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A Study on the Behaviour of H-shaped Beam-to-Column Connections with Newly Reformed T-Stubs

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Abstract

In steel structures, a column connected to a beam is assumed to be rigid for efficient stress transmission between each component of the structure. In analyses and designs of structures, the connection parts of structures are assumed to have rigidity that means the ability to provide stable rotations and deliver moment at panel points. A pinned connection style only has rotations. This study demonstrates the basic connections designed using reformed T-stubs, which are close to semi-rigid connections. The results of this paper verify the following: 1) the leverage effect of the tension connection part does not occur in the given steel structures, 2) the semi-rigid parts of the unified T-stub connections results, gradually, in a restored force situation under the action of repeated load.

Keywords: beam-to-column, connection, T-stub, semi-rigid, steel structure.

1 Introduction

The connections of recent structures, which are being enlarged with multiple stories play extremely important roles in complete structures. Since they directly affect the safety of buildings, there is a need to ensure the safety of structures through proper analysis. In particular, the joint connecting beams with columns should maintain the structural stiffness of the building and stress delivery; it should also demonstrate joint strength and deformation ability from the design stage when considering workability.

The current design and analysis of the connections of steel-structure buildings in general are assumed to be rigid or pinned. Since the column-beam joint of actual buildings carries a binding force on moment delivery and rotation to a certain degree, the safety of the frame and economic design are being applied to the behaviour of actual structures.

The actual behaviour of such connections is defined as a semi-rigid connection; many studies are conducted on the impact of semi-rigid connections [1-3]. Nonetheless, there are actually many unsolved problems as a result of the uncertainty of the prediction of the moment-rotation relationship and the materials and shape of the connections, added to that the lack information concerning the basic materials. Therefore, skeleton analysis or connection design methods have not been considered.

In this study a nearly semi-rigid unified T-stub that improves the rotation force by allowing a clearance width to the flange to promote the compression resistance force of the T-stub close to the rigid connection is manufactured. It enables easy construction and quality control as well as superior strength and strain ability compared to the welded beam-column connections and tested influences of variables on connections.

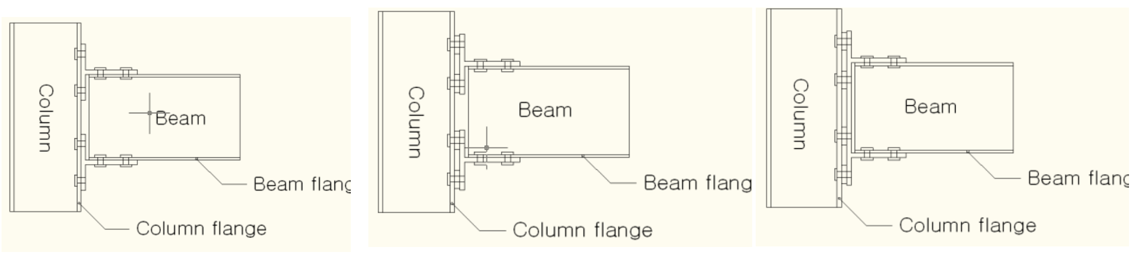
This study is aimed to observe the structural behaviour and promote the efficiency and applicability of the connections through this test. To present the basic methods of the design and analysis of a T-stub close to semi-rigid connections, this study integrally joined the connections of the beam-column connections to apply the results of the actual behaviour and examine the effectiveness of the initial rigidity.

If the beam-to-column connections are joined with high-strength bolts, the rigid connection cannot maintain the initial angle as a result of the relative displacement between members. On the other hand, pinned connection carry a certain level of moment-resisting force owing to skid resistance [4]; hence the importance of accurately measuring the relative rotation angle between the beam-column members to identify the correlations of the moment-rotation angle of the connections.

2 Tests of connections of unified T-stub

2.1 Test plans

In this study, connections were made using the unified T-stub, and repeated loading tests were conducted. The study examined the possibility of creating semi-rigid connections based on the test results by analysing and examining the moment-rotation angle relationships using the unified T-stub and by selecting the initial rigid influence factor.



(a) Existing T-stub (b) Improved T-stub (c) Unified T-stub

Figure 1. Connections of T-stub

The materials used for tests are shown in Table 1. The tests selected the initial rigid influence factors to check the behaviour of the semi-rigid connection as the extension; to identify the behaviour of the unified T-stub, the T-stub thickness was fixed at 8mm, and the extension, at 16mm as shown in Table 2. Bolt intervals were set at 80mm~160mm, and bolt diameters, to 16mm~24mm. Based on these variables, tensile and compressive factor tests were conducted to check the load-deflection relations [5-8].

