# Assurance of Reliability in Fabricated Steel Structures Through Nondestructive Testing

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RELIABILITY in steel fabricating and erection through nondestructive testing is becoming a very important part of shipbuilding, bridge construction, and building construction. Requirements for nondestructive tests, so far as the method to be used and the techniques and criteria to be applied, are usually based upon current practices in other industries. Nondestructive testing in the structural industry and, for that matter, all inspection procedures, should be evaluated based upon the end result desired. Often rigid quality *assurance* requirements are imposed where only good quality *control* procedures are necessary.

The acceptance standards chosen for a particular nondestructive test technique and application are often based upon acceptance requirements derived from nondestructive tests using a different method. Even when acceptance criteria recognize the ability and limitations of a particular technique, they seldom are based upon service experience or anticipated failure conditions. In fact, most of our acceptance criteria can be traced directly back to the ASME Boiler Code. Most of the considerations which go into the designing of a boiler are not valid for fabricated steel structures of other types. Reliability of welded structures at a cost commensurate with the value obtained can only be achieved when nondestructive tests, methods, techniques, and acceptance standards are designed around the specific application to which they will be applied.

The reliability of fabricated steel structures is very high. The most obvious indication of this reliability is the total lack of failure indices (for example, in terms of lives lost) as a function of bridge, building, or ship usage. Yet, some fabricated steel structures fail. In addition, the modern use of welding as the primary joining technique provides a continuous structure whose failure can be more catastrophic in some ways than that of older riveted or bolted structures.

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Before we give full credit for this reliability to the designers, fabricators, and inspectors of fabricated steel structures, we must remember that they take advantage of higher safety factors than those, for example, for aircraft or automobiles. To some degree this is justified in that fabricated structures such as bridges are usually individual designs whose loading, especially in the future, is indeterminate.

Most structural failures have not originated from conditions which might have reasonably been anticipated and policed with nondestructive testing. However, the advent of welded construction and the continually increasing loads, generated for the most part by our expanding technology, provide us with areas in modern fabricated steel construction where reliability should be additionally assured by nondestructive testing.

The use of nondestructive testing for fabricated steel structures is relatively new and thus suffers from a youthful lack of background. The early needs for inspection have been met by adopting inspection philosophies, acceptance criteria, and testing methods from allied fields. Most commonly plagiarized has been the ASME Boiler and Pressure Vessel Code. Quite often the result has been anything but appropriate to the desired end reliability.

## QUALITY CONTROL OR QUALITY ASSURANCE

The first question which should be asked in the planning of nondestructive testing for fabricated structures deals with inspection philosophy. Which areas, if defective within the bounds of normal process quality, are critical enough to cause failure? Each such area must be inspected to assure reliability of the structure. As I have used the term, this is Quality Assurance. In truth, few areas require this type of inspection. However, most of the inspection required of the fabricator today is stated in those terms. The use of nondestructive testing for Quality Control would be far more appropriate in most instances. A quality control inspection assumes that a fabricating process by its nature will produce some

