Reinforcing Steel Members and the Effects of Welding

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Reinforcing structural steel compression members to increase the cross-sectional area or decrease slenderness by attaching additional bars, plates, angles and channels is an economical method of increasing load-carrying capacity. Supplemental reinforcement has been installed under various loading conditions. In most cases the attachment is achieved by welding, although bolting may be chosen for some particular technical or administrative reason. The author has been involved in both methods, and usually experience and the specific conditions dictate which attachment method is more appropriate. This paper presents a review of several proposed reinforcement methods and discusses factors that must be considered for each. The focus of this paper is welded reinforcement methods, although an appropriate reference to a bolted study is made.

Whenever the existing steel members are in good condition and their composition is known, the welding requirements are straightforward. However, for older unknown or corroded steel, other factors are involved, such as weldability, contaminants and deep pitting. These issues were addressed by Tide[1] and Ricker[2] in earlier papers and are not repeated herein.

A few case-study papers by Spraragen,[3] O'Sullivan[4] and Donovan[5] are available to highlight successful procedures that have been used in the past. Many of the issues identified by Spraragen are as applicable today as when he first enumerated them in 1944. However, since 1944 our knowledge of welding, welding procedures, fatigue and residual stress has greatly increased and the severity of some of the effects that concerned him have been mitigated. O'Sullivan tested trusses that had been reinforced (bolted) with and without applied load and determined that there was no substantial difference in the ultimate strength between the two procedures. However, when the trusses were reinforced under load, he determined that there was a 50 percent increase in deflection before full cross-sectional yielding occurred. It should be noted that when bolted reinforcement is considered there will be a reduction in the net section of the original cross-section resulting from the new bolt holes.

Single column laboratory tests have been reported by Nagaraja Rao[6] and one of the reported conclusions was that the ultimate strength of a column reinforced under load actually increased above a comparable column reinforced without load because of the beneficial effects of improved residual stress distribution.

Recently published papers by Ricker, Brown[7] and Tall[8] have addressed the issue of reinforcing compression members (columns) under loaded conditions. It appears that to some degree these authors have ignored the earlier lessons reported in 1944 by Spraragen and reproduced herewith:

> "It is regrettable that many of the investigators taking stress measurements did not fully understand the phenomena involved. For example, elastic stress and plastic flow (distortions) are sometimes confused. Moreover some investigators have been partially deceived by adjustment under load where peak residuals through initial yielding of the material (plastic flow) have been ironed out and thereafter the structure behaves on the basis of calculated strength."

For the most part Tall recognized that the complex distribution of residual stresses across the column cross-section is the key parameter affecting column strengthening under load. After appropriately developing his position, Tall concluded that for columns carrying design loads, their reinforcement under load is possible and safe—provided the loads and the design are checked to ensure that code requirements are met. Unfortunately, it was not clear as to what he meant. If this differentiates between the stress levels in the original and the reinforcing member, the author disagrees. However, if he is referring to an average stress value, then the author concurs with this recommendation. It should be emphasized that the stipulation "*columns carrying design loads*" implies that at the time of strengthening a safety factor in excess of 1.67 exists. For long compression members the safety factor is at least 1.92. Whenever less than maximum live load conditions are encountered, the safety is even larger.

Unfortunately Tall devoted excessive discussion to the benefits of rearranging the residual stress distribution pattern. Actually Hall[9] has shown that the residual stress distribution in steel shapes is probably non-symmetrical, and Tide[10] has presented figures showing that the specification design equations essentially represent a lower bound capacity as compared to test results. There have been ample tests conducted to verify (ASCE,[11] Galambos[12] and Tide[13]) that fabrication (welding) effects do not alter the performance of steel members below the values predicted by AISC's[14,15] Specification. In general, placing a weld bead along the

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flange tips (or flame heating the flange tips) of compression members increases the capacity that at best is approximately 16 percent and the cost/benefit ratio is questionable. The amount of increase is dependent on the column slenderness ratio, mill cooling and cold straightening procedures.

Tall's final recommendation, that use of intermittent welds is counterproductive since a less than optimum residual stress pattern results, needs qualification. If the intent is to increase the column capacity (16 percent or less) by placing a bead of weld (or flame heating) the tips of the flanges, then he is correct. However, for the more likely condition of attaching cover plates, then the author disagrees with his recommendation because the effects of welding (improved residual stress pattern) is small compared to the increased capacity resulting from the cover plates. Except for fatigue considerations, intermittent welds are a professionally recognized practice incorporated in AISC's Specifications which result in minimum heat input and manpower. As a result, they are very economical. According to the specifications, for a properly designed compression member reinforcement, consideration of residual stresses for overall compression member behavior is not required.

Brown derived a procedure for reinforcing compression members under load. The author does not question the mathematical technique that was developed, but rather the initial assumptions. It is not reasonable to ignore either the residual stresses from the initial mill rolling or subsequent stresses resulting from welding. As stated above, in most cases residual stresses can be ignored because they have been accounted for in the design equations, or they do not increase the compression member capacity by a known or predictable amount. It is important to emphasize the phrase "*in most cases*" since there may always be an exception. The mathematical model chosen by Brown assumed the original compression member (the core) had a buckling load independent of the reinforcing members. For most practical applications this is physically not possible. Once cover plates are welded to the core, the two must act compositely because they have been rigidly and continuously attached. Consequently, these physical conditions invalidate his definitions of length L_1 and L_2. The reinforcing member stiffness provides additional stiffness and restraint for the core member. As a result, localized yielding becomes a lesser problem for the reinforced compression member as compared to the unreinforced original (core) member. Reiterating a previous statement, the applicable AISC Specifications have chosen equations that represent a lower bound to the test results. Unless it can be shown that the compression residual stresses have been dramatically increased such that local buckling is imminent, computation of separate stress levels for different components to determine overall member capacity is not justified.

A similar disagreement exists concerning Ricker's procedure. Arbitrary elastic stress levels were computed that do not reflect actual conditions in compression members. In his procedure, the resulting design is considered overly conservative compared to our current state of knowledge of residual stresses and compression member behavior.

Prior to this point in the discussion, only static stress conditions have been considered. If cyclic stress conditions exist, indicating fatigue may be a factor, a more conservative approach is warranted. The fatigue category of the original member and the reinforcing details must be established as given by Fisher.[16,17] Thereafter and in conjunction with this knowledge, the appropriate reinforcement size and detail can be designed. It is always preferable that the welding be performed under static conditions, but under controlled conditions welding can be performed under cyclic loading.

In summary, a review has been made of recent papers that propose techniques and conditions when designing reinforcing for compression members while under load conditions. The author disagrees with these procedures, for the most part, because they do not represent actual physical conditions. Furthermore, these techniques could be misleading because more critical conditions could be overlooked, which in turn could result in dangerous situations. It is not necessary to know the actual residual stress level, but the impact on local and overall buckling must be understood and considered. Before considering reinforcing compression members under load, the following factors should be considered and made part of the design process:

- Are the current and future loads static or cyclically applied?
- What is the ratio between the in-situ load and the original design load?
- What is the type and condition of the steel?
- Is local buckling a possibility?
- How does the stability of each individual compression member affect the overall stability of the whole system?
- What safety factor must be maintained during the reinforcing operation?

The above procedures have been successfully applied by the author numerous times to reinforce steel compression members. In each case the reinforcing was specifically designed for the particular applications and conditions.

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