- Technical Paper -

PERFORMANCE EVALUATION OF HORIZONTAL LOOP JOINTS IN PRECAST CONCRETE BEAMS USING RBSM

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ABSTRACT

In loop rebar joints, the bond stress of straight parts and bearing pressure of curved parts can be utilized effectively, the joint length can be shortened compared with the conventional lap joint. From such an advantage, adoption of cast in situ loop rebar joints is increasing. The performance evaluation of loop joints has been studied under various specifications and conditions according to various structural conditions of the site, although there are many researches on loop joints arranged vertically to beams or slab members. The horizontal loop joints are also useful depending on construction conditions, however, they have not been investigated sufficiently yet, and the failure mechanism is unknown. In this study, the failure mechanism of the precast beam using the horizontal loop joints and the influence of the reinforcing bars inside the loop were investigated by experiments and numerical simulations.

Keywords: 3D-RBSM, Horizontal Loop Joints, Precast Concrete Beams, Inner reinforcing bars in Loop.

1. INTRODUCTION

In loop rebar joints, the bond stress of straight parts and bearing pressure of curved parts can be utilized effectively, the joint length can be shortened compared with the conventional lap joint. The vertical type loop joints are most commonly used in precast elements arranged vertically to beams or slab members, have been investigated experimentally by many researchers according to various structural conditions of the site. The horizontal loop joints are also useful depending on construction conditions .e.g. in key vertical joints of precast wall panels subjected to shear loading and so on. Due to the limited use of the horizontal type loop joints as shown in Fig. 1, they have not been investigated sufficiently yet and their failure behavior mechanism is unknown.

Several types of reinforced cast in situ joints are being applied in precast concrete members now a days, designed on the specifications by the different design codes .e.g. loop connections (horizontal and vertical types), headed bar connections, lapping of bars with straight ends or with U-hook or with L-hook, and prestressing etc. [1]. Many researchers in the past only conducted experimental investigations on limit analysis, fatigue strength, static strength and failure modes of cast in situ loop connections of precast reinforced elements considered various varying parameters loaded under direct flexure or tension [2] [3] [4] [5] [6].

The current paper mainly deals with the failure mechanism of the precast beams using the horizontal type loop joints and the influence of the inner reinforcing bars inside the loop, investigated by the both experimentally and numerically.

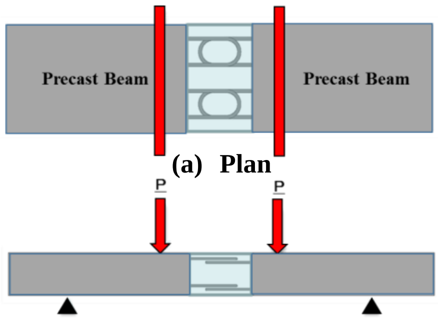

Fig. 1 Horizontal Loop Joint

2. NUMERICAL MODELS OF ELEMENTS

Concrete is modeled using 3D-RBSM based on the formulation of Yamamoto et al. [7]. The discrete type three-dimensional Rigid Body Spring Model (3D-RBSM), consists of aggregation of rigid elements interconnected through normal and tangential springs along their interfaces of the boundaries. The 3D-RBSM has been referred as an effective numerical framework for the evaluation of nonlinear mechanical response of concrete quantitatively such as crack propagation (crack width, spacing and direction of crack), shear transfer behavior of cracked surfaces, and compression failure behaviors including localization and constraint pressure dependence [7] [8]. Cracks initiate and propagate through the interface boundaries and thus is strongly affected by the mesh design. To address this, random

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geometry of rigid particles is generated using Voronoi diagram [8].The models proposed by Yamamoto et al [7] are also applied to the constitutive models of the springs as shown in Fig. 2. The reinforcing bar is modelled as a series of beam elements that can be freely located within the structure, regardless of the concrete mesh design. The reinforcing bar is attached to the concrete particles by means of zero-size link elements. For the reinforcing bar, the bilinear kinematic hardening model is applied. The bond stress–slip relation is provided in the spring parallel to the reinforcement of linked element. The springs in the direction perpendicular to the reinforcing bar axis are linear elastic and are given a sufficiently large stiffness. That is, the relative displacement between the RBSM element and the reinforcing bar is neglected in that direction. For the bond stress–slip relation, a model [8] including softening is based on the assumption that applied cover thickness is relatively small as shown in Fig. 3.

