Review and Recommendations

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•IN HIS opening remarks, Mr. Scurr has correctly stated that the huge expansion of plant and personnel required by the magnitude of the Interstate Highway Program

> . . . has undoubtedly contributed to a condition which resulted in imperfections in construction that might not have occurred in a normal program. The public and political interest inherent in such a program has probably resulted in a tendency to magnify some of the imperfections out of proportion to their real significance in producing a satisfactory finished product.

Mr. Scurr points out that if a "tolerance curve" or a "statistical approach" to determine the limits of what is acceptable or not acceptable is to be established, research would be necessary to determine the limits for unquestioned acceptance, qualified acceptance subject to correction or penalty, and absolute rejection. He calls attention to the proposed AASHO Guide Specifications 105.3, Conformity with Plans and Specifications, stating that the intent of this clause "reaffirms the principle of exercise of engineering judgment." However, he states this does not give the inspector any reassurance or protection when his judgment may be questioned. "Only a statistically developed range of permissible tolerances can give such assurance."

Mr. Amirikian has very ably outlined the tolerances in welded construction. These are dimensional (warping, alignment, and fit), and welding tolerances (quality and acceptability of welds). Dimensional tolerances are specified in the AWS Code for Buildings and for Bridges and do not cause any problem. In fact, advances in welding technology may even permit a reduction in these tolerances. Problems in welding tolerances arise from the definition of an acceptable weld and development of inspection methods to assure acceptable welds.

Questions concerning inspection methods can be separated into two categories: (a) inspection of visible defects and (b) inspection of hidden defects. Mr. Amirikian feels that inspection of hidden defects is not clearly implemented in the codes. The code limits internal defects but does not specify the use of nondestructive tests for detecting the internal defects nor methods of evaluating the results of such tests. According to Mr. Amirikian, it is this matter of evaluation, particularly where radiographic testing is concerned, that leads to the greatest amount of controversy and litigation. In his opinion the present codes are too rigid. He feels that good visual inspection should suffice for buildings, and supplementary inspection should be utilized only where excessive cracking is observed. Magnetic particles and dye penetrants are most satisfactory for such cases. He feels that the use of ultrasonics and radiography should be confined to testing welds subject to cyclic stresses.

Mr. Amirikian feels the present code requirements are needlessly restrictive on the utilization of welded construction and that more liberal tolerances can be safely allowed if code authorities and industry will cooperate in researching tailored codes and educating designers to use them. We would question his broad statement: "Present code requirements for weld quality are much too rigid for a reasonable assurance of adequacy." What is "a reasonable assurance of adequacy" for a building where life and property are in jeopardy?

Mr. Amirikian is also concerned with, and seems to be trying to discourage, the application of radiography to building construction. We believe the fault is not in the radiographic codes but in the application and interpretation of radiographs. This fault

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can only be overcome by proper training and good experience of the radiographic technician, inspector, and engineers. Radiography has contributed more toward improving the quality of both the base material and the weld deposit than any other nondestructive method or combination of methods of testing used in present inspection procedures. Use of radiographic inspection in building construction or any other field should be limited to those applications where evaluation of radiographs is practical and in accordance with the governing code.

The writer cannot agree with Mr. Amirikian that weld defects should be permitted in excess of the code. Welding methods and design used today place a greater responsibility on the weld, welder, inspector, and engineer than it did 30 years ago. It is very true that great care should be exercised in determining the extent of probing and in evaluating the importance of the revealed defects. Therefore, the welding inspector should be experienced and qualified to evaluate the deficiency and the extent of repairs necessary.

The writer agrees with Mr. Amirikian that welding tolerances should not be unrealistic and that any adopted tolerances should be consistent with safety. However, it should be emphasized that it is as equally important to have qualified inspectors as it is to specify qualified welders and welding procedures. One without the other will not achieve the objective of economic and safe welded construction, regardless of tolerances in the code.

Mr. Moss calls attention to the cooperative work of ARBA and BPR committees in advocating the use of a statistical approach in the analysis by acceptance tests of materials and performance in highway and bridge construction projects. He outlines the problems today in highway construction and cites the application of statistical approach to problems in industry and on the AASHO Road Test.

No one engaged in highway and bridge construction will deny the need for proper tolerances for quality control. However, it is questionable whether standard deviation curves and standard numerical limits can be determined which will be workable throughout all the states. The trend appears to be to write everything into the specifications, but it is doubtful standard specifications can be written which will be uniformly applicable in all the states under varying job and climatic conditions and will virtually eliminate the necessity of on-the-job decisions by the inspector and the engineers.

