Design and experiments on a new railway bridge system using concrete filled steel pipes

Design and Experiments on a New Railway Bridge System using Concrete Filled Steel Pipes

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Summary

A new railway bridge system has been developed using steel pipes as the main girders, which are filled with concrete or air mortar depending on the span positions, and are also composite with concrete slab. This new girder could be not only economical but reduce noise and vibration induced by trains. Columns and piles are also concrete filled steel pipes. Pipe to pipe joint using concrete is applied to the pile-column and girder-column joints. This new bridge system is widely studied by analysis and experiments, among which three experiments are explained in this paper. Design detail of this bridge system is also presented.

1. Introduction

A new railway bridge system has been developed using steel pipes as the main girders as shown in fig. 1. The pipe girder is filled with concrete near the intermediate supports, whereas it is filled with air mortar, which is very light mortar mixed with air bubbles, around span-center to reduce the self weight. RC slab and the girder is designed to work as a composite member in the positive bending moment zone. This girder is expected to reduce noise and vibration levels induced by trains, which is the main disadvantage of conventional steel girders for railway bridges. Steel pipes are produced at steel mill and little fabrication is required to make them bridge girders, therefore it could be very economical compared with the welded plate girders. Double pipe girder, consisting of two pipes with different diameter and filled with concrete in between as shown in fig.2, could be used for larger span bridges.

Columns and piles are also concrete filled steel pipes as shown in fig. 1. Pipe to pipe joint with concrete is applied to the pile-column and girder-column joints. In this joint the upper pipe is inserted into the lower pipe, and concrete are poured into the gap of both pipes. Spiral ribs are attached on the pipe surface to increase relative friction of both pipes. This joint is very simple and firm, and so it could eliminate concrete footing, which also reduces the construction cost.

This new bridge system is widely studied by analysis and experiments, among which three experiments are reported in this paper: bending tests, shear connector tests and noise tests. This bridge system is to be applied to the planned railway bridges and the design detail is also presented.

2. Bending Tests

Bending tests of pipe girders are carried out by the method shown in fig.3. Two groups of specimens shown in fig.2 are tested. Bending strength and behavior of concrete filled steel pipe

