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Mechanical Splices for Seismic Retrofitting of Concrete Structures

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Abstract. As an alternative to lap splicing, mechanical splices can be used for retrofit purposes. They are generally most economical than traditional lap splices when available spacing or length makes laps difficult to utilize. Mechanical splices are frequently used in new construction. However, their use is limited and not practical for use in retrofitted structures. However, if the bars to be joined do not need to be threaded in order to be connected with a special mechanical splice, such mechanical splices can be useful. It is presented a proposal of using two types of mechanical splices for retrofit purposes. Cycle Tension and cycle tension-compression tests are presented and discussed. It was found that mechanical splices are suitable and have acceptable response under seismic loads.

1. Introduction

Lap splices depend on quality of concrete and/or confinement by transverse reinforcement. Mechanical splicing provides load path continuity in the reinforcement, independent of the condition of the concrete. The one shown in figure 1 is composed of a hollow threaded steel tube to couple two reinforcing bars with threaded ends. This type of splice is not suitable for retrofit purposes since bars need to be threaded and threading bars embedded in concrete is nearly impossible.



Figure 1. Type of mechanical splices using threaded bars for new construction.

ACI 318 -14 [1] indicates that tension lap splices are not allowed for #14 or #18 bars. Lap splices add to congestion of the concrete section in elements near beam-column joints. An alternative solution is the use of mechanical splices.

Poorly confined lap splices cannot develop large ductility. The failure is brittle once slip between the spliced bars begins. Figure 3.3 represents the differences of deformation responses under tension axial load of a poorly confined lap splice and mechanical splice. Elwood, et.al, on the update of ASCE/SEI 41 Concrete Provisions [2] consider also the deficiencies related to the use of lap splices, especially for cases where the splice length is shorter than required by the code.

ACI 318-14 [1] code requires that mechanical splices develop at least $1.25f_y$ (f_y : nominal yield



strength). For seismic applications, Type 1 splices must develop $1.25f_y$, however Type 2 splices must develop the specified tensile strength of the bar.

2. Mechanical splice for retrofitted uses - Replacing damaged existing bars

After an event that causes damage to a structure, the damaged bars may have to be removed if they are buckled and bent. Figure 2 shows damaged bent bars which can be repaired by installing new bars that are mechanically spliced (coupled) to the existing bars. For this study, splices which do not need end-bar preparation were considered. Once the bar is removed the splice sleeve can be positioned over the existing bars and a new bar is introduced where the bent bar was removed. The splice sleeve is then moved to center on the location where the existing and new bars meet. The bars are held tightly in the sleeve with bolts that are torqued to a prescribed level. The system is designed to develop 100% or 125% of nominal yield strength of the bars as ACI 318-14 [1] requires. There are different types of couplers that vary according to the process of the installation.

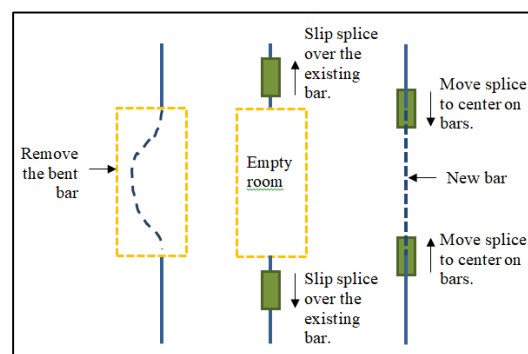


Figure 2. Advantage of mechanical splice to replace bent bars.

Two different mechanical splice configurations were evaluated. The first is the Short Mechanical Splice Lenton SMS and Long Mechanical Splice Lenton LMS produced by Erico. There are different number of bolts depending on size of bar. Short Mechanical Splice - SMS consists of a 6.8 in. steel cylinder with 6 bolts. These bolts are located into one longitudinal line which go through along the splice. Seating of the pointed bolts reduced the cross sectional area of the bar about 5%. The material used for this type of splice is also Grade 60. Long Mechanical Splices – LML consists of a 10 in. length steel cylinder with 8 bolts, two outer bolts with rounded ends and 6 interior bolts with pointed ends. Similar to the short mechanical splices, the rounded and pointed end bolts are located along a plane one through the splice. Rounded point bolt at the end of the sleeve in intended to prevent the bars from fracturing in the splice so that the requirement for specified ultimate strength is achieved. Figure 3 shows SMS and LMS, and figure 4 shows the interface between the rebar and the mechanical splice.

