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Steel Bridge Design in Harmony with Concrete in Recent Korea

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Abstract: Steel and concrete are typical materials for bridge construction. Both materials have their own characteristics such as strength, weight and material cost, installation cost and speed, and durability. Bridge design engineers always compare these two materials, and they spend a lot of time and research to optimize the use of both materials. In many cases, optimum results can be obtained when properly mixing steel and concrete. In this paper, I will look at several bridges recently designed and constructed in Korea using steel and concrete in harmony. It also explores how the steel and concrete are mixed in the bridges, and what are the advantages of using them

Key words: Steel bridge design, composite bridge, hybrid bridges, bridge design in harmony, cable-stayed bridge, extra-dosed bridge, skyline study, different materials, UHPC (Ultra-High Performance Concrete).

1. Meaning of Harmony

Steel and concrete are great materials for bridges. Each material has its own characteristics such as weight and cost, strength, durability, installation speed and so on. Steel and concrete bridges often compete with each other. Sometimes, only one of the two is quickly selected without looking for hidden values. Therefore, the concept of "Steel, concrete together" makes the choice of materials more carefully, which in turn enables more efficient and valuable bridges. Bridge engineers spend a lot of time choosing materials to use. In many cases, the best result can be obtained when steel and concrete are harmonized. The range of "Harmony" used in this presentation is limited to the next two cases:

(1) Steel-concrete hybrid bridge;
(2) Different materials for the main structures.

2. The Range of "Harmony"

2.1 Steel-Concrete Hybrid Bridge

A steel-concrete hybrid bridge is a type of bridge where the girder consists of two distinct cross-sections, one made of steel and one made of concrete. The connection part normally transmits bending moments as well as axial and shear forces. Usually, it is abbreviated as a hybrid bridge. It will be included in the range of harmony.

2.2 Different Materials for the Main Structures

The main structures in a bridge are such as girders, arch ribs, piers, pylons, cables and so on. The materials of them are usually designed with steel, concrete or both as required. Using different materials for the main structures will be included in the range of harmony as shown below.

3. Where Is "Harmony" Useful in a Bridge?

Modern bridges are required to have social and cultural functions as well as linking function. Therefore, in many cases, bridges need to be beautiful and harmonious to become loved by people. In the process, we often face some problems. When choosing materials for solving them, many engineers are no longer tied to past customs.

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Fig. 1 Steel-concrete hybrid bridge.

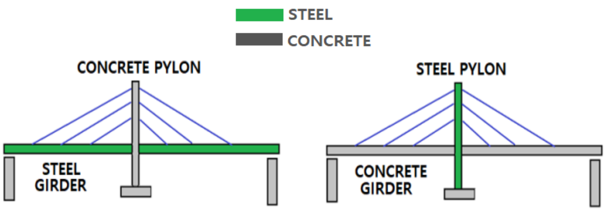


Fig. 2 Different materials in cable-stayed bridge.

Therefore, the concept of "harmony" is considered important. It could be useful in the following cases.

- To develop a new shape of bridges;
- To increase the structural efficiency;
- To overcome the structural difficulties;
- To make the construction easier and faster;
- To minimize the construction cost;
- (or combined).

4. Several Bridges in Recent Korea

There are several bridges that are recently opened or under construction in Korea. It also explores how the steel and concrete are harmonized in the bridges, and what are the advantages of using them.

2015: Baekjeon bridge;
2018: Chuncheon bridge;
2019: Cheonsa bridge;
2021: Seohae railway bridge;
2022: Kwangam bridge.

4.1 2015: Baekjeon Bridge

(1) Introduction:

This bridge, opened in 2015, is located in the South area of Korea. Its original design was all concrete box girders, and its construction method was composed of "FCM (Free Cantilever Method)" for long spans and "ILM (Incremental Launching Method)" for short spans as a typical solution.

(2) Construction as in-situ concrete is not easy because the pier height is over 100 meters. Moreover, the site is in a mountain valley. The problem with the original design was the increased cost due to the safety & quality risks from the high-rise work and the dual construction methods. So, the original design was finally changed.

