Quality Control of Structural Steel

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•THE wide variety of structural steels now available, the predominating and ever-increasing use of welded designs, and the rapid pace and the magnitude of today's construction activities have caused great changes in structural steel inspection, both in methods and in importance. Responsibilities of the inspector of structural steel production, fabrication, and erection have greatly increased in the last decade. An intimate knowledge of the properties and behavior of these modern steels, as well as of the production, fabrication, and erection facilities, is absolutely necessary for proper quality control.

Structural steel is inspected in three distinct phases: (a) in the mill, (b) in the fabricating shop, and (c) at the construction site. Customarily, mill inspection is the responsibility of the producer; shop inspection is carried out both by the fabricator and the owner or engineer; and field inspection is largely the responsibility of the owner or engineer. Inspection by the manufacturer and fabricator is carried out through their own quality control forces, and by the owner and his engineer through inspection agencies specially employed for this purpose or by their own trained groups of inspectors.

INSPECTION IN THE MILL

In the manufacture of steel, tight controls are exercised by the various steel mills. During the melting process of each individual heat of steel, constant checks are made by the mill's metallurgists and samples for chemical analyses are taken during the pouring of ingots directly from the ladle. Additional chemical analyses or "re-checks" are made from the solidified ingots. These tests, as well as the physical tests on samples from the rolled material, are usually witnessed by the customer's inspector for conformity with specifications.

If these tests fail to meet any one of the many requirements, a ruling is sometimes sought from the customer for acceptance of the material. In many cases a slight deviation from specifications in chemical composition or a small decrease in the yield, ultimate strength, or other physical properties of the material may be acceptable to the customer depending on the final use of the material. In such cases the final decision is made by the engineer.

Where deviations from the specifications are too great or where even slight deficiencies are not acceptable to the customer or to the mill's quality control personnel, that particular heat of steel is downgraded and sold as a less valuable steel, or it may be scrapped and returned to the furnace.

Laboratory tests are only part of the inspection performed during the manufacture of steel. From the time a furnace is charged to the moment a load of steel leaves the mill on the way to the fabricating shop, watchful eyes assure that the final product is of the best possible quality and conforms in all respects to the governing specifications and to the customer's special order. Representatives of the mill's metallurgical department record all components of a heat as it is charged into the furnace, the temperature in the furnace, the elapsed time until the furnace is tapped, and other important data. Visual checks are made of each ingot before it is placed in the soaking pit in preparation for rolling.

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At the soaking pit, reliable inspection is of greatest importance. Ingots of various heats and of many different types of steel may be in the soaking pits at one and the same time, their only identification being a mark on the inspector's chart. Only the greatest care at this point can prevent the occurrence of "mixed steel," i. e., the intermixing of different kinds of steel into the rolling of a particular product. That such mixing of steels rarely occurs testifies to the alertness and competence of the inspection personnel. In those rare cases where the wrong steel goes through the rolling mill, inspection will usually spot such a mistake by the color of the hot steel or by the particular way it behaves during rolling or shearing. To eliminate further any possibility of a mix-up, additional laboratory spot tests are made from scrap material cropped from the billets as they go through the rolling mill. The working of the steel in the fabricating shop, such as the ring of steel under the punch and the appearance of the slugs, as well as its welding characteristics, constitute additional checks on the use of the proper steel.

Recent developments of a continuous casting method, eliminating the use of ingots and the need for reheating in soaking pits, are promising. As a matter of fact, some test installations are now in actual use. It is hoped that this will, in the not too distant future, lead to the end of all soaking pits and the inherent possibility of mixed steel.

A final visual inspection is made of the finished rolled material. Individual pieces not conforming to rigid specifications of appearance and dimensional tolerances are properly conditioned to acceptable standards or rejected. The finished material is carefully marked with numbers and symbols denoting heat number, type and size of steel, manufacturer's name or trademark, and the acceptance stamp of the customer's inspection agency. Steels of different types are edge painted in different colors in accordance with a standardized color scheme and this method of identification is continued in the fabrication shop.

INSPECTION IN THE FABRICATING SHOP

In the ideal situation, inspection in the structural fabricating shop is performed by two different organizations working in close cooperation but independently of each other. One group is the fabricator's own quality control force, the other is the customer's inspector.

Thorough inspection is usually provided by the quality control organization of a competent and reliable fabricator. However, for this inspection force to be truly effective, it must be outside of the jurisdiction of the shop superintendent. This has been recognized in recent years by several large fabricators who made their quality control personnel directly responsible to the plant manager or to their engineering department.

