

Cyclic loading of Exterior Beam - Column Joint with Threaded Headed Reinforcement

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Abstract

In Reinforced concrete structures, beam column joint is the most critical region in seismic prone areas. In structural concrete, the provisions for anchorage of straight bars and hooks occasionally present detailing problems due to the long development lengths and large bend diameters that are required, particularly when large diameter reinforcing bars are used. In many cases, the requirements for straight bar anchorage and lap splices cannot be provided within the available dimensions of elements. Hooked bars can be used to shorten anchorage length, but in many cases, the bend of the hook will not fit within the dimensions of a member or the hooks create congestion and make an element difficult to construct. Similarly, mechanical anchorage devices can be used to shorten lap splice lengths, but they frequently require special construction operations and careful attention to tolerances. Experimental work was conducted on exterior beam-column joint specimens with T-type mechanical anchorage. Welded and threaded headed reinforcement bars were used as T-type anchorage with short development length. The specimens were constructed and tested to assess the anchorage strength of headed bars under cyclic loading. The experimental results demonstrated that the specimen with T-type mechanical anchorage exhibited significant improvement in seismic performance load-displacement capacity, stiffness degradation, and also reduced congestion of reinforcement in joint core.

Keywords: Anchorage Bar, Beam Column Joint, Bearing, Bond, Shear Stress. T-type anchorage

INTRODUCTION

Many reinforced concrete (RC) buildings, such as non-ductile RC frames, designed during the 1950s through 1970s existing today in many parts of the world do not satisfy the current

seismic design requirements. These buildings generally do not possess adequate ductility due to poor detailing of reinforcement. Observations made on the failures of the existing structures due to earthquakes reveal that strengthening or retrofitting is necessary due to (i) Poor detailing of joint reinforcement, (ii) Deficient materials and inadequate anchorage length of beam reinforcement, (iii) Improper confinement of joint region by transverse reinforcements, (iv) Changes in the current design detailing requirement and (v) changes of loads due to frequency of earthquakes and alterations of earthquake zones.



Figure 1: Beam column Joint fails due to shear failure in Kocaeli Earthquake

The failure of beam-column joints is the major contributor for the collapse of buildings due to earthquake excitation. It establishes the need for engineering approach to adopt efficient and economical methods to improve the joint performance. The need for study of earthquake effects on structures was realized when earthquakes occurred through the 1960s and 1970s causing irreparable damage and human loss. The design of joints was not given importance in the framed structures designed for gravity loads or gravity and routine live loads only. This causes severe problem in the

event of an earthquake. Several studies led to the development of ASCE-ACI 352 Committee. Recommendations for the design of reinforced concrete beam-column joints (connections) in the year 1976. But there is a lot that has still not been understood about beam-column joint and research needs to highlight these issues.

Shear mechanism of exterior bema column

For the design purposes, the horizontal component of the joint shear stress can be calculated from the combined effect of: (i) Diagonal strut mechanism, to consider the contribution of concrete in the joint; and (ii) Truss mechanism, to consider the contribution of the joint shear reinforcement. Figure 2 shows the forces in the beam bars, the joint mechanism and the force components in the joint for calculating the joint shear strength.

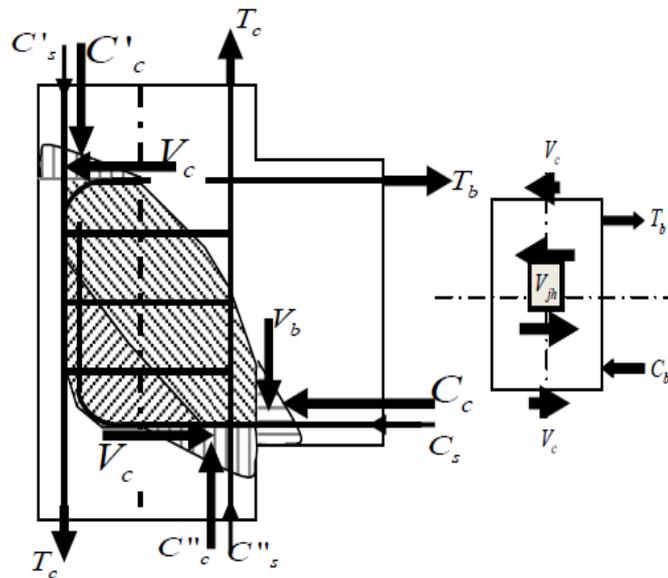


Figure 2: Shear mechanism of exterior beam column joint (drawAutoCAD)

