The Reinforcement of Steel Columns

LAMBERT TALL

There may be a need for a steel column to have load-carrying capacity additional to that planned in the original design. Columns may be reinforced by the addition of material in the form of cover plates, or by changing the residual stress distribution to a more favorable one by the laying of a weld, or by a method that combines both of these effects. For columns carrying design loads, their reinforcement is possible and safe. The strength of reinforced columns is identical for the conditions of reinforced under load and reinforced under no load. The maximum effect of reinforcement is obtained when the reinforcing weld is as close as possible to the edge of the flange of the base shape.

INTRODUCTION

There may be a need for a steel column to have load-carrying capacity additional to that planned in the original design. The column may be already in place and the reinforcement may need to be carried out under load or with the load temporarily relieved.

Columns may be reinforced by the addition of material in the form of cover plates, or by changing the residual stress distribution to a more favorable one, or by a method that combines both of these effects. The effect of the addition of material is obvious, and warrants no further consideration here. This paper is concerned with those cases where welding is used for the reinforcement, either alone or with cover plates. The discussion is limited to rolled wide-flange shapes as the shapes to be reinforced, and the loads are restricted to static loads.

Reinforcement is usually understood to be the welding of cover plates to the flange of the shape (Fig. 1). Figure 2 indicates the reinforcement of a shape by the laying of a weld bead on the flange tip, which may be the only option available in some conditions and which improves column strength by changing the residual stress distribution.

COLUMN STRENGTH

The strength of a steel compression member is a function of a number of parameters, such as the yield point, effective length, eccentricity of load, and residual stress magnitude and distribution.[1,2,3,4] While all of these parameters are important, those that come into play in this discussion are the residual stress magnitude and distribution. Residual stresses are those internal stresses set up in a member due to plastic deformations such as those due to cooling after welding.[2,3] Since the residual stresses exist in the cross section before the application of load, their effect is to reduce the load-carrying capacity from that which it would have been otherwise.[1,2,3,4] Equilibrium requires the existence of both tensile and compressive residual stresses in the cross section (Fig. 3), yet it is only the compressive residual stresses that contribute to the reduction of compressive strength. The magnitude and distribution of residual stresses in a structural shape is normally of academic interest only; however, it may be possible and desirable to ensure that the residual stress distribution is modified to a more "favorable" one, where the term "favorable" means that the loss of compressive strength is a minimum. (Note that a favorable residual stress distribution reduces the negative effects of residual stress, it cannot increase basic strength above what it would be if no

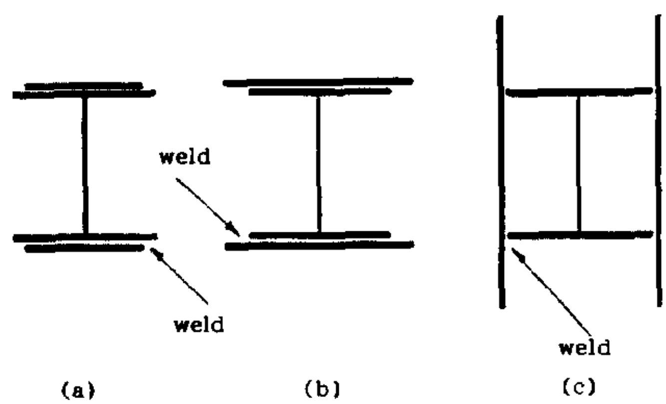

Fig. 1. Reinforcement by Cover Plates

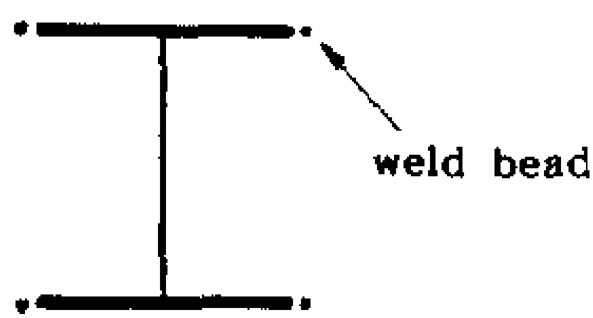

Fig. 2. Reinforcement by Welding

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residual stresses were present. The presence of residual stresses always reduces strength.) The simplest way to change the residual stresses into a more favorable distribution is through the application of heat, either by welding or by flame-cutting. Both welding and flame-cutting have a concentrated source of heat input which produces a highly non-uniform temperature distribution and thus residual stresses with a relatively high magnitude—the residual stresses will be at the yield point in tension at the weld or at the flame-cut edge (Fig. 4).[5] A favorable residual stress distribution may be defined as one where tensile residual stresses are positioned so that the critical portions of the cross section will remain elastic under a compressive load.

