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Towards Green Bridges

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ABSTRACT:
There is no industry standard to define a green bridge. Green standards have been successfully implemented in other industries and can be used as a guide for developing a green standard for bridges. The goals of green design include reducing life cycle costs, energy use, greenhouse gas emissions, pollution emissions, waste, and the use of non-renewable resources to sustainable levels.

The Greenbridges standard proposed herein is meant to provide a starting point for discussions between bridge professionals and the existing developers of highway and infrastructure sustainability rating systems. Greenbridges has a total of six prerequisites and thirty-nine points grouped into seven categories. The categories are: materials & resources, alternative transportation, project delivery process, construction activity, maintenance & access, environment & water, and energy.

Until a standard is available, three primary strategies for reducing environmental impacts of bridge projects are to design for minimum life cycle costs, to use recycled materials to the maximum economical extent, and to provide preferential access to alternative (non-single-occupancy motor vehicles) transportation modes.

IMPETUS FOR GREEN BRIDGES

The goals of green design include reducing life cycle costs, energy use, greenhouse gas and pollution emissions, waste, and the use of non-renewable resources to sustainable levels. According to our code of ethics, Professional Engineers "are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations." ASTM E2114 defines that sustainable development "meets the needs of the present without compromising the needs of future generations."

It is clear that the existing global patterns of energy use and levels of greenhouse gas emissions are unsustainable. Engineers working in all industries, including the bridge industry, are charged with making the necessary changes.

RECYCLED MATERIALS

A logical first step towards greener bridges is to favor recycled, recyclable, and industrial by-product materials.

Recycled Steel

Structural and reinforcing steel in the USA contains 96% total recycled content (59% post-consumer) as a matter of course. Steel recycling is economically driven by the scrap value of approximately 0.25 dollars per pound. It is to steel's benefit that it is already highly recycled and recyclable, however the process remains energy intensive. Worrell (1999) documents many opportunities for improving the energy efficiency of the steel industry. However, these changes will primarily be driven by government policy decisions, not by revisions to bridge steel specifications. There is no opportunity for bridge engineers to specify "green" steel.

Concrete & Pozzolan Cements

There are significant opportunities for bridge engineers to specify "green" concrete because the energy use and greenhouse gas emissions vary drastically depending on the mix used. Five percent of the world's greenhouse gasses are attributed to the Portland cement used in concrete. China is the world's largest emitter of carbon dioxide; twenty percent of which is attributed to their kilns used for cement production. Portland cement emits more than one ton of carbon dioxide for every ton of cement produced.

Greenhouse gas emissions are zero for pozzolan cements. Use of naturally occurring pozzolan cements (of volcanic origin) dates back to the Roman Empire, as documented by Vitruvius in 25 B.C. Similar natural pozzolan cements were used for the substructures of the Oakland-Bay Bridge and Golden Gate Bridges; both constructed in California in the mid-1930's.

Modern pozzolan cement, referred to as Supplementary Cementing Materials (SCM) or mineral admixtures, are typically not volcanic in origin, but industrial by-products such as fly-ash, blast furnace slag, and silica flume. They, therefore, have no carbon emissions associated with manufacture. Unlike Portland cement, pozzolan cements have no carbon emissions associated with calcination.

Concrete made with a blend of Portland cement and pozzolan cement admixtures has been well established in the bridge industry for over 50 years. Typical specifications call for fifteen percent of the cement, by weight, to be fly-ash with the remainder Portland cement. High performance concrete commonly uses silica flume admixtures of up to ten percent.

Several recent bridge projects have successfully utilized higher percentages of pozzolan cements. The St. Anthony Bridge in Minnesota reduced the carbon emissions associated with cement by up to 85% by using mixes with 69% slag, 16% fly ash, and 15% Portland cement. The New York Times (2009) wrote a positive article and graphic diagram on the "green" concrete used for this bridge. The Sunshine Skyway Bridge in Florida used concrete mixes with fly ash content of 50% replacement for Portland cement. The Cooper River Bridge in South Carolina used 43% fly ash; the low permeability of this concrete allowed for the use of uncoated rebar to meet a 100-year design life.

The use of pozzolan cements as admixtures has focused on the lower material costs and improved material properties, such as permeability and strength, when compared with pure Portland cement. The reduced energy use and greenhouse gas emissions have merely been a happy side-benefit. To date, the majority of bridges built with high percentages of pozzolan cement have been design-build projects with construction cost savings and improved materials properties driving the material selection. Traditional design-bid-build projects have rarely used high percentages of pozzolan cement, instead defaulting to standard specifications instead of project specific concrete mix design.

