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EFFECT OF USING HIGHLY CONFINED SHORT LAP-SPLICE REINFORCEMENT ON SEISMIC PERFORMANCE OF EXTERIOR BEAM-COLUMN JOINT

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ABSTRACT

The present paper aims to examine the behavior of exterior beam-column joints with different reinforcement details of their columns: continuous and lap splice longitudinal bars were adopted as design parameter. The experimental program was carried out at the Concrete Research Laboratory at Housing and Building Research Center in Egypt; included three exterior reinforced beam column joints that were tested under the effect of quasi-static cyclic loading. One sample was designed according to the provisions of the current seismic design codes and served as a control sample. Columns of the other two samples were detailed with well confined shorter lap spliced longitudinal reinforcement. The overall behavior of the beam-column joints and conclusions are discussed in this paper.

Key words: Lap-splice, beam-column, confined, exterior joint, seismic.

1. Introduction

The lap splice in the reinforced concrete columns in the old buildings was usually designed as compression lap splice, usually from 20 to 24 times of bar column main steel reinforcement, and just above slab and not confine properly.

Since 1970, many researchers studied the behavior of columns with lap splice like: Aboutah et al. [1] tested specimens had a splice length of 20 d_p and detailed according to the provisions of ACI318-63.The test results revealed that the reference samples with short lap splice exposed to the collapse because of poor of bond before reached to their capacity moments at the critical section

Lynnet et al. [2], He studied eight samples to study the behavior of the columns, of which three samples were lap splice length between 20 to 25 times of bar column main steel reinforcement and located at base of column, he observed that all sample failed in shear.

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2. Research objectives

Study effect of column longitudinal reinforcement details, e.g. continuation or lap-splice details of steel bars above the column-beam joint, affect the performance of a well detailed beam-column joint? This study was selected length of lap splice $20d_p$ times as pervious researchers [1]and [2] and also $15d_p$ to study the behavior changes within comparability, but both samples well conferment by transverse reinforcement as the code requirements.

3. Experimental program

The test was carried out at the Concrete Research Laboratory at Housing and Building Research Center in Egypt. Three 2/3 scale exterior reinforced beam-column joints were tested under quasi-static displacement control technique. In all specimens the column was loaded by constant compressive axial load, while the free end of the beam was subjected to cyclic load in order to simulate the case of Seismic action [3].

Order to naming the specimens, R-CO was used to describe the control sample (continuous steel reinforcement), R-SP15 was used to describe the second sample (lap splice length is 15 d_p) and R-SP20 was used to describe the thread sample (lap splice length is 20 d_p)

3.1 Test specimens

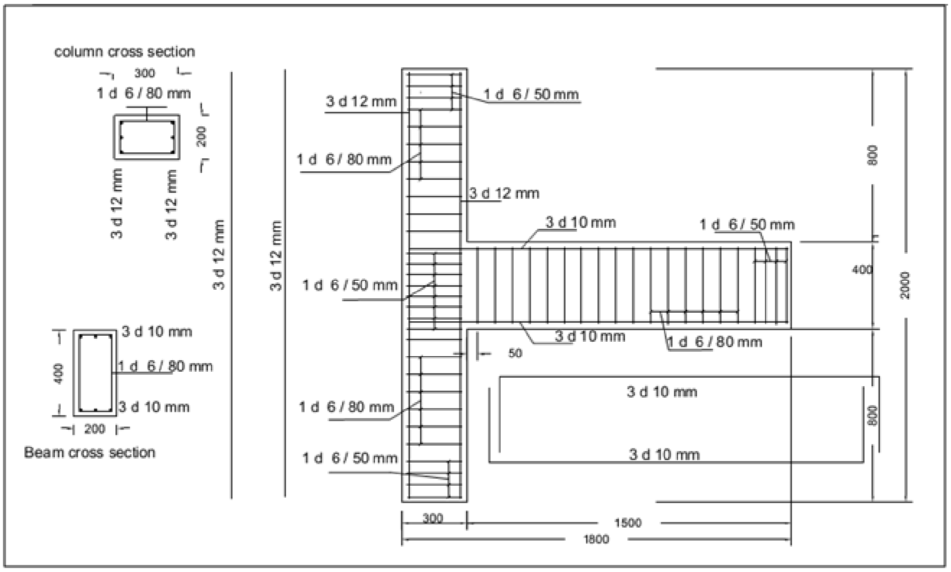
All specimens were designed according to concept of strong column - weak beam, the section capacities are designed to have the ratio $\sum M_c$ / $\sum M_b$of1.2 for all specimens, they have identical concrete dimensions, the column had a rectangular cross section of 300 mm depth, 200 mm width and 2000 mm clear height while the beam have a rectangular cross section of 400 mm depth and 200 mm width and 1500 mm clear span from column face. The first specimen R-CO is the control joint of ribbed steel and the followed two specimens (R-SP15, R-SP20) were detailed with $15d_b$ and $20d_b$ lap-splice and well-confined by transverse reinforcement. The dimensions and reinforcement details of test specimens are shown in Fig.1and Table 2.