As shown in Figure 2, the equilibrium of forces acting above the horizontal plane passing through the centroidal axis of the exterior beam-column joint is as follows.

- a) In terms of external forces: $V_{jh} = T_b - V_c$
- b) In terms of internal forces: $V_{jh} = V_{ch} + V_{sh}$

Horizontal component of joint shear force,

$$V_{jh} = V_{ch} + V_{sh}$$

Where, V_{ch} is the horizontal component of diagonal compression strut

$$V_{ch} = D_c \cos \alpha = C_c + \Delta T_c - V_{col}$$

V_{sh} =Horizontal joint shear force resisted by horizontal reinforcement by truss mechanism.

$$V_{sh} = A_{jh} f_{yt}$$

Where,

D_c = Diagonal compression strut at angle “ α ” to horizontal axis of joint

C_c = Concrete compression force

ΔT_c = Force in steel transmitted through bond to strut, over depth “ c ” of the flexural compression zone in the column

V_{col} = Shear force in column

A_{jh} = Horizontal joint reinforcement

f_{yt} = Yield strength of joint reinforcement

A_{jh}^{core} = Horizontal c/s area of the joint

Headed Bar

Headed bars, as shown in Figure 3, provide an alternative to hooked bars and assist in alleviating steel congestion. Previous research on headed bars may be divided into two categories: performance of headed bars in realistic structural systems, and investigation of the mechanics of the headed bars under idealized conditions. Previous structural system studies include a number of beam-column joint investigations, where headed bars were used for longitudinal reinforcement, and slab-column joint investigations, where headed bars were used for shear reinforcement. The reliability and applicability of the headed bars were validated in these studies and, consequently, guidelines on the use of headed bars were introduced in ACI 352R-028 and ACI 421.1R-08. These guidelines provide guidance on general application of bars but do not provide direct estimates for the anchorage strength of headed bars.



Figure 3: Different headed bars and hooks bars

An exterior beam-column joint is an ideal application for headed bars due to the high level of reinforcement congestion that occurs. In this application, the variation of bond strength along the bar and the anchorage strength are dependent not only on the materials but also on the geometry of the

reinforcing bar and the state of stress in the beam-column connection. In this paper, idealized exterior beam-column joint tests were conducted to evaluate the concrete contribution to the anchorage strength of headed bars. Failure modes regarding headed bar anchorage in an exterior beam-column joint can be classified as shown in Figure 4. All failure modes are induced as a result of the tensile force on the anchored headed bar. Side-face blowout failure occurs when inadequate side cover is provided. This can be alleviated when proper side cover is provided.⁸ Concrete breakout may occur when an effective beam depth is greater than 1.5 times an embedment length.¹⁴ This case is rare due to the typical relative depths used for beams and columns as well as the higher strength and stiffness provided by most columns. A pullout mode of failure can occur if the net head area is less than 4 times the bar cross-sectional area. The pullout capacity of headed bars can be calculated using Section D.5.3 of ACI 318-08.15 When proper embedment and head geometry is used, a joint shear failure mode governs the response of the exterior beam-column joint. In this paper, the anchorage strength of headed bars under a joint shear failure mode is investigated through experiments and a new model to predict the strength is proposed.