There is significant opportunity for increased use of pozzolan cements in the bridge industry; the majority of fly-ash, a proportion of which is structural grade, continues to be landfilled.

Concrete has no scrap value. When demolishing existing concrete structures, the waste concrete will likely be landfilled unless the contract documents require recycling. The reinforcing steel, however, is likely to be recycled regardless. Per the Steel Recycling Institute, 65% of the reinforcing steel from concrete structures demolished in the US in 2006 was recycled. To remove the reinforcing steel, the concrete must first be crushed.

Aggregates for Concrete
When locally available, by-product aggregates including waste rock from quarries, mines or mills, are environmentally preferable to virgin aggregates.

Recycled & By-Product Wearing Surfaces

It is common in many states for reclaimed asphalt pavement to be recycled into hot-mix or warm-mix pavement and for reclaimed concrete pavement to be recycled as aggregate for new pavements. Concrete made with reclaimed concrete aggregate has reduced strength, but is suitable for barriers, pavements, and non-structural applications. Crushed waste concrete is also commonly recycled (downcycled) for use in highway base courses or fill.

Lightweight synthetic aggregates made from a blend of fly-ash and recycled plastic have been developed by the University of New Hampshire. This synthetic aggregate can be used in lightweight concrete that meets ACI standards and is awaiting field tests for bridge decks.

"Synthesis of Highway Practice 199: Recycling and the Use of Waste Materials and By-Products in Highway Construction" by Collins and Ciesielski (1994) provides an extensive review of available materials and uses. Examples include using shredded scrap tires and roofing shingle waste in wearing surfaces. Using scrap tires in asphalt has been found to increase pavement life and reduce road noise.

Recycled Plastic Piles

The primary bridge related application for recycled plastic piles has been for pier protection fenders, in conjunction with recycled plastic lumber. Various styles and manufacturers of plastic piles are available. They typically consist of a recycled plastic matrix, a uv protecting additive, and structural reinforcement. The structural reinforcement can be glass fibers embedded in the plastic matrix or bar-sized cages of steel, fiber glass or FRP. Recycled plastic piles have been used by CalTrans, New Jersey DOT, Virginia DOT, New York State DOT, and the Port Authority of NY&NJ.

The US Navy has used recycled plastic piles with internal steel reinforcing bars at installations around the world to replace timber fender systems. Per Alling (1998) of the Naval Postgraduate School, while the initial material costs for plastic piles are more expensive than timber (approximately double), the plastic piles have significantly lower life cycle costs due to decreased maintenance and replacement costs (plastic piles last double to ten times longer).

A different style of composite pile consists of an FRP tube (not recycled plastic) filled with otherwise un-reinforced concrete. Virginia DOT has experimentally used these piles as load carrying members for the pier foundations of two bridges.

Construction Waste

Bridge construction projects generate large amounts of construction waste which typically is landfilled. Green building projects often divert 95% of the construction waste for recycling or re-use. The extra labor required to sort the waste is more than paid for by the scrap payments and elimination of landfill tipping fees. The online Construction Waste Management Database developed by the National Institute of

Building Science can provide the contact information for nearby companies that haul, collect, and process recyclable construction debris.

Recycled Materials Standards

Countless existing standards, published by AASHTO, ASTM, ACI and others are available to specify the recycled materials discussed herein for bridge work. The "User's Guide for By-Products and Secondary Use Products in Pavement Construction" published by Recycled Material Resource Center of the University of New Hampshire (2009), provides a thorough and up-to-date reference.

EXISTING GREEN DESIGN STANDARDS

There is no industry standard to define the attributes of a green bridge.

Two existing highway sustainability rating systems, Greenroads and GreenLITES, have been applied to bridge projects. The Federal Highway Administration (FHWA) is in the process of creating a Sustainable Highways rating system, to be released at the end of 2010. Since these systems have been created and weighted for highway and not bridge projects, it is not yet clear that they are fully applicable.

The American Society of Civil Engineers (ASCE), in partnership with the American Public Works Association (APWA) and the American Council of Engineering Companies (ACEC), is creating an sustainable infrastructure project rating system, to be released at the end of 2010. Harvard University has also established the Zofnass Program which is creating a framework for evaluating infrastructure sustainability. Since both of these programs aspire to rate the sustainability of all forms of infrastructure, at all scales, they aspire to be applied to bridge projects.

It is not yet clear which, if any, of the above systems will be implemented by the bridge industry and become a standard.

