

Structural Steel Construction Tolerances

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•THE ARTICLE by Congressman Jim Wright and the comments by Senator Randolph to AGC support Mr. Scurr's view that the public interest in the highway program has resulted in a tendency to magnify some of the imperfections out of proportion to their real significance. Most of the irregularities which have been brought to light and highlighted in the "exposés" of the highway program appear not to involve questions of the adequacy of the established tolerances. For example, right-of-way acquisitions have no bearing on construction tolerances and yet irregularities in this area of activity seem to be the major subject of discussion in the news media. Many other irregularities involve situations where established tolerances cover the required quality and accuracy of the finished product but have been ignored. If these observations reflect the true situation, then changes in construction tolerances should be carefully considered so that they do not reduce tolerance limits unnecessarily or impose tolerance specifications to achieve accuracy of workmanship for accuracy's sake.

However, there has been very real evidence of an increase in the incidence of poor workmanship as the pace of the highway construction program was stepped up. As an institute vitally interested in highest quality workmanship in all fabricated steel work, the AISC finds reports of such evidence disturbing and is eager to take part in the activities of any task force to establish improved workmanship standards.

There are, no doubt, a number of reasons for establishing tolerances; however, the following are probably the most compelling ones as far as steel construction is concerned:

1. Accuracy required for structural integrity. Probably the best example of a tolerance to insure structural integrity is the straightness requirement for metal compression members. Generally, the straightness requirements for structural members are those published in ASTM A-6, which encompasses the dimensional tolerances for plain material as produced by the mills. The limits provide for material which is satisfactory for average work and within the capabilities of the mills to produce on a mass production basis without resort to special operations that increase costs. For compression members, however, the straightness tolerances of ASTM A-6 are usually tightened somewhat in most specifications due to the consequences of a compression member failure and the increase in tendency to buckle as eccentricity is increased. For the most part, the tolerances for welded members are the same as those for rolled members produced under ASTM A-6, even though rolling mill practice has only limited direct bearing on welded built-up members. One particular tolerance requirement to insure structural integrity involves the tilt or out-of-square limits for flanges. It can be readily seen that a bad match on the tilt of the abutting flanges would make welding a proper joint difficult.

2. Accuracy required for dimensional function. Structural adequacy would not be affected by inaccuracies in the fabrication of roadway expansion devices, but if the camber of such a device does not match the crown of the roadway, the paving trades cannot properly execute their work.

3. Accuracy required for appearance. In this category are the web plates of a plate girder which were buckled out of plane between stiffeners due to welding distortion. Such a member, within reason, would be as strong structurally and as functional dimensionally as a similar girder without such inaccuracies; however, strictly for appearance it might be desirable to limit this out-of-flat condition.

One aspect is common to all of the above examples. All are dependent on the requirements of the user or the functional purpose of the piece or structure as a whole. The ability of the producer is not relevant. This is as it should be. Modern machines and techniques are capable of producing work of sufficient accuracy to satisfy the realistic requirements of structural integrity, dimensional function, and appearance.

To guide the discussion in this seminar, comments were requested relative to four specific topics:

1. The adequacy of existing specification tolerances. As previously pointed out, much of the deficient workmanship which has been the subject of discussion has resulted from irresponsibility on the part of those actually executing the work and those charged with checking and inspecting the results. No amount of tightening the limits of existing provisions or increasing the number of provisions to achieve greater refinement of the rules will improve the quality of the work if failure to adhere to the rules continues. Evidence that the tolerance provisions are too loose would be found where all provisions are met and the resulting piece or structure is not functionally satisfactory. Also, an indication that the existing tolerances are inadequate might be found where unsatisfactory results are produced because there are no rules to cover the particular situation. Since cases of this nature apparently do not exist, it can only be assumed that existing tolerance specifications provide adequate rules if they are observed.

2. The desirability of modifying existing tolerance as a result of current developments in materials and construction methods. The thought here is to make tolerance limits more restrictive as improvements in machines and technique make greater accuracy more easily attainable. Objectively, however, tolerances should proceed from the requirements of the end product. To establish closer limits on the required accuracy of workmanship than is required for the proper performance of the individual piece or structure would be to specify refinement and a high degree of accuracy for accuracy's sake. And cost of the work increases by a geometric function as the required accuracy approaches the zero tolerance area. Thus, even though modern equipment may be readily capable of producing work to a greater degree of perfection, the realization of the increased accuracy in the end product will not be without cost if the fabricator is required to guarantee such accuracy by the terms of the contract or specification. For example, in high-strength bolted joints, if a tolerance on the misalignment of the plies of material that make up a joint is limited to a 1/32-in. offset at the edge of a hole as compared with 1/16-in. permitted offset, there would be no measurable difference in the strength of the joint. Thus, with a 100 percent increase in the permitted inaccuracy, or with a 50 percent decrease in the tolerance limit, there would be no difference in the functional quality or appearance. Reducing the tolerance limits simply because machines and techniques may make such accuracy attainable would serve no useful purpose and would most certainly result in increased cost.

