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AN INNOVATIVE HOOK-CLIP FOR PERFORMANCE IMPROVEMENT OF REINFORCED CONCRETE TIED COLUMNS

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SUMMARY

This paper presents a simple-to-place device, called “hook-clip”, which can be used to hold the legs of the conventional 90° hook ties or crossties in reinforced concrete columns at the sites, so as to effectively improve their performance. The hook-clip invented is to prevent premature opening of the legs of the hooks. Static compression tests on a number of specimens clearly demonstrated the effectiveness of the clips in restraining the vertical reinforcing bars at the tie positions, resulting in the bars buckling in about half the buckling length of those in specimens without hook-clips and hence higher sustained load at the same level of strain. At a large axial strain of 0.04, columns with hook-clips were able to sustain a loading comparable to that of columns confined with 135° hook ties. Preliminary test results of a medium size column under cyclic loading are also presented.

INTRODUCTION

Although extensive studies of reinforced concrete columns confined with 135° hook ties have been carried out [e.g. Kent and Park 1971; Mander et al. 1988; Park et al. 1982; Sheikh and Uzumeri 1980], very little work has been focused on the performance of 90° hook ties, inspite of the fact that crossties with 135° hook at one end and 90° hook at the other are permitted by ACI Code [1995] even in areas of high seismic risk. Razvi and Saatcioglu [1989] tested 2 specimens with 90° hook ties and their results indicated that they were inferior to columns confined by 135° hooks at axial strains in excess of about 0.015. Shiekh and Yeh [1990] investigated the behavior of tied columns with different reinforcement and tie configurations under medium to high axial load levels and flexure. Crossties with 90° hooks were reported to cause brittle failure and to be harmful rather than beneficial, especially at high axial loads. Lynn et al. [1996] tested eight full-scale reinforced concrete columns having details widely practiced before mid 1970’s in U.S.A. and including 90° hook tie details among others. Cyclic load-displacement curves were obtained for light and moderate level axial loads. Poor performance of 90° hook ties was evident, leading to rapid loss of gravity load resistance.

The deficiency of 90° hook ties in columns was witnessed in past earthquakes in bridges [e.g. Seible et al. 1995], reinforced concrete buildings [EQE. 1995], and steel reinforced concrete structures [Azizinamini et al. 1997]. Despite their poor performance, 90° hook ties are still used extensively worldwide in low to moderate seismic risk regions because of the ease of their placement, when compared with the 135° hooks. Ninety-degree hook ties are even more appealing in developing countries where laying of reinforcing bars is quite commonly not practiced to an acceptable standard of precision, making it extremely difficult to put 135° hook ties in place. In view of the importance of vertical load resistance members, it is extremely desirable to have sufficient inherent ductility (to cope with very rare earthquakes) even in low seismic risk zones. It is also equally important to improve the performance of conventional crossties with 90° hooks to ensure their confinement effectiveness, which is essential in areas of high seismic risk. This paper presents a simple-to-place device called “hook-clip” to be clipped onto the conventional 90° hook ties or crossties at the sites so as to effectively improve their performance. The effectiveness of the hook-clip was examined in comparison with specimens with conventional 90° and 135° hook ties under static concentric compression loading. Preliminary test results of a medium size column under cyclic lateral loading are also included.

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THE HOOK-CLIP

To prevent premature opening of the ties, it is envisaged to provide a supplementary tie or "hook-clip" holding the legs of the hooks and embedded in the concrete core. The clip would provide an inward thrust resisting the opening of the ties after the concrete cover spalls off. Fig. 1 shows the details of the clip proposed for binding 9 mm diameter ties or smaller. The hook-clip may be employed to clip the legs of any hoop tie or crosstie with 90° hooks (see Fig. 2). With the clips prefabricated, the clipping operation can be done easily at the site. No welding is needed.

