Reliability in Building Construction Through Nondestructive Testing

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Before World War II, structural welding was used only by a few pioneer-spirited designers. Then they had difficulty finding fabrication shops that were willing and able to accept welded work of any magnitude. At the same time, welding was used for making repairs and for strengthening existing structures under conditions that would be considered less than desirable even today. Yet this was not considered a contradiction. There was no other way to make these repairs or renovations—so welding had to be used.

Structural welding almost ceased during World War II. Emphasis was on producing war material—ships, tanks, machinery, some portable building frames, and the like. Designers and fabricators of buildings had to turn from their usual work to war production. Time was the critical factor in this work. Any design, material, or process that would result in getting the work done sooner was employed. Here was an opportunity to prove the advantages of welding. Savings in material, dead weight, and production time were realized through welding. Mistakes were made, but through them people were educated. The concept of weldability was developed. Thousands of welders were trained under government programs.

With the end of the war, building designers and fabricators were ready and eager to use welding. Their wartime experience could now be used advantageously for their more usual pursuits. Fabrication shops had new and efficient welding equipment. Much of the riveting equipment was old and worn. An ample supply of trained welders could be drawn from. As expected, the day of structural welding had arrived.

Today, welding is the principal method for joining steel building frames in the shop. It ranks with high tensile steel bolts as one of the two principal methods for erecting structural steel.

Until the advent of structural welding, steel for buildings was bought and used on the basis of the scantiest requirements for mechanical properties. With welded designs and fabrications it has become necessary to become concerned with the metallurgical properties and quality of steel used. Service requirements must be considered. New steel specifications have been prepared by ASTM for steels of weldable grades.

About ten ASTM structural steel specifications now are in use. All of them specify chemical as well as mechanical requirements. In each specification some mention is made of the weldability of the steel covered.

Today, steel building construction is welded construction. Everyone is anxious to make more than full use of the advantages welding offers. Architects design buildings with larger clear areas between supports and with higher ceilings. Buildings are hung from the roofs instead of resting on the ground. Structural shapes are made by joining plates and standard rolled shapes into new and irregular shapes and sizes. Taller structures are being built with heavier members than ever used before.

The CBS Building in New York City rests on a grillage of steel girders which have flanges as thick as 6 in., welded to webs as thick as 3 in. More recently, 6-in. thick welds have been required for the First National City Bank Building in Chicago.

In the field, 3½-in. welds were made in joints of the trusses forming the frame of the American Telephone and Telegraph Exhibit Building at the New York World's Fair.

The diversity of structural shapes made possible by welding is illustrated by the oval "ring" girders of varying diameters forming the football shape which was the IBM Building at the New York World's Fair. The tapering box sections forming the cruciforms from which the five-tier Vierendeel trusses of the Yale Rare Book and Manuscript Library were made are another example. There have even been designs of triangular beams.

In the beginning, the use of welding for buildings was met with scepticism. "How can I be sure a weld is good?" was a usual question when a welded design was proposed. This same question is still being asked by some designers today. Nondestructive testing and

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inspection have contributed to providing the answers to this question. They have helped secure the adoption of structural welding. Unfortunately, the pendulum in many cases has swung too far in the opposite direction. Once convinced of the adequacy of welding, quality may be ignored with costly consequences.

NEED FOR RELIABILITY

What is needed today as much as, if not more than, acceptance inspection and nondestructive testing is the use of practices which would establish the reliability of welded joints. If reliability were assured, nondestructive testing would serve only to verify that the welding was good, not to ferret out the poor welding resulting from poor welding practices.

Too much stress is placed on final inspection. For one thing, this can be costly. The cost of 100% radiographic examination, for example, may equal or even exceed the cost of making the welds. Even more serious is the fact that much of the final acceptance inspection is not timely. A practice taking hold in the structural field is the ultrasonic inspection of work after it is completed and delivered, maybe even erected. Where quality control has been ignored up to this point, excessive defects are found. Inspection by this method is very cheap. Resulting corrections are costly to all parties and delay completion of the structure.

In one instance a structural frame which cost two million dollars required repairs costing $250,000 and completion of the project was delayed for about three months.

In a word, the concept of "reliability" needs to be introduced and promoted for use in structural welding. With reliability as an accepted concept, weld quality can be predicted and weld costs more accurately controlled.

Resistance to the reliability concept has been great, but it is beginning to break down. Where reliability practices have been used, they have proven to be economical and advantageous.

In the concept of reliability which I have advocated, the following factors are encompassed: material properties and quality; welding practices including the suitability of a given welding process or method for a given material in a given range of thicknesses for given service conditions; standardized welding procedures; weld quality requirements; quality assurance practices; inspection for acceptance. There follows a discussion of each factor.

