCE 465, Prerequisitos Académicos para la Licenciatura y la Práctica Profesional–*Academic Prerequisites for Licensure and Professional Practice*–da buenas razones por las que debería adoptarse un nuevo modelo educativo. El modelo propuesto pretende fortalecer la capacidad cognitiva de los ingenieros y fomenta las prácticas que trabajan en cooperación y armonía con el paisaje –la naturaleza– para el beneficio de la sociedad.

Palabras claves: educación, ingeniería, medio ambiente, el conocimiento, la naturaleza

1. PANAMA CANAL SOLUTIONS

Ferdinand de Lesseps and his French engineers approached construction of an interoceanic canal across Panama based on their Suez experience. They had no consciousness that a different technical theory was necessary to embrace the forces of water and earth at work in the landscape of Central America only 9° above the equator. The landscape of Panama is very dissimilar from the desert of Egypt located 30° above the equator. After de Lesseps' failure, the Americans, believing in their ability to force a sea level canal, also failed to appreciate the landscape and pursued a technical approach similar to that of the French. The first American Chief Engineer, John Findley Wallace, lasted only one year, from June 1904 to June 1905, before resigning. His resignation was probably as much from a personal fear of yellow fever as from a failed appreciation of the project landscape. But, even here, he failed to recognize that his fear of yellow fever was part of the project landscape.

When Wallace accepted the Chief Engineer position he faced two immediately recognizable issues: the first was the landscape issue of disease and the second was the technical challenge of moving a tremendous quantity of material within the context of a tropical environment. As a railroad engineer of considerable experience he understood construction methods and selected Bucyrus steam shovels to excavate the Culebra Cut (Gillard).

At the same time President Theodore Roosevelt, because of his 1898 experiences with tropical diseases in Cuba, sent Col. William Crawford Gorgas (an Army physician) to Panama with orders to take charge of the hospitals and sanitation work. But Wallace did not understand the landscape of disease and failed to support Dr. Gorgas.

The second American Chief Engineer sent to Panama was John Frank Stevens. Stevens, a native of Maine, had spent years surviving frontier conditions across the full length of the North American continent before going to Panama. David McCullough (1977) when describing Stevens put emphasis on the man's closeness to nature: "… a survivor of Mexican fevers, Upper Michigan mosquitoes, and Canadian blizzards." Here was an engineer who understood landscape, a man who took time to study the landscape that framed and impacted his projects. Through the deep mud, tropical heat, and the drowning rains of the Isthmus he walked the canal line from Colón on the Atlantic Ocean to Panama City on the Pacific Ocean. To the landscape issue of disease he immediately gave Dr. Gorgas full backing with men and supplies.

Such studies of landscape were once not unusual for those designing and building projects. Walter Shanly, who with his brother Francis, built more miles of railroad in Canada and the United States than any other engineer always walked his projects. In April 1851, after examining the ground for the Prescott to Bytown (Ottawa) railroad, Walter wrote Francis (Walker 1957):

> *I have done all I want to do and know more about the county … from Prescott to Bytown than any other live man, don't care who he is. I … must have walked 300 miles, all on snowshoes except yesterday's work when I made 17 miles on bare ground.*

The technical solution to the physical landscape of Panama was not a question of digging a long trench. It was an understanding of two fundamentals the Greeks had named thousands of years before – water and earth. Stevens paid attention to the landscape of water during his many walks; he experienced the rains and he observed the Chagres River in flood. Before Congress, in 1906, Roosevelt's engineer argued to embrace the power of the Chagres' water to lift vessels in a lock system instead of trying to control the energy of such torrents of water. Stevens also argued that to dig a 150 ft (46 m) wide sea level ditch would create endless landslide problems and not allow sufficient space for ships to maneuver. Success follows attention to landscape and in the case of the Panama Canal it was John Stevens' attention to water and earth.

