# EXPERIMENTAL STUDY ON RC BEAMS USING MECHANICAL SPLICES WITH DIFFERENT QUALITY AND STAGGERING LENGTH

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**ABSTRACT**

Nowadays, mechanical splices are commonly used in construction of reinforced concrete structures. It is a crucial issue for the structural engineers to determine what type of reinforcement splices should be used and where they should be located in the structures. Japan Society of Civil Engineers (JSCE) Standard stipulates that mechanical splices must be staggered in the longitudinal direction at least the sum of the splice length and 25 times the bar diameter (25d+l). It means that staggering must be ensured in all cases. However, it is demonstrated that no staggering may be the best solution for constructability. As a matter of fact, this staggering requirement was first established in JSCE Standard 1982 and has not been modified until now. It maintains the old practice and must be improved for the new condition in Japan. In this study, the behavior of RC beams using mechanical splices with different quality and staggering length under cyclic loading was investigated. The quality of splices was controlled by insertion length of reinforcing bars into the mechanical splices: 02 thread pitches, 03 thread pitches and 06 thread pitches (full insertion). The mechanical splices staggering lengths included (25d + l), (12.5d + l) and 0. The test results show that the beams using mechanical splices that could not develop yield strength of rebar (02 thread pitches insertion) is very weak. The strength of the beams using mechanical splices that could develop over 120% yield strength of rebar (03 thread pitches and 06 thread pitches) does not depend on the staggering length. The staggering length has effect on improving cracking behavior and ductility of the beams. The full insertion mechanical splices (06 thread pitches insertion) that could develop over 140% yield strength of rebar can be used at the same cross section with almost no difference with the beam without mechanical splice.

**Keywords:** Mechanical splice, RC beam, cyclic loading, staggering length, crack width

## 1. INTRODUCTION

In RC structures, mechanical splicing method was used to connect steel bars end-to-end by using the coupler. This method enables the bars to behave in a manner similar to continuous lengths bars.

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Therefore it is applied popularly in construction of RC structures. Japan Society of Civil Engineers (JSCE) Standard (2007) stipulates that “Splices shall not be clustered at the same cross-section of the members and the standard distance between two staggered splices in the longitudinal direction shall not be less than the sum of the splice length and 25 times the bar diameter”. This maintains the old mythology of staggering length (25d + l) being required at all times (d is bar diameter, l is splice length). It is difficult in some cases to provide mechanical splices with this distance and no staggering may be the best solution for constructability.

The objective of this study is to clarify the influence of low quality mechanical splices and their arrangement on the behavior of RC beams. In the beginning, properties of mechanical splices were checked by tensile test. The quality of splice was controlled by insertion length of reinforcing bars into the coupler. Then, nine RC beams using mechanical splices with different quality and staggering length were prepared and tested under cyclic loading. Three types of staggering of mechanical splices were examined, including (25d + l), (12.5d + l) and no staggering (mechanical splices arranged at the same cross section). The test results included load – displacement curves, ductility, crack width, crack patterns and failure modes of the beams are taken into account.

## 2. TENSILE TEST OF MECHANICAL SPLICES

The D19 deformed steel bars with nominal strength 345 N/mm2 were used in this test. The bars had rolled-on deformations with the profile similar to the shape of a threaded coupler so that the bars can be mechanically spliced using the couplers. The mechanical splice is shown in Figure 1.

