A REVIEW PAPER ON NEW TECHNIQUE TO IMPROVE THE DUCTILITY OF STEEL BEAM TO COLUMN BOLTED CONNECTIONS

Mr Ajinkya Deshmukh[1], Prof. Nikhil Landage[2]

[1]PG student, civil engineering department, MIT – ADT School of engineering, Pune, Maharashtra, India

[2]Asst. Professor, MIT – ADT School of engineering, Pune, Maharashtra, India

Abstract: A new technique to improve the robustness of steel end plate connections is presented in this paper. Existing commonly adopted techniques alter the stiffness of the beam or the endplate to improve the connection's robustness. In this study, the robustness is enhanced by improving the contribution of the bolts to the rotational capacity of connections; the higher the bolts' elongation, the higher the rotational capacity that can be achieved. However, the brittleness of the bolt material, combined with its diminutive length, results in negligible elongation. Alternatively, the load path between the endplate and the bolts can be interrupted with a ductile element to achieve the required elongation. This can be achieved by inserting a steel sleeve with a designated length, thickness, and wall curvature between the endplate and the washer. The proposed sleeve should be designed so that its ultimate capacity is less than the force in the bolt at failure; accordingly, the sleeve develops a severe bending deformation before the failure of any connection components. The proposed system is expected to enhance the rotational capacity of the connections, ranging between 1.5 to 2.5 times that of the standard connection.

1. Introduction

The performance of steel structures subjected to extreme loading has received increased attention in recent years [1–4]. Existing studies have highlighted the significance of connection configuration and associated parameters in enhancing the overall structural performance and avoiding progressive collapse. Due to the limited ductility provided by the connection components, researchers have often focused on various methods to enhance the ductility of connections by increasing their rotational capacity; see Figure 1. Note that in Figure 1, connections for fire and seismic actions are included to illustrate the various concepts to enhance the ductility under different extreme load scenarios. It should also be noted that these extreme scenarios may occur together [5,6]. The concept of a structural 'fuse', i.e., a zone undergoing severe plastic deformation formed in the floor beam, is often used for the seismic design of steel frames. Development of the fuse requires a strong connection relative to the beam section. This can be achieved by either strengthening the connection region (using stiffeners and haunches) to avoid plasticity of any component of the connection [7] or weakening the beam by trimming away steel parts from the beam flanges (RBS) [8] or the beam web (RWS) [9] at designated locations. During a fire event, a higher rotational capacity of connections is generally required to allow the beam to develop into the catenary phase without failure of the connection components. Thus, researchers have proposed formed end plates that can plastically deform during the catenary action [10,11]. It is clear from the previous discussion that improving the ductility relies on modifying either the stiffness of the beam or the endplate. The rotational capacity of the steel connection is primarily controlled by the least ductile members within the load path. These are usually the bolts [12,13]. Traditional analysis and design of T-stub connections treat the bolts as a boundary condition to the endplate [14].

Consequently, high elongation of the bolt is required to achieve a high rotational capacity of the connection [15]. In common practice, the most frequently used bolts tend to be from high-strength steel grades of 8.8 and 10.9, which reach their ultimate strength at a strain of ~0.05 [16], followed by a sudden fracture, while mild steel can achieve a strain of 0.2 [17] without failure. In addition to this, the relatively small length of the bolt leads to a reduced contribution to the connection's rotational capacity compared to the endplate.

