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Earthquake responses of FRP-concrete bridge piers

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ABSTRACT

Because of limited resource and awareness of conservation engineers are looking for new more eco-friendly construction materials. In addition, the disadvantage of conventional RC composites due to long-term impact of reinforcement corrosion should be avoided. In this work the impact of earthquakes on a bridge pier made of natural fibre reinforced polymer-concrete composites is investigated. The earthquakes are simulated by a shake table, and the bridge deck is simulated by a top mass. Since reinforcement steel is not used, the structure has less mass. Consequently, the impact of the earthquake load can be significantly reduced due to less activated inertia force. Fibre reinforced concrete has also higher damping in comparison to conventional concrete. The experimental results clearly reveal the merit of the composite materials.

1 INTRODUCTION

Enhancement of the performance of civil infrastructure using fibre reinforced polymer has been performed in the past. Artificial fibres, i.e. glass or carbon fibres, are often used (e.g. Mirmiran et al. 1997). Because of awareness of conservation researchers are gradually considering natural fibres, e.g. hemp, flax or coconut fibres as possible eco-friendly alternatives. The effectiveness of the fibre reinforcement depends not only on the properties of the fibre, but also on the bond between fibres and surrounding concrete. The bond depends strongly on the concrete properties and the condition of the fibre surface. The stresses activated by the loading, the distribution and orientation of fibres play also a significant role (Wang and Chouw 2018). Wötzel et al. (1999) investigated the durability of hemp fibre reinforced components to be applied as

automotive parts. Mohanty et al. (1997) and Li et al. (2007) studied the influence of an alteration of natural fibre surface on the performance of composites. Ali et al. (2012 and 2013) investigated the static and dynamic properties of coconut fibre reinforced concrete (CFRC). Since these properties are strongly affected by the bond between randomly distributed fibres and surrounding concrete, the authors also considered the bond at the fibre-concrete interface by performing fibre pull-out tests. Figure 1 shows the test set-up. Depending on the loading considered the best bond might not be the best. A strong bond will impede the mobilisation of the surrounding concrete, because the fibres will simply snap once they reach their strength limit. An early breakage of fibres will limit the overall energy dissipation of the fibre-concrete composite.