All green standards require more than just a publisher. They also require a dedicated professional staff to administer project applications and documentation.

PROPOSED GREEN BRIDGE STANDARD

The proposed Greenbridges standard has a total of six prerequisites and thirty-nine points grouped into seven categories. The categories are: materials & resources, alternative transportation, project deliver process, construction activity, maintenance & access, environment & water, and energy. A summary of each category is provided below. Details of each point are found in Appendix A, including references to similar points in the LEED, SPiRiT, and Greenroads standards.

The Greenbridges standard proposed below is not meant to be a functioning green standard. It is meant to provide a starting point for discussions between bridge professionals and the developers of highway and infrastructure sustainability rating systems.

The Greenbridges standard proposed below draws from three existing green design standards: LEED, SPiRiT, and Greenroads. LEED is an acronym for Leadership in Energy and Environmental Design; this standard certifies green buildings. LEED is administered by the US Green Building Council, a non-profit organization founded in 1993. SPiRiT is the Sustainable Project Rating Tool developed by the US Army for their facilities. Since 2000 all new army facilities and infrastructure have been required to be built to green standards. Greenroads was introduced in 2009 to certify roadway and pavement projects. This standard was developed at the University of Washington with funding from the federal US Department of Transportation as well as several state and regional departments. Greenroads documentations states "Bridges, tunnels, walls and other structures are not explicitly considered in Greenroads, but they are not explicitly excluded either." and "Comments are welcome regarding adjustments that would need to be made to be more reflective of sustainable activities for bridges and tunnels."

Materials & resources
Six Credits: Use materials that are recycled, recyclable, and industrial by-products. One credit is earned for recycled material content of 20% with additional credits accumulated for 40%, 60%, 80% and 90%. Use regionally extracted and manufactured materials to reduce the impacts of shipping. Regional is defined by an eight hundred kilometer (500 mile) radius from the project site.

Alternative transportation
Five Credits: Encourage transportation alternatives to single occupancy motor vehicles. Provide pathways for pedestrians and cyclists. Provide designated lanes for busses, light-rail transit, car pools, and low-emission vehicles.

Project delivery process
One Prerequisite: Perform bridge life cycle cost analysis in accordance with NCHRP Report 483. Perform life cycle assessments, using the free software eiolca.net, to compare the environmental impacts of competing bridge proposals.
Seven Credits: Use design charettes to develop context sensitive solutions. Consider future uses and demolition/salvage of the bridge. Develop innovative designs. Include green design accredited professionals.

Construction activity
Three Prerequisites: Divert 75 % of the on-site construction and demolition waste from landfills for reuse or recycling. Control erosion and stormwater. Prepare a construction noise mitigation plan.
Six Credits: Track water and electricity use. Provide on-site environmental awareness training. Reduce fossil fuel use and emissions of the construction equipment.

Maintenance & access
Two Credits: Produce a maintenance manual at the time of design, including estimated maintenance activities, frequencies and costs. Provide safe and productive maintenance access.

Environment & water
One Prerequisite: Comply with the applicable environmental laws.
Nine Credits: Minimize destruction to the local ecology around the bridge site. Minimise erosion, stormwater sedimentation, construction dust, particulate, noise, and light pollution. Minimise the heat island effect. Prefer the redevelopment of brownfield or urban sites instead of developing agricultural or wetland sites. Use native vegetation with no irrigation.

Energy
One Prerequisite: Commission the bridge electrical systems after construction to verify that the actual energy used conforms to the design values.
Four Credits: Minimise the life cycle costs of the bridge electrical equipment and lighting. Sign a multi-year contract to procure grid-source green electricity.

The proposed Greenbridges standard will be used to award points to bridge projects. A designated minimum point value (15 points, for example) will be required for a bridge project to be certified as green.

LIFE CYCLE ASSESSMENT
Life cycle assessment can be used during the study phase of bridge projects to compare the environmental impacts of competing proposals. Carnegie Mellon University has developed free software, available at www.eiolca.net, which is well suited for the assessment of bridge projects.

The first step is to perform a bridge life cycle cost analysis in accordance with NCHRP Report 483 (as mandated by SAFETEA-LU legislation). This total life cycle cost includes agency, user, and vulnerability costs. The agency costs include design, construction, maintenance, rehabilitation, and salvage/disposal.

Life cycle costs are the inputs used by the www.eiolca.net software to determine the project outputs in terms of global warming potential, conventional pollution, toxic releases, energy use, as well as employment and economic activity. The life cycle assessment of each bridge is estimated to require 40 man-hours to perform.