Location	Specification	Material quality
Column	H-250×250×9×11	SS400
Beam	H-350×175×7×11	SS400

Table 1. Materials used

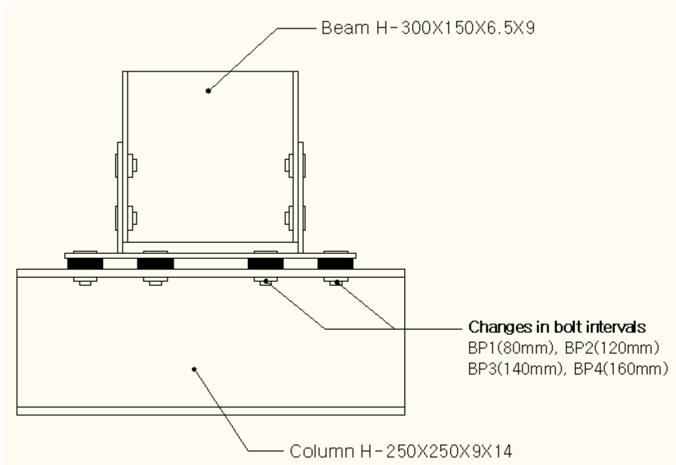
<table>
<tr><th>Sample name</th><th>T-stub thickness (mm)</th><th>Extension (mm)</th><th>Bolt interval (mm)</th><th>Bolt diameter (mm)</th></tr>
<tr><td>BP1</td><td rowspan="7">8</td><td rowspan="7">16</td><td>80</td><td rowspan="4">20</td></tr>
<tr><td>BP2</td><td>120</td></tr>
<tr><td>BP3</td><td>140</td></tr>
<tr><td>BP4</td><td>160</td></tr>
<tr><td>BD1</td><td rowspan="3">120</td><td>16</td></tr>
<tr><td>BD2</td><td>20</td></tr>
<tr><td>BD3</td><td>24</td></tr>
</table>

Table 2. List of Samples

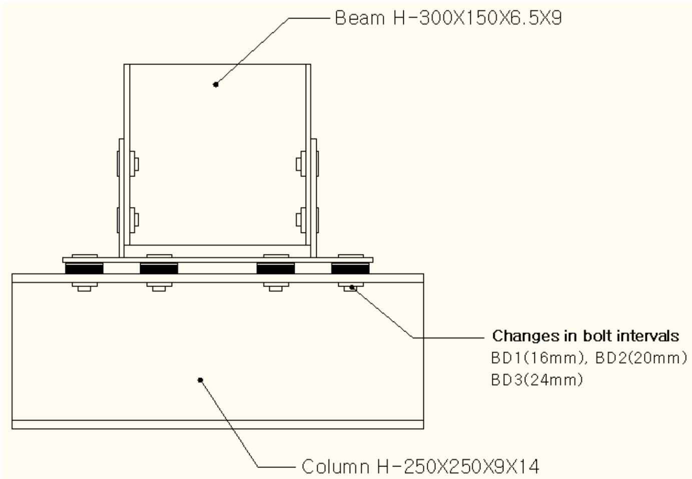
The existing improved T-stubs were connected to two separate members on the beam flange to share the tensile strength and compressive force; if flange buckling occurs to the beam member, each T-stub featuring a different character shares the stress. This was the reason that it was impossible to obtain an accurate value of the moment-rotation angle. Therefore, this test connected the existing separated T-stub to a single body to satisfactorily carry the force of the beam member, enabling accurately checking of the value of the moment-rotation angle.

The quality of all materials used for the tests was SS400. The beam member used H-350×175×7×11, and the column member, H-250×250×9×11. The length of the member was 1,500mm for the beam and 1,200mm for the column.

The test fixed the entire thickness of the improved T-stub at 8mm; the basic manufacturing sizes were as follows: extension of 16mm, bolt interval of 120mm, and bolt diameter of 20mm. The value was analysed by changing the bolt intervals and diameters. First, four bolt intervals were used: 80mm, 120mm, 140mm, and 160mm; the bolt diameters were 16mm, 20mm, and 24mm. To connect the beam-column members, eight -F10TM20 high-strength bolts were fastened at a standard tensile strength on both sides of the beam flange, and four bolts, on the column flange using an auxiliary loading device. The shapes of each sample are shown in Figure 2.



(a) Parameter according to bolt intervals



(b) Parameter according to bolt diameter

Figure 2. Detailed drawings of samples

2.2 Loading conditions and test method

To check the strength of the unified T-stub, simple tension and compression tests were conducted. As a loading method, the columns were installed horizontally, and the beams, in cantilever form. Afterwards, the sample was totally fixed to the frame with F10T-M20 high-strength bolts. The force was applied using 1000kN capacity tension and compression oil jacks, and the displacement was measured with a displacement gauge installed on the left and right sides of the sample according to the displacement distance. Compression load cells were used to check the load, with a dial gauge installed in both directions of the loading point on the top of the beam to measure flexural displacement.

In addition, 100mm displacement gauges 1 and 2 were installed on top of the beam for use in checking the displacement in the left and right directions, and 25mm and 50mm displacement gauges were installed at the bottom of the column so that the slipping of the sample itself and the entire structural frame can be identified. The connection rotation angle was calculated after the displacement of the compressive and tensile part as measured by the improved end-plate on both ends was averaged and by dividing the difference of the value by the depth of the girder. In addition, the connection moment was calculated by multiplying the load by the distance from the loading point to the connection [1-3].

