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Static and seismic behaviours of innovative hybrid steel reinforced concrete bridge

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ABSTRACT

Bridges using rolled steel H-section seem to be economical compared with plate girder bridges due to lower material and fabrication cost in the short-span length. The rolled steel H-section is a compact section and no stiffener is necessary. However, as the maximum available web height of the rolled H-sections is 900 mm, the applicable span-length is 20–25 m. A new composite girder bridge was proposed using rolled steel H-section to extend the span-length. The superstructure consists of continuous rolled steel H-girders composite with the RC slab, and the substructure is RC piers. The girder and the pier are rigidly connected by concrete and reinforcements to resist large negative bending moment at the joints. Experiments were conducted with the partial SRC bridge model, which showed that the proposed structure with a rolled H-girder had high ultimate strength with good ductile property, and attained the full plastic moment. A FE model was established considering material non-linearity and shear transfer between steel and concrete and compared with the experiments, which showed good agreement and clarified the load transfer mechanism. A trial design with the SRC highway bridge was carried out, confirmed that the applicable span length can be extended to 50 m. Seismic performance of the SRC system was verified by dynamic analysis, showed sufficient strength and ductility for strong earthquake with peak acceleration of 810 m/s^2. Cross beams were eliminated in the new SRC bridge because the girder height was low, which was verified by FEM analysis with the full bridge model.

1. Introduction

The girder bridge using steel rolled H-sections is competitive and economical in short spans due to low material and fabrication costs. The rolled steel H-beam is a compact section and no stiffener is necessary for girders. However, the maximum available web height of the rolled H-beam is about 900 mm, the applicable span length for a road bridge is about 20 m for simple spans and 25 m for continuous spans. In a continuous structural form, the intermediate support area is subjected to negative bending moment and is usually more critical than the span centre, which limits the span length.

For a simply supported girder where the bending moment is positive along the span length, the composite girder consisting of the steel H-girder and the reinforced concrete (RC) slab is rational. The steel girder is in tension and the RC slab is in compression. However, for a continuous composite girder, the RC slab is tension and does not contribute much at support joints, where large negative bending moment exists.

A new form of steel and reinforced concrete (SRC) composite girder bridge was proposed using a rolled steel H-section [1]. The superstructure is a continuous girder with the rolled steel H-section which is composite with the RC slab. Steel/concrete composite bridges are commonly used all over the world because of the attractive appearance and efficient structural rationality. The steel girders and the RC piers are rigidly connected by reinforced concrete at the pier top. The rolled H-beams are strengthened around the joints by being covered with reinforced concrete, which forms the SRC section and increases the resisting capacity of the section at support joints. The proposed SRC bridge using rolled steel H-section is basically a multi-span rigid frame bridge structure and is expected to be competitive and economical compared with the welded plate girder bridges.

Experiments were conducted with the partial SRC bridge model [2], and the bending strength and the load transfer mechanism at the steel-concrete rigid joint was investigated. Finite element model was then developed, considering material non-linearity and shear connections between steel and concrete. The FE model was applied to the experiments and compared with the test results to clarify the behaviours of the rigid joints and to verify the FE model.

A trail design was conducted with a road bridge with the maximum span length of 50 m, and safety verification of the sections was performed by the limit states design method. Furthermore, the structural performance of the proposed bridge form against ultra-strong earthquakes was studied by dynamic analysis. These studies were intended

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to confirm that the new SRC bridge using rolled H-girders is feasible for a much longer span bridge than the existing one.

In this SRC bridge with rolled H-girders, the web height is only about 900 mm and the steel girder is composite with relatively thick RC slab, which can provide sufficient stiffness against transverse forces without cross beams. Therefore, the cross beams could be unnecessary in the new SRC bridge, which was also verified by FEM analysis with the full bridge model.

2. Structural form

The structural form of the proposed steel and reinforced concrete composite girder bridge with rolled H-beam section is illustrated in Fig. 1 and Fig. 2. The super-structure is a continuous girder with the rolled steel H-section and the RC slab, and the sub-structure is the RC piers. The girder and the pier are rigidly connected by concrete and reinforcements. The concept of this new structural form is that the steel/concrete composite girder resists the positive bending moment at the span centre and the steel girder covered by reinforced concrete section (SRC) resists the negative bending moment at the rigid joints. As shown in Fig. 3, this new SRC bridge is basically a multi-span rigid frame structure and the applicable span length is expected to reach almost double the existing ones.

In order to achieve a reliable composite rigid frame bridge, shear forces must be transferred between the steel girder and the RC part. Perfo-bond rib (PBL) shear connectors were welded to the upper and lower flanges of the steel girders in the rigid joint area. The PBL consists of the steel plate with holes, into which reinforcements go through. The steel girders were covered by reinforced concrete at around 15% of the span length near the support joints. Sufficient amount of reinforcements in the cross-section were installed longitudinally and stirrups were also arranged at proper intervals.