3. SIMULATION OF HORIZONTAL LOOP JOINTS IN PRECAST BEAMS

3.1 TEST OVERVIEW AND NUMERICAL MODELLING

In this study, two different type of test specimens are discussed here, ordinary reinforced concrete beam and precast beams joined through cast in situ horizontal type loop joints, represented by case 1 and case 2, respectively. The case 2 is further subdivided into horizontal type loop joint with inner reinforcing bars (case 2-1) and without inner reinforcing bars (case 2-2) inside the loop as shown in Fig. 4. The geometrical dimensions (all are in mm) of test specimens (case 1 and case 2) are shown in Fig. 5 and in Fig. 6, respectively. The broken lines represent cast in situ reinforced loop joint, the concrete compressive strength of the adjoining precast beams is 56.8 MPa and of cast in situ joint is 43.4 MPa. The yield strength (f_y) of the steel reinforcement (D32, D22 and D16) is 388 MPa. The present study was initiated with the investigation of case 1 and case 2.

After analysis of the case 1 and case 2, the new series (case 3) was considered by increasing the vertical distance between main loops rebar of case 2 by 10 mm (34 mm to 44 mm). Firstly, the main objective of that 10 mm increment between main loops was to provide construction ease at the site during placement and thus reducing the erection time. Secondly, to investigate the change of steel amount of inner reinforcing rebars inside the loop on the structural performance of the cast in situ joint. Therefore, it was important to investigate the effect of above-mentioned parameters on load carrying capacity and deformed behavior of loop joint. In this regard, the complete detail of all the test series has been shown in Table 1. In numerical simulations, the half model was analyzed. An axis of symmetry was considered along the depth of the specimens. The fine mesh, average mesh size around 10 mm (less than the distance between main loops) selected at the joint region considering area of more interest, compared to ends with relatively large mesh size as proposed constitutive model is required to use an element size of about 10 to 30 mm. The numerical models corresponding to all the cases have been shown in Fig. 7. The green surface here represents the symmetrical face of the model.

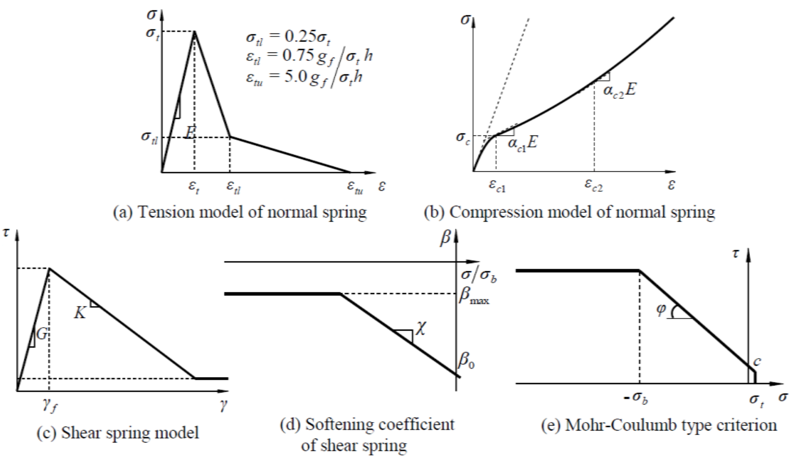


Fig. 2 Constitutive model for concrete (Yamamoto et al., 2008)

