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Performance Appraisal of Steel Connection in Low Rise Buildings

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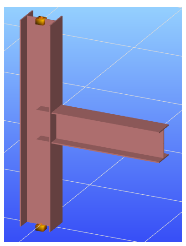
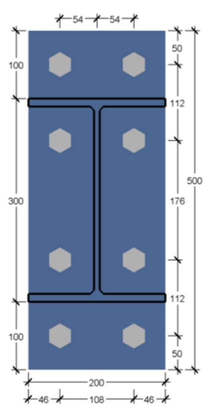
Graphical abstract





Abstract

Steel construction allows fast and economical method of construction which also fulfills the requirement of clients. Especially low-rise building such as industrial building is the most common in steel frame. There are few common types of connection that are commonly being used in the industry such as flush end plate connection and extended end plate connection. This research is conducted to evaluate the performance of end plate connection as the common steel connection in low-rise buildings. Software ConSteel is used to evaluate the performance of identified connections by analysis. At the end of the research, an optimize design of end plate connection maybe recommended based on the performance and serve as a basic of improvement and guidance of safety.

Keywords: Low-rise building, end plate connection, performance appraisal

Abstrak

Selain dapat mencepatkan dan menjimatkan cos pembinaan, pembinaan keluli juga dapat memenuhi keperluan pelanggan. Struktur bingkai keluli ialah struktur yang paling biasa digunakan terutamanya untuk bangunan bertingkat rendah seperti bangunan industri. Terdapat beberapa jenis sambungan yang biasa digunakan dalam industri seperti siram sambungan plat hujung dan lanjutan sambungan plat hujung. Kajian ini dijalankan untuk menilai prestasi sambungan plat hujung sebagai sambungan keluli yang biasa dalam bangunan bertingkat rendah. Perisian ConSteel digunakan untuk menilai prestasi sambungan yang telah dikenal pasti dengan menggunakan kaedah analisis. Pada akhir kajian, reka bentuk sambungan plat hujung yang telah dioptimumkan boleh disyorkan berdasarkan prestasi dan fungsinya sebagai asas untuk dijadikan panduan serta meningkatkan keselamatan dalam kerja pembinaan.

Kata kunci: Bangunan bertingkat rendah, sambungan plat hujung, penilaian prestasi

1.0 INTRODUCTION

Steel constructions are commonly used to build a large span scale project because it is easier and more economical as compared to concrete construction. Beams and columns are connected by specific designed connections to ensure its durability and robustness. The connections between beams and columns are essential because it is the only component that connects the main structural member together. Connections are necessary when two different members meet together. For instance, a column and an end of a beam which are attached to each other. The responsibility of a connection is not only to secure the ends of elements where they meet, but also to deliver the bending moments, shear forces, compressions and torsions (twisting effects) between the members. In an ordinary beam to column connections, a variety of different types of connection can be applied such as fin plates, end plates, web or flange cleats and haunch connections [1].

There was a case of a five stories building 221 feet by 271 feet in plan at suburban Boston location collapsed after reconstruction and the completion of the erection of steel framing. [2] The lateral load resistance and stability of the building is provided by series of rigid frames. A rigid frame is where beams and columns are rigidly connected to each other so that there is no rotation between the members. In this case, there were two connections which should be moment connection but they were not made. Thus, the collapse was most probably initiated by the failure of the welded connection between the particular columns and erection angle attached at the third floor.

The end-plate connection method has obvious economic advantages during manufacturing and installation, which is the reason it is widely used in a large number of steel frame structures. Because of its flexible connection method, the constrained stiffness of beam to column is effectively reduced and energy dissipation capacity is stronger. However, the construction forms of the end-plate connections are relatively complex with a large number of variable parameters. The initial stiffness and moment resistance of the joint are increases with the end-plate thickness. The available rotation capacity decreases with the end plate thickness. This is particularly evident for the extended endplate configurations. Therefore, brittle components such as the bolts are likely to fail before the end-plate which behaves in a ductile manner. [3] Stiffeners are secondary plates or sections attached to beam webs or flanges to stiffen them against out of plane deformations. Almost large scale projects like main bridges beams will have stiffeners to enhance the performance of beams. Most of the stiffeners are attached vertically to the web but some very deep beams also have horizontal stiffeners. The advantage of stiffening of the end-plate is to provide a significant increase in the moment resisting capacity and the initial stiffness but lead to a reduction of the connection ductility. [4]