Usually, the quality of inspection reflects directly on the competence of the shop's management. It is quite obvious that even in the best shops there is a continuous rivalry between the superintendent, responsible for running his shop at the least possible cost, and the shop's chief inspector, intent on keeping quality standards at a high level. It is one of the functions of the plant manager to arrive at a satisfactory medium between these two opposing views and to make decisions stick, no matter what the cost. Where this condition exists, the customer's inspector usually only serves to increase the inspection force, to submit deviations from plans or specifications to the engineer for decision and in general to keep the customer informed about progress of the work in the shop.

Unfortunately, good and reliable shop inspection by the fabricator is not as prevalent as one would hope. It is generally limited to the larger companies and the extent of inspection is almost proportional to the size of the fabricating shop. In the average small shop, production and inspection control is in the hands of the same person, the shop superintendent, and in most of these shops inspection by the fabricator is greatly limited. There, the importance of constant inspection by the customer cannot be overemphasized.

A good inspector, familiar with the shop, will usually seek and receive cooperation from the shop workers and foremen and will experience little trouble in getting minor deficiencies corrected without complaint at a higher level. In cases where shop errors

or substandard work require referral to higher levels, every effort must be made by the engineer to back up his inspector in arguments with the shop. Unfortunately, customers or their engineers are frequently requested by the fabricator to accept deficient or inferior fabrication, the excuse being difficulty of obtaining replacement material and the need of meeting delivery dates. These excuses are generally made to avoid the cost of proper repairs that may have to be made on an expedited basis. It is the duty of the engineer to resist these attempts, to insist on satisfactory workmanship in accordance with plans and specifications, and to uphold rejections where they are warranted. Only by firmness in his dealings with the fabricator can the engineer uphold the authority of his inspector. Once the inspector's authority is undermined the quality of workmanship deteriorates.

Inspection in the shop by the fabricator's and the customer's inspectors consists primarily of the continuous examination of all fabrication to assure a product in accordance with plans and specifications, and of workmanship equal to the best general practice in modern shops. The duties include (a) a check on the material to determine not only that the correct type of steel is used in accordance with approved plans but also that the material has received the inspector's approval stamp at the mill; (b) a check on layout, cutting, punching, riveting, welding, and all other fabricating operations to assure conformance with the many standard rules and the engineer's special requirements; (c) a check on the preparation of the steel surfaces for application of the shop coat of paint, inspection of the proper manner of paint application at a satisfactory ambient temperature and proper film thickness, and insistence on an adequate drying period, which will provide a good base for future paint coats and will help to assure a long life of the structure; and (d) a final check of the completed work prior to shipment from the shop. In addition to these visual duties, inspectors are now almost routinely required to perform, witness, and interpret various methods of nondestructive testing of welds, castings, and forgings.

Usually, the work of the customer's inspector is not limited entirely to review of shop operations. He can perform invaluable service to the engineer by regular weekly or monthly reports or by special communications, reporting on progress, adherence to schedules, unusual occurrences, or expected troubles. Close contact between the inspector and the engineer, who usually is at great distance from the fabricating shop, is essential for the satisfactory performance of inspection services. Occasional visits by the engineer to the shop to discuss pending matters with the inspector will greatly help to bolster the inspector's attitude toward the job and his authority among the shop personnel.

Ground storage must be given adequate attention, particularly with reference to deterioration of the shop paint and of the unpainted surfaces from atmospheric and weather conditions or from the possible detrimental effects of the ground or cinders on which the material may be stored. Attention must be given to proper sequence of storage with respect to erection requirements to avoid unnecessary rehandling, with its accompanying greater hazard of damage. Trusses, girders and similar fabricated pieces should be checked after loading for shipment to make sure that they are adequately supported and not subjected to stress conditions for which they were not designed.

INSPECTION AT JOB SITE

Once the fabricated steel arrives at the job site, inspection for the proper performance of the work on heavy construction usually is done by the engineer. As a rule, responsibility on the contractor's side for the proper erection of the steel rests with the various gang foremen or "pushers" who are mostly interested only in a speedy and safe completion of the job. It is, therefore, important that the engineer employ a well-trained staff of inspectors to check all phases of field erection.

Proper inspection in the field starts with a thorough check on workmanship and condition of the material received from the fabricating shop or ground storage. This should include a check on the camber of built-up girders and on the alignment of welded members prone to distortion during shipment. Particular attention should be given to the erection equipment and procedures to assure performance and sequence of erection

ments and submit them to various destructive and nondestructive tests. Testing samples, which incidentally could be part of a welder qualification test, is relatively inexpensive. Such early inspection efforts will provide proof that the procedure specified or used can or cannot produce a good weld. Samples kept at the site will serve as ready reference for an acceptable weld standard. Furthermore, such sample testing will provide a record of weld properties and soundness that often would be impracticable or impossible to obtain from a finished product.

