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SEISMIC BEHAVIOUR OF BRIDGE STRUCTURES MADE OF NATURAL FIBRE REINFORCED POLYMER-CONCRETE COMPOSITE

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Abstract. *In contrast to current conventional construction materials, i.e. steel or steel reinforced concrete, natural fibre reinforced polymer-concrete composite is environmentally friendly. In addition to the reduction of structural mass and thus the inertia forces activated in the structure during an earthquake loading, the most significant advantage is the avoidance of the long-term effect of corrosion on the integrity of the structures. In this paper a preliminary result of a simple bridge pier, made of flax fibre reinforced polymer and coconut fibre reinforced concrete, under earthquake loadings is discussed. The ground motions are simulated stochastically based on Japanese design spectrum for a hard soil condition. Shake table experiments are performed. The consequence of double tube confinement of the coconut fibre reinforced concrete core for the responses of the structure is presented.*

1 INTRODUCTION

Bridge structures made of conventional construction materials, steel and concrete with steel reinforcement, especially in coastal regions deteriorate with the time due to corrosion of steel. The usage of non-corrosive materials, e.g. glass or carbon fibre reinforced polymer (G/CFRP), in civil infrastructure is very limited because of the high initial cost. The other factors that impede the usage of G/CFRP are the unknown long-term performance, risk of fire and non-yielding behaviour of the materials. The reinforcement can take many forms, e.g. of glass fibre reinforced polymer rods [1]. Even though these materials have the potential to replace steel as reinforcing material due to their significant properties, e.g. high strength, its usage is mainly for retrofitting earthquake prone structures [2].

To overcome the high cost natural materials can be utilized without compromising the strength of the composite material and thus can lead to construction materials for structures in the future [3]. Raftery and Kelly [4] proposed the usage of basalt fibre reinforced polymer for strengthening timber structures. Cheah [5] investigated the usage of flax fibre in traditional earth houses. Ali et al. [6-8] proposed the usage of coconut fibre reinforced concrete for low-cost earthquake-resistant low-damage structures, especially in earthquake regions in developing countries. The low-damage structures are achieved by letting each structural member to move relative to each other. Hence, each structural member performs rigid body movements whenever the earthquake loading exceeds a threshold. To ensure the re-centering the structural members have interlocking keys. In addition to re-centering after an uplift movement the keys have the function to transfer eventual shear forces.

The natural materials considered in this study are flax and coconut fibres. The pre-fabricated flax fibre reinforced polymer (FFRP) tubes serve as lightweight permanent form-works for fresh coconut fibre reinforced concrete (CFRC) core. The pre-fabrication of the tubes accelerate the construction process [9]. Under axial loading the tubes provide confinement and thus enhance the compressive strength of the FFRP-CFRC composite. As flexural structural members, in addition to the standard function of an internal resistance in the compressive zone the concrete core provides an internal support of the outer FFRP tube and enhances the buckling resistance of the whole composite. The randomly distributed coconut fibres enable a distribution of small cracks over a large region and thus contribute to the ductility of the FFRP-CFRC composite and enhance the material damping [10-14]. As anticipated the behaviour of this environmentally-friendly FFRP-CFRC composite is strongly determined by the bond between FFRP and CFRC [15].

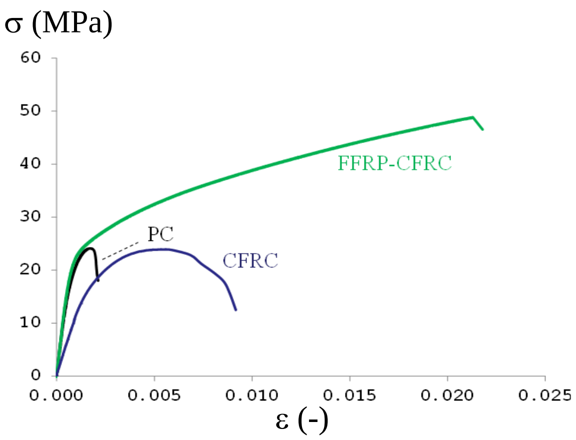

Figure 1. Effect of natural fibre on the stress-strain relationship of the composite

In contrast to current conventional seismic design of steel reinforced concrete structures the use of natural fibre reinforced polymer instead of steel reinforcement will reduce the total structural mass and also avoid the long-term corrosion effect of steel. Because of the smaller mass and the corrosion-free materials the new composite structures can withstand more loads and require less running maintenance cost. The research focuses on engineering design of new composite structural members and assembled structures. FFRP and CFRC will be used to carry the activated tensile and compressive stresses, respectively.