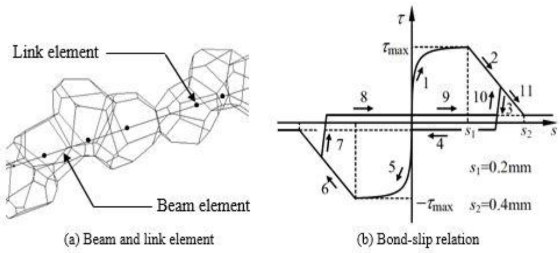
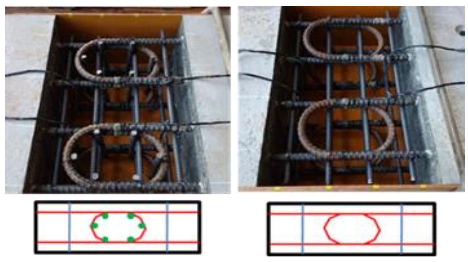


Fig. 3 Reinforcing bar and bond interface models (Yamamoto et al., 2014)



Case 2-1 Case 2-2

Fig. 4 Horizontal loop joint with and without inner reinforcing bars

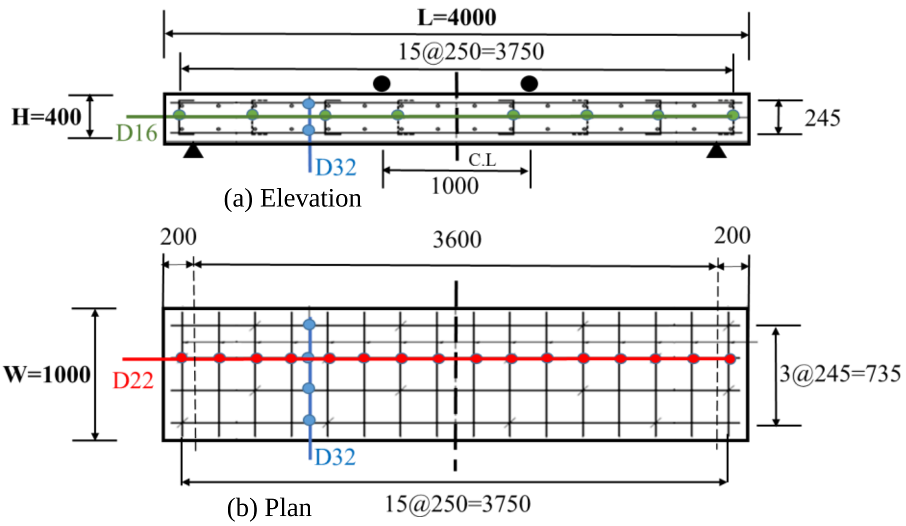


Fig. 5 Ordinary RC beam (Case 1)