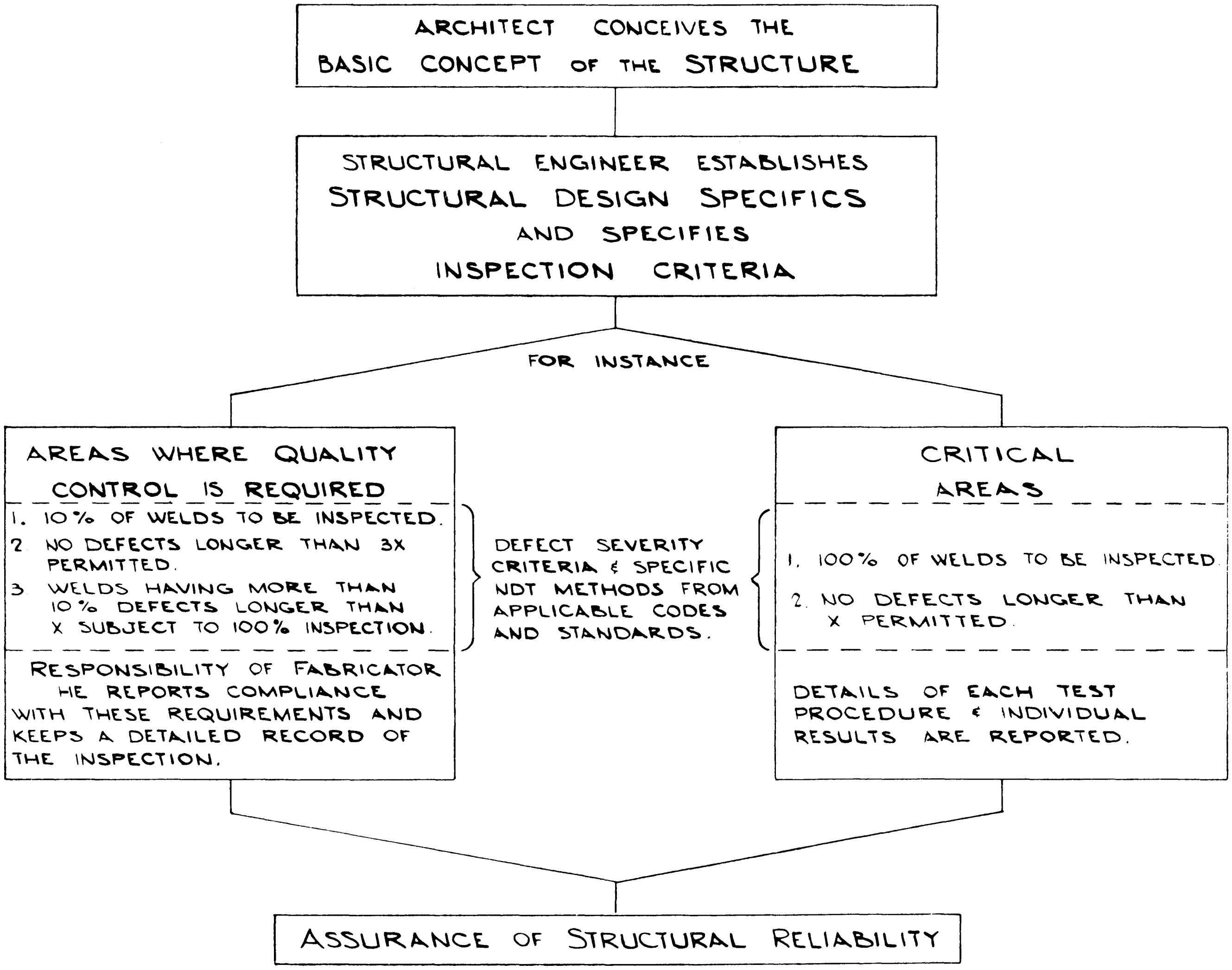


*Figure 1*

discontinuities and monitors quality to assure that an adequate level of quality is adhered to. Only conditions clearly beyond the bounds of normal process quality are repaired. Quality Control inspection is obviously an appropriate function of the fabricator, since it should rapidly feed back information to his production supervision; overall quality is important, not individual imperfections. The operation of an adequate quality control inspection system by the fabricator should provide the user of the structure with assurance of its reliability except where critical areas exist which require individual Quality Assurance inspections. Figure 1 gives a graphical representation of such an inspection.

### ACCEPTANCE STANDARDS

Having set up an inspection plan to meet the needs for quality control and assurance, levels of defect tolerance should be established. Within the framework of the inspection plan, an analysis of the most severe probable failure cause should be made. Table 1 provides some rough guidelines for such an analysis.

A comment is in order concerning the criteria for ship hulls, since the brittle failures during World War II represent the most catastrophic epidemic of fabricated steel structure failures in history. Metallurgical control of hull plate has practically eliminated this failure cause. George Vedeler, Managing Director

