SUSTAINABLE DESIGN & CONSTRUCTION OF LONG SPAN BRIDGES

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Abstract

With the growing awareness of environmental protection, one of the critical concerns while undertaking major infrastructure projects the world over is *sustainability*. Sustainability can be defined as the art of designing a project so that resources are available for generations to come, duly considering the environmental, ecological, economic and socio-cultural environments. Hence major bridge projects all over the world are now gearing up to meet the sustainability requirements besides techno-economical issues.

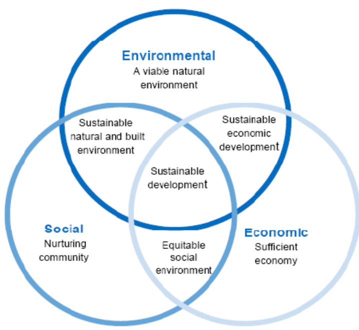
Sustainability is the maxim of the 21st century. Business as usual energy and consumer practices are under scrutiny in the wake of depleting natural resources and food shortages

In addition, with global warming becoming a real concern, energy conservation andcarbon reduction are major considerations in such projects during not only design and construction phase but also service. Integration of aesthetics poses another dimension to the challenge.

Key Words: Sustainability, Energy Conservation

1.0 Introduction:

Sustainability can be epitomized as "…*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Extrapolating from this basic definition, sustainable bridge can be defined as that one that is conceived, designed, constructed, operated, maintained and finally dismantled in such a fashion that these activities demand as little as possible from the natural, material and energy resources of the surrounding supporting community. So in practice, sustainable bridge design is not about strictly environmental concerns, or only about energy conservation. Instead, it is a more holistic review and evaluation of a bridge project merits and compatibility with the flora and fauna on both micro and macro scale. In order to produce a sustainable bridge project, each of the activities right from planning to completion and operation needs to be considered from sustainability viewpoint



As depicted in the Figure on the side, a sustainable bridge is one that can be constructed and operated without significantly impairing the environmental, social and economical requirements, thereby ensuring adequate resources and a healthy environment for future generations. A major bridge project is no longer seen as a massive cement and steel giant. It is treated as a living entity brought into life to be synergetic with the environment in which it is constructed. A major bridge with all the effort and investment shall be designed and built to serve satisfactorily during its intended life.

For sustainable bridge design to be successful, there is a need for a paradigm shift away from using economy as the main criterion for bridge design. A greater importance needs to be put on environmental factors, even if addressing these factors may apparently increase the initial cost of the bridge. Sustainable bridges need less energy for operation and maintenance. *Hence by evaluating the 'whole-life' costs of the sustainable bridge that includes inspection, maintenance and repairs over the designed life period, it is possible that the sustainable design may have a higher cost upfront but may have considerable cost savings over its life span.*

The sustainability of infrastructure is now accepted as a key issue in many parts of the world and it is essential that the construction industry recognizes the important role it has to play and responds positively to the associated challenges. Within our transportation network, crucial for the continued economic growth of our nation, bridges form a critical part. Deficiencies in the durability/strength of bridges which necessitate repairs/replacement can lead to considerable disruption/congestion within the network and have a very negative impact on sustainability.

Sustainable design have a pronounced effect for long span bridges as they demand maximum site preparation, consume maximum material, have larger environmental impact. However, these issues are to be addressed even for medium spans to the extent applicable within the overall framework.

2.0 Requirements of sustainability:

Factors that have been identified to have significant contribution towards enhancing sustainability and promoting cost efficiency are listed below:

1. Lower energy input/ Embodied energy
2. Use of sustainable materials- locally available, reusable, recyclable, least waste
3. Simple & Innovative techniques of construction, operation, monitoring, repairs & rehabilitation
4. Increased durability
5. Simplified deconstruction

Based on these founding principles and the rather refined guidelines already available for 'green building' concepts, yardsticks for sustainable bridges can be summarized into three categories:

2.1 Embodied energy:

It is a measure of the burden placed by construction on our natural resources and can be estimated as *the total primary energy that has to be extracted from the earth to per m^2 of plan area for bridges*. To this, operational energy used during their lifetime has to be added. It is estimated that the embodied energy varies from 16 to 75 GJ per m^2 of ridge deck.

Based on study, it is concluded that the short span concrete structural form gives the lowest values while the longer span steel or composite structure the highest. Interestingly, it is seen that a well-engineered longer span bridge using innovative materials and techniques can be almost as environmentally friendly as a shorter span structure where sustainability issues are not considered.