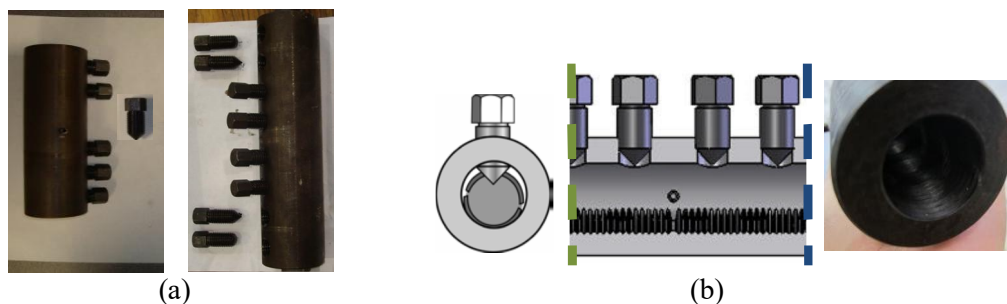


Figure 3. Short (left) and Long (right) Mechanical Splices for retrofitting purposes (a), Bolts tighten the bar with the interior sleeve of the mechanical splice (b).

3. Mechanical splices in special moment frames in high seismic zones

The manufacturer's data for the mechanical splices indicate that the long mechanical splice meets the requirements Type 2 and Type 1 splice (large deformation and high strength). The bars to be coupled should be A-615 and A-706. For short mechanical splice, it meets the requirement for Type 1 splice when the bar is A-615 (high strength), however this short mechanical splice could be used as Type 2 when the bar is A-706 (large deformation). Table 1 summarizes the requirements for the selection to the type of mechanical splice.

Table 1. Provisions for the selection of the mechanical splices [1].

Type of Splice	ASTM Specification for bars	ACI-318 Seismic Provisions Type (location)	Requirement Strength of bars (ACI 318-11)	Requirement Strength of bars (AASHTO)
Short Mechanical Splice	A-706	Type 2	1.25 fy & 1.0fu	1.35fy
Short Mechanical Splice	A-615 & A-706	Type 1	1.25 fy	1.35fy
Long Mechanical Splice	A-615 & A-706	Type 1 and Type 2	1.25 fy & 1.0fu	1.35fy

For rehabilitation purposes, it should be observed that these bars can come from structures that may be quite old. Properties of the bar are very important in order to choose the appropriate mechanical splice. Table 2 shows comparisons of different old types of reinforcing bars. Long mechanical splices are capable to work with old bars A-615 of building build from 1968, and short mechanical splices are allowed to be used with bars used in structures build from 1974. However, if it is used a bar with the same characteristics of A-615 (min yield and tensile strength), the long mechanical splice can be applied. An example is the bar type is A432 Grade 60 which has same value for minimum yield and tensile strength, then it can be repaired a structure built after 1959 using the long mechanical splices.

Short mechanical splices could be used to retrofit columns for structures build after 1974, considering the splices as Type2. However, considering the short mechanical splices as a Type 1, they can be used in the rehabilitation of structures built after 1959, similar to the long mechanical splice case.

Table 2. Reinforcing bars 1911 to present, ASTM specification, minimum Yield and Tensile Strengths in psi [3].