3.2 Material properties

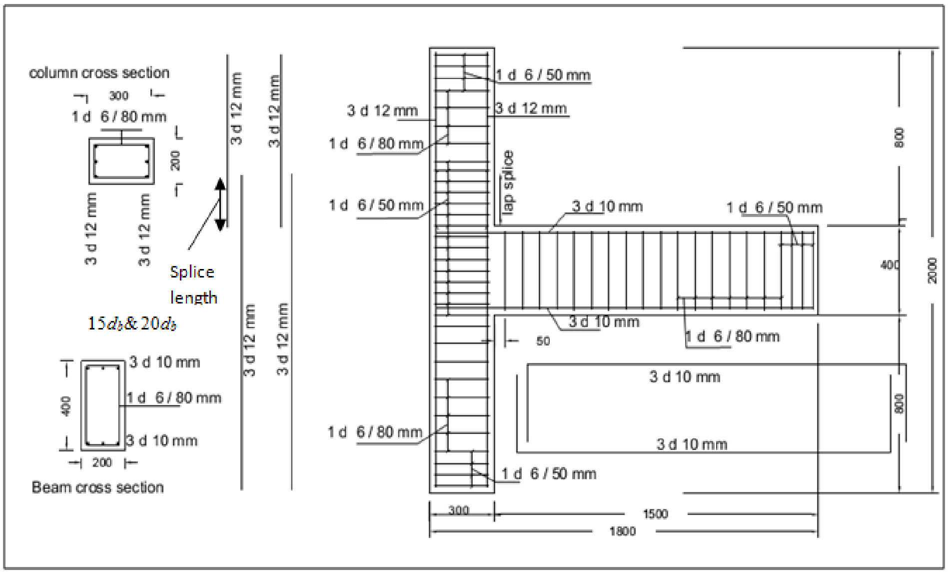
The concrete mixes used to cast the specimens were developed through trial batching using the absolute volume method. The mixes were designed to develop standard cubic strengths of 30 N/mm².the concrete mix consisted of fine aggregate, coarse aggregate, cement, water. A concrete test cube was cast for mix to determine its mechanical properties at same time as the beam-column joint. Quantities of materials required for 1 m³ was (712 kg fine aggregate, 1081 kg coarse aggregate, 350 kg cement and 192.5 liter water). High strength steel-deformed types of 10,12mm diameter and steel-smooth type 6 mm were used in specimens' reinforcement properties shown in Table 1.

Table 1.
Properties of steel bars reinforcement.

Diameter (mm)	Grade	Yield Strength (N/mm²)	Max. Strength (N/mm²)	Ultimate Strength (N/mm²)
6	24/35	335.1	531.1	379.3
10	36/52	578.1	678.3	541.8
12	36/52	509.0	644.9	565.9



a) specimen R-CO



b) Specimens R-SP15 & R-SP20

Fig. 1. Reinforcement details for test Specimens.

