ACHIEVING DUCTILE BEHAVIOR OF MOMENT CONNECTIONS—PART II

The results of additional tests provide further confirmation that weld metal toughness is key in achieving ductile performance of new and repaired moment connections

Table 1: Connection details of test specimens

			A-2	A-3	A-4	A-2R
Beam	**Flange**	Electrode	E70T4	E7018	E70TG-K2	E7018
		Back-up bars & weld tabs	Removed	Removed	Removed	Removed
		Reinforcing fillet weld[1]	3/8” E71T-8	3/8” E7018	3/8” E70TG-K2	3/8” E7018
	Web	Bolted	10 bolts A325 1” dia.	No	No	10 bolts A325 1” dia.
		Welded	No	E7018[2]	E71T-8[2]	1/2” fillet E7018[3]
Panel zone		Continuity plates	No	Yes	Yes	Yes
		Doubler plate	No	No	No	No

[1] On both weld root and toe

[2] Complete-joint-penetration groove weld connecting beam to column flange

[3] Reinforcing fillet weld around three sides of web shear tab

Table 2: Charpy V-notch toughness of weld metals used

Type of Electrode		**E70T4**	**E70TG-K2**	**E70TG-K2**	**E7018**
Min. CVN toughness (ft.-lbs.) at -20 degrees F		none req.	20	20	20
CVN toughness from laboratory test* (ft.-lbs.)	-20 degrees F	NA**	20	NA	110
	at 70 degrees F	10	57	NA	144

* Using samples fabricated along with the test connection

** Not available

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(This article presents the results of two follow-up tests on full-scale moment connections. The results of the first three tests were reported in the January 1996 issue. Of the two specimens, one is a fully welded connection fabricated with E70TG-K2 flux cored electrode and the other is a connection that was previously tested to failure (weld fracture)and subsequently repaired by replacing the cracked E70T-4 welds with E7018 weld metal, which has a specified minimum notch toughness. Both connections performed well and demonstrated sufficient ductility and energy dissipation capacity.)

THE TWO NEW MOMENT CONNECTION SPECIMENS STUDIED, identified as A-4 and A-2R, are each composed of an A36 W36x150 beam (flange F_y = 38 ksi, web F_y = 46 ksi, tensile coupon test) and an A572 Gr. 50 W14x311 column (F_y = 58 ksi, mill report). However, the specimens were different in connection detail.

Specimen A-4 represented the details of a fully welded moment connection fabricated with E70TG-K2 flux cored electrode, while A-2R simulated a connection that was damaged by cracks severing beam flanges from the column and then repaired using E7018 as the replacement weld. A-2R was the A-2 from the previous study, which had failed due to brittle fracture of the flange welds. For the second test, 8-in. lengths of the cracked beam flanges—including the fracture surfaces—were removed. The removed flange segments were replaced with two pieces of A36 plate. They were welded to the beam flanges and web and then to the column face with complete-joint-penetration groove welds.

Table 1 summarizes the connection details of specimens A-4 and A-2R. For comparison, the connection details of specimens A-2 and A-3, tested earlier, also are given. The required Charpy V-notch toughness values for the weld metals used and the values determined from laboratory tests are given in Table 2.

TEST RESULTS

The specimens were tested dynamically using the same test setup and procedure as in the previous tests (Figure 1). A lateral bracing system was installed before the start of the tests to prevent lateral torsional buckling of the beam. Consequentially, lateral deformation of the beam in the plastic range was better restrained as local buckling developed in comparison with specimen A-3 (tested earlier).