The laying of a weld bead onto a column's flange tips (Fig. 2), changes the residual stresses there from the usual compressive value into tension at the yield point. This more favorable residual stress distribution results in a marked improvement in column strength (Fig,. 5).[6] (No additional material is involved in the reinforcement, that of the weld bead being neglected in strength considerations.)

The term "reinforcement" normally describes the welding of cover plates to the flanges of a shape (Fig. 1). The increase in strength resulting is substantially greater than for welding alone because of the combined effect of the additional material of the cover plates and the more favorable residual stress distribution. Figure 6 shows the residual stresses in a rolled shape of A7 steel (W8 × 31 shape with a yield point of 37 ksi) and in the reinforced shape after a 7 × 3/8 in. plate has been welded to the flange tips. Figure 7 indicates test results for the same shape, *L/r* = 48, showing a 10% relative increase in strength after reinforcement.[7] It should be noted that the actual absolute increase in strength would be considerably higher, since the non-dimensionalized strength in Fig. 7 is defined with respect to the yield strength of the total cross section which differs before and after reinforcement.

Additional information on the effect of a favorable residual stress distribution is obtained also when a comparison is made between the strength of welded shapes built up from UM plates and built up from FC plates.[1,5] Thus, Fig. 8 shows the residual stress distribution of such shapes,[8] and Fig. 9 shows the comparison of column strength, both theoretical and experimental.[3] While the welding process does reduce the magnitude of the original high tensile residual stresses at the flange tips which had been flame-cut, nevertheless the final residual stresses there are tensile (or occasionally very low compressive, depending on the welding