3.3 Test set –up

Figure 2 shows the steel frame where samples were tested at the Concrete Research Laboratory at Housing and Building Research Center in Egypt also shows the devices, which used to take readings. Types of instruments were used; load cell to measure the applied beam and column loads., A LVDT was attached to the bottom face of the beam at a point 250 mm away from the beam end, parallel to the direction of the applied cyclic load, to obtain the beam tip displacement, Electrical strain gages were used to measure the steel strains of the top longitudinal reinforcement of the beam.

Table 2.
Samples reinforcement details.

Specimen	Beam			Column				Joint	
	Long. R ft.	Transverse R ft.		Long. R ft.	Transverse R ft.		Lap splice	Transverse R ft.	
	As	Bar size (mm)	Space (mm)	Bars	Bar size (mm)	Space (mm)		Bar size (mm)	Space (mm)
R-CO	3#10 + 3#10	6	80	3#12 + 3#12	6	80	—	6	50
R-SP15	3#10 + 3#10	6	80	3#12 + 3#12	6	80	15d	6	50
R-SP20	3#10 + 3#10	6	80	3#12 + 3#12	6	80	20d	6	50

3.4 Test procedure

The samples were tested under quasi-static displacement control technique. The cyclic load was applied at the tip of beam test joints. while the column loaded by constant axial load was 0.15fc'Ag.The control sample (R-CO) was loaded by cyclic load with corresponding to displacement 1.5 mm at cycles from 1 to 3 and 3 mm displacement at cycles 4 to 5 in order to determine the value of yield displacement which occurred at sixth cycle with 6.14 mm as shown in Fig 3.

After determining yield displacement for the control joint the test was continued by loading the specimen by loads equal to multiples of the recorded yielding displacement up to failure. In this way the rest of the samples tested after knowing the value of yielding displacement

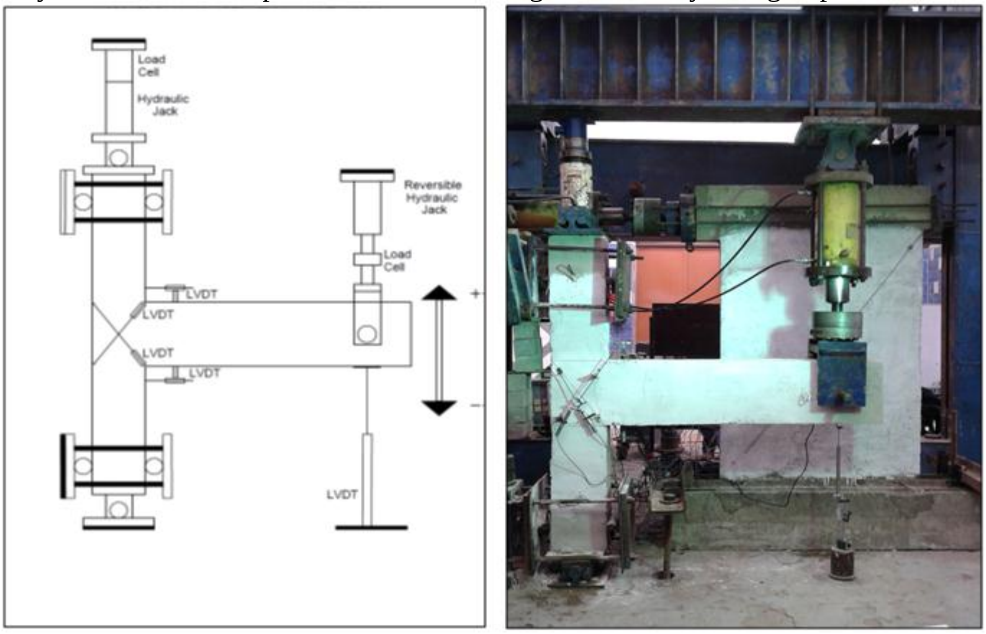


Fig. 2. Test arrangements.

