Low Cyclic Fatigue behavior of Extended End plate Connection

G Durairaj, C Arunkumar and N Umamaheswari*

Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur-603203,Tamilnadu,India.

Email: *njuma_sus@yahoo.com

Abstract. The aim of this research work is to study low cyclic fatigue behavior of extended end plate connection by changing the connection geometrical parameters. In spite of numerous researches performed in end plate connection, works related to cyclic fatigue behavior of steel connections is found to be less. Five number of beam-column connection specimens were tested under cyclic loading condition. The low cyclic fatigue behavior was examined for varied end plate thickness keeping the diameter of bolt as constant and vice versa. The displacement approach as per FEMA 461, was used to investigate the moment capacity of the connection. The moment-rotation hysteresis curve was obtained for each specimen and fatigue life was calculated based on number of cycles required for failure of specimen. Using the relation between plastic strain, fatigue life and moment capacity, total hysteresis energy was calculated. From the comparison of results of five specimens tested, the one used with thicker end plate has shown better performance in terms of moment capacity as well as energy dissipation.

Keywords: cyclic loading; FEMA 461; plastic strain; fatigue life; hysteresis energy

1.Introduction

In a steel framed structure, elements of connection may be subjected to repeated loading which is termed as fatigue. If the failure of the element is occurred within ten thousand cycle, then it is considered as low cycle fatigue failure. Low cycle fatigue is a type of cumulative damage which is closely associated with fracture. Once the fracture occurred, there will be significant loss of strength and flexural rigidity of the beam column connection happens. Low cycle fatigue behavior of connection is mainly depending on connection geometry and number of cycles of loading. Hence, cyclic performance of connection needs to be studied in order to assess the fatigue behavior. AhamedGhobarah et al. studied the shear capacity of the column panel zone. The doubler plates are very effective to enhance the shear capacity of the column panel zone. The doubler plates are very effective to enhance the shear capacity of the column. The end plate effectively controlled the inelastic deformation of the panel zone and increased the panel shear strength upto 40% [1]. John B.Mander et al. investigated the low cycle fatigue behavior of semi rigid connection. The fatigue life is expressed as a function of plastic strain using the analogous relationship of Manson-Coffin [2]. Yorgun and Bayramoglu reported that for the end plate fully welded to the beam flange, there is no deformation in the welds [3]. Richard Liew et al. studied the influence of positive and negative moments and moment rotational response of cruciform composite joints [4]. YI Maggi et al. stated that failure in end plate connection is mainly associated with formation of yield lines of plate and bolt tension failure [5]. Lachal et al. have used haunches in the end plate connection to strengthen the beam column joint and to dissipate the seismic energy [6]. Malaga Chuquitaype and Elghazouli reported that energy-based fatigue model gives more favourable results than the linear Miner’s rule damage accumulation [7]. Chemin Lim et al. have investigated the end plate stiffened bolted connection to develop life cycle fatigue model using constant and varying amplitude loading [8].
Blazoermelj et al. have proposed the criterion for crack initiation based failure prediction of steel structural components exposed to low-cycle fatigue loading [9]. Morrison et al. examined the influence of bolt spacing on the bolt force magnitude and distribution in the end plate connection [10]. Yanzhiliu et al. have stated that fatigue strength of blind bolts under variable amplitude fatigue loading is lower than the corresponding value for constant amplitude [11]. The main objective of the present study is to examine the low cyclic fatigue behavior of end plate connection prepared with the varied parameters of end plate thickness and bolt diameter. From the calculated fatigue life, hysteresis energy was obtained for each specimen.

2 Experimental Investigation

This experimental program was conducted to study the behavior of beam-column connection with end plate, subjected to low cyclic fatigue loading. The connection parameters varied are bolt diameter and end plate thickness. This section provides details regarding specimens, test set-up and loading history.

2.1 Specimen configuration

The details of the specimen used for tests is shown in Table 1.

| Specimen ID | Column section | Beam Section | Diameter of bolt in mm | Thickness of end plate in mm |
|-------------|----------------|--------------|------------------------|-----------------------------|
| Specimen 1  | ISMB 150       | ISMB 100     | 10                     | 14                          |
| Specimen 2  | ISMB 150       | ISMB 100     | 12                     | 14                          |
| Specimen 3  | ISMB 150       | ISMB 100     | 16                     | 14                          |
| Specimen 4  | ISMB 150       | ISMB 100     | 16                     | 12                          |
| Specimen 5  | ISMB 150       | ISMB 100     | 16                     | 10                          |

2.2 Test setup

The schematic view of load setup for testing of the beam-column with extended end plate connection is shown in figure 1. The specimen has been fixed over the loading frame with top and bottom restrained from movement as shown in figure 2. The hydraulic jack and load cell were placed at the end of the bottom portion of beam for applying load. The load was applied using displacement control approach. The displacement was measured at the beam end using dial gauge. The load cycles were given as per load history until the specimen failed.
2.3 Loading history

The displacement approach followed in this experimental study is as per provisions given in FEMA 461 [12]. The loading history is given in Table 2.

| Displacement in mm | No. of Cycles |
|--------------------|--------------|
| 2.50               | 10           |
| 3.00               | 3            |
| 3.60               | 3            |
| 4.32               | 3            |
| 5.18               | 3            |
| 6.24               | 3            |
| 7.44               | 3            |
| 8.94               | 3            |
| 10.72              | 3            |
| 12.86              | 3            |

3. Results and Discussion

The objective of the present research is to test the low cyclic fatigue of end plate connections keeping the parameters as end plate thickness and bolt diameter. The hysteresis of five beam-column connection specimens under consideration, their failure pattern and fatigue life has been studied. The hysteresis energy was also obtained for each specimen. This section consists of the results obtained from the experimental study and the related discussions.