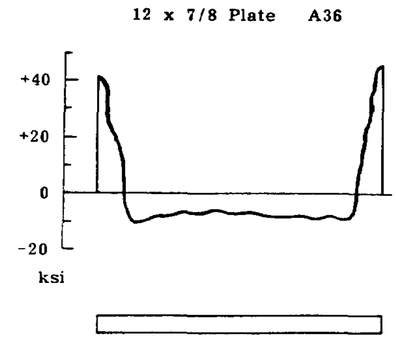

Fig. 4. Residual Stresses in Flame-Cut Plate

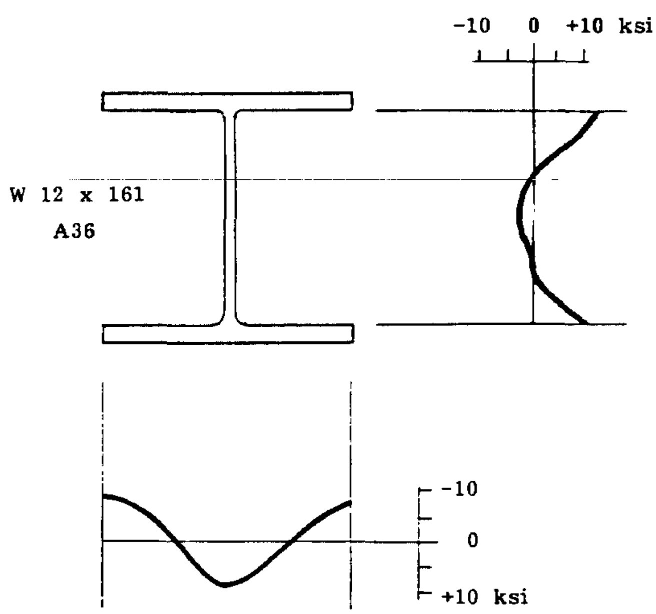

Fig. 3. Residual Stresses in Rolled Shape

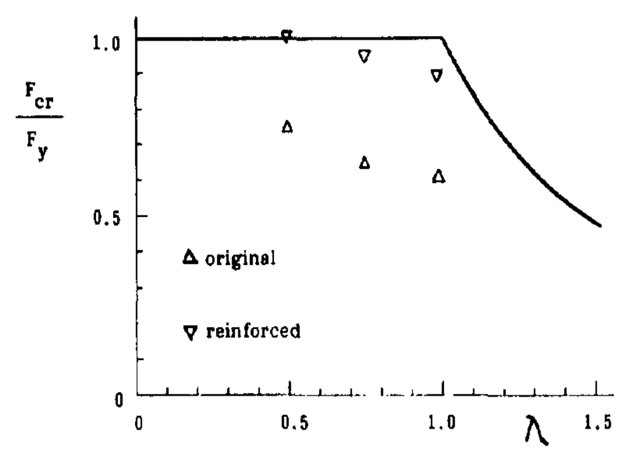

Fig. 5. Strength of Columns Reinforced by Welding

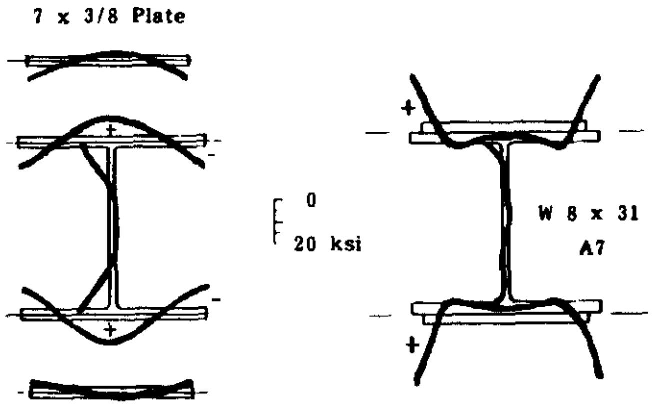

Fig. 6. Residual Stresses in Reinforced Shape: Before and After

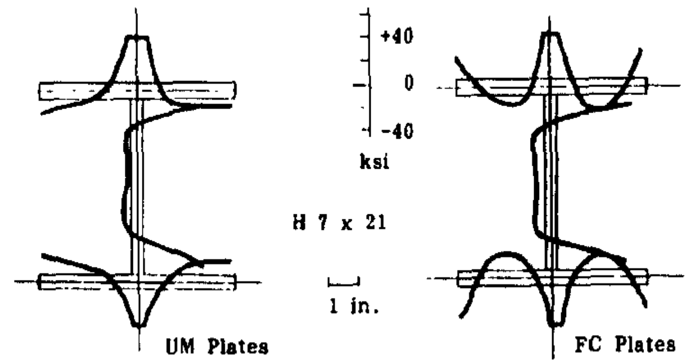

Fig. 8. Residual Stresses in Welded Shapes

parameters and geometry of the shape) such that the final residual stress distribution is favorable since the material remaining elastic under load is furthest from the buckling axis. Normally, FC plates are used for the fabrication of welded shapes as a convenience—the use of UM plates is discouraged as they result in a less favorable residual stress distribution in the shape. (Actually, UM plates are not normally used for fabrication because the edges are not perfectly straight due to the rolling process, and need to be flame cut for straightness.)

The concept of "Multiple Column Curves" has been under consideration.[1,2] It is of interest that the order of magnitude of the improvement in column strength by using a more favorable residual stress distribution is such that Column Curve 1 could be used for design instead of Column Curve 2, although only for rolled shapes of light and medium size with a weld bead placed on the flange tips. However, a weld bead placed on the flange tips of a welded shape built up from flame-cut plates or on the flange tips of a heavy rolled shape would not improve strength significantly, so that no change in column curve would be expected.

REINFORCEMENT UNDER LOAD

Although many columns can be reinforced while carrying load without creating an unsafe condition, this is not advisable as a general rule, and if it is carried out, then it should be only after an analysis for safety.

