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Loop connection with fibre-reinforced precast concrete components in tension

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ABSTRACT

Overlapping of reinforcement bars or loops is often used to connect precast members. The precast units have projecting bars, usually with a full 180° hook, which are embedded in situ in concrete after erection. This paper studies a tension joint using direct overlapping loops, evaluating the influence of the addition of steel fibres to the in situ concrete. Other variables studied were the diameter of the loop bend and the presence of transverse reinforcement in the loop. The results indicate the possibility of reducing the joint width between precast elements by using steel fibres. An expression based on strut and tie theory is proposed to calculate the connection's strength, and it provided a good approximation to the experimental results.

1. Introduction

The precast elements are fabricated in series, limiting onsite work to the assembly of elements by lifting equipment. This work stage includes the realisation of connections between these elements so as to guarantee the transfer of actions between them and ensure the structural integrity of the complete structure. To maintain a rapid speed of construction, which is one of the principal advantages of pre-fabrication, simple connections which can be realised within the smallest possible width should be chosen so as to also minimise the material and labour costs involved in this stage.

In the case of connections subject to tensile loads, overlapping with loop-shaped bent bars is a classical way to transfer this load between precast elements [1,2]. However, few studies have been carried out using this type of connection so far [3–8]. One of the advantages of the use of this type of connection is the fact that the loop-shaped anchorages are capable of transferring the stresses between the reinforcement and the concrete over a shorter length than that necessary for straight bars, which allows the connection joint's width to be reduced.

In straight anchorages, the transmission of forces happens via bond stresses. In loop-shaped anchorages, next to bond stresses, radial stresses are also mobilised, which transmit to the concrete, via compression, part of the force to be anchored. Following the FIB manual [9], the radial stresses on the loop lead the inclination of compressed struts between the opposing loops, by means of which the tensile force is transferred from one element to the other (Fig. 1). The diagonal inclination generates a tensile force normal to the loop's plane, which should be resisted by a transverse reinforcement placed inside the loop, at the two ends of the overlapping loops, in order to avoid splitting of the concrete in the loop's plane.

The splitting of the concrete in the loop's plane can also be avoided by the addition to the concrete of steel fibres that will fill the connection. The presence of steel fibres increases ductility and tensile strength and improves the concrete's deformation properties. What should also be considered is the possibility of reducing the anchorage length due to the improvement of the bonding between steel and concrete provided by the addition of the steel fibres to the concrete matrix. For this reason, the use of steel fibres in this type of connection can be advantageous.

2. Research significance

The aim of this research is to study a tension joint formed by the overlapping of reinforcement loops, evaluating the influence of the loop's bending diameter, the presence of transverse reinforcement placed inside the loop, and the presence of steel fibres added to the concrete at the joint. The overlapping of reinforcement loops is

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Nomenclature

A_c	cross-sectional area of concrete core
A_{cn}	transverse section of the strut
A_t	area of transverse reinforcement
b	width of connection (dimension parallel to the load direction)
c	concrete covering perpendicular to the loops
D	diameter of the bend of the loop bar
E_c	mean value of tangent modulus of elasticity of concrete
Es	modulus of elasticity of reinforcement
F_u	ultimate load at connection
F_t	force on transverse reinforcement
FT	flexural toughness of concrete
f_c	mean value of concrete cylinder compressive strength
$f_{ct,sp}$	mean value of concrete splitting tensile strength
$f_{c,dc}$	mean value of concrete cylinder compressive strength obtained from stress–strain curves
$f_{ct,f}$	mean value of concrete flexural tensile strength
f_u	failure strength of reinforcement
f_y	yield strength of reinforcement
G_f	fracture energy of concrete
h, w_t	dimensions
ℓ_e	reinforcement's anchorage length
ℓ_0	overlap length between the loops
N_y	yield load of one leg of the loop bar
r	radius of the bend of the loop bar
s	spacing between overlapping loops
t	thickness of test specimens
TR	toughness ratio of concrete
V_f	fibre volume
α, β, θ	angle; strut inclination
Φ	mechanical ratio of transverse reinforcement
ϕ	diameter of the u-bar
$\sigma_{c,rad}$	radial concrete stress
σ_u	maximum tensile stress at loop reinforcement
ν	effectiveness factor

useful when one wishes to decrease the length of the lapping of bars. This reduction of the overlapping length is especially interesting for the connections between precast elements, resulting in smaller joint widths to be filled with concrete in situ. The overlapping length of reinforcement loops can be decreased even more by the presence of steel fibres in the in situ concrete. Furthermore, the fibres can simplify the execution of the connection due to the reduction of the reinforcement ratio, especially for the reinforcement normal to the loop's plane. There are few works in the literature on this type of connection, although it is widely used [3–8]. There is even less published work about the application of steel fibres in joints with overlapping of reinforcement loops.