The multiplicity of structural steels offered the designers today is enough to make knowledgeable materials personnel stop and think. For the designer who blithely selects a material for his structure on the basis of the data supplied in the literature of the steel companies, troubles lurk. It is nice to consider higher strength steels with lighter sections or the ability to carry heavier loads. However, the fact that higher strength steels have been obtained by modifications in the chemical and metallurgical properties of the steel cannot be ignored. These changes affect the weldability of the material. They may impose more costly and more critical control of the welding. All steels are not as readily welded by all welding processes. All steels are not as readily welded in thicker sections.

Whatever the steel used, mill reports of the steel should be obtained. They should be checked by the fabricator, and the designer as well, to be sure the properties satisfy the material requirements specified for the work. The steel should be examined for cleanliness and soundness.

For the fabricator who orders the steel or combination of steels shown on a design drawing and then proceeds to weld them with unfamiliar welding materials or welding processes, simply following the recommendations of a supplier, without careful consideration and some understanding, there lies serious and costly troubles.

If a fabricator is to use a steel that is new to his shop or a new welding material or a new welding method or process, he must assure himself that any one of these or any combination of them he is considering will produce results which are satisfactory when the work is performed under the particular conditions existing in his shop.

The tests needed for this assurance may well be in excess of those required for welding procedure qualification by Appendix D of the AWS Building Code or derivations thereof. For example if 3- or 4-in. deep welds are to be made, testing of welds made in 1-in. plate, as required by Appendix D, very likely will not reveal any of the problems which the greater thicknesses could present.

Welding procedures have been qualified since welding was first used. Unfortunately, the tests prescribed for structural welding largely remain the same. The original qualification tests in the 1-in. thickness were written when to contemplate welding in thicknesses much in excess of 1-in. was to be unrealistic. While all requirements for welding procedure qualification and all discussions of the subject point out that the prescribed tests are minimum, this is too often ignored.

Some developmental testing, even destructive testing, may be in order. Short sections of prototype joints are often useful in evaluating a steel or welding process. They can reveal difficulties which would otherwise not be anticipated. More efficient ways to obtain the desired end result may be found.

WRITTEN WELDING PROCEDURES

The terms "welding procedure" and "welding procedure qualification" are often confused. How a weld is made constitutes a "welding procedure." The testing of a welding procedure to prove its adequacy is known as "welding procedure qualification." It comprises a series of tests to measure the mechanical properties, chemistry, soundness, or whatever other properties are of particular concern.

Every weld made is made according to a welding procedure. Even when the welder was told to "weld securely" and he decided what welding current, voltage, filler metal, preheat, position of welding to use, he had formulated a welding procedure. The only trouble with this practice is that the welding procedure remains in the mind of the welder, known only to him and changeable at his whim.

For today's complex welding the welder is no longer given this charge. He is expected only to deposit sound welds following instructions given to him by someone more technically qualified. One problem remains. For the most part welding procedures are transmitted orally.

If reliability is to be obtained in weld production for structural work, all welds of the same kind should be made the same way in the same shop. This can happen only if *written* welding procedures, covering each and every weld to be made on a job, are used. This concept has met with opposition in the structural field—at least at each first encounter with it.

Standard building codes, including the AWS Building Code and the AISC Specification, should make written welding procedures mandatory. Until they do, it will be necessary to include a requirement to this effect in Job Specifications for each structure. As has been the case in the past, each fabricator on first encountering this requirement will protest loudly that it is unreasonable and is just so much more paperwork. By the time the job is done, if past experience is a criterion, the value of the written welding procedure will have been proven to another organization. It should not be necessary to do this on an individual basis, but this is the case for now. In each instance where written welding procedures have been required for a job, where it has been possible to check later shop conditions, it has been found that all future work has been done with written welding procedures—whether required by the Job Specifications or not.

The advantages of written welding procedures cannot be overstressed. Reliability is assured when every welder makes the same kind of weld in the same way and any deviation from the standard procedure is easily recognized by competent supervision. Changes are deliberate—to suit some special conditions or to improve existing practices.

Written standard welding procedures make costing of the welding more realistic. Estimated welding costs can be verified in production.

Using standardized written welding procedures, reflecting a shop's particular facilities and practices, can reveal basic problems, which can be corrected early in fabrication before they become epidemic. Welds made to written welding procedures—competently used and enforced—can be expected to be uniformly acceptable. The defective weld will be the rare exception, not the rule. Written welding procedures are vital to the introduction of reliability to structural welding.

If all of this sounds good but seems impractical, consider the following two cases.

The Yale Rare Book and Manuscript Library was nondestructive tested and inspected to a degree beyond that which would be used for the more usual building with beam-to-column type connections. Not an inch of cross section of this frame is without welding. Reassurances were required not only for the architect and engineer, for whom welding was new, but for the fabricator as well. Written welding procedures were required by the Job Specifications. They were produced by the fabricator with many labor pains. In the course of preparing them, it was necessary for the fabrication personnel to figure out how they were going to do the work.

The resulting welding procedures were in no way special. They merely reflected what should normally be done if good structural welding practices were followed. Yet preplanning necessitated by the preparation of the welding procedures paid off. The rate of repair, even with inspection more searching than usual, was about 2 percent—an unusually low figure for this type of work.

