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SHEAR PERFORMANCE OF RC FOOTING BEAMS BY CAP-TIE SYSTEM USING WELDED STIRRUPS

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ABSTRACT: In this study, a cap-tie system for welded main bars-stirrups is newly proposed. To investigate the structural performance of footing beams with the proposed cap-tie system, ten beam specimens are tested. The main test variables are concrete strength and cap-tie type. The anti-symmetrical bending shear test is conducted for the specimens that are designed to fail by shear before yielding of main bars. Test results show that the shear capacities of cap-tie specimens are similar or greater than those of ordinary RC specimens, and those can be evaluated safely by the Arakawa formula. Moreover, expansion of bond splitting cracks of cap-tie specimens is inhibited. It is suggested that the cap-tie system can improve the bond strength of RC beams.

1 INTRODUCTION

Recently, reinforced concrete footing beams using welded connections between main reinforcing bars and stirrups have been popular for low-rise RC buildings and wooden houses. Using the welded connections, workers at construction field can easily arrange steel bars. To use the welded connections for wider footing beams in which double-layered main bars are arranged, a cap-tie system for welded main bars-stirrups is newly proposed. Figure 1 shows the manufacturing procedure and the section of proposed footing beams. At first, main bars and stirrups are welded and formed to mesh-shape by flash welding using the dedicated machine. After that, the mesh-shape bars are folded as to be U-shape. This U-shape bars consist of main bars and the lower part of stirrups of footing beam. In case of ordinary arrangement for beams, stirrups have 135° hooks to anchor the stirrups to the main bars. In case of the proposed system, stirrups are fixed and anchored only by welding. Cap-tie is set to confine the upper main bars after placing the U-shape bars into the mold. Cap-tie has also the anchorage part by welding bars or 90° hooks that are formed in 3-dimensional shape.

The purpose of this study is to investigate shear performance of RC footing beams manufactured by proposed cap-tie system. The anti-symmetrical bending shear test is conducted. Main variables are concrete target strength and cap-tie type. Test specimens are designed to fail by shear to confirm the shear performance of proposed system.

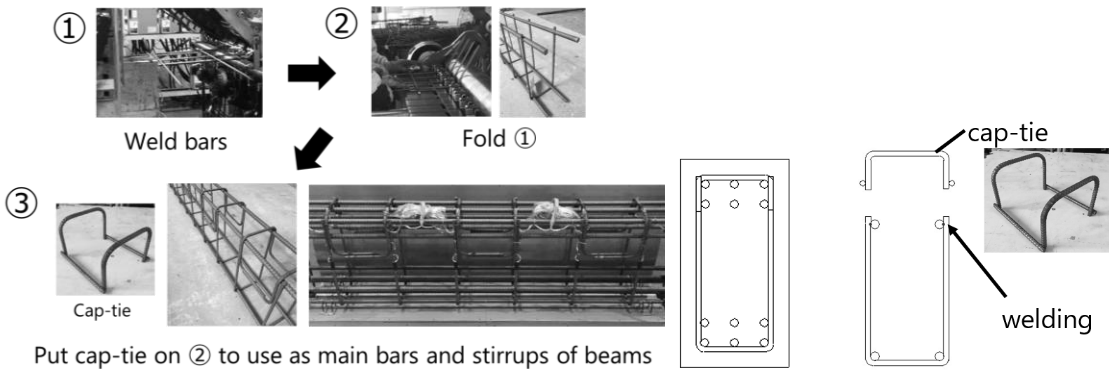

Figure 1. Overview of proposed cap-tie system

2 EXPERIMENTAL PROGRAM

2.1 Specimens

Table 1 shows specimens list, and Figure 2 shows specimen dimensions and the arrangement of reinforcing bars. The specimens are designed to have similar cross-section as that of practical footing beams which have double-main bar. The cross-sectional size is 220mm × 440mm, a clear span length is 1260mm, and stubs are arranged at both ends of the specimen. Main bars at the four corners are welded with stirrups. The other main bars are fixed to the cap-tie or positioning bars with thin wire. D10 bars are used for stirrups at 200mm intervals. Concrete target strength is 18MPa and 30MPa, they are lower limit and upper limit of practical use. The specimens are designed to fail by shear to confirm the shear performance of proposed system.

