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Experimental study of prequalified status of flush end plate connections

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Abstract Seismic design of steel structures is an essential part of the design process. Egyptian loading code development process continues in a high rate to catch up with emerging new concepts and standards. Steel design codes (ASD and LRFD) are not developing in the same speed, which prevents the full utilization and application of loading code. The above reason leads to the need for evaluating flush end plate connections from prequalification point of view according to international standards. Due to the lack of sufficient experimental data on flush end-plate connections, an experimental program was conducted to investigate this topic. Six flush end-plate samples were designed according to the Egyptian code for steel construction (ECP205 ASD) using different beam and column sections, bolt diameters and grades. A cyclic loading pattern defined by international standards was used in the testing process, and the performance was evaluated accordingly. Evaluation of M–Φ curves showed that in some cases flush end plate connections satisfy the strict requirements for prequalification. However, beam sections having limited depth fail to achieve prequalification criteria for the connections. Reduced web may be used to enhance the connection status and is investigated in one of the samples to evaluate its impact on connection performance and the failure mode. The proposed staggered hole configuration showed a promising performance.

Introduction

Seismic design of steel structures has taken major steps since the 1994 Northridge earthquake Tremblay [1]. Seismic design codes try to cope with the rapid changes in seismic design procedures and concepts. Current codes utilize the design spectrum method

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to estimate seismic forces on structures. One of the key aspects of the response spectrum analysis is the response modification factor (RMF), which reduces earthquake loads due to the nonlinear structural behavior. Two values of RMF can be used for moment resisting frames. Using a high RMF value requires that the frame possesses sufficient ductility. Ductility requirements for steel structures are defined in international codes such as AISC [2] and standards like FEMA350 [3]. The requirements vary from one country to another according to loads, factor of safety, design methods, and construction methods. To date, Egyptian steel structure design codes ECP-ASD [4] and ECP-LRFD [5] do not include any seismic provisions to ensure the ductility of steel structures. Lack of seismic provisions leads to two major problems; the first is that the designer is unable to utilize a high value of the RMF, resulting in an uneconomic design. The second problem is that evaluation and retrofitting of existing steel structures are limited to the use of the smaller RMF, which constrains the assessment. Each country has its own methods of erection and construction, which are reflected on the standards of the country. AISC [6] and RCSC [7] define the state of snug tightened connection and the installation procedure for bolts. ECP-ASD [4], which is the most used code for steel design in Egypt, does not address the installation, plate surface condition and the definition of bearing type connection.

AISC [2] lists three major conditions that must be fulfilled in moment resisting frames in order to be considered special moment frames and to achieve high ductility. These conditions are: members slenderness, column stress ratio and connection ability to sustain predefined percentage of beam moment capacity combined with certain rotation angle. Connections fulfilling previous requirements are said to be "prequalified". FEMA350 [3] demonstrates how to prequalify a connection or define its status. The process requires performing quasi-static test with predefined loading pattern such as SAC97 [8] on the joint. Researches in end plate moment connection have been initiated in the last century, however, limited number of experimental researches in the area of flush end plate connections have been conducted. Experimental work and proposed basis of design were presented by Jenkins et al. [9] and Thomson and Broderick [10,11] have studied seismic response of flush end plate connections experimentally, and concluded that connection stiffness is overestimated while its moment capacity is underestimated using a proposed Eurocode model. The papers presented a test setup that was modified and used in this current experimental program. Hedayat [12] presented a reduced web technique to enhance post-Northridge connection ductility, which triggered the idea of staggered web configuration, which is tested in this paper.

This paper presents an experimental program, which is a part of a comprehensive research conducted by Hassanien [13] including six samples designed according to ECP [4] and AISC [14] to evaluate its seismic performance. The test results are used to verify the numerical models, which were developed in that research. The design is based on thick plate assumption, which limits the failure of the connection to bolt failure and prevents the formation of any plastic hinges in plate.

Experimental program

A series of six tests designed to investigate the behavior, load capacity and failure mode of flush end plate connections were carried out. The tests were conducted at the laboratory of the Housing and Building Research Center (HBRC), Egypt. The studied parameters were bolt diameters, bolt grades and arrangements. The connections were designed such that the head plate does not reach its yield stress, hence, the plate thickness was conservatively chosen to ensure such assumption and match AISC requirements for thick end plates. IPE 160 and HE120A beam sections were selected to study different bolt spacings and arrangements. Both beams have the same bending strength since their section moduli are almost equal to avoid its effect on connection strength. Fig. 1 shows a general layout of the test setup. The specimen dimensions and components are summarized in Tables 1 and 2. Beam length in all specimens was 1000 mm from the point of load application to the column face. This distance was chosen as the least probable distance in order to decrease the moment applied on the specimens to the least value. Butt welds were used to join the end plate to the steel beam. To examine the effect of web holes on connection behavior and plasticity, one sample, S4, was designed considering staggered holes in its web as shown in Fig. 1.

Instrumentation

The instrumentations were designed to measure the applied loads, deformations along the specimen and strains at specific locations in the specimens as shown in Fig. 2. Electrical strain gauges, with 10 mm grid length, were glued to measure strains at different locations at the connection zone during different stages of loading. Four linear variable displacement transducers (LVDTs), with an accuracy of 0.01 mm, were used to measure displacements at different locations in the specimens.

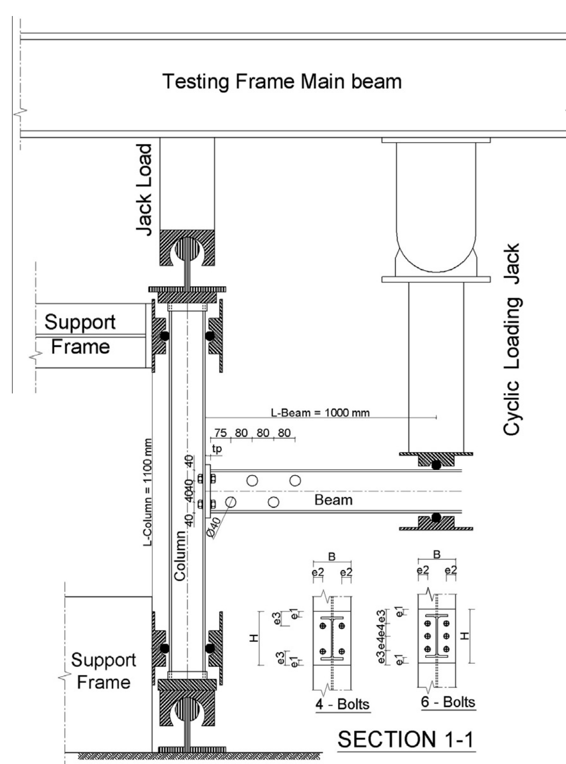

Fig. 1 Experimental test set up (dimensions in mm).