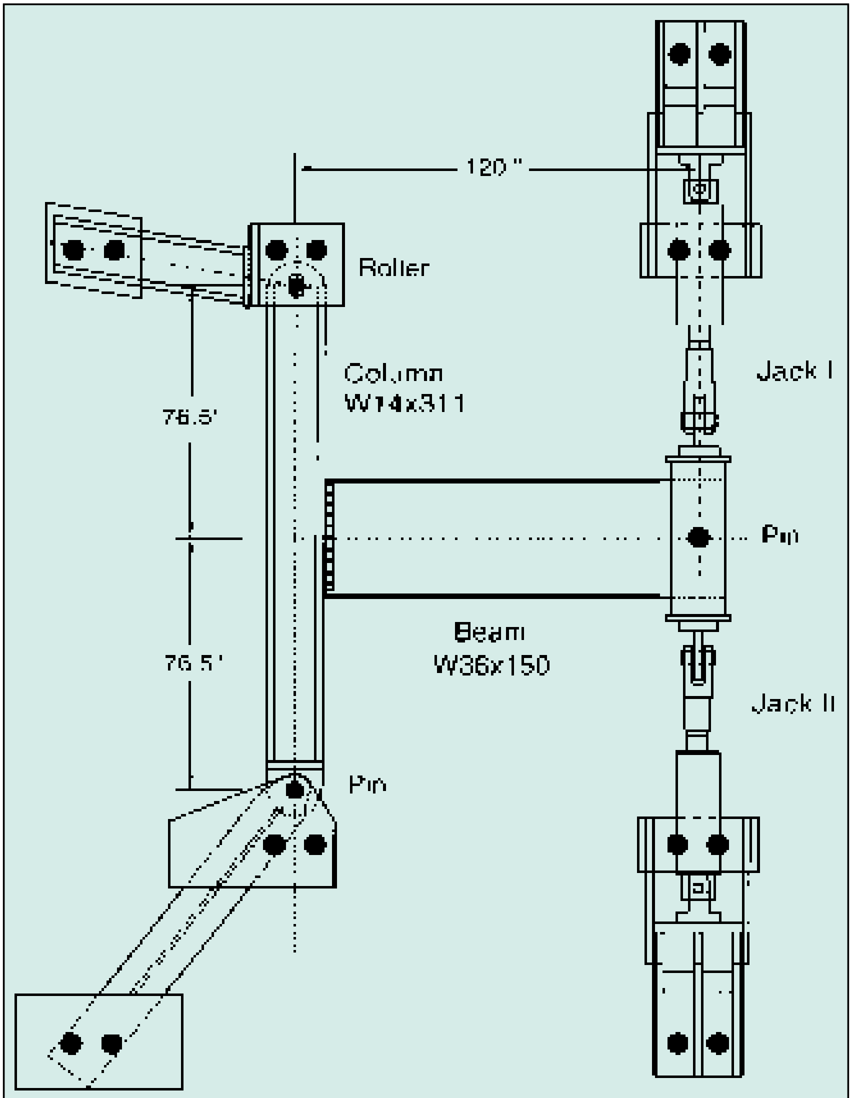


Figure 1: Full-scale moment connection test specimen and setup

Table 3: Connection performance

Specimen	Max. Bending Moment at Column Face	Max. Displacement (inches)	Plastic Rotation (Radian)
A-2	$0.92M_p$	2.00	0*
A-3	$1.22M_p$	3.84	2.57%
A-4	$1.21M_p$	4.91	3.74%
A-2R	$1.41M_p$	4.96	3.79%

* There was no plastic hinge rotation because the maximum bending moment reached was less than M_p, even though some minor plastic deformation was observed near the weld access holes

Specimen A-4 provided excellent plastic deformation and energy dissipation capacity. As shown in Figure 2, extensive yielding and local buckling deformations were observed in the beam web and flanges during the large displacement cycles. Because of inelastic local buckling, the specimen experienced appreciable strength degradation. The test was stopped after three cycles of $5\Delta_y$, where Δ_y is the yield displacement of the specimen. Near the end of the test, a few small cracks were observed at the weld toes of the beam flange and web connec-

Figure 2: *Beam yielding and buckling of Specimen A-4 (E70TG-K2 electrode)*

Figure 3: *Stable crack at access hole of Specimen A-4 after large rotation*

tions. These cracks were, however, very stable and did not propagate rapidly. Figure 3 shows a crack that formed at a weld access hole.

