STUDY OF INSPECTION METHODS AND QUALITY CONTROL FOR WELDED HIGHWAY STRUCTURES

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The primary purpose of weld inspection in highway structures is the control of weld quality. This purpose can be fulfilled, in part, by the detection and elimination of flaws which may cause failure.

There are numerous methods of inspection available to detect flaws in a weld. However, no matter what method is used, it is necessary to determine if the severity of the observed flaw is sufficient to warrant correction. Numerous recommendations and discussions are available to assist in this determination, but the inspector must make the final evaluation and decision. If these flaws are objectionable, a satisfactory weld can generally be obtained by proper incentive for the welder or by changes in the welding procedure.

In general, weld flaws can be classified into five categories: lack of penetration, cracks, slag inclusions, porosity, and harmful surface defects. The acceptance or rejection of the weld is usually determined by limits specified in each of these categories. Although various specifications require rejection of welds based on different relative severities for the different types of flaws, nearly every specification requires rejection for lack of penetration or the presence of a crack. The bases for rejection for the other types of flaws are so varied that often only general indications of them can be presented.

The available methods of inspection may be divided into three general categories: destructive tests, proof tests, and nondestructive tests. Normally, the destructive tests, such as tension and bend tests, are mechanical and are used to determine whether the welder is qualified to fabricate the actual structural weldment or if the welding procedure will yield a satisfactory welded joint. Since the part is usually tested to failure, its usefulness as a component of the structure is destroyed. Therefore, these tests are generally conducted on a standard series of test specimens or on a sample specimen of one of the structural components.

Proof tests are another type of mechanical test and consist of applying to the structure or member a load or pressure equal to or exceeding that expected in service. The load or pressure applied to the structure should not, however, be great enough to damage the structure or to cause failure later at the service load or pressure. The selection of the proof load, required to indicate whether there are defects that might result in adverse behavior or failure in service of the structure or component part, is a matter of experience and judgment. Although proof tests are required for many types of welded structures, their use for welded highway structures is very limited because of the nature of the loads and design criteria for these structures. Since their use is limited, no further discussion of proof tests will be presented in this report.

The third, and the most widely used, type of inspection method is the nondestructive test. The methods of nondestructive inspection may be divided into the following classifications: visual, trepanning, radiography, dye penetrant, magnetic particle, and ultrasonic. None of these inspection methods completely fulfills the requirements for
the inspection of all types of weldments. It is necessary, in most cases, to supplement a basic inspection procedure with one or more of the other inspection methods. The types of tests required for inspection of a specific structure or component of a structure may vary considerably, depending on many factors associated with the design and loading of the structure. For example, if failure of the weld will cause severe damage to the structure and possibly loss of life, a searching sensitive inspection procedure will be necessary to insure adequate weld quality. The selection of the inspection methods and the acceptance criteria are generally based on the judgment and experience of the designers and owners of the structure.

In addition to loading and design criteria for a structure, there are numerous other factors which should be considered when selecting inspection methods. In certain cases, some of the methods mentioned above cannot be used because the necessary equipment is not portable enough to be available at the point of inspection. If this limitation does not exist, the decision as to the type of inspection method is generally based on one or more of the following considerations: sensitivity or resolution required, material to be inspected, geometry of material, method of fabrication, and types of defects possible or expected. Because of the differences in relative importance of the various welds in a structure, any of these factors may determine or control the method of inspection for the different welds.

A survey was conducted in 1960 of all state highway departments to determine which of the inspection methods they use for the various components and members of welded highway structures. A number of changes occurred in the welding practices of the highway departments after this survey and in 1963, the American Welding Society (AWS) issued a new specification (1) which incorporated a number of changes in the requirements and recommendations for weld inspection for bridges. Also, since the original survey, the amount of welding in highway bridges had substantially increased and a number of highway departments had changed their inspection program. To bring the information in the original survey up to date, requests for a review of the weld inspection information were again sent to all state highway departments in November 1963. Their replies to these surveys indicate the overall judgment and experience of a number of engineers and inspectors, and provide excellent guidance for the selection of the inspection methods and for the development of an inspection specification. A summary of both surveys and a detailed listing of the replies of the highway departments to the 1963 survey are presented later in this report. With a study of the sensitivity and uses of the different inspection methods and an examination of the procedures used by the various highway departments, inspection procedures necessary for the proper control of weld quality in highway structures can be better selected. Detailed inspection specifications are not presented in this report; however, references are made to a number of currently available inspection codes.