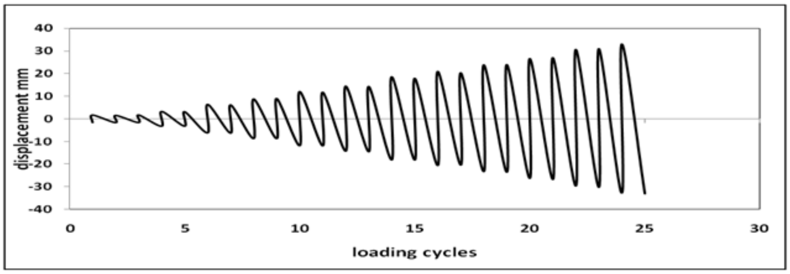


Fig. 3. Sequence of cyclic loading.

4. Test results

At the peak of each loading cycle, the cracking pattern was marked to help in obtaining information necessary for So that we can describe the failure mechanism of each test sample. All samples from the flexural cracks of poetry has suffered from the weak levels of displacement, In the cycles that followed these cracks spread along the beam to a distance measured from the column face and their widths increased The final failure of this joint was characterized by developing flexural plastic hinge over an average length measured from the beam-column interface

4.1 Crack Pattern and Failure Mode

The final crack patterns in different specimens are shown in Fig.4. In all specimens the first crack occurred from first loading cycle, then beam was loaded until the top steel bars of the beam were yielded in the loading cycle No (6, 5 and 3) for specimens R-CO,R-SP20 and R-SP15 respectively. The beam was loaded to reach the maximum load and the test continue up to strength degrade from 25% in this cycle the load reached to ultimate. Test was continuo up to failure was happened in loading cycle No23 for specimens R-CO, R-SP20 and loading cycle No 25 for specimen R-SP15. After the end of the test and raising parts of collapsed concrete were measured distance at which cracks have spread in the body of the beam and found as follows (900mm,750mm and 800mm) for specimens R-CO , R-SP20 and R-SP15 respectively. Also observed the plastic hinge occurred at the distance measured for column face (150mm, 152mm and 128mm) for specimens R-CO, R-SP20 and R-SP15 respectively.

4.2 Loads carrying capacity of specimens

The values recorded loads and displacements attendant during the various stages of testing in Table No.3, beam capacity = 34 KN .R-CO sample reached to 87% and 60% from beam flexural failure loads for positive and negative loading direction respectively (average is 73.68%) . However R-SP20 sample reached up to 97% and 71% from beam flexural failure loads for positive and negative loading direction respectively (average is 80.5%) and R-SP15 reached up to 94% and 66% from beam flexural failure loads for positive and negative loading direction respectively (average is 84.26%).[8]

This means that the lap splice has contributed to increasing the capacity of carrying loads a percentage ranging from 8% to 18% in positive and negative direction of loading and in average formula 6% for R-SP15and 10%.for R-SP20.

Table 3.
loads carrying capacity and attendant displacements.

sample	Crack				Yield		Maximum				Ultimate			
	Pcr	dcr	Pcr	dcr	Py	dy	Pmax	dmax	Pmax	dmax	Pu	du	Pu	du
R-CO	14.7	1.5	-10.3	-1.58	-23.9	-6.15	39.6	12.1	-28.4	-8.68	29.7	33.1	-20.4	-33.1
R-SP15	15.9	1.57	-16.1	-3.13	-16.2	-3.13	40.5	18.2	-31.1	-17.7	32.1	35.7	-22.7	-35.4
R-SP20	20.1	1.7	-14.4	-1.58	-32.6	-6.14	38.4	9.06	-34.8	-11.9	33	33.6	-24.3	-32.8