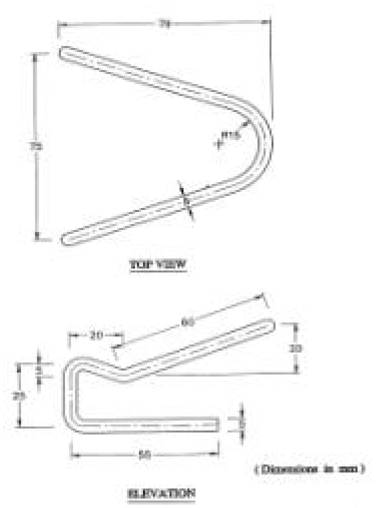


Figure 1: Detail of hook-clip

Figure 2: Hook-clips engaging 90° hoop ties and crossties

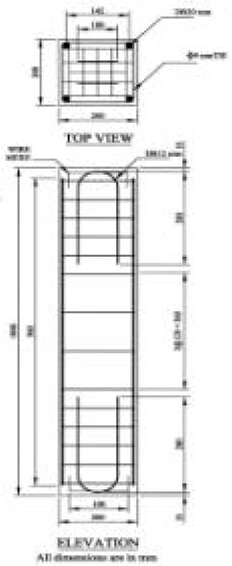
TEST SPECIMENS AND TEST SETUP

Small sized column specimens with 200 mm by 200 mm in cross section and 1000 mm in length served as test specimens. Each was reinforced with 4 longitudinal deformed bars of 20 mm (DB20) nominal diameter. The center 360 mm portion of the column was bound by ϕ 9 mm round bars spaced at 120 mm. Close tie spacings of 50 mm were provided in the rest of the column to prevent failure in the end zones. The ties were supplied with hooks (90°or 135° depending on specimens) with an inside radius of 2 times the tie diameter and an extension of 60 mm. The tie spacing of 120 mm is smaller than that stipulated by ACI [1995] which allows 200 mm for low ductility detailing in low to slightly moderate seismic zones. The close spacing was chosen in view of the higher demand on the ties in providing lateral restraint for the longitudinal bars when buckled in shorter unsupported lengths. Consequently, a higher demand was also imposed on the hook-clips in order to prevent the ties from premature opening. The clips were made of 5 mm diameter round bars and embedded 75 mm in the concrete core. The yield strength and modulus of elasticity of the clip steel were 450 MPa and 206,600 MPa, respectively.

It should be noted that large longitudinal bars were used so that at longitudinal bar buckling, a large outward thrust would be exerted on the ties, which would in turn try to pull the hook-clips out of the confined core. Furthermore, the design was meant for regions of low to moderate seismicity, with detailing conforming to ACI Code, which allows for substantially larger spacings of longitudinal and transverse reinforcements than those allowed in higher seismic risk areas.

Three sets of specimens designated C135, C90 and CL90 representing columns with 135°, 90° hook ties, and 90° hook ties with hook-clips, respectively, were tested, each set consisting of ideally identical reinforcement. Table 1 lists the relevant data of the test specimens. Fig. 3 depicts the drawing of a typical column specimen (without hook-clips). Normal weight concrete with a maximum aggregate size of 20 mm and a slump of 75 mm-125 mm was used. Typical stress-strain curves of the reinforcing bars used are shown in Fig. 4.

Each test specimen was instrumented with LVDTs on four faces with nominal gauge lengths of 200 mm. The columns were loaded at a slow strain rate using a 5000-kN hydraulic compression testing machine.



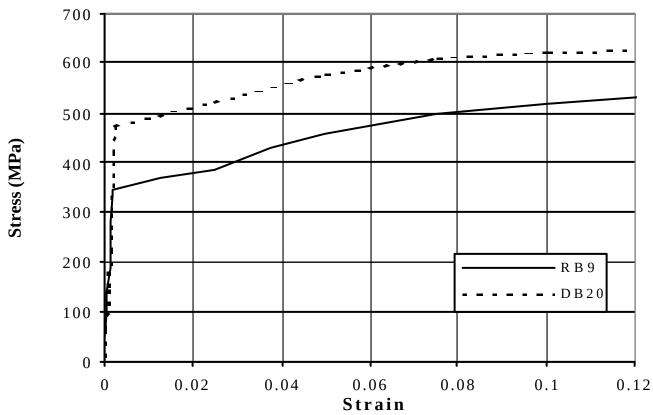


Figure 3: Detail of typical reinforced concrete column specimen (hook-clips not shown)

