The Framework of Sustainability for Engineering Design Considerations

By: Dr. Patricia D. Galloway, P.E., PMP

Abstract

The engineer's challenges focus on repairing and rehabilitating existing infrastructure to meet the needs of future generations by providing more sustainable infrastructure and on devising methods of mitigating air pollution, providing clean water, and transporting people by means other than gasoline-consuming vehicles. With respect to new construction, the design and construction of green buildings pose for engineers considerable new challenges that include the need for additional education, conformance to new standards, and collaboration with multiple stakeholders—the latter a process with which many 20th-century engineers were not entirely comfortable.

Fundamental components to sustainable development include: environmental protection, economic growth, and social equity. The biggest challenge to engineers is how to achieve a balanced approach to economic development, environmental protection and social well. Over the coming years, social impact is going to be a major consideration for all engineered projects. While environmental impact assessments are now common, we will begin to see social-economic and human impact assessments performed before projects can proceed.

This keynote will address the following questions: What is the project cost that represents the best values from the perspective of achieving the project objectives? Have the life-cycle costs been analyzed to determine the total cost of project delivery over its expected life? Have environmental factors been included in the valuation of assets and services? How does the project interact with the natural environment? Are there any concerns relative to the material or product proposed which may have potential future negative impacts on the project depending on the use application? How the person living next door is going to view the project. How can the project be best integrated into the community? Will the health, diversity and values of the community be maintained or enhanced for the benefit of future generations? Is the life expectancy of the selected materials and/or products the same relative to the social expectation of how long the project will function as designed? Is there a need for future inspections of any aspect of the project regarding it structural integrity to assure its sustainability over the expected design life?

The 21st Century Engineer will need to concern him or herself with the integration of social science, engineering and environmental management. It is the understanding of social management systems that will critical for assuring that successful integration.

Sustainability Defined

Designing a project in the 21st Century involves new considerations often overlooked or not thought of in the past. As engineers, we have chosen a profession that enhances the quality of life. The role and responsibility of the engineer has always been to protect the public, health, safety and welfare. Thus, the main objective of engineers is to develop proper infrastructure for supporting the effort in achieving its welfare. However, today the engineer's role and responsibility goes beyond protecting today's public, but to the protection of future generations and the environment. New risks are emerging relative to how the engineer produces the design, including the assumptions thereto. Public works projects are constructed for the public welfare; thus consideration as to the project's long term impact to the society and ultimate client objectives play an important part in the engineer's role and responsibility in designing the project.

There is perhaps no greater need on earth at this moment than sustainability. Distilled into its simplest form, sustainability is the practice of adequately meeting current needs while ensuring that future needs will be adequately met. Fleshed out a bit more, sustainability is the practice of ensuring that all of the world's inhabitants—from those living in the most developed nations to those living in the most underdeveloped nations—are ensured adequate food, shelter, and sanitation, now and in the future.

One of the greatest challenges to ensuring sustainability is population growth. The world's population is expanding at the rate of between 80 million and 100 million per year and this growth shows no signs of abatement. The three segments of the world's population—those living in developed nations, those living in developing nations, and those living in underdeveloped nations—are not equal in terms of need, however. The needs of each sector are quite different, and the engineer must understand those differences and how best to address them when planning infrastructure projects that adhere to the principles of sustainable design.

Challenges to Sustainability

Within the developed nations, which are the most advanced, urbanization presents the greatest challenge. For example, nearly 80 percent of the population of North America resides in urban areas despite the vast areas of land available to support this population. Comparable percentages of urban dwellers are found in Asia, Europe, and Australia as well. In the developed nations, therefore, the 21st-century engineer must address an aging infrastructure, which was constructed at a time when little consideration was given to sustainable development. Major urban areas are confronting problems associated with decaying infrastructure systems, air pollution, traffic congestion, the destruction or despoliation of such natural resources as trees and streams, and the contamination of drinking water sources. The engineer's challenges here focus on repairing and rehabilitating existing infrastructure to meet the needs of future generations by providing more sustainable infrastructure and on devising methods of mitigating air pollution, providing clean water, and transporting people by means other than gasoline-consuming vehicles. With respect to new construction, the design and construction of green buildings pose for engineers considerable new challenges that include the need for additional education, conformance to new standards, and collaboration with multiple stakeholders—the latter a process with which many 20th-century engineers were not entirely comfortable.

