End Plate Connections in Plastically Designed Structures

A. B. ONDERDONK, R. P. LATHROP AND JOSEPH COEL

A REVOLUTIONARY improvement in design methods is resulting from the development of practical applications of the plastic strength theory of structural steel design. This could not be accomplished without the new design specifications reflecting the capabilities of these new theories, high tensile bolts and improved welding machines and techniques. Much has been said recently of the savings in tonnage per project in applying the plastic theory to the design of structures. However, theoretical economy, i.e., use of lighter sections, is not enough; the structural engineer must assure that the increased cost of intricate connections to develop the lighter members to their full potential does not offset any savings accrued solely by tonnage reduction.

The new AISC Specification is the outcome of years of research and testing; its issuance has modified and liberalized structural design in steel. This new realistic approach to the true capacities of steel, properly designed, reflects appreciable savings in the cost of steel construction without lowering the safety requirements with which we are so familiar.

Perhaps the most significant and useful aid to the structural engineer is the plastic theory of design. By adopting specification provisions for this theory, the AISC has enabled the engineer to make more efficient use of the material with which he is working, thereby effecting economy in design and construction. Continuity in steel design has now come of age. Continuous design in structural steel is dependent on the connections of framing members to their supporting columns. Heretofore, and even now, these connections have successfully provided continuity by the welding or riveting of the members to form a rigid connection at the columns. Continuing research, the general acceptance of high tensile strength bolts and the requirements of the new AISC Specification have now made moment connections feasible and economical by bolting.

The authors are Consulting Engineers with Onderdonk & Lathrop, Glastonbury, Connecticut, and are Professional Members of AISC.

Two buildings, recently designed in our office, typify the savings in connection time resulting from two-way plastic design with bolted moment connections. Economies realized extended far beyond speeding up construction: design time was reduced, steel tonnage was lowered and shallower beams and girders meant less wall masonry per floor. These particular buildings, a one-story school in Connecticut and a seven-story office building in Virginia are selected for discussion to indicate the savings in such disparate types of structures.

Connections were designed so the welding would be done under controlled shop conditions, with no field welding required. This did cause a slight increase in fabrication costs which was more than offset by the saving in erection costs. This was proved by the very real and practical test of the contractor's selection of this type of connection over field welded connections which were offered as an alternate to bidders.

Although most structural engineers are quite familiar with plastic design, probably few engineers are familiar with end plate moment connections. There is much research in progress to develop theories and applications of bolted moment connections. For the busy consultant interested in further developing the use of this type of connection, three articles from the *Proceedings of the AISC National Engineering Conference* are recommended reading: the first paper was presented in 1959 by Professor F. W. Shutz, Jr., of Georgia Institute of Technology and is entitled "Strength of Moment Connections Using High Tensile Strength Bolts". The second paper was presented in 1962 by Robert O. Disque, Chief Engineer, AISC, and is entitled "End Plate Connections". The third paper, presented in 1963 by Professor R. T. Douty (now with the University of Missouri) and Professor W. McGuire of Cornell University, is entitled "Research on Bolted Moment Connections—A Progress Report".

Professor Shutz establishes the superiority of high tensile strength bolts over the common rivet for those connections which place the fasteners in tension or which cause combined shear and tension. As a result of his research he has established methods of analysis and design for this type of connection. Mr. Disque's paper describes the practical applications and problems of end plate connections from an engineering and fabricating point of view. It also describes physical tests that have been made and the fabricating techniques developed by the Mulach Steel Company in Pittsburgh. The third paper by Professors Douty and McGuire summarizes the results of continuing research at Cornell University and describes some of the successes that are met with this type of moment connection.