The environmental impacts associated with construction and maintenance have a similar order of magnitude over the life of the bridge. This is based on typical annual bridge maintenance costs of 1% of bridge replacement costs, as reported by Yanev (2007) of the New York City DOT.

Since a large proportion of maintenance resources are used to maintain paint, joints, and drainage, bridge designs that minimize or eliminate this work are preferred.

Which structural material is environmentally preferable: steel or concrete? Bridge engineers can answer this question for specific projects by performing life cycle assessments of the competing proposed design alternatives. Life cycle assessments published by Horvath (1998), Dennison (2004), and Struble (2004) indicate that embodied energy and greenhouse gas emissions are of the same order of magnitude for steel and concrete bridges. Concrete bridges using high percentages of pozzolan cement will tend to be environmentally preferable when compared with painted steel bridges.

BRIDGES AND CLIMATE CHANGE

The Transportation Research Board published Report 290 (2008) entitled "Potential Impacts of Climate Change on US Transportation". This report says "there is a need for making changes in [design] standards that focuses first on long-lived facilities, such as bridges (page 11)." The report indicates that the solution for dealing with climate change will be a combination of two strategies: adaptation and mitigation.

The adaptation strategy means adjusting to the climate changes that will occur. In terms of bridge design, this means designing based on weather model predictions instead of historical weather data. Twenty-first century weather will not be the same as twentieth century weather. There will be a need for our bridges to withstand higher sea levels, increased storm loads and frequencies, and increased temperature ranges. This adaptation strategy will be implemented by updating and revising the existing AASHTO bridge design specifications that will apply to new bridge designs. Adaption will also require assessing and retrofitting existing bridges.

The mitigation strategy means reducing the severity of climate change by reducing greenhouse gas emissions. The green standards and project sustainability rating systems are part of the mitigation strategy that is in the process of being deployed in industries across the economy and the world.

COSTS ASSOCIATED WITH GREEN BRIDGES

Bridges with lower life cycle costs will tend to have lower environmental impacts, in terms of material and energy use. In other words, the least expensive bridge alternative is also likely to have the least associated emissions and embodied energy. The key is to consider the total costs for design, construction, use, maintenance, demolition, and salvage; not merely initial construction cost. Policy makers have responsibility for internalizing externalities.

Many recycled materials, including steel, pozzolan cements, wearing surfaces aggregates, and construction waste, are cost competitive – in terms of both initial cost and life cycle cost – with the virgin alternatives.

Davis Langdon (2006) performed detailed investigations into the costs associated with LEED and found "there is no significant difference in average [construction] costs for green buildings as compared to non-green buildings." Kats (2003) came to a similar conclusion when investigating the costs associated with the thirty-three LEED certified municipal buildings built by the state of California. The Federal GSA decided to fund its green building mandate by allocating a 2.5% construction budget increase. RSMeans estimates that average additional costs associated with green building construction are 2% to 5%, the majority of which are attributed to design and engineering.

Whichever estimate is used, the sources agree that the initial investment in green building is rewarded by many times over the life of the structures. This is due to lower life cycle costs in the form of decreased energy, water, and waste use.

This indicates that applying green standards and project sustainability rating systems need not increase bridge construction costs and will certainly reduce life cycle costs and maintenance costs in particular.

THE MARKET FOR GREEN BRIDGES

Twenty-three billion dollars of LEED certified green buildings were constructed in the USA in 2007, including nearly three billion dollars of office buildings for government agencies.

Hundreds of green buildings have been constructed by agencies that own bridges, such as: Virginia DOT, Caltrans, US Army Corps of Engineers, MTA Bridges & Tunnels, Federal DOT, New York City DOT, and the Seattle DOT. Many additional municipalities, including the state of Arizona and the city of Chicago, have created mandates for all new facilities to be built to LEED certified green buildings.

The development of the Greenroads design standard was sponsored by the DOTs of Washington State, California, Texas, and Minnesota.

This indicates that green standards and project sustainability rating systems have the potential to create an active and growing market.

CONCLUSION

Green design has entered the public consciousness and the mainstream newspapers and magazines. The public, the taxpayers, the politicians, and the policy-makers want to be assured that public funds are being used to build environmentally friendly infrastructure.

Green standards, a.k.a. sustainability rating systems, are a tool that can encourage existing “best practices” to see more widespread use. They can also spur innovation to speed the development of new “best practices.” Green design standards have been successfully implemented in other industries. Now is the time for their application to the bridge industry.