2.2 Embodied CO_2:

This represents the total carbon dioxide released into atmosphere during resource extraction, manufacturing, transportation, insertion and maintenance of the various bridge components for entire life span. It is estimated that half the CO_2 emissions occur during maintenance. CO_2 for construction of a bridge is between 1 and 5 tonnes per m^2 of deck area. Thus the challenge for bridge designers is to achieve minimum total CO_2 emissions over the entire life span.

2.3 Total Life Cycle Cost:

Whilst the initial 'costs' are useful it is the 'cost'/'energy use' over their full life that is more significant. In this context the importance of maintenance-free bridges like

Integral Bridges for medium spans can be best understood. By designing a bridge without movement joints and which is integral from one abutment to the other the maximum resistance to chloride penetration is obtained. As a further step the timely and appropriate application of protective coatings which can be applied whilst it is in service, can delay the need for bridge repair. Thus by using these methods and some of the innovative approaches detailed later in this paper the life of specific types of bridges can be greatly enhanced and the total life cycle 'cost'/'energy use' reduced.

2.4 Life Cycle Analysis:

LCA is a tool used to measure environmental performance of the structure. The concept is to track the production of an item from start to finish, measuring inputs (fuel, electricity etc) and outputs (pollutants, CO2, solid wastes etc) at every step along the way, from the extraction of the raw material to the end of the item's life. In other words, it is a 'cradle-to-grave' analysis that looks at the environmental impacts of raw material extraction, material manufacturing, construction, energy use during life time, and end of life deconstruction. It is a "rational, quantified approach to determine specific environmental impacts", which include both the resources used and the waste products created.

3.0 Means of achieving sustainability:

Having understood the requirements and yardsticks, the various means of achieving sustainability are grouped into following categories:

3.1 Sustainable sites:

The requirements of a sustainable site location are –

- Provides most acceptable connection to existing developments and has the potential to usher in further development and tourism
- Provides Value addition to the economic and social life of the connected areas
- Causes Least disturbance to environment and land use
- Provide considerable savings in time and fuel consumptions
- Having least impact of supports (piers/ abutments) on water and aquatic life
- Employs best practices in sedimentation and erosion control

Taking cue from the above, some of the practices already being followed are:

3.1.1 Preference shall be given to sites that allow supports to be placed on land and not on water. This can be achieved by making use of longer spans, shorter crossing distances and the topography.

3.1.2 Route passing through nature reserves can be avoided, by making an S-shaped bridge as shown in the Fig.1.

3.1.3 Similarly, setting the bridge abutment on a slope shall be avoided which will cause slope damage. If possible, bridge can be extended into a tunnel to reduce its impact on the slope. (Fig.2)

3.1.4 Possibility of redevelopment of *Brown field* sites can be considered.

3.1.5 Locating site on historic sites shall be avoided. If the bridge is to be built on a historic site, improvements shall be made to the facilities and to access to the site.

3.2 Bridge Configuration:

Bridge configuration refers to the details like- type of bridge, material & type of construction, lane disposition, underway clearances and other salient geometric features. Some of the good practices in the regard are:

3.2.1 Provision for future lanes will avoid need for future heavy rehabilitation or additional bridges.

3.2.2 Use of alternative transportation through High Occupancy Vehicles (HOVs) can be encouraged by providing dedicated travel lanes for exclusive use of HOVs like- Buses & carpools.

3.2.3 Transitways can be provided for future use of public light rail or bus.

3.2.4 Separate lanes can be earmarked for exclusive use of common transportation like bicycles and pedestrians.

Based on the above aspects, various alternatives shall be examined- not only for the alignment but also the span configuration, type and overall dimensions

3.3 Environment Impact assessment & Energy Audit:

Prior to the commencement of the project, a Preliminary Environmental Impact Assessment study shall be undertaken for the project and approved by the concerned authority. Baseline data shall be established as reference data for "Environmental Monitoring and Auditing (EMA) for various construction activities including dredging and offshore disposal of spoils, piling, construction machineries and equipment during the Construction Phase.

Fast-track construction techniques can be adopted to minimize construction time and thereby overall energy requirements. Development and use of renewable energy technologies on a net zero pollution basis shall be encouraged.

Environmental Audit shall be undertaken by a statutory authority with following objectives:

- Checking the implementation of specified environmental mitigation measures
- Reviewing environmental monthly report, methodology, sampling and testing procedures as compared to the base line data
- Identifying potential environmental issues and recommend appropriate in-time mitigation measures

3.4 Materials and techniques:

Material selection is an integral and vital component of the design process for sustainable construction. Choice of bridge material shall be appropriate for the site and the future maintenance and recycling of the structure.

Materials extracted and manufactured within the region can be made full use of, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation over longer distances. Similarly material released from the bridge shall be recyclable or reusable.