The challenges in developing nations are concentrated on improving infrastructure to support rapidly growing urban populations. Growing urban populations, however, pose challenges not only within developing nations but globally as well. In 2000, 47 percent of the world's population resided in urban areas. It is estimated that by 2030 the urbanization rate will be over 60 percent (United Nations 2004). While this urbanization will greatly promote social and economic development, it will also create social, economic, and environmental problems. The models used in the past in the developed nations, however—models that inflicted environmental abuses, for example—must be abandoned in favor of new models that emphasize sustainability. Lessons learned from engineering and construction projects in urban areas developed in the past must be carefully reviewed, and a concerted effort must be made not to repeat the mistakes of the past.

Underdeveloped nations might at first appear to present the greatest challenges. However, the infrastructure requirements of an underdeveloped country are quite basic: meet the essential needs of human life—that is, adequate food, water, and sanitation. Establishing the ability to transport agricultural products to market, to food-processing plants, and then to the population and the ability to construct safe and reliable water and sanitation systems are the most pressing priorities. Engineers can play a role in determining what types of food-processing plants are required in a region as well as in determining what means of transport would be most efficient in delivering the food to the population. And while sanitation is key to preventing disease among the populations of underdeveloped nations, thoughtful consideration must be given to the level of sophistication of any proposed sanitation plant or water treatment process. For example, advanced wastewater plants may seem an obvious solution. But if a location is so remote as to make the delivery of spare parts difficult or if the educational level of a population is such that maintenance cannot be performed satisfactorily, then an advanced wastewater treatment plant may not be the best approach. Perhaps a gravity-fed sewer system would be the most practical solution. In any event, the engineer must be capable of recognizing potential problems and devising the most practical solutions for ensuring sustainability.

An important point to bear in mind is that the level of technological advancement in developing and underdeveloped nations significantly defines the parameters within which the 21st-century engineer will be working in these nations, and it is important for the engineer to understand these technological limitations as well as the potential for future technological advancements.

The questions the 21st-century engineer must answer before embarking on any project in a developing or underdeveloped nation are these: Is the current population able to use and maintain the technologies to be employed on a project? Does the population have the ability to deal with the required computer and other hardware upgrades that must be performed?

Sustainable Design

Sustainable design is becoming the expected standard, not just a "green thought". Peter Kydd of the UK noted that Sustainable Development provides a solid foundation from which we work to develop projects that balance environmental, societal and economic concerns and results in an improved state for generations to come. Dr. Gro Garlem Brundtand, a Norwegian politician who was asked by the Secretary General for the United Nations to establish and chair the World Commission on Environmental and Development, produced a 1987 Commission entitled “Our Common Future” that defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet our needs.”

This article highlights the impact of sustainability in the design process and the risks to be considered in light of the heightened role and responsibility of the engineer in the 21st Century.

The Framework of Sustainability for Engineering Design Considerations

The UN Commission highlighted these fundamental components to sustainable development: environmental protection, economic growth, and social equity. These components led to a concept developed by John Elkington, the founder of the firm SustainAbility in the UK, of the triple bottom line concept. The triple bottom line concept requires a balanced approach to economic development, environmental protection and social well being-or EES for short.

The biggest impact of the triple bottom line concept is on how engineers, planners, designers, and managers continue to deliver a best practice solution to our clients. Over the coming years, social impact is going to be a major consideration for all engineered projects. While environmental impact assessments are now common, we will begin to see social-economic and human impact assessments performed before projects can proceed.

When to apply best practice is different when looking at the perspectives of both the client and the engineer. Simple questions that we as engineers should now be asking in this triple bottom line concept include questions from economic, environmental and social perspectives. The engineer should be providing the best value and longevity to the public taxpayer, in public project considerations.