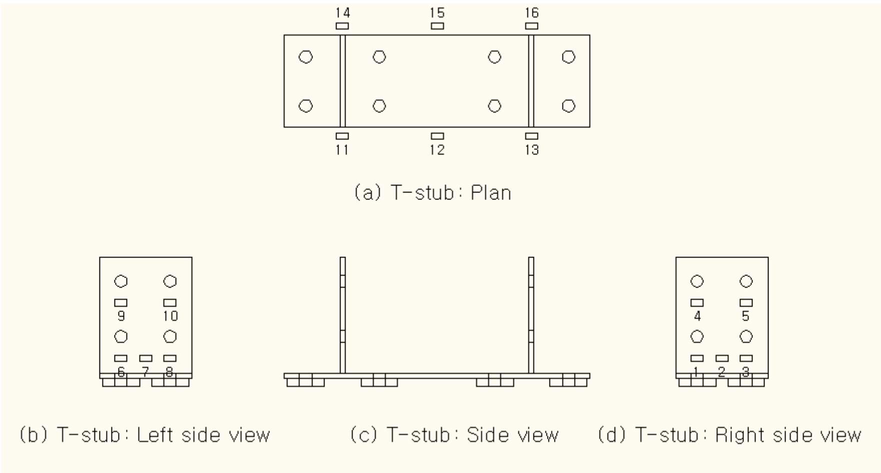


Figure 3. Installation of strain gauge

$$\Theta_j = (Tension\ \delta_1 + Compression\ \delta_2) \div d(depth\ of\ girder) = \delta / d \quad (1)$$

$$\text{Moment : } M = \text{Load} \times \text{Distance} = P \times 150\text{cm} \quad (2)$$

To check the strain rate of each sample, sixteen strain gauges were installed on the unified T-stub to which loading was applied under the condition that samples behave in a symmetrical manner; data logger boxes were connected to enable real-time checking of strain rate so that the conditions of all gauges can be checked after initializing the data. Load was applied to the top of the cantilever form to check the maximum displacement. The location of the electric displacement gauges and strain gauges attached to the sample are shown in Figure 4.

3 Test results and analyses

To check the strength of the T-stub used on the connection, compressive and tensile factor tests were conducted covering each sample. The results of the tests are shown in Tables 3, 4, 5 and 6 and Figures 5 ~ 11.

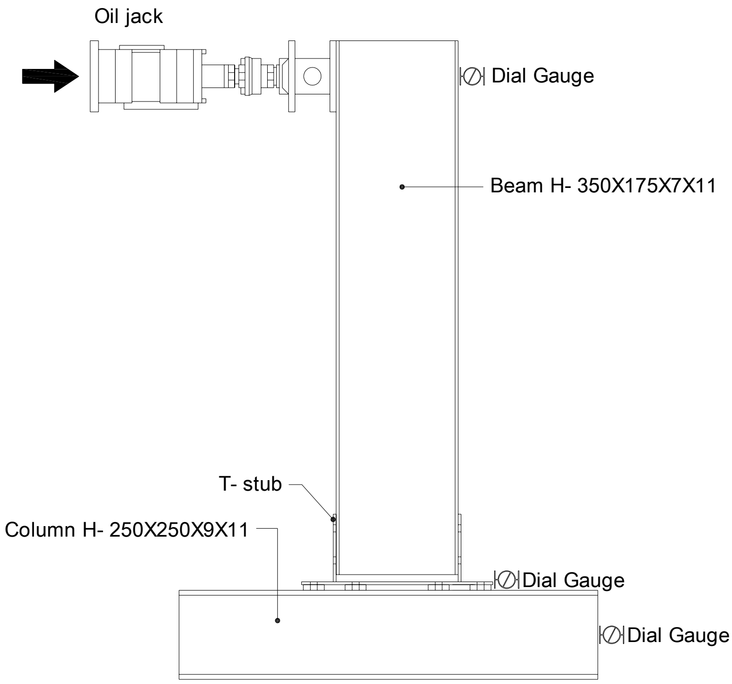


Figure 4. Installation of the unified T-stub

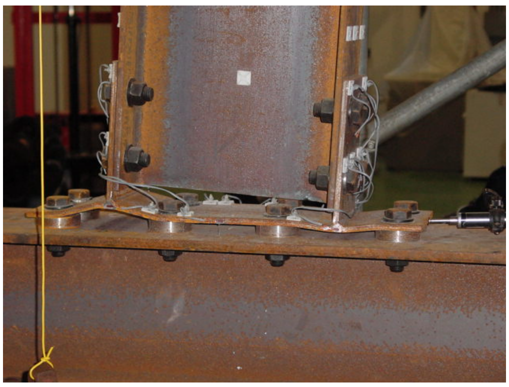


Photo 1. Testing BP sample
(strain gauge)

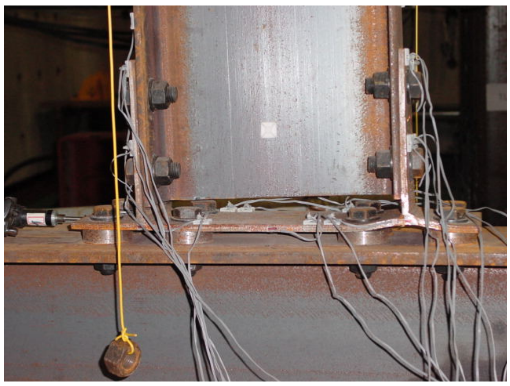


Photo 2. Testing BD samples
(strain gauge)

During the process of testing, single sound or continuous sound was generated on the end-plate due to the slipping of the high-strength bolts joining the connections through repeated loading; cracks were easily found as well as a result of to the surface corrosion at the point where a high level of force was applied.