reinforcement is necessary to sustain a diagonal compression field rather than to provide confinement to compressed concrete in joint core. Tsonos et al (1993) suggested that the use of crossed inclined bars in the joint region was one of the most effective ways to improve the seismic resistance of exterior beam-column joints. Wallace et al (1998) demonstrated that the use of headed reinforcement had eased specimen fabrication, concrete placement and the behaviour was as good as than similarly constructed specimens with standard 90° hooks for beam-column corner joint. Chutarat&Aboutaha (2003) reported that the use of straight-headed bars in the exterior beam-column joint for cyclic response were very effective in relocating potential plastic regions. Murty et. al. (2003) reported that the ACI standard hooks for anchorage of the longitudinal beam bar with hairclip type transverse joint reinforcement were more effective and this combination of anchorage with joint reinforcement is easy to construct and can be used in moderate ductility demand situations. Uma & Sudhir (2006) in their review of codes of practices considered ACI318, NZS 3101: Part-1 and Eurocode-8 EN1998-1, regarding the design and detailing aspects of interior and exterior beam-column joint. Lee & Yu (2009) proposed extension of ACI design methods to cover the use of mechanical anchorage for eccentric beam-column joints. They reported that cyclic behaviour of exterior beam-column joints can be significantly improved by attaching double mechanical device on each beam bar within the joint. Bindhuet. al. (2008) in their experimental investigations validated with analytical studies carried out by finite element model indicate that additional inclined reinforcement bar improves the seismic performance of the exterior reinforced concrete beam-column joints. The use of headed bars has become increasingly popular for relatively large reinforced concrete (RC) structures that are exposed to extreme loads such as strong earthquakes or blasts, often providing an adequate solution to steel congestion (Chun et al 2007; Kang et al 2009, 2010). Sagbas et. al. (2011) in their FEA Computational analysis compared with experimental test results seismically and non-seismically designed joint detailed for the effect of shear deformations. Misir&Kahraman (2013) proposed a seismic strengthening technique for non-seismically detailed beam-column joints of existing reinforced concrete buildings using pre-fabricated SIFCON composite blocks.

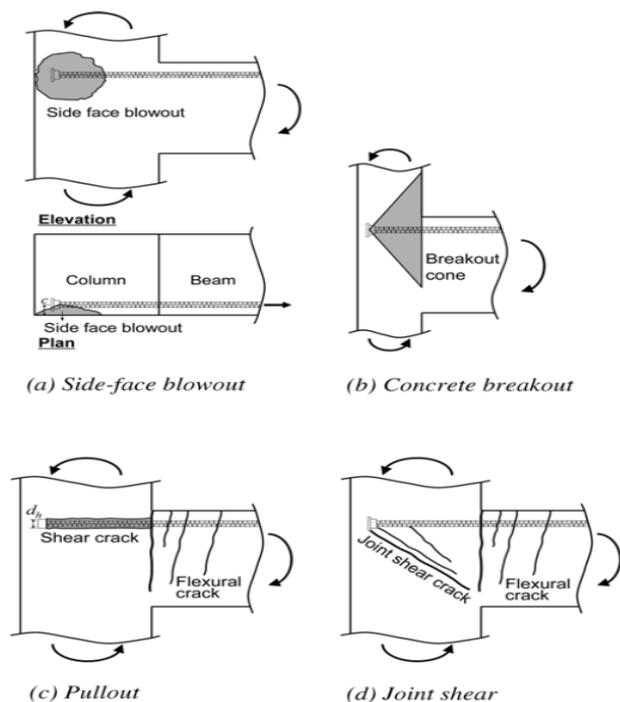


Figure 4: Failure modes joint due to headed bar

Literature Review

Park & Paulay (1975) recommend the detailing of joints for the earthquake resistance structures using bent-up bars, stub-beam with bent-up bars and mechanical anchorage for serving as anchorage as well as effective ties for confinement in the joint core of the exterior beam-column joints. Paulay (1989) suggests that, as in the case of linear element, joint shear