(3) One-body launching idea was invented. The six form-travelers required for FCM have become unnecessary. And safety and quality are ensured by eliminating high-rise work with the ILM construction for all bridges. But, a challenge had come to pass through 130 meters.

(4) To overcome the span 130 meters, the front part was replaced with a steel box instead of a concrete box. As a result, the whole bridge was constructed by ILM method only. It became a "Hybrid bridge".

(5) Summary of alternative:

A long-span concrete box was replaced with a steel box.

A steel box was permanently connected to concrete box on the ground before it was launched.

- In-situ concreting is always on the ground.
- Safe & fast construction became possible by one-body launching.
- The construction cost was decreased.

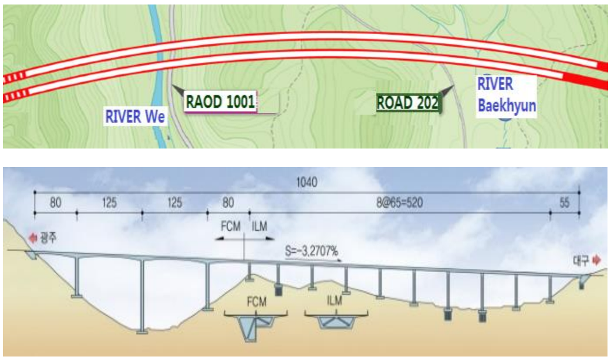


Fig. 3 Initial plan & profile of Baekjeon bridge.

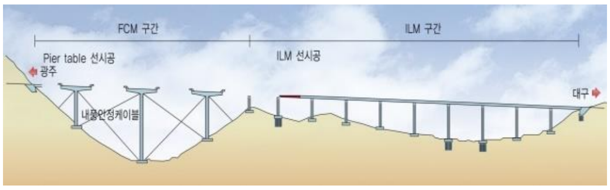


Fig. 4 Initial construction method of Baekjeon bridge.

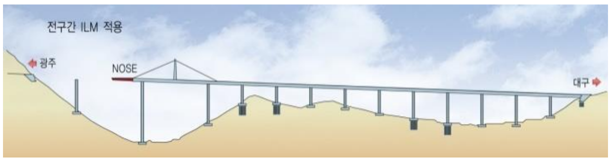


Fig. 5 New construction method of Baekjeon bridge.

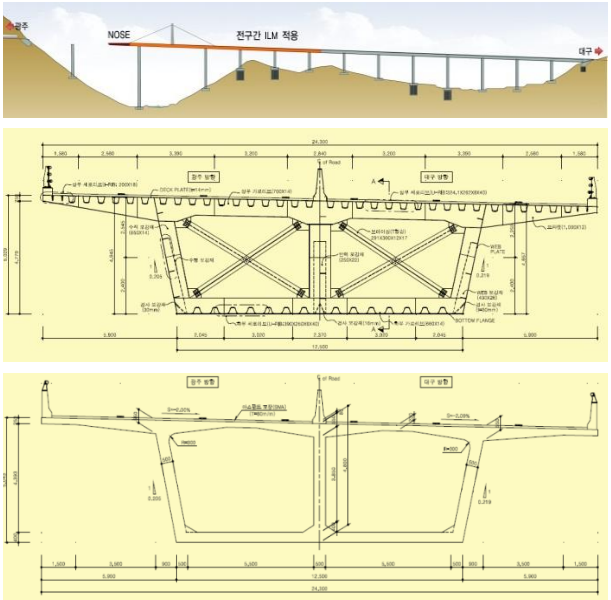


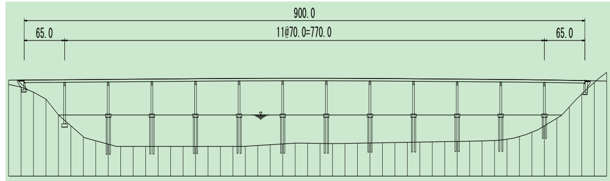
Fig. 6 One body launching by hybrid girder.