ASTM Spec	Years		Steel Type	Grade 33 (Structural)		Grade 40 (Intermediate)		Grade 50 (Hard)		Grade 60		Grade 75	
	Start	End		Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile
A15	1911	1966	Billet	33,000	55,000	40,000	70,000	50,000	80,000				
A408	1957	1966	Billet	33,000	55,000	40,000	70,000	50,000	80,000				
A432	1959	1966	Billet							60,000	90,000		
A431	1959	1966	Billet									75,000	100,000
A615	1968	1972	Billet			40,000	70,000			60,000	90,000	75,000	100,000
A615	1974	1986	Billet			40,000	70,000			60,000	90,000		
A615	1987	Present	Billet			40,000	70,000			60,000	90,000	75,000	100,000
A16	1913	1966	Rail					50,000	80,000				
A61	1963	1966	Rail							60,000	90,000		
A616	1968	1999	Rail					50,000	80,000	60,000	90,000		
A160	1936	1964	Axle	33,000	55,000	40,000	70,000	50,000	80,000				
A160	1965	1966	Axle	33,000	55,000	40,000	70,000	50,000	80,000	60,000	90,000		
A617	1968	1999	Axle			40,000	70,000			60,000	90,000		
A996	2000	Present	Rail Axle			40,000	70,000	50,000	80,000	60,000	90,000		
A706	1974	Present	Low-Alloy							60,000	80,000		
A955M	1996	Present	Stainless			40,000	70,000			60,000	90,000	75,000	100,000

4. Test Program

4.1. First Set of Mechanical Splices - Cyclic Tension Axial Load Test

A set of 4 spliced bars was tested under cyclic tension axial load. Two Long Mechanical Splice and two Short Mechanical Splices were tested [4]. The nomenclature used for each specimen is MS-L1 and MS-L2 for the two long mechanical splices and MS-S1 and MS-S2 for the short mechanical splice. Table 3 summarizes the specimens tested. ASTM specification of each bar is listed. Length of the specimen and extensometer used is also listed too. The type of steel bar was A-706 Grade 60 for all the new bars used in the specimens. It was studied the Type 2 mechanical splice for Short Mechanical Splices and Long Mechanical Splices. Figure 4a shows the test setup.

Table 3. Specimen details for the cyclic tension test.

Specimen	Condition		ASTM Specification	
	Top Bar	Bottom Bar	Top Bar	Bottom Bar
MS-L1	New	New	A-706	A-706
MS-L2	New	New	A-706	A-706
MS-S1	New	New	A-706	A-706
MS-S2	New	New	A-706	A-706

It was found that the SMS specimens failed at the contact of the point end bolt because the reduction of bar's area due the pointed bolt, however the rupture of LMS specimens was at the rebar 4in outside the sleeve since the rounded bolts do not reduce the bar's area as pointed ones do. Figure 5b shows failure pattern of both types of mechanical splices.

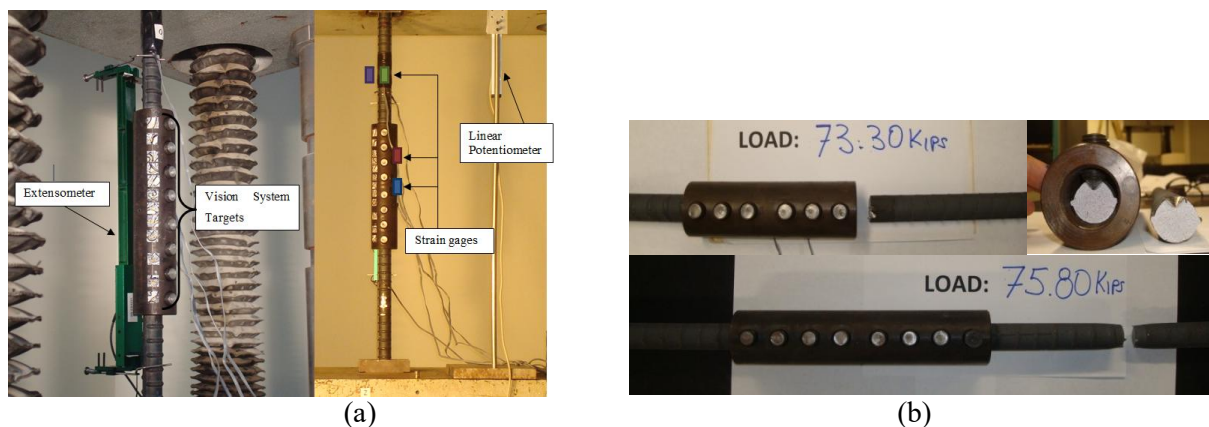


Figure 4. Instrumentation for MS-L1 Test (a), Failure pattern for SMS and LMS (b) [5].