Testing Program

The specimens are divided into two groups, each group comprising of two specimens, with different anchorages. The specimen with T-type headed bar followed as per ACI-352 (2002). The specimen with conventional 90° bent hook followed as per ACI-318 (2011) and the specimen with full anchorage followed as per Exterior beam-column joint study 1187, IS-456 (2000) is designated as shape detail. To relieve steel congestion within the joint while promoting proper

bearing, use of a circular head with (A_{brg}/A_b) of approximately 4 is common. Prior experimental research 4,7,8 has shown that this head size is appropriate to ensure anchorage both in the elastic and inelastic deformation ranges, and a minimum ratio of $(A_{brg}/A_b) = 4$ is specified by ACI 318-08. The head size standard of $(A_{brg}/A_b) = 4$ is relatively easy to maintain in practice. The size of $(A_{brg}/A_b) = 9$ was originally recommended by the previous 1998 version of ASTM A970,9 which is often impractical; for this reason, the specification that requires (A_{brg}/A_b) of at least 9, no longer exists in ASTM A970-04.

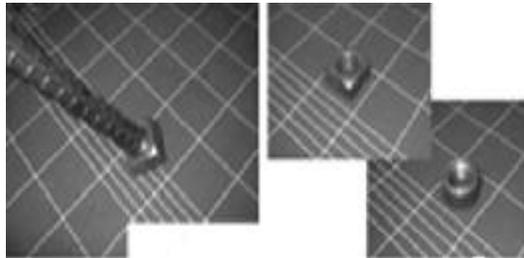


Figure 5: Different head size

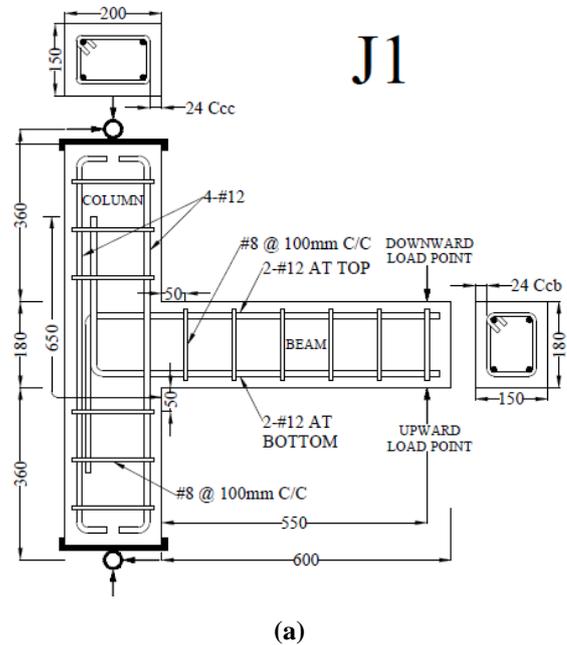
Material Properties

Headed deformed bars with a bar diameter of 12 mm were used in this study. Three types of head geometries used for pullout tests. For reversed cyclic tests of the beam column joint, small circular heads were chosen based on the pullout test results. All headed bars and heads were made of steel with a specified yield stress f_y of 415 MPa. The specified concrete strength was 30 MPa. Headed and hooked bars used for seismic tests had similar actual yield strengths of $1.2f_y$ and $1.15f_y$, respectively, where f_y is the specified yield strength of 400 MPa. Different concrete mixes were used for pullout and seismic tests. For each test, two and three concrete cylinders were tested and averaged, respectively. Stress-strain relations were obtained for all 100 x 200 mm concrete cylinders and steel coupons with a length of 450 mm.

