FRPRCS-14, Belfast - June 2019

STRUCTURAL STRENGTHENING OF CONCRETE FOOTINGS USING FRP AND EXTERNAL PRESTRESSING

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Abstract

For bridge footings with insufficient structural capacities, size enlargement is a commonly used retrofit method, and the connection between the existing and the new concrete is generally achieved by dowel-splicing. In this research, two new strengthening systems utilizing CFRP or external prestressing are proposed. The composite action at the old/new concrete interface is achieved by external CFRP or external prestressing forces. Compared with dowel-splicing connection, the new connection is more practical and efficient. As punching shear is the dominating mode of failure in the bridge footing, finite element models were built using Abaqus CAE to investigate the effectiveness of the proposed systems on improving the footings' punching shear capacity. This paper will present the results of strengthened square footings with external prestressing or CFRP composite systems.

Keywords: Bridge Footing, CFRP, External Prestressing, Punching Shear, Finite Element Model

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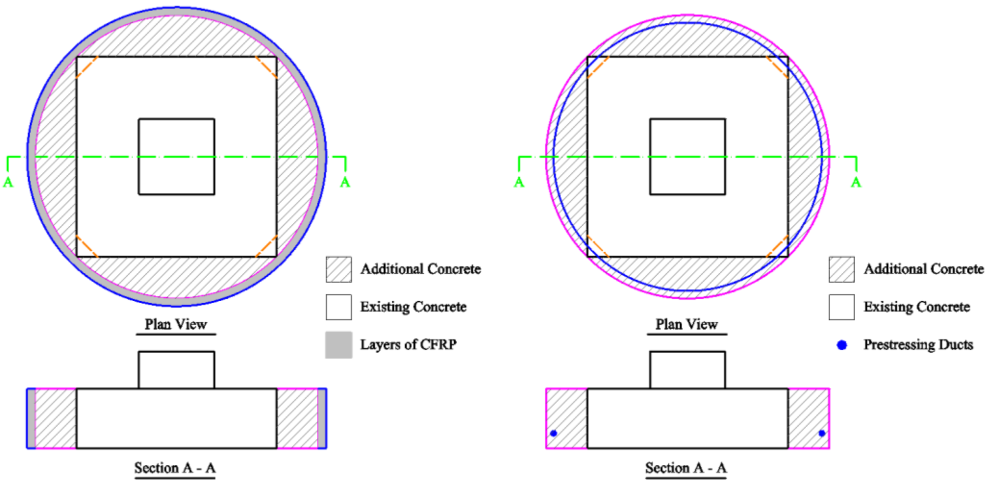
Introduction

Bridge footing plays an essential role in transferring the load from superstructure to the soil underneath. It may require strengthening due to structural deficiencies, such as insufficient shear or bending capacities. However, very limited tests have been conducted to verify these methods. FHWA [1] proposed different retrofit strategies for spread footings: The overturning capacity can be enhanced by increasing the footing size and addition of piles. The shear capacity can be improved by increasing the footing depth, addition of horizontal prestressing bars, and placement of additional vertical bars in drilled holes to act as additional shear reinforcements. The bending capacity can be enhanced by adding a reinforced concrete overlay or by installation of horizontal prestressing. In Saiidi's research [2], the depth of footing was increased with a reinforced concrete overlay, and the plan dimensions were also enlarged. Dowels were applied at the contact surface to connect the additional concrete with the original footing.

Proposed Strengthening Systems

In traditional footing strengthening methods, dowel connections are generally used at the interfaces between new and original concrete. Although effective, it is troublesome to drill the holes and install the dowels. To address this problem, in this paper, two new strengthening systems utilizing CFRP (CFRP strengthening system) (Figure 1(a)) or external prestressing (prestressing strengthening system) (Figure 1(b)) are proposed. In these two methods, the connections at the contact surface are achieved by the composite action, provided by either CFRP wrappings or circular prestressing strands.



(a) (b)

Figure 1: (a) CFRP strengthening system; (b) Prestressing strengthening system

Finite Element Model

In this paper, the investigations of the efficiency of two proposed systems were carried out using the finite element software Abaqus, adopting explicit analysis. All footings were square spread footings, having two different sizes: 3m and 5m. The shear span to depth ratio was 1.5, and the regular reinforcement ratio was 0.75%. A total of 10 models were investigated: two original footings, two footings retrofitted with 4 layers of CFRP, two footings retrofitted with 8 layers of CFRP, two footings retrofitted with 10 strands, and two footings retrofitted with 30 strands. For footings retrofitted with 4 layers of CFRP, the full depth was wrapped. While for footings retrofitted with 8 layers of CFRP, 4 layers were installed at full depth, and the other 4 layers were only installed at the bottom half of the depth (tension side).

Material properties

For concrete in compression, the stress-strain relationship proposed by Yang [3] is adopted. Under uniaxial tension, since concrete experiences cracking, its behaviour was simulated by a stress-crack displacement relationship, suggested by Hordijk [4]. The properties of CFRP are the same as the ones used by Obaidat [5].

Interaction contact and boundary condition

In every model, reinforcements are considered fully bonded with concrete. In order to minimize the friction between the steel strands and the duct, pre-greased strands in plastic sheathing will be used. Therefore, in the finite element models, the contact between concrete and prestressing strands is simulated as frictionless. Since bond failure is not considered, the CFRP is assumed to be fully bonded with concrete. All nodes on the top surface of the column are constrained in all degrees of freedom.