METHODS OF INSPECTION

Welding inspection has become an integral part of any weld fabrication. Through the years, experience has been gained which has helped considerably in defining the requirements necessary for welding inspection. The inspection methods selected are, however, still largely dictated by judgment and experience.

In this report, the principles underlying the operation of each of these inspection methods are briefly explained and an attempt is made to evaluate their adaptability to fulfill the requirements necessary for welding inspection in welded highway structures.

Visual Inspection

It should be pointed out that in the broad sense, all methods of welding inspection may be considered visual. In this report, however, visual inspection is considered inspection performed without the use of auxiliary equipment other than small hand pieces, such as a flashlight or a magnifying glass.

Because of the expense involved and the time required, it is generally impossible to examine thoroughly the internal and external condition of every weld in a highway structure. Therefore, it is necessary to have a comprehensive visual inspection.
method available during and after completion of welding. Since the only equipment commonly used in visual inspection is a light weld-size gage and magnifying glass, the cost of a complete visual inspection program is generally limited to the cost of inspection personnel. Numerous guides are available to assist the inspector in making decisions concerning the reliability or quality of a weld (2-7).

Visual inspection should begin on the component parts and be performed at various stages during fabrication. With a knowledge of the quality of the weldment at the different stages of fabrication, the decision to accept or reject the weld can then be based on a number of factors.

At the time of fit up, the material should be inspected. A check of the size and shape of the pieces should be made and all heavy scale, grease, paint and oil should have been removed. After root chipping or gouging, inspection is recommended because of the importance of the initial weld pass in the overall behavior of the weldment. The initial pass tends to cool very quickly thereby trapping gas. Also, because of the rapid cooling, this pass is highly susceptible to cracking. Therefore, every stage of welding should be checked because when the welding is completed, only the surface can be inspected visually. As each layer of the filler metal is deposited, the inspector should, if possible, check the layer for defects. Before the subsequent layer is deposited, visible defects, such as cracks, are accessible and can be remedied. On completion of welding, a visual examination should be conducted to determine conformance to specifications, weld appearance, external flaws (cracks, crater cracks, overlap, undercut, etc.), and dimensional accuracy of the weldment.

In many instances, visual examination of each layer of filler metal is not possible. In this case, however, an indication of the internal condition can be obtained from the external appearance of the weld. In general, if a welder has taken care to place the final passes properly, he has done so also on the other passes.

Although the final acceptance of most structural welding is determined mainly from the appearance and visual inspection of the weld, critical welds require supplemental internal and external inspection in conjunction with a thorough visual examination. It should be emphasized, however, that although in many instances these other methods are necessary, they are principally used to supplement a well-conducted visual inspection program.

Visual examination, it should be pointed out, is limited to surface imperfections, and sensitivity depends on width of defect, light reflection, degree of surface smoothness and, most of all, the skill and judgment of the inspector. However, the following quality factors can usually be determined by visual means (3):

1. Dimensional accuracy of the weldment (including warping);
2. Conformance of the finished weld to specification requirements regarding the extent, distribution, size, contour and continuity of welds;
3. Uniformity of weld appearance; and
4. Surface flaws, such as cracks, overlaps, undercuts, surface porosity and unfilled craters.

It should be emphasized that the correct evaluation and interpretation of any discrepancies in the appearance of a weldment is the essential part of visual inspection. To provide a proper evaluation, it is necessary to have a sound knowledge of the service requirements of the weldment and of the welding processes involved in its fabrication, as well as the judgment and experience required to evaluate the quality of the weldment.

Trepansing

Trepansing (3, 8) consists of the removal and examination of a small disc or ring containing the weld by means of a tubular tool with sawteeth around its end. Although classified as a method of nondestructive testing, trepanning does destroy a portion of the weldment. In many cases, such as locations where brittle fracture or fatigue behavior is critical, the removal and subsequent rewelding may be more damaging than the initial defects. However, a trepanning plug is sometimes necessary since it provides an excellent sample for metallurgical studies.
The equipment necessary for trepanning is relatively inexpensive. In addition to a large air or electric drill, the only tools necessary for removing the plug are a holder for the drill, a pilot drill, and a hole saw. The pilot drill, usually ¼ in. in diameter, is used first to drill the guide hole. The hole saw is then used to remove the sample. If necessary, the hole may then be rewelded.