3. Experiments

Bending tests were conducted with the partial SRC specimen [2], which has a reverse L-shape shown in Fig. 4. The objective of the test was to investigate the bending strength and ductility of the steel-concrete rigid joint and to clarify the load transfer mechanism from the girder to the pier at the rigid joint. The test specimen was scaled down to half of the actual bridge model, using rolled H-beam section. The embedded length of the steel girder at the rigid joint was approximately twice the girder height to provide adequate embedded length. A half of the length of the steel girder was covered by RC to form SRC.

3.1. Experimental set-up

The structural steel used in the test was mild steel SS400 with a yield stress of 338 MPa. The specimens had a length of 3500 mm and a height of 1720 mm. The RC slab had a width of 1000 mm and a depth of

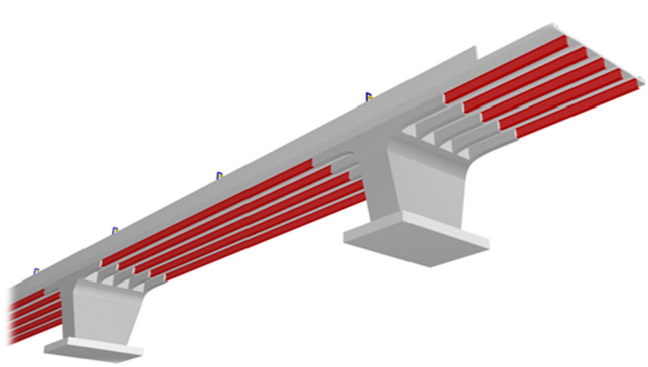

Fig. 1. The SRC girder bridge with rolled steel H-section.

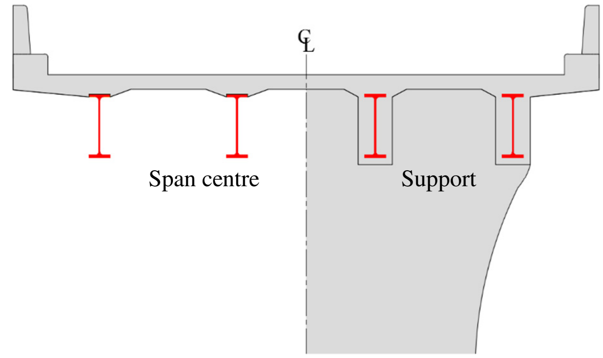

Fig. 2. Cross-section of the SRC bridge.

100 mm, with an additional 50 mm depth of the haunch. The concrete slab had reinforcement steel bars of SD295 with a yield stress of 388 MPa. The reinforcement bars were 19 mm in diameter and spaced at a pitch of 100 mm. It was arranged in one layer at the slab centre. The rolled H-beam consisted of a web with 440 mm in height and 11 mm in thickness, and upper and lower flanges with 300 mm in width and 18 mm in thickness. About half length of the steel girder was covered by RC with a section of 500 × 590 mm, forming the SRC section. The measured cylinder strength of concrete was 30.0 MPa. The RC pier had a cross section of 1000 mm × 900 mm. The reinforcement was SD345 with a yield stress of 374 MPa and with a diameter of 25 mm at a pitch of 125 mm (D25@125). The general layout and dimension of the designed specimen is shown in Fig. 5.

The Perfo-bonded rib (PBL) shear connectors were used at the beam-column rigid corner joint to prevent shear slippage between the steel and concrete interface. The PBL consisted of steel plates with a height of 100 mm, a thickness of 12 mm and a length of 800 mm. There were 60 mm diameter holes at the centre. The PBLs were welded to the upper and lower flanges of the rolled H-girder. Reinforcement (D22) were installed in the holes. Stirrups were also used to bond the steel girder and the RC pier. The PBL arrangement and details are shown in Fig. 6.

3.2. Test procedure

The specimen was incrementally loaded at the end of a cantilever beam and the vertical and horizontal displacements were monitored. The capacity of the loading machine was 625 kN and the test was terminated when the jack reached the maximum capacity. Concrete cracks were carefully checked at each loading step at the slab and around the beam-column rigid joint.

Vertical and horizontal displacements were measured at the loading position. Strains of the steel girder, the RC slab, the RC rigid joint, the RC column and the reinforcements were measured by strain gauges. The results obtained by experiments are presented with the FEM analysis in Section 5.

4. Finite element model

4.1. FE model

FEM has been commonly used to simulate structural behaviours of composite bridges and experimental results were often verified by FEM analysis [3–11]. Considering these past studies, a finite element model was developed for the current structure using the FEM program ABAQUS [12] and applied to the experimental specimen to clarify the behaviours of the rigid joints. The steel girder and the concrete slab, column and beam were modelled as a solid element (C3D8R), and the steel reinforcements as a truss element (T3D2) with two nodes and three translational degree of freedom were adopted [3,4,6,7,9,10]. The shear