The test variables are concrete strength, cap-tie type and intervals of cap-tie. In case of ordinary arrangement for beams, cap-tie have 135° hooks to anchor it to the main bars. The proposed cap-tie has the anchorage part by welding bars or 90° hooks that are formed in 3-dimensional shape. In this study, three types of anchorage shape for cap-tie are investigated. Figure 3 shows the cap-tie type and its interval. Type I has welded anchorage bars between two cap-tie bars. Type II has 3-dimentional shape folded into from one steel bar. Type III has folded anchorage parts in an axial direction and is used by two pieces in pair. Cap-ties are arranged alternately as single layout, or consequently as double layout.

Table 1. Specimen list

Specimen No	Common item	Concrete target strength (MPa)	Cap-tie	
			Type	Interval
No.1 (No.6)	Section *b*×*D* (mm)=220×420		Ordinary arrangement	
No.2 (No.7)	Shear span ratio 1.5		I	
No.3 (No.8)	Main bar 6-D16(SD490) p_t=1.55%	18 (30)	II	Single
No.4 (No.9)	Stirrup 2-D10@200(SD295)		III	
No.5 (No.10)	p_w=0.32%		III	Double

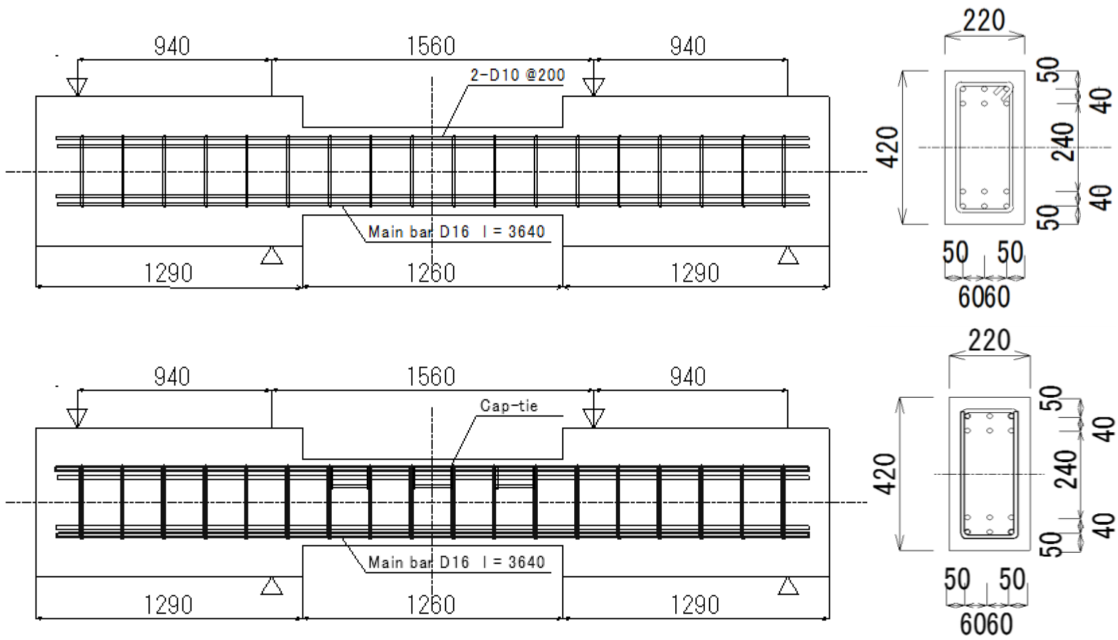

Figure 2. Specimen dimensions (upper specimen: No.1 and No.6, lower specimen: No.2 and No.7)

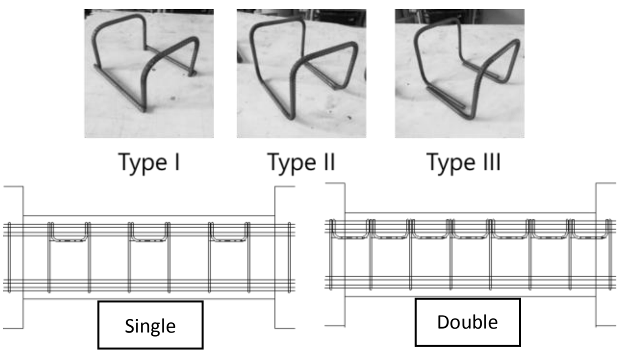

Figure 3. Cap-tie type and interval

2.2 Materials and loading method

Table 2 shows mechanical characteristics of reinforcing bars, and Table 3 shows those of concrete. SD490 bars are used for main bars to fail by shear before yielding.