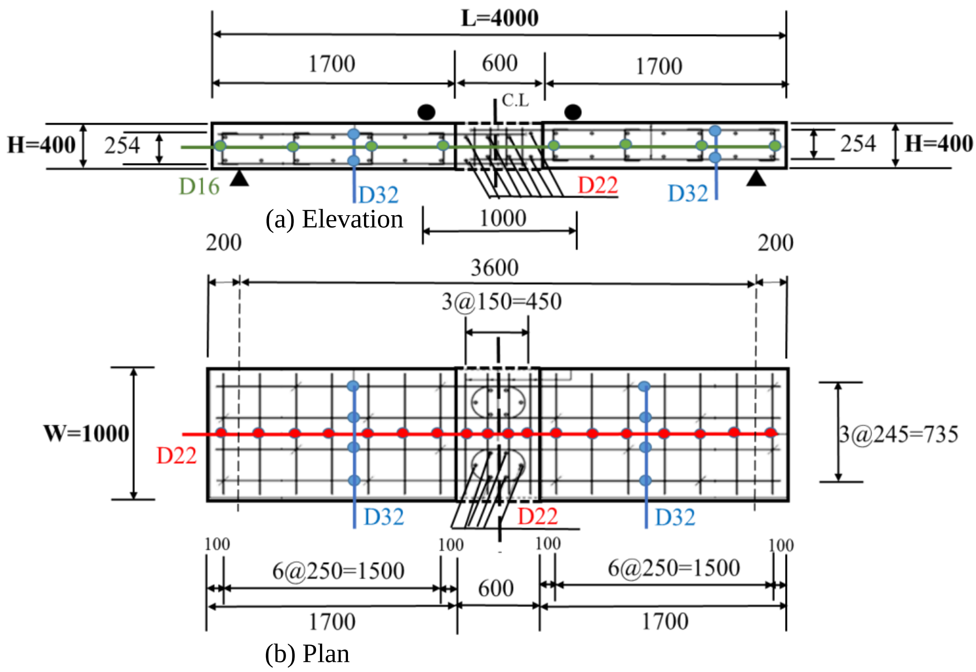
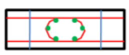
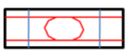
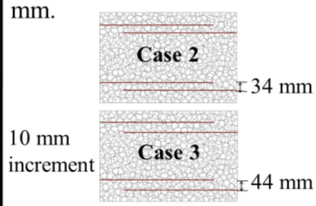
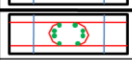
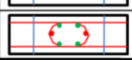


Fig. 6 Precast beams with loop joint (Case 2)

Table 1 Detail of Specimens

Series	Type	Distribution Rebar in Loop	Specimen Detail	Remarks
1	Case 1	Nil		Ordinary RC beam
2	Case 2-1	D22×6		Loop with inner reinforcing bar
	Case 2-2	Nil		Loop without inner reinforcing bar
3	Case 3-0	Nil		Distance between main loops has been increased by 10 mm. 
	Case 3-1	D22×6		
	Case 3-2	D22×2		
	Case 3-3	D32×2		
	Case 3-4	D22×8		
	Case 3-5	D22×4 and D32×2		