Fig. 7 Site view during launching.

4.2 2018: Chuncheon Bridge

(1) Introduction:

This bridge, opened in 2018, will be the entrance to the LEGOLAND, the first in Korea. Its basic design was a straight girder bridge, which was composed of steel-concrete composite sections.



Span: 65.0 m + 11@70.0 m + 65.0 m = 900.0 m

Width: 25 m (cars) + 4.0 m (people + bicycles) = 29 m

Fig. 8 Initial layout of Chuncheon bridge.

(2) Design concept:

The bridge budget was small, so it was difficult to design beautifully over the whole bridges. So we thought of a simple bridge that children would love, in the middle of the bridges. Finally, a complete circle was chosen which was believed to express the pure heart of children.

(3) Circular pylon is not an effective structure, because it tends to crush when subjected to vertical loads from stay-cables. Thus, the materials of the girder and the pylon were analyzed in various ways.

Fig. 9 New concept for Chuncheon bridge.

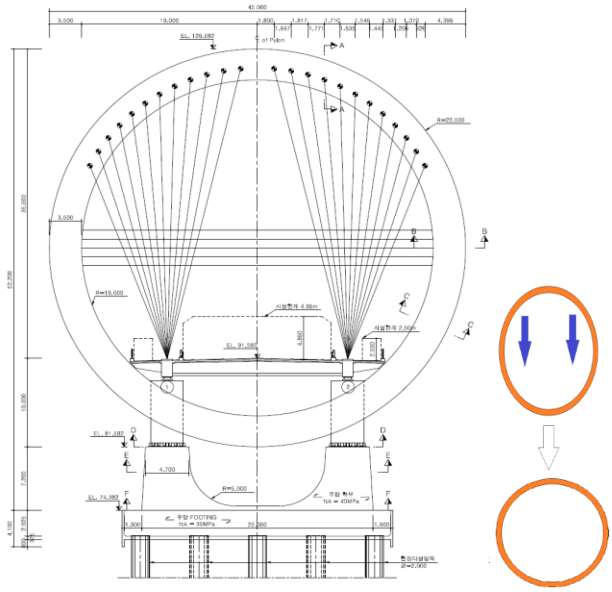


Fig. 10 Structural pylon of Chuncheon bridge.

Case A is a concrete pylon with a steel girder. In this case, the concrete pylon was not good, because its thickness became too thick, even using pre-stressing.

Case B is a steel pylon with the same steel girder. In this case, the steel pylon was possible, but the cost became much higher.

Case C is a normal concrete girder with a steel pylon. In this case, the steel pylon was not possible, because the girder was too heavy.

Case D is a slender concrete girder with the same steel pylon. In this case, the steel pylon became OK due to less weight of the girder.

(4) Finalized bridge layout:

As for the final layout, the steel circular pylon was completed with a reasonable cost using lighter concrete girders thanks to UHPC (), where the slab thickness is 15 cm and 10 cm for roads and sidewalks, respectively. The bridge was opened in the summer of 2018. It is now the first UHPC cable-stayed bridge in the world as a road bridge.

- Span & Width: L = 100 m + 100 m, B = 29.5 m;
- Girder material: Concrete (fck = 180 MPa, K-UHPC);
- Pylon: Steel box + horizontal ties.

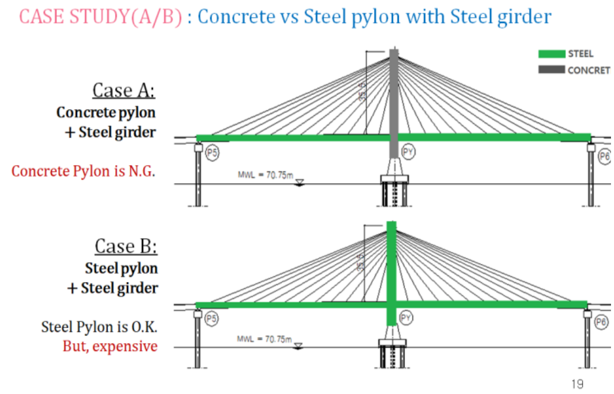


Fig. 11 Case study A&B for Chuncheon bridge.