Figure 4: Stress-strain relationships of reinforcing bars

Table 1: Details of column specimens

Specimen	Concrete strength MPa	Longitudinal reinforcement			Lateral ties			Hook angle degree
		Main bar	f_y MPa	ρ_{gross} (%)	Diameter mm	f_{yh} MPa	ρ_h (%)	
C90-1	31	4DB20mm	475	3.14	8.9	350	1.2	90
C90-2	31	4DB20mm	475	3.14	8.9	350	1.2	90
C90-3	35	4DB20mm	475	3.14	8.9	350	1.2	90
CL90-1	31	4DB20mm	475	3.14	8.9	350	1.2	90 with clips
CL90-2	31	4DB20mm	475	3.14	8.9	350	1.2	90 with clips
CL90-3	35	4DB20mm	475	3.14	8.9	350	1.2	90 with clips
C135-1	31	4DB20mm	475	3.14	8.9	350	1.2	135
C135-2	31	4DB20mm	475	3.14	8.9	350	1.2	135
C135-3	35	4DB20mm	475	3.14	8.9	350	1.2	135

Notes: fy = yield strength of longitudinal reinforcement ; fyh = yield strength of ties
ρ_{gross} = ratio of longitudinal steel area to gross column area
ρ_h = ratio of volume of tie steel to volume of concrete core measured to centers of the tie

TEST RESULTS

Effectiveness of hook-clips

As expected, soon after the concrete covers were spalled off, the 90° hook ties which were most severely loaded started to open up under the outward thrust resulting from the lateral movement of the longitudinal bars during buckling, with a rapid decrease in load carrying capacity. This clearly indicated that these ties were not able to restrain the longitudinal bars at the tie positions, with the consequence of the vertical bars buckling in approximately twice the tie spacing (see Fig. 5). In contrast to the conventional 90° hooks, the clips in CL90 specimens were able to prevent premature opening of the 90° hooks, leading to effective restraint of the vertical bars at the tie positions, and resulting in the vertical bars buckling in about half the buckling length of those without clips, when buckling commenced, as depicted in Fig. 6. In fact, the clips in all specimens were still holding the hook ends even at sufficiently large strains in excess of 0.040, although the legs of the hooks did slide along the sides of the ties in two specimens.

The overall performance of the specimens with 135° hooks was slightly better than the CL90 series. As expected, the 135° hooks effectively confined the core up to a large axial strain (of about 0.045), after which there was also a tendency for one of the legs to open up. The buckling shape of the longitudinal bars was also similar to the specimens with hook- clips as can be seen in Fig. 7.

Figure 5: Typical failure mode of column specimen type C90

Figure 6: Typical failure mode of column specimen type CL90

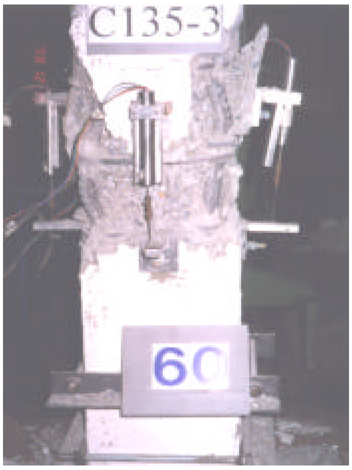


Figure 7: Typical failure mode of column specimen type C135

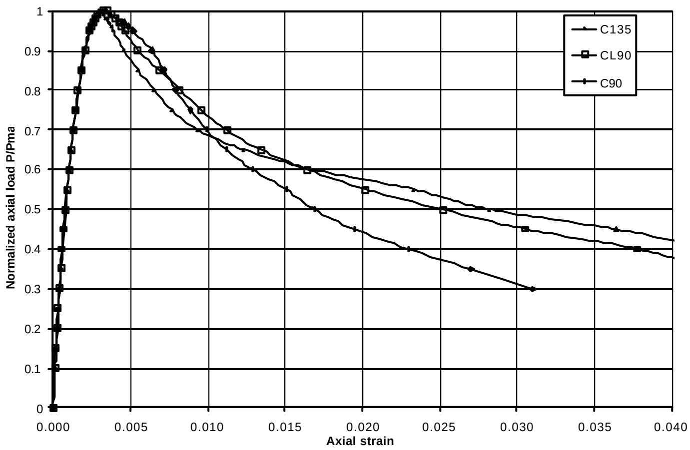


Figure 8: Average normalized load – strain relationships for different tie configurations