Although trepanning is not used very extensively in present engineering practice, it is the most suitable method under several conditions. It is sometimes the most satisfactory inspection method when only one side of a specimen is available, when a metallographic test is necessary, or when spot sampling is desired.

If the sample is to be used for a metallographic test, the specimen is usually either cleaned by acid or ground, polished, and etched until there is a clear definition of the weld structure. The metallurgical structure may be examined for number of layers of filler metal, microstructure, weld profile, weld contour or hardness, and fusion.

If trepanning is used as a spot sampling method, a sample is generally taken at about every 50 ft of welding. When a defect is located, additional specimens are taken until the limit of the defective welding has been established. Where a single defect in a weld might result in a serious failure, a complete subsurface examination (radiographic or ultrasonic) should be used. Spot checking or sampling is only useful in controlling the average quality of the welds.

Radiography

Radiography (3, 4, 5, 9, 10) includes a number of inspection methods for the determination of the internal quality of a weld. The three basic methods employ X-rays, gamma rays or fluoroscopy. Although variations of all three methods are used for inspection purposes, this discussion is limited to X-ray and gamma-ray radiography because of their extensive use. The use of fluoroscopy to examine welds in a welded highway structure is normally not feasible.

Basically, radiography is the passing of rays through an object; the rays land on a film or screen, revealing or recording the internal structure of the test object. X-rays and gamma rays are electromagnetic waves of short wavelength capable of penetrating materials opaque to longer light waves. Some of the radiation passing through the object is absorbed, depending on the wavelength, the density of the material and its thickness. However, more radiation passes through a void in a uniform thickness of material than through the material itself. Since radiation affects photographic film in proportion to intensity and time, the area of film under the void receives more radiation and appears darker as a shadow image.

The basic operation of both radiographic methods is essentially the same; however, the operation, cost and construction of the equipment varies greatly. X-rays are produced by electrical means, are generally limited to one direction, and occur only when the power source is operating; gamma rays are radiated from isotopes and are continuously transmitted in all directions. Because each may be best suited for different applications, it is not easy to compare their merits. The longer wavelength of X-rays results in higher contrast radiographs; therefore, where high contrast is needed, X-ray radiography is more suitable. Isotopes radiate gamma rays in all directions and allow the simultaneous inspection of a number of specimens. However, the principal advantage of isotope radiation is that it is very portable and does not require any additional power source, but extreme care must be taken in operation to guard against radiation hazards.

Some of the numerous factors that affect the selection of the type of radiography are material density, thickness of material, time available, accessibility and economics. For example, the initial cost for X-ray equipment is relatively large, whereas the initial cost for a gamma-ray source is less but repeated replacement is necessary because of its decay.

X-ray machines are available in sizes from 10 to 1,000 kv or more. However, highway structure inspection is generally limited to 200-kv machines because the larger capacity units are very difficult to transport.
There are four radioactive sources commonly used in gamma radiography—cobalt-60, iridium-192, thulium-170 and cesium-137. The choice of the source generally depends on the type and thickness of material to be inspected, maximum allowable exposure time, cost, sensitivity and frequency of exposure. For thicknesses larger than about 2 in., it is almost a necessity to use an isotope source because the size of X-ray machine required is large and difficult to transport, whereas a small change in the size of the radioactive source is all that is necessary in isotope radiation.

After selecting the radiographic source to be used, the specimen is exposed to this source. The radiographic film, which has been previously placed against the specimen on the side away from the source, is also exposed. The amount of radiation received by the film depends on the density of the specimen material. A defect within the material will cause an increase or decrease, depending on the type of defect, in the radiation reaching the film. For example, a slag inclusion in a weld will appear as an irregularly shaped light shadow on the radiograph. This defect can be readily distinguished from porosity and cracks, which appear as rounded dark shadows of varying sizes and as a fine straight or wandering dark line, respectively.

