Innovation in Long Span Concrete Bridges

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1. Introduction

There has already been a great deal of innovation in long span concrete bridges, but is there still scope for further innovation? Today, most of the obvious solutions have already been tried, and concrete long span bridges typically take the form of cable-stayed bridges or arch bridges. In Japan, where 75% of the terrain is mountainous, long arch bridges have an extensive history. This paper includes a new conceptual approach for half-through arch bridges, and proposes a solution that can produce economic and easy-to-build arch bridges.

Japan was also the location for the world's first extradosed bridge, the Odawara Blueway Bridge constructed in 1994, which marked the debut of a structural form that could cover span lengths for which cable-stayed bridges are uneconomic. This represented a major innovation in thinking about the design of stays. Cable-stayed bridges and external-cable structures could be conceived as points on the same continuum when determining the maximum allowable stress for stays. Taking this approach enables the use of stays with allowable stress in a continuous range between $0.4f_{pu}$ and $0.6f_{pu}$. Moreover, the allowable stress can be determined according to the range of live load stresses in the cables. Instead of the conventional approach of stipulating a single value of allowable stress for the whole structure, the structure could be designed with different values for each stays. This design method was formalized in Japan's specifications for highway bridges, enabling engineers to produce more rational designs for stays.

Innovation in cable-stayed bridges and extradosed bridges consists of finding ways to make the main girders lighter. Recently, there has been remarkable progress in composite structures that permit lighter main girders, including the successful construction of many corrugated steel web bridges and composite truss bridges. Further progress is now being made in Japan with the construction of bridges using a new form of composite structure, the butterfly web. Butterfly web structures use panels of steel or fiber reinforced concrete as an alternative to a double warren truss, and make it possible to achieve a similar level of lightness to corrugated steel web bridges. This paper presents a number of initiatives to reduce the weight of cable supported bridges, focusing mainly on Japan, in the hope of providing ideas for further innovation.

2. Long Span Half-through Arch Bridges

The half-through arch bridge is an extremely attractive structure, but it has tended to be avoided due to the difficulty of construction. In the new concept for half-through arch bridges introduced in this paper, the deck is used as one part of the arch structure, and this resolves several issues. Connecting the deck to the arch causes the axial force of the arch to pass to this section. In such cases, the lower section arch and deck are constructed first, allowing the upper section arch to then be constructed on top of the deck. In the case of a single plane arch, a certain portion of the axial force is passed to the deck, enabling the arch placed between the outbound and inbound lanes to be reduced in size and simplifying the suspension details. Out of consideration for erection, a corrugated steel web design is suitable for the deck structure in such cases.

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3. Long Span Cable Supported Bridges

Reducing the weight of the superstructure is the key to innovation in long span bridges supported by cables. The reason is that this approach enables stiffness to be increased without increasing girder weight. Lighter weights are enabled by using stronger concrete or designing composite structures. In pursuing such designs, it is important to explore how to attain an optimum overall solution for the whole composite structure when determining the extent of use and strength of steel members and costly high-strength materials. Some examples of composite girder construction are given in this paper.

Extradosed bridges have become popular structures for spans of 150m-250m, taking a place between conventional girder bridges and longer cable-stayed bridges. However, it is useful to consider whether using extradosed bridges for longer spans would be structurally and economically feasible. Consequently, we will investigate whether the technologies for producing lighter main girders described above have the potential to enable the construction of longer spans.

We consider a cable-stayed bridge with a central span of 435m, and compare it with an extradosed bridge having the same span length but with shorter main towers, about 60% of the height of the towers for the cable-stayed bridge. The girder cross-section is 3.5m high in the cable-stayed type bridge, and 5.5m in the extradosed type, using a single plane of stay cables and struts inside the box girder. The cable-stayed bridge uses a conventional box girder, but the extradosed bridge uses a butterfly web to counter the increase in weight due to the larger girder height. Consequently, the superstructure weight is unchanged, but the stiffness of the main girder is doubled. Japanese standards permit a maximum allowable stress of $0.6f_{pu}$ for stay cables, even for this sort of long span extradosed bridge. The number of cables required is about 20% more than for the cable-stayed bridge, but because the weight reduction technology has produced a stiffer main girder without an increase in weight, the main towers can be shorter, which makes this structure very competitive in earthquake-prone Japan. This demonstrates that a long span extradosed bridge with reduced weight main girder is feasible.

4. Conclusions

This paper examined the scope for further innovation in long span concrete bridges. It has introduced an innovative long span half-through arch bridge concept, and demonstrated the feasibility of long span cable supported structures, particularly extradosed bridges. The half-through arch bridge is structurally elegant, and can be easily constructed by ensuring that arch action also acts on the main girder in the central section. This structure enables a design with a large arch rise, making it more economical than conventional arch bridges.

It is clear that there is still potential for innovation in long span cable-stayed bridges and extradosed bridges by using composite structures to reduce the weight of the main girder. A number of cable supported structures using a composite structure have already been realized. The paper has also shown that efficient composite truss designs can be constructed by using an optimized mix of concrete and steel in combination with a cable supported structure. Furthermore, use of the butterfly web, an innovative structure, provides many benefits for maintenance as well as weight reduction. It can produce sustainable structures that are more durable than other composite structures and provide substantial reduction of maintenance costs. In mechanical terms, a composite bridge can be an extremely rational structure.

This sort of emergence of new materials is another major driver of innovation. I firmly believe that girder weight reduction from concrete bridges and structural challenges will lead to a new generation of innovation.