The repaired connection, A-2R, showed an even greater load-carrying capacity than the original specimen A-2, and also exhibited good ductility and energy dissipation capacity. Extensive yielding in the beam web and flanges was observed in a large area centered about 16 in. (approximately one-half d) from the column face (Figure 4). The location for the yielding and buckling area was farther from the column face than in specimens A-3 and A-4. Therefore, specimen A-2R carried the largest bending moment at the column face of all the tested specimens. There are two reasons for the shift of the yielding and buckling region. First, the 1-in-by-12-in.-by-8-in. A36 steel plates had slightly higher yield strength and were also thicker than the beam flange. In addition, the ½-in. fillet welds connecting the shear tab to the beam web moved the beam web buckling region away from the column face. The connection failed after cracks had formed at the weld toes adjacent to the weld access holes. These cracks gradually extended in a stable manner as the cyclic load was increased. Eventually, the crack in the bottom beam flange penetrated its full thickness and severed the beam flange from the flange replacement plate (Figure 5).

The load vs. displacement hysteresis loops are plotted in Figure 6 for specimens A-2, A-3, A-4 and A-2R. Table 3 compares the maximum bending moment, the maximum beam displacements and the maximum plastic beam rotations of the four specimens. The bending moment at the column face is expressed as a function of M_p, the plastic bending moment of the A36 W36x150 beam. The displacement is the beam deflection measured at the point of load application. The plastic rotation was calculated for all the specimens by assuming a plastic hinge formed at a half beam depth away from the column face. The data listed in Table 3 are those obtained just before the final fracture of a flange or the end of a test.

CONCLUSIONS

The results presented in this article provide further confirmation that ductile behavior can be achieved in welded moment connections if electrodes with mandatory toughness requirements are used in making welds in conjunction with improved detailing. Further research is necessary to determine what minimum toughness is required.

- ✔ Test A-4 indicates that the self-shielded, flux-cored electrode E70TG-K2 may be used to fabricate moment connections that develop good ductility and energy dissipating capacity. Further research is needed to extend this conclusion to other self-shielded flux-cored electrodes with similar toughness properties.
- ✔ A comparison of specimens A-2, A-3 and A-4 suggests that there is a need to impose a fracture toughness requirement for weld metals for future construction in order to insure that premature weld fracture, as observed in most of the steel connections damaged in the Northridge earthquake, will not occur.
- ✔ Test A-2R indicates that connections with fractured beam flange welds can be repaired by removing the damaged welds and rewelding the flanges with the tougher electrodes.
- ✔ Test A-2R also indicates that bolted web connections reinforced with fillet welds around the shear tab can behave as well as a fully welded web connection. Connecting the shear tab to the beam with fillet welds on three sides delayed the beam web buckling and improved the force transfer mechanism in the overall connection.