For instance, relative to economic considerations, what is the project cost that represents the best values from the perspective of achieving the project objectives? Have the life-cycle costs been analyzed to determine the total cost of project delivery over its expected life? Economic analysis is critical in the material selection process. Have environmental factors been included in the valuation of assets and services? According to the U.S Army Corp of Engineers, selection of all components, systems and materials for civil works projects should be based on their long-term performance. Before making final recommendations to a client, the engineer has a responsibility to analyze life-cycle costs and to inform the client about the short-term and long-term cost considerations. Engineers must recognize that materials and their service life differ greatly.

With respect to environmental questions, how does the project interact with the natural environment? Are there any concerns relative to the material or product proposed which may have potential future negative impacts on the project depending on the use application?

Looking at social impacts, the engineer should ask how the person living next door is going to view the project. How can the project be best integrated into the community? Will the health, diversity and values of the community be maintained or enhanced for the benefit of future generations? This in time will require the engineer to look at specific aspects of the project relative to its materials and products. Is the life expectancy of the selected materials and/or products the same relative to the social expectation of how long the project will function as designed? Is there a need for future inspections of any aspect of the project regarding it structural integrity to assure its sustainability over the expected design life? An engineer has a legal responsibility to determine whether or not the product being specified will perform its intended function for the specific project in which the design is performed. Hence, before specifying a particular project, the engineer must be aware of the characteristics, applications, potential deficiencies and limitations of the product.

Sustainability then represents the best engineering approach and the recognition that no project exists in a vacuum but in a social and natural context that affects the project and is affected by it in turn. As Sir Mark Moody Stuart observed at the 2002 United Nations World Summit on Sustainable Development in Johannesburg, "even those companies at the forefront of sustainable development are closet to the start of the journey. We are very much on the first rung of the ladder".

Asset Management

One of the key aspects of the triple bottom line approach in sustainability is asset management-one area that engineers have not paid much attention, but should in the context of emerging risks and our increased role and responsibility for the protection of the public health, safety and welfare. Improving the durability of structures reduces the need for maintenance, repair, strengthening or replacement. The management of structures thus becomes more cost-effective in whole life terms. Structures last longer while meeting safety and functional requirements.

Asset management is a strong contributor to sustainable projects. In fact, it is an integral to the economic efficiency part of the triple bottom line concept and supportive of environmental as well as social objectives. Asset management is a systematic process used to maintain, upgrade and operate physical assets cost effectively. Increasingly, cities and state governments are looking towards adopting asset management.

While the need for the method of asset management has in the past been constrained by budgetary considerations, it now stands as a top priority. However, the management system to determine the level of service and maintenance and repair remains in its infancy stage. One tool which is used in asset management is the life-cycle cost analysis (LCCA) to evaluate the long-term efficiency of competing investment options. A key tenet of asset management is a process of early intervention taken before project failure that will minimize the cost stream. Projects will deteriorate over time and thus inspections, maintenance and operability are critical tasks that should be considered in infrastructure projects today. Thus, asset management calls for a comprehensive assessment of all costs: design, construction, operations; and maintenance-the LCCA analysis.

An Example of Questions to be Raised Regarding Sustainability

In presenting the above concepts, I have chosen an example regarding the importance of product selection and asset management considerations and how the engineer's decision affects how all phases of a project may be affected and how future product performance could affect the economic, environmental and social aspects of the sustainability model.

Product Selection-What Does "Or Equal" Mean

Pipe is an essential part of any transportation project when it comes to drainage or in projects transporting sewage away from or transporting water to people, yet the type of pipe product available for the engineer's decision varies significantly from concrete, corrugated metal, ductile iron and HDPE or PVP (plastic flexible) pipe. Storm drainage pipe are classified as either "rigid" or "flexible" pipe. Reinforced concrete pipe is a rigid pipe. Plastic and metal pipe are classified as "flexible" pipe. "Flexible" designs and "rigid" pipe designs are unique designs that must not be interchanged. While the project may be a complex multi-million roadway or water/wastewater treatment facility, it may be a simple as a community housing development. Regardless of the complexity, the decision made by the engineer regarding the pipe product selection can have a major impact to the performance or sustainability of the project over its expected design life. Design of any pipe system requires knowledge of material properties, installation conditions, and external loads. All of these elements combine to define the behavior of the installed pipe.