2.0 SOFTWARE ANALYSIS

In order to obtain an efficient and accurate model simulation method, the analysis was conducted in ConSteel 9.0 and a separate module CSJoint 9.0. All the analysis in CSJoint module is based on the standard procedure of Eurocode 3. -Part 1 to 8, these entire procedures are covered by the module, ConSteel. Both material and geometry nonlinearities were also considered.

2.1 Modelling

The end-plate connection of steel frame consists of steel beam, column, end plate, rib stiffeners of end plate, column stiffeners and high strength bolts. In order to validate the accuracy and applicability of the end plate connection model, a simulation of experimental end plate connection model done by Wang M. [5]. The model consisting of a welded H-shaped beam H-300 × 200 × 8 × 12 (mm) and a welded H-shaped column H-300 × 250 × 8 × 12 (mm). Figure 1 shows the assembly of a beam and column. The bolts are grade 10.9 and size M20. The thickness of the end plate is 20 mm and all of the steel are made of grade S355. The layout of bolts and connection details is shown in Figure 2. The bolts were pre-stressed to 155 kN and 225 kN. Both ends of column were placed with fixed supports which prevent it to move in horizontal, vertical and out of plane directions. Moreover, it is also put the restriction on rotational movement in these three directions. The beam is considered the symmetrical conditions.

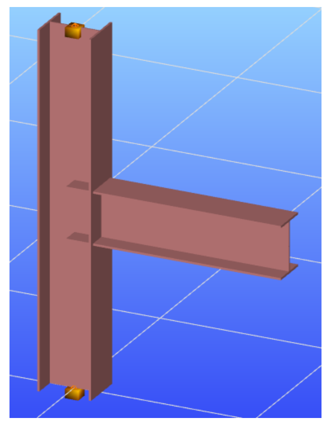


Figure 1 Model with supports

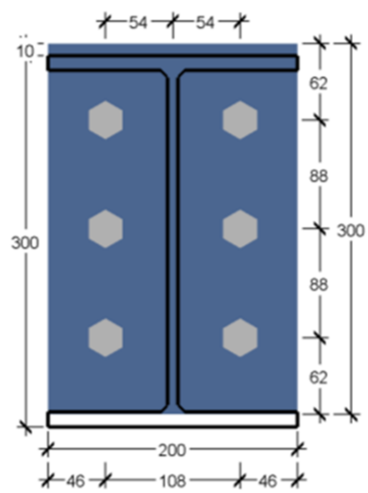


Figure 2 Layout of flush end plate connection

2.2 Verification of Model

The loads were applied at the end of the beams as shown in Figure 3 and the deflections were recorded. Experiment result shows linear result before 120 kN was applied to it and non-linear result after 120 kN. However, the comparison is slightly different because there are restrictions of modeling pre-stressed bolt in the module. Therefore, the deflection is much larger than the experiment. The comparison result from the model in the linear phase compared well to the experiment result. Figure 4 shows the comparison of experiment result and model result.