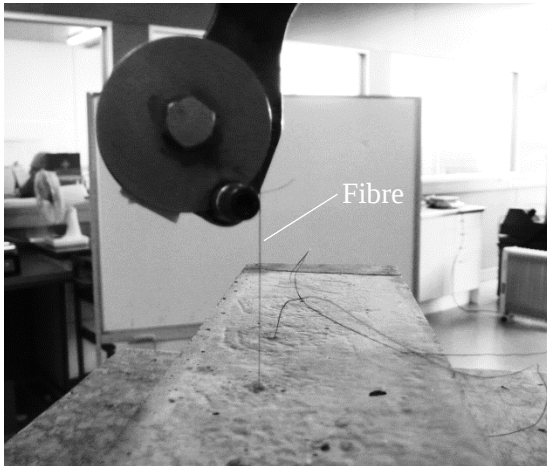


Figure 1: Test on coir-concrete bond strength

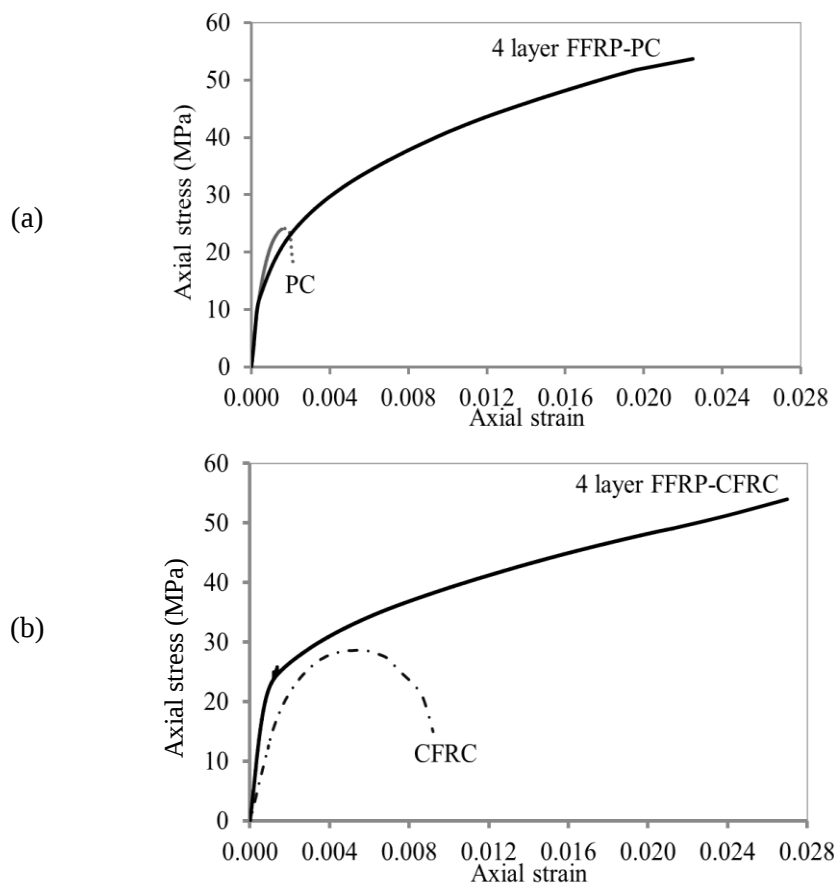


Figure 2: Influence of flax and coconut fibres on the compressive strength of the FRP-concrete composite. (a) Without and (b) with coconut fibre

The influence of coconut fibres on the compressive strength of the composite can be seen from a comparison between the stress-strain relationships in Figures 2(a) and (b). The relationships are obtained from compressive tests of cylinder specimens (Yan and Chouw 2013). The dotted line and dashed-dotted line show the compressive strength and the ductility of the specimen. The coconut fibres slightly increases the composite strength, and more significantly the ductility of the composite. To further enhance the composite performance an outer confinement by flax fibre reinforced polymer (FFRP) layers has been introduced by Yan and Chouw (2013a-c). The influence of six FFRP layers on the compressive strength and ductility can be seen by comparing the results without confinement (dotted and dotted-dashed lines) with the solid line in Figure 2. Confinement of FFRP layers clearly significantly improved the performance of FFRP-CFRC composites. To further enhance the performance of the composite Chen and Chouw (2016 and 2018 a, b) introduced a double confinement by using an outer and inner FFRP tubes. The loss of strength due to removal of parts of the CFRC core can be compensated by the strength of the inner tube. In addition, the double confinement flax fibre reinforced polymer (DFFRP) has another advantage, because the less concrete is used, the DFFRP-CFRC composite has less mass. Consequently, in the case of dynamic loadings the structures will experience less impact of the dynamic load.

In the following section the usage of FFRP-CFRC and DFFRC-CFRC composites as a bridge pier in earthquakes is discussed.

2 TEST SET-UP AND RESULTS

Figure 3 shows the set-up of the tests. The model bridge pier has a height of 1 m (see Figure 3(b)). The inner diameter of the outer tube is 10 cm and that of the inner tube 3 cm.