It may be felt that such an example is absurd, but actual examples may be cited which are even more absurd. In one instance, a fabricator was required to purchase specially ground undersized reamers because an inspector found by using a micrometer that a standard reamer produced holes slightly larger than its nominal size. He was interpreting 1/16 in. larger than the nominal size of the bolt as meaning not more than 0.0625 in. Tests at Illinois University have demonstrated that holes 1/8 in. larger than the nominal size of the bolt result in no loss of strength. Therefore, in this case, refinement of the accuracy of alignment of holes beyond present limits would avail nothing.

There may be areas where the improvements in materials and construction procedures should be taken into account, for example, where the requirement for accuracy in the finished work or the improved usefulness of a more accurate piece or structure would be possible now, but in the past was economically unattainable. In such a case, a joint effort on the part of the owner-designer and the producer to work out an economical balance between the desired and the attainable would be beneficial.

3. The desirability of development of so-called tolerance curves. The statistical approach to the measurement of the acceptability of a large number of identical mass-produced items is well recognized in modern practice. It is the only feasible method for checking such things as fasteners, and a good example of its use may be found in the new Recommended Practice for Acceptable Quality Level for Standard Commercial Bolts, Screws, Nuts, Rivets and Similar Fasteners, approved by the Industrial Fasteners Institute in July 1963. Tables of major and minor defects for various fasteners are provided, as well as a schedule of size of sample required and the accept and reject percentages for various quality levels. The system is workable for mass-produced items of this type that are purchased in large quantities, but unworkable for structural elements other than fasteners and similar items.

As the author understands "statistical approach," a large number of similar items are required. It is impossible to apply statistics to one or two similar items. Either the piece has dimensional characteristics and properties which make it suitable or it does not. It cannot be rejected and replaced by another similar item from a bin. From this point of view, how may the statistical approach be applied to structural components?

On the other hand, a different sort of "tolerance" curve may have been implied. Reference has been made to different levels of acceptability in which unqualified acceptance would be accorded work that is within specified limits. Work containing defects falling outside the limits for unqualified acceptance could be accepted if the defects are corrected. This seems to have been the situation for many years in fabricated steel work. For example, there is no reason why material with unfair holes should not have the holes welded up, the surface ground smooth, and new holes properly drilled. After such corrective work, the piece would be as good as a piece in which holes were properly located in the first place. It is not apparent how a tolerance curve would be applicable in this case. Either corrections could be made by means which do not harm the material and the piece made to conform to the primary required accuracy limits of workmanship standards or it should be rejected.

The final item on which comments were requested was relative to the type of research necessary to establish tolerance values. Over the years, many thousands of steel structures have been built. Each one of these might be thought of as a research structure as far as tolerance limits are concerned. Where such past work has revealed the need for the establishment of tolerances, that has been done; where no such need has been demonstrated, no specified tolerance provisions have been put into effect. This is as it should continue to be in the future.

Before concluding, it would be well to point up one area wherein some improvement may be possible. The problem occurs because of a difference of opinion between shop inspectors and field inspectors. On occasion, reports are received where work has been checked and approved by the owner's agent in the shop only to be rejected by the field inspector. Obviously, where dimensional errors are involved or where there is a real deficiency involving the adequacy of the piece, the fabricator should make corrections without question. However, where workmanship tolerances are involved which are purely a matter of opinion between two inspectors, the added cost of making corrections in the field over the cost of reworking in the shop should be the owner's responsibility. For example, there are differing opinions as to what constitutes adequate grinding of butt-welded splices in tension flanges. Another example involving quality requirements is the interpretation of radiographs. It seems strange that a joint may be approved on the basis of a radiograph and shipped, only to be rejected later on the basis of another interpretation of the same picture. No doubt, it will be impossible to eliminate the human factor, and most individuals connected with construction would not favor working under a system of tolerance limits so complete that engineering judgment was eliminated.

In summary, based on a sampling of the opinions of knowledgeable fabricators from all parts of the country, the tolerances for fabricated structural steel work which are presently in force are considered to be adequate. Any new tolerance provisions should objectively be based on the requirements for structural integrity, dimensional function, and appearance. Tolerances should not be made more restrictive simply because new

machines and techniques make refinement possible. Where it is appropriate, a statistical approach to tolerances is much to be desired, but in the case of fabricated structural steel, it does not seem to provide a useful technique.