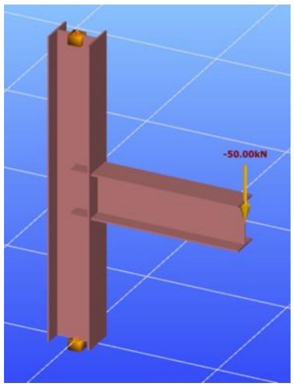


Figure 3 Model under loading condition

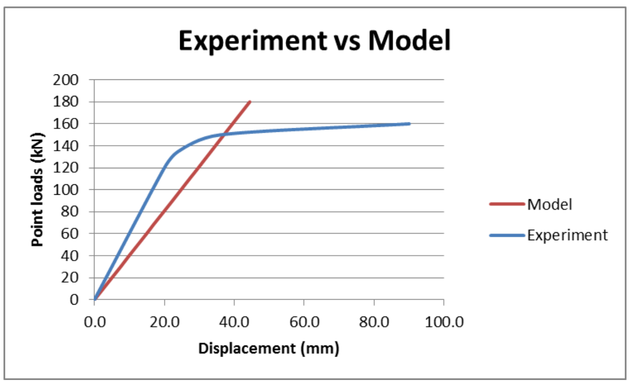


Figure 4 Point loads vs displacement

The simulation of the model has limited information and need additional time to detail out of the information in order to capture the nonlinear behavior.

2.3 Parameters

The deflections of the end-plate connections are relatively complex with a large number of variable parameters such as bolt sizes, bolt grades, types of connection, and grades of end plate. The simulations were carried out with two types of connection, namely flush end plate and extended end plate connection. The maximum load applied is according to the moment resistance of each connection that was calculated by the module as local buckling failure is triggered if the imposed loads are exceeding the moment resistance. The loads were acting on the beam as a point load at the end of the beam. Loads are increased with 5 kN and 10 kN intervals in order to capture detail deflections of the beam. Four bolt sizes M16, M20, M22 and M24 were studied because they are the commonly used size of bolts. And grade 8.8 and 10.9 are mostly found in the major construction usage but only grade 10.9 is used in this research due to limitation of time. Plate dimensions are modified according to detail from experiment and grades S275 was applied because it is also generally used in construction. During the simulation, the position of loading must be applied precisely. That is because the position of loading will affect the moment applied on the connection. After the simulation, the end point shall mark correctly to obtain the accurate deflection. Figure 2 shows the layout of bolts of the flush end plate connection while layout of bolts of extended end plate connection is shown in Figure 5.

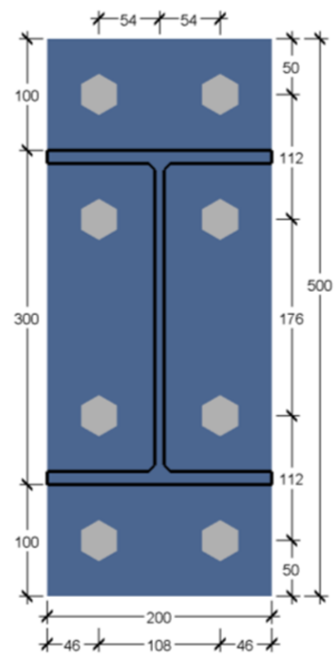


Figure 5 Layout of extended end plate connection

3.0 DATA COLLECTION AND ANALYSIS

The properties of flush end plate connection and extended end plate connection are calculated by the module and tabulated as Table 1 and Table 2 below. The deflections at the end of the beam caused by the amount of loads that was applied are shown in Table 3 and Table 4. Figure 6 and Figure 7 represent the graphical presentation. The maximum load that can be applied is calculated as equation below.

Moment resistance÷Length of beam=Maximum load

Table 1 Properties of flush end plate connection

Bolt Size	Moment resistance (kNm)	Shear resistance (kN)	Moment utilization (%)	Shear utilization (%)	Maximum load (kN)
M16	78.64	304.04	100	22	65.53
M20	93.40	415.70	100	19	77.83
M22	97.17	415.70	100	20	80.98
M24	98.12	415.70	100	20	81.77

Table 2 Properties of extended end plate connection

Bolt Size	Moment resistance (kNm)	Shear resistance (kN)	Moment utilization (%)	Shear utilization (%)	Maximum load (kN)
M16	109.99	415.70	100	22	91.66
M20	130.90	415.70	100	26	109.08
M22	135.55	415.70	100	27	112.96
M24	137.22	415.70	100	28	114.35