2. To Educate an Engineer

Construction engineering is a series of technical activities throughout the project delivery process that influence design, [and] support construction means and methods decisions, … (Jaselskis et al. 2011). This characterization came from a U. S. National Science Foundation supported conference held at Virginia Polytechnic Institute and State University (Virginia Tech) in the fall of 2010. The conference brought together academics and industry leaders to better understand and strengthen the connection between scientific theory and engineering practice.

Engineering is an applied science and in no other engineering specialization is this fact more relevant than in construction engineering. The challenge, for construction engineering academics and industry practitioners, is to transfer a method, technology, or practice that can be supported in the theoretical sense to application in the environmentally impacted but specific project location. To successfully bridge the gap between engineering theories and practice requires that the practitioner have a clear understanding of the project environment – landscape. Landscape should be understood here in the broadest of terms. It encompasses technical parameters, physical conditions, and even the cultural setting of the project.

This interrelationship between technical knowledge and landscape is not understood by many engineering educators and as a result it is also not comprehended by countless practicing professionals. The evidence that many in the profession lack an appreciation for how landscape drives the application of technical solutions is found in the documentation of so many project failures. The blame for this lack of connectivity, between theory and practice, rests to a great extent on the university and how engineering knowledge is passed to the next generation. At the conclusion of the Virginia Tech conference, Dr. Michael C. Vorster, Professor Emeritus and Keynote Speaker, described the academic situation succinctly "We teach too much and our students learn too little." Recently the U. S. National Academy of Engineering reached a similar conclusion. The Academy's document *Educating the Engineer of* 2020 (2005) calls on engineers to consider new elements in design solutions such as the impact on the socio-cultural systems and to consider historical awareness, another way of saying a broader awareness of landscape.

The successful practice of engineering is built upon a solid foundation of technical knowledge in concert with an ability to comprehend the landscape in which a project is placed. The ancient Greeks spoke of earth, water, air (or wind), and fire as primary elements that correlate to the notion of landscape as it relates to understanding the environment. Ancient engineers obviously approached their work in terms of these primary elements. They had a deep understanding that the control of forces is for practical purposes impossible and that it is better to appreciate a force and work with it to accomplish a project. Their thought patterns embraced ideas of transforming by embracing prime forces. They clearly understood the effects of location and environment–landscape on a project. The competency of modern engineers must be founded on a similar ability–the ability to analyze, synthesize, and evaluate technical solutions from a landscape perspective.

3. A LACK OF UNDERSTANDING

Project owners rely on the construction knowledge of their engineers and constructors to deliver quality work. This fact is evident in how the construction industry has, over the last 40 years, moved away for the old detailed "means and methods specifications" that were once found in project documents. Today project specifications provide guidance and direct a constructor's attention to important information necessary for delivering quality work. It is assumed that both the design engineer and the constructor are technically competent and have knowledge of the scientific theory that underlies the guidance in the specifications. Nevertheless, in too many cases, engineers are not well grounded in the engineering theory and completely ignore the landscape of a project. If the landscape is not observed and understood it is impossible to properly apply engineering theory and achieve a successful project outcome.

A large reservoir built in the early years of the 21st century experienced severe cracking of its interior soil-cement face flat-plate within one year of project completion. These large cracks are evidence of material shear failures, which represent weak planes in the soil-cement. Shear failure cracks are much larger in width of opening than the normal thermal cracks that are expected on soil-cement surfaces. A superficial review of this project including the specifications and quality control documents serves to demonstrate this need for matching theory and landscape.

The project design included a 40.64 cm (16 in.) thick soil-cement liner on the up-stream (interior) slope of the reservoir embankment. This soil-cement was laid parallel to the embankment's 3:1 (H:V) slope, hence the term flat-plate. The flat-plate soil-cement extended from approximately the bottom of the reservoir up to the maximum pool elevation. Above the maximum pool elevation the embankment had 2.59 m (8.5 ft) of additional height to its crest. To protect this upper area the design engineer specified stair stepped soil-cement. The function of the soil-cement in both sections was to prevent erosion of the underlying earthen embankment.