As for the changes in the sample intervals, the breaking load of the sample with a narrow interval was greater than that of the sample with wide intervals; the strain of the T-stub was also less.

With regard to the sample with changed bolt diameters, there was a significant difference in the initial displacement; as the displacement increased, however, there was almost no difference. This was believed to be attributable to the negligible effect of sectional loss resulting from the effect of the bolt diameters on the connection strength.

Photo 3. Testing BP samples

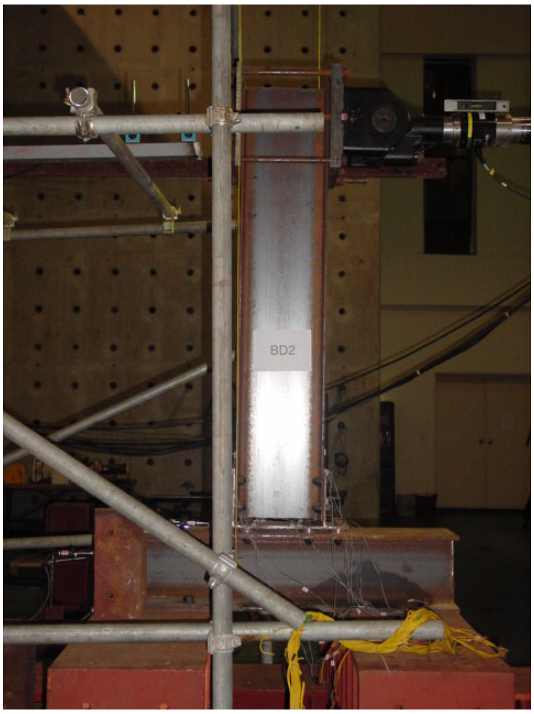


Photo 4. Testing BD samples

3.1 Analyzing the maximum load-strain rate

The BP1～BP4 samples were tested using as variables the bolt intervals of 80~160mm. The value of the strain gauge at each point and the related graphs are shown below. The result revealed that the breaking load was 64.28kN, the highest level in the case of BP1. As for the maximum strain rate of each point of strain gauge, the BP1 sample read No. 11, the BP4 sample, No. 13; the BP2 sample was No. 14, and the BP1 sample, No. 16 as the highest value. BD1～BD3 samples were tested using as variables bolt diameters 16~24mm; the outcome values of the strain gauge in each point and related graphs are presented below. The results show that the breaking load was 51.73kN as the highest level in the case of BD 3. As for the maximum strain rate of each point of strain gauge, the BD3 sample reading was No. 11, BD3 sample, No. 13, BD3 sample, No. 14, and BD3 sample, No. 16 as the largest value.

Sample name	Breaking load (kN)	Max. displacement (mm)	Max. moment (kN·cm)	Angle of rotation (rad)
BD1	32.27	51.26	4,840.5	0.1709
BD2	37.72	55.57	5,658	0.1852
BD3	51.73	94.79	7,759.5	0.3160

Table 3. Test results of BD sample by strain gauge location

Sample name	Breaking load (kN)	No. 11 Location maximum strain rate ($\times10^{-6}$)	No. 13 Location maximum strain rate ($\times10^{-6}$)	No. 14 Location maximum strain rate ($\times10^{-6}$)	No. 16 Location maximum strain rate ($\times10^{-6}$)
BD1	32.27	334	1,536.9	611.7	349
BD2	37.72	367.8	1,767.7	591.1	740.3
BD3	51.73	1,561.3	3,086	1,073.4	3,337.5

Table 4. Test results of BD sample by strain gauge location

Sample name	Breaking load (kN)	Max. displacement (mm)	Max. moment (kN·cm)	Angle of rotation (rad)
BP1	64.28	90.39	9,642	0.3013
BP2	37.38	93.61	5,607	0.3120
BP3	33.77	97.68	5,065.5	0.3256
BP4	19.90	50.93	2,985	0.1698

Table 5. Maximum load-strain rate graph of BP sample

Sample name	Breaking load (kN)	No. 11 Location maximum strain rate ($\times10^{-6}$)	No. 13 Location maximum strain rate ($\times10^{-6}$)	No. 14 Location maximum strain rate ($\times10^{-6}$)	No. 16 Location maximum strain rate ($\times10^{-6}$)
BP1	64.28	5,050.8	836.9	709.3	11,969.7
BP2	37.38	1,961	1,186	1,541.6	4,876.8
BP3	33.77	906.3	1,813.7	368.7	2,111.1
BP4	19.90	1,365.2	2,709.8	1,466.5	702.7

Table 6. Maximum strain rate by BP sample strain gauge location

3.2 Analyzing load-displacement relationships

Figures 5~11 present the test results for each sample. After loading, high-strength bolt slip occurred at the displacement control of 7mm given approximately 4mm of loading point displacement. The impact noise was generated continuously from the 28mm displacement control point, and a crack was confirmed to have occurred on the bottom plate starting from the displacement control 14mm in the case of T-stub displacement.