Table 3 Amount of displacement according to load for flush end plate

Point load (kN)	Displacement (mm)			
	M16	M20	M22	M24
5.00	1.4	1.3	1.3	1.3
10.00	2.7	2.5	2.5	2.5
15.00	4.0	3.9	3.7	3.7
20.00	5.2	5.0	4.9	4.8
25.00	6.5	6.2	6.1	6.1
30.00	7.8	7.5	7.3	7.3
35.00	9.1	8.7	8.6	8.5
40.00	10.4	9.9	9.8	9.7
45.00	11.7	11.2	11.0	10.9
50.00	13.0	12.4	12.2	12.1
55.00	14.3	13.6	13.4	13.3
60.00	15.6	14.9	14.6	14.5
65.00	16.8	16.1	15.8	15.7
65.53	17.0	-	-	-
70.00	-	17.3	17.0	16.9
75.00	-	18.6	18.3	18.1
77.83	-	19.3	-	-
80.00	-	-	19.5	19.3
80.98	-	-	19.7	-
81.77	-	-	-	19.7

Table 4 Amount of displacement according to load for extended end plate

Point load (kN)	Displacement (mm)			
	M16	M20	M22	M24
10.00	1.5	1.5	1.4	1.4
20.00	3.0	2.9	2.9	2.8
30.00	4.5	4.3	4.3	4.2
40.00	5.9	5.7	5.7	5.6
50.00	7.4	7.2	7.1	7.0
60.00	8.9	8.6	8.5	8.4
70.00	10.3	10.0	9.9	9.8
80.00	11.8	11.4	11.3	11.5
90.00	13.3	12.8	12.7	12.6
91.66	13.5	-	-	-
100.00	-	14.3	14.1	14.0
109.08	-	15.5	-	-
110.00	-	-	15.5	15.4
112.96	-	-	15.9	-
114.35	-	-	-	16.0

Figure 6 Point loads vs displacement of flush end plate

Table 1 and 2 clearly indicate that the major concern is on the moment capacity of the connection. Although the moment capacity is fully utilized but the shear capacity is only utilized a small portion of its shear capacity. Therefore, the maximum load that can be applied depends on the moment capacity of the connection. It is also shown that the moment capacity of extended end plate connection is larger than that of flush end plate connection. It also shows that the load that can be applied on extended end plate connection is greater than flush end plate connection.

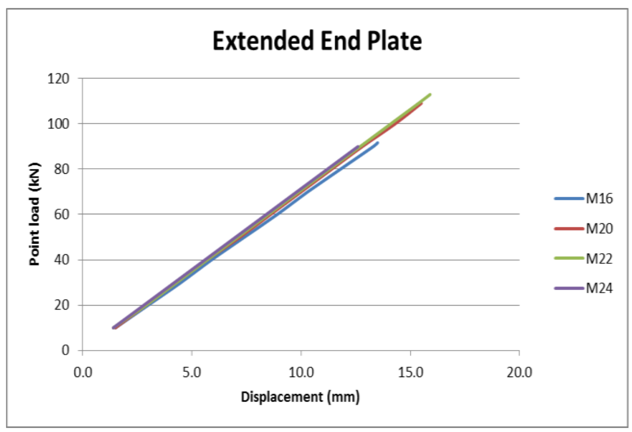


Figure 7 Point loads vs displacement of extended end plate

Both graphs show linear results where the beam can return to its original position if the load is removed. The deflection of the M22 and M24 in the linear region results in very close comparison overlapping and only appear M22 after 75 kN in Figure 6 and 90 kN in Figure 7. The M24 bolt has technically smaller deflection compared to M22 when the same amount of load was applied. From the graphs above, it is obvious that M16 has more deflection compared to others sizes of bolt when the same point load was applied. However, bolt sizes M20, M22 and M24 only have relatively small difference of deflection when the same point load was applied. However, from Table 3 and 4, M24 only has slightly smaller deflection than M20 and M22 when the same point load was applied.

4.0 DISCUSSION AND RECOMMENDATION

4.1 Flush End Plate Connection

In the case of flush end plate connection, moment and shear resistance shown in Table 1 were calculated by the module. It is also expected to be stronger when the size of bolt is increased. The moment resistance increased from 78.64 kNm to 98.12 kNm when the size of bolt is increased from M16 to M24. Meanwhile, the shear resistance also increased from 304.04 kN to 415.70 kN. The shear resistance does not change from bolt size M20 to M24. This is probably due to the maximum shear resistance of the end plate and the beam.