Table 4 presents the different values in loads response of each case of specimen. It can be seen that the value of yielding stress is similar for long and short mechanical splice. The fractures stresses are very similar among each other because the failure of each specimen was under the rupture of the steel bar. It is also noticed that both short and long splices meet the requirements of ACI318-11 and AASTHO for Type 1 and Type 2 splices.

Table 4. Results of first set of mechanical splice and acceptance criteria [4].

Specimen	ASTM bar	0.79 in ²		Type of Failure
		Yield Stress of bar (fy) (ksi)	Fracture Stress of bar (fu) (ksi)	
MS-L1	A-706	60.92	96.75	Rupture of bar 4in above the splice
MS-L2	A-706	61.36	96.51	Rupture of bar 4in above the splice
MS-S1	A-706	62.22	87.83	Rupture of bar in edge of splice
MS-S2	A-706	62.54	93.33	Rupture of bar in edge of splice

Every mechanical splice meets the requirements for Type 2 and Type 1 splice

4.2. Second Set of Mechanical Splices - Compression-Tension Cyclic Axial Load Test

This set of tests includes 6 mechanical splices, 2 long mechanical splices and 4 short mechanical splices. In the two first specimens, new bars were used, and in the last 4 specimens with short mechanical splices, a new bar and a bar previously yielded were used together. This is reproducing the condition of a member which was repaired after suffered buckling of the longitudinal rebar. The nomenclature used for each specimen is MS-L3 and MS-L4 for the two long mechanical splices and MS-S3, MS-S4, MS-S5 and MS-S6 for the short mechanical splices. A-615 Grade 60 bars were used. Table 5 contains how previously deformed the rebar was for each specimen of SML and LMS. The tension-compression machine and the installed specimen is shown in Figure 5a.

Table 5. Results of first set of mechanical splice and acceptance criteria [4].

Specimen	Condition		ASTM Specification	
	Top Bar	Bottom Bar	Top Bar	Bottom Bar
MS-L3	New	New	A-615	A-615
MS-L4	New	New	A-615	A-615
MS-S3	New	4Yield	A-615	A-615
MS-S4	1.5Yield	New	A-615	A-615
MS-S5	4Yiel	New	A-615	A-615
MS-S6	New	1.5Yield	A-615	A-615

During the tests, there was no fracture of any part of the mechanical splices. The bolts behaved as one piece together with the mechanical splice. However, buckling of the bars appeared when the deformation reached $-3\epsilon_y$ at compression loads, Figure 5b shows the specimen MS-S3 after buckling of the bar that had been previously yielded. The mechanical properties of this bar were changed under the previous compression-tension axial load test. It was reached tension deflections more of $+8\epsilon_y$ and under compression deflections more than $-3\epsilon_y$. The specimen failed by the fracture of the previously yielded bar in the contact zone with the last bolt of the mechanical splice as Figure 5c shows.

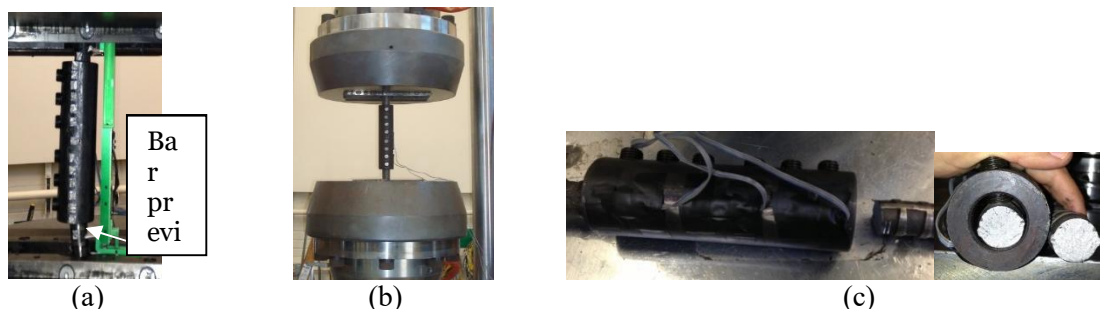


Figure 5. Test Setup for the compression-tension cycle test and details of the mechanical splices tested [4] (a), Buckling failure under compression load [4] (b), Failure under tension load: previously bar yielded was fractured [4](c).