The specimens are subjected to anti-symmetrical bending shear moment. The positions of supported and loaded points are also shown in Figure 2. The 2MN universal testing machine is used for the monotonic loading.

Table 2. Characteristics of reinforcing bar

Diameter Type	Yield strength (MPa)	Elastic modulus (GPa)	Yield strain (%)	Tensile strength (MPa)	Elongation (%)	Note
D16 SD490	540	194	0.279	705	18.2	Main bar
D10 SD295	335	189	0.177	471	24.7	Stirrup

Table 3. Characteristics of concrete

Target strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Splitting tensile strength (MPa)
18	19.7	22.1	2.02
30	36.8	31.0	2.96

3 TEST RESULTS

3.1 Shear force-translational angle curve

Figure 4 shows shear force-translational angle curves of each specimen. Translational angle is defined as the relative deflection between both stubs divided by clear span.

The maximum load was observed with opening shear cracks and yielding of stirrups in specimen No.1, the ordinary specimen. After that, the load decreased gentry. In specimen No.6, shear cracks appeared through compression zones of the ends of the specimen after yielding of stirrups. After that, the peak load was observed and the load dropped remarkably. The curves of cap-tie specimens are similar to those of ordinary specimens until 0.015 rad. of translational angle. Shear capacities of cap-tie specimens are similar or greater than those of ordinary specimens. The difference of cap-tie types did not show a significant deference in shear capacity.

Additionally, loud sounds were heard around 0.03rad. of translational angle during test of cap-tie specimens with rapidly dropping of load. From the visual observations by shaving off concrete after loading, the sounds were because of coming off a stirrup from a main bar at upper side of beam (Figure 5). Similarly, applied load of specimen No.9 drastically decreased due to rupture of a stirrup around 0.04rad.

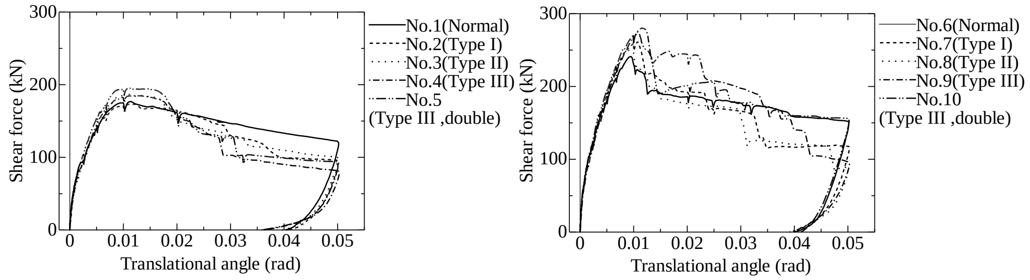

Figure 4. Shear force-translational angle curves

Figure 5. Coming off a stirrup from a main bar

3.2 Crack pattern

Bending cracks occurred at the ends of the beams. After that, shear cracks of 18MPa series specimens occurred at 80-90kN of shear force, and those of 30MPa series specimens occurred at 160kN. Bond splitting cracks along main bars of 18MPa series specimens took place and they increased, but those did not expand in cap-tie specimens. Those of 30MPa series specimens were not observed. Shear cracks were also restrained from expanding by cap-tie.

Figure 6 shows crack patterns of specimens at 1/100 rad. of translational angle. Shear cracks are dominant especially in 30MPa series specimens. Restraint of bond splitting crack are observed in 18MPa series cap-tie specimens.