**Figure 1: Mechanical splice**

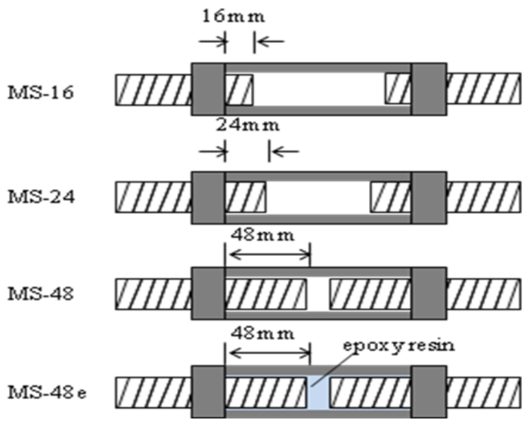


**Figure 2: Tensile test specimens**

To produce some qualities of mechanical splices, insertion length of the bar into the coupler was controlled. There were three types of insertion lengths studied (Figure 2), including: 2 thread pitches (MS-16), 3 thread pitches (MS-24) and 6 thread pitches (MS-48). The test results are shown in Table 1 and Figure 3. The strains were measured over 180 mm length (included the mechanical splice) of the specimens. Observably, specimen MS-48e has the same behavior with the D19 bar, with the same yield strength, yield strain, ultimate strength and failure mode. Specimen MS-48 has almost the same ultimate strength as the specimen MS-48e, the failure mode is also bar-break type but with a lower stiffness. Specimen MS-24 could obtain the yield strength of D19 bar but with had a lower ultimate strength and stiffness and failed due to slipping out of the bar from the coupler. Specimen MS-16 could not obtain the yield strength of the D19 bar (about 80%), had very low stiffness and also failed due to slipping out of the bar from the coupler. Among these four, the specimen with best quality is MS-48e and the one with lowest quality is MS-16.

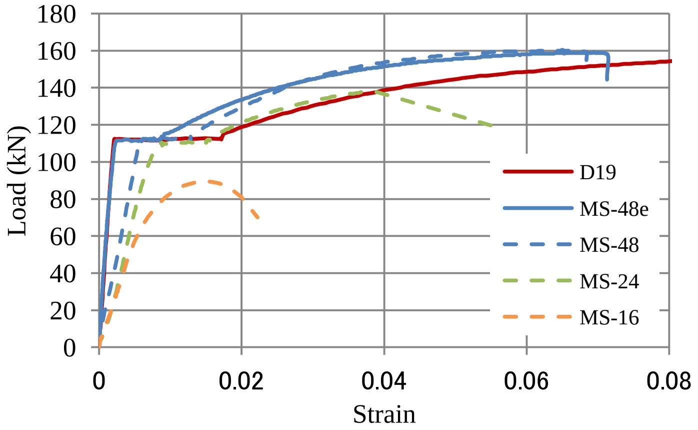


**Figure 3: Tensile test results**

**Table 1: Tensile tests results**

| Type | $P_y$ kN | $P_u$ kN | $P_u/P_{D19}$ | Failure mode |
|---|---|---|---|---|
| D19 | 112 | 159 | 142% | BB |
| MS-16 | - | 90 | 80% | SO |
| MS-24 | 112 | 138 | 123% | SO |
| MS-48 | 112 | 160 | 143% | BB |
| MS-48e | 112 | 159 | 142% | BB |

*BB: Bar break; SO: Slipping out*

## 3. RC BEAM TEST

### 3.1. Specimen

To examine the flexural behavior of RC members using low quality mechanical splices, a total of nine RC beams were designed and constructed. All beams were 3 m of length with a span of 2.5 m and 300 mm square cross section. Figure 4 shows the beam general configuration. The beams were longitudinally reinforced by four D19 steel bars and transversely reinforced in shear span by D10 stirrups with 100 mm spacing. All four types of mechanical splice tested in tensile tests were used in the beams. Mechanical splices were located in the 800 mm uniform bending moment region which was obtained by applying two symmetric concentrate loads 400 mm away from mid span. No stirrup was used in this region in order not to disturb the crack patterns. Three types of mechanical splices arrangement were used: no staggering, 348 mm (12.5d + l) staggering and 585 mm (25d + l) staggering.