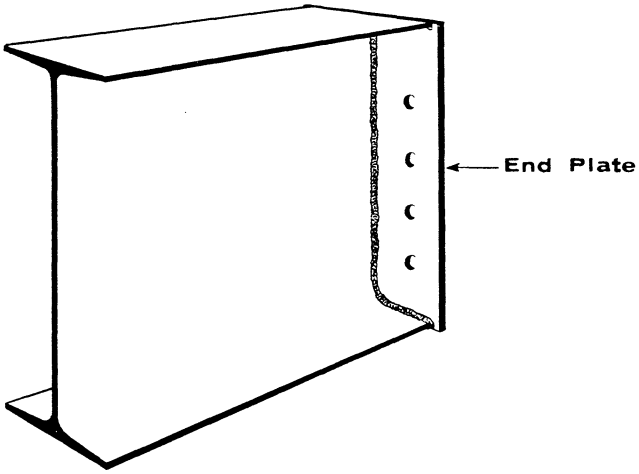

Figure 1

End plate connections (Fig. 1) are simply prepared in the shop by welding a plate flat against the end of the beam. Holes are sub-punched and reamed or drilled to correspond with the bolt holes in columns or girders. In the field the unit is swung into position and high strength bolted to the connecting member. This type of connection can be used for simple shear connections or for moment connections. The degree of moment resistance capacity depends on the engineer's requirements in his design. Depending on moment requirements the plate can be extended above and below the beam flanges to provide space for extra bolt holes and greater moment arm for the leverage that may be required. This type of connection has presented no problem in design, fabrication or erection. Figs. 2 and 3 show moment connections using end plates at columns and girders respectively.

Proven advantages of end plate moment connections as compared with the use of tees top and bottom are:

1. Fewer pieces to handle
2. End plates usually can be sheared; tees have to be burned
3. Alignment with connecting members is not affected by beam depth variations due to rolling tolerances
4. Greater savings in weight of material used

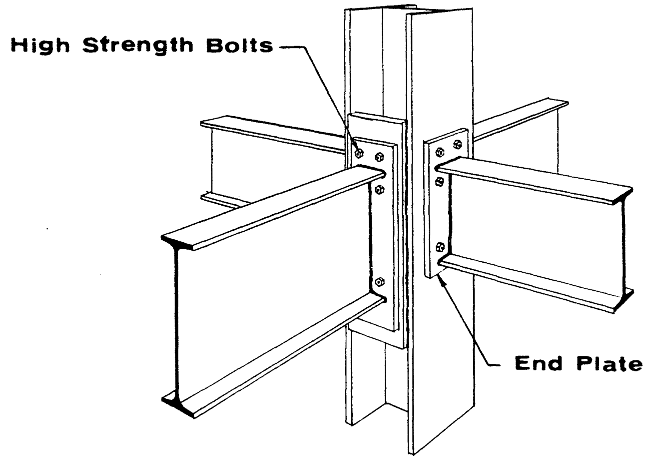

Figure 2

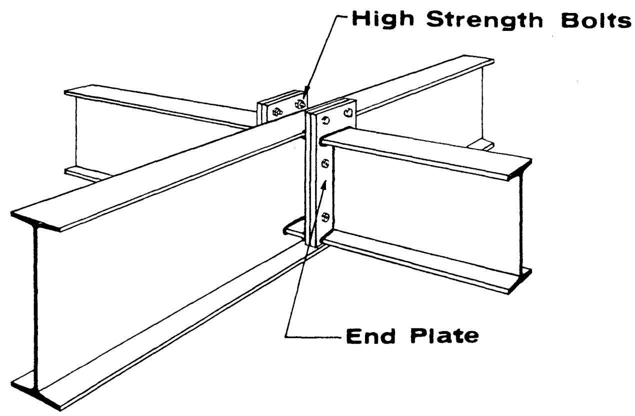

Figure 3

5. Shop welding is economical and assures good weld control. In light construction, fillet welds will usually be used

In the two previously mentioned projects designed by our office, two-way plastic design in steel was chosen for the framing system after careful investigation of other structural systems such as reinforced concrete, composite design, prestressed precast concrete and others. Advantages of structural steel designed for two-way continuity can be listed as:

1. Reduced steel and foundation costs due to savings in weight
2. Reduced construction costs due to minimum size and depth of steel
3. All steel set at the same top elevation, thus further reducing construction costs by reducing floor-to-floor dimensions

The one-story Harriet Beecher Stowe School in Enfield, Connecticut, is rectangular in shape, approximately 100 x 370 ft, and has four column lines with varying bay sizes readily framed by continuous beams and girders. Two expansion joints were provided in the roof framing system which also included a 4-ft canopy around the perimeter of the building. The construction cost of \$527,000 indicated a square foot cost of \$14.25. The total weight of steel was 121 tons and the continuous field connections were designed for either welding or bolting. The steel contractor selected field bolting at a saving of \$10.40 per ton over field welding. The square foot cost of steel erection was \$1.12. Full moment connections were achieved by using end plates fillet welded to the beams or girders. The end plates (see Figs. 4 and 5) were secured to each other with high tensile bolts.