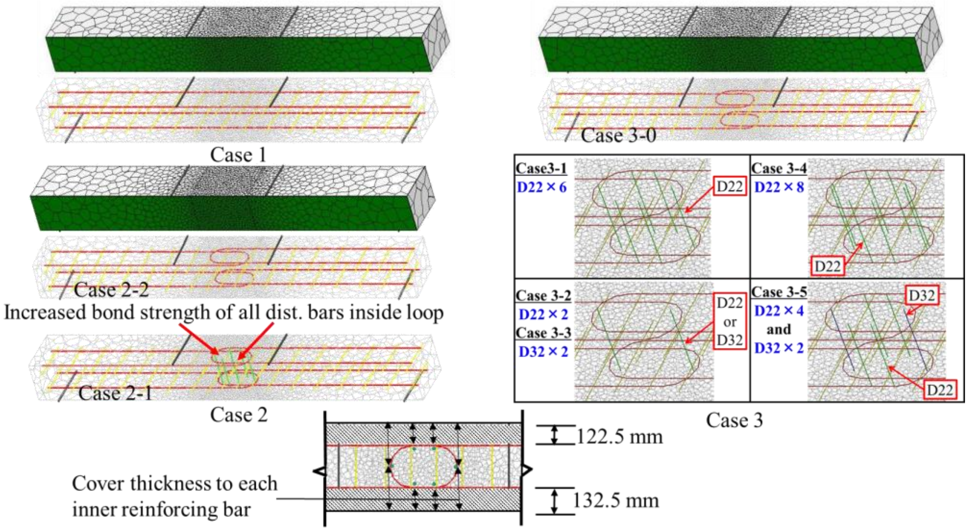


Fig. 7 Numerical models

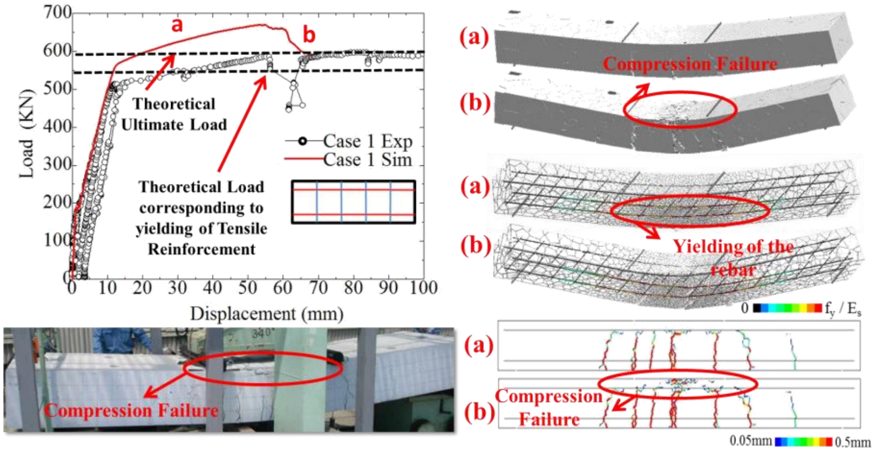


Fig. 8 Experimental and numerical simulation results of ordinary RC beam

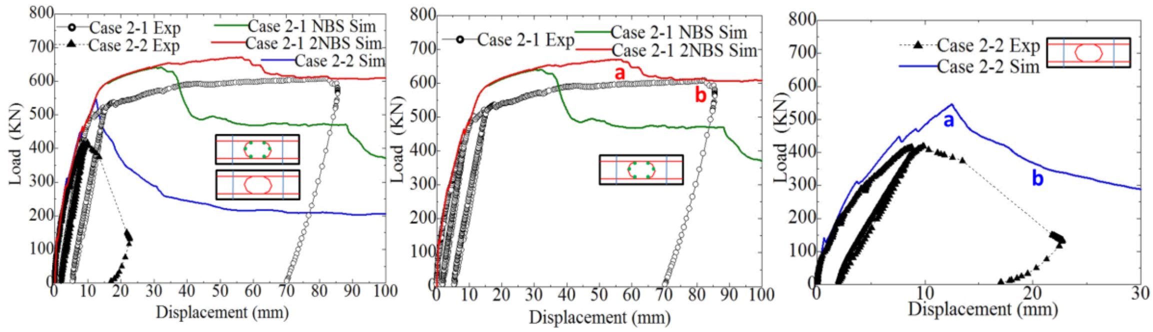


Fig. 9 Load displacement relations Case 2

4. RESULTS AND DISCUSSION

4.1 CASE 1 (Ordinary RC beam)

The normal RC beam was been analyzed by both experimentally and numerically. Fig. 8 shows that the numerical simulation results (load displacement) and deformed behaviors were found to be in good agreement with experimental results. The numerical simulation captured the compression failure effectively same as that of experimentation as shown in Fig. 8.

4.2 CASE 2 (Precast beams with loop joints)

Fig. 9 shows that the proposed model captured the brittle behavior (case 2-2) before the loop reinforcing bar yielded in the absence of the inner reinforcing bar, although the numerical simulation results tend to evaluate larger maximum load compared to the experimental results. The cover thickness of the inner reinforcing bars within the loop as shown in Fig. 7 by arrows, was much larger than that of the main loop reinforcing bars. It is well known that the bond strength depends on the concrete cover thickness (Iizuka et al. 2011) [9]. In the numerical simulation for case 2-1, the