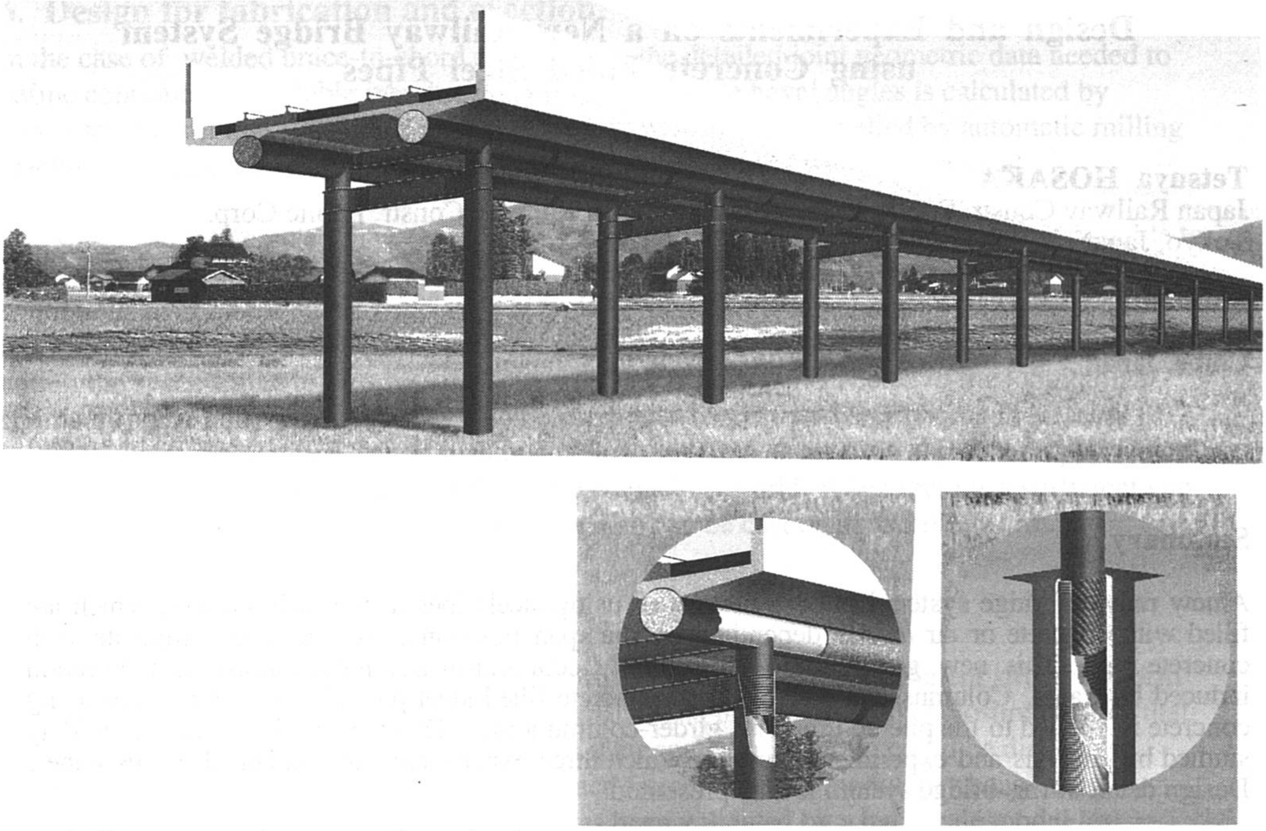


Fig.1 Illustration of a new railway bridge

girders with concrete slab are mainly studied in the first group (T1 to T3). T1 is concrete filled double steel pipe girder, T2 concrete filled double steel pipe girder with concrete slab and T3 steel pipe girder with concrete slab. Bending strength and behavior of air mortar filled steel pipe girders are studied in the second group (M1 to M6). M1 is made only of steel pipe. Air mortar with compressive stress of 7, 14, 57kg/cm^2 , light aggregate concrete with compressive stress of 325kg/cm2 and normal concrete with compressive stress of 460kg/cm^2 are filled in the pipes of M2, M3, M4, M5 and M6 respectively. Density of air mortar of M2, M3 and M4 is 0.50,0.54 and 1.12 respectively.

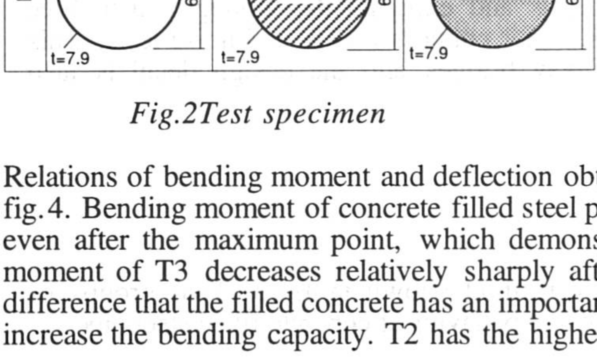


Fig.2Test specimen

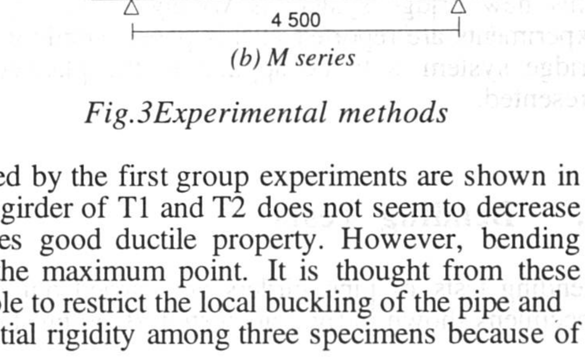


Fig.3Experimental methods

Relations of bending moment and deflection obtained by the first group experiments are shown in fig.4. Bending moment of concrete filled steel pipe girder of T1 and T2 does not seem to decrease even after the maximum point, which demonstrates good ductile property. However, bending moment of T3 decreases relatively sharply after the maximum point. It is thought from these difference that the filled concrete has an important role to restrict the local buckling of the pipe and increase the bending capacity. T2 has the higher initial rigidity among three specimens because of the RC slab, but just after the yield point the RC slab is collapsed, and therefore the ultimate strength is the same as T1.