Normalized axial load-strain relationships

The peak load for each specimen is tabulated in Table 2. As expected, the peak loads would be practically not influenced by the details of the tie hooks because confinement provided by all hook configurations is essentially equivalent at small strains.

Fig. 8 depicts the average normalized axial load-strain relationships for specimens in each series. Because of some inconsistency in load control the results for the C135-2 specimen were deemed inconsistent and were therefore discarded. For the 90° hook tied specimens, the load-deformation curve descended rapidly soon after reaching the maximum capacity, indicating loss of confinement due to the opening up of the ties, whereas specimens with hook-clips showed decreasing rate of drop in load carrying capacity. It is evident that the CL90 specimens were much superior to the C90s. The latter practically failed at a strain of about 0.030 while those with hook-clips were still able to carry a significant load of 45% of the peak load at this strain. In fact, the CL90 specimens exhibited load-deformation characteristic quite similar to those confined with 135° ties.

Table 2: Test results - peak loads

Specimen	C90-1	C90-2	C90-3	CL90-1	CL90-2	CL90-3	C135-1	C135-3
Concrete Strength, MPa	31	31	35	31	31	35	31	35
Experimental Peak Load, kN	1805	1940	2000	1795	1910	1980	1830	2020

THEORETICAL AXIAL LOAD-STRAIN CURVES

By assuming a uniform axial strain distribution and suitable stress-strain models for the unconfined concrete shell, the confined concrete core as well as the longitudinal steel bars, one can compute the theoretical axial load-strain relationships based on perfect bond between concrete and steel.

In view of the poor performance of the columns with conventional 90^o hooks, and the prevalence of previous work on columns confined with 135^o hooks, only the axial load-strain curves for the CL90's are presented. Fig. 9 shows the average test results of CL90-1 and CL90-2 (whose compressive strengths were the same at the time of testing) together with the predicted curves based on the well known Modified Kent and Park [Park et al. 1982] and the Mander [1988] models. The corresponding results for CL90-3 are plotted in Fig. 10.

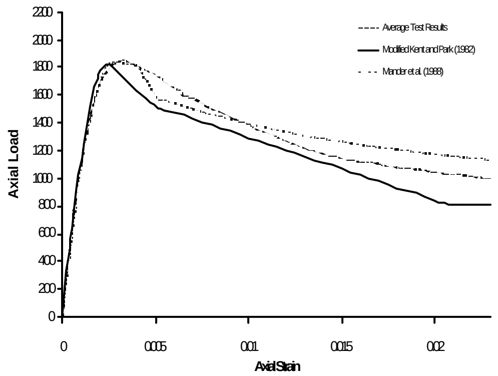


Figure 9: Comparison of theoretical and experimental axial load-strain curves-Column CL90-1 and CL90-2

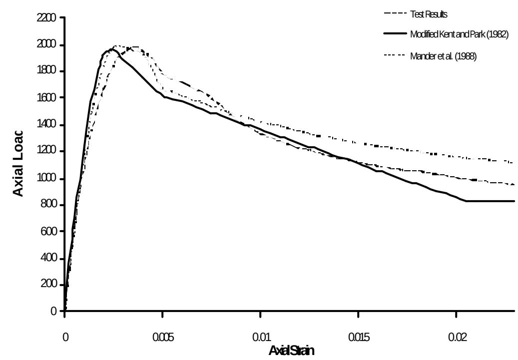
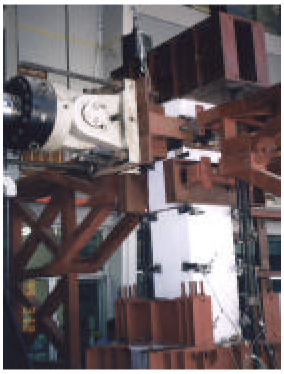


