DISCUSSION

Commentary on Highly Restrained Welded Connections

Paper presented by American Institute of Steel Construction (3rd Quarter, 1973)

Discussion by **Norman B. Jones**

The commentary by the American Institute of Steel Construction was a most welcome initial compilation of information regarding the very timely subject of lamellar tearing of welded connections. Numerous helpful suggestions are presented throughout the article, but the writer believes that the concern of the members of the design profession has been underestimated. Surely something more definitive and quantitative can be done to insure the statement in the Conclusion that "the great majority of welded connections are not subject to conditions that induce lamellar tearing."

In late July, 1973, it was reported that extensive lamellar tearing had appeared in transmission tower joints where "the tower plates ranged from only $\frac{3}{8}$- to $1\frac{1}{16}$-in. thick." [1,2] The illustration given of the original design details pointed out a tear location in a plate only $\frac{1}{2}$-in. thick. Little wonder that the same publication later reported a case where designers of a 32-story building had elected to use all-bolted connections for the framing.[3]

In order to use the many applications customary for the welded joint illustrated in Fig. 22, we need better guidelines to insure that we will be safe from lamellar tear possibilities. Are there actually definite thicknesses of column (or beam) flanges where tearing is not a problem? Are the suggestions noted in Fig. 21 reasonably economic, and at what thicknesses should they be required? Is there a sequence or procedure for shop welding the stiffeners of Fig. 22 that might reduce restraint for the field welding of the connecting flanges? Is preheat before such field welding helpful in reducing tear possibilities? For what thicknesses of flanges? Are rolled flanges more or less susceptible to lamellar tear than plates?

As these few questions indicate, the writer hopes that there may be available considerably more helpful and definitive information than was included in the commentary. There could be no mistake in making such quantitative detailed information available to the design profession as rapidly as possible.

REFERENCES

1. *Engineering News-Record, July 26, 1973, pg. 14.*
2. *Engineering News-Record, October 18, 1973.*
3. *Engineering News-Record, November 1, 1973, pg. 16.*

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Discussion by **W. A. Milek**

The discussion by Mr. Jones expresses the questions of many designers relative to the phenomenon of lamellar tearing and his comments are appreciated. Unfortunately, definitive answers to the deceptively simple and clear questions are not available under the present state of engineering knowledge. It was exactly because of the fact that no way has been found to quantify the individual effects of the many factors involved that the Committee prepared a summary of general information derived from research reports that were available from around the world, rather than a compendium of specific recommendations.

The intent was to give designers and fabricators alike a general understanding of the mechanics of the phenomenon and a recognition of the fact that the many factors that bear upon the problem must be considered together; each considered separately can either ameliorate or compound the tendency for tears to develop. No solution dealing with a single factor, nor with a combination of several factors, can be counted upon to provide a guarantee that difficulty will not be encountered in susceptible connections.

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Even though some new information has been developed as a result of considerable research effort since the Commentary was published, definitive (quantitative) answers to the stated questions should still be avoided, since such answers might be erroneously construed as implying some guarantee of a solution for specific cases. Honest questions deserve honest answers; therefore, the following comments are offered in an attempt to be responsive, but with full recognition that definitive answers cannot be given.

Q. "Are there actually definite thicknesses of column (or beam) flanges where tearing is not a problem?"

A. In the context that definite thickness means a threshold thickness below which no consideration of the potential for lamellar tearing exists, the answer is "no." Thickness of material is indirectly related to the potential for lamellar tearing. Tears are caused by contraction due to cooling of solidified weld metal under conditions of high restraint. The larger the weld nugget, the greater will be the shrinkage that must be accommodated. Since there is generally some proportionality between size of weld deposit and thickness of material, tearing is more often encountered in thicker materials, but the magnitude of weld contraction to be accommodated, rather than material thickness *per se*, is the important factor. Similarly, although the restraint is related to thickness in many cases, heavily stiffened thin material can also provide restraint equivalent to that of unstiffened thick material. Practical experience has shown that lamellar tearing is a highly unlikely phenomenon in material less than $\frac{3}{4}$ to 1 in. in thickness, even though a few instances involving thinner material have occurred, as Mr. Jones points out. In laboratory research on joints restrained so as to intentionally produce lamellar tears, it has been observed that tears are not initiated until 4 or 5 weld beads have been deposited and cooled. Thousands of buildings, each using many connections typical of those shown in the AISC Manual, have been built with beams and columns of the frequently used sizes without developing lamellar tears. Beyond these comments, it would be imprudent to suggest specific guidelines.