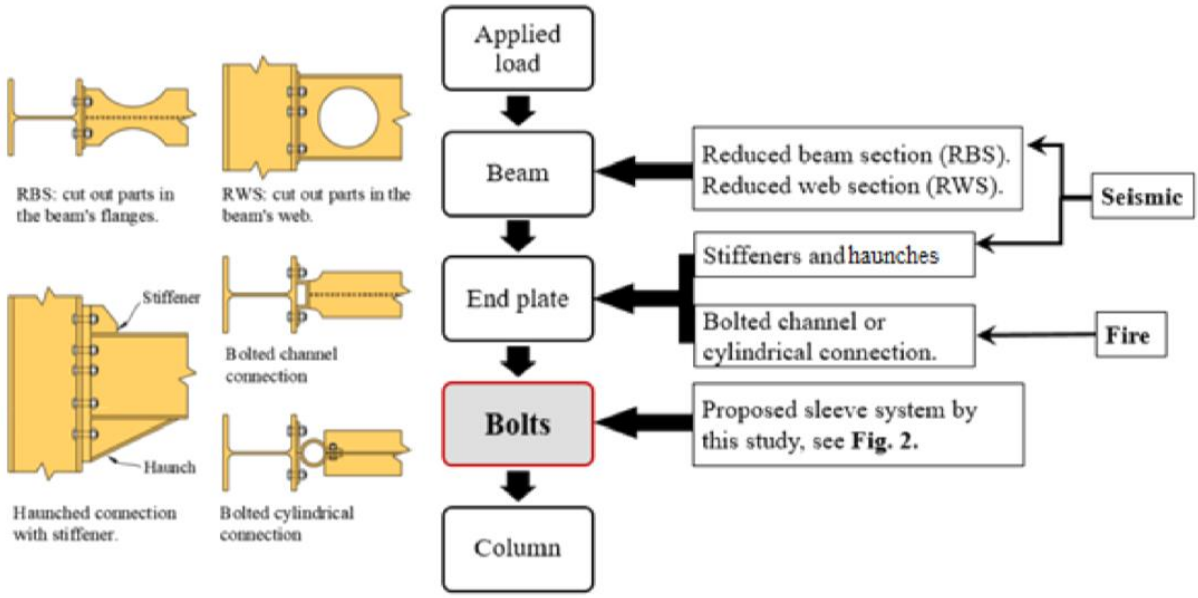

Figure 1. Various methods to increase the ductility of connections.

This present study proposes a novel technique to increase the rotational capacity of endplate connections by enhancing the bolt contribution to the system behaviour. Figure 2 schematically illustrates the proposed system. A steel sleeve with designated length, thickness and wall curvature is placed over the bolt between the endplate and the washer. The sleeve is a shell of revolution that resists the applied load by combining membrane and bending stress. The bending stresses become significantly large as the ratio of sleeve thickness to the curvature radius increases. The curvature in the sleeve wall ensures that the sleeve ultimately fails in bending rather than by instantaneous buckling. This curvature can be defined based on the amplitude at the mid-length of the sleeve and the corresponding geometrical equation of the waveform. Theoretically, there are countless geometrical configurations, including the waveform and the number of waves; however, the practical constraints posed by the manufacturability, the cost and optimum structural performance can limit these alternatives. Examples of these various waveforms are shown in Figure 2. Positive and negative Gaussian curvature is applicable for the identical waveform. However, the latter requires washers with precise dimensions as the outer radius of the sleeve can be larger than the washer radius after introducing the amplitude. Furthermore, the bearing between the sleeve with negative Gaussian curvature and the washer can result in high internal forces in the washer, which may require a non-standard thick washer. Therefore, only the sleeve with the positive Gaussian curvature is considered in this study.

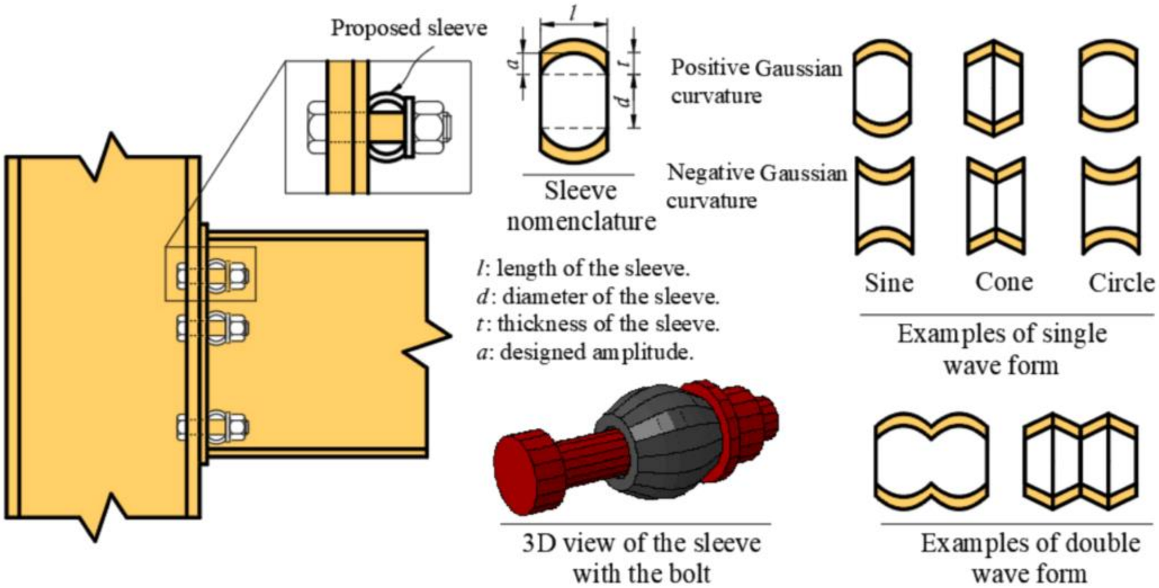

Figure 2. Proposed connection incorporating the sleeve.

This paper will focus on the single sinusoidal waveform (SSW) sleeve configuration. A sine wave is considered as it is frequently used to define the initial imperfection profile of shells for buckling analysis [19].

2. Literature Review

2.1 DEFINITION

Literature Review is a mirror which reflects the past views and presents the future perspectives. It is imprudent and wasteful to proceed with any study without knowing what has already gone before. The sources related to the study will guide looking into the problem to fill any gap in the research area. Therefore, an essential aspect of an investigation is the literature review. The review of literature adds strength to the present study. A literature review is a critical summary of research on a topic of interest, often prepared to put a research problem in context or as the basis for a project (Polit, F.D, Hungler B.P 1999). A Literature review is a compilation of resources that provides the groundwork for further study. An excellent quality article is the one which opens the doorway for further study and guides the researcher. The critical group of articles may include research findings, theory articles, and published literature reviews (Abdullah 1992).