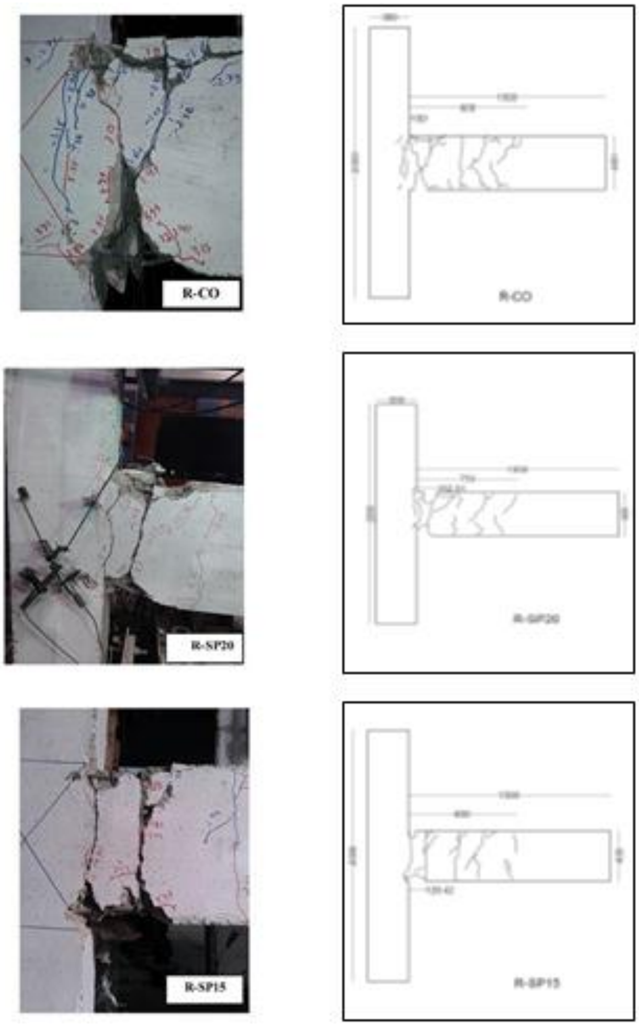


Fig. 4. Crack Patterns of test Specimen sat failure point

4.3 Hysteretic loops

The hysteretic loops of specimens are presented in the form of displacement versus corresponding applied load to beam shown in Figure from5 to 7, which have well been recognized as an effective qualitative means of evaluating the seismic performance. R-CO sample continued to resist loads until drift equal (1.88% and 1.86%) for positive and negative direction of loading respectively then the sample began in the loss their stiffness and then collapse, while R-SP15 sample resist up to drift (2.35% and 2.34%) for positive and negative direction of loading respectively and R-SP20 resist up to drift (2.18% and 2.1%) for positive and negative direction of loading respectively. From the curves observed that the joints reached to maximum drift at failure (2.65 %, 2.69 % and 2.86 %) for specimens (R-CO, R-SP20 and R-SP15) respectively.

This means that the lap splice has contributed to increasing drift a percentage ranging from 13% to 26% in positive and negative direction of loading before failure starting and at final has contributed to increasing drift up to7.92% for R-SP15 and 1.5% for R-SP20

Figure 8and figure 9 show the average and envelop of loads and displacement relations.