Clearly, transverse welding must never be carried out on any column under load, since the complete cross section will

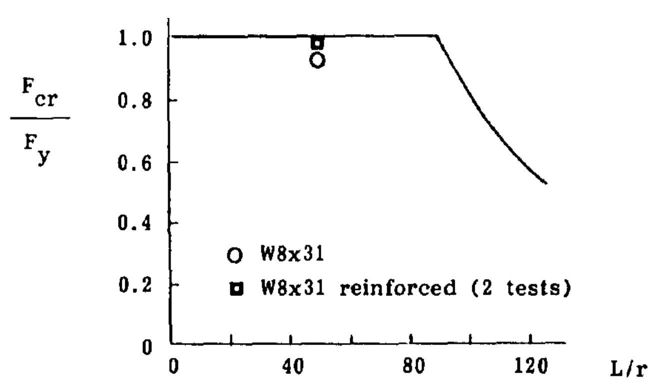

Fig. 7. Strength of Column Reinforced by Cover Plates

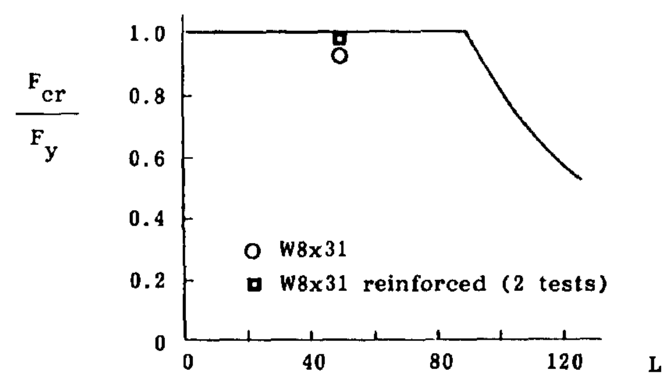

Fig. 9. Strength of Welded Shapes

be affected by the temperature rise. Thus, it is critical that only one flange of the column be welded longitudinally at a time so that only one flange tip of the cross section will be plastic at any one time. The amount of plastification of the flange tip during welding depends on the heat input from the welding, and thus on the welding parameters such as speed of welding and weld size.[9, 10] For a ½ in. thick plate, 4 in. wide, welded at an edge, the approximate temperature distribution curves are shown in Fig. 10.[9] Noting that the yield point is a function of temperature,[9,10] and that, for A36 steel, the value of the yield point has dropped to about 22 ksi at 1000°F, then it may be concluded from Fig. 10 that the maximum distance of flange material of a welded edge that will have a temperature above 1000°F and hence have its yield point lowered to 22 ksi is no more than 1 in. from the edge. Flanges thicker and wider than 8 × ½ in. would show an even lesser effect of lowered yield point since the weld bead would remain the same in size even for a heavier flange.

From the above discussion, it may be concluded that, if the working load currently on the column corresponds to an allowable stress that is no more than about 22 ksi for A36 steel, then the column may be welded safely without removing the load. If the current working load on the column corresponds to an allowable stress above 22 ksi for A36 steel, then a buckling analysis should be conducted assuming that a one-inch width of one flange tip has yielded and is thus lost to the buckling resistance. This latter case implies an eccentric load on an unsymmetric cross section, that is, biaxial bending of a beam-column, which is complex for cases other than short columns.[2]

While a detailed buckling analysis is recommended in the latter case, it is of interest to note than an experimental study of the reinforcement of columns under load[7] showed that the welding process had no discernible effect on a W8 × 31