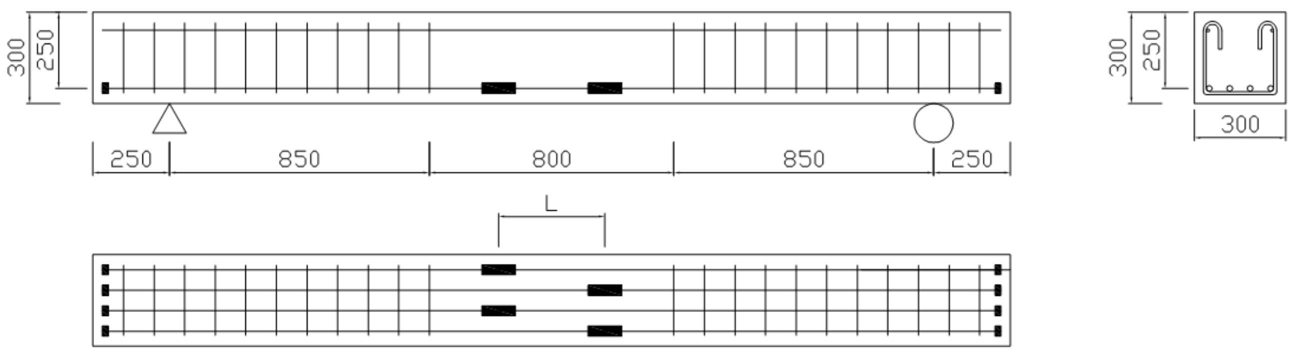


**Figure 4: Beam dimensions (in mm)**

The tests variables are shown in Table 3 which includes quality of mechanical splices and their arrangement inside the beams. Ready-mix concrete was used for the beams. Cylinder specimens (100mm x 200mm) were prepared for the compression tests. After casting, all beams were cured in the experiment room condition. The compressive strength of concrete was checked at the day of testing and the results were also shown in Table 3.

**Table 3: Test variables and concrete strengths**

| Beam | Mechanical splice types | Staggering length (mm) | $f'_c$ ($N/mm^2$) |
|---|---|---|---|
| B1 | - | - | 36.2 |
| B2-16-0 | MS-16 | 0 | 38.3 |
| B3-16-12.5 | MS-16 | 348 | 37.9 |
| B4-16-25 | MS-16 | 585 | 37.0 |
| B5-24-0 | MS-24 | 0 | 36.8 |
| B6-24-12.5 | MS-24 | 348 | 34.3 |
| B7-24-25 | MS-24 | 585 | 34.6 |
| B8-48-0 | MS-48 | 0 | 33.8 |
| B9-48e-0 | MS-48e | 0 | 31.5 |

### 3.2. Instrumentation and loading method

Figure 5 shows the set up of the test. The beams were tested under four points bending test. Electrical strain gages were used to measure the strains of reinforcement bar in the pure flexure region as well as the strains of concrete at the extreme compression face at mid span. Displacement transducers were used to measure the deflections of beams at mid span and at two points of applied loads. Additional two displacement transducers were set up at two supports of the beams to measure the support displacements. Crack widths were measured along pure flexure region by using Pie-shape displacement transducers.

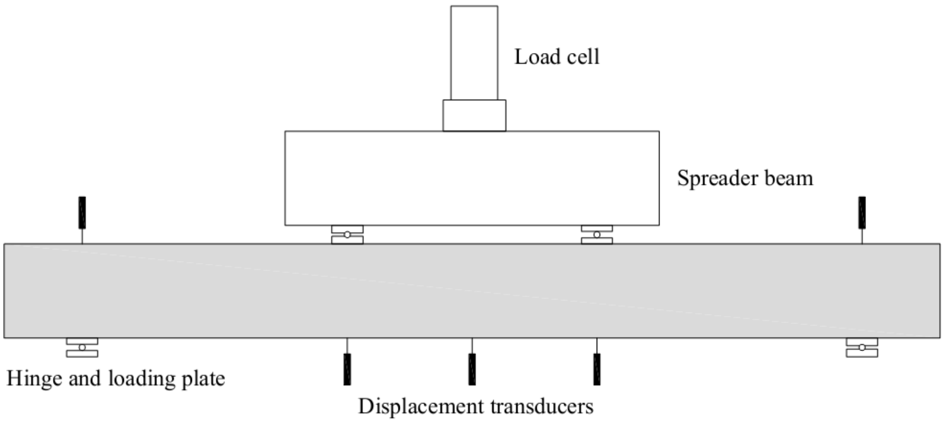


**Figure 5: Test set up**

Load was applied using a 300kN hydraulic actuator. To examine the performance of mechanical splices in RC beams, the cyclic loading method was applied. At first, 30 cycles were applied for each of three load amplitudes: 0.5Psy, 0.7Psy and 0.95Psy (Psy is nominal yield load of D19 bar). After yielding of the beam, the test is continued by applying load controlled by displacement until failure. All of the data were recorded by using a data acquisition system.

### 3.3. Test results

Experiments results will be discussed by focusing on envelop load-displacement curves, estimation of ductility, failure modes and cracking behavior of the specimens.