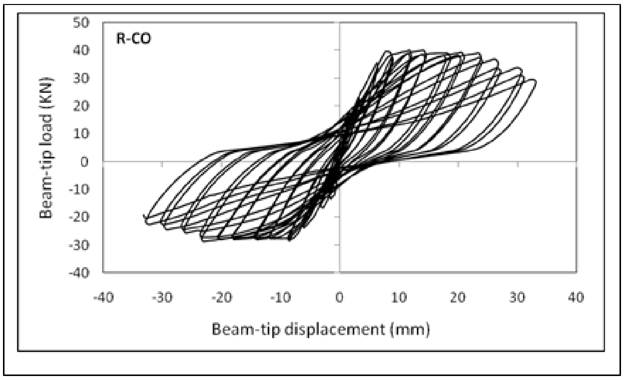


Fig. 5. Load-Displacement Hysteresis Loop for Specimen R-CO

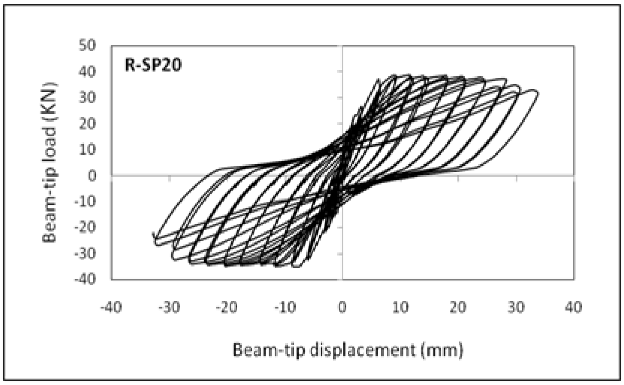


Fig. 6. Load-Displacement Hysteresis Loop for Specimen R-SP20

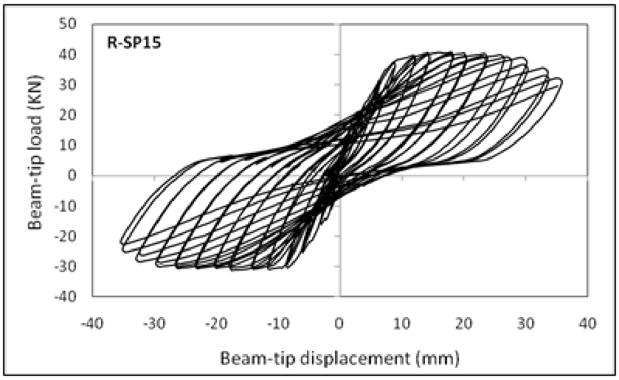


Fig. 7. Load-Displacement Hysteresis Loop for Specimen R-SP15

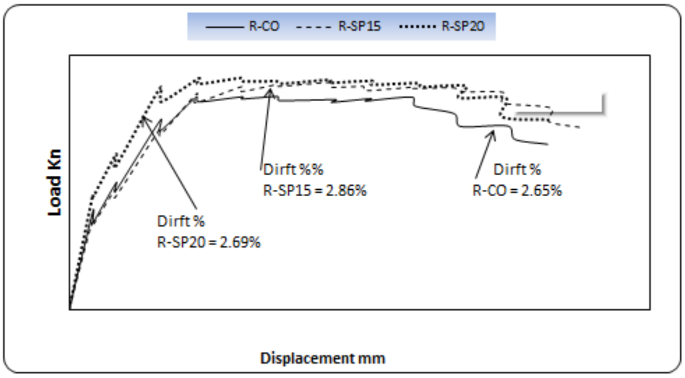


Fig. 8. average loads and displacements curves for test specimen.

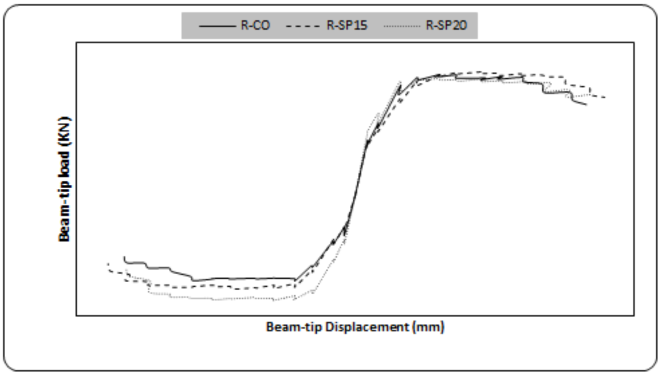


Fig. 9. Load-Displacement Envelope for test specimen.

