(I5) Steel and Concrete Hybrid Structures in Japan Railways

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In Japanese Railways, hybrid construction made up of a combination of steel and concrete, such as concrete encased steel and concrete-filled tubular steel construction, has become a focus of attention as a structure capable of satisfying the various demands. In the first half of this paper, we will introduce examples of the application of hybrid construction to railway structures in Japan, followed in the latter half by an overview of the Design Standard for Railway Structures (Steel-Concrete Hybrid Structures).

Key Words : *steel and concrete hybrid structure, railway, concrete encased steel (SRC) member,concrete-filled tubular (CFT) steel column, SRC slab*

1. Introduction

There has been a tendency in Japanese railways toward an increase in the construction of urban civil engineering structures in close proximity to commercial railway lines, such as projects to reinforce transport capabilities and the construction of continuous grade separations. Therefore, there is a demand for construction capable of readily assuring the safety of the construction even in narrow confines and capable of shortening the construction period.

At the same time, there is also considered to be a need for structures with outstanding economic viability and with a high level of earthquake resistance capable of withstanding large-scale earthquakes such as the earthquake that occurred in the southern part of Hyogo Prefecture in 1995. Furthermore, there are also increasingly strong demands by society for beautification in urban structures.

Hybrid construction made up of a combination of steel and concrete, such as concrete encased steel and concrete-filled tubular steel construction, has become a focus of attention as a structure capable of satisfying these various demands. That is because the use of steel material as supports or forms makes it possible to assure safety, simple construction and shortened construction period and also because the effect that can be gained by using steel and concrete in combination makes it possible to expect strong bearing capacity and flexible deformation properties.

From 1970s, there were many examples of the application of hybrid construction to railway structures, especially composite girders and concrete encased steel structures. Composite girders were used on the Sanyo Shinkansen Line instead of steel girders in order to reduce noise. In addition, concrete encased steel and concrete-filled tubular steel construction was also used in confined construction areas on viaducts and in stations on the Tohoku Shinkansen Line. Mixed structural systems such as hybrid rigid-frame construction combining steel beams and reinforced concrete columns were also used on the No.3 Ayase viaduct on the Joban Line[3). Thus, attempts to apply hybrid construction to railway structures are not necessarily a recent phenomenon in Japan.

In the first half of this paper, we will introduce examples of the application of hybrid construction to railway structures, followed in the latter half by an overview of the formulated *Design Standard for Railway Structures (Steel-Concrete Hybrid Structures)* in 1998.

2. Application Examples

We will now introduce some examples of construction of hybrid structure in Japanese railways.

(1) Conversion of track embankments to elevated track using concrete-filled tubular steel columns

Higashi Matsudo Station on the Musashino Line is a station that was newly constructed as a part of the Kamishiki land readjustment project in Matsudo City, Chiba Prefecture. The purpose of this construction project was the conversion of double-track banked sections to elevated track and the construction of new stations. Spanning with lattice girders is the method in general use; however, since the construction period would be prolonged with nighttime work involved, temporary embankments were built on the banked surfaces on both sides of the commercial line as indicated in **Fig.1**. Then the railway tracks were temporarily moved to the top of the temporary embankment and a rigid-frame viaduct was constructed above the embankment. After completion, the railway tracks were moved to the viaduct and the existing embankment were removed. The main piers of the viaduct have a concrete-filled tubular steel structure and the upper and underground beams are of reinforced-concrete construction. In the design of the concrete-filled tubular steel piers, the tubular steel is regarded to be an aggregation of steel reinforcing bars and the construction was carried out in the same manner as reinforced-concrete construction[4].

(2) Viaducts using concrete encased steel beams and concrete-filled tubular steel columns

The Akita Shinkansen construction project included the construction of a viaduct with a length of about 1.1km branching off from the viaduct of the Tohoku Shinkansen Line, at a point 700m north of Morioka Station, to the existing Tazawako Line. Since the construction was carried out in a densely-populated residential area, the work space was limited and there were restrictions in construction noise and vibration. Furthermore, there were extremely stringent restrictions on the construction period. Taking these severe restrictions into account, the viaduct was constructed with lock-auger combined soil-cement composite tubular steel piles, concrete-filled tubular steel columns and concrete encased steel beams, as indicated in **Fig.2**. In the design, the bearing capacity of the rigid frame was calculated considering confined effect.