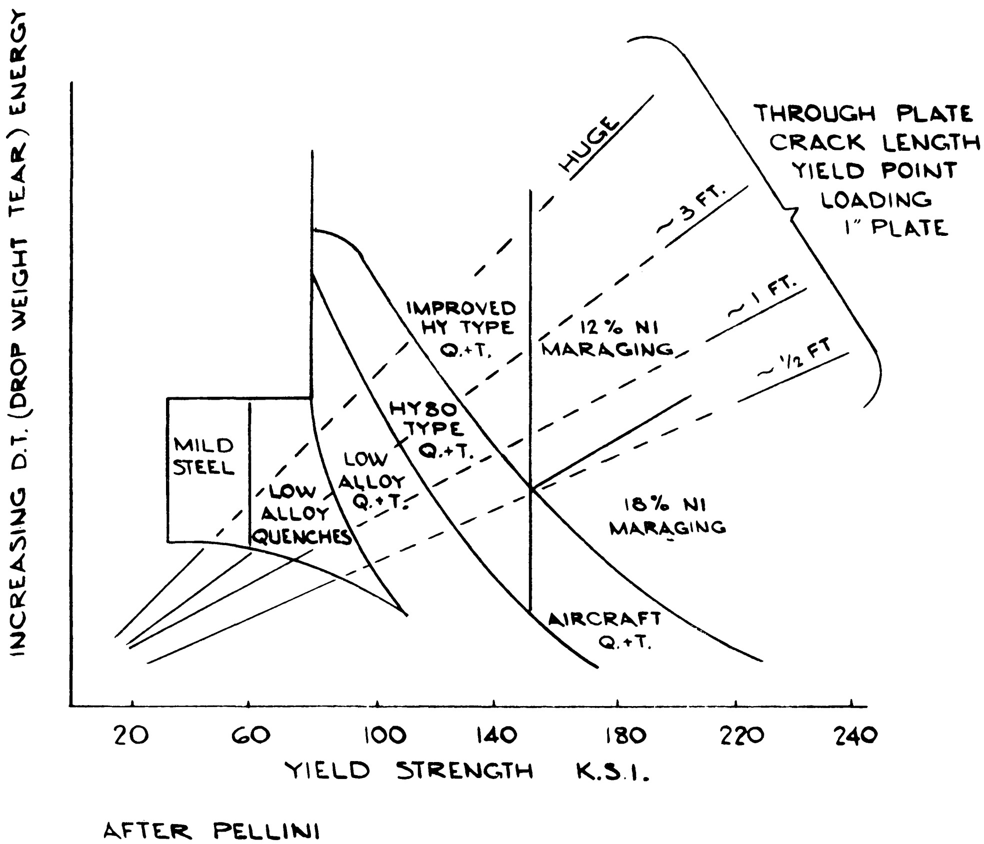


*Figure 2*

of Det Norske Veritas, in Ship Structure Committee Report No. 140 summarizes the results of 119 failures of ship structures in postwar ships. Of these, only two were attributed to brittle fracture; the rest were caused by fatigue. A ship hull exists in a medium whose minimum temperature is about 30°F. This makes prevention of brittle fracture relatively easy. Other structures such as the ship's cargo handling equipment and bridges see lower temperatures.

Having assigned the most probable failure cause, and considering the continuing inspection a structure will receive (especially in the case of fatigue), levels of defect tolerance can be specified. Such an analysis, of course, should also consider design details, loads, and the strength level of the steel used.

Obviously, the individual engineering firm cannot tailor-make defect tolerance limits for each structure. Rather the code writing bodies who generate our specifications should approach their job as I have just suggested, using as a basis for future codes the actual service of the various types of structure.

I do not believe that a detailed discussion of defect tolerance levels is appropriate at this time. However, I would like to present one example of the discrepancies that exist today. Table 2 summarizes a great many of the defect severity codes used today.

**Table 1**

| Structure | Failure Causes (in order of importance) |
|---|---|
| Ship hull | 1. Fatigue<br>2. Gross failure in the absence of fatigue or brittle fracture<br>3. Brittle failure |
| Ship cargo handling structures | 1. Brittle failure<br>2. Gross failure<br>3. Fatigue |
| Bridge | 1. Brittle failure<br>2. Fatigue<br>(2) can provide the initiating point for (1) |
| Building | Gross failure in the absence of fatigue or brittle fracture due to loading above the yield point under earthquake conditions |

**Table 2**

| Specification | Slag: Individual Inclusion ($T$ = Plate Thickness) | Slag: Grouped Inclusions ($L$ = Largest Inclusion Length) | Other Defects |
|---|---|---|---|
| Navy Nuclear | $T/4$ | $T/4$ in 6″ | No cracking, lack of fusion, lack of penetration<br>Porosity: Descriptive charts |
| ASME Boiler & Pressure Vessel Code, Section VIII | $T/3$ | $T$ in $12T$, except when distance between inclusions exceeds $6L$ | No cracking, lack of fusion, lack of penetration<br>Porosity: Descriptive charts |
| Bureau of Public Roads, Bridge Welds | $T/3$ | Spacing must exceed $9L$ (minimum size) | No cracking, lack of fusion, lack of penetration<br>Porosity: Handled as slag |
| AWS Bridge Code | $T/3$ | Spacing must exceed $9L$ (minimum size) | No cracking, lack of fusion, lack of penetration<br>Porosity: Handled as slag |
| Ship Structure Committee, Hull Weld Recommendation | $T/2$ | $T/2$ in $6L$ | No cracking, lack of fusion, lack of penetration<br>Porosity: Handled as slag |
| Navy Hull Code (Ultrasonic Code) | | | |
| Class I: Large | | Any large defect | *Large* and *small* refer to ultrasonic amplitudes roughly corresponding to: |
| Small | $T/2$ | $T$ in 12″. Spacing must exceed $2L$ | |
| Class II: Large | ¼″ | Spacing must exceed $2L$ | *Large:* cracking, lack of fusion, lack of penetration |
| Small | | $2T$ in 12″. Spacing must exceed $2L$ | *Small:* slag porosity |
| Class III: Large | ½″ | Spacing must exceed $2L$ | This class has a less critical sensitivity level than I and II |
| Small | | $2T$ in 12″. Spacing must exceed $2L$ | |
| Oil and Water Storage Tank Welds | $2T/3$ | | |
| AWS Building Code | $2T/3$ | $T$ in $6T$. Spacing must exceed $3L$ | No cracking, lack of fusion, lack of penetration<br>Porosity: Handled as slag |

