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Seismic Design Requirements of Steel Connection and Cost Comparison

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***Abstract* - Sound connection design is essential for safety and economy of steel structures. Economical connection designs mostly take into account practicalities of fabrication and erection. True behavior of connections is complex, variable and very difficult to analyse exactly. One of the most important aspects that one needs to take into account when designing a steel structure is the dissipative mechanism of the structure as well as structural properties of connection. The objective of this paper is to explain the properties of steel connection i.e. connection strength, stiffness and ductility. These properties are the major concern for seismic design. And also explain how to reduce cost of connection in steel structure.**
Keywords: connection, structure, strength, stiffness, ductility

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I. INTRODUCTION

While designing for seismic event steel structures must be able to accurately approximate the response of structure beyond plastic range. As a consequence a mechanism must be supplied within some elements of the structural system so to accommodate the large displacement demand imposed by earthquake ground motions. In most cases, good seismic design practice has incorporated an approach that would provide for the ductility to occur in the members rather than the connections. This is especially the case for the steel frame structures, were the basic material has long been considered the most ductile of all materials used for building construction.

II. STRUCTURAL PROPERTIES OF STEEL CONNECTION

i. CONNECTION STIFFNESS

The connections stiffness can be taken as the slope of the M−φ curve, (Fig. 1). Since the curves are nonlinear from the start, it is possible to define this stiffness based on tangent approach or on secant approach. A tangent approach is viable only if the analysis programs available can handle a continuous, nonlinear rotational spring. Even in this case, the computational overhead can be large and this option is recommended only for verification of the seismic performance of irregular structures. In most designs, for regular frames, a secant approach will probably yield a reasonable solution at a fraction of the calculation effort required by the tangent approach. A joint may be classified as rigid/fully restrained (FR), nominally pinned/simple or semi-rigid/partially restrained (PR) according to its rotational stiffness, by comparing its initial rotational stiffness. A nominally pinned joint shall be capable of transmitting the internal forces, without developing significant moments which might adversely affect the members or the structure as a whole. A nominally pinned joint shall be capable of accepting the resulting rotations under the design loads. According to EN 1993-1-8, the joints may be classified based on their rotational stiffness, by comparing its initial rotational stiffness with the bending stiffness of the connected members.

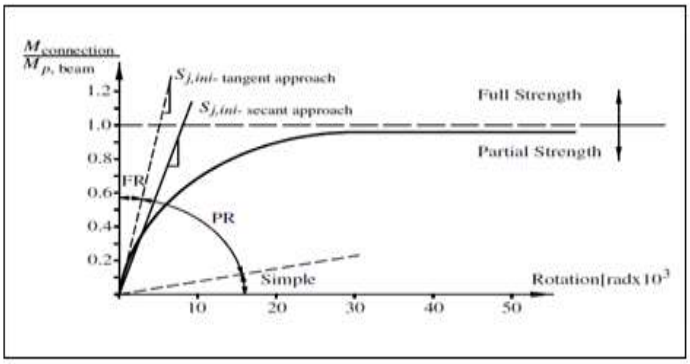

Fig. 1 Connection classification by stiffness and strength

1) The connections are classified as being rigid if

$$S_{j,ini} \geq \frac{E\, k_b\, I_b}{L_b}$$

Where k_b = 8 for frames where the bracing system reduces the horizontal displacement by at least 80% and k_b = 25 for other frames, provided that in every storey $k_b/k_c \geq 0.1$

2) The connections are classified as being nominally pinned if

$$S_{j,ini} \leq \frac{0.5\, E\, I_b}{L_b}$$

where k_b – The mean value of I_b/L_b for all the beams at the top of that storey, k_c - the mean value of for all the columns in that storey, I_b – the second moment of area of a beam, I_c – the second moment of area of a column, L_b – the span of the beam (centre-to-centre of columns) and L_c – the storey height of a column..

ii. Connection strength

A connection can be also be classified in terms of strength as either a full strength, nominally pinned or partial-strength. The design resistance of a full strength joint shall be not less than that of the connected members, while a partial-strength connection can only develop a portion of it. A nominally pinned joint shall be capable of transmitting the internal forces, without developing significant moments which might adversely affect the members or the structure as a whole. For classifying connection according to strength, it is common to non dimensionalize the vertical axis of the M−φ curve by the beam plastic moment capacity, Mp, beam, as is shown in Fig. 1. Connections not capable of transmitting at least 25% of the design resistance for full strength connections are classified as nominally pinned.