Comparisons between steel, concrete and steel composite materials indicate that their embodied energies are similar and that the benefits of an efficient design are more significant than the choice of material.

3.4.1 Concrete:

Concrete particularly cement is a major energy sink due to its sheer volume of production and also environmentally unsustainable due to large quantities of CO2 evolution associated with its manufacture.
A significant advantage for the use of concrete is that it is the most widely used material, which means that it is often considered a local resource. Reduction in transport cost of concrete will add not only to economy but also to the green points.

Incorporating sustainable principles into the ingredients of concrete further contributes to the cause. Using cement substitutes like fly-ash, GGBFS & other such recycled material, carbon footprint of concrete is further reduced.

3.4.2 Precast concrete:

PC products are considered effective green building products because of their superior performance, minimal environmental impact, quick manufacturing turnaround and reduced life cycle costs. However they can be made even more environmental friendly product if carbon accelerated curing technique is adopted where CO_2 is used steam in curing process. This process also makes the product stronger, less porous, and more durable. The production cycle is also significantly shortened when CO_2 is used in the curing process instead of steam.

3.4.3 Steel:

It is estimated that production and fabrication of one ton of structural steel involves release of one ton of CO_2. However considering that it is 95% recyclable, it is a viable option for green construction. Additionally steel offers the flexibility of design and speed of construction.

3.4.4 New materials ideal for sustainability:

- **High Performance Concrete** and Ultra High Strength Concrete upto150 MPa– being of very high strength and more durable, drastically reduces the sizes of various bridge components, thereby influencing the overall costs and maintenance efforts
- **Prefoam concrete** – Being lightweight, easier to handle and erect, but not for high stress locations
- **Carbon sequestered concrete-** less carbon footprint as CO_2 is effectively recycled for curing of concrete- ideal for major precasting yards
- **Self Compacting Concrete-** environmental friendly as no noisy and heavy vibration mechanisms required, can be easily pumped with near zero slump (Fig.3 & Fig.4)
- **Self Curing concrete** (with polymer admixture) – ideal for situations where water is a premium.
- **Cement Replacement** with fly ash, silica fumes or GGBFS- All these materials are available in plenty and can be effectively used almost upto 50%. Additional advantage of more durability and chemical resistant
- **Recycled materials** – like sintered reservoir mud to prepare lightweight concrete-encourages use of local materials available in plenty
- **Fibre Reinforced Polymer (FRP)** - FRP composite bridge decks deliver viable solutions to meet critical needs for rehabilitation of existing bridges and construction of new bridges. Fig.5 depicts section of FRP deck and Fig.6 shows the erection of FRP deck. Primary benefits of FRP decks include:
    - Durability (highly resistant to corrosion and fatigue)
    - Lightweight -80% less compared to concrete decks
    - High service life- two to three times
    - Rapid Installation – twice as fast
    - Lower or competitive life-cycle cost
    - High quality manufacturing processes under controlled environments
- **Manufactured Sand**: This is sand *artificially produced* from rock, using the technique of vertical shaft impactor, where rock is subjected to impact and cleavage attrition to result in consistently good quality sand having uniform gradation and shape. This type of sand further contributes to sustainability and strength due to reduction in water and cement demand on account of lower levels of silt and clay.
- **Synthetic lightweight aggregates**: Produced by sintering locally available material like reservoir mud and fly ash, the concrete made of lightweight aggregates can have strengths upto 50MPa. Being light weight also is seismically favourable as it attracts less inertial forces during an earthquake.
- **Concrete with recycled construction wastes:** Though not a well-established practice, use of recycled demolition and construction waste for buildings has lot of potential in contributing towards sustainability. Several experimental studies have proved that this type of concrete can be used in bridge projects for ancillary works like paving blocks, drain slabs, retaining walls and pavement sub bases.

3.5 Innovations in design and construction technique:

3.5.1 Design:

The basic principle of sustainable design involves assembling the entire design team at the onset of the project, in order to set the goals of the design not only from a programmatic standpoint, but also from a green and energy consumption standpoint. Every decision taken during the design process is based on promoting energy efficiency, minimal site disturbance, healthier environments and reduction in the use of virgin material. N order to produce a truly sustainable structure, each of the tasks needs to be considered from a sustainability standpoint. Sustainable goals need to be considered and accounted for at every phase of planning, design, construction and maintenance.

Through increased knowledge of materials reflected in design code development, more efficient designs can be developed that make full use of our current understanding of material performance and structural behavior.

3.5.2 Construction techniques:

3.5.3 Integral bridge (Fig.7):

Integral Bridges, without movement joints and bearings, are ideal for are ideal for medium spans. As the bridge is integral from one abutment to the other, maximum resistance to chloride penetration is obtained. As a further step the timely and appropriate application of protective coatings, can enhance durability.