**Table 3**

| Method | Quality Control or Quality Assurance | Depth of Inspection | Comments |
|---|---|---|---|
| Visual | Quality Control | Surface | Least expensive (subjective) |
| Mag. Particle (& dye penetrant) | Quality Control | Surface | In a sense aids to visual acuity where tight defect tolerance limits exist. (subjective) |
| Ultrasonics | Quality Control & Quality Assurance | Volume Inspection | As used today the method is often subjective but can be quantified to make it a valid quality assurance test |
| Radiographic | Quality A & Quality C | Volume Inspection | The expense of this method and the direct record obtained make this a quality assurance tool |

With the exception of the new Navy Hull codes, each of these requirements is based on the ASME Boiler Code as modified by committee action. The Navy codes have the same origin but have been modified by the application of modern fracture mechanics. Contrast this table with the work reported by Pellini of the Naval Research Laboratory as shown in Fig. 2. Pellini reports defects sizes for catastrophic failures in the absence of fatigue and brittle fracture. (This work would be most applicable to building fabrication.) The magnitude of difference between defect tolerance limits used in practice and those which might be predicted as necessary from Pellini's work are enormous. On the other hand, the effect of material properties on the defect tolerance limit reported by Pellini is ignored by current specifications.

**NONDESTRUCTIVE TESTING METHODS**

When an inspection philosophy with regard to quality control and quality assurance has been established and defect tolerance limits determined, the techniques of nondestructive testing appropriate to these prerequisites can be chosen. For the purposes of this discussion the various methods are summarized in Table 3.

Beyond this simple listing, a number of other factors exist. Not the least of these are the individual characteristics of each nondestructive testing method. As an example, let us compare the characteristics of radiography and ultrasonic testing. Radiography detects changes in density and is thus most sensitive to voids having significant volume. Ultrasonics depends upon reflection and is thus more sensitive to defects characterized by good reflecting surfaces, which are usually of most concern (cracks, incomplete fusion or penetration). Table 4 summarizes these characteristics.

**Table 4**

| Defect | Normal Concern | Ultrasonics | Radiography |
|---|---|---|---|
| Porosity<br>Slag<br>Incomplete Penetration<br>Incomplete Fusion<br>Cracking | Increasing Concern ↓ | Increasing Detectability ↓ | Increasing Detectability ↑ |

The choice of radiography for a quality assurance test, because of its unquestioned direct record value, is thus modified by the technical limitations of the method.

At the present time, ultrasonic testing of welds suffers from the common requirement that older radiographic defect severity limits be used. These limits recognize radiography's inability to detect tight defects and specify rejection of smaller slag defects in proximity to one another in an attempt to screen out more serious crack-like defects which, unseen, may be associated with them. Ultrasonics sees these crack-like defects directly. On the other hand, accurate ultrasonics measurement of small slag defects in proximity is demanding and time consuming. Obviously, the details of defect severity limits should be appropriate to the nondestructive testing methods used.

## SUMMARY

The reliability of fabricated steel structures can be assured through the use of nondestructive testing. Intelligent and efficient use of nondestructive testing for this purpose requires consideration of the following three factors:

1. Inspection Philosophy:
   Are quality control and quality assurance tests applied intelligently and in the proper context? This is the responsibility of the structural steel fabricator and his customer.
2. Defect Severity Limits:
   Do they reflect the service requirements of the type of structure for which they are specified? This is usually the responsibility of specification writing bodies.
3. Nondestructive Testing Methods:
   Are the best methods specified to meet the requirements of the particular inspection philosophy and defect severity limits? This is the responsibility of the fabricator and his customer. However, specification writing bodies must clearly indicate the method for which particular defect severity limits are intended.

The systematic approach to structural reliability proposed herein, if honestly applied, should increase the reliability of fabricated steel structures while reducing the costs of inspection and related repairs. It is my personal feeling that such an approach will uncover some areas where current standards must be tightened. However, the overall effect will undoubtedly be one of considerable economy.