2.2 STUDY OF LITERATURE

Xuhong Qiang[1] , Frans S.K. Bijlaard[2] , Henk Kolstein[3] and Leen Twilt[4] this paper dealt with the behaviour of high strength steel (HSS) endplate connections at ambient and elevated temperatures using ABAQUS. The detailed F.E. model considered material and geometric non-linear effects, large deformations and contact interactions. This paper highlighted the main challenges in modelling endplate connections. Validation against experimental results showed that the proposed F.E. model could reproduce the behaviour of mild steel endplate connections with reasonable accuracy. Using HSS instead of mild steel as endplate material, this model can predict the performances of HSS endplate connections both at ambient temperature and under fire conditions. A parametric study found that a thinner HSS endplate enhanced the ductility of connection at average and under fire conditions and achieved the same load-bearing capacity as a mild steel endplate connection. This finding is promising for further investigations on improving the robustness of endplate connections in the fire.

Hongxia Yu, Ph.D. [1] ; I. W. Burgess[2] ; J. B. Davison, Ph.D. [3] ; and R. J. Plank[4] this paper reported on test results on flush end plate connections at ambient and elevated temperatures. The experiments aimed to investigate the behaviour of connections at the ends of unprotected beams in fire situations, when they may be subjected to significant tying forces and large rotations at elevated temperatures due to high beam deflection. A change in the first fracture mode was observed with increasing temperature as the failing component became the bolts rather than the endplate as the strength of bolts reduces faster than that of steel in fire. At elevated temperatures, the use of thicker end plates can enhance the peak resistance but reduces the rotational capacity of the connection. Finite-element analyses were performed to simulate the tested connections and gave predictions very close to the observed behaviour of the connections in both the loading and the post-peak resistance phases for all the tests at high temperatures. Via these simulations, minor cracks in the endplate, which were widely observed during the tests, were found to have little effect on the overall resistance. Development of the forces in each bolt row showed that, at the peak resistance of the connection force, their distribution could be far from uniform, which emphasizes the need for the full load-displacement-temperature relationships of bolt rows in simplified _component-based_ analysis methods.

Saber Moradi, S.M.ASCE[1] ; and M. Shahria Alam, M.ASCE[2] stated that steel beam-column connections with post-tensioned (P.T.) elements are proven systems that provide adequate stiffness and strength and ductility while eliminating permanent deformations in a moment-resisting frame subjected to seismic loading. In this study, detailed three-dimensional finite-element (F.E.) models of steel beam-column connections with P.T. strands were developed and analysed under cyclic loading. Efforts were made to overcome challenges in performing the non-linear F.E. analysis of large-scale P.T. connections, which involves gap opening and closing behaviour and contact and sliding phenomena. Geometric and material nonlinearities, preloaded bolts and strands were also considered. Through a verification study, the results from the F.E. models were validated against prior experiments on interior P.T. connections with top-and-seat angles. Parametric studies were also conducted to investigate the effects of three factors on the cyclic performance of P.T. connections. The factors investigated in this study were: the presence of beam flange reinforcing plates, the yield strength and strain hardening of steel angles, and the amount of initial post-tensioning force in the strands..

Mohamed A. Shaheen* , Andrew S. J. Foster* , Lee S. Cunningham presented a novel approach that separated designing bolted connections for strength from designing for ductility. By inserting a steel sleeve with a designated length, thickness and wall curvature between the endplate and the washer, the load path between the endplate and the bolts could be interrupted, promoting a more ductile response. Endplate connections with various sleeve geometries are numerically investigated using a validated F.E. model to prove the concept of the proposed method. The proposed system substantially enhanced the rotational capacity up to 2.92 times that of the standard connection. In addition, an elastic response consistent with standard connections is maintained, indicating that the proposed system is compatible with existing codified flexible design approaches without modification.

2.3 CRITICAL APPRAISAL

Connection in steel structure is the first point of failure when the structure is overloaded, under fire or under many other conditions. So, to increase the structure's ductility, it is essential to focus on the minor ductile parts in the structure. While studying the literature, we have found a gap that the least amount of research has been done to increase the ductility, increasing the length of bolts. If this attempt to increase the robustness of the connection is successful, it will be a significant step in the industry.

2.4 NEED FOR RESEARCH

Steel structures are now being widely used in the construction industry as new methods such as pre-engineering buildings are gaining popularity because of the low installation cost and time consumption. However, the research on increasing the load-bearing capacity of the building is still an interesting topic for researchers to study—the use of prefabricated structures and gaining popularity in commercial construction in India. The need to reduce cost and increase the structure's safety is a priority in the research and innovation of steel structures.

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