Gamma-ray and X-ray radiographic inspections are usually conducted according to the AWS specification (1, Appendix E), ASTM Specification E 94-52T, or the ASME Boiler Code for Unfired Pressure Vessels.

After obtaining an indication of the defects in a radiograph, the inspector must decide if they are severe enough to require correction. Several sets of reference radiographs are available to assist in this determination: ASTM Specification E 99-63, U.S. Navy Bureau of Ships Radiographic Standards, and the International Institute of Welding International Collection of Reference Radiographs of Welds. These reference radiographs show typical examples of the various defects encountered in welding and indicate the relative severity of each one. The limits of acceptability are defined in the applicable specifications.

The selection of one of the methods of radiographic inspection as the prime or supporting method of inspection in any welded structure is based on the evaluation of the advantages and disadvantages of the inspection method. The advantages are as follows:

1. Permanent record of inspected weldment, thus making it the most positive inspection method within its range;
2. Positive identification of defects; and
3. Good sensitivity in that defects with thicknesses of less than 2 percent of the thickness of the base material can be found.

The disadvantages (depending on the type of radiographic source) may be summarized as follows:

1. Health hazard from radiation requiring precautionary measures during operation;
2. Cost of equipment;
3. Size and weight of equipment and time loss for exposures (directly related factors since size and/or weight may be reduced in many instances if additional time is allowed for exposure and vice versa);
4. Applicable to only a limited number of joint types and only when both front and back of weld are accessible; and
5. Results available only after film has been exposed and developed (not true of fluoroscopy).

In determining the relative value of the advantages or disadvantages, the type of structure to be inspected should be considered. The many disadvantages generally preclude the use of radiography for 100 percent inspection of a part of a structure unless a service failure of that part would endanger the life of the structure and the lives of individuals. It should be remembered that radiography is not the final answer in inspection methods, but rather an aid to the control of weld quality.
Dye Penetrant Tests

Dye penetrant tests (4, 11) are limited to the detection of surface defects and subsurface defects with surface openings. These tests are highly sensitive and are useful in detecting very small surface discontinuities. Dye penetrants are especially useful in inspecting nonmagnetic materials where magnetic particle tests cannot be used. The flow properties of the penetrants enable detection of defects that would not be seen by visual or other means of inspection. This method is applicable to all homogeneous materials except those of a generally porous nature where the penetrant would seep into and drain from the pores in the surface.

The cost of inspection with dye penetrant is relatively small since the only materials necessary are prepared solutions or powders of penetrant, emulsifier, and developer. The basic steps of the operation are as follows:

1. Liquid penetrant is applied to surface of object;
2. Time is allowed for liquid to penetrate defects;
3. Excess penetrant is removed by emulsifier;
4. Absorbent powdered material (or liquid) is applied to the surface;
5. Developer acts as a blotter and draws out penetrant in defects; and
6. Penetrant diffuses in developer indicating location of defects.

After the defects are located by the dye penetrant, additional examination by other methods of inspection may be desired to indicate further the extent of the defect.

Magnetic Particle Tests

Magnetic particle tests (4, 6, 12) may be used to detect, in ferromagnetic materials, discontinuities at the surface, and under certain conditions, those which lie completely under the surface. Nonferromagnetic materials or any other material which cannot be strongly magnetized cannot be inspected by this method. However, with suitable materials, magnetic inspection is highly sensitive to surface defects.

There are three basic operations in a magnetic particle test:

1. Establishing a suitable magnetic field in the test object;
2. Applying magnetic particles (in either dry form or solution) to the surface of test object; and
3. Examining the test object surface for accumulation of the particles (indication of defect) and evaluating the defect.

The tests are usually conducted in accordance with ASTM Specification E 109-63.

The only appreciable cost for this type of inspection is for the equipment to produce the magnetic field. In general, one of the following types of equipment is used: alternating current, direct current, half-wave rectified current or permanent magnets. In some cases, motor generator welding machines may be used as a source of power and the only additional cost is the magnetizing prods.

For the detection of surface cracks, an a.c. magnetizing current should be used; for subsurface defects, a half-wave rectified current with dry magnetic powder is necessary. Therefore, equipment is needed that will produce either half-wave or alternating current. The selection of the type of current is determined by the depth of penetration desired by the magnetic field.