#### 3.3.1. Envelop load-displacement curves

Figure 6 shows the envelope load–displacement curves of the specimens. With regard to the stiffness, at earlier stages (before flexural cracking), the load–displacement curves of all specimens are close to each other regardless of the using mechanical splices. This is because that the behavior of uncracked beams is determined by the gross moment of inertia of the concrete cross section. Upon cracking, since the flexural stiffness of specimens is mainly dependent on the reinforcement, the specimens using mechanical splices experience distinct degradation of flexural stiffness whereas the stiffness of the specimen without mechanical splice reduces slightly. It can be observed from Figure 6 that as the load increases, the rate of stiffness degradation after the initial flexural crack of the specimen using mechanical splices increases higher than that of specimen B1. Although the mechanical splices used in each specimen had different load-strain relationship as shown in the tensile test results, the beams using them exhibits quite the same stiffness. It means that the quality of mechanical splices inside the concrete is improved due to restrain effect of concrete to the mechanical splices. Another reason is that the mechanical splice only occupied at a very small part compare to the whole length of the beam so its effect to the beam stiffness is not significant.

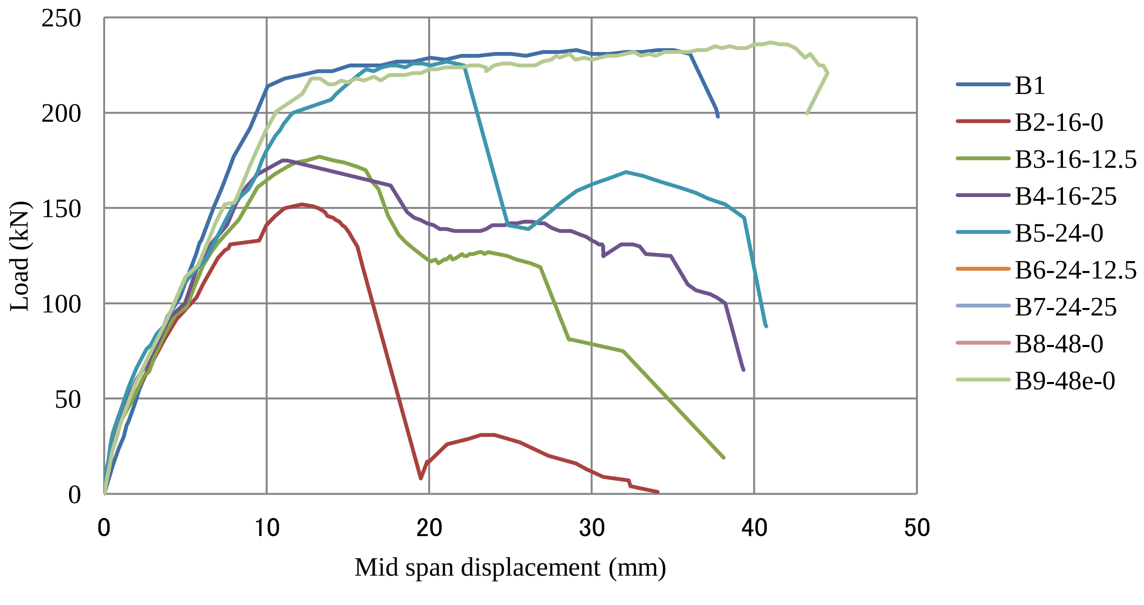


**Figure 6: Envelope load – displacement curves**

The beams using MS-16 mechanical splices (B2, B3, B4) show the lower strength than the beam without mechanical splice (about 65 ~ 75%). The beams using MS-24, MS-48 and MS-48e mechanical splices could achieve peak loads slightly larger than the beam without mechanical splice. This can be explained by the strength of the mechanical splices used in the RC beams. The MS-16 mechanical splices could develop only 80% yield strength of D19 steel bar. For the other types of used mechanical splices, they could develop yield strength of D19 steel bar. Because the mechanical splices were located in the constant moment area, the applied loads on the continuous steel bar and mechanical splices in this area were the same. Consequently, the beams strength corresponded to the strength of mechanical splices used.

### 3.3.2. Estimation of ductility

Ductility is defined as the capability of a structure to undergo deformation after yielding without any significant reduction in yield strength. Because the beams using MS-16 mechanical splices could not achieve yield strength as the beam without mechanical splice, they are not taken into account for estimate on of ductility. Table 4 shows the ductility ratio of each beam. The results show that the ductility of RC beam reduced when using mechanical splices. There are some factors affect the ductile behavior of the beams can be seen: strength of mechanical splices, staggering length of mechanical splices and epoxy injection into mechanical splices. The beams using MS-24 mechanical splices are less ductile than the beams using MS-48 and MS-48e mechanical splices. The beam using mechanical splices at the same cross section and (12.5d + l) staggering mechanical splices have almost the same ductile but the beam using (25d + l) staggering mechanical splices behaved more ductile. The beam using epoxy injected mechanical splices is more ductile than the beam using mechanical splices without epoxy.