(3) Continuous concrete encased steel girders with T-shaped cross-sections

The Susohanagawa Bridge was constructed of double-span continuous concrete encased steel girders and is characterized by T-shaped cross-sectional structures, as shown in **Fig.3**. The concrete in the region of tension, which does not contribute to bearing capacity seen in conventional slab girders (welded H-steel embedded girders), has been reduced to the minimum. Various effects due to the reduction of the dead load of the girder have been reported, such as the possibility of longer effective span of girders, more compact cross section of bridge piers, and smaller diameter and number of foundation piles[5].

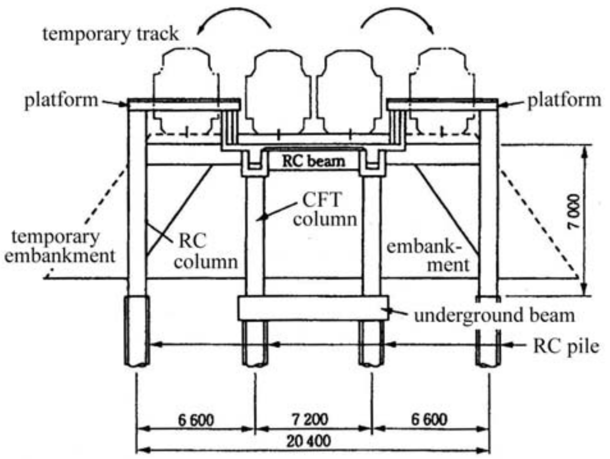

Fig.1 Conversion of track embankments to elevated track using concrete-filled tubular steel columns