When the inspector is operating the equipment, he may obtain indications of surface discontinuity, subsurface discontinuity, or nonrelevant magnetic disturbance. With little experience, he can readily differentiate between them. However, to differentiate between the various types of subsurface discontinuities, such as slag inclusions, inadequate penetration, and incomplete fusion, requires considerable experience.

The indication of a surface defect is usually a sharp line (orientation) of magnetic particles since the magnetic field is broken at the defect. The indication of a subsurface defect is formed by the defect forcing the magnetic flux lines to break through the weld surface and appears as a slight orientation or "gathering" of the magnetic particles above the defects at the surface of the weld. As the depth of the defect increases, the size of the defect must increase, so that even a slight orientation of the particles will occur.
A permanent record of the defect may be obtained by making a line sketch or photographing the magnetized particles. The magnetic particles may also be transferred in their magnetized position from the weld to a permanent record sheet by transparent adhesive tape.

This method of inspection of welded highway structures has found its main use in the examination of non-critical but load-carrying welds. In the case of welded built-up girders, it is commonly used to inspect the flange-web fillet welds and as an alternate method for compression and web butt welds. In each of these instances, its major purpose is to locate severe surface defects, such as cracks, rather than subsurface defects.

For normal field applications and many shop uses, the magnetizing current available is too low for detection of subsurface defects. Its use, therefore, should be limited to welds where subsurface defects will not be critical in determining the behavior of the weldment. This method, as all other methods of inspection, should not be used as the sole inspection technique but as a supplement to a complete visual inspection program.

**Ultrasonic Inspection**

Although ultrasonic inspection (3, 5, 13, 14) has been used in other fields and in some phases of structural inspection for a number of years, it has only recently been introduced in the inspection of welded highway bridges. Because of its undeveloped potential, ultrasonic inspection offers possibilities for reliable weld inspection. Not only can ultrasonic inspection be used for flaw detection, but also for thickness measurements and study of the metallurgical structure.

This method of inspection makes use of an electrically timed wave of the same type as sound waves but of a higher pitch (1 to 25 megacycles per second). The signal wave is propagated into the test piece and a portion of the signal is reflected by any discontinuities. The original and reflected signals are shown on a cathode-ray tube by a series of "pips" or vertical indications. Since the length of time (or distance between pips) is proportional to the distance traveled, the distance to the discontinuity, if any, can be determined. By taking readings at several locations and interpreting the width and height of the pip, an indication of the relative size and shape of the discontinuity can also be obtained. The procedures outlined in ASTM Specification E 113-55T are usually the bases for the inspection.

The use of ultrasonic inspection is limited, though, by the following basic deficiencies (3):

1. Lack of a permanent photograph of weld defects;
2. Great dependence on the skill of the operator; and
3. Difficulty in establishing a standard of acceptance.

A photograph of the screen of the cathode-ray tube can be taken to give a type of permanent record. Some of the advantages of ultrasonic testing are high sensitivity (greater than radiography), greater penetrating power (detects flaws in steel thicknesses up to 20 ft), fast response, need for access to only one surface of specimen, and portability of equipment (units available weighing only 35 lb). Although there are several difficulties encountered in the use of ultrasonics for inspection of welded highway structures, these are rapidly being overcome, yielding an accurate, rapid and relatively inexpensive method of inspection.

At present, ultrasonics is used extensively by engineers in the inspection of welds in several types of structures, for example, oil storage tanks and gas pipelines. The transfer of this method to extensive use in structural applications and the inclusion of this method as an acceptable inspection procedure in the specifications seems only a matter of time.

**Destructive Testing**

Destructive tests give a numerical measure of the property under consideration and are tests to failure or destruction. They are usually limited to qualification tests.
conducted to indicate the ability of a welder to fabricate a weldment that he will later be required to fabricate in an actual structure or to obtain a comparison between two or more welding procedures. In welded highway structures, normally the only type of destructive tests required are those indicated in the AWS Specifications (1, Section 5, Appendix D).

It can readily be seen that destructive testing of any component part of a highway structure would not be feasible and, most likely, the repairs required by removal of the part from the structure would be detrimental and more damaging than any defects found in the component.