Figure 1 shows the relationship between compressive stress σ and the axial strain ε. In the case considered the compressive strength of the concrete core is about 22 MPa. The inclusion of coconut fibre does not increase the compressive strength. However, the ductility of the coir-concrete composite does increase significantly. A confinement of the coir reinforced concrete core due to the outer FFRP tube leads to an increase of the compressive strength to more than double of that of plain concrete (PC). It also enhances the ductility of the FFRP-CRFC composite significantly [11]. The ductility of the composites is strongly determined by the bond strength between natural fibres and surrounding matrix and the bond strength at the interface between FFRP and CRFC [7, 15].

In this paper a simple bridge pier is investigated. The earthquake loading is simulated by a shake table. The impact of the earthquake loading can be further reduced by having even less mass. Instead of a solid CFRC core double FFRP tubes can be used. The inner FFRP tube serves as inner permanent formwork. The consequence of the earthquake magnitude and the additional inner tube for the seismic behaviour of the FFRP-CFRC bridge pier is presented.

2 FFRP-CFRC BRIDGE PIER UNDER AN EARTHQUAKE LOADING

Figure 2 shows a scale model of the bridge pier with a CFRC core diameter of 10 cm. The inner and outer FFRP tubes have the thickness of 3.05 mm and 5.3 mm, respectively. The inner diameter of the inner tube is 2.5 cm.

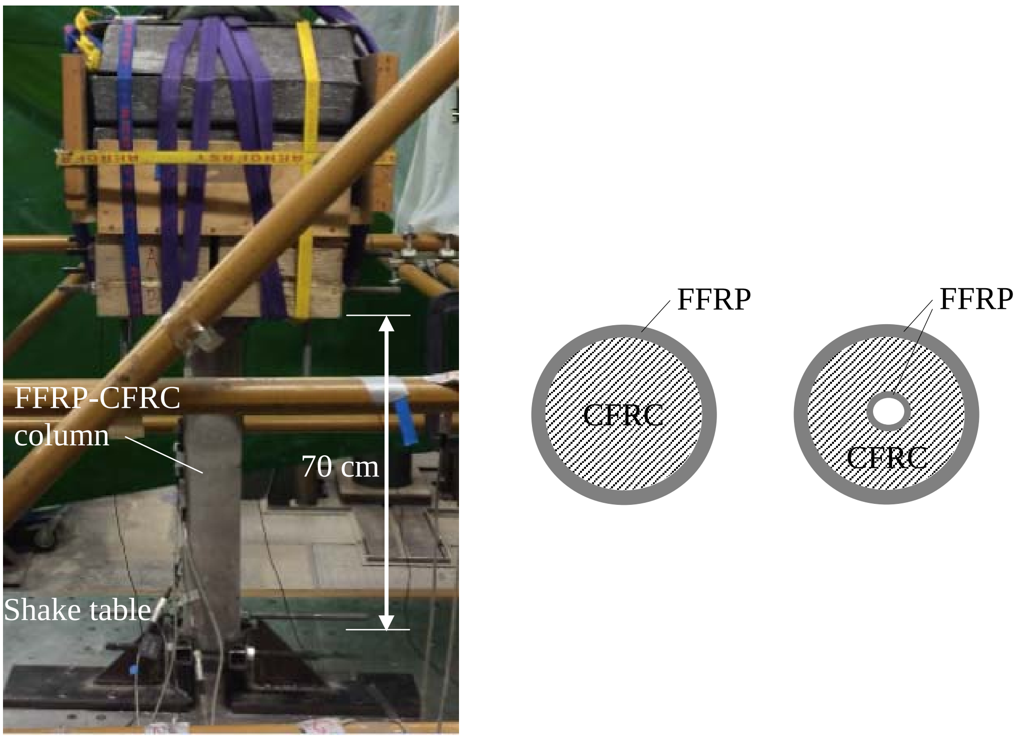

Figure 2. Single and double FFRP tubes confined CFRC composite bridge pier

The bridge girder is simplified as a single degree of freedom. Two different pier systems, i.e. CFRC core confined by single FFRP tube and by double FFRP tubes. The top mass is selected so that the fixed base fundamental frequency of both systems is about 2.929 Hz. The system period is then 0.34 s. Figure 3 shows the response spectrum of the two stochastically simulated ground motions based on Japanese design spectrum for a hard soil condition (bold dashed line) [16]. It can be anticipated from the spectra that the bridge pier structure will experience the strongest excitation. The simulated ground motions have a peak ground displacement (PGD) of 30.82 cm.