3. Experimental programme

The experimental programme consisted of the execution of 24 tensile tests on prismatic models with dimensions of 360 mm × 530 mm × 150 mm, which simulated the connection between precast elements, consisting of the overlapping of two steel bars, 10 mm in diameter with a full 180° hook, which are embedded in concrete. Fig. 2 shows the dimensions of the model that was used in the test and that consisted of three blocks separated by a joint of 15 mm. The central part was representative for the connection and its width was kept constant and equal to 110 mm. The reinforcement's overlap length was set equal to 90 mm, and the distance between the loops' planes was 20 mm (Fig. 3). Previous studies by the authors showed that a loop-shaped reinforcement embedded in concrete with 1% steel fibres, similar to those used in this work, is capable of reaching the steel's yield limit before being pulled out with an anchorage length of only 90 mm. In the case of the use of 2% steel fibres, the anchorage length can be reduced to 50 mm [10]. In this way, the overlap length used in the tested connection, 90 mm, represented approximately half of what would have been recommended by the FIB [9].

Steel bars of 16 mm diameter and bent in the shape of a loop were anchored in the end blocks. The steel bars projected out of the model and were attached to the test device, allowing the application of a tensile force on the connection. The end blocks were conveniently reinforced in order to avoid the failure of these blocks

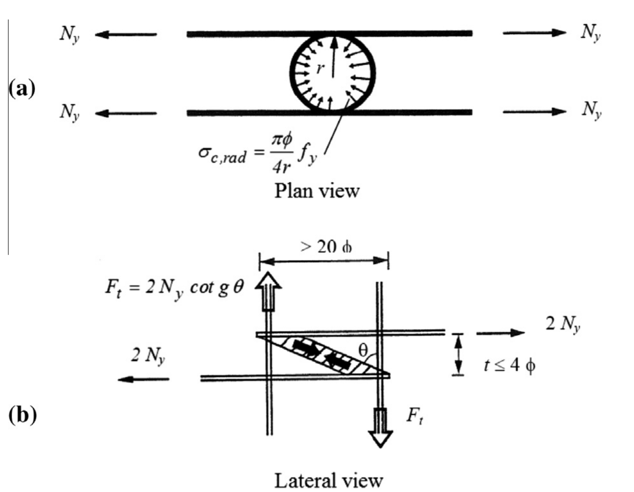

Fig. 1. Transfer of forces at the loop connection: (a) radial stresses, and (b) inclined compressed struts between the overlapped loops [9].

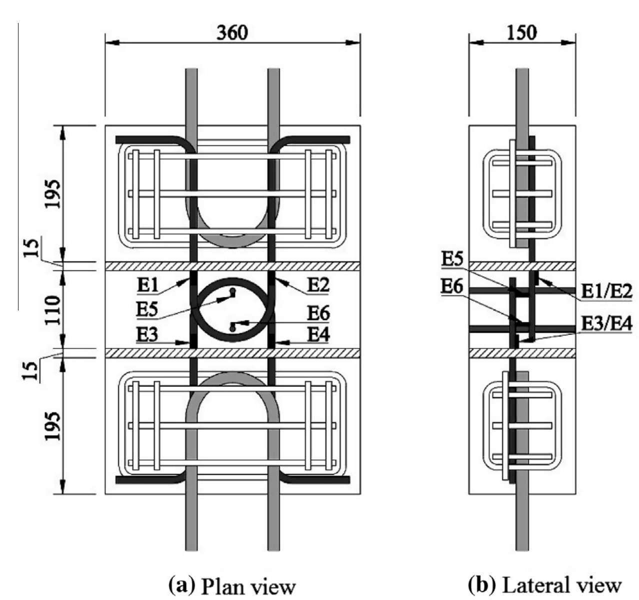

Fig. 2. Dimensions of test specimen, in millimetres, and position of strain gauges at the connection.