4.4 Displacement ductility factor

It is necessary to have the beam column joint behavior in the earthquake-proof facilities will behave in ductile manner when exposed to earthquake loads. Ductility that are characteristic that allows the structure of which is subject to a large deformations after the initial deformation resulting from yield not loses its strength suddenly. [4] and [5]

The displacement ductility factor is the ratio of the maximum deformation that can element can undergo without significant loss of initial yield resistance to the initial yield deformation. Table 4 gives the experimental results of ductility factor, the values of the ductility factors indicate that the specimens (R-CO, R-SP15, and R-SP20) can be considered as ductile beam column joints.

Table 4.
Displacement Ductility of Test Specimens

sample	Displacement in mm				Displacement ductility factor DDF
	Yield	Ultimate			
		+ direction	- direction	average	
R-CO	-6.15	33.13	-33.12	33.13	5.39
R-SP15	-3.13	35.74	-35.43	35.59	11.37
R-SP20	-6.14	33.64	-32.79	33.22	5.41

4.5 Energy dissipation capacity

The structures are designed to be damaged not to be collapse when exposed to earthquakes. The earthquakes produce energy can be dissipated through the behavior of concrete elements that the concrete elements in the structure can resist earthquakes in case of dissipate of energy without resulting loss of strength. The energy dissipation is the area enclosed by the hysteretic loop; it is important factor in the seismic design and evaluation of the structure. When its value is reduced that means greater the level of damage.[6]

The cumulative energy dissipated for test specimens R-CO, R-SP20 and R-SP15 is (11286, 12975, 15015 KN.mm) respectively. This means that the lap splice has contributed to increasing the energy dissipated a percentage ranging from 15%for R-SP20 and to 33% for R-SP15.

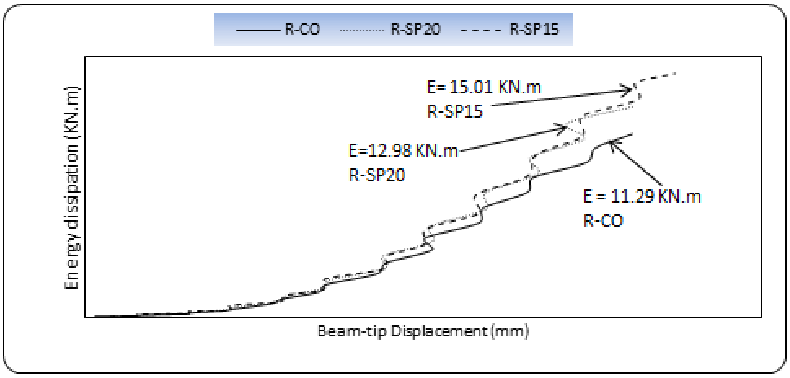


Fig. 10. cumulative energy dissipated for test specimens

4.6 Stiffness

Stiffness can calculate the approximate way, in each cycle load as follows: slope of the peak-to-peak line [7]. It was plotted the relationship between stiffness and its corresponding displacement at every cycle load as shown in Figure 11.It may be observed that the stiffness was (13.6, 15.13 and 11.57 KN/mm) for specimens R-CO, R-SP20 and R-SP15 respectively. That means stiffness of R-SP20 increased by 11% from that of R-CO and as for R-SP15 stiffness decrease by 15% from that of R-CO.

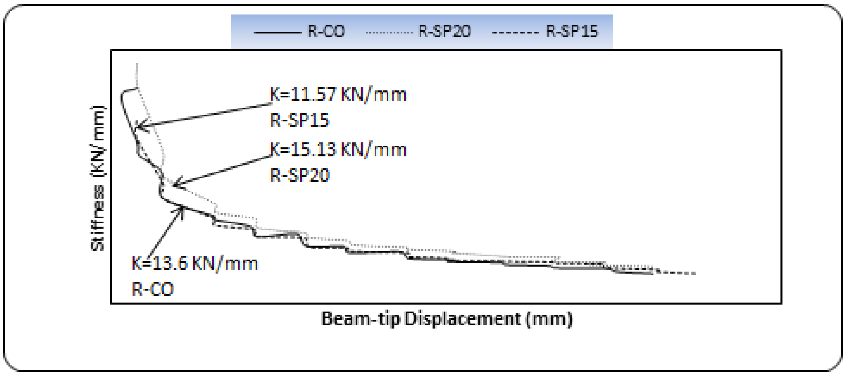


Fig. 11. Stiffness degradation for test specimens

5. Conclusions

The purpose of this investigation was to evaluate the effect of using well confined short lap splice reinforcement on seismic performance of exterior beam column joint. Following conclusions have been drawn from this study:

