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# Investigation of the behaviour of flexible and ductile ECC link slab reinforced with FRP

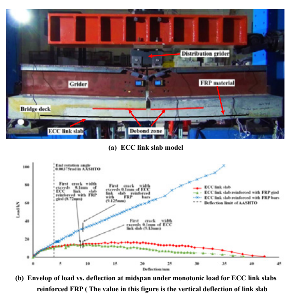
Y. Zheng *, L.F. Zhang, L.P. Xia

*Department of Civil Engineering, Dongguan University of Technology, Dongguan, Guangdong Province 523808, PR China*

## HIGHLIGHTS

- A flexible and durable link slab is proposed by using FRP reinforced ECC components.
- Mechanical properties of ECC materials with different composites are reported.
- A suitable ECC material is developed by the admixture of different binders.
- The strain compatibility of the proposed link slab at high strain levels is obtained.
- Using FRP bars in ECC link slab results in larger tension stiffening behaviour.
- The localisation of stress in ECC link slab is avoided by using FRP reinforcement.

## GRAPHICAL ABSTRACT




(a) ECC link slab model

(b) Envelop of load vs. deflection at midspan under monotonic load for ECC link slabs reinforced FRP ( The value in this figure is the vertical deflection of link slab corresponding to 0.1mm crack width)

## ARTICLE INFO

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## ABSTRACT

In this paper, a flexible and ductile link slab used to eliminate the expansion joints in the bridge deck system was proposed and investigated through a comprehensive study, including material design and structural experimental investigation. This novel link slab utilises highly ductile Engineered Cementitious Composites (ECC) and non-corrosive Fibre Reinforced Polymer (FRP) reinforcement. At the first stage of this study, an experimental investigation was carried out to evaluate the influence of compositions on the mechanical behaviour of ECC materials, particularly emphasis on flexural behaviour. The test and analytical results established the feasibility of attaining a type of ECC composite material with high deflection capacity, multi-cracking behaviour and small crack width (0.05 mm), which is suitable for the application of link slab in bridge deck system. Thereafter, the proposed ECC material combined with FRP reinforcement was adopted to conduct link slab specimens in full scale bridge decks. All the test specimens were tested under monotonic repeated loading. The performance was described based on the load-deflection/moment-rotation response, strain development, cracking and energy absorption. The influence of FRP reinforcing materials on the link slab structural performance was presented and discussed. The significant enhancement of deflection capacity and crack-width control in ECC link slab reinforced with FRP bars suggests that the use of ductile ECC and non-corrosive FRP reinforcement can be effective in extending the service life of joint-free bridge deck system.



* Corresponding author.
*E-mail address:* zhengy@dgut.edu.cn (Y. Zheng).

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## 1. Introduction

A majority of high-way bridges are composed of multiple-span steel or prestressed concrete girder simply supported at piers. The girders support cast-in-place or precast concrete decks. In this deck system, mechanical expansion joints are typically designed and employed to facilitate both rotations and lateral movements between simply supported adjacent bridge spans due to thermal expansions, shrinkage, creep and girder deflections due to service loads. In addition, those expansion joints are designed to protect the substructure from exposure to corroding substances by provided watertight seal between the adjacent bridge decks over piers and abutments. However, it is well reported that the mechanical joints are expensive to install and maintain. Deterioration of joint functionality due to debris accumulation can lead to severe damage in the bridge deck and substructure. The durability of girder ends, bearing and supporting structures can be compromised by water leakage and flow of deicing chemicals through the deteriorated joints [1,2]. As a consequence, mechanical expansion joints have been found to have a negative influence on all stages during the service life of bridge structures [3].