SPECIFICATIONS

It is of primary importance that specifications be practical and that their provisions be attainable by the contractor with reasonable effort. Requirements that are too rigid and constraining will usually not improve the quality or performance of the work but will always add significantly to the cost. Clear, precise specifications are important not only to the performance of a job but also as a tool for the inspector. The more voluminous they are, the more there is a chance for discrepancies and contradictions and the less they are read and observed by the personnel performing the work.

Confusion and increased production cost created by the duplication of standards and specifications for materials, fabrication and inspection is high, even if it cannot be measured in dollars and cents. Qualified national organizations such as ASTM, AASHO, AWS, and AISC, representing producers and consumers, industry and government, scientists and engineers, have thoroughly prepared specifications for practically all phases of construction. Yet the federal government, the various branches of the armed services, states, municipalities, and even private engineers insist on their own forms or standards, which more often than not are merely duplication of existing national standards. Such individualism and conflicts can hardly be justified.

Specifications for a particular application should always take into account the intended service application of the structure. The method, location, and amount of destructive testing should be specified clearly to avoid later arguments and extra charges. The type and amount of acceptable defects in welds should be defined with the greatest clarity. Acceptable tolerances must be defined wherever practical.

Where there are welds, there are defects. To require repair of defects that definitely do not affect the service requirements of the structure and to enforce needless specifications for fabrication and inspection would add unnecessary costs for preparation of parts, longer welding time, and excessive inspection and testing. These efforts should be concentrated on the critical areas of a structure where they represent money well spent. Such realistic procedures will produce a fully adequate and economical structure.

RESPONSIBILITY FOR INSPECTION

Much has been written in the last year or two about who should be responsible for inspection. Proposals have included (a) the complete abandonment of inspection by the engineer because of recent court decisions in matters of responsibility for accidents; (b) placing responsibility for inspection on the construction contractor, as is the present policy of the Corps of Engineers; and (c) establishment of a Federal Inspection Bureau along the lines used in some European countries. However, the majority of the views expressed the opinion that the engineer should inspect the construction of his designs. This is the way it should be. Only the designing engineer knows all the assumptions on which his design was based. He may have spent many months developing details based on certain criteria of which only he is fully aware and whose execution in the field can only be obtained by proper inspection by himself.

The current practice by architects of having field inspection on buildings performed on the basis of infrequent visits to the site by the designing engineer is at best poor inspection. The lack of a thorough appreciation of those on the job site of the basic design requirements and behavior of materials often leads to costly corrective actions or inferior work. It is strongly recommended that this grossly inadequate practice be given close scrutiny by the engineering profession.

The policy of federal and state agencies of inspecting with their own staffs the construction of designs developed by consulting engineers may be satisfactory for the ordi-

in accordance with previously approved plans. All field connections must be carefully checked to make certain they carry the loads for which they were designed. In high-tensile bolt connections, 10 percent of the bolts should be torque-checked by the inspector. Locked-in stresses caused by improper sequence of making connections or by forcing members to fit must be avoided, and remedial steps have to be proposed and supervised by the inspector. In special instances, stress measurements or other observations must be made by the inspector to verify the actual behavior of a structure in comparison with design assumptions.

On any project involving welding on stress-carrying members, welders must be prequalified in accordance with the requirements of the American Welding Society. Attention must be given to the use of the proper welding rod and necessary preheat for the various types of steel. Low-hydrogen electrodes must always be oven-dried and no welding should be permitted during rainy or extremely humid weather, except under controlled conditions.

Finally, the work of the painters has to be inspected carefully because in general nothing will affect the future maintenance cost to the owner more than the quality of the original paint job. Any damage in the shop coat must be touched-up before application of the field paint. Surfaces to be painted have to be cleaned of all dirt, rust, oil, and grease.

In addition to inspecting the performance of the work, the inspector should review safety requirements and insist that the work site be kept clean of refuse, rubbish, and other fire and safety hazards.

NONDESTRUCTIVE TESTING

Hand-in-hand with the increased use of welding, both in the shop and in the field, has come a tremendous increase in the demand for nondestructive testing. The most common methods are dye-penetrant, magnetic particle, radiographic, and ultrasonic inspection. The proper selection of one method to the exclusion of the others will depend on the type of joint to be tested and the type of defect expected to be found.

Dye-penetrant is primarily used to check for surface cracks. It is easy to use and inexpensive but somewhat messy, and is therefore applied infrequently. For surface and near-surface defects, magnetic particle inspection is used today almost exclusively. It will expose any surface crack or discontinuity no matter how small. If properly used on the initial beads of large, multiple-pass welds, it may in many instances obviate the need for radiographic inspection of the finished joint and prevent expensive repairs.