All the specimens were cracked at the first cycle of loading, there is a convergence in the form of cracks and the spread of the beam and finally occurs of plastic hinge in beam then the failure was happen, failure in all joints is flexure failure mode and can be considered in all test specimens as a ductile beam column joints but the lap splice has played a clear role in the following:

- Development of steel yielding such as in cycle No (6, 5 and 3) for specimens R-CO, R-SP20 and R-SP15 respectively.
  Delayed the collapse of specimen such as cycle No23 for specimens R-CO, R-SP20 and loading cycle No 25 for specimen R-SP15.
- The lap splice has contributed to increasing the capacity of carrying loads a percentage ranging from 8% to 18% in positive and negative direction of loading and in average formula 6% for R-SP15 and 10%.for R-SP20.
- The lap splice has contributed to increasing drift a percentage ranging from 13% to 26% in positive and negative direction of loading before failure starting and at final has contributed to increasing drift up to 7.92% for R-SP15 and 1.5% for R-SP20
- The lap splice has contributed to increasing the energy dissipated a percentage ranging from 15% for R-SP20 and to 33% for R-SP15.
- The lap splice has contributed to increasing the stiffness of R-SP20 increased by 11% from that of R-CO and as for R-SP15 stiffness decrease by 15% from that of R-CO.

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تأثير استخدام وصلات قصيرة (التسليح الرئيسي للاعمدة) والمقيدة جيدا علي سلوك وصله خارجيه لكمرة مع عمود تحت تأثير احمال الزلازل.

الملخص:

ان منطقه اتصال الكمرة والعمود تعد اخطر المناطق بالمنشأت المقاومه للزلازل خاصه عند تعرضها الي مقدار كبير من القوي المصاحبه للهزة الارضيه علي سبيل المثال فأن سلوك هذه المنطقه قد يعبر ان سلوك المنشأ بأكمله.

نظرا لان اسياخ حديد التسليح محددة الاطوال لزم الامر عمل وصلات في حديد التسليح مثل الوصل عن طريق اللحام او الطرق الميكانيكيه الا ان افضل الطرق من الناحيه الاقتصاديه والتشغيليه هي عمل الوصلات عن طريق التداخل بمقدار الطول المحدد بالكود طبقا للمواصفات.

تهدف هذه الدراسه الي معرفه سلوك وصله خارجيه لكمرة مع عمود في حاله عمل تغير في التسليح الرئيسي للاعمدة (مستمر او وصلات) وكان هذا هو المتغير الرئيسي في هذه الدراسه. حيث ان العينات لها نفس الابعاد الخرسانيه.

العمل الحالي عباره عن دراسه عمليه اجريت في معمل بحوث الخرسانه بالمركز القومي لبحوث البناء والاسكان بجمهوريه مصر العربيه.وشملت الدراسه عدد 3 عينات, العينه الاولي كانت هي العينه المرجعيه والتسليح الرئيسي للعمود حديد مستمر صممت علي ان تكون مطابقه لاكواد الزلازل الحاليه,اما العينه الثانيه والثالثه في حديد الاعمدة الرئيسي به وصلات (15 مرة قطر السيخ و 20 مرة قطر السيخ).

تم اختبار العينات واخذ القراءات الممكنه والمتاحه ,تم دراسه وتحليل النتائج وعمل المنحنيات المفسرة للنتائج ,وبعد ذلك تم عمل الاستنتاجات والتوصيات.

الكلمات الداله: وصله ,كمرة مع عمود ,مقيدة ,وصله خارجيه ,زلازل.