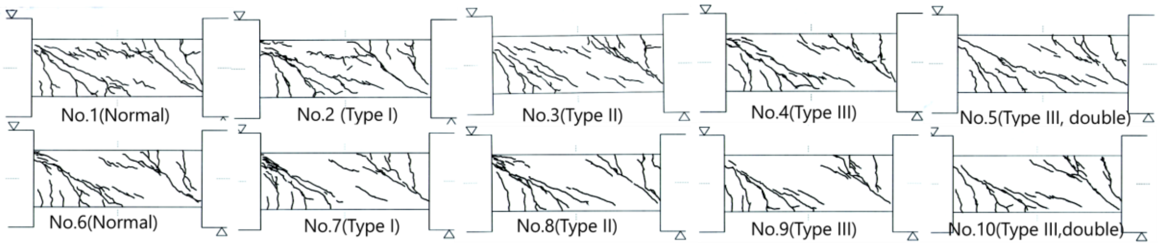

Figure 6. Crack patterns of specimens at 1/100 rad. of translational angle

3.3 Local deformation

To measure local deformations, tested beam section was divided into four sections and displacement transducers were set as shown in Figure 7. Conceptual drawings of bending deformation and shear deformation are also sown in the figure. Figure 8 shows shear force-bending deformation curves and shear force-shear deformation curves until total deformation of 30mm. Bending deformation and shear deformation was calculated by measured curvature and shear strain obtained from displacements for each section, respectively.

Shear deformation is predominant in all specimens. Especially in 18MPa series specimens, shear deformation increases around the peak load. It is considered that that corresponds to yielding of stirrups. Shear deformation of cap-tie specimens are greater than those of ordinary specimens at section 3 and section 4.

4 EVALUATION OF SHEAR CAPACITY

The obtained maximum shear force of each specimen is evaluated by existing calculation formulas that are adopted for ordinary RC beams. The shear capacity is calculated by Arakawa's formula (Eq.1) and Ultimate Strength Earthquake-Resistant Design Guidelines of RC

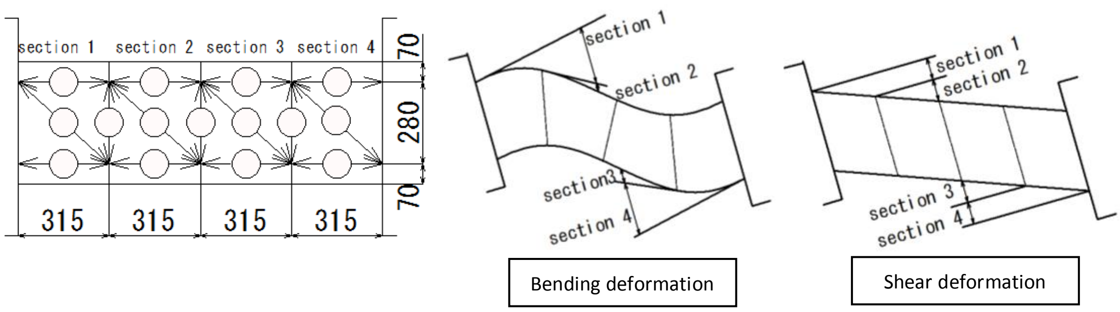

Figure 7. Location of displacement transducers and conceptual images of deformation

No.1(Normal) No.2(Type I) No.3(Type II)
No.4(Type III) No.5(Type III,double)

