Impacts of Local Socio-Economic-Political Constraints on the Selection of Bridge Type, Form, and Aesthetics

Phani Ram Gollapudi[1], Satish Chandra Dendukuri[2], Satish Brahmalla[3]
[1]*Lead Bridge Engineer, Ramboll Engineers, India*
[2]*Associate Professor, Department of Civil Engineering, Vignan's Foundation For Science, Technology & Research, India*
[3]*Assistant Professor, Department of Civil Engineering, Jayamukhi Institute of Technological Science, India*

Abstract: This article discusses the problem of '*Template Bridge*' building practices adopted in India. The '*Template Bridges'* are designed and built in most traditional ways using age old proven methods without any consideration for structural aesthetics, efficiency, or innovation in the process of building these bridges. These '*Template Bridges'* though able to serve their function, lack in aesthetic value and disregard engineering efficiency and innovation. These bridges do not incorporate sustainability and resilience criteria into their design or construction methods. The authors attempt to dig deeper into social, economic, and political constraints that stifle engineers and constructors to innovate and evolve new structural forms that help build sustainable and efficient bridges. The authors present a detailed discussion about these social, economic, and political constraints and their impacts on bridge efficiency, form, and function by providing case studies. The authors conclude that overcoming these constraints, and investing in our engineering and human resources will pave the way to building novel and sustainable bridge infrastructure.

Keywords: Bridge, Type, Form, Aesthetics, Social, Economic, Political

1. Introduction

Bridge engineering is as much of an art as it is science. The process of engineering a bridge involves several major stakeholders and hence several approving bodies. Bridges are public structures in most of the situations and as such, several public agencies and governing authorities are closely involved since the conception of a bridge to its construction, maintenance and until its final demolition or reconstruction phase (Johnson, 2017). Bridges are not just structures that are standing for function; they stand for many reasons. Bridges represent pride, they represent advancement, they reflect societal development and advancement. They symbolize the pride of their societies. They establish infrastructure dominance. Bridges reflect innovation and creativity, they showcase artwork. They stand to speak about history, human evolution and the future of civilizations. However, despite all these important aspects that need to be considered in the process of engineering a bridge, many times cost, and function are the only two aspects that are considered in the process of building the majority of the bridges. The authors very much recognize the innovative and challenging bridges that have been built in India in the recent times. Figure 1 shows Prestressed Concrete segmental wing and spine road bridge at Durga temple in Vijayawada (India) whereas Figure 2 shows the cable-stayed bridge in Mumbai (India) as one of the major spans of the Bandra-Worli Sea link. These kinds of bridge structures stand for function, novelty, aesthetics, innovation and reflect the engineering and infrastructure advancement India has achieved in the last decade or more.

Figure 1: Flyover to bypass Durga Temple In Vijayawada, India (Vaartha, 2020)

Figure 2: Cable-Stayed Span on Bandra-Worli sea bridge Mumbai, India (Expedia.com)

However, the real benefits of engineering advancement are limited to a few special projects undertaken by accomplished design and build corporations. Most of the commonly seen regular bridges are built out of a template that considers only cost and structural strength. During the author’s long engineering career, there have been many instances of intense curiosity on why a particular bridge was not built in a specific form or type versus the shape or type it was actually built. Chances for functional efficiency, innovation and creative aesthetics were missed out on a large number of bridge engineering works. The reasons are easy to comprehend, the real factors that have major influence in the engineering process of a bridge in India are significantly different from the factors that are considered elsewhere in developed countries in other parts of the world.

This paper starts by introducing the factors that are to be considered in the selection of bridge type and form in accordance with the principles of bridge engineering. The discussion details how to blend form and function with efficiency, innovation, novelty and aesthetic aspects of the bridge. Followed by this, the authors put forward the most commonly seen trends in engineering and building bridges in India. Examples of missed opportunities for aesthetics, advancement, and innovation in bridge construction are quoted. The causes behind these missed opportunities are discussed. The socio-economic and political factors that cause bridges to be built in routine and orthodox fashion without thought for innovation and aesthetics are discussed in detail.

2. Selection of Bridge Type and Form

A bridge type or structural form are selected based on many factors. The first and foremost factor is the function of the bridge. Points such as the topography of the bridge, the soil conditions, the traffic on the bridge, the types of loads, the span of the bridge, the location, the material and labor availability, and symbolic reasons play important role in selecting the material of the bridge and its engineering (Johnson 2017). For example, arch bridges are preferred where the terrain is remote and strong rock is available around abutments. Concrete bridges are preferred for common road bridge applications such as grade separation. Steel Truss bridges are traditionally used for railroad crossings for their lateral stability and strength. Cable stay and suspension bridges are considered when very large spans are involved and special bridges are needed. Concrete box girders bridges are considered when long spans and high traffic loads are expected (Vineeth et al, 2019). Similarly economic constraints, construction challenges, availability of skills and labor also tend to alter the preference of bridge types (Johnson, 2017). However, these are typical applications. Time and again, out-of-box structural forms and bridge types are tried out by engineers and architects for various reasons specified earlier. Aesthetics which considers blending the bridge function with overall living environment around it is a very important factor to be considered in deciding the form of a bridge. For instance, a bridge built in a vibrant neighborhood cannot be boringly typical. It needs to reflect the vibrancy of the community around it and help enhance it further. The structural form, the shape, the colors, and lighting enhance the aesthetics.