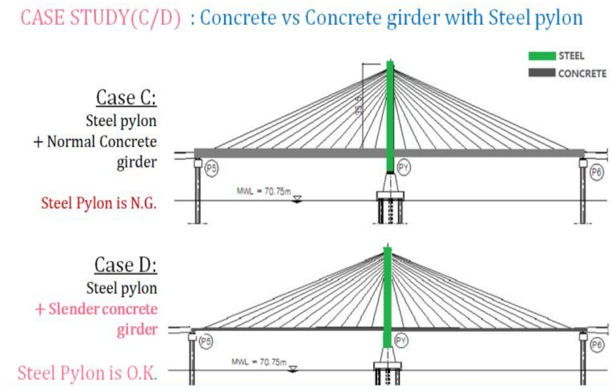


Fig. 12 Case study C&D for Chuncheon bridge.

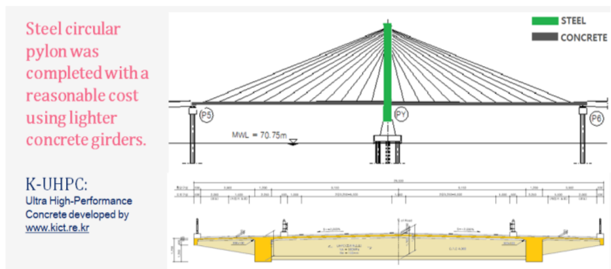


Fig. 13 Case study C&D for Chuncheon bridge.

Fig. 14 View during construction of Chuncheon bridge.

Fig. 15 Bird's eye-view of Chuncheon bridge.

4.3 2019: Cheonsa Bridge

(1) Introduction:

Cheonsa bridge, opened in 2019, has a main span of 510 meters. However, the width is only 12.5 meters wide for 2 lanes. So it became one of the slenderest bridges. The main challenge in the design was its aerodynamic stability during its construction and in-service. We had to do something to make the "structural system" stronger and more stable.

(2) Finalized bridge system:

So we studied the well-known solutions such as widening box, separating box, intermediate piers and so on. But, by using these methods, the cost highly increased. Finally, it was concluded that it wasn't necessary to use expensive solutions if we use a proper hybrid system as follows.

- Side spans are constructed in advance with a concrete box.
- The main span is constructed later as a steel box using stay cables.
- All bundled back-stay cables are anchored to side pier-heads.

(3) Hybrid bridge solution gave many advantages:

- This bridge became very stable during its construction and service.
- The number of stay cables was minimized.
- A tie-down system was not needed.
- Cable arrangement provides a more open and dynamic view.
- This bridge will give us the best value with safety and aesthetic view.

Fig. 16 South-west sea and Cheonsa bridge.

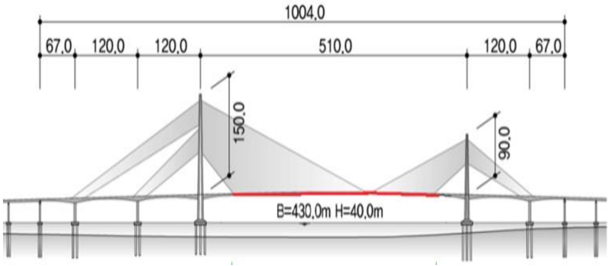


Fig. 17 Structural shape for Cheonsa bridge

Fig. 18 Night view of Cheonsa bridge.

Fig. 19 Pylon during construction of Cheonsa bridge.