The design engineer's original erosion protection design had the stair stepped soil-cement extending from the bottom of the reservoir to the crest of the embankment. Later during a project cost review the flat-plate design was selected because it required less soil-cement material. The decision being based on the idea that less material equates to reduced project construction cost. The final design did retain the stair stepped soil-cement for the last 2.59 m (8.5 ft) of the embankment.

However, a landscape matter not considered was the project's physical location. This reservoir's geographical location is in a region where afternoon thunder showers regularly occur during the summer months and winter can bring heavy rains as well. It is also in a location where hurricanes are a common occurrence.

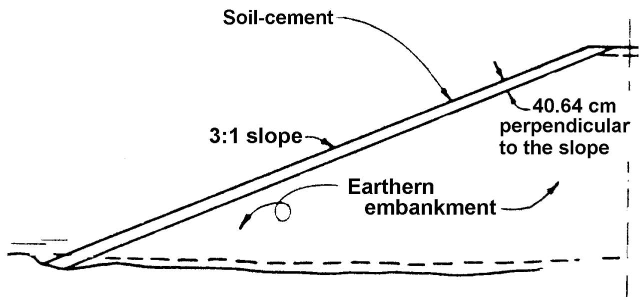

Figure 1. Flat-plate soil-cement.

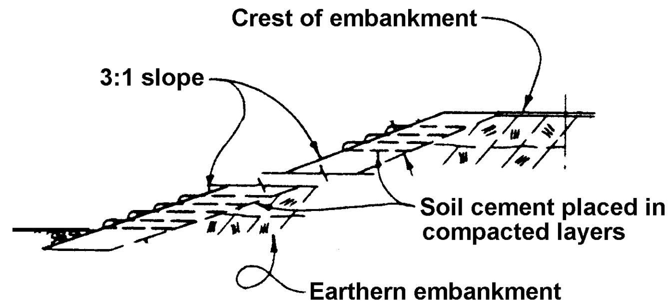

Figure 2. Stair stepped soil-cement

3.1 Technical Knowledge – Time

One of the specifications for the reservoir project stated: "Compaction of each layer shall be done in such a manner as to produce a dense surface, free of compaction planes, in not longer than one and one-half (1½) hours from the time cement is added to the mixture." This statement in the specifications is based on studies by G. West as published in Geotechnique (West 1959) which is also referenced in the American Concrete Institute (ACI) soil-cement document ACI 230.1R-90 (*State-of-the-Art* 1990). Based on technical knowledge concerning the hydration of cement, this specification served notice as to the importance of time in achieving material density. The guidance should be part of the fundamental body of knowledge for those who work in the area of soil stabilization.

The contractor constructing the soil-cement did not have an understanding of the need to control the time required to compact of the mixed soil-cement. Inspection reports, prepared by on site quality control personnel, fail to indicate any checking of the time duration between soil-cement mixing to include the adding of water and when lift compaction was completed.

The extent and width of the individual cracks in the flat-plate soil-cement at the reservoir are indications of shear failures and one of the causes of the cracks was *continued rolling of the soil cement after the initial set of the cement.*

When a truck delivering more soil-cement or compaction equipment made just one more pass over a soil-cement area that had already achieved initial set, shear failure resulted and some of the cement did not reset leaving a fracture that manifested itself later as a open crack. Because of the lack of adequate quality control inspection reports it was not possible to identify specifically which shear failure cracks resulted from rolling after the cement had begun to set.

3.2 Technical Knowledge – Compaction Equipment

The material used to produce the soil-cement was granular and by project specification could not contain clay/silt lumps. The engineer's compaction equipment specifications stated:

> *The equipment shall provide uniform compaction across the width of the equipment for each pass. The use of trucks, tractors, or other hauling equipment shall not be allowed for compaction of soil-cement mixtures.*

Instead of using vibratory soil compactors that are effective on granular materials and then pneumatic compactors for finish rolling, the contractor decided to use pneumatic tired tractor units and the trucks delivering the soil-cement mixture from the plant to compact the flat-plate soil-cement. When a truck is used as a roller, the wheels (which are separated by considerable lateral distance) displace the material laterally rather than accomplishing uniform compaction across the mat. Support is achieved as the cement begins to set which is also when compaction should be discontinued. Despite the statement in the specifications the inspectors and the engineer of record for the project made no objection to the contractor's selection of tractor units for compacting the soil-cement.