**Table 4: Ductility of specimens**

| Beam | Yield | | Failure | | Ductility |
|---|---|---|---|---|---|
| | Load | Disp. | Load | Disp. | |
| B1 | 218.6 | 11.49 | 197.9 | 37.77 | 3.29 |
| B5-24-0 | 201.0 | 11.96 | 192.8 | 23.18 | 1.94 |
| B6-24-12.5 | 201.0 | 12.24 | 194.5 | 22.00 | 1.80 |
| B7-24-25 | 202.7 | 11.67 | 197.1 | 29.24 | 2.50 |
| B8-48-0 | 202.7 | 14.18 | 202.2 | 40.99 | 2.89 |
| B9-48e-0 | 216.0 | 13.60 | 199.6 | 43.24 | 3.18 |

### 3.3.3. Failure modes of beams

The failure modes of beams are shown in Figure 7. The beam without mechanical splice failed after significant strain of tensile reinforcement with crushing of the compression concrete at the maximum moment zone. For the others beams using mechanical splices, the failure modes are so different. The MS-48 and MS-48e mechanical splices as shown in tensile test results could achieve bar break type failure. Therefore, the beams using these types of mechanical splices failed in the same manner as the beam without mechanical splice. The beams using MS-16 mechanical splices failed because of slipping out of the rebar from the mechanical splices. For the beams using MS-24 mechanical splices, it was observed that first the rebar slipped out from mechanical splices then the beams still had bearing capacity and finally the compression concrete crushing.


(a) Slipping out (b) Slipping out then crushing (c) Concrete crushing

**Figure 7: Failure modes of beams**

### 3.3.4. Cracking behavior

There was no crack until the cracking moment was reached in the pure bending zone. These first cracks were predominantly vertical and perpendicular to the direction of the maximum stress induced by the bending moment. After the first cycle of 0.5Psy, no more new cracks appeared and only the extension of the existing cracks could be observed. The experimental crack width (w) measured at the level of longitudinal reinforcement is shown in Table 5. As seen in the table, the large cracks located on near coupler positions. The reason is that the strains near mechanical splices developed with higher values than the other locations and the concrete cover at mechanical splices were smaller than the others. Those are known as two important factors affect to the crack width. About the average crack spacing (s), the specimens using mechanical splices at the same cross section is smaller than the specimens using mechanical splices with staggering length (7 cracks compared to 8 cracks in 800mm constant moment area).

**Table 5: Crack width and average crack spacing**

| Beam | $w_{max}$ (mm) (at $0.95P_{sy}$) | | $w_{average}$ (mm) (at $0.95P_{sy}$) | | s (mm) |
|---|---|---|---|---|---|
| | At bar | Near coupler | At bar | Near coupler | |
| B5-24-0 | 0.22 | 0.53 | 0.13 | 0.35 | 133 |
| B6-24-12.5 | 0.18 | 0.45 | 0.11 | 0.35 | 114 |
| B7-24-25 | 0.13 | 0.54 | 0.1 | 0.28 | 114 |
| B8-48-0 | 0.21 | 0.42 | 0.12 | 0.24 | 133 |

## 4. CONCLUSIONS

Tests of nine RC beams under cyclic loading were conducted to study the influence of quality and staggering length of mechanical splices on the behavior of RC structures. The following conclusions can be drawn:

- Full strength mechanical splices (48mm of insertion length and injected epoxy) that could develop 140% yield strength of rebar can be arranged at the same cross section without significant changes from the beam without mechanical splices.
- The effect of epoxy injected in mechanical splices is increasing ductility, reducing crack width but does not increase the strength of the beam.
- It will be very dangerous if using the mechanical splices that are not able to achieve yield strength of the steel bar.
- Staggering length of the mechanical splices bar does not affect the strength of the beam but it will have a better cracking behavior and ductility if the staggering length is increased.

## 5. ACKNOWLEDGMENTS

This study was carried out supported by Grant-in-Aid for Scientific Research (B). The authors would like to acknowledge members of Structural Material Laboratory of Saitama University for their support. Special appreciation is extended to Tokyo Tekko Company Ltd. staffs for their contributions during various stages of the experimental program.

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