The second project, using two-way plastic design of the horizontal framing with bolted moment connections, with elastically designed columns, is the seven-story

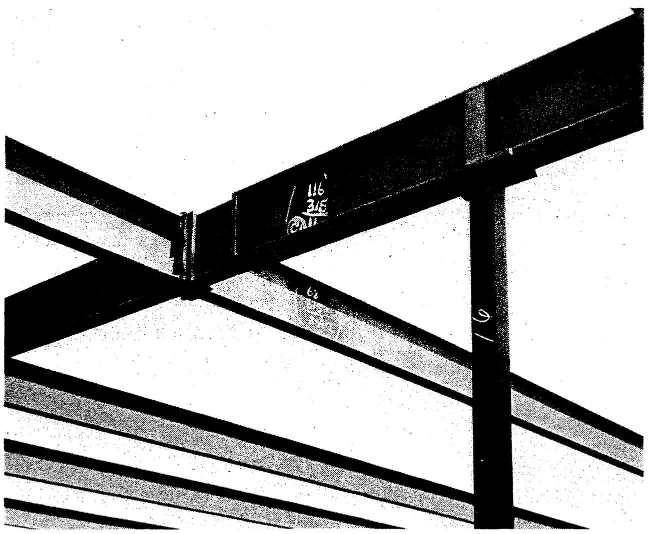

Fig. 4. Continuous girder splice and beam moment connections, Harriet Beecher Stowe School

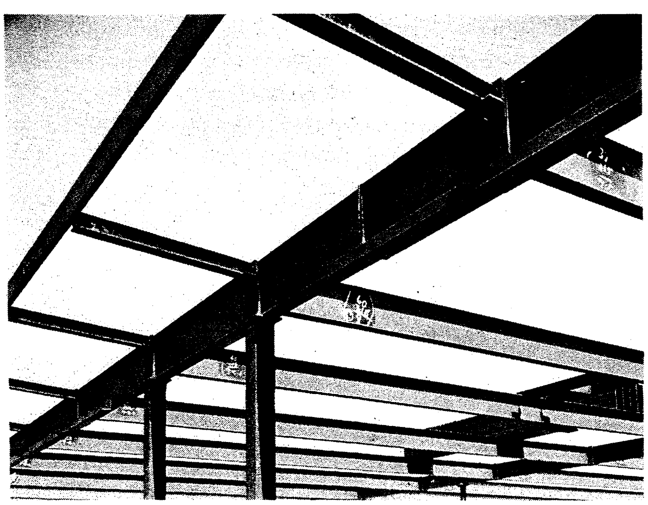

Fig. 5. Canopy details, Harriet Beecher Stowe School

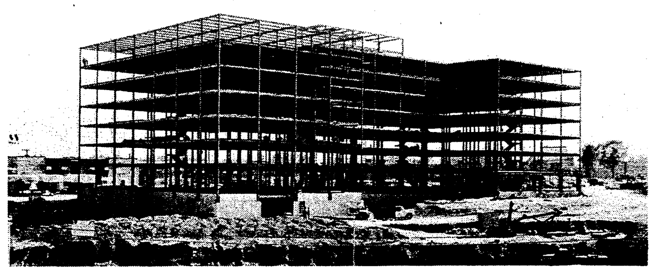

Fig. 6. Seven-story G. S. A. building, Fairfax, Virginia. The 940 tons of steel plus floor deck were erected in 50 working days

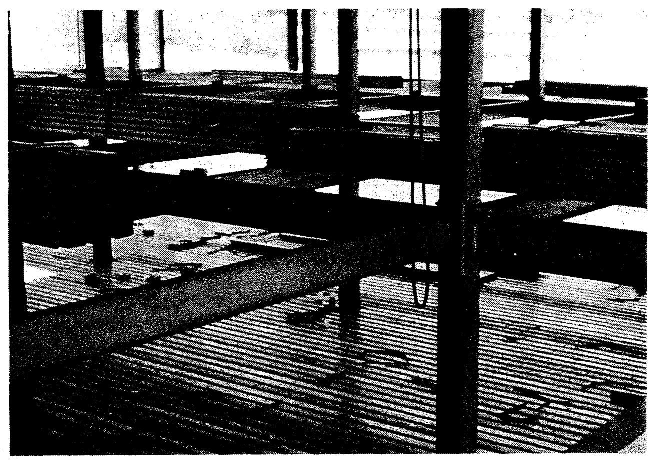

Fig. 7. Interior of G. S. A. office building, showing moment connections for beam-girder connection and moment connections at column

G. S. A. office building in Fairfax County, Virginia (Figs. 6 and 7). The building has two wings 86 × 142 ft connected by a center section 105 x 110 ft providing 237,200 sq ft of office space and 36,200 sq ft of basement parking and utility space.