By using tractor units instead of full width rollers, the contractor was applying concentrated loads to the soil-cement. The tractor units did not provide the force application necessary to uniformly compact the bulky shaped soil particles (sand) of the soil-cement mix. The compaction specification had correctly informed the contractor of the importance of equipment requirements necessary to accomplish the densification of the material.

The extent and width of the individual cracks in the flat-plate soil-cement at the reservoir are indications of shear failures and one of the causes of such cracks was *inappropriate compaction equipment used to compact the mat*.

The contractor's failure to establish a standard rolling pattern including uniform compaction procedures for overlapping lanes or compaction passes (e.g., a count of the number of passes required for initial breakdown and final smoothing) meant that the foreman and operators never knew if the mat had been properly compacted or if over compaction occurred. The project specifications had included a provision for a test pad to prove the compaction equipment and compaction process but this proof of process action was never completed. So there was nothing to guide the compaction operations or to provide a reference for quality control. As a result there were no inspection reports that addressed the rolling pattern as there was no established pattern. For that reason it is not possible to identify specifically which shear cracks resulted from excess rolling. Repeatedly the inspection reports did note the use of different truck types for compaction and placement of single and then dual soil-cement lifts. These two aspects of the contractor's approach further complicated monitoring of the soil-cement compaction work.

3.3 TECHNICAL KNOWLEDGE – MAT THICKNESS

Proper compaction begins with uniform lifts. "If the soil-cement is placed too thick, adequate compaction near the bottom of the lift may not be achieved. Layers placed too thin have a tendency to spall and unravel." (Bass 2000) Similarly, the US Army Corps of Engineers advises that "… careful attention needs to be paid to achieving uniform thickness." (*Use* 2000)

The finished flat-plate soil-cement was by the contract specification to be 40.64 cm (16 in.) in thickness measured perpendicular to the slope. Project soil-cement specifications required "… uniform surface layers of such uncompacted thickness that when compacted each layer shall not exceed 22.86 cm (9 in.) nor be less than 15.24 cm (6 in.) in thickness." The design engineer had envisioned a two lift construction process.

Variations in lift thickness added to the difficulty of achieving compaction and to over compaction in some areas. The contractor used dozers to dress and walk the flat-plate soil-cement to the correct line and grade (mat thickness) after the rolling by the trucks. Such dozer work is an indication that the finished mat was not to the proper thickness. Additionally, this dozer activity created thin sheets of uncompacted soil-cement over the mass of the compacted flat-plate. These thin sheets soon separated from the lower compacted material.

Because of the contractor's failure to establish grade control procedures to monitor placement and compaction of the soil cement and the lack of adequate quality control inspection reports it is not possible to identify specifically which shear failure cracks resulted from thin lifts. Thin lifts will cause shear failures, therefore still another cause of the observed cracks was *variations in mat thickness at the time of compaction*.

3.4 LANDSCAPE – WEATHER

Both ACI and the Portland Cement Association (PCA) have statements in their soil-cement guidance documents about the importance of the subgrade in compacting soil-cement and in achieving a quality product. The statement in ACI 230.1R-90 (*State-of-the-Art* 1990) section 6.2.2.4 reads: "The mixed soil-cement should be placed on a firm subgrade, … . Soft or yielding subgrade shall be corrected and made stable before construction proceeds." Following this guidance the project specification stated: "In all cases prior to placing soil-cement, deficiencies in the underlying material shall be corrected, resulting in a restored compacted subgrade to 95 percent of maximum density, … ."