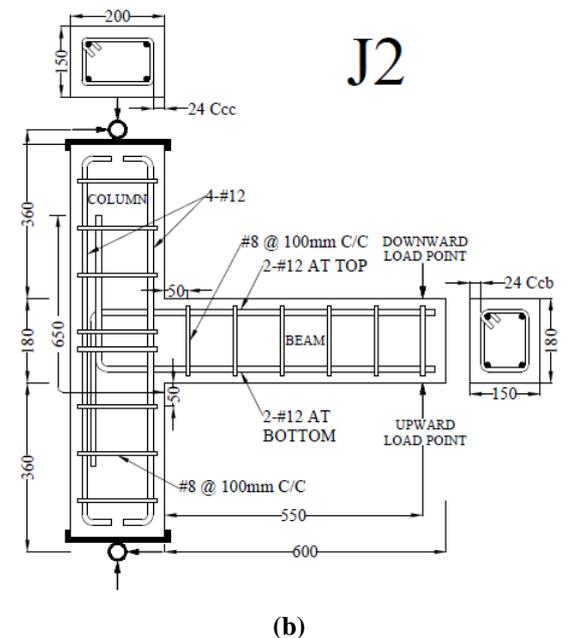
Experimental set up

An experimental program was developed to investigate anchorage behavior of headed bars. Details of the specimens are presented in Figure 6 and 7. The specimens were tested with the column in a vertical position, as shown in Figure 6 and 7 the force couples were monotonically increased until failure. The compressive force was applied to a bearing plate across the full length of the column. The tension force and compression force was applied through automatic double acting jack to the anchored headed and hooked bars. The specimens were designed in accordance with ACI 352R-02 except shape for the provisions regarding transverse reinforcement in the joint and the embedment length of a headed bar. Main test variables include embedment length and bar diameter, the size of head specimen is $(A_{brg}/A_b=2.5)$ and

the clear side cover of $2.5db$ for a beam bar in an exterior joint is a common case, providing that the diameters of column bars and hoops are equal to $1db$ and $0.5db$, respectively. Side-face blowout failure is precluded with the clear side cover of $2.5db$. For comparison, two specimens with hooked bars were tested for each headed bar diameter examined. The embedment lengths for the hooked bar specimens were chosen to be equal to the longest and shortest embedment lengths of headed bars for each diameter. Shown the figure in reinforcement cage.

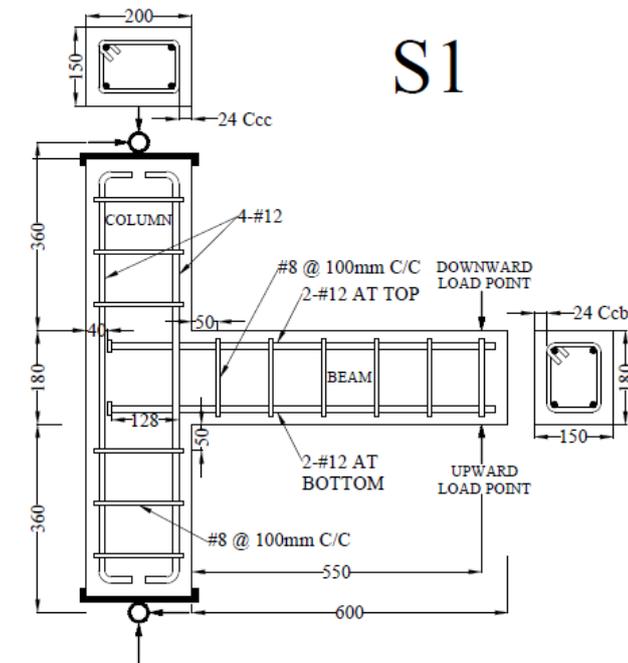


(a)