However in India, it has been noticed that the aesthetics of the bridge are highly disregarded when it comes to selection of bridge type and form that blends with its function. Many a times, a template bridge is built in most of the locations. For example, reinforced concrete girder or slab bridges are the most common bridge types in many towns in the country. Even those bridges that have been built in recent times still follow this trend. The authors were curious as to what could be the reasons behind this template bridge design and construction that lacks aesthetic appeal, novelty and innovation in its design and build process.

It has been understood that several social, economic, political and capability constraints play a major role in inhibiting innovation and aesthetic consideration in bridge building. In short, these socio-economic-political and capability constraints decide the bridge type and the structural form to be used. In most of the situations, going for template bridge offers the least path of resistance thereby minimizing the challenges to bridge owner agencies, builders, engineers and contractors. However, this greatly cripples innovation, efficiency and sustainability of the bridges while promoting complacence, bureaucracy, and status-quo. This should be demarcated from structural standardization; while standardization in engineering and construction greatly improves efficiency and quality, it does not hinder innovation, evolution, and improvements. In the following sections, the authors discuss the various types of constraints that contribute to boring bridge engineering and construction practices prevalent in India which hinder efficiency, innovation, and sustainability of our bridges.

3. Social Constraints

Social practices play a major role in trying or resisting atypical and novel structural forms. Social practices inadvertently seep into professional spaces. Trying out new and novel methods can be construed as non- adherence to compliance. Following standard practices minimizes the resistance be it for the engineer or the bridge owner or builder. So the path to least resistance is often preferred. This stifles innovation and novelty. To quote a real experience in this regard, when the author approached the Indian railway authorities for approval on road over bridges for the Hyderabad Metro Rail Project, the most common concern from the approving authorities was that they have been always building steel bridges whereas the proposed bridge in this case is a precast prestressed concrete box girder (PSC) bridge. Apparently, the engineers and officers from Indian Railways wanted to go with the path of least resistance and go with steel girder bridge which they are used to seeing for their structural bridges. Unfortunately, the biggest chunk of time lost on the Hyderabad Metro Rail project superstructure was attributed to this non-typical material and design shown in Figure. Eventually, due to the high visibility of this mega project, the PSC box girder designs prevailed. A very valuable time was lost though. However, many day-to-day bridge projects never dare to propose non-standard material, or atypical form or design because they will never see through the approval process by the government engineers and builders.

Figure 3: Hyderabad Metro Rail Bridge, Hyderabad (L&T Metro Rail, 2014)

Another aspect of social norms that severely hinders novelty and innovation in bridge structural forms is bureaucracy and corruption. Bridge projects are public projects and need government funding in many cases. As such government officers and engineers at local, state, and central level play very important role in every stage of bridge building starting from conception till the end of its service life. Non-standard and novel bridge forms and designs bear the biggest brunt in the line of approval process from these officers and engineers. Bureaucracy causes major delays in the document approval process, land acquisitions, material procurement, funding impacting the project timelines. Non-standard or novel methods already receive extra scrutiny and cynicism. Officers tend to perceive these non-standard structural forms as potential risks and try to avoid them or delay them. Added to this is the problem of corruption. Engineering and construction approvals are seriously delayed or eventually the proposals are cancelled altogether. Engineers being aware of these social norms know the fate of their novel proposals and try to comply with standard forms and designs (Vemuri & Jonnalagadda, 2023) to minimize the resistance and delays. Another chance to build a novel, efficient, functional, and aesthetic bridge is lost. Instead a typical bridge that is not aesthetically pleasing and functionally inefficient is built once again.

The next major social constraint to innovation and novelty in bridge building is the fear of mistakes and the resistance to own those mistakes due to fear of professional or legal liability (Jonnalagadda & Vemuri, 2023a). This phenomenon is not limited to India, its prevalent even in advanced countries. The intent of professional and legal liability in civil engineering is to design and build structures that are safe for occupants during their service life. However, these very liabilities invariably stifle innovation and creativity. Building standard structures with proven methods is the easy way. The bigger damage in the process is the habit of not even trying proven systems that are efficient and aesthetic because they may not be a standard normally followed in the local context. In these cases, there is no risk involved, it could be just a matter of complacence and laziness.