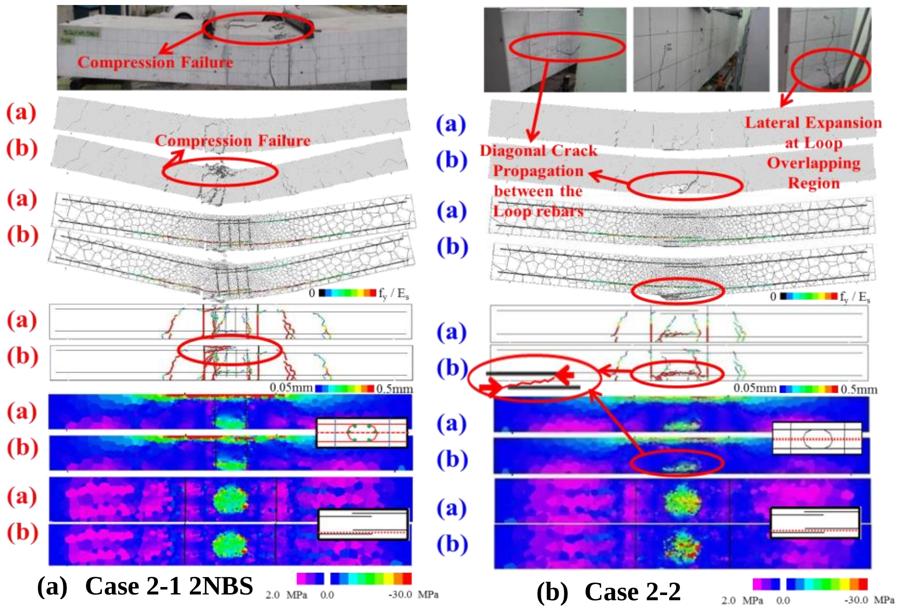


Fig. 10 Experiment photos, deformed shape, cracks pattern and stress distribution of Case 2

bond strength evaluated as being doubled of normal bond strength, (case 2-1 2NBS) was considered only for the inner reinforcing rebars within the loop. The deformation behavior, crack pattern and stress distribution of case 2-1 2NBS and case 2-2 have been shown in Fig. 10, respectively. It can be observed the model captured the cracking patterns, deformation and failure modes, effectively. Furthermore, it can also be investigated from the crack diagram, the failure of the loop joint in the case 2-2 was caused by the propagation of the diagonal crack due to the shear stress between the loop reinforcing bars. Inner reinforcing bars have vital role in suppressing the occurrence and propagation of the diagonal cracks between the rebars of tensile loops. In the case 2-1 with normal bond strength (NBS), although it is not shown here, after the loop reinforcing bars yielded, before the compression failure occurred at the upper side of the beam, the failure mode between the loop reinforcing bars was recognized same as observed in the case 2-2. It can be observed from the results of case 2-1 2NBS in Fig. 9, by increasing the bond strength only for the inner reinforcing bars, the model captured the deformation performance and the ductile failure mode as observed in the experiment of case 2-1.

4.3 CASE 3 (Precast beams with loop joints)

After the numerical validation of case 1 and case 2, the numerical simulation was extended for case 3. The bond strength only for the inner reinforcing rebars which had large cover thickness within the loop than main tensile loop rebars evaluated as doubled of normal bond strength (2NBS) was also considered for the numerical simulation of case 3. The numerical simulation results of case 3 are shown in Fig. 11.

The vertical increment of 10 mm distance between the main loop reinforcement reduced the peak load of case 3-0 and case 3-1 compared with the case 2-2 and case 2-1, respectively. The peak load reduced as the diagonal crack propagated easily between tensile

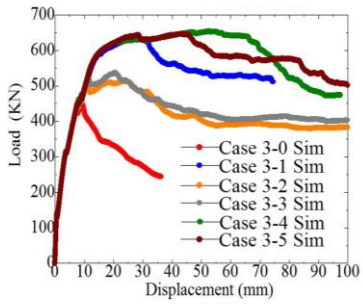


Fig. 11 Load displacement relations Case 3

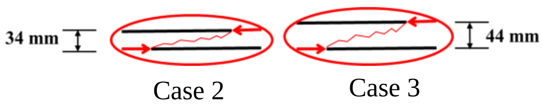
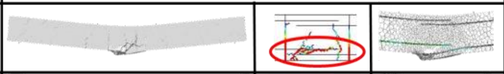
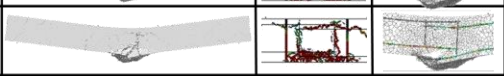
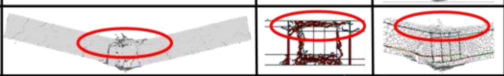
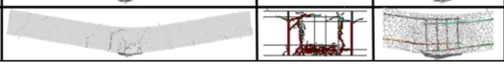