Relations of bending moment and deflection obtained by the second group of experiments are shown in fig.5. The maximum bending moment of steel pipe specimen M1 is improved nearly double by the filled concrete in M6 and M5. Air mortar filled specimens M2 to M4 also increase the maximum bending moments, but they are not as large as M6 or M5. However, it should be noted that ductile property is greatly improved in M4 compared with M2 and M3. This means that air mortar with strength over 50kg/cm^2 could restrict the development of local buckling of steel pipe and, therefore, could avoid sharp decrease of bending moment after the maximum point.

Relations of applied moments and strains of slab concrete and filled concrete of T2 are shown in fig.6. Strains of upper and lower slab concrete increase linearly with applied moments in the first stage, but the RC slab collapses when the strain reaches about 3400μ. After this, strain of filled concrete starts to increase sharply, which suggests the neutral axis lowers and filled concrete starts to contribute to the bending capacity. The strain finally reaches at about 4800μ due to so called the confined effects of filled concrete.

Strain distributions of steel and concrete of T2 are shown in fig.7. Strains of inner pipe, outer pipe, slab concrete and slab reinforcing steel bars are on the same linear lines on the different bending moment levels, which suggests these elements behave as one piece. Though, filled concrete behaves differently in the large bending moment levels, and so, adhesion does not seem to exist between pipes and filled concrete. Since the strains of pipes and slab concrete distribute on the linear line, the RC calculation method based on the Bernoulli Euler Principle could be applied. Fig.8 shows experimental data and calculated values by RC method in cases T-2 and T-3. Both values have good agreement within the elastic zone, but the experimental values are about 15% large the calculated values which do not include the confined concrete effect.

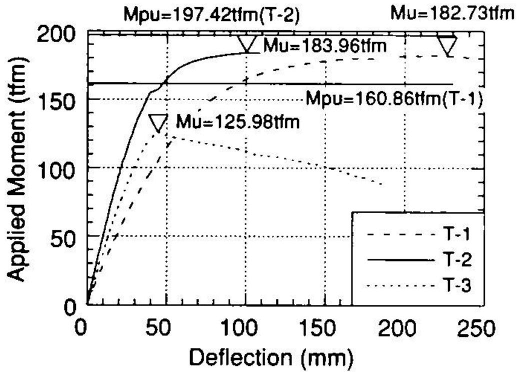


Fig.4 Moment displacement curve (T1 to T3)

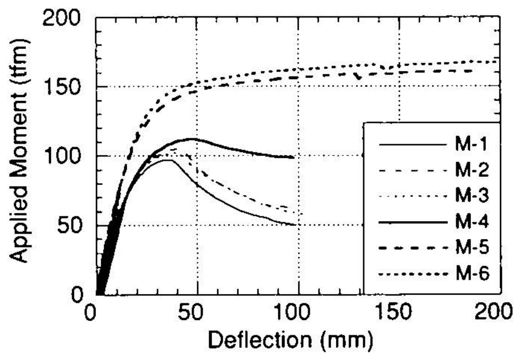


Fig.5 Moment displacement curve (M1 to M6)

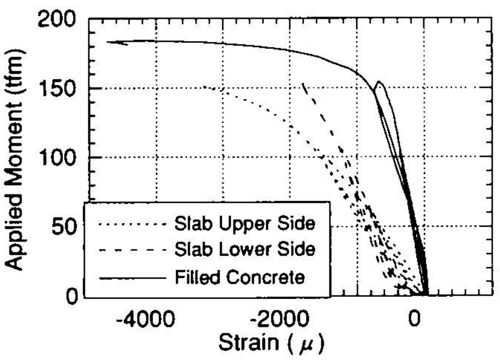


Fig.6 Concrete strain curves (T2)