4. Economic Constraints

Economic reasons cited by funding authorities are another common reason for lack of variety and aesthetics in bridge engineering. Nonstandard or atypical designs inadvertently increase the costs of structure not only due to special needs such as new shuttering, skilled labor, engineering and construction costs or special maintenance needs. All these special needs increase the cost of the project However, the focus of the discussion in the current context is not about special innovative projects but it is about the complacence and inability to switch to atypical but proven structural forms from the typical forms routinely used. For instance, most of the bridge flyovers in small urban cities and rural areas in India on highways employ reinforced concrete bridges (Kumari et al, 2022). These projects may have never considered the use of prestressed girders, stone arch bridges or steel arch bridges or composite steel-concrete bridges which are neither special nor novel. These bridge forms are different from the typical reinforced concrete bridges that have been built for the last few decades.

In such scenarios, the additional cost of implementing atypical structural forms that enhance function and aesthetics is not significant unless the bridges are very large. A mere increase of 10% to 20% of the initial cost of construction and engineering can offset long term life cycle costs. The aesthetics enhance the landscape of the bridge surroundings while enabling the bridge to perform its function more efficiently. The enhanced form can be designed in such a way to reflect local culture or history. For instance, the bridge that is built across the college campus in Vijayawada city Many times bridges that have innovative structural forms and good aesthetics have become important piece in the history of the place and got connected to the people and communities they served. The bridge runs through a college campus (called VR Siddhartha Engineering College) in Kanuru village of Vijayawada. As such a concrete or steel arch bridge would have been perfect structural form for the main span of this bridge inside college campus. The arch form would blend the bridge with the soul of the surrounding educational community and transform the ambient space into a architectural marvel that reflets the knowledge, hope and enthusiasm of the student community. A great opportunity was missed.

Figure 4: Road Bridge through VR Siddhartha Engineering College Campus, Vijayawada, India

Local governments which usually own the majority of the bridges, often overlook long term maintenance and life cycle costs in bridge construction. While the standard bridge types such as reinforced concrete bridge are generally economic and cheaper in the short term, their long term maintenance costs and the overall life cycle costs can be higher as compared to other structural forms (Jonnalagadda & Vemuri, 2023b). For instance, prestressed concrete bridges when combined with precast construction are found to have less deterioration, fewer maintenance issues and longer life spans (Ram, 2021). This means lower life cycle costs. Bridge infrastructure sustainability is a major issue. In many countries including India major bridge inventories are ageing (Jonnalagadda, 2016). Even though the average age of bridge is just around 40 years, many bridges in the US have major structural issues. These structural issues and maintenance costs are adding huge burden to the local government transportation departments. This can be reduced by incorporating sustainable and resilient design practices during the bridge building process. Resilient structures remain performing at a specified level of service in the event of a severe weather event (Jonnalagadda et al, 2023). Sustainable bridges have low life cycle costs while serving their communities efficiently over long periods of time without any major closures, repairs, or rehabilitation issues. In the context of sustainability and resilience needs of bridge infrastructure, it is required to redefine the economy of bridge building. Typical stereotype bridge designs may result in lower near term engineering and construction costs because the designs are very standard, approvals are easy to get, drawings are readily available and regular workers are familiar with the construction process (Jonnalagadda & Vemuri, 2023b).

However, their long term costs may be higher because these are built in the old fashion and are not the most efficient ones. Repairs that come more often due to poor materials or inefficient methods can raise long term costs. The service life of these stereo type bridges is low at under 40 to 50 years before they need reconstruction. Rehabilitation and reconstruction of bridges is an expensive task in the wake of high labor costs. The overall life cycle cost of these bridges after accounting for initial engineering, construction, repairs, maintenance, rehabilitation, or reconstruction costs averaged per year of life of the bridge may be much higher than an alternative efficient bridge form that accounts for long term service and life span (Jonnalagadda et al, 2023). In view of this, it is required for the bridge owners and local government agencies to change their perspective and consider alternate nonstandard or atypical structural forms and types in bridge building process. It is important to evaluate multiple bridge types and forms during the initial bidding process and consider overall life cycle costs, functional efficiency, service life, and aesthetics. On the contrary, sticking to familiarity, old structural bridge forms and materials are major deterrents to building bridges that last long, aesthetically beautiful and blend in with the surrounding landscape, history, and culture of the community.

5. Political Constraints

Bridges are usually part of bigger infrastructure plans of the local towns and cities. As such bridge building is most likely intertwined with the politics of regional infrastructure development activities. Land acquisition and procurement of right of the way is an important exercise in bridge building. However this task is not easy, especially when the proposed bridge layout goes through zones of conflict or areas of high interest. The lack of political support, the conflict of interests and the associated requests for change in alignment of the bridge can cause great delays in commencing the bridge construction. In the process, several demands about the type of bridge, its costs, its appearance or its very purpose could be raised. Vested interest groups try to modify it as per their wishes.