The office floor system consisted of lightweight concrete fill on cellular steel deck. The first floor system consisted of structural concrete slabs using a corrugated steel form system for positive steel reinforcing. Fireproofing was achieved by use of a fire-rated acoustic tile ceiling and also by spraying the first floor soffit. Steel columns were fireproofed by encasing with concrete or masonry.

Continuous design resulted in a savings of 436 tons of steel, over a preliminary design with simple beams and girders. The total weight of steel was 940 tons (at a cost of \$306 per ton, erected) or 6.5 lbs of steel per square foot. With tight commitments for completion of the entire project, speed in steel erection was a prime object. The entire 940 tons were erected in 50 working days, thus enabling the contractor to proceed that much sooner in placing the floor deck.

In the fabrication and erection of framing members fitted with end plate connections, several problems arise if the fabricator is not familiar with this type of connection. Like most pitfalls, these can be avoided by forethought in the detailing and fabricating processes:

1. The sequence of the shop fillet welds must be scheduled with due respect for the tendency of locked-up welding stresses to cause warping of plates under one-inch in thickness. By "balancing" the welding processes, minimal warpage should result.
2. The matching of end plates and bolt holes is essential. Therefore, it behooves the fabricator to drill (or sub-punch and ream) all similar plates from a master template rather than to depend upon individually measured holes in each plate. Strangely enough, even in the most exacting of shops the layout man's ruler occasionally varies in length.
3. The basic process of forming structural sections by hot-rolling often results in sweeps or involuntary camber in beams, all within ASTM tolerances. If end cuts are laid out without regard to either this natural phenomenon or localized distortions in the section, the faying plates will not butt firmly in the field. The solution to this problem is to set the cutting saw so that both end cuts are made perpendicular to the axial line connecting the ends of the beam. In this manner both the lead cut and tail cut will be parallel.
4. When the girders have narrow flanges, particularly the newer B-sections, the shallow space between the girder web and the back side of the girder's plate (Fig. 3) often will not permit insertion of a bolt shank. The bolts then must be placed from the outside, nuts behind the plates and tightened by the bolt head. There is no structural drawback to this method of installing bolts.
5. Similarly such a shallow space does not give the erector enough room to drift the beams into place using the normally needle-shaped spud wrench handle. Here again, tradition must be broken and a shorter, blunt drift pin should be used.

The ultimate proof of the lower cost of end plate connections is that the steel fabricator chose this type over welded continuous connections, when given the choice in submitting his bid. This indicates that the cost of avoiding the above pitfalls is more than offset by overall savings in time, materials and labor.

With the experience gained on these initial projects our office has continued to apply these techniques with gratifying results and great savings in cost. Recently we were retained for a redesign of a ten-story college dormitory building. After making comparative cost studies we determined that continuous plastic design of girders, end plate moment connections for girders to columns, and end plate moment connections for wind bracing would be the most economical framing system. On the basis of pre-filed steel bids for this project our redesign cut steel tonnage from 320 tons to about 240 tons with a corresponding reduction in cost from $118,000 to $79,000. The redesign also doubled the spacing of columns in the longitudinal direction, allowing more flexibility in room arrangement. These costs are for steel framing only, and do not reflect the further savings in foundation cost. Poor soil conditions required that a pile foundation be used and it has been estimated that an additional savings of approximately $25,000 was realized in the foundation costs. It is increasingly apparent to our firm that the use of these design techniques results in built-in economy of material.

It is our belief that structural steel has developed into a truly versatile material and its use is no longer confined to simple post and beam construction. With the ever progressing concepts and the continued ingenuity of the structural engineer, structural steel framing will continue its adaptability to new shapes and forms.

PROJECT CREDITS

Project: Harriet Beecher Stowe Elementary School, Enfield, Connecticut
Architect: Walter R. Furey, Enfield, Connecticut
Structural Engineer: Onderdonk & Lathrop, Glastonbury, Connecticut
Contractor: John Romano, Enfield, Connecticut
Structural Steel Fabricator: Topper & Griggs, Farmington, Connecticut

Project: Office Building for General Services Administration Fairfax, Virginia
Architects: Munson, Mallis, Bradley, Patterson & Burgener, Springfield, Massachusetts
Associate Architects: Vosbeck-Ward & Associates, Alexandria, Virginia
Structural Engineers: Onderdonk & Lathrop, Glastonbury, Connecticut
Contractor: Eugene Simpson & Brothers, Inc., Alexandria, Virginia
Steel Fabricator: Southern Iron Works, Inc., Springfield, Virginia