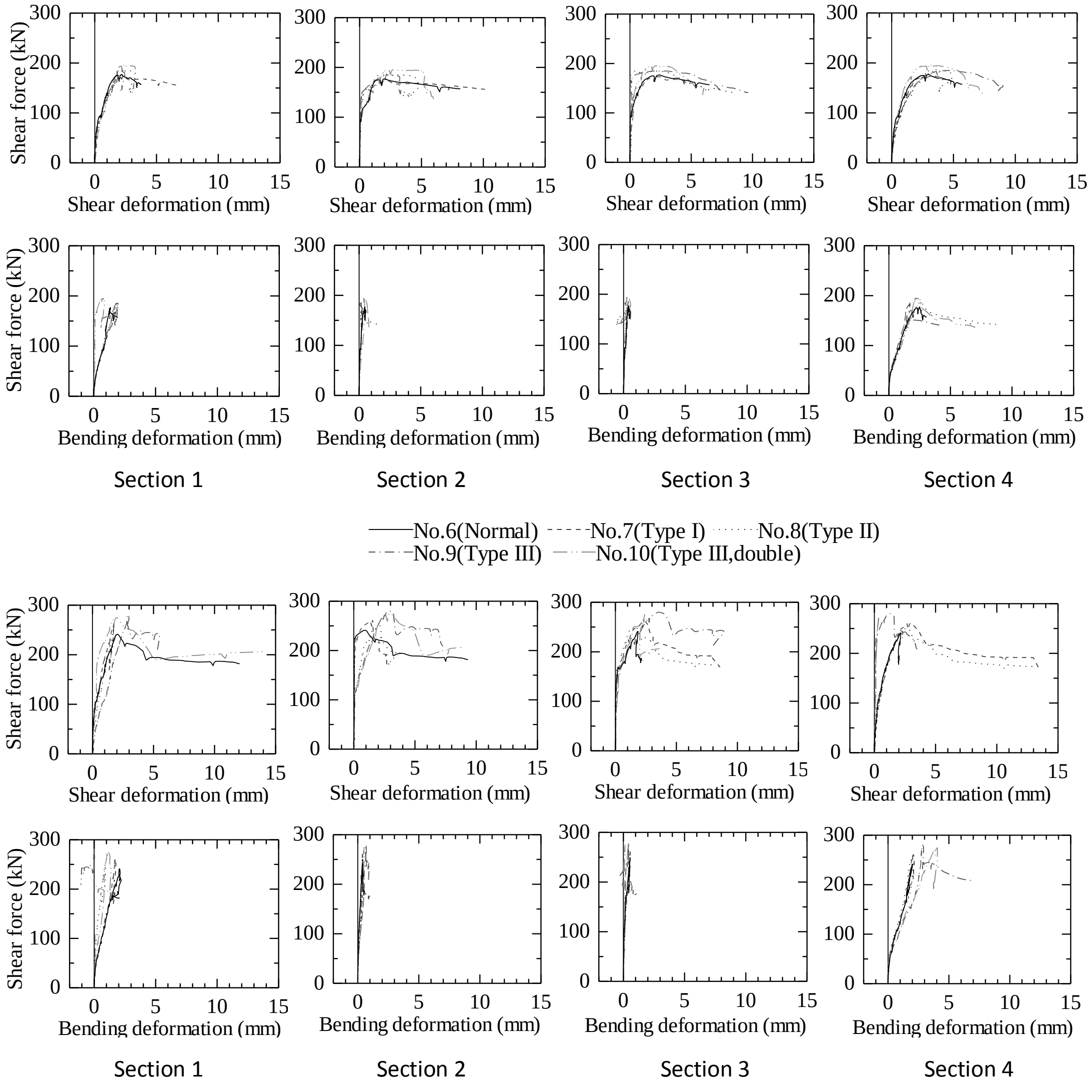

Figure 8. Shear force – local deformation curve

building (Eq.2) by Architectural Institute of Japan (AIJ (2010), (1990)). Figure 9 shows the comparison between the obtained maximum shear force, ${}_eQ_{max}$, and calculated shear capacities, ${}_cQ_{su}$. All values are normalized by calculated bending capacity, ${}_cQ_{mu}$, by formula of AIJ standard (Eq.3) (AIJ (1988)). The values of the ratio of ${}_cQ_{su}$ to ${}_cQ_{mu}$ are smaller than 1 for all specimens, principally the specimens fail by shear as observed in loading test. Table 4 shows the list of the values of ${}_eQ_{max}$, ${}_cQ_{su}$, and other items.

$$ {}_cQ_{su} = \left\{ \frac{0.115 k_u k_p (180 + \sigma_B)}{M/Qd + 0.12} + 2.7\sqrt{p_w \cdot \sigma_{wy}} \right\} b \cdot j \tag{1} $$

$$ \begin{aligned} {}_cQ_{su} &= b \cdot j_t \cdot p_w \cdot \sigma_{wy} \cdot \cot\phi \\ &\quad + \tan\theta \cdot (1-\beta) \cdot b \cdot D \cdot \nu \cdot \sigma_B / 2 \end{aligned} \tag{2} $$

$$ \begin{aligned} {}_cQ_{mu} &= Mu / (L_0 / 2) \\ Mu &= 0.9 a_t \cdot \sigma_y \cdot d \end{aligned} \tag{3} $$

Table 4. Calculated shear capacity and bond capacity

	Unit	18MPa series			30MPa series		
		Normal RC	Cap-tie single	Cap-tie double	Normal RC	Cap-tie single	Cap-tie double