All these political constraints can seriously affect the layout, the structural form, bridge type, the design and construction methods used for the bridge. For instance, the viaduct construction for Hyderabad Metro Rail project in India had been severely delayed for several years due to the interference caused by vested interest groups. Changes in alignment of the viaduct along the city, the locations of metro stations, the start and end of the route, several span lengths and foundation locations have changed quite a bit throughout the project. These political decisions did not consider the engineering interests of the bridge viaduct. As a result, the cost of the bridge went up drastically. At some locations, the type of the bridge, its material and span had to be changed. Political constraints play as big of a role as economic and social constraints and limit to settling for typical, routine designs in place of trying efficient structural forms. Political constraints can also indirectly lead to social and economic constraints.

6. Capability Constraints

As mentioned in previous sections, building non-standard bridges requires non-standard shuttering, skilled labor, nonstandard equipment, technical competency in engineering and construction methods. This means more educated engineers, more technical resources and access to special equipment and availability of skilled labor within an available budget. For majority of bridges in India which are built in small towns and villages, this is not easy for local governments by any means. Thus the natural tendency will be to go towards routine structural bridge forms. This is a totally an issue of capability to get technical, mechanical, and manual labor skills on table to complete the project.

However, building nonstandard bridges requires competent engineering capabilities from the approving government engineers too. In major and high impact projects, the government agencies typically outsource the review and proof checking of the engineering and construction procedures to competent private engineering firms. But, in case of low impact, less critical projects the category which most of the common bridge projects fall into, government engineers are assigned the engineering and construction review methods. Government engineers are typically familiar with standard structural forms and methods and often do not get the required training and experience in the evolving bridge engineering methods. Naturally, these engineers do not encourage engineering and construction of non-standard bridges because they will not be able to perform a detailed review and vetting of the design and construction process. Complex bridge building involves investing in new technologies, materials and human resources. Long span bridges such as cable-stayed, suspension bridges, segmental box forms, arch bridges need high strength materials. High Strength Concrete (HSC), Fiber Reinforced Concrete (FRC), Ultra-High Performance Concrete (UHPC) and their variants provide highly durable and robust concrete members and high strength joints (Jonnalagadda & Vemuri, 2023c). However manufacturing these high performance concretes and designing structural members with these types of high strength materials is a challenging task for Engineers unless they invest in research and development activities proactively in order to be able to understand their design and construction philosophies (Jonnalagadda & Chava, 2023). This could take decades of hard work and preparation. Our engineers simply do not have the resources, time or budget to perform these long term knowledge building investments. The liability issues add to the above mentioned woes. In the midst of all this, the government engineers' resort to the easiest option of going with standard bridge that is very commonly built in the locality without any thought about the form, function, aesthetics or efficiency. For example, in the city of Vijayawada across river Krishna, the bridge referred to as 'Kanaka Durga Varadhi' is built as two separate bridges over 47 spans. This could be a perfect case to try a cable-stayed bridge. Instead the authorities built a very routine concrete girder bridge. A cable-stayed bridge here could have been a right choice of form and function as a signature bridge for this city of 25 lakh people reflecting its culture and landscape where the river Krishna meets the Bay of Bengal with the famous Durga temple on its banks.

Figure 5: Kanaka Durga Varadhi over river Krishna, Vijayawada, India

7. Conclusions

It is noticed by the authors that for most of the bridges in India except special and socially visible bridges, the structural form, type, design, and construction are very routine and typical. No serious consideration is being given for efficiency, aesthetics, or innovative form of the bridge in the process of engineering and construction. Because of such practices, bridges are lacking in aesthetics, functional efficiency, and novelty even though they are able to serve their purpose and function.

These kinds of bridges can be referred to as '*Template Bridges'* because they are designed and built out of template. These template bridges deteriorate early, have higher life cycle costs due to maintenance requirements and have no aesthetic appeal. Some of these bridges do not blend with landscape, history and culture of the surrounding community because the structural form of the bridge does not capture any of these.

Social, economic, political and capability constraints drive government agencies, builders and engineers towards choosing these template bridges in most situations when a bridge is needed. The authors discussed these constraints in detail along with examples in specific instances. The authors believe that 'Template Bridges' are major hindrance to novelty, efficiency, innovation and aesthetics in bridge engineering. The authors strongly recommend that factors such as efficiency, aesthetics, form, function, local history, culture, sustainability and resilience should be given serious consideration in determining structural form and type of bridge that is most pertinent to the context.

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