Figure 10: Comparison of theoretical and experimental axial load-strain curves-Column CL90-3

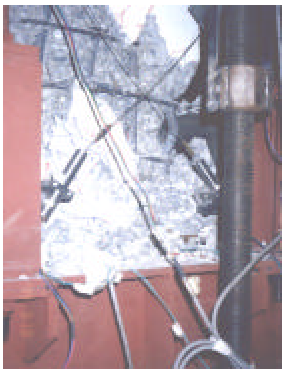
In computing the theoretical values, the strength of the concrete in the specimens was taken as 90% of that obtained from the standard cylinder tests. The spalling strain was assumed to be 0.005. Furthermore, buckling of the longitudinal bars was ignored, and the bars were assumed to have an elastic-perfectly plastic stress-strain relationship. Since the loading capacity of columns with moderate confinement generally drops more than 20% from the peak value when buckling of the vertical bars takes place, which corresponds to an axial strain of about 0.015 in the CL90 series, these assumptions are reasonable for the prediction of theoretical axial load-strain relations in the useful range of the column. It may be observed that, in general, the Mander model gives a better estimate of the axial load carried by the CL90 columns at small strains up to about 0.010. For larger strains in the range of 0.010-0.015, the Mander model overestimates the load capacity (by about 10-14%) while the Modified Kent and Park model gives a more conservative and closer estimate. Beyond the axial strain of about 0.015, a more refined analytical method is needed to account for buckling of the longitudinal bars and deterioration of the concrete core, which are neglected in this study.

PRELIMINARY CYCLIC LOAD TEST

With the promising performance of hook-clips evidenced in monotonic static load tests, investigation on the behavior of a cantilevered column of medium size (400 mm x 400 mm x 1500 mm) under a moderate level of axial load (0.30 f_c' times the gross sectional area) and cyclic lateral loading was carried out. The reinforcement consisted of 16-20 mm diameter longitudinal bars bound by sets of one 9 mm diameter hoop tie with two crossties spaced at 120 mm spacings. Hook-clips were used to engage the 90° hooks of the ties and crossties (Fig. 2). Preliminary test results did confirm the effectiveness of the hook-clips in restraining the vertical bars at the tie positions after the specimen was subjected to 7 cycles of lateral load reversals with a maximum displacement ductility factor of about 4. As is evident from Fig. 11, the hook-clips successfully tied the 90° hooks, resulting in the buckling shape of the vertical bars in resemblance with that in the monotonic compression test. An extensive test program is currently underway to investigate the cyclic performance of hook-clips.



(a)



(b)

Figure 11: (a) Cantilevered column under cyclic load test; (b) Effectiveness of hook-clip in restraining vertical bars at tie positions

CONCLUSIONS

The hook-clips invented are effective in improving the performance of axially loaded columns confined with 90° hook ties, as evidenced from the buckling lengths of the longitudinal bars in specimens with hook-clips being about half of those in specimens without hook-clips, when bar buckling commenced. The latter specimens practically failed at a strain of about 0.030 while a significant portion of the peak load could still be carried by the specimens with clips by virtue of the better confinement enhanced by the hook-clips and the higher buckling strength of the vertical bars. In fact, the overall performance of the specimens with hook-clips was comparable to that of columns confined with 135° hook ties. The theoretical axial load-strain relationships can be reasonably predicted by using the Mander concrete model for strains prior to incipient buckling.

Conventional 90° hook tied columns do not possess sufficient ductility for a safe environment in the event of a rare earthquake. The effectiveness of hook-clips in improving the performance of tied columns can contribute to earthquake risk reduction in low to moderate seismic risk zones, especially in developing countries where changes in construction habit cannot be easily effected. The easy-to-place hook-clips would provide an attractive alternative solution, subject to further extensive research work on their cyclic performance.

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