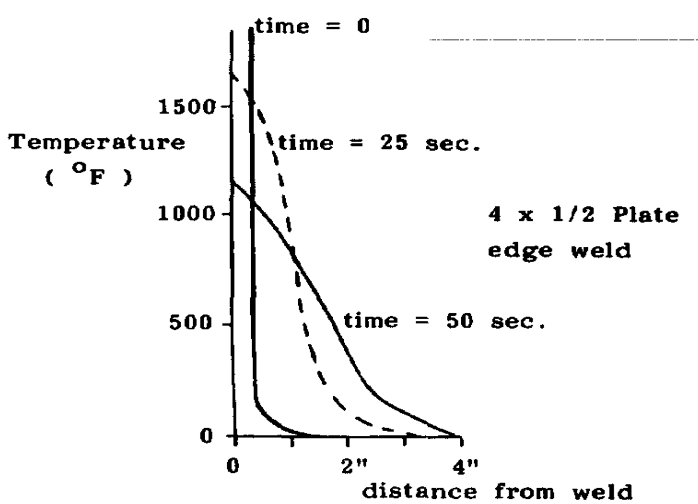

Fig. 10. Theoretical Temperature Distribution Curves

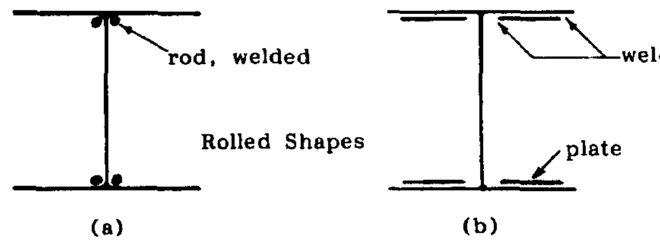

Fig. 11. Reinforcement Not Recommended

column of A7 steel (37 ksi yield point, *L/r* of 48) loaded to a compressive stress of 25 ksi. It was concluded that: "The influence of welding is confined to a very small area in the vicinity of the weld. The material properties in the major portion of the section are not affected enough to reduce the strength of the section." Since the cross-sectional area plastified by the weld bead becomes relatively smaller as the size of the column cross section increases, it appears that columns heavier than a W8 × 31 may be welded longitudinally under load without distress—however, a definitive statement on this must await the results of further study.

It is of interest that the residual stresses in the reinforced shape of Fig. 6 are identical for both cases of reinforcement under load or reinforcement under no load.[7] Further, in Fig. 7, the test results for the reinforced shape are identical for both cases of reinforced under load or reinforced under no load.[7]

SOME PRACTICAL CONSIDERATIONS

The width of cover plates used to reinforce shapes has a lower limit in size, but effectively no upper limit, if the intention is to secure a favorable residual stress distribution. The width of the cover plate should be no narrower than the width of the flange less a sufficient space for the weld to be deposited—this ensures that the weld is as close as possible to the edge of the flange to be effective in changing the residual stress there to tension. When the cover plate is wider than the flange, the width depends only on the usual design considerations of width-thickness limitation.

While any location of additional steel by welding is possible in the reinforcement of columns, the maximum effect is obtained only when the weld is as close as possible to the edge of the flange of the base shape, as noted above. Thus, a location close to the juncture of flange and web would create additional tensile residual stresses there with accompanying addition of compressive stresses at the flange tips—thus, a lowering of strength from the residual stress effect which would tend to negate the increase obtained from the additional material. Examples of existing reinforcing practice which actually contribute little if any additional strength are shown in Fig. 11. (The situation in Fig. 11b could represent a net increase in strength if the inside welds were placed first, followed by the outside ones.)

Flame-cut plates are normally used as cover plates. While this is not a critical requirement for cover plates of a size similar to that of the flange since the welding process affects both simultaneously, it becomes very important for relatively wide cover plates for the cases shown in Fig. 1b and 1c. In these cases, the favorable residual stress distribution results from the flame-cut edge of the cover plates, and the weld contributes very little, if anything, to improving column strength.

The use of intermittent welds is not recommended. While they are prohibited in fatigue situations, their use in the reinforcement of building columns is counterproductive at the flange tips and only marginally useful at the juncture of flange and web (such as in Fig. 11) as far as residual stress formation is concerned.

CONCLUSIONS

1. The reinforcement of steel columns by cover plates welded to the flanges normally improves column strength because of the combined effect of additional material and the creation of a favorable residual stress distribution.
2. The deposit of a weld bead onto a column's flange tips introduces a more favorable residual stress distribution resulting in a marked improvement in column strength.
3. The reinforcement of a column may result in the column being assigned a higher column curve, if the concept of multiple column curves is considered.
4. Flame-cut plates, rather than UM plates, are normally used for the reinforcement of columns.
5. For columns carrying design loads, their reinforcement under load is possible and is safe—the loads and the design should be checked to ensure that code requirements are met.
6. The maximum effect of reinforcement is obtained when the reinforcing weld is as close as possible to the edge of the flange of the base shape.
7. The strength of reinforced columns is identical for the conditions of reinforced under load and reinforced under no load.
8. The welding of rods or plates to the juncture of flange and web does not contribute additional strength since the residual stress effect tends to cancel the additional material effect.
9. The use of intermittent welds for reinforcing is not recommended.

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