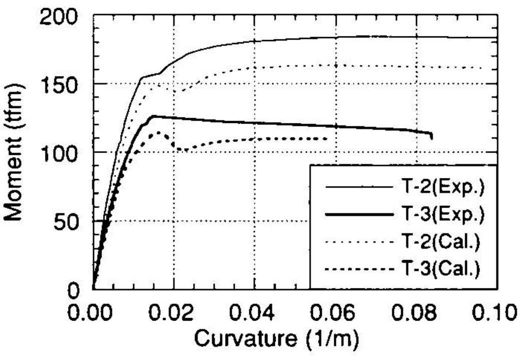
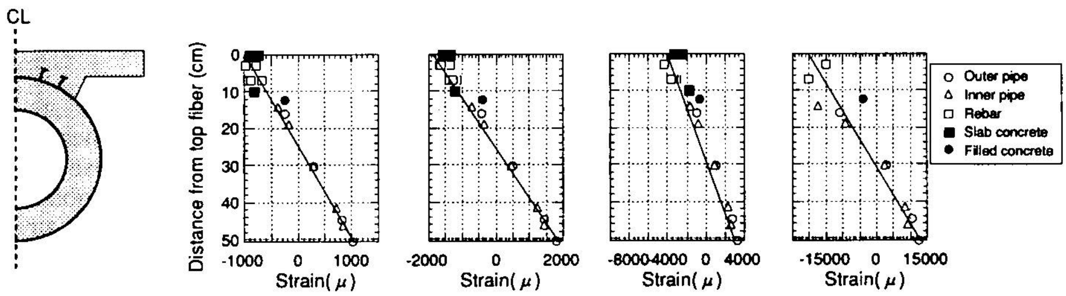


Fig.8 Comparison of experiments and RC calculation(T1 to T3)

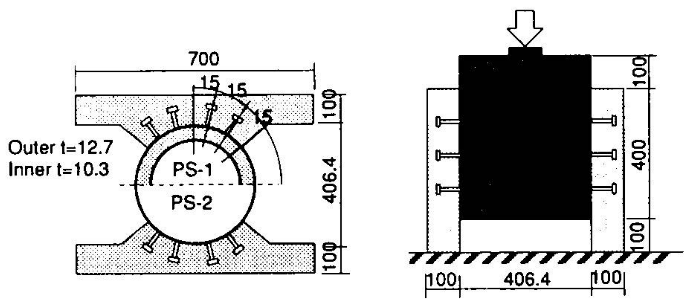


(a) Ma=66.4tfm (b)Md=105.6tfm (c) My=154.4tfm (d) Mu=184.0tfm

Fig.7 Strain distribution (T2)

3. Shear Connector Tests

Concrete slab is connected to the pipe girders with studs, and composite action is expected in the positive bending moment regions. However, the shape of the girder is different from the usual I-girders, therefore the shear strength is studied by the push-out tests as shown in fig.9. Two specimen, double pipe girder (PS-1) and single pipe girder (PS-2), are tested. Fig.10 shows relation of applied loads and relative slip between the slab and the pipe. It is understood from this figure that stiffness starts to decrease at applied load about 60tf, and the maximum load occurs at relative slip about 8mm. Ultimate shear strength of a stud of PS-1 and PS-2 is 5.68 and 5.67tf which agree with the 5.97tf calculated by Fisher formula. These results show that composite action is secured for the tube section by the stud type shear connectors.



(a) Cross section (b) Elevation

Fig.9 Experimental methods and specimen

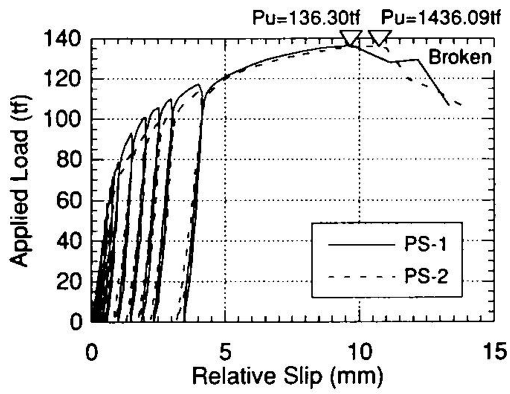


Fig.10 Load and relative slip curve

4. Noise Reduction Measurement

Noise and vibration levels of various girder sections are measured with the tapping device. Seven girder sections shown in fig.11 are tested: steel plate girder, steel plate girder with concrete panel attached, steel pipe, double steel pipe with concrete filled, steel pipe filled with air mortar with compressive stress of 7kg/cm^2, steel pipe filled with concrete and RC girder. Section modulus of all the sections are equal to compare on the equal basis. The tapping device shown in fig.12 consists of five hammers weighing 500g per each. The five hammers hit the concrete base on top of the specimen, at time interval of 100ms, with verocity of 88.5 cm/s. Microphones are set at 0.1m, 1m and 2m apart from the test specimen to catch the noise. Accelerometers are attached on three points of the specimen surface.