Perhaps we are hoping to arrive at Utopia too fast for the present system. Even with the statistical approach skilled and well-qualified inspectors—the same type of inspectors and engineers who had the engineering know-how to build good roads and bridges in the past—will still be required on the job. We have good men on the jobs. By backing up these men, weeding out the nonperformers, and displaying a little more "rugged individualism," we can continue to turn out good work.

This is not to say we should not improve, revise, and discard, if necessary, obsolete and unworkable specifications. The states are continually doing this. We should approach this problem in the same way we plan and design our highways and bridges—by careful review of the problem, taking into consideration all the aspects and factors involved to arrive at the best solution.

Mr. Lyman presents some very interesting and pertinent comments from several well known bridge engineers on construction tolerances for prestressed concrete. The AASHO-PCI Manual for Inspection of Prestressed Concrete referred to is an excellent guide for prestressed concrete construction.

Mr. Dean's summation is worth repeating:

> The published tolerances are not to be considered forever binding.... Improvements and modifications will surely be developed; any set of dimensional tolerances should be applied with judgment and some understanding of member function.

We agree with the comments on camber and that further study is needed on this problem, particularly ultimate camber. Dimensional tolerances do not present much difficulty in established fabricating plants. Problems at bearing seats are minimized by use of elastomeric bearing pads. These will absorb up to $\frac{1}{8}$-in. twist in the bearing surface.

A good point is made by Mr. Thurman: "With allowable tension under full design loads, I feel that the accuracy of the prestressing force assumes more significance than previously." In California, we think we are achieving better accuracy in stressing the tendons with load cells developed by our Materials and Research Laboratory.

We do not concur with the idea of penalties for a secondary range of tolerances. This could be a very controversial matter. The penalty, if there is this provision in the specifications, should be harsh enough to discourage continued infraction. Generally, the remedial work is minor and the member can be restored to full structural value. If the structural adequacy of the member is questionable, it should be discarded.

The information and data collected by Mr. Lyman, together with the results of studies now under way by the PCI, should help to provide more realistic and workable tolerances in prestressed concrete.

Defining concrete as a "manufactured" material, Mr. Anderson states "the application of scientific tolerancing in concrete construction has not been considered to any extent in engineering or design procedure." This lack of tolerance information, he says, has led to misunderstanding and controversy. Characteristic of designs of the past cast-in-place structures were conservative working stresses and adequate margins of safety.

"Qualitative and quantitative tolerancing will become a part of the engineering and design procedure," Mr. Anderson says. The present trend toward ultimate strength design using higher stresses, lighter sections and high-strength steels will demand greater precision of concrete manufacturing and workmanship.

Tolerances are necessary in concrete construction, Mr. Anderson states, in relation to integrity and safety of the structure, aesthetics or appearance of the work, and economics, involving cost to owner, designer, or contractor.

On the subject of structural intergrity, Mr. Anderson begins with the "manufacture" of concrete and points out the influence of manufacturing tolerance on concrete quality. He refers to a paper by Mr. Abdun-Nur in the ACI Journal of January 1962. This paper presents cogent arguments for a specified tolerance in concrete strengths. We agree with Mr. Anderson that a minimum strength concrete is not a realistic specification and is not being met. The advancement of precast construction with higher stresses and thinner sections requires better and more realistic controls. In regard to dimensional tolerance we agree wholeheartedly that poorly constructed forms will not give dimensional integrity and will increase costs.

With strict interpretation of specifications, exercise of engineering judgment will not be acceptable practice. Tolerances must be established that are practicable and will insure quality work. Mr. Anderson summarized suggested tolerances by ACI for conventional concrete bridges and for precast concrete construction. A more liberalized table of tolerances proposed by precast manufacturers is also given. Any proposed tolerances will be considered too restrictive by some, at least in part, and too lenient by others.

It will take time for observation, study, and comparison to arrive at practical and workable tolerances acceptable to everyone.

Mr. Anderson's paper is thought provoking and, from his background of experience, offers practical suggestions for improving bridge specifications in regard to construction tolerances.

With the availability of various good form materials and with any kind of desire to produce good work there should be little need for tolerances in bridge specifications on surface appearance. How long will a concrete surface on a bridge remain uniform in appearance?

In summation, we believe we do not have to sacrifice quality to determine practical and reasonable limits or tolerances.