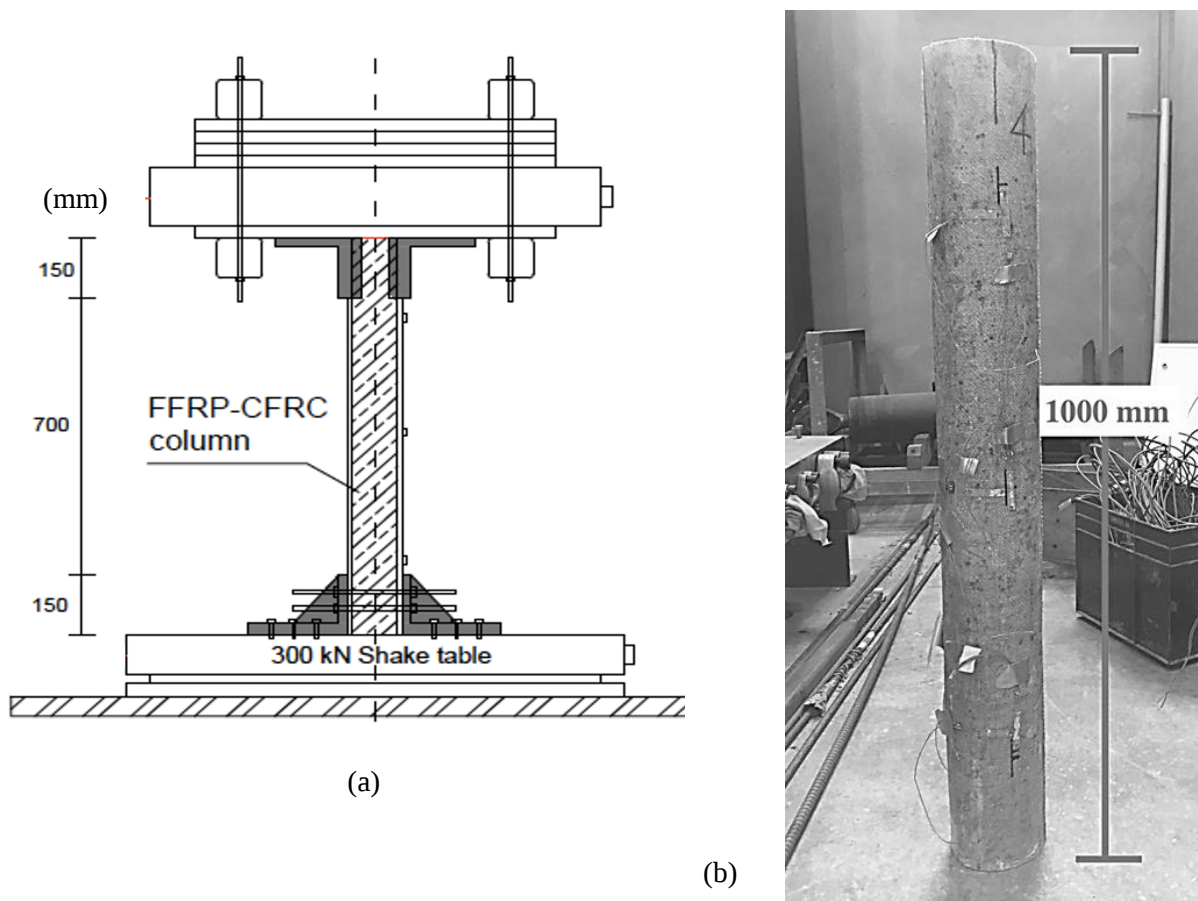


Figure 3: Test set-up. (a) Bridge pier model and (b) FFRP-CFRC composite

To incorporate the bridge deck a mass of 550 kg is placed on the top end of the bridge pier. It is assumed that the pier is fixed at the base. A shake table movement simulates the earthquake excitation. In total 15 ground motions with different magnitudes were considered. They were stochastically simulated based on the Japanese design spectrum for a hard soil condition (JSCE 2000).