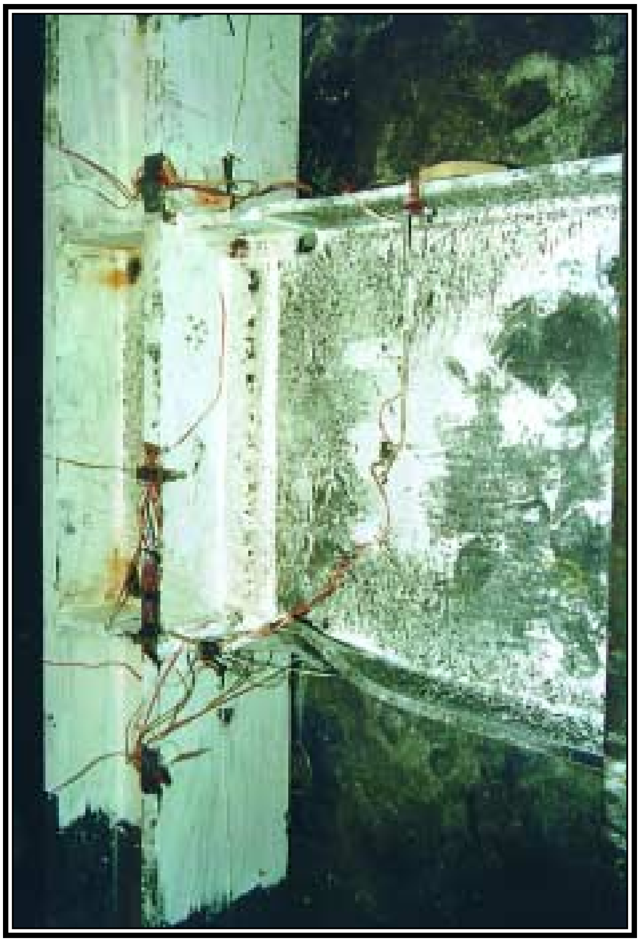


Figure 4: *Beam yielding and buckling of Specimen A-2R (E7018 electrode)*

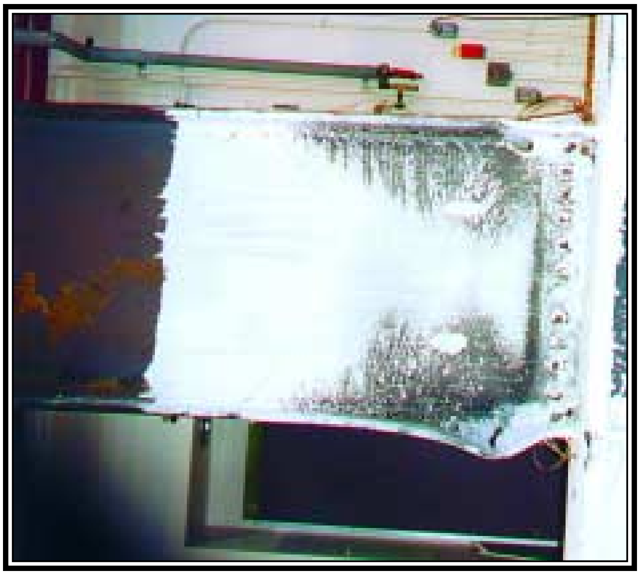
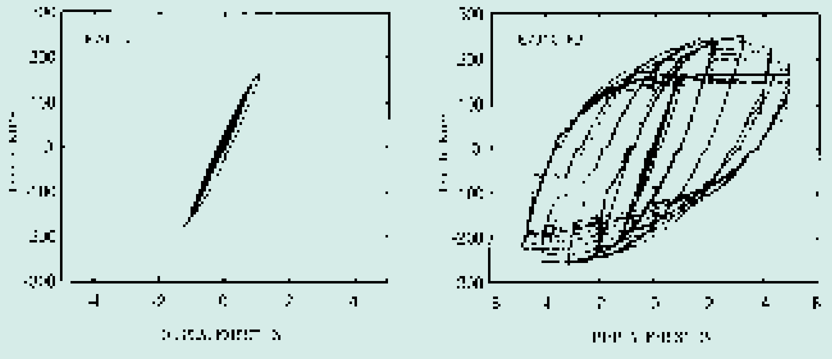
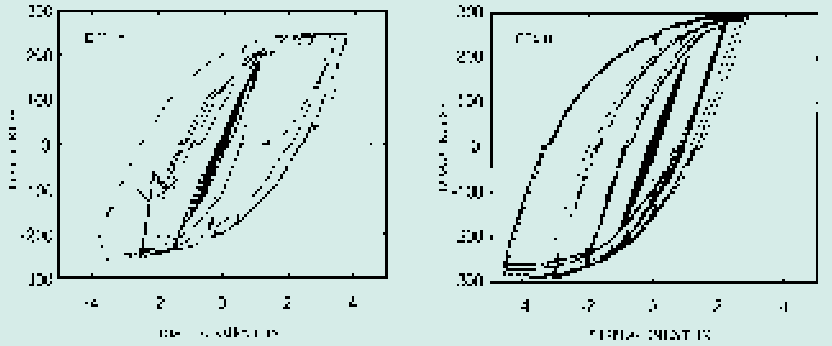


Figure 5: *Fracture failure of Specimen A-2R at high ductility levels*



(a) Specimen A-2 (b) Specimen A-4



(c) Specimen A-3 (d) Specimen A-2R

Figure 6: Load vs. displacement relationships of test connections

- ✔ The use of continuity plates and enhanced web connections can significantly contribute to improvements of the behavior of welded moment connections.

The conclusions presented are based on the limited tests reported here and in a previous article. The tests represented exterior connections joining an A36 beam and an A572 (Gr. 50) column. Further research is necessary to examine the behavior of interior connections as well as connections having different combinations of beam and column materials.

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