iii. Connection ductility

Connection ductility is a key parameter either when the deformations are concentrated in the connection elements, as is the typical case in semi-rigid connections, or when large rotations are expected adjacent to the connections, as in the case of ductile moment frames with welded connections. The required ductility will depend on the flexibility of the connections and the particular application (for example, a braced frame in a no seismic area versus an unbraced frame in high seismic area). A connection can be classified as ductile based on both its absolute and its relative rotation capacity. The design code EN 1998-1 has introduced three levels of structural ductility class connections with design concepts and range of reference values of the behavior factors: low ductility class (DCL), medium ductility class (DCM) and high ductility class (DCH). For medium and high ductility classes, specific requirements are introduced concerning structural ductility (behavior factor q), element ductility (cross sectional classes), material (yield strength hand toughness) and joint ductility (rotation capacity).

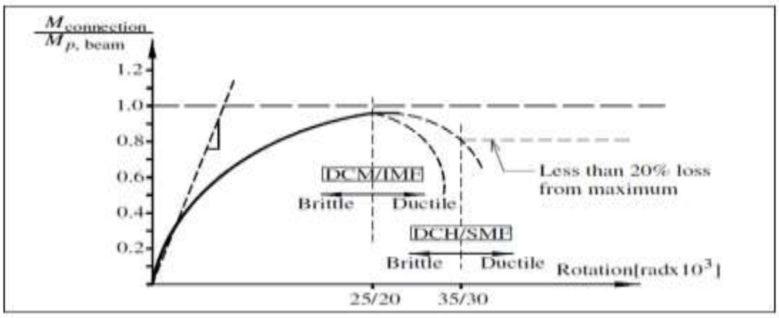

Fig 2. Connection classification by absolute ductility

III. COST OF CONNECTION

Usually cost of fabrication and erection constitute as high as 50% of the total cost of steel structures, per tonne of material used. Hence, designers of connections have a great responsibility in reducing the overall cost of steel structures.

Factors affecting design cost:

Important factors affecting connection design costs are discussed below:

• Connection design takes up a significant part of the overall design cost of steel structures and decisions made at this stage considerably influence the fabrication and erection costs.

• The connection designs should be done using simple and standard cases, so that using design tables, connections can be designed and detailed rapidly. Such tables considerably reduce repetitive calculations, improve accuracy and speedup fabrication.

Factors affecting fabrication/erection costs:

Important factors in improving productivity, decreasing cost of fabrication and erection of connection work are discussed below:

• Repetitive use of standard detail

The repetitive use of standard details spread the cost of learning, cost of setup, cost of templates etc. over a large number of products/components to be fabricated, thus reducing the cost and time required for fabrication. Special, complicated and precise fitting details should be avoided or minimized.

• Ease of joining

The detail should provide easy access to welding and bolting. The positioning of members should be simplified with temporary supports to facilitate quick release of the handling equipment, ease of adjustment and alignment and quick joining.

• Appropriate mix of automatic and manual fabrication

The productivity of numerically controlled automatic machineries (NC machines), and continuous submerged arc welding is very high compared to manual methods. The quality is usually superior. However, their setup costs are high. Hence, automatic fabrication methods are appropriate in large volume jobs.

• Choice of connection method

Generally welded connections are more direct and more efficient, but require more elaborate preparation and machinery compared to bolted connection. This has generally led to the use of welding in shop and on ground field connections and the use of bolting at the erection connections.

IV. CONCLUSION

1. A very important aspect that needs to be taken into consideration, when performing the seismic design of steel structures, is the dissipative mechanism of the structure. In the case of moment frames the seismic energy dissipative mechanisms ensure the consumption of energy by the plastic deformation of certain parts of the structure.
2. Due to the fact that the structural properties of connection subjected to cyclic loads can be determined only through experimental testing the global analysis as well as the design of the constructive details becomes very laborious when one chooses to direct the plastic hinges to the connection's elements.
3. Generally welded connections are more direct and more efficient, but require more elaborate preparation and machinery compared to bolted connection.
4. In India, the cost advantage of shop fabrication is party off set by different excise duty rates between the shop and site fabricated components as well as low productivity equipment and process used in shop practices. Transportation cost also dictates the economy of shop fabrication.

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