Because of the project's location in an area subject to rain on a regular basis, sections of embankment that had originally been compacted to the specified 95 percent of maximum density were often soggy and soft when placement of the flat-plate soil-cement commenced. At such locations the subgrade could not support compaction of the fresh soil-cement mat and shear failures resulted.

Many inspector reports stated that between stations XX+10 and XX+90:

> "The contractor is having difficulty in achieving density results."
> "It was found that subgrade under the geo textile liner was yielding."
> "It appears that the soil-cement was unable to meet density due to soft subgrade."

The extent and width of the individual cracks in the flat-plate soil-cement at the reservoir are indications of shear failures and the primary cause of many cracks was *lack of required subgrade support*.

It was very easy to identify locations where weak subgrade caused soil-cement cracking. The project daily reports provide weather information including rain fall and at locations where the contractor placed soil-cement immediately after a period of rain major and extensive cracking was observed. It is not clear why the inspectors and the engineer allowed the work to proceed when the subgrade needed remedial action.

3.5 Technical Understanding

The extent and width of the individual cracks in the flat-plate soil-cement at the reservoir are clear indications of shear failures induced in the mat during the spreading and compaction of the fresh mix. While the important factors necessary to the construction of quality soil-cement were called out in the project specification:

- The contractor failed to perform the work according to these specifications;
- The inspectors and quality control staff failed to track the important construction parameters: time, compaction equipment and process, and mat thickness; and
- The design engineer allowed substandard work to proceed without objection.

These were all technical failing and illustrate a lacking of understanding of the fundamental principles that were the basis for the project specifications. For a single project to have so many engineering failures is a disgrace to the profession and a clear indictment of our education processes. Educators have failed to impress upon students a clear understanding of the importance of fundamental principles.

3.6 Landscape Understanding

While flat-plate soil-cement can be successfully built on slopes as steep as 3:1 (H:V), as demonstrated by many past projects, the design does present construction challenges. The first and most obvious construction difference between stair stepped soil-cement and flat-plate is compaction because the rollers are operating on a slope and the densification energy is, consequently, not being applied normal to the layer of soil-cement. In the case of a 3:1 slope and a 22.86 cm (9 in.) lift the difference in thickness of material in the applied direction of the compaction forces is 1.24 cm (0.5 in.) and in the case of a 40.64 cm (16 in.) lift the difference in thickness of material in the applied compaction direction is 2.2 cm (0.9 in.). This means that more energy is required to achieve the desired densification of the lift. The compactive effort can be increased by 1) making more passes with the compaction equipment, 2) using heavier rollers, or 3) by decreasing the lift thickness. All three of these approaches to densification of the flat-plate soil-cement on the 3:1 slope caused the engineer and constructor problems.

Technical Knowledge Time – When the number of roller passes is increased the result is a longer time duration necessary to achieve the prescribed density. This solution can therefore result in extending the compaction process duration beyond the time limit when hydration of the cement develops the initial set of the soil-cement mix.

Technical Knowledge Compaction Equipment – Using heavier rollers offers a satisfactory solution to the problem but in this case the contractor used the trucks that were on the project for hauling and did not bring to the work the proper compaction equipment. This may have been in consideration of the safety issue that results from operating rollers on slopes. But once it was decided to use the trucks a rolling pattern should have been established.

Technical Knowledge Mat Thickness – The decision to place flat-plate soil-cement on the 3:1 slope changed the mat thickness with respect to compactive energy. Many attempts by the contractor to manipulate the thickness of the soil-cement lifts testifies to a partial understanding of its effect on the compaction process but a standard process was never settled upon. At the same time the use of a dozer to adjust thickness after compaction should have been recognized by both the engineer and constructor as a non-solution.

In today's universities, are students taught to think about these issues and how each impacts the quality of the completed project?

Landscape Weather – The engineer completely failed to appreciate the weather environment – landscape – where this project was located. Thinking only in terms of material cost, no consideration was given to the difficulty of maintaining the density of the embankment slope upon which the soil-cement was to be placed. To have a productive soil-cement production operation requires access to a continuous sequence of areas ready for placement. In a location where rains are prevalent having sufficient work area for a soil-cement operation can be a problem. Any soil-cement embankment placement area that is saturated by a rain must be reworked and again brought to the required density before placement of the mix can proceed. It seems that no one considered this construction detail when the decision was made to change from a stair step soil-cement design.