Plate shear occurs when the shear load exceeded 415.70 kN. Plate shear is the end plate or beam starts to deform before the bolt fracture. The moment capacity of the connection is fully utilized and shear resistance is only utilized about 20% when the maximum load applied.

The loads interval is 5 kN in this case because the maximum that applied on the M16 bolt connection is only 65.53 kN. Thus, more than 10 points for each different sizes of bolt can be used to plot a more accurate graph. The maximum loading that can be applied increased as expected from 65.53 kN to 81.77 kN. When the load applied is exceeded the maximum load calculated then failure such as local buckling and zone deformation between end plate and bolt will occur.

The deflections of the beam can be observed clearly by the Table 1 and Figure 6 above. It shows that M16 has relatively smaller capacity and larger deflection occurred as compared to other sizes used when applied the same loading condition. On the other hand, M20, M22 and M24 have the similar results and M20 has the larger deflection while M24 has the smallest deflection when the same amount of loading is applied. M24 performs the most capacity and shows the smallest deflection among all.

4.2 Extended End Plate Connection

Moment and shear resistance shown in Table 4.2 were calculated by the module. The result was expected to be stronger than flush end plate connection. It is also expected to be stronger same as the flush end plate connection while the size of bolt is increasing. The moment resistance increased from 109.99 kNm to 137.22 kNm when the size of bolt is increased from M16 to M24. However, the shear resistance of all the bolt sizes are the same as 415.70 kN. This is a similar case to flush end plate connection where plate shear occurs when the shear load exceeded 415.70 kN. The moment capacity of the connection is fully utilized but shear resistance is increased from 22% with M16 bolts to 28% with M24 bolts when the maximum load applied.

The loads interval is 10 kN in this case because the maximum load that was applied on the M16 bolt connection is only 91.66 kN. Thus, there are about 10 points for each different sizes of bolt can be used to plot a more accurate graph. The maximum loading that can be applied increased as expected from 91.66 kN to 114.35 kN. When the load applied is exceeded the maximum load calculated then failed through local buckling and zone deformation between end plate and bolt will occur.

The deflections of the beam can be observed clearly by the Table 2 and Figure 7 above. It shows similar result from the flush end plate connection. However, the load capacity is much higher than flush end plate connection. It shows that M16 has relatively smaller capacity and larger deflection occurred as compared to other sizes used when applied the same loading condition. On the other hand, M20, M22 and M24 have the similar results and M20 has the larger deflection while M24 has the smallest deflection when the same amount of loading is applied. And M24 has the most capacity and smallest deflection among all.

4.3 Recommendation

Overall, extended end plate connection has better performance than flush end plate connection. Although the number of rows of bolt is more in extended end plate than flush end plate but there is a significant growth of performance in extended end plate connection. In addition, the change of functionality of a structure is greatly depends on the strength of the structure. This is because a stronger structure is flexible of carrying loads that due to the change of functionality in future. Therefore, extended end plate connection is recommended in steel frame construction.

From the results above, M24 has the best performance compared to other sizes of bolt in both cases. However, there is no significant difference of using M20, M22 and M24 size bolts. The optimum size that should be used would be M22 because its performance is at the middle of M20 and M24. On the other hand, M16 also can be used for connection of minor usage. Some of the connections require lesser moment and shear capacity in order to sustain imposed loading conditions.

5.0 CONCLUSION

As a conclusion, model simulation by the software is able to capture the performance of the linear part. The simulated models are successfully performed and analyzed. In low rise building, extended end plate connection and both bolt sizes M16 and M22 are recommended by their optimize performances.

By the research, the objectives of the research are accomplished. The result is able to serve as the basis for improvements in the way buildings and connections are designed, constructed, maintained, and used as well as guidance for industry, safety officials and public safety.

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