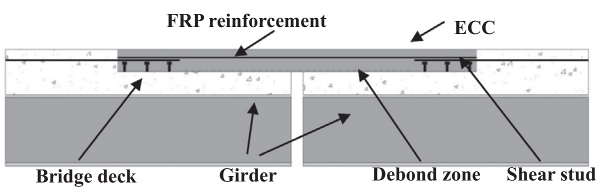


**Fig. 1.** Link slab of ECC reinforced with FRP.

A possible approach to solve the durability problem and reduce the high cost of maintenance in expansion joints is the elimination of mechanical deck joints in multi-span bridges. As a result, continuous and jointless bridge decks have been suggested and proposed [4]. One type of jointless bridge design proposed by a number of researchers is the application of link slab elements within bridge decks [5], which is used to connect the two adjacent simple-span girders. Caner and Zia developed the experimental investigations of the structural behaviour of jointless decks and proposed design procedures for the link slab [6]. These investigations revealed that the link slab subjected to bending under traffic loading rather than axial elongation. This concept and design method proposed by Caner and Zia have been adapted in bridge and highway since they were firstly introduced. Thereafter, further research reported in the literatures suggested the use of ductile concrete materials know as engineered cementitious composites (ECC) reinforced with standard steel reinforcement [7–9]. The ECC link slab concept was developed based on the high ductility and tight crack-width in ECC materials for structural application, which was investigated and reported in the literatures [10,11]. Subsequently, a field demonstration was carried out by Lepech and Li in the Michigan Department of Transportation [12]. In the literature by Lepech and Li [12], the ECC link slab was designed to resist an expected

**Table 1**
Mix proportions.

| Test specimens | Binder | | | | | W/B ratio | S/B ratio | Superplasticiser/% | PVA/% | Antifoaming agent/% |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | Fly ash | Limestone powder | Metakaolin | Micro-Silica fume | | | | | |
| Basic | 0.5 | 0.5 | – | – | – | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| PVA-2.3 | 0.5 | 0.5 | – | – | – | 0.257 | 0.364 | 0.10 | 2.3 | 0.14 |
| PVA-2.6 | 0.5 | 0.5 | – | – | – | 0.257 | 0.364 | 0.10 | 2.6 | 0.14 |
| S/P-0.324 | 0.5 | 0.5 | – | – | – | 0.257 | 0.324 | 0.10 | 2.0 | 0.14 |
| S/P-0.403 | 0.5 | 0.5 | – | – | – | 0.257 | 0.403 | 0.10 | 2.0 | 0.14 |
| FA-0.6 | 0.4 | 0.6 | – | – | – | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| FA-0.7 | 0.3 | 0.7 | – | – | – | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| LS-0.05 | 0.5 | 0.45 | 0.05 | – | – | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| LS-0.1 | 0.5 | 0.4 | 0.1 | – | – | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si-0.05 | 0.5 | 0.45 | – | – | 0.05 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si-0.1 | 0.5 | 0.4 | – | – | 0.1 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si-0.02 | 0.48 | 0.5 | – | – | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si/LS-0.02/0.08 | 0.4 | 0.5 | 0.08 | – | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si/M-0.02/0.04 | 0.44 | 0.5 | – | 0.04 | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si/M-0.02/0.08 | 0.4 | 0.5 | – | 0.08 | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Sup-0.12 | 0.4 | 0.5 | – | 0.08 | 0.02 | 0.257 | 0.364 | 0.12 | 2.0 | 0.14 |
| Sup-0.14 | 0.4 | 0.5 | – | 0.08 | 0.02 | 0.257 | 0.364 | 0.14 | 2.0 | 0.14 |
| Si/LS/M-0.02/0.04/0.04 | 0.4 | 0.5 | 0.04 | 0.04 | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.14 |
| Si/LS/M/X-0.02/0.04/0.04/0 | 0.4 | 0.5 | 0.04 | 0.04 | 0.02 | 0.257 | 0.364 | 0.10 | 2.0 | 0.00 |

**Table 2**
Basic performance of antifoaming agent.

| Types | Appearance | Content of active matter | PH Value | Compatibility |
|---|---|---|---|---|
| Mineral oil | Emulsion | 19% | 7–8 | Mild floating oil |

**Table 3**
Material properties of PVA fiber.

| Types | Length/mm | Diameter/um | Tensile strength/MPa | Elastic modulus/Gpa |
|---|---|---|---|---|
| PVA fibre | 12 | 39 | 1600 | 47.29 |