WELDING INSPECTION IN STATE HIGHWAY DEPARTMENTS

As stated previously, changes in welding procedure and inspection methods necessitated, in November 1963, the updating of the 1960 survey of inspection procedures of each of the 50 states, Puerto Rico, and the District of Columbia. Forty-six of the departments replied to the original inquiry, whereas all 52 departments replied to and are included in the 1963 survey. A summary of the significant information in the replies to the 1963 survey is given in Table 1. In several instances, specific information is not shown in the summary table because only general information was included in the highway department's reply.

It should be noted that although the methods of inspection used by the highway departments vary widely, the number of states permitting shop and/or field welding is increasing rapidly. In 1960, only 78 percent of the highway departments replying indicated use of welding as a primary fabrication method but, by 1963, 50 of the 52 highway departments, or 96 percent, were using welding as a primary fabrication method. Although not listed in the summary table, the U.S. Bureau of Public Roads permits welding on Interstate highway projects and, on occasion, has encouraged the states to use welding in cooperative projects. The Bureau specifies on welded bridges in which it cooperates that the state require thorough visual inspection and magnetic particle inspection of 1 ft in every 10 ft of fillet welds (ASTM Specification E 109). In addition, it specifies for field welds radiographic inspection of 100 percent of all tension and compression splices, including splices subjected to stress reversal, and for shop welds radiographic inspection of 100 percent of all tension splices subjected to reversals of stress and 25 percent of each compression and shear splice. If 10 percent of the 25 percent of the latter splices are defective, then the remaining 75 percent must be radiographed.

Table 1 indicates that the majority of states permitting welding require radiographic inspection in addition to visual inspection of the tension butt welds. However, for compression butt welds, the use of radiographic inspection is not so extensive. For fillet welds, magnetic particle inspection is used to a large extent because of its immediate response and low cost.

It should be pointed out that each state follows the present AWS Specifications (1), which require only visual inspection of the welds with provisions included for radiographic, magnetic particle, dye penetrant or ultrasonic inspection. The current specifications do, however, encourage the use of radiographic inspection, especially for groove welds carrying primary tensile stress. In addition, in the AWS specifications there are standard qualification tests for welds and for welders. It should be noted that before welded structures of steel other than ASTM A 373, A 36 or A 441 structural steel can be designed on the basis of the AWS specifications, modifications both in inspection and welder qualification must be made in the specification requirements.

An analysis of the replies from the 46 highway departments to the 1960 inquiry shows that 36 of the groups were using welding as a method of initial fabrication or were, at the time of their reply, planning a welded highway structure. Of these, 24 (67 percent) indicated they were requiring some radiographic inspection. The remaining states either used a comprehensive program of visual inspection or the specific types of inspection were not designated. In several instances, magnetic particle inspection techniques were specified for fillet welds. However, none of the departments
<table>
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**Notes:**
- Weld reinforcing bars only.
- All splices subjected to stress reversal, but not more than one-third of each splice beginning at point of maximum tension.
- Additional welds as specified on plans.
- Shop welds—25% R.
- 90% of all primary stressed shop welds, 100% of all primary stressed field welds; MP used occasionally, DP used most often.
- Of tension side.
- As specified on drawing.
- Commercial field inspection; tension only if span less than 200 ft; tension only.
- Currently designing two steel bridges to determine cost of steel structures.
- Built-up girders shop welded; secondary members may be field welded.
- When required by specifications or when extra shop splices permitted on long girders.
- Not to exceed 25% of weld length.
- Web tension side.
- On plate girders, not on rolled beams.
- When butt-welded.
- Welding of primary stressed members limited to shop.
- State inspector present.
- Portion only.
- Tension side and top 14 in. of compression side (vertical), sonic and R spot check.
- Fillet welds of T-1 are 100 ft.
<table>
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<tr>
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*F = fabricator; S = state highway department or independent laboratory.
*R = radiography; MP = magnetic particle; DP = dye penetrant; unless otherwise stated, visual inspection also used.
indicated the use of dye penetrant or ultrasonics as a required, or even alternate, inspection procedure.