In the case of stair stepped soil-cement once the first few lifts are completed it is relatively easy to maintain a solid work surface even after rain events. The majority of the placement surface is the previously laid soil-cement thus all that is necessary is to sweep off the surface water and possibly cut back into the embankment on the inside edge to find unaffected (properly compacted) material. Considering the landscape of the project a stair step design would have greatly increased the efficiency of the construction operation and the quality of the finished work.

The lack of understanding as described here of both the technical and situational aspects of an engineered project, point to a failure in how engineers are educated in the university. Recognizing that such problems as described here are all too common the American Society of Civil Engineers has for over ten years sought to improve and move engineering education into the 21st century.

4. A BETTER EDUCATION PROCESS

The Board of Direction of the American Society of Civil Engineers adopted Policy Statement 465, Academic Prerequisites for Licensure and Professional Practice (PS 465) in 2001. PS 465 boldly counseled the need to reconstruct the academic foundation of professional practice. The underlying rationale for this recommendation was the awareness that "a bachelor's degree is becoming inadequate for licensure and practice of civil engineering at the professional level – that a new model for civil engineering education is needed to prepare practitioners for increasingly complex work in which they will be engaged in the 21st century." (Policy 2002)

Recognizing the need for change PS 465 explained that to prepare engineers for the challenges of the future there must be "…appropriate engineering education and experience requirements as a prerequisite for licensure." Those who formulated PS 465 were aware that the profession's principal means of changing the way civil engineering is practiced lies in reforming the manner in which tomorrow's civil engineers are prepared, through education and early experience, to enter professional practice. (ASCE 2007)

ASCE is working to support implementation of PS 465 defined a Body of Knowledge (BOK) for entry into the practice of civil engineering at the professional level (*Civil Engineering Body* 2004 and 2008). Using Bloom's Taxonomy (Bloom 1956) an ASCE committee described outcomes where minimum levels of cognitive achievement were specified. Bloom and his coauthors described a hierarchy of cognitive ability starting with 1) knowledge or the ability to recall previously learned material: 2) comprehension, the ability to grasp the meaning of material; 3) application, the ability to use material in a new situation; 4) analysis, the ability to ascertain the components of the material; 5) synthesis, the ability to reorganize the material to form something new; and finally 6) evaluate, the ability to judge the reorganized material. A practicing engineer needs more than the ability to remember previously learned material (i.e., knowledge recall). An engineer must possess a much higher degree of cognitive ability that allows application of knowledge to new situations – the landscape of a project. Bloom's work is more than a half century old yet many engineering students still encounter courses in the university requiring aptitude at only the lowest possible level, that is, the recall of information.

Together the profession and academics must push to change engineering curricula. It is vitally important that students be mentored at developing the three upper levels of cognitive ability. Failing to rise to this challenge will fulfill Leonhard Bernold's prediction that "college education will be replaced by much cheaper Internet-based engineering programs that look a lot like the lecture-oriented teaching of today." (Bernold 2005)

The failure of many engineers to apply knowledge at higher cognitive levels is demonstrated by tragic news stories every day, from the reservoir case just detailed to crane collapses. The Big Blue crane accident at the Brewer's Ball Park Stadium project in Milwaukee, Wisconsin on July 14, 1999 (Schexnayder 2003) is another illustration of the need to enhance an engineer's appreciation of landscape. The accident involved a 1,500 tn maximum lifting capacity crane hoisting a 400 tn steel roof section. During the lift the crane collapsed killing three construction workers.

The upper levels of Bloom's Taxonomy are analysis, synthesis, and evaluation. From the perspective of a practicing engineer, the Milwaukee crane incident brings the needs of construction engineering education into clear focus.