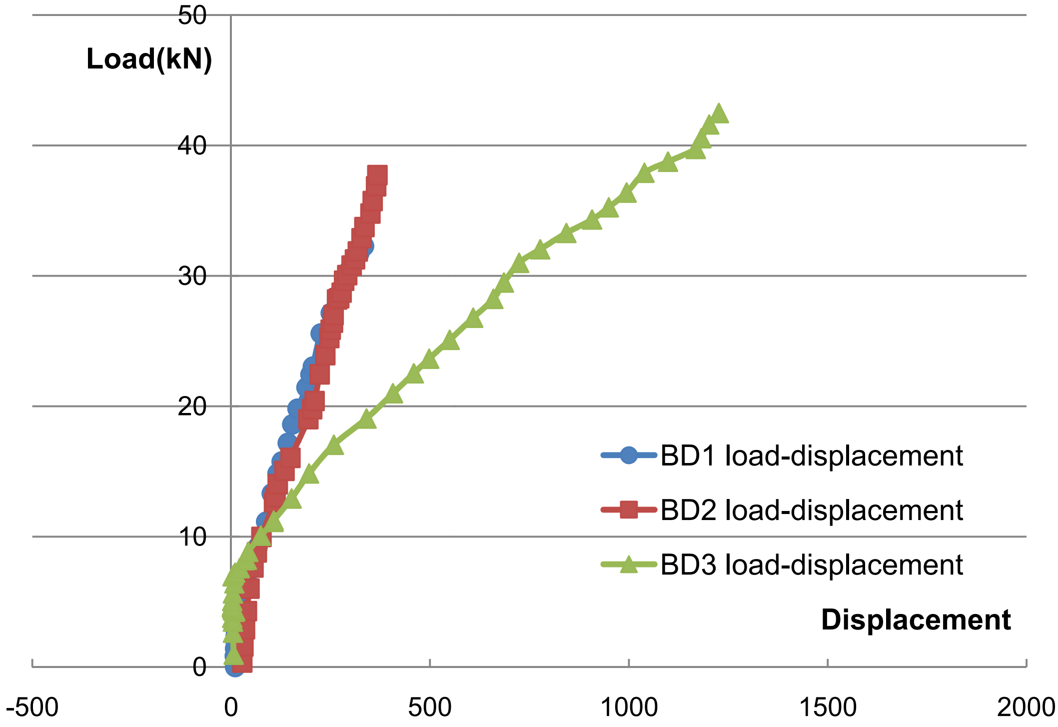


Figure 5. BD11 sample load-displacement rate

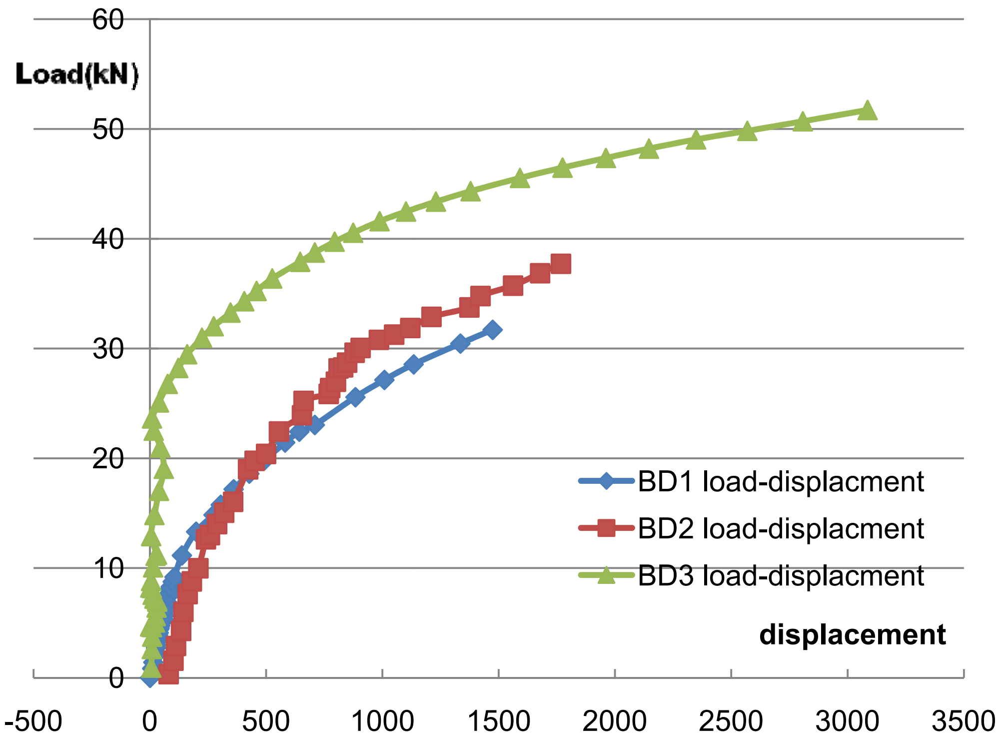


Figure 6. BD13 sample load-displacement rate

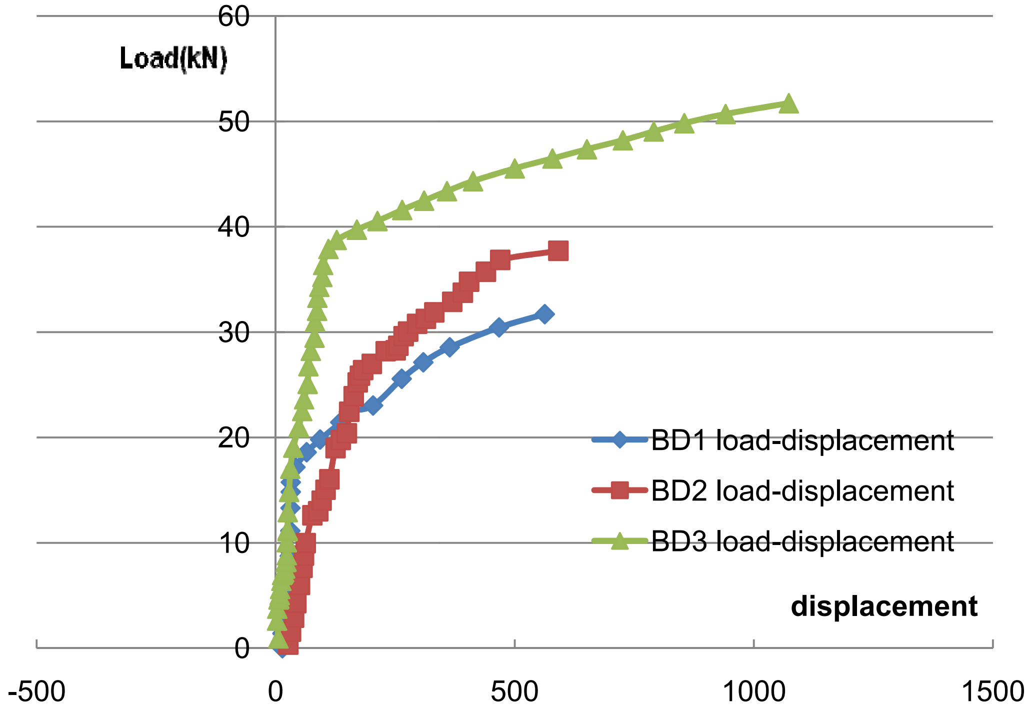


Figure 7. BD14 sample load-displacement rate

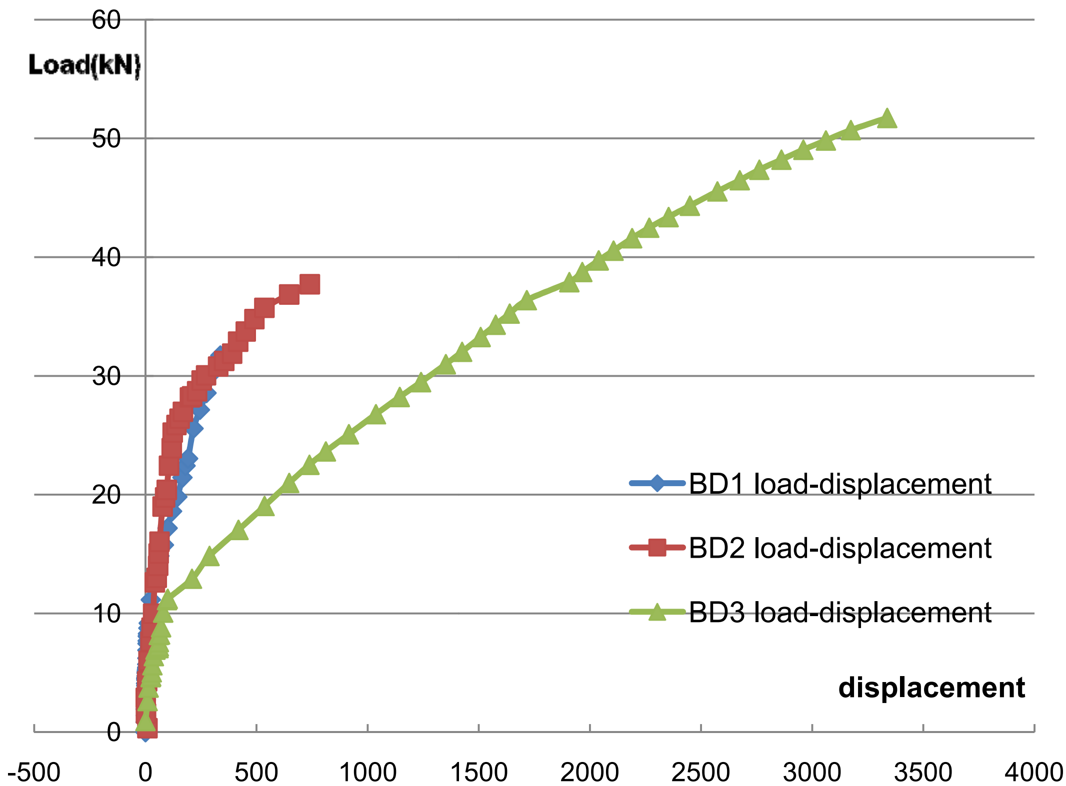


Figure 8. BD16 sample load-displacement rate

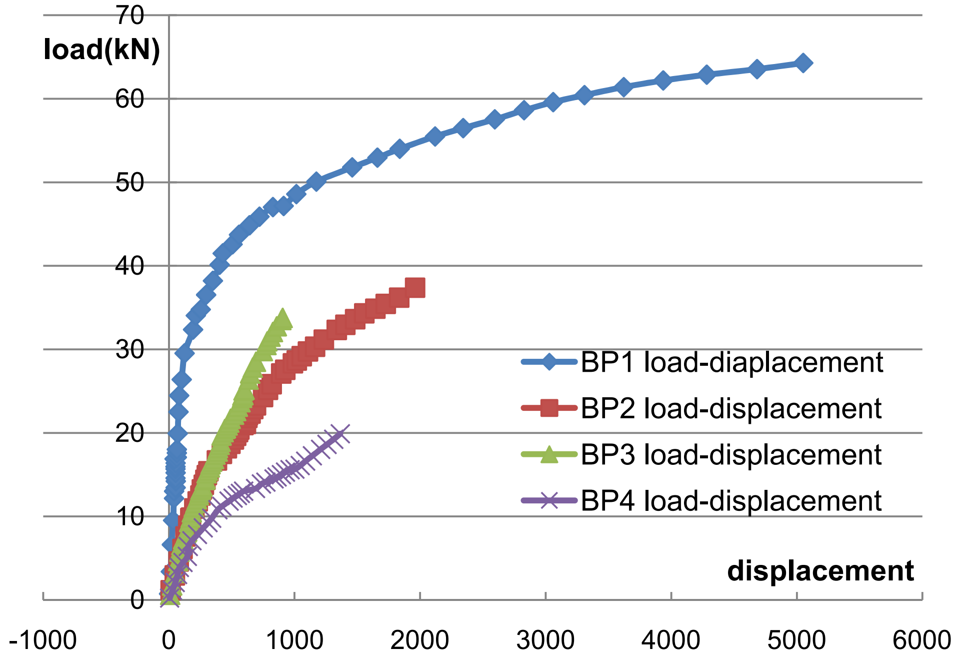