In another case, a 20-story building was fabricated and erected with little or no concern or inspection by the Engineer or Architect. Then, when erection was about complete, an ultrasonic inspection of a random number of joints was scheduled as the basis for acceptance of the structural steel. The fabricator became alarmed. If repairs were found to be necessary at this point, the method of repair could well be quite involved. The cost of field repairs would certainly be much higher than if the same defects had been found in the shop.

The concern of the fabricator was instinctive. It was not justified. The welding had been done according to written procedures, under competent supervision and with internal quality control. Of 600 welds in the structure, 60 were randomly selected for inspection. Of these 60 inspected, 6 were found to contain weld defects. Of these 6 only one contained defects beyond the level permitted by the AWS Code. Total repairs—one weld.

Surely you have guessed by now that this fabricator has used written welding procedures on every job he has done since, whether required by the Job Specification or not. Actually, this is easy now. Structural welding is largely repetitive. It is a matter of selecting the welding procedures previously used and tested which are applicable to the work at hand. Occasionally some development and testing are needed to evaluate improved methods or new materials.

QUALITY CONTROL

Weld quality requirements in the AWS Building Code, which forms the basis for practically all the welding requirements for buildings in the United States, are empirical. Their origin is obscure. They derive from the past, when manual metal arc and oxyacetylene welding of relatively thin material were used for structures. The requirements were made severe enough so that they would assure that welded structures would be absolutely fail-proof. Although somewhat relaxed today, the weld quality requirements currently used could not be defended on a valid rational basis. Inconsistencies exist. In some instances the weld quality requirement prohibits an extent of defect which is acceptable for the adjacent steel in the members being joined. This is certainly incongruous. The quality requirements do not reflect the effect of defects of a certain size on welds of greater thicknesses as compared to the same defects in welds in thinner metal.

A study of weld quality and the effect of defects on welds of different types for different service requirements would be most productive. It would likely result in some relaxations, possibly even some more stringent requirements. The AISC Committee on Quality Criteria and Inspection Standards, organized about one year ago, is beginning to look into this subject.

Every fabricating organization should have its own quality control organization. The size and nature of such a group would be based on the size of the plant and the nature of its work. A quality control group should function without regard to inspection for acceptance that may be imposed by the customer. The quality control department should apply any nondestructive (and even occasional destructive) test methods considered to be necessary to assure that when the work is inspected for acceptance by the customer, by whatever means he may choose to use, it will be found to be acceptable on the basis of reasonable and previously-specified acceptance standards. Of course the quality control department will also be on the lookout continually to be sure that the written welding procedures are being followed.

A good quality control department is a source of profit. If the first welds made for a job are thoroughly and knowingly scrutinized objectively, the best way to do the work with the greatest assurance of consistent good quality will result.

As an example, unless shop supervisors and quality control are most insistent, slag removal from weld layers may be less than thorough. If quality control personnel persistently demand more thorough slag removal, this will become a habit and welds will be free of slag. Yet failure to do this can be most costly.

An owner, who was dubious about the reliability of welding as a means of joining structural steel, asked his Engineer during a visit to the site, how he could be sure the welding was good. Thinking to convince the owner, the Engineer had some radiographs taken of a few welds. To his dismay, not an inch of welding on the films was without heavy slag. Investigating further, more radiographs were taken. The results were the same. Had there been insistence on the cleaning of slag from the start of welding, this condition and its attendant costly repairs and delays would not have been necessary.

Do not dismiss this example as atypical. It is found too often when weld quality is ignored.

Nondestructive testing, whether for quality control or for acceptance inspection, should be performed by competent personnel using standard weld quality requirements.

Visual inspection should be used regardless of any other method of inspection to be used. It is fast and can be revealing. Appearance, location of welds and even gross defects such as cracks, undercut and slag can be found by visual inspection. If a weld crack is visible to the naked eye, little will be gained by radiographing the joint; yet this is done.

If radiography is used, the technique should be appropriate. Films should be read by someone competent to read and interpret them. The same is true of magnetic particle inspection. It is especially true today of ultrasonic inspection personnel.

Ultrasonic inspection is finding increasing use and favor for building construction. It is relatively inexpensive, it is quick, it is searching. The problem today is to find personnel competent to use this method. The examination of butt welds in splices has been pretty well established. "Ultrasonic Testing Inspection for Butt Welds in Highway and Railway Bridges," prepared by the U. S. Department of Transportation and for sale by the Superintendent of Documents, is an excellent document. When welds other than butt welds in splices have to be inspected, much difference of opinion arises as to the appropriate techniques to use and interpretation of the indications.

In summary, it can be said that the means for assuring consistent good welding in the field of building construction are available. They can be used to advantage. Rather than imposing an economic burden on this work, cost reductions would result. What is needed most is dissemination of this information. Educational programs directed at designers, at fabricators and at inspection personnel are badly needed.