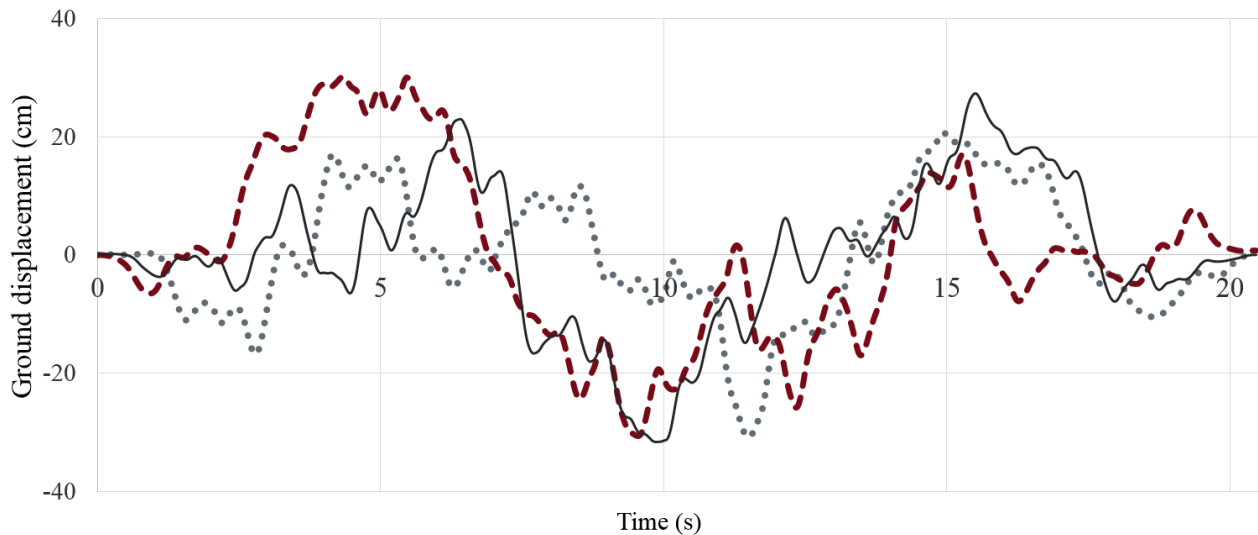


Figure 4: Time history of the ground motions

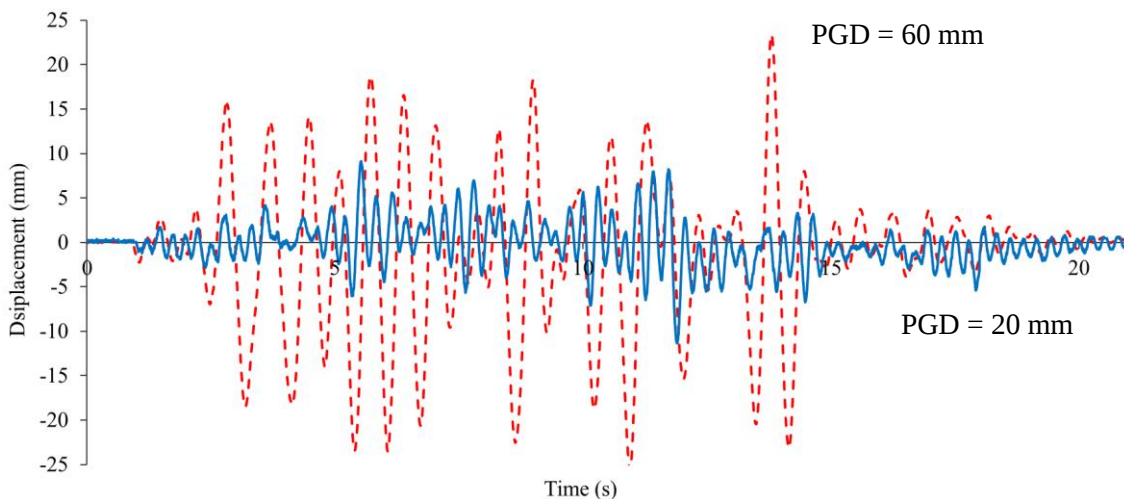


Figure 5: Influence of PGD on the bridge displacement with FRP-CFRC composite pier

Figure 4 shows three of the simulated ground motions with similar peak ground displacements (PGD). In order not to damage the bridge pier in the first test, the first tests were performed with a PGD of 20 mm. In the following experiments gradually increased PGDs were considered. Figure 5 shows the displacement time history of the bridge deck. While the pier behaves linearly, a clearly higher frequency of the response can be seen (solid line). The dashed line shows not only much larger response due to a higher PGD of 60 mm, the elongation of the response period is also visible. In all experiments the specimens did not show any damage to the outer FRP layers. A longer period of the response can be caused by micro slippages at the interface between the inner FRP layer and the CFRC core.