At first glance, the public "client" may simply look at different piping products or systems as "alternatives" or "material substitutes" without regard for the use or application. Often engineers find themselves in a position to choose a particular pipe product because the client has requested a specific type or because of a misconception that the use of "an or-equal" clause in a contract is applicable no matter what the pipe product is selected. Engineers find themselves presented with only partial facts, for example the price of a particular product, which may then lead to other false impressions that because the pipe product alternative requested is less expensive than its alternatives, that the overall project may be less. However, engineers need to be aware that this is simply not the case and by making such an assumption adds an unnecessary risk to the project. Furthermore, in today's projects where sustainability must be taken into consideration, as required in the ASCE Canon of Ethics as well as in some Professional Engineering Practice Acts, engineers cannot simply ignore the fact that the client's request may not be appropriate or in accordance with the overall engineering practice that an engineer is bound by under its contract relative to exercising its obligation according to a standard of care-either defined in the contract, or by the law of the jurisdiction in which the engineer is practicing.

For example, US standards, ASTM and AASHTO, have both recognized that flexible pipe is actually a liner and not considered a structure unlike concrete pipe. As a liner, the design process is far different from that used when designing a project using concrete pipe. For instance, the design of a project using flexible pipe is not complete until the surrounding soil envelope has been totally evaluated by a soils engineer, fully understood and design calculations performed to determine the deflection and other properties that the pipe will exhibit under those specific soil characteristics, construction and user loads and environmental factors. This soil-pipe interaction further requires the engineer to fully design the trench and trench supports, which unlike in other pipe alternatives may be considered a contractor's means and methods, are considered part of the design when using flexible pipe. Furthermore, the engineer must be present during the installation of the pipe since the design is not fully complete until that soil envelope and pipe interaction has completely taken place. These additional considerations will increase the design costs relative to the overall project that may not be currently considered by the engineer when determining pipe product alternatives.

Life Expectancy

Not only is the design different for rigid and flexible pipe, but the design life expectancy is highly dependent on the application and use. For instance, concrete pipe has been around for more than 100 years and used in public infrastructure projects for more than 100 years. Thus, it has a proven design life of 100 years which allows a confidence level based on knowledge of the performance of concrete pipe in specific applications. However, corrugated metal pipe may obtain up to a 50-year life in most environments. Plastic pipe, in contrast, has only been around for approximately 40 years and often less in public infrastructure projects. Thus, its "proven" design life is limited. While flexible pipe is lightweight and flexible, its service life greatly depends on the installation and surrounding soil of the embankment, which will add to the installation of the cost of the pipe. In this case, the engineer must consider life expectancy of the pipe application in determining whether concrete or other pipe alternatives should be used for a particular application relative to its “sustainability” for future generations.

Inspection

Inspection has become a critical component of asset management. In the example of selecting flexible pipe over other pipe alternatives, deflection is important to achieve its function. Yet, it has also been shown and so noted in US standards on flexible pipe, that deflections greater than 5% can constitute failure. Thus, the requirement for flexible pipe as noted in US standards such as ASTM and AASHTO for inspections to be performed no less than 30 days after installation become critical in the expectations of the future performance of the pipe product. In addition, inspections of flexible pipe used in culverts (report prepared by the Transportation Research Board) and of various highway projects (conducted by the Kentucky DOT), note that flexible pipe continued to deflect over time and in some instances had failed from the design criteria initially set out. The costs for repair or replacement then become an added cost to the overall life-cycle costs. ASTM covers procedures for using Least Cost Analysis (LCA) techniques to evaluate alternative pipeline materials, structures, or systems that satisfy the same functional requirement. The LCA technique uses the well established economic principles that have been used by economists and other professionals for decades to evaluate the present value constant dollars to install and maintain alternate drainage systems. This includes planning, engineering, construction, maintenance, rehabilitation and replacement and cost deductions for any residual value at the end of the proposed design life.

