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Seismic retrofit of plain concrete piers of railroad bridges using composite of FRP-steel plates

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ABSTRACT

This study is planed to solve the overturning problem and manifestation of tensile cracking of plain concrete piers of railroad bridges. For the overturning problem, earth anchors are used to fix the bottom of a pier to a rock-foundation using prestressing cables. Composite of Fiber Reinforced Polymer (FRP) and steel plates (FSP) are attached longitudinally on the surface of the pier to prevent cracking. Then, FRP band strips are wrapped onto the composite of FRP and steel plate to provide lateral confinement. Push-over tests in field show that the earth anchors are effective in preventing the overturning of the pier, and that the FSPs and the FRP strips prevent the cracking of concrete and increase the strength in bending.

1. Introduction

A total of 287 in-service Korean railroad bridges are being carefully reviewed in order to clarify the earthquake-resistance capability in terms of superstructure unseating possibility, the shear capacity of the bearings, the flexural capability of the bridge piers, and the potential for foundation overturning [1]. Most of these bridges use a type of open-steel-plate-girder (OSPG) bridges with plain concrete gravity piers constructed without consideration of an earthquake-resistant design; the word ‘open’ here means that such bridges do not have a track, as shown in Fig. 1. Given that these types of bridges were built in long ago, from the 1910s to the 1930s, processes associated with severe superstructure aging, such as corrosion, have been repeatedly noted several times despite the fact that a few superstructure replacements were done in accordance with maintenance efforts [2,3]. However, no plain concrete gravity pier and footing system has been retrofitted for the purpose of strengthening or maintenance for a long period of time. The OSPG bridges have two serious problems related to the pier and the footing. First, the cold joint at the middle of the pier is highly vulnerable to cracking due to tensile stress by lateral loadings such as braking or seismic loading. Second, the footing does not use piles that get into the soil. Thus, the possibility of pier-overturning due to lateral loading is high.

The increased seismic hazard on the Korea peninsula and the annual flooding affect the safety of the piers of the OSPG bridges [4]. Thus, special attention should be given to railroad structures in accordance with the consistent flood damage caused by typhoons and the increasing earthquake events in the vicinity of the Korean peninsula. Several seismic retrofitting methods have been developed mainly for reinforced concrete (RC) structures. However, no method for plain concrete structures has been formulated, as plain concrete structures are rare in-service in the world. The major retrofitting methods for RC structures involve the use of steel [5,6] or Fiber Reinforced Plastic or Polymer (FRP) jackets [7,8]. Both methods provide external passive confinement in the lateral direction and increase the ductile behavior of RC columns that do not have sufficient seismic resisting capacity. In addition, the concrete jacketing method [9,10] is preferred occasionally for the following reasons: (1) its relatively low price, (2) its suitability for the repair of crushed concrete, and (3) its increasing cross-section. Recently, Shape Memory Alloy (SMA) wire jackets were developed and proved to confine concrete effectively [11,12]. However, the jacketing methods mentioned above are not appropriate for the plain concrete piers of OSPG bridges, as the piers require reinforcement in the longitudinal direction as well as in lateral confining reinforcement. Steel, SMA wire, and FRP jackets provide lateral confinement but not longitudinal reinforcement.

Thus, this study plots a retrofitting plan to prevent the overturning at the footing and cracking at the cold joints due to lateral loading events. Earth anchors are used against the overturning failure. In addition, FRP-steel plate (FSP) strips in the longitudinal

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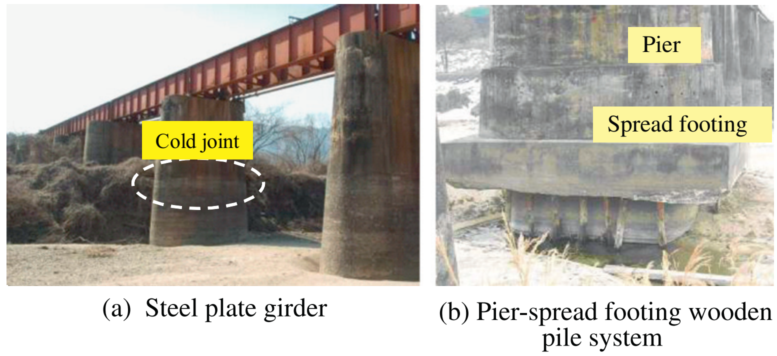

(a) Steel plate girder (b) Pier-spread footing wooden pile system

Fig. 1. General views of open-steel-plate-girder railroad bridge.

direction are used against tensile cracking while FRP band strips in the transverse direction are used to provide lateral confinement. The goal of this study is to assess the performance of each retrofitting scheme through a series of push-over tests in the field.