It can be seen at Figure 6 the hysteretic response of the LMS and SMS specimens, where a drop of load while the direction of load is presented. It may be due la accommodation of both bars and the sleeves together to the bolts of the splice, especially the previously yielded bars. Table 6 summarizes the values of axial load and strain for tension and compression yielding loads and strain values

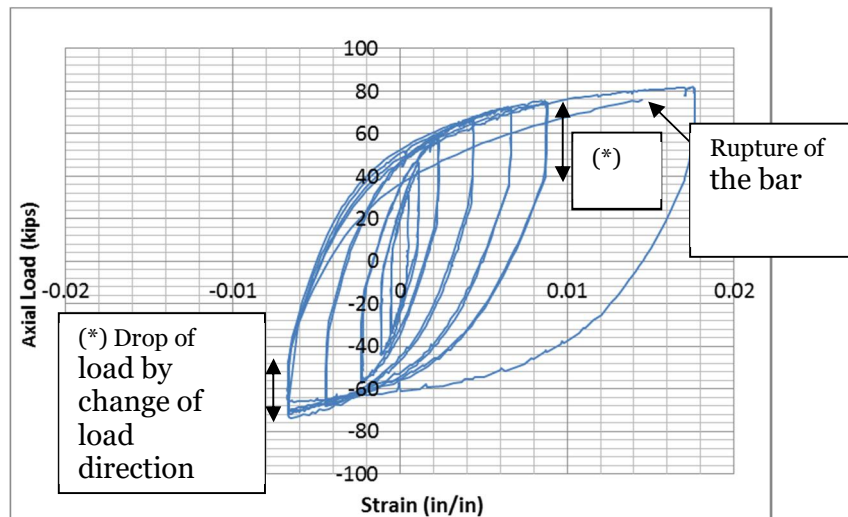


Figure 6. Strain Deformation of the system measured by the Extensometer [5].

Table 6. Results of first set of mechanical splice and acceptance criteria [4].

Specimen	Fracture Stress of bar (fu) (ksi)	Meet requirements for Type 1 ?	Meet requirements for Type 2 ?	Type of Failure
MS-L3	109.24	Yes	Yes	Rupture of bar above the splice
MS-L4	109.54	Yes	Yes	Rupture of bar above the splice
MS-S3	96.77	Yes	Yes	Rupture of 4 Yield bar on the edge of splice
MS-S4	85.75	Yes	No	Rupture of 1.5 Yield bar on the edge of splice
MS-S5	72.09	No	No	Shear failure of the bolts on the new bar zone
MS-S6	82.76	Yes	No	Rupture of 1.5 Yield bar on the edge of splice

#8 bar Grade60 A-615

5. Conclusions

For selection of mechanical splice for the rehabilitation of columns, short mechanical splice behavior proved to be suitable for hinge areas with large deformations and high forces especially where there may be difficulty installing the long couplers. These splices can satisfy Type 2 and Type 1 splice requirements if A-706 is used. However, the long mechanical splices should be used wherever there is sufficient room for installation and are suitable for both A-615 and A-706 bars.

More test data is recommended to optimize mechanical splices. The behavior of short splices might be improved if the pointed end of the last bolt is replaced with a rounded end. The reduction of the bar area will not be as great and the splice may meet the requirement for Type 2 splices using A615 bars.

It is also recommended that long mechanical splices using previously yielded bars and new bars be tested. Despite the fact that long mechanical splices performed adequately under high loads and large deformations, previously yielded bars were not tested in the long splices.

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