A summary of the inspection methods and requirements reported for each of a variety of the welds found in welded highway structures is given in Table 2. The principal welds considered are tension butt, compression butt, web splice, and fillet. The table indicates clearly that as the importance of the weld in the overall safety of the structure or component member increases, the inspection requirements become more severe. In the case of tension butt welds, almost 100 percent of the departments now using field or shop welding require thorough examination (radiography) of the interior quality of the weld. In the case of the less critical fillet welds, 66 percent require magnetic particle inspection and only one required any radiographic inspection (1 percent of the length).

In addition to the substantial increase in number of departments using welding as a primary fabrication method, three major changes appear to have occurred in the last few years in the requirements for welding by the highway departments (Table 1):

1. The percentage of departments either making their own nondestructive weld inspection or having it conducted by an independent laboratory under their supervision has doubled, from 44 to 88 percent. Although in the 1960 survey, 28 percent of the replies did not indicate the agency responsible for inspection, there appears to be a change in policy from making the fabricator responsible for the nondestructive testing to placing the responsibility with the state or its agent.

<table>
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*a Based on number of departments using welding as primary fabrication method, unless otherwise indicated.
*b Based on number of requests sent to highway departments.
*c Based on number of departments replying to requests.
*d For shop welding.
2. For the various butt welds, there is considerably more emphasis on radiographic inspection. In all three categories of butt welds, the number of states requiring radiographic inspection has increased significantly.

3. The importance of some type of nondestructive testing for the fillet welds has been realized as a means of checking for surface defects and as an incentive source for the welders. Over 70 percent of the departments now require some type of nondestructive testing, in addition to visual inspection, for fillet welds.

From the analysis of the replies from the 1960 and 1963 surveys, it appears that the policies of the various highway departments are approaching more closely, at least as a minimum, the current requirements of the U.S. Bureau of Public Roads for Interstate bridges. This trend is probably to be expected, since at the present time a large percentage of major bridge construction is connected with the Interstate system.

SUGGESTIONS FOR DEVELOPMENT OF WELDING INSPECTION SPECIFICATIONS

The development of a welding inspection specification requires the consideration of a number of integral factors. These factors include not only the type of inspection procedures to be used with each different connection detail, but also the weld quality standards desired, the inspection capabilities of the inspecting agencies, the integrity of the welders, and the quantity of welding to be used in fabrication.

A number of general inspection standards are currently available to serve as a guide in the development of a standard for a particular agency. Since the AWS specification (1) is used most widely and covers most of the basic areas to be considered when preparing either an entirely new standard or a supplement to an existing specification, it will be used as a basis for this discussion.

Basic Areas of Consideration

In the development of the inspection specification for welded highway structures, the basic areas of inspection and quality control to be considered are inspection of materials, welding procedure qualification, welder and welding operator qualifications, inspection procedures for various weldments, and quality control requirements for weldments.

The requirements for inspection of materials usually need only to specify that the materials used conform to the specifications. The basic specifications generally indicate the tolerances which are to be allowed and the necessity for cleanliness of the material.

The qualification tests for the welding procedure and the welder and welding operator are essential. The purpose of the procedure qualification tests is to indicate, through a series of static tests, whether the electrode, welding position, heat treatment, speed of electrode travel, etc., specified can be used to fabricate a sound weldment. In the case of the welder qualification tests, the purpose is to insure, through a standard series of static tests, that the welder is capable of producing a satisfactory weld using a qualified welding procedure. The limits of acceptability for the procedure and welder qualification tests are generally those outlined in the current AWS bridge specifications (1). It should be pointed out that the limits specified by AWS are for ordinary structural steels and the high-strength low-alloy structural steels; if higher strength steels are to be used, some change in the requirements will be necessary.

The selection of the inspection procedure for a given weldment is, most often, the result of the experience and judgment of the specification writer. In the selection, he must consider, for example, the type of stress to which the weldment will be subjected, the effect of a partial or complete failure of the weldment on the overall behavior of the structure, the accessibility of the weldment, the materials being joined, and the welding procedures and welders to be used. Although some considerations are more important than others, it is necessary to look at all factors simultaneously.