2. FSP and behavior under tension

FRP-steel plate (FSP) is a type of sandwich composite consisting of a steel plate between two FRP plates. Thus, FSP is a type of hybrid materials. In general, carbon FRP (CFRP) or glass FRP (GFRP) plates cannot be fixed by anchoring because they may be split easily by a large tensile load. Thus, most of FRP plates or sheets are attached with adhesives; the popular adhesive is epoxy. However, when a thin steel plate is placed between two FRP plates, the composite can be fixed by anchoring as the thin steel plate resists splitting stress. This study conducted tensile tests for CFRP and GFRP sheets and for steel plates to measure their mechanical properties. The thickness of the thin steel plate was 0.8 mm. The thickness of the CFRP sheet was 0.11 mm, though it became 0.2 mm with the resin. The GFRP sheet had a thickness of 0.77 mm (and 1.0 mm with resin). Three specimens of CFRP and GFRP sheets and steel plates were tensioned. The average values of the test results are listed in Table 1. The Young's modulus and the yield stress of the steel plate were 204 GPa and 194 MPa, respectively. The Young's moduli of the CFRP and GFRP sheets were 224 and 37.4 GPa, respectively. Their respective ultimate tensile strengths were 3311 MPa with a corresponding strain of 0.0153 and 778 MPa at a strain of 0.0209.

For the tensile test of FSPs, three different CFRP plates and one type of GFRP plate were prepared. The weights of carbon fiber for every 1 m of the three CFRP plates were 40, 80, and 120 g, respectively. The corresponding value of the glass fiber for the GFRP plate was 200 g per 1 m. Table 2 illustrates the types of specimens. Three specimens for each type of FSPs were prepared. Generally, failure of the FSPs occurred due to fracturing of the FRP sheets outside. The behavior of the FSPs was typical bilinear behavior without, however, a clear yield point, as shown in Fig. 2. This result stemmed from a combination of the linear behavior of the FRP sheets and the bilinear behavior of the steel plate. The steel plate inside yielded but was not fractured concurrently with the fracturing of the FRP sheets. Stiffness softening from the load–strain curves in Fig. 2 was observed at approximately the yield strain of steel, 0.002. This indicated that the steel plate inside yielded. Table 3 shows the specific average values from the tests including

Table 1
Mechanical properties of the FRP sheets and steel plate.

Materials	Tensile/yield stress (MPa)	Young's modulus (GPa)	Fracture strain (m/m)
Carbon FRP	3311	224	0.0153
Glass FRP	778	37.4	0.0209
Steel plate	194	204	–

Table 2
Types of FSP specimens.

Material types	Specimen	Composite
CFSP	CFSP-040	0.8 mm steel plate + CFRP 40 g/m
	CFSP-080	0.8 mm steel plate + CFRP 80 g/m
	CFSP-120	0.8 mm steel plate + CFRP 120 g/m
GFSP	GFSP-200	0.8 mm steel plate + GFRP 200 g/m

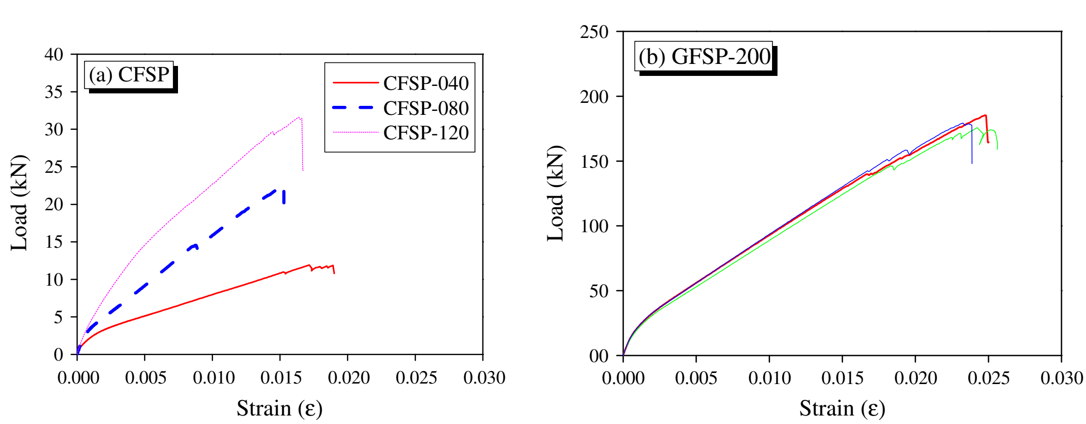

Fig. 2. Behavior of FSP specimens in tension.