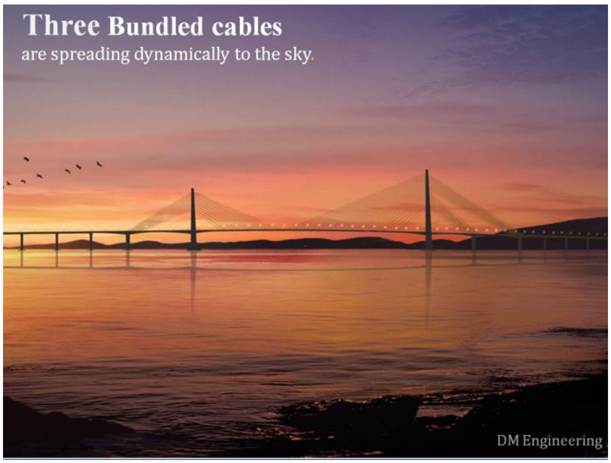


Fig. 20 Three bundled cables of Cheonsa bridge.

Fig. 21 Initial design for Seohae railway bridge.

4.4 2021: Seohae Railway Bridge

(1) Introduction:

Seohae railway bridge, crossing the Pyoungtack lake in the West of Korea, is under construction and will be completed in 2021. The width of the lake is 2.6 km and the bridge site is wide and flat. So tourist spots have been being developed along the lakeside. The original design was a series of 80 meters long rectangular trusses. It was not “Cost effective” and it was far from “Aesthetic”.

Several skylines of the whole bridges to be placed were studied at first. Finally, we chose the moving curve that seems to be friendly to people.

(2) Main bridge layout:

Five simply supported arches were decided. The span of the largest middle arch is 137 meters long. Arch ribs are adjusted to be asymmetric with golden ratio. Hanger cables have the radial directions to the arch ribs. Steel girder and steel arch ribs have edged box sections. Concrete piers like big bowls are in harmony with steel arches.

(3) Approach bridge layout:

The main girder is a simply supported composite truss. Its length is 70 meters out of 90 meters span. The piers are like PHI-shape with a 20 m-long pier head. It looks a hybrid bridge. This bridge became to have stable concrete piers in harmony with the steel girder.

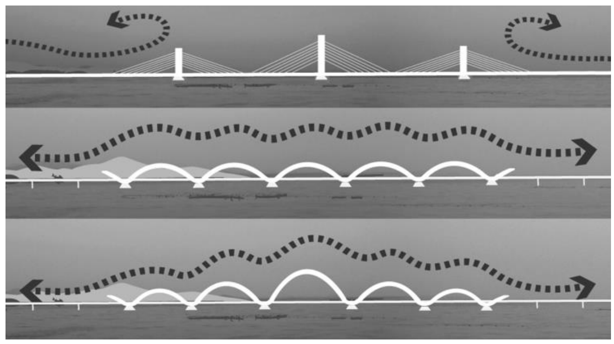


Fig. 22 Skyline study for Seohae railway bridge.

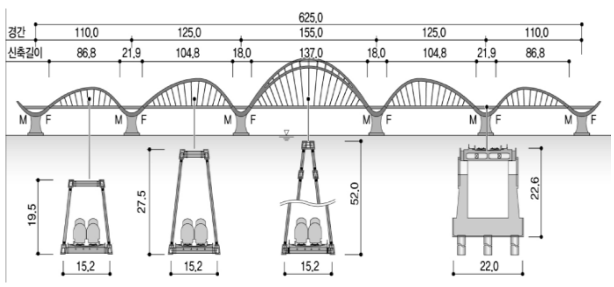


Fig. 23 Structural shape for Seohae railway bridge.

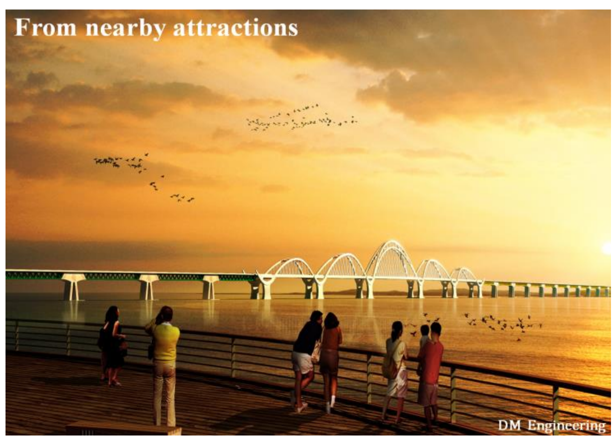


Fig. 24 View of Seohae railway bridge from nearby attractions.