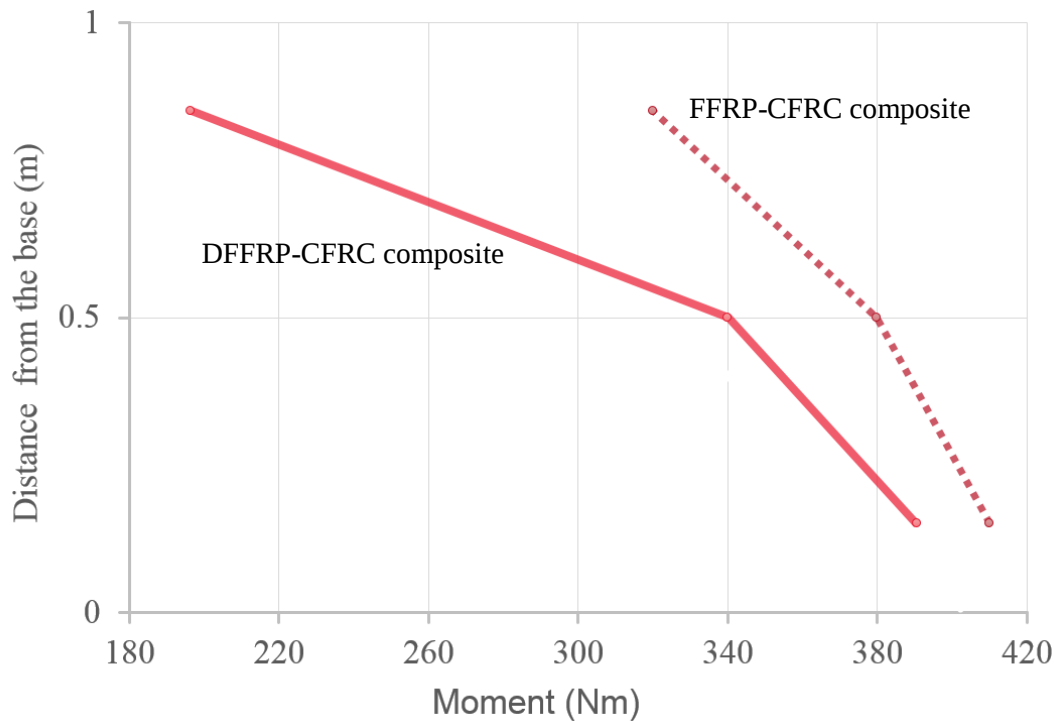


Figure 6: Influence of DFRP on the bending moment development due to a ground motion with the PGD of 20 mm

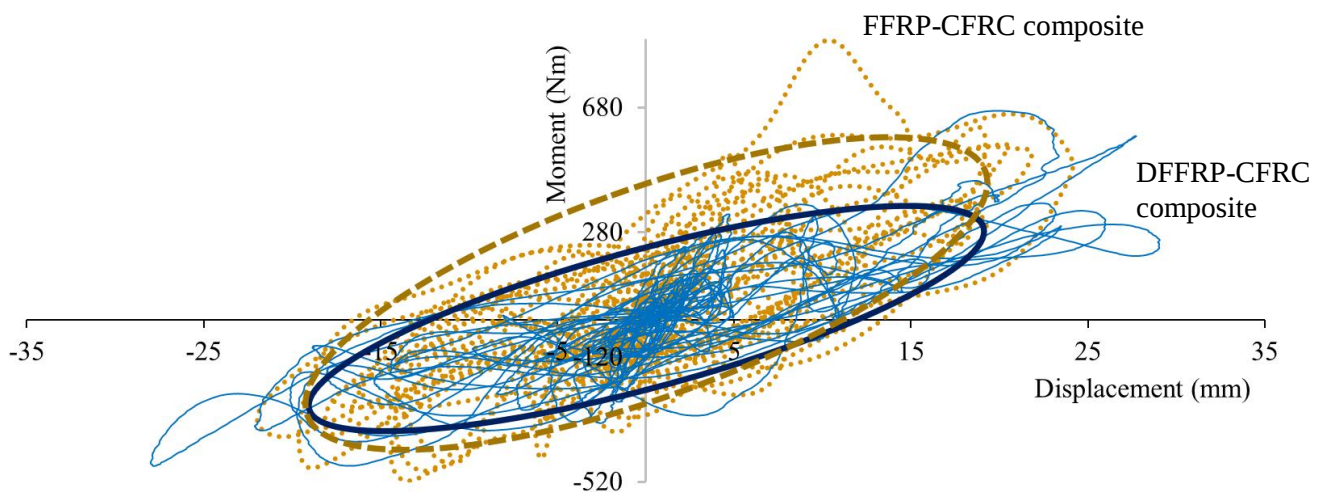


Figure 7: Effect of DFRP on the energy dissipation capability of the composite pier under a ground motion with the PGD of 80 mm

Figure 6 displays the influence of a double-tube confinement on the development of bending moment with the height of the bridge pier due to a ground excitation with a PGD of 20 mm. The usage of double tubes (solid line) clearly can significantly improve the behaviour of the bridge structure, even though less concrete was used. To reveal the performance under a much higher loading a PGD of 80 mm was considered. Figure 7 shows the relationship between bending moment at the base and the displacement of the bridge deck under the excitation with a PGD of 80 mm. The bold solid and dashed lines indicate roughly the energy dissipation while responding to the loading. In the case considered the bridge pier with a single-tube confinement dissipates more energy.

3 CONCLUSIONS

To contribute to an eco-friendly structures natural fibres, i.e. flax and coconut fibres, were used. Flax fibre reinforced polymer (FFRP) was used as inner and outer confinement of the coconut fibre reinforced concrete (CFRC) core. The composite was used as a pier of a simple bridge. Shake table experiments were performed to evaluate the bridge pier performance. Two pier configurations were considered, i.e. bridge pier with single and double confinements.

The results reveal:

1. An introduction of an inner confinement can significantly improve the seismic performance of the bridge due to less structural mass while the structure still has a similar strength.
2. In all cases considered no damage to the outer FFRP layer can be observed. The elongation of the period of the response can be caused by a partial loss of interface bond between FFRP surface and the adjacent CFRC core.
3. In the case presented a bridge pier with a single-tube confinement dissipated more vibration energy.

4 ACKNOWLEDGMENTS

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