The selection of quality control requirements is also a result of the judgment of the specification writer. Although a number of tests have been conducted to obtain the
critical factors in the determination of weld strengths and the acceptable limits of these factors, a number of different opinions still exist in this area. All known specifications do, however, reject welds with visible cracks, undersize welds, undercutting and overlap. These defects may readily be detected by visual, dye penetrant, or magnetic particle inspection. It is the limits for porosity and fusion defects in which variations for size and frequency of occurrence occur. Since porosity and fusion defects are internal defects, they are normally detected only by radiographic or ultrasonic inspection techniques. The limits for radiography are usually those set by the AWS specifications (1, Appendix E), ASTM Specification E 94-62T, and the ASME Boiler Code for Unfired Pressure Vessels. As the use of ultrasonic inspection techniques in welded highway structures increases, a set of standards similar to those now available for radiography will probably be developed.

Inspection Methods for Welded Joints

Requirements insuring adequate visual inspection for all welds must be included in the specification. Many defects in weldments may be detected before the use of a more thorough inspection technique, and, in many cases where the members are of a secondary nature, the requirement of visual inspection is sufficient.

In welded highway structures, the types of weldments which may require additional inspection, beyond visual inspection, may be divided into the following general categories: (a) tension butt welds, (b) compression butt welds, (c) web splice welds, (d) major fillet welds, and (e) secondary fillet and butt welds. In the determination of the type and amount of inspection to be required, consideration should be given to the type of stress to which the weld will be subjected and the seriousness of a failure of the weld. For tension butt welds, it is, therefore, recommended, and almost universally accepted, that complete radiography of these welds be required. However, in the case of the compression butt welds and web splice welds, the requirement of 100 percent radiography is probably not necessary. If experience shows that acceptable welds normally will be obtained, then a requirement of a reduced percentage (generally about 25 percent) of weld radiography is generally sufficient if the option is included to radiograph all of the remaining welds in the event defects are observed.

Major fillet welds would include mainly flange-web welds and cover plate attachment welds. Although internal defects in these welds are undesirable, they are generally not sufficiently detrimental to require internal inspection. A number of states specify magnetic particle inspection for these welds. However, since in nearly all applications this inspection technique can only detect surface defects, a thorough visual inspection will yield almost the same results. Nevertheless, one benefit of magnetic particle inspection is its psychological effect on the welder and the resultant improvement in his performance. For this reason it is believed desirable to include limited requirements for magnetic particle inspection of major fillet welds in any inspection specification for major structures.

For secondary fillet and butt welds, a thorough visual inspection program should be adequate. Such inspection should locate all cracks and external geometrical defects serious enough to be of concern.

A thorough examination of available test data, a review of current practices of highway departments and a study of the available inspection techniques indicate that the following general requirements should be included in the development of any inspection specifications for welded highway structures:

1. For all welds, a thorough visual inspection should be made on completion for cracks, undercut, overlap, and incorrect size. If possible, visual inspection of major groove welds should be conducted after each pass during fabrication. Dye penetrant inspection may be used as a supplement, provided all penetrant and developer is completely removed from unfinished welds before any additional welding on the joint is initiated.

2. For major groove welds, radiographic inspection should be conducted on 100 percent of all primary stressed tension butt welds and 25 percent of all primary stressed compression butt welds and web splice welds in girders. However, for
compression butt welds and web splice welds, a requirement should be included that the remaining weld length be radiographed if more than 10 percent of initial radiographs show welds that should be rejected. The locations of the initial radiographs should be selected at random. Quality control requirements should be selected from one of the recommended standards previously listed.

3. For major fillet welds and secondary welds, no additional inspection beyond visual inspection should be necessary under normal conditions. However, if the fabricator does not have sufficient experience in welding, it may be desirable to require that 10 percent of all major fillet welds be inspected using the magnetic particle method. Although there is some doubt about the capability of magnetic particle inspection to indicate more information than a thorough visual examination on defects of fillet welds, the use of another inspection technique and the possibility of every weld being examined generally insures the integrity of the welder.

ACKNOWLEDGMENTS

This report has been prepared as a part of an investigation being carried on under a cooperating agreement between the Engineering Experiment Station of the University of Illinois, the Illinois Division of Highways, and the U.S. Bureau of Public Roads. The authors wish to express their appreciation to the state highway officials who supplied the information used herein. The cooperation and guidance of the Project Advisory Committee are gratefully acknowledged.

REFERENCES