3.1 Hysteresis

Five specimens were tested under cyclic loading and the results were plotted as hysteresis curves as shown in figure 3(a), 3(b), 3(c), 3(d) and 3(e) for specimens 1, 2, 3, 4 and 5 respectively. The maximum moment and rotation of each specimen were obtained from tests.

It is observed from the above graphs, that the loading and unloading path are the same in the elastic range. The loading history significantly affects the shape of the hysteresis curve of individual cycle. Pinching was observed due to separation of the end plate and column flange. The strength, stiffness and hysteresis loop area of connection was found to increase due to increase of end plate thickness.
When increasing the thickness of end plate from 10 to 14 mm keeping bolt diameter the same, the ultimate moment capacity has been increased by 64%. When increasing the diameter of bolt from 10 to 12 mm, the ultimate moment capacity is increased by 69%, eventually when increasing the diameter of bolt from 12 to 16 mm it is observed that there is no significant change in moment capacity. The positive moment capacity is higher than the negative one for all five cases.

3.2 Failure of specimen

The failure pattern was observed for all connection specimens and is shown in figure 4(a) and 4(b) for specimens 1 and 4 respectively. When the ultimate moment is reached, the end plate started getting separated from the column flange. Because of the cyclic loading, yielding started from either tension or compression side of the connection specimen. The bolt slippage was mainly occurred due to incremental plastic deformation in end plate. The behavior of the connection is affected significantly by varying bolt diameter. The failure of end plate connection specimen started from bottom for specimen 1 and from top for specimen 4 as shown in Figure 4(a) and 4(b).
3.3 Fatigue life study
The fatigue life, plastic strain, average cyclic energy, and total hysteresis energy of all connection specimens under consideration has been calculated [2] and is given in Table 3.

| Specimen ID | Fatigue Life | Plastic Strain rad | Avg. Cyclic energy / cycle kNm | Total hysteresis energy kNm |
|-------------|--------------|--------------------|--------------------------------|-----------------------------|
| Specimen 1  | 38           | 0.0165             | 0.055                          | 1.988                       |
| Specimen 2  | 41           | 0.0161             | 0.163                          | 6.368                       |
| Specimen 3  | 54           | 0.0147             | 0.0782                         | 4.016                       |
| Specimen 4  | 50           | 0.0151             | 0.0593                         | 2.822                       |
| Specimen 5  | 47           | 0.0154             | 0.0541                         | 2.42                        |

The maximum plastic strain was calculated as 0.0165 rad for the end plate connection fabricated with 10 mm diameter bolt and 14 mm end plate thickness. The end plate connected by bolts of smaller diameter behaves in a more ductile manner than the larger one. While increasing the bolt diameter from 10 mm to 12 mm, the hysteresis energy was found to increase by more than two times. Due to the increment of the thickness of end plate, the hysteresis energy was found to increase by 66% if the end plate thickness is increased from 10 to 14 mm.

4. Conclusions
The present experimental study investigated the low cyclic fatigue behavior of the end plate connection keeping parameters as bolt diameter and end plate thickness. The hysteresis of five beam column connection specimens under consideration, their failure pattern and fatigue life has been studied. The following conclusions are drawn,

- When increasing the thickness of end plate from 10 to 14 mm, keeping bolt diameter the same, the ultimate moment capacity is increased by 64%. The strength, stiffness and hysteresis loop area of connection was also found to increase due to increase in end plate thickness.
- When increasing the diameter of bolt from 10 to 12 mm, the ultimate moment capacity is increased by 69%, eventually when increasing the diameter of bolt from 12 to 16 mm it is observed that there is no significant change in moment capacity. It can be inferred that, when increasing the bolt diameter, thickness of the end plate also needs to be increased to get desired results.
- Because of the cyclic loading, the separation of end plate will originate from either compression or tension zone of connection specimen.
The fatigue life is directly proportional to bolt diameter and end plate thickness used in connection specimens. Due to increase of bolt diameter and end plate thickness, fatigue life is increased. The hysteresis energy was found to increase up to 66% while increasing the end plate thickness.

References

[1] AhamedGhobarah, Robert M Korol and Ashraf Osman 1992 Journal of Structural Engineering 118 1333-53.
[2] John B. Mander, Stuart S. Chen and Gokhan Pekcan 1994 American Institute of Steel Construction, Engineering Journal 3 111-22
[3] Yorgun C and Bayramoglu G 2001 Journal of Constructional Steel Research 57 1309-20.
[4] Richard Liew JY, Teo TH and Shanmugam NE 2004 Journal of Constructional Steel Research 60 221-46.
[5] Maggi YI, Goncalves RM and Leon RT 2005 Journal of Constructional Steel Research 61 689-708.
[6] Lachal A, Aribert JM and Loho G 2005 Advances in steel structures 21 353-58.
[7] Malaga Chuquitaype C and Elghazouli AY 2010 Engineering Structure 32 1600-16
[8] Chemin Lim, Wonchang Choi and Emmett A Sumner 2012 Engineering Structure 41 373-84
[9] Blazcermenlj, Primoz Moze and Franc Sinur 2016 Journal of Constructional Steel Research 117 49–63
[10] Machel Morrison, Shahriar Quayyum and Tasnim Hassan 2017 Engineering Structure 151 444-58
[11] Yanzhiliu, Jian Chen, Xiaofei Zhang and Ding Tan 2018 Journal of Constructional Steel Research 148 16–27
[12] FEMA 461 Interim testing protocols for determining the seismic performance characteristics of structural and Non-structural components Federal Emergency Management Agency Washington DC