Results and discussion

All models failed by punching shear, including the two original footings. During analysis, the reinforcement never reaches its yield stress. Specified by ACI, the punching shear shall be resisted by the critical sections which are located a distance *d/2* from the edge of the column. Based on this, the punching shear capacity of each model can be calculated using Equation (1). $A_{Footing}$ is the total area of original footing or retrofitted footing, and $A_{Critical}$ is the area surrounded by the critical sections.

$$V_n = P_{Fail} \cdot \frac{A_{Footing} - A_{Critical}}{A_{Footing}} \tag{1}$$

Table 1: Punching shear capacity of each model (Unit: *kN*)

Footing Size	Original Footing	CFRP Strengthening System		Prestressing Strengthening System	
		4 Layers	8 Layers	10 Strands	30 Strands
3m	9170	11434 (25%)	12039 (31%)	14377 (57%)	23692 (158%)
5m	24864	28201 (13%)	30207 (21%)	33368 (34%)	52142 (110%)

CFRP strengthening system

The load-deflection curves of the models retrofitted with CFRP are shown in Figure 2, and the punching shear capacity of each model is calculated (Table 1). The result indicates the CFRP strengthening system enhanced footing's punching shear capacity. Using the same retrofit materials, the improvement on the footing with smaller size is larger. When more CFRP layers are applied, the further improvement is not significant.

Prestressing strengthening system

The load-deflection curves of the models retrofitted with prestressing are shown in Figure 3, and the punching shear capacity of each model is calculated (Table 1). The result indicates the prestressing strengthening system enhanced footing's punching shear capacity. Using the same retrofit materials, the improvement on the footing with smaller size is larger. When more prestressing strands are applied, the further improvement is significant.

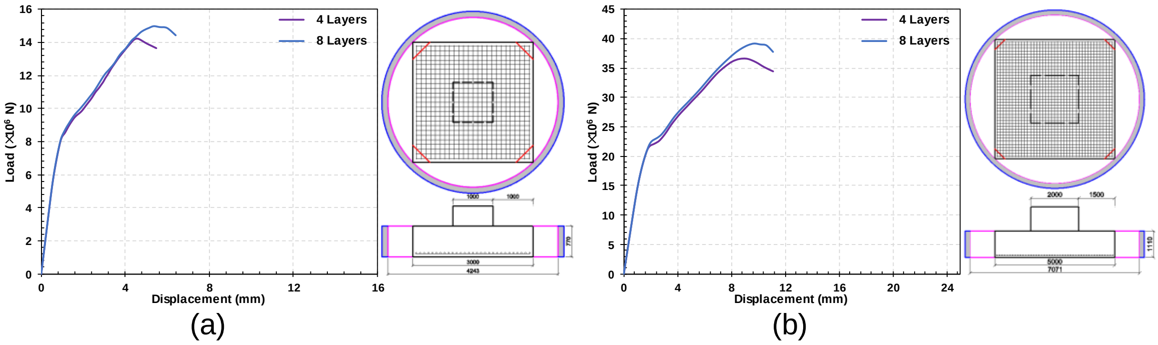


Figure 2 The load-deflection curves of footings retrofitted with CFRP: (a) 3m (b) 5m

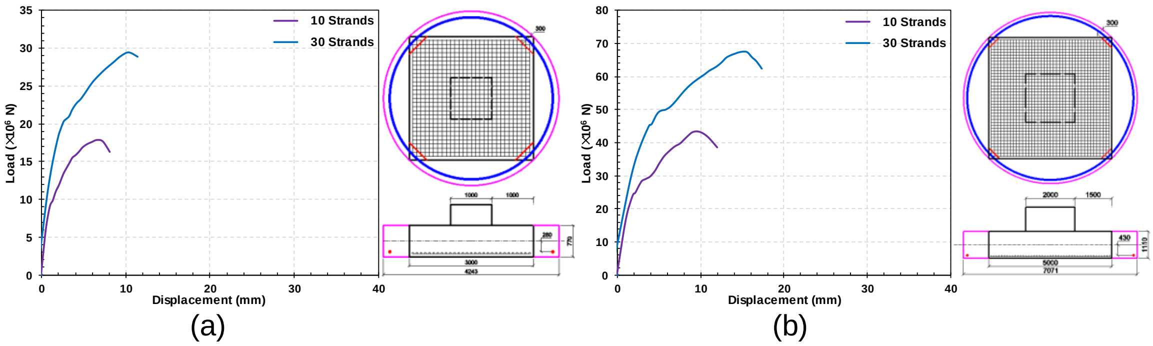


Figure 3 The load-deflection curves of footings retrofitted with prestressing: (a) 3m (b) 5m

Conclusions

Based on this research, the following conclusions were drawn: (1) Both of the proposed strengthening systems obviously enhanced the spread footing's punching shear capacity, (2) For the CFRP strengthening system, when the amount of CFRP applied was adequate to overcome the separation at the contact surface, the CFRP system slightly improved the punching shear capacity, (3) For the prestressing strengthening system, larger improvement was achieved as it was an active system, and (4) Prestressed CFRP system should be investigated, as it will probably show significant improvement.

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