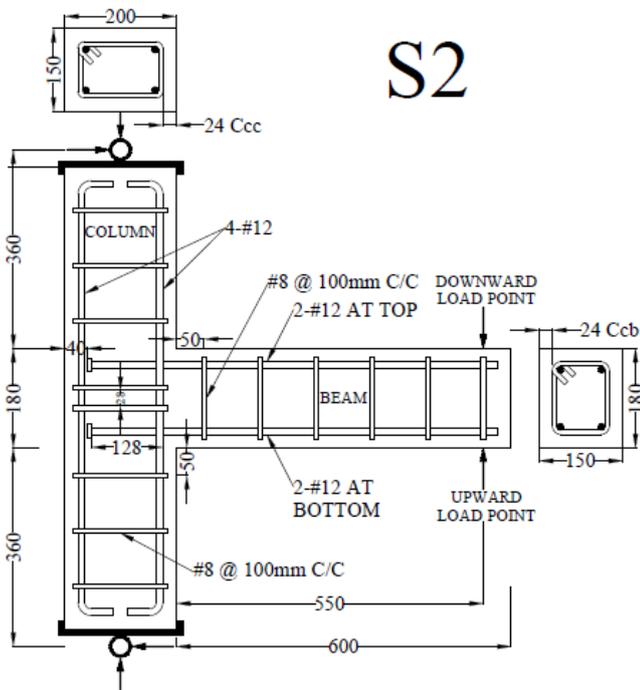


(b)

Figure 6(a) IS 13920:1993 [No Confinement],
 (b) IS 13920:1993 [with Confinement]

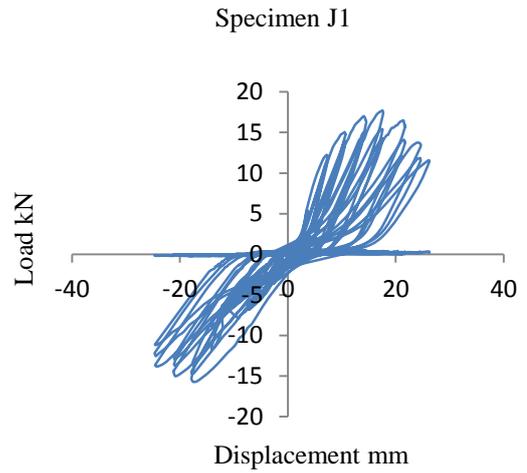


(c)

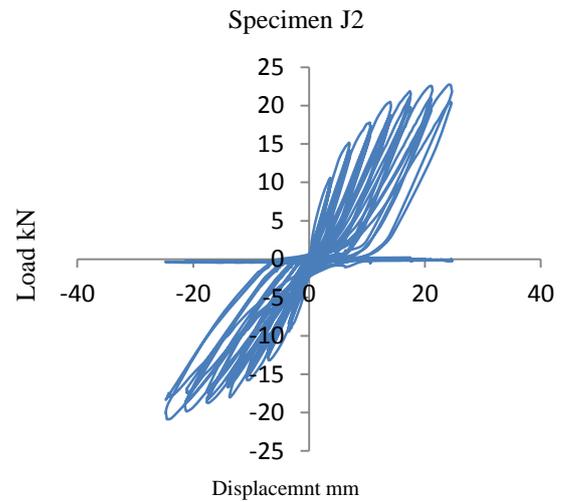


(d)

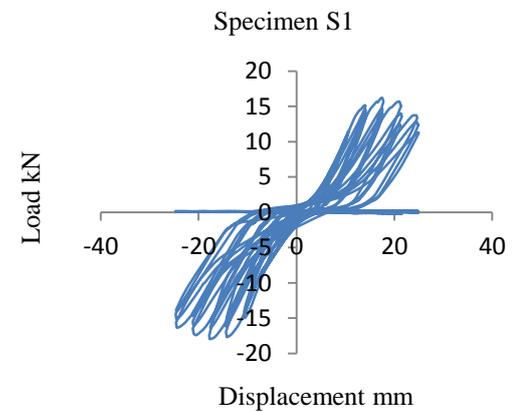
Figure 7(c) ACI-352 (2000) [No Confinement],(d) ACI-352 (2000) [with Confinement]