- Did the project engineers do ***analysis*** considering the loads imposed by the roof section on the crane under wind effects? It seems that no one criticized, examined, or tested conditions against even the known loads.
- Did the engineers ***synthesize*** the loading conditions – play out "what if" scenarios considering differing reach requirements, different wind conditions from different directions, the crane not being perfectly level, effect of acceleration and deceleration during the swing, and effect of combinations of these possibilities?
- To speed the project schedule, the roof sections were designed to the maximum capacity of the crane. Those sections could have been designed in smaller sections and the risk would have been reduced significantly. This consideration relates to ***evaluation***. Where was the comparison of risk or where was the evaluation of landscape conditions?

Professors with extensive industry experience are more likely to assign open-ended problems and projects that include teamwork and writing. Such problems cause students to analyze, synthesize, and evaluate. Open-ended problems that emphasize the three upper levels of cognitive ability require more time to develop. In addition, the professor must assess student work in a subjective manner as these problems have no single best answer. The grading process is part of the learning process as it is necessary to explain the ramifications of ideas. This is not a grading procedure with which most professors or students are comfortable. Construction professionals who have been actively engaged in real projects where they held positions of responsibility and decision making have experience accepting responsibility for decisions and can be very good at presenting and appraising open-ended problems. Three common approaches for bringing industry experience into the classroom are:

1. Encourage tenured professors to engage in consulting activities with industry.
2. Cooperate with industry to develop summer internships for young professors who lack practice experience.
3. Have professor of practice positions in the mix to faculty positions. These should be full-time, eminently-qualified, distinguished professional-engineering practitioners with exemplary teaching abilities.
4. Use non-tenure track instructors (these could be full or part-time) who lack the PhD but have extensive practice experience to teach some courses.
5. Have an industry advisory council that provides mentors for faculty members, especially for fresh PhD hires.

The presence of professors with extensive industry experience can radically change how engineering schools prepare students for industry careers and satisfy the ABET Professional Component Criterion 4, particularly the (b) component to "provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other." (Criteria 2006) The diversity of backgrounds and experiences that *professors of practice* and instructors with practice knowledge bring to a program is the best method for moving construction engineering education to higher levels of cognitive achievement as recommended in the ASCE's Body of Knowledge documents and can teach students to step back and consider the landscape that frames a project.

5. CONCLUSION

As the world population is expected to grow 2-3 billion by 2050, engineers will play an increasingly important role to help meet our global challenges. All too often, today's engineers solve problems using a monotonic approach when in fact a muli-dimensional approach provides a better solution or the only successful solution. In fact, success on many challenging construction projects occurs when engineers truly consider the "landscape" of the project. More than ever, engineers need an education that considers more holistic approaches to solving problems that take into account not only the technical but also the cultural, socio-economic, and environmental factors as part of the solution. Both ABET and ASCE recognize this need and encourage a more broad-based approach to education and life-long learning. Educators need to do a better job teaching students the importance of using broad-based critical thinking to solve engineering problems. The future skill set of an engineer depends more and more on someone who can not only be technically competent but one who is worldly in their understanding and have a curiosity to really appreciate the nature of the problem that is being solved.

Currently, Professor of Practice positions, in the sciences, are active in eight major universities in the United States. Among these are Carnegie Mellon, Colorado, Duke, Georgia Tech, Harvard, MIT, Lehigh, and Syracuse. Noteworthy is the similarity among virtually all such programs regarding non-tenure track status; strength in teaching and service focused on professional practice; and extensive experience and knowledge in the "world" of practice for their discipline. In general, the two main goals of the Professors of Practice position are to 1) give students direct access to professional practice and 2) to mentor students by presenting a holistic understanding of the professional. The exact duties of such a position differ from campus to campus. MIT, for example, expects that the Professor of Practice teach at least one subject per year, but also have a deep commitment to research projects. On the other hand, at Duke, a Professor of Practice is evaluated primarily on teaching and administrative activities with some emphasis on research. Each school can decide what would be the most beneficial to its program.

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