Noise levels collected by 0.1m microphone and acceleration levels on the surface are shown in fig. 13. It is understood that the noise and acceleration levels have the similar tendency in all the cases. It is clearly shown that non-composite steel section, PN-1A and PN-2, have higher noise and acceleration levels than those of other composite sections. The air mortal filled pipe PN-4 is effective compared with non-composite sections, but the double pipe model PN-3 and concrete filled pipe PN-5 is more promising as good as concrete section PN-6. These experiments prove that concrete or mortar filling can reduce noise and vibration levels of steel pipe girders.

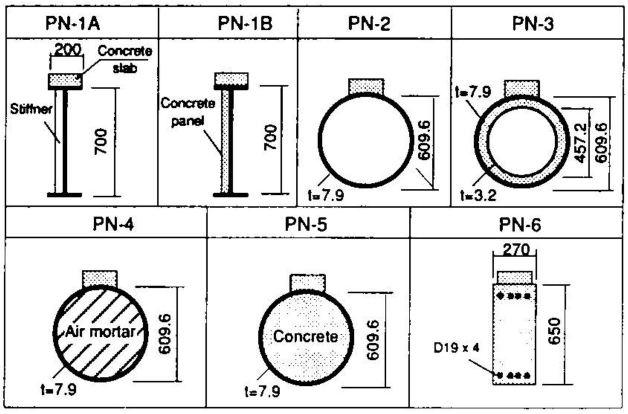


Fig.11 Test specimen

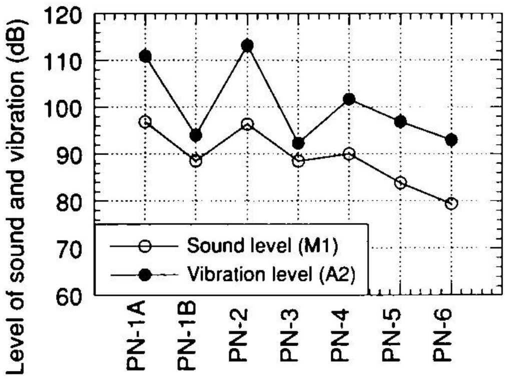


Fig.13 Measured data

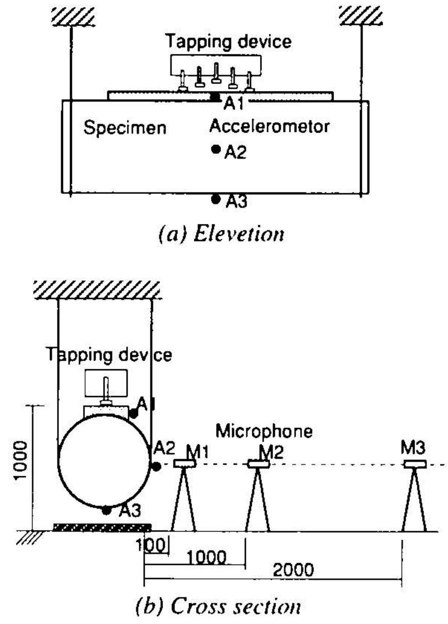


Fig.12 Measuring tools

5. Design of a New Railway Bridge

This new bridge system is proposed for railway bridges in the suburbs of Tokyo. Fig. 14 shows the general dimension of the bridge: five-span continuous girder bridge with each span-length of 20m. The deck level is about 10m above the ground. The bridge has two railways with train live load of 15 ton per wheel. Lateral force with 28% of dead loads is taken as seismic load.