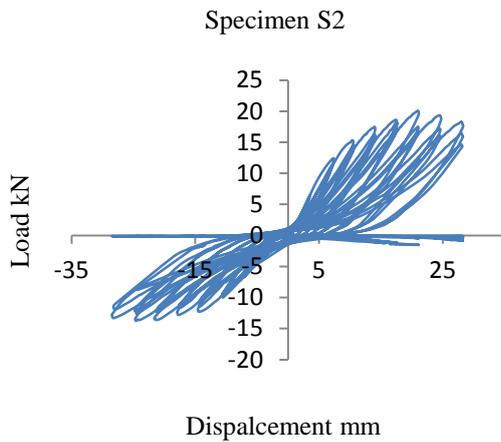
(a)



(b)



(c)



(d)

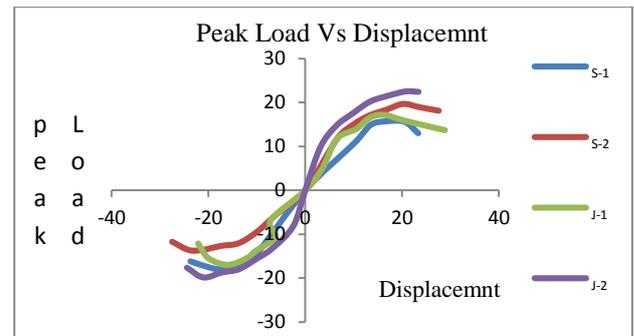


Figure 8 Peak Load Vs Displacement

Figure 7 Specimen details and hysteresis loop of exterior beam column joint(a) Hysteresis loop joint -1 (No Confinement), (b) Hysteresis loop Joint-2 (with Confinement), Hysteresis loop joint -1 (No Confinement), Hysteresis loop Joint-2 (with Confinement)

Table .1 Peak load Vs. Displacement

Specimen ID	Yield specimen (mm) Δy	Ultimate loading (kN) P_u		Average ultimate Load kN(P_u)	Ultimate displacement (mm) (Δu)		Average ultimate Load kN(Δu)	Average displacement ductility factor (mm) ($u = \Delta u / \Delta y$)	Average stiffness kN/mm ($K = P_u / \Delta y$)
		+ve	-ve		+ve	-ve			
J-1 13920 Bent-up bar (No Ring)	3.91	17.18	16.98	17.08	23.83	22.13	23.98	5.87	4.39
J-2 13920 Bent-up bar (with ring)	3.09	22.51	19.85	21.18	23.44	24.47	23.95	7.75	6.85
S-1 headed bar with steel fiber (No Ring)	10.99	17.97	17.97	17.97	23.7	23.7	23.7	2.15	2.15
S-2 headed bar with steel fiber (with ring)	6.636	19.64	13.62	16.63	28	28	28	4.22	4.22

RESULT AND DISCUSSION

The seismic tests were conducted to investigate the applicability of headed bars with threaded and welded type. The test data were assessed to examine the effect of the head size, shape and head attaching techniques on the anchorage behaviour under cyclic loads. The result from 1/3 scale seismic testing of a joint with headed bars were evaluated by comparison with a companion specimen with hooked bars and by using the acceptance criteria of ACI 374.1-05. Based on the test result, the following conclusions were reached.

- 1) No brittle concrete break out occurred for any headed bars in pullout, provided that the head size (A_{brg}/A_b) was at least 2.5 and embedment depth was $11d_b$.
- 2) The loading condition (monotonic Vs. repeated), head shape (circular Vs. Square), and head-attaching techniques (threading Vs. Welding) did not influence the anchorage behaviour substantially during testing.
- 3) The headed bar with large heads ($A_{brg}/A_b = 4.2$) exhibited higher anchorage strengths than the heads bar with small heads ($A_{brg}/A_b = 2.6$ to 2.9)

- 4) The satisfactory seismic performance, such as suppressed joint shear deformation, indicate that reduced joint confinement does not influence adversely on the headed bar anchorage in the interstory joints, likely due to the different bearing stress transfer path provided by the external truss formed above the joint. This implies a possibility that the amount of transverse reinforcement in the exterior interstory joint may be reduced when headed bars are utilized (versus hooked bars).

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