Fig. 12 Diagonal crack propagation

loops in case 3 compared with case 2 as shown in Fig. 12. The Fig. 11 also shows that varied steel amount of inner reinforcing rebars inside the loop increased the peak load. The peak load increased in case 3-2 and case 3-3 compared with case 3-0 but showed the loop type failure i.e. the propagation of the diagonal crack as shown in Fig. 12, caused the concrete between loops to lose the stress transfer mechanism and hence tensile stress at the lower edge of the beam could not be transferred, leading to a failure before the yielding of the tensile reinforcement. In case 3-4, the compression failure occurred at the top side of the beam. The case 3-5 showed the slightly better performance among all cases except case 3-4, however produced the loop type failure after yielding of the rebar. In case 3-5, due to progress of softening of the bond slip model (Fig. 3) between inner reinforcing rebars and concrete, the diagonal crack propagated between the tensile loop reinforcement and thus caused the loop type failure. All the cases showed the loop type failure except case 3-4. Furthermore, the case 3-4 showed the maximum peak load among all the cases. It can be seen from Table 2, although the case 3-5 has the maximum steel ratio (total

Table 2 Deformed behaviors of Case 3

Type	Deformed Behaviors at Post Peak Stage (0.05mm – 0.5mm; 0 – f_y / E_s)	Mode of Failure	Steel ratio within Loop	Summation of the Circumferential Length of Distribution rebar within loop
Case 3-0		Loop failure before yielding of rebar	Nil	Nil
Case 3-1		Loop failure after yielding of rebar	2.76 %	420 mm
Case 3-2		Loop failure before yielding of rebar	0.92 %	140 mm
Case 3-3		Loop failure before yielding of rebar	1.89 %	200 mm
Case 3-4		Compression failure	3.69 %	**560 mm**
Case 3-5		Loop failure after yielding of rebar	**3.74 %**	480 mm

area of steel reinforcement inside the loop/ total area of concrete inside the loop) within loop compared with the case 3-4, however the case 3-4 has more summation of the circumferential length of the inner reinforcing rebar than case 3-5. More the summation of the circumferential length of the inner reinforcing rebar within the loop provided the more bond resistance capacity and hence produced more confinement to the concrete inside the loop and thus prevented the occurrence and propagation of the diagonal crack between the tensile loops and yielded the compression failure.

5. CONCLUSIONS

In this study, the failure mechanism of the horizontal loop joints and the role of the inner reinforcing bars were highlighted by experimental and numerical simulations.

1) The failure of the loop joint without inner reinforcing rebars within the loop was by the occurrence of diagonal cracks in the tensile loop region. The presence and bond strength of the inner reinforcing bars in the loop joint have the vital importance in suppressing the diagonal crack occurrence and propagation, thus reducing the loop type failure.
2) For simulations with higher precision, it is necessary to adequately evaluate the bond characteristics of the inner reinforcing bars which have relatively large cover thickness.
3) The deformation capacity of the loop decreased with the increased of loop interval.
4) The change of steel amount of inner reinforcing rebars inside the loop did not show any significant change on the loop failure mode. The surface area of the inner reinforcing rebars within the loop has more influence on the deformation performance and failure mode of the loop joint.

In order to investigate the influence of the position of inner reinforcing bars, it is necessary to consider a separate study in which only the inner reinforcing bars position is changed by fixing the steel amount of the inner reinforcing bars inside the loop.

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