Environmental Considerations

Environmental considerations are also an important aspect of sustainability. If proper design or installation is not performed when using flexible pipe, failures may result causing property damage. Numerous examples have been documented relative to pipe floating out of the ground either flooding or causing property damage or failed roadways/drainage systems and/or misuse of the application and choice of flexible pipe has led to incidents of fire or other potential environmental issues. If these events occur, then there are far greater consequences on communities. Thus, the “social impact” becomes a condition in the design process.

Life Cycle Costing

Life-cycle costing is an important element of asset management and should be an integral part of the design process. While particular products may be less expensive relative to the product itself, the cost of the design process, the inspections during construction, and the operations and/or maintenance to be performed post construction must be applied in consideration of that product choice as these activities can significantly alter the overall life-cycle cost. As noted earlier, inspections may not be as soon or as frequent for concrete pipe as required for flexible pipe. Longevity depending on the application may be a consideration impacting future repair or replacement costs.

Conclusion

In today's environment, the client is looking to the engineer to provide solutions that will not only be in the best interest of "today" but will serve as a solution for "tomorrow" and the "future". Sustainability considerations, life-cycle costing and asset management considerations are all areas that an engineer should be addressing along with the risks that may arise based on decisions to be made in these considerations which in turn may fall to an expected standard of care. Also important to the engineer in its design process is the knowledge of a particular product performance as obtained in the public domain as any assumptions made in the design process will also be used in any standard of care allegations should the project fail to meet its design and/or client objectives. The example of pipe product selection is just one example, but the process is true no matter what component of the project is under consideration.

As interest in sustainability develops, increasingly we find ourselves questioning how best to plan, design and implement projects that will be a long-term benefit to our clients and communities. Governments must take a major role if true sustainability of our infrastructure projects is to be achieved. For instance, Australia, in 2005, made the decision to shift the sustainability debate from the natural to the built environment. Benchmarks were noted as needing to be developed in order to measure success. In David Orr's 2004 book, "The Last Refuge: Politics, Patriotism, and the Environment in an Age of Terror", he notes one of the biggest challenges to a sustainable society is the change needed as our roles as citizens and in government relative to the transition to a sustainable society including providing information that can inform the public's discussion regarding decisions for the future. Orr's largest concern was society's efforts to develop a sustainable consciousness. We as engineers have a major role to pay in this challenge.

Our role as engineers to protect the public health and welfare has now become embodied with sustainability concepts. These are confirmed by the codes of ethics and Professional Engineering Acts so noted earlier. Identification of risks and consideration of actions to be taken should risks occur are becoming the expectation and not a concept of the future to be solely performed by "management consulting firms" without the engineer's input. If sustainability consists of employing concepts of life-cycle costing, asset management, and future impacts to society, what happens if the engineer fails to take into consideration such steps in its design considerations? One such liability could be an assertion to follow a standard of care. This assertion may further be compounded if the engineer failed to fully evaluate a product relative to information that was available to him or her relative to the design, standards and applicability. A failure to meet a standard of care may be deemed to be negligent. Negligence is serious and the potential consequences to the engineer could be quite high. Legal aspects and court room and arbitration testimony foreign to most engineers, yet this lack of understanding is what is now coming back to haunt the engineer.

In conclusion, engineers must understand the concepts of sustainability and now those concepts are applied in our designs and constructed projects. Our role and responsibilities have heightened in our need to protect the public health safety and welfare and the environment. Economic, environmental and social perspectives are all now key elements facing the 21st Century Engineer. Failure to take into account these considerations may lead to a failure to meet an expected standard of care, which in turn may lead to dire consequences. Whether it is designing pipe, a dam, a highway or a building, we must face new challenges in delivering the best practice solutions to our clients.