Radiography is presently the most popular form of nondestructive inspection, especially for butt welds. It has the primary advantage of furnishing a permanent record that can be viewed any place and any time. However, the geometry of some joints precludes the use of this method. Furthermore, the potentially dangerous rays necessitate the temporary closing-off of the testing site, a costly requirement and of special disadvantage in the field.

The application of ultrasonic inspection has increased rapidly in the last few years. Its greatest limitation is still the need for highly trained and reliable technicians, needed not only for operation but also for interpretation of its findings. The absence of a permanent record must be weighed against its relative ease and speed of application when there is a choice between this method and radiography.

Standardized reference photographs for radiographic inspection of welds and castings are available to permit correct identification and correlation with acceptable performance criteria. No such uniform and generally applicable standards for easy use in the structural fabricating shop exist as yet for ultrasonic inspection. Efforts at standardization are presently under way in the fabricating industry and it is hoped that a uniform national standard for identification will be made available soon.

DESTRUCTIVE TESTING

Nondestructive testing, especially in the field, may be costly and time-consuming, particularly if staging or closing-off of the work area is required. Fortunately, it is frequently possible, especially on highly repetitive welding jobs, to make sample weld-

nary project. Even so, the authors have reservations about this procedure. In important or complex cases, representatives of the engineer, empowered with adequate authority, should be available at the construction site at all times for guidance of and consultation with the government inspector.

In recent years it has become more and more prevalent to engage construction firms as managers or consultants on large construction projects and charge them with the coordination, supervision, and inspection of the work performed by the various contractors on the project. While it is advisable to obtain the recommendations of competent contractors for complicated structures—and this is a common practice followed by responsible engineers during the design stage—it is very doubtful that construction contractors, by the very nature of their experience and their lack of design appreciation, are qualified to perform inspection in the traditional way envisioned by the designer and in the best interest of the owner. Experience indicates that under this arrangement subconscious partiality and expediency often override considerations of quality and workmanship.

COMPETITIVE INSPECTION SERVICE

Good inspection on behalf of the owner, in addition to constant vigilance by the inspection agency, is largely dependent on the attitude and actions of the owner and his engineer.

The owner must be willing and must find a way to pay for adequate inspection service. Reference is made to the detrimental but customary way of taking competitive bids for off-site inspection services, a practice that has been thrust upon the engineer in some cases by existing local laws, in other instances by past practice or by agency regulations. This practice has been the cause of cutting of prices in a highly competitive field, which has led to progressive reduction in services rendered, and often to substandard inspection. If continued, the practice can eventually result in such poor inspection as to be a complete waste of money.

For inspection services to be effective, they must be considered as being at professional level fully as much as other engineering services required for the job. Adequate compensation to assure competent supervision should be made to the owner's own inspection staff or should be negotiated by the engineer on behalf of the owner with a reliable inspection agency on a cost basis that permits the necessary attention the work requires. The cost of steel inspection is extremely modest in relation to the total project cost and to the importance of obtaining a sound structure. Only a very small percentage increase in the project cost applied to this phase of the work would assure the optimum in inspection service.

ENGINEER'S DUTIES

In addition to convincing the owner of the necessity of paying for adequate inspection, the engineer must function in several ways to assure the attainment and constant maintenance of high-level inspection. The engineer must in the development of the design make the proper selection of steels consistent with fabrication requirements and service conditions of the structure. He must develop details that can be fabricated as well as adequately inspected, painted, and repaired, if need be, in the shop or in place in final position. Prior to the start of work in the mills and plants, the engineer should assure himself by investigation that the inspection agency under consideration is by past records and reputation fully experienced in the work to be performed, that the agency has available for this work the required trained personnel, and that the fee asked is sufficient to provide the high standards of inspection desired. The engineer, at the very start of inspection, may well have an initial conference with representatives of the inspection agency in which the nature of the work is described and the highest type of service insisted upon.

The engineer or his delegated representatives should not only constantly review all the inspection reports submitted to him, but he or his representatives should frequently and periodically visit the mills and plants to be continuously informed of all problems there by first-hand observations and to be intimately aware of the progress of the work.

These frequent meetings and accompanying discussions with the plant and inspection forces will encourage the close relations between the engineer and his inspection forces essential to a satisfactory performance. This procedure will lead to boosts in morale, will frequently uncover lags in progress, and will furnish the necessary background for corresponding corrective discussions with the fabricator's management. The visits also will provide checks on the standard of inspection and on the size of staff applied to and needed for this work.

Only in these ways will the public and the owner be best served and the work be performed in the manner rightfully contemplated by the designer.