Figure 9. BP11 sample load-displacement

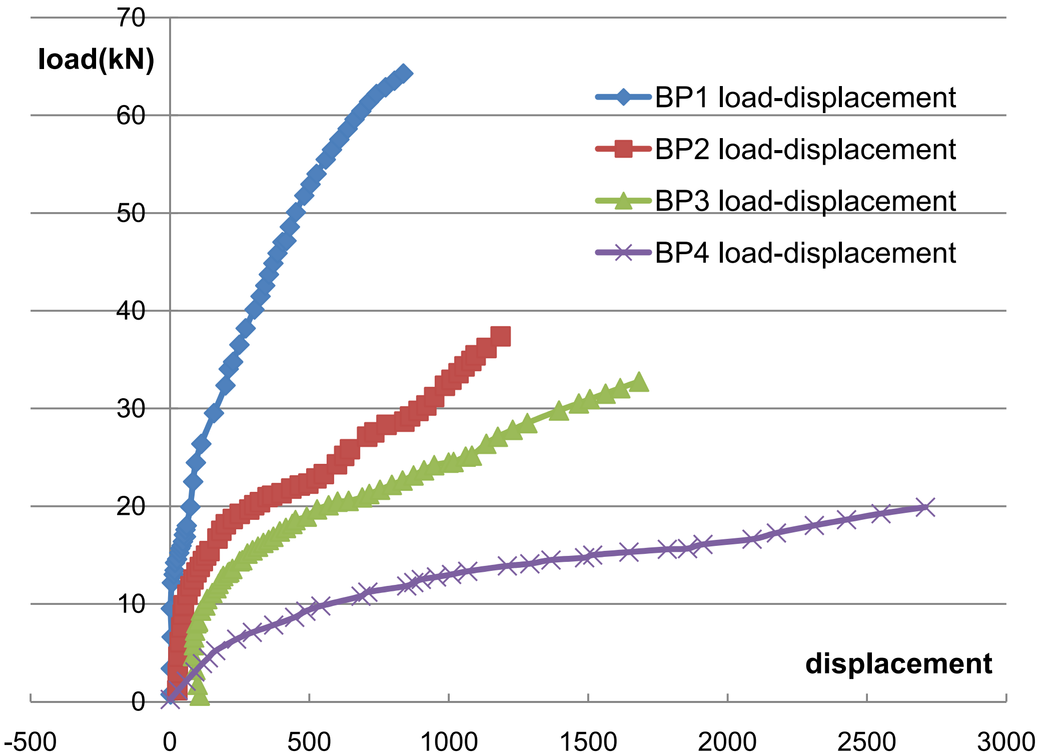


Figure 10. BP13 sample load-displacement rate

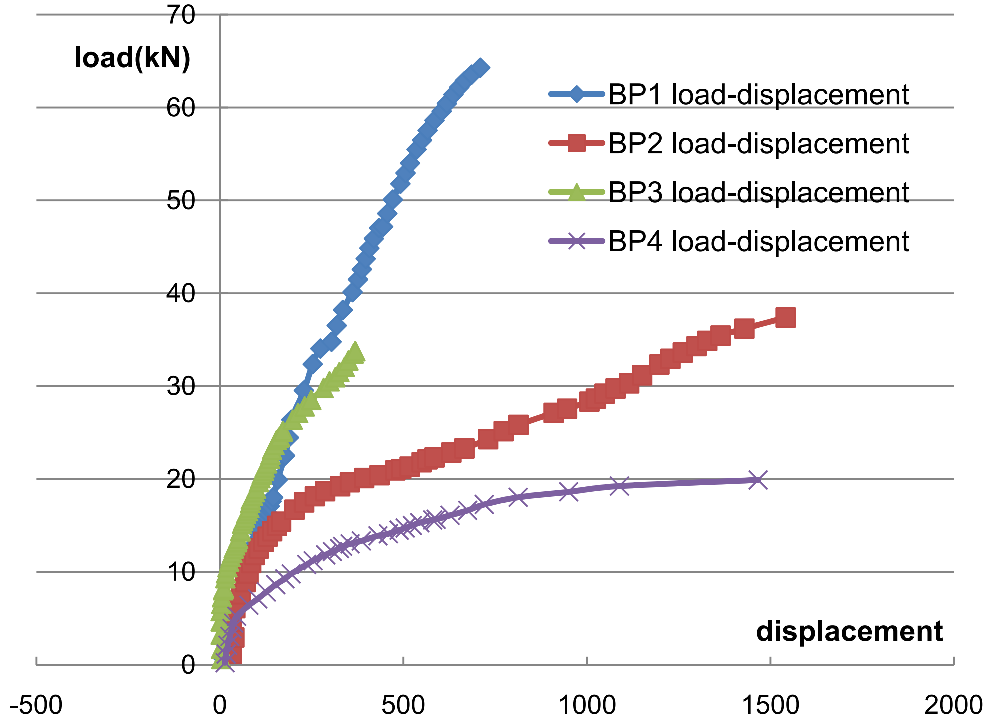


Figure 11. BP14 sample load-displacement

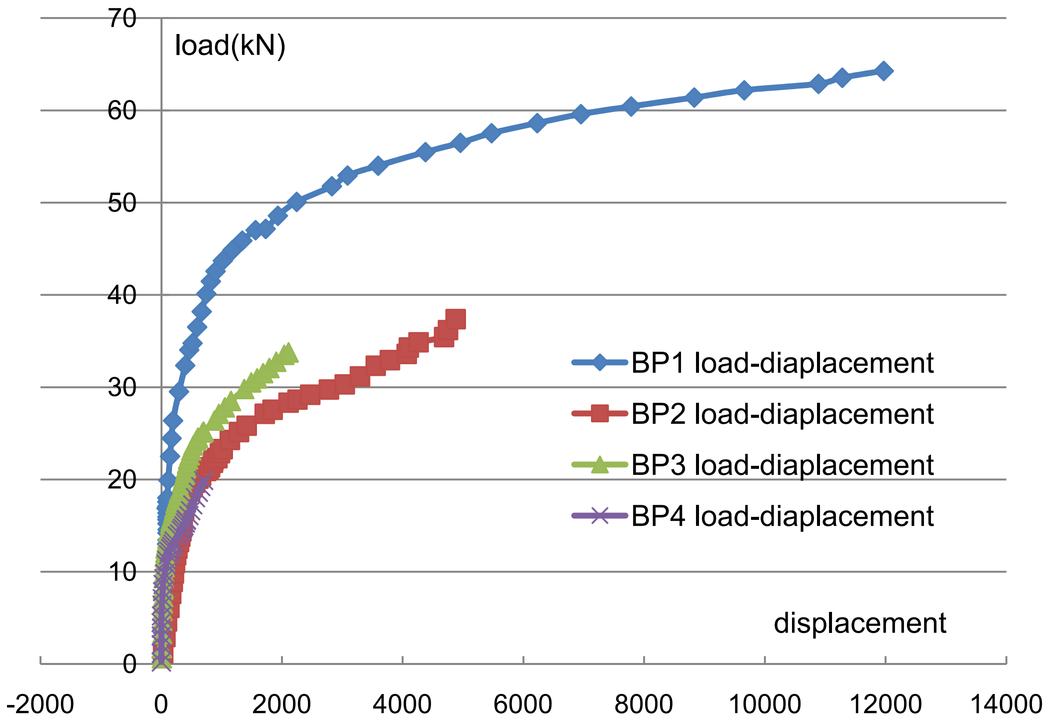


Figure12. BP16 sample load-displacement

4 Conclusions and remarks

This study verifies the possibility of connections using a structurally improved T-stub. The beam-to-column connections are joined with the unified T-stub, and simple and repeated loading tests are carried out to measure the structural behaviour of initial rigidities. The following conclusions are represented in this study:

1) In the case of tests changing the high-strength bolt intervals, the magnitude of failure load is lower in wider intervals, whereas the strain rate is higher.
2) In the case of tests changing the high-strength bolt diameters, there is no difference to the magnitude of the breaking load or strain rate even though the diameters are increased.

It is therefore verified that bolt diameters are not important factors for improving the rigidity of connections.

Acknowledgement

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