Sub-structure consists of piles and columns. Piles are a new composite pile consistnig of steel pipes and soil cement with diameter of 1.2m and length of 19.4m. During the steel pipe is lowered with drilling device, cement milk is poured and mixed with soils inside the pipe. When the pile comes to the bottom position, base concrete is poured, and then the drilling device is pulled up. Spiral ribs are attached on the outer surface of the pile when it is rolled at the steel mill to increase the friction of pipe and soil cement solid. Major advantages of this new pile are quick installation, low noise level, and no removal of soil.

Concrete filled spiral pipes with diameter of 1.0m are used as columns. These pipes have good ductility and resistance against earthquakes. Ductile ratio up to 6 to 8 can be usually expected. A column is inserted into a pile, and concrete are pored into the gap. The spiral ribs are attached on the outer surface of the column and the inner surface of the pile, which improve the friction and strengthen the joint. This pipe to pipe joint with concrete has been widely studied by Takano, Isibashi, Kamata and Kinoshita[1]. They carried out experiments and found that this connection has high initial rigidity, good ductile property, and high ultimate strength, when spiral ribs are attached on the surface and overlap length is over 1.5 D (D: column diameter).

The super-structure is the two pipe girder system with pipe diameter of 1.117m. Concrete is filled inside the pipe girder near the piers, where negative bending moment is dominant. Air mortal is filled inside the pipe girder around span center, where positive bending moment is dominant and therefore composite effects of girder and RC slab can be expected. The air mortar is expected to reduce the noise level, but is not expected in bending strength. The stab pipe with spiral ribs is welded to the girder at intermediate support, inserted into the column and connected to the column by the same method used as the pipe to pile connection. Prefabricated composite slab is used to support the train loads.

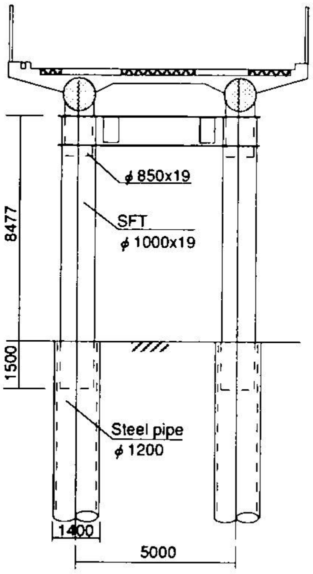


Fig.15 Sub-structure

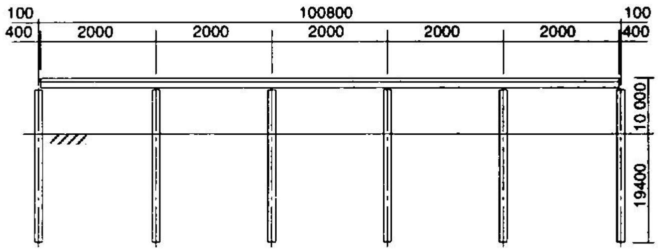
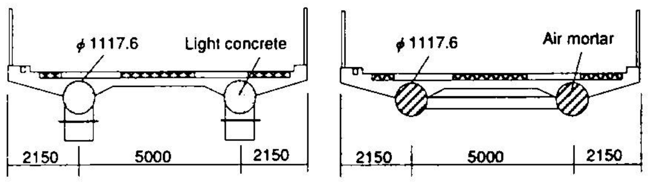


Fig.14 Layout of the new bridge



(a) Near support *(b) Span center*

Fig.16 Cross section of girders

6. Conclusion

The new railway bridge system using concrete or air mortar filled steel pipes are proposed and studied by analysis and experiments. The experiments show that the concrete filled steel pipes have high ultimate bending strength and good ductility. Air mortar with compressive stress over $50kg/cm^2$ could improve ductile property. Concrete slab and pipe girder have adequate shear strength by using studs. These pipe girders could reduce noise and vibration levels induced by trains.

The construction methods and cost of this new bridge are investigated for the planned railway bridges. It is found that estimated construction period is only 14 months to complete one kilometer long bridges. The estimated construction cost is substantially lower than that of the conventional steel bridges. It is concluded from this study that this new railway bridge system is feasible and economical.

Reference

1)Takano, Ishibashi, Kamata & Kinosita: Column-pile joints made of steel pipes filled with concrete, Fourth World Congress on Joints and Bearings, September, 1996.