Maximum shear force $_eQ_{max}$	kN	177(No.1)	173(No.2) 187(No.3) 185(No.4)	195(No.5)	241(No.6)	261(No.7) 250(No.8) 280(No.9)	275(No.10)
Calculated shear capacity $_cQ_{su}$	kN	153 (Arakawa's formula) 175 (Ultimate guideline)			196 (Arakawa's formula) 229 (Ultimate guideline)		
Stirrup ratio for bond capacity calculation p_w	%	0.32	0.65	0.97	0.32	0.65	0.97
1st layer bond strength τ_{bu1}	N/mm^2	2.43	3.45	4.46	3.12	4.19	5.25
2nd layer bond strength τ_{bu2}	N/mm^2	1.57	2.29	3.00	1.99	2.74	3.49
Bond capacity V_{bu}	kN	127	149	167	220	245	264

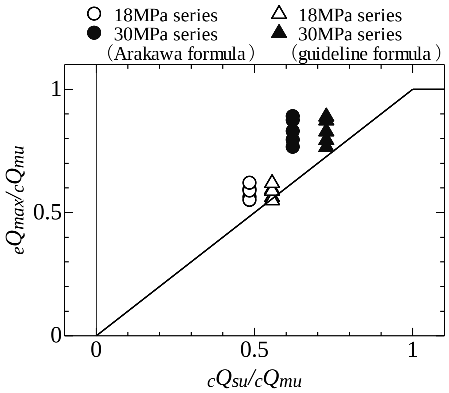

Figure 9. Comparison of shear capacity

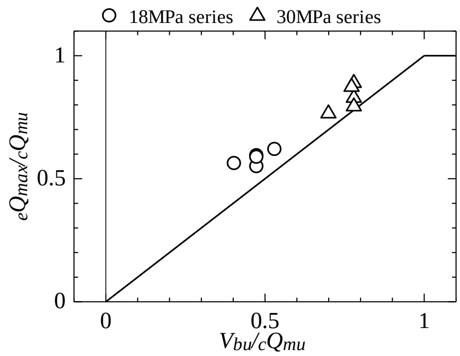

Figure 10. Comparison of bond capacity

From Figure 9, all plots except for specimen No.2 lie upward the line. Especially in case of Arakawa's formula, shear capacities of all specimens can be evaluated safely by Arakawa's formula.

Bond splitting cracks of cap-tie specimens tend to be inhibited at upper main bars of beams especially in 18MPa series. It is difficult to evaluate bond capacity directly since specimens failed by shear. However, it is considered that cap-tie can improve bond strength of main bars, so evaluation by bond capacity formula is carried out. The bond capacity, V_{bu}, is calculated using Toughness Guaranteed Earthquake-Resistant Design Guideline (Eq.4 – Eq.6) by AIJ (AIJ (1999)). Based on the assumption that both cap-ties and stirrups confine the main bars, the cross-sectional area of cap-tie is added to stirrup ratio in case of upper main bars calculation. Table 4 also lists the items for bond capacity calculation and the calculated results.

$$V_{bu} = \sum(\tau_{bu}\varphi)j_e + \left\{\nu\sigma_B - \frac{2.5\left(\sum(\tau_{bu}\varphi)\right)}{\lambda b_e}\right\}\frac{bD}{2}\tan\theta \quad (4)$$

$$\tau_{bu} = \alpha_t\{0.085 b_i + 0.10\}\sqrt{\sigma_B} + k_{st} \quad (5)$$

$$k_{st} = (54 + 45 N_w / N_1)(b_{si} + 1)p_w \quad (6)$$

Figure 10 shows comparison of calculated bond capacity, V_{bu}, and the maximum shear force, $_eQ_{max}$. Each values are normalized by $_cQ_{mu}$ as similar with Figure 9. The calculated bond capacity increases with increasing of the number of cap-tie. The obtained maximum force tend to increase as the calculated value also increases. There is a possibility that cap-tie can improve bond strength of RC beams. For further discussions, it is necessary to conduct the experiment using specimens that fail by bond.

5 CONCLUSIONS

To investigate the structural performance of footing beams with the proposed cap-tie system, ten beam specimens are tested. The followings are concluded.

(1) Shear capacities of cap-tie specimens are similar or greater than those of ordinary RC specimens.

(2) Shear capacities of cap-tie specimens can be safely evaluated by existing formulas adopted for ordinary RC beams.

(3) The expansion of bond splitting cracks of cap-tie specimens is inhibited in 18MPa series specimens. It is suggested that the cap-tie system can improve the bond strength of main bars.

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