Q. "Are the suggestions noted in Fig. 21 reasonably economic, and at what thickness should they be re quired?"

A. Yes, they are economic if rework is avoided. No, they are not economic when used where not required. Sequencing of weld beads, buttering, and peening are workmanship techniques which should be under the control of the fabricator and his welding engineer. In general, contract specifications should avoid stipulating "how to do it" provisions, since if step-by-step procedures are established by the contract the designer must be willing to accept the responsibility if success is not achieved. Designers should specify details which will cause a minimum of weld contraction and minimum restraint to the contraction; the fabricator should use his experience and technical knowledge and various workmanship techniques to minimize the effect of the strain and restraint conditions that result from the connection design.

Q. "Is there a sequence or procedure for shop welding the stiffeners of Fig. 22 that might reduce restraint for the field welding of the connecting flanges?"

A. Stiffeners themselves can contribute significantly to restraint, but variations in the shop welding procedures for such stiffeners will probably have little bearing on the restraint to the contraction strains of the field welds at the outside face of the column flange. It must be remembered, however, that, independent of field welds, a potential for producing lamellar tears at the inside face of the column flanges does exist. Stiffener and weld details and welding procedure can significantly affect this possibility. Stiffeners may be required for one or more of three reasons: (1) to prevent crippling at the toe of the fillet [AISC Spec. Formula (1.15.1)]; (2) to prevent general buckling of a thin column web [AISC Spec. Formula (1.15.2)]; or (3) to prevent localized overstress of beam tension flange welds when the column flange is thin [AISC Spec. Formula (1.15.3)]. Only for the third case is a weld between the stiffener and the column flange actually required. In any event, welding of stiffeners to columns should be by means of fillet welds. Full penetration stiffener welds can be justified only in the case of a true fatigue condition, which is highly improbable in building construction.

Q. "Is preheat before such field welding helpful in reducing tear possibilities? For what thickness flanges?"

A. Probably yes. Laboratory tests have indicated that preheat and interpass temperatures do have a beneficial effect. See Oates and Stout, *Welding Journal*, November 1973. However, systematic investigation of the effect of preheat temperatures is still underway, and it is conceivable that this work may lead to specific recommendations. In any event, proper preheat and interpass temperatures are important for the deposition of sound welds for reasons independent of possible beneficial effect on tearing; thus, specification requirements should be adhered to. It is not known whether preheat and interpass temperatures higher than those presently specified are most beneficial.

Q. "Are rolled flanges more or less susceptible to lamellar tear than plates?"

A. No difference. Lamellar tearing results from inevitable contraction strains due to cooling of solidified weld metal in the presence of high restraint which forces the total strain to concentrate within an extremely short gage length. Thus, the unit strains may be many times larger than even longitudinal yield point strains for the base metal. When connected parts meet in a tee configuration, a triaxial state of stress is induced at the face of the head of the tee. Under these circumstances, the longitudinal strain in the direction of the stem of the tee tends to force a volumetric change in the head of the tee which any solid material cannot accept to a practical degree.

Even in the presence of known lamellar tears which were intentionally initiated, externally applied stresses necessary to cause fracture have been observed to be several times higher than full allowable design stresses (Oates and Stout, Welding Journal, November 1973). This demonstrated fact is not surprising and should be a source of comfort to designers, because the forced strains due to weld shrinkage in the presence of high restraint are at least one order of magnitude larger than the strains that are introduced by design stresses. Stresses due to applied design loads will not initiate lamellar tears. Stresses due to static applied design loads probably will not propagate tears that inadvertently are not detected by ultrasonic testing. Because lamellar tears occur infrequently, but always during fabrication or erection at a time when they may be detected and corrected, and also do not result from design stresses which may induce stress in the through-thickness direction, they should not be a source of major concern.

The geometry of joints and connections is the most important and controllable factor that influences the phenomenon. All other factors can only ameliorate or compound the tendency toward lamellar tearing once the restraint and strain from weld contraction are established by the arrangement and size of connected parts. Maximum attention should be given to avoiding susceptible details wherever possible.