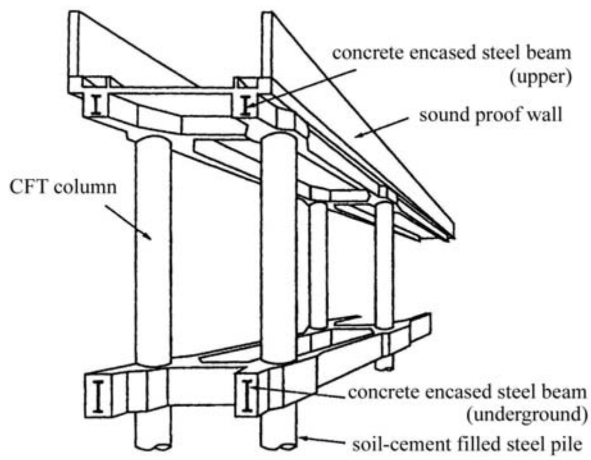

Fig.2 Hybrid bridge structure for elevated track

Photo 1 Multi T-shaped SRC girder bridge

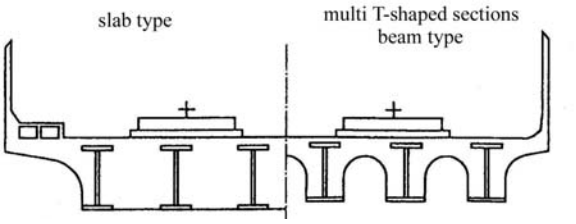

Fig.3 Concrete encased steel continuous girder with T-shaped cross sections

Photo 2 Hokuriku Shinkansen Hokurikudo Overbridge

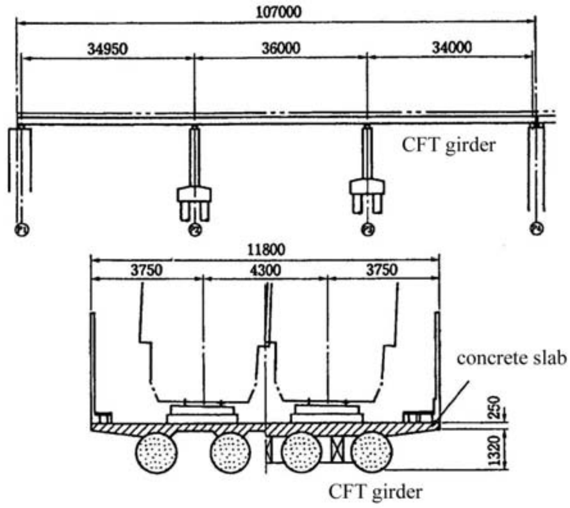

Fig.4 Concrete-filled tubular steel girder

(4) Concrete-filled tubular steel girders

A Concrete-filled tubular (CFT) steel girder[6)] is quite a new, unprecedented type of hybrid structure. It is composed of a circular steel tube, which is available on the market, and infilled concrete. This structure can omit building up of steel plate girders or formwork for concrete main girders. Then it can promote laborsavings and reduce construction cost.

Although the circular steel tube has relatively low section efficiency as a girder, the CFT shows strong bearing capacity, excellent deformation properties[7)8)] and outstanding reduction effect of noise and vibration in railway running operation[9)].

The CFT steel girders were used in a part of Hokuriku Shinkansen Hokurikudo Overbridge, shown in **Photo 2**. Because of spatial restriction under tracks and needs for execution efficiency and low noise, the CFT was selected for the main girders. Cross section of the bridge is shown in **Fig.4**.

The bridge is three-span continuous bridge with four CFT main girders. For the main girders, circular steel tubes (max. 1300mm dia. x 34mm thick.) were used. To ensure seismic performance, rubber bearings were implemented to distribute seismic lateral force.

In positive bending moment area, cellular mortar was filled in the circular steel tubes for the purpose of reducing noise and vibration, normal concrete was used for the slab, and stud dowels were used for shear connection between the girders and the slab. In negative bending moment area near intermediate supports, lightweight concrete was filled in the steel tubes, steel fiber reinforced concrete was used for the slab and new type perforated steel plates were used for shear connection.

The bridge was constructed near the coast of the Japan Sea. The construction site was expected to be severe corrosive environment. To protect the bridge from corrosion and to minimize the maintenance, unpainted high performance weathering steel was used for the first time in the world. In addition, full cross section field welding of joints and rust stabilization treatment on the steel surface were performed to form protective rust layer, to prevent outflow of rust water in initial state and to improve environmental performance.

(5) Through truss bridges with SRC slab

The first continuous through-truss bridge with SRC slab is adopted for Kamogawa Bridge[10)] in Kyoto, shown in **Photo 3**. Thereafter, several other bridges have been constructed.

Photo 3 Kamogawa Bridge

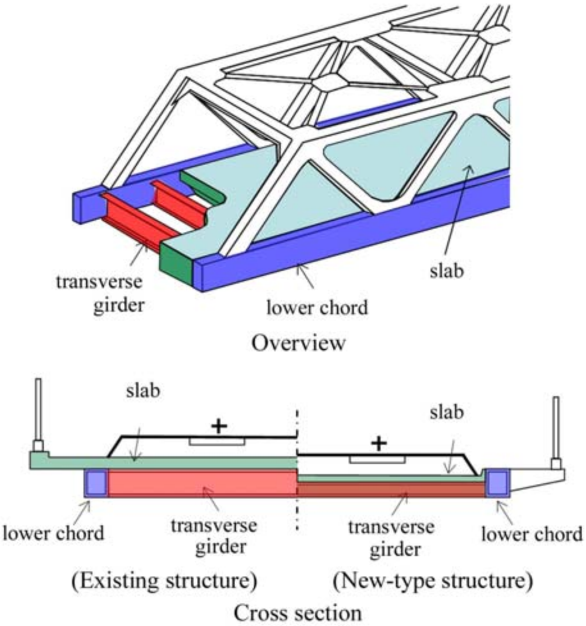

Fig.6 Through truss bridge with SRC slab

In existing through-truss bridges, an RC slab is implemented upon a floor system of longitudinal and transverse steel girders. In the new system, those girders and slab can be composed together as an SRC slab, as indicated in **Fig.6**. The SRC slab has following advantages:

(a) The system can reduce slab and girder height, so that it can be applied to places in narrow spatial restriction of girders and can also allow the level of tracks to be constructed in the minimum.

