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| Office of Independent Oversight | Director, Office of ES&H Evaluations<br>Date: 05/29/09 | |
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## 1.0 PURPOSE

Within the Office of Independent Oversight, the Office of Environment, Safety and Health (ES&H) Evaluations' (HS-64) mission is to assess the effectiveness of those environment, safety and health systems and practices used by field organizations in implementing Integrated Safety Management and to provide clear, concise, and independent evaluations of performance in protecting our workers, the public, and the environment from the hazards associated with Department of Energy (DOE) activities and sites. A key to success is the rigor and comprehensiveness of our process; and as with any process, we continually strive to improve and provide additional value and insight to field operations. Integral to this is our commitment to enhance our program. Therefore, we have revised our Inspection Criteria, Approach, and Lines of Inquiry for internal use and also we are making them available for use by DOE line and contractor assessment personnel in developing and implementing effective DOE oversight and contractor self-assessment and corrective action processes on this WEB page.

## 2.0 APPLICABILITY

The following Inspection Criteria document is approved for use by the Office of ES&H Evaluations.

## 3.0 FEEDBACK

Comments and suggestions for improvements on these Inspection Criteria, Approach, and Lines of Inquiry can be directed to the Director of the Office of ES&H Evaluations on (301) 903-5392.

## NUCLEAR FACILITY CONSTRUCTION- STRUCTURAL STEEL

### Inspection Criteria

The following DOE directives and industry standards are applicable to the extent that they are referenced in design basis documents and contract specifications:

- Quality assurance programs are established and implemented in accordance with 10CFR830, Subpart A, *Quality Assurance Requirements,* ASME NQA-1, *Quality Assurance Requirements for Nuclear Facilities Applications,* DOE Order 414.1C, *Quality Assurance,* and DOE Order 226.1A, *Implementation of DOE Oversight Policy.*
- Structural steel is fabricated and erected in accordance with the American Institute of Steel Construction, *Manual of Steel Construction.*
- Structural steel embedments and anchorages are fabricated and installed in accordance with the American Concrete Institute Standard ACI 349.
- The chemical and physical properties of structural steel, fasteners, and weld filler materials meet the requirements specified by the American Society for Testing and Materials (ASTM) standards referenced by design specifications.
- Individuals inspecting structural steel fabrication and erection are qualified in accordance with the requirements of American Welding Society Standard AWS D1.1 or the American Society for Nondestructive Testing Standard SNT-TC-1A.

### Inspection Activity

Observe the following construction activities and review records and design documentation to assess the quality of structural steel fabrication and erection and to determine if requirements specified by design basis documents, contracts, and applicable codes and standards have been met:

- Review the construction specifications related to structural steel construction and ascertain whether the specified technical requirements conform to the requirements of the construction contract, design basis documents, and referenced codes and standards.
- Review structural steel construction procedures and verify that they are appropriate and adequate related to procurement and storage of structural steel materials and fasteners, erection of structural steel, specify adequate quality control inspection practices, and provide adequate controls for design changes.
- Observe ongoing construction work to determine if structural steel work activities and the quality of work meet the requirements of applicable specifications, procedures, drawings, and codes.
- Observe quality control (QC) inspection activities and examine completed structural steel work to assess the effectiveness of the QC program. Review the qualification of QC inspection personnel.
- Review records documenting quality of completed structural steel installation. Review the QA surveillance/audit program for structural steel construction activities.

### Inspection Lines of Inquiry

- Fabrication of Structural Steel and Qualification of Materials

- Are procurement specifications consistent with design basis documents and contract requirements for materials such as structural steel members, fasteners (bolts, nuts and washers), weld filler materials and welding supplies, and miscellaneous items such as shims, base plates, and anchor bolts?
- Are the requirements for the steel fabricator's shop inspection program clearly stated in the contract documents?

  Note: Structural steel is typically furnished by an offsite steel supplier who prepares fabrication drawings, also called shop drawings, from the design drawings; purchases various sizes of structural steel shapes; and fabricates the beams, columns, and other shapes shown on the drawings from the purchased structural steel. The fabricator may use a third party inspection organization to perform the shop inspections.
- Has the structural steel fabricator established the following controls to ensure the quality steel fabricated for the construction project:
  - An approved NQA-1 quality assurance program that has been audited by the general contractor or a designated third party;
  - Structural steel fabrication drawings approved by design engineers;
  - A receipt inspection program to verify purchased structural steel shapes meet purchase specification requirements;
  - A quality control inspection program including controls for inspection of fabricated beams, columns, and other members to assure that steel members were fabricated within dimensional tolerances, bolt holes are proper size, located within tolerances, and welds meet requirements of the American Welding Society (AWS) Code;
  - A welding program and a weld inspection program that meets applicable requirements;
  - Audits of steel suppliers; and
  - An adequate number of qualified QC inspectors?
- Are fasteners and washers