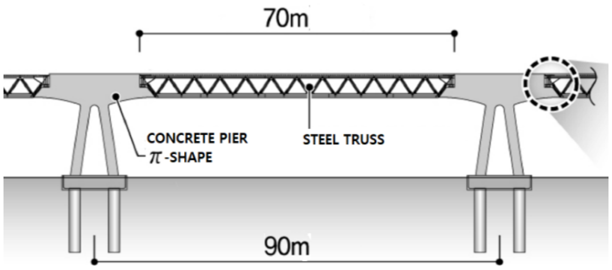


Fig. 25 Approach bridge layout of Seohae railway bridge.

Fig. 26 Harmonized piers & girders in Seohae railway bridge.

4.5 2022: Kwang-am Bridge

(1) Introduction:

Kwang-am bridge will be one of the bridges on a new expressway between Seoul and Sejong City. It will be completed in 2022. The initial design was set up by a "Concrete box girder bridge" with in-situ concrete. The main span is 145 meters long. Study for bridge types was carried out in two steps.

Step 1. Girder bridge vs. extra-dosed bridge as a concrete bridge:

(a) The box depth at the piers reaches almost 10 meters. It does not give people a nice view.

(b) Therefore, it was preferred to use the "Extra-dosed bridge", which can reduce the depth of the super-structure

Step 2. Concrete girder vs. steel girder as an extra-dosed bridge:

(c) The extra-dosed bridge is normally made of concrete in both girders and pylons.

(d) Finally, this bridge became the extra-dosed bridge using the steel girder. It makes the construction easier and faster.

Fig. 27 Case A and B for Kwang-am bridge.

Fig. 28 Case C and D for Kwang-am bridge.

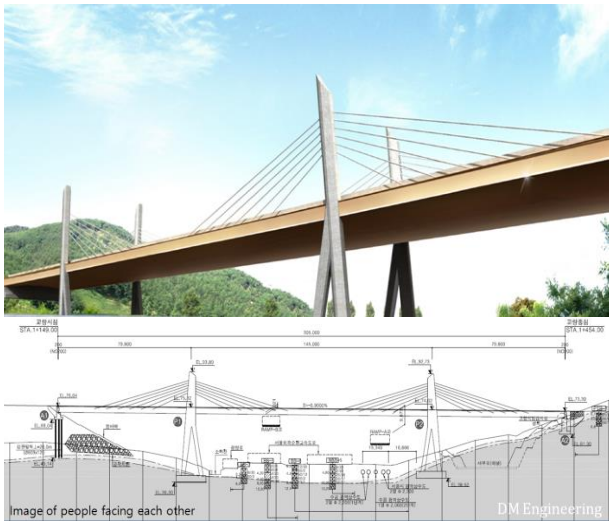


Fig. 29 Extra-dosed bridge having steel girder for Kwang-am bridge.

(2) Extra-dosed steel bridge is under construction. The extra-dosed bridge, which has been applied only to concrete bridges, will be applied as a steel bridge, providing a slender & colored line. In addition, the self-weight became reduced, which gave freedom to the shape of the pylons. Finally, they have image of people facing each other.

5. Conclusion

Thanks to advances in technology, the boundary of concrete or steel in bridges is gradually disappearing. The time has come when concrete is replaced by steel and steel is replaced by concrete. What matters is to get the best value, which ties everything together. Therefore, the concept of “Harmony” can be important for the future of bridges.

Several bridges, using steel and concrete in harmony, have been designed and constructed in recent Korea, where we have come to know that the harmony technique is useful in the following cases:

To develop a new shape of bridges,

To increase the structural efficiency,

To overcome the structural difficulties,

To make the construction easier and faster, and

To minimize the cost.

I look forward to more research and best practices for steel bridges in harmony with concrete.

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