(b) Steel weight of girders can be reduced by a large margin.

(c) The most part of steel girder, which is one of major sources of noise in truss bridges, is covered with concrete, then the noise can be reduced.

In the case of Kamogawa Bridge noted above, the construction cost was greatly reduced by applying SRC slab and the effect of noise reduction is also reported.

3. Overview of the new design standard

Photo 4 Design Standard for Railway Structures (Steel-Concrete Hybrid Structures)

Despite we had many application cases of hybrid structures for railway, we had no unified standard or specification for design of hybrid structures before 1990s. Consequently, it became necessary to establish a design standard that enables design thoroughly reflecting the distinctive features of hybrid structures. A technical committee of experts was thus formed in 1992 with the Railway Technical Research Institute acting as the executive office. As the result of careful deliberations over a period of five years, proposed design standard for hybrid railway structures was drafted. In March, 1998, the Ministry of Transport announced *Design Standard for Railway Structures (Steel-Concrete Hybrid Structures)*, hereinafter called *Hybrid Structures Standard*. The front cover of the standard is shown in **Photo 4**.

The steel-concrete hybrid structures described in the standard refer to composite structures composed of concrete encased steel members and concrete-filled tubular steel members. In addition, the standard also applies to mixed structures in which composite members comprised of different types of materials are combined into one single structural system, such as rigid-frame viaducts which are made up of beam members of concrete encased steel construction and column members of concrete-filled tubular steel construction, as previously noted example of viaduct in Akita Shinkansen Line.

The standard is comprised of General Provisions, Part 1 Concrete Encased Steel Structures and Part 2 Concrete-Filled Tubular Steel Structures.

The following is a summary of the major characteristics of the design standard.

(a) It has become possible to apply the standard to the design of hybrid structures composed of members of concrete encased steel construction and concrete-filled tubular steel construction.

(b) Recent research advances from both Japan and abroad have been incorporated and design methods are based entirely on limit state design method.

(c) More depth has been given to the verification methods of ultimate, usage and fatigue limit states of concrete encased steel structures.

(d) In regard to the examination of the ultimate limit state, in particular, the method for the evaluation of bearing capacity has been broadly revised based on the outcome of loading tests of beams and columns.

(e) In regard to the examination of earthquake resistance, design method was established assuming the plastic deformation properties (ductility) of concrete encased steel members. Therefore, quantitative evaluation method for member ductility required for design was included.

(f) In regard to concrete-filled tubular steel structures, as in the case of concrete encased steel structures, verification methods were stipulated for the ultimate, usage and fatigue limit states. In regard to the examination of earthquake resistance, design method was likewise adopted that assume plastic deformation properties and quantitative evaluation method was stipulated for the ductility of members required for design.

(g) Quantitative evaluation methods were stipulated for the bearing capacity of column-foundation joints and column-beam joints in mixed structures in which concrete encased steel structures and concrete-filled tubular steel structures are the primary members.

After *Hybrid Structures Standard* had been published, *Design Standard for Railway Structures (Seismic Design)*, hereinafter called *Seismic Design Standard*, was published in 1999. In *Seismic Design Standard*, articles concerning with seismic design, seismic performance verification and seismic structural detail of hybrid structures were reviewed and revised to those that are available for large-scale earthquakes. Currently, seismic design of hybrid structures is carried out according to *Seismic Design Standard*.

4. Conclusions

We have presented an introduction to examples of the application of hybrid construction to railway structures and an overview of the Design Standard for Railway Structures (Steel-Concrete Hybrid Structures), which was formulated to promote the standardization of the design of hybrid structures.

In addition, English translated summary of *Hybrid Structures Standard* will be published soon and the standard itself will be revised in several years.

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