3.5.4 Aluminium alloy bridge decks (Fig.8):

Aluminum has been used in various ways in hundreds of bridge structures around the world, and most remain in service today, including some for more that 50 years.
Aluminum alloy bridges can be used where their light weight, high strength-to-weight ratio, and excellent corrosion resistance satisfy service requirements and justify the additional initial cost. When considered on a life-cycle cost basis, aluminum bridges components have clear superiority.

3.5.5 Corrugated steel-web composite girder bridge (Fig 9 & 10):

By using corrugated steel plate to replace concrete web, it can reduce 15% self weight.

3.5.6 Precast piers (Fig 11 & 12):

Construction of new bridges in metropolitan areas can cause great public disruption. Completing the constructions in a rapid and clean manner has become a key consideration.

3.6 Smart Bridge technology:

The innovative combination of reliable existing technologies for heating and cooling of buildings with low maintenance, sustainable and durable bridges are the major components of the SMART BRIDGE TECHNOLOGY. This will lead to complete new Bridge concepts allowing Integral Bridges with unlimited total length. This will cause reduction of temperature expansion in the bridge due to heating/ cooling of superstructure. Use of geothermal energy with e.g. energy piles is made use of. The required operative energy is provided by use of photovoltaic panels.

3.7 Recycled plastic kerbs (Fig.13):

As name suggests, the prefabricated kerbs are manufactured from recycled plasics. Being light, it is easy to transport, handle and install. Even dismantling and replacing is easy. It has further recycle value at the end of bridge life.

3.8 Bridge Maintenance Management

Performance of a bridge in service depends on probability assessment of failure carried out at the design stage to determine design parameters, workmanship, material deterioration and maintenance requirements. These factors can be evaluated in a reliability management study and there are various methods through which a longer service life can be achieved. Besides, service life of bridges depends much on maintenance strategy and commitment to asset management.

Remote monitoring systems can be installed to reduce frequent physical inspections. Accessibility of various components is vital for their longevity by providing maintenance ladders, exclusive maintenance vehicles etc.

4.0 Conclusion:

Bridges are vital link in the transportation network crucial for the continued economic growth of our nation. Hence any deficiencies in the durability/strength of bridges necessitating repairs/replacement leads to considerable disruption/congestion in the network and have a very negative impact on sustainability. Experience of countries where sustainable bridges are already being built, shows that the benefits of sustainable construction are immense and far outweigh any negative aspects, considering the overall performance during service life of the bridge. Hence it is high time that we realize that *sustainability* is an indispensable ingredient in the process of designing major bridge projects in the overall interests of the community, of the nation and of the whole world.

Further study and research is required to consolidate and establish the design concepts, material selection and construction techniques that suit our nation the best. Also the standard metrics to be adopted for assessment of sustainability practices and accord grading shall be devised, similar to the grading concept for ‘green buildings’

With the growing awareness for environmental protection and reduction of GHG, it is incumbent upon us engineers to master the art and technique of delivering bridges that are not just safe and economical but also socially and environmentally acceptable for generations to come!

Sustainable Bridges

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Fig.1

Fig.2

Alignment Planning

Fig.3

Fig.4

Self Compacting Concrete

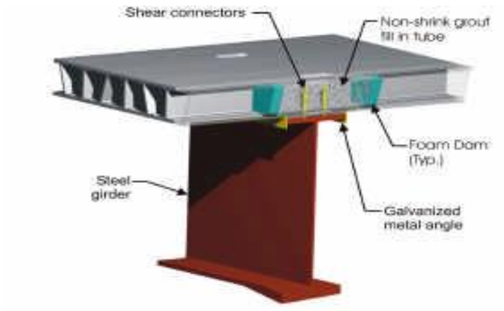

Fig.5 FRP Panel

Fig.6 FRP deck erection

Fig.7 Integral Bridge

Fig.8 Aluminium deck

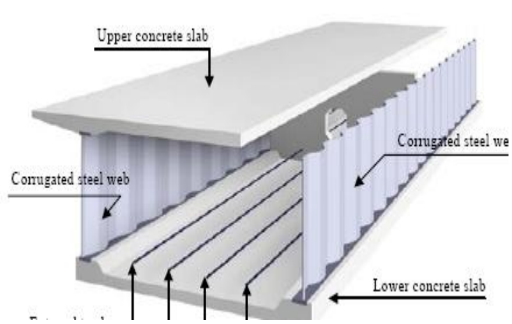

Fig.9 Details of corrugated steel web

Fig.10 Bridge with corrugated web

Fig.11 Precast pier

Fig.12 Precast pier erection

Fig.13 Recycled plastic kerb