In order not to damage the structure immediately, the experiments were performed with gradually increasing PGD. With increasing PGD it can be expected that the fundamental frequency of the structure will reduced, i.e. with increasing fundamental period the structure will experience roughly the same excitation as can be estimated from the response spectra in Figure 3. The first experiment was performed with the ground motion of PGD = 20 mm, i.e. only 6.5% of the original excitation. The subsequent experiments on the same structure were performed with an increasing PGD up to 90 mm, i.e. 29.2% of the original excitation. Following each subsequent experiment the fundamental frequency is determined from the free vibration of a snap-back test. Following the 90 mm PGD experiment the system has a fundamental frequency of 2.44 Hz or a fundamental period of 0.41 s.

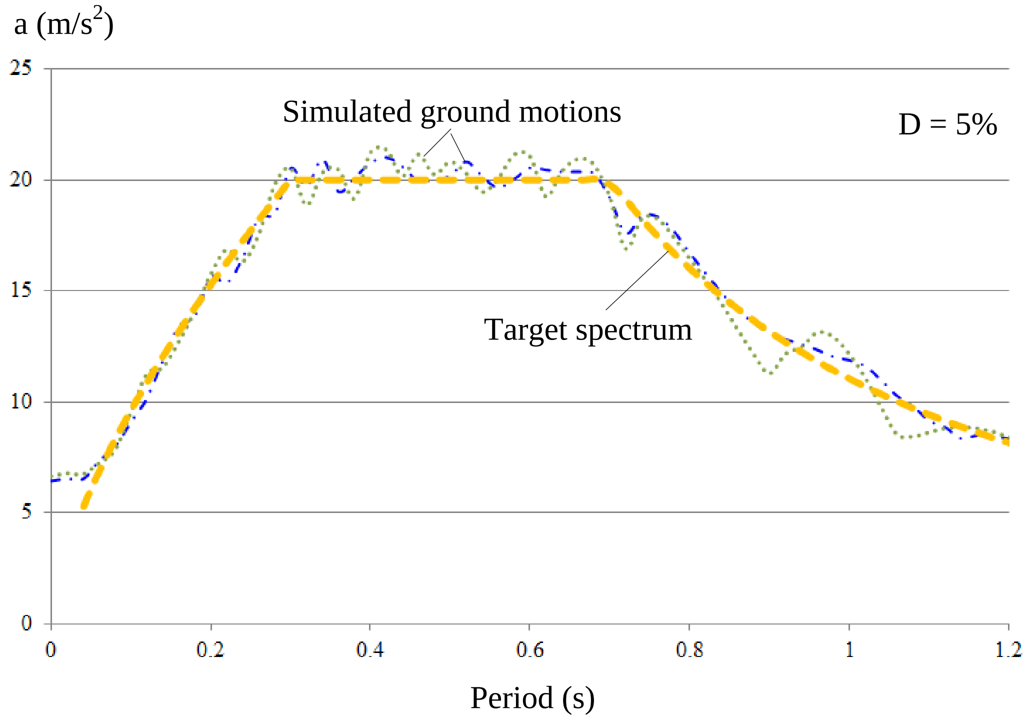

Figure 3: Simulated ground excitation and Japanese design target spectrum for a hard soil condition.

Figure 4 shows a comparison between the displacements at the top of the same bridge pier due to the same ground motion with an assumption of undamaged (linear behaviour) and damaged bridge pier. The bridge pier has only one FFRP tube confinement. The linear response is obtained from the experiment with a very small PGD of 20 mm while the nonlinear response is achieved with PGD of 90 mm. In order to compare the two results, the linear response is multiplied by a factor of 4.5. The response of the stiffer linear system can be clearly seen in a shorter period (solid line) in comparison with the nonlinear response (dashed line). In the case considered the stiffer linear system responded with smaller amplitudes. The damage to the bridge pier could take place at the interface between FFRP tube and CFRC core. Previous preliminary study with much stronger ground excitation resulted in no damage to the FFRP tube [17]. In the case considered, also no damage to the FFRP tube was observed.

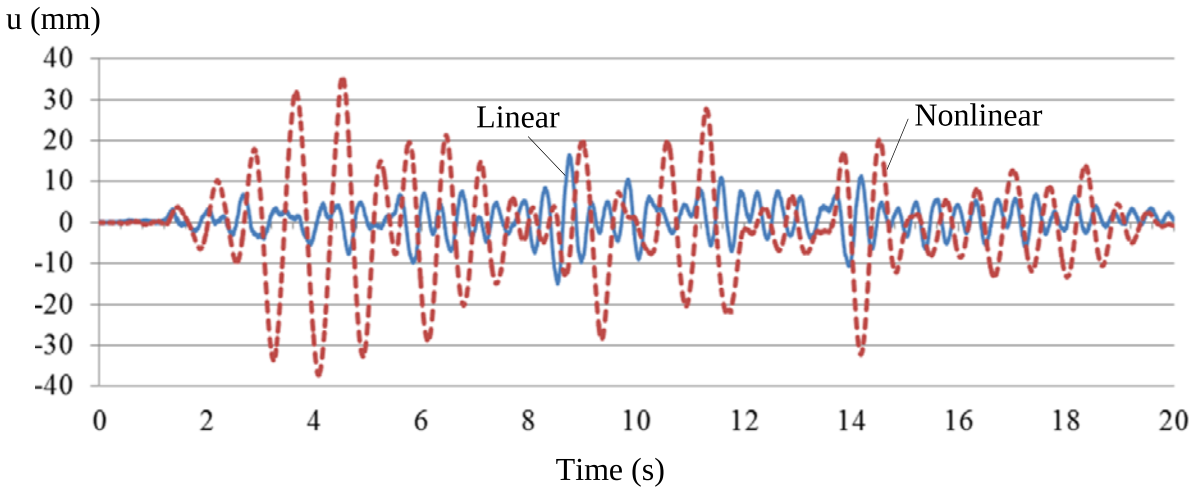

Figure 4. Displacement at the pier top

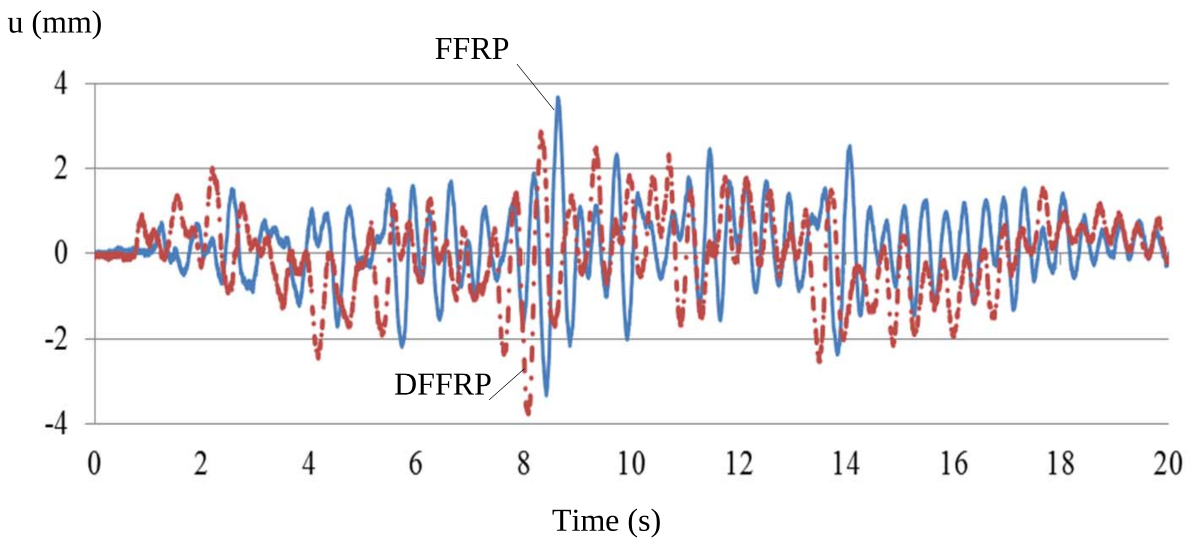

Figure 5. Influence of double shells on the top pier displacement

Figure 5 shows the influence of double FFRP tubes on the linear response of the top displacement of the bridge pier. The ground motion considered has the PGD of 20 mm. The maximum response of the bridge pier with one and double FFRP tubes is 3.68 mm and 3.77 mm, respectively. Despite less materials are used in the case of double FFRP tube pier, both maximum displacements are almost the same.

3 CONCLUSIONS

New construction materials consist of flax fibre reinforced polymer (FFRP) and coconut fibre reinforced concrete (CFRC) composite is investigated for possible usage in earthquake-resistant structures. A simple bridge pier is constructed. Single and double FFRP tubes were used as permanent formworks for CFRC core. The ground motions are simulated based on Japanese design spectrum for a hard soil condition.

The results show:

- The bond at the interface between FFRP tube and CFRC core is critical for the seismic performance of the bridge pier.
- The usage of double tubes can have significant advantage, since less mass is considered.
- Linear bridge piers with single and double FFRP tubes perform in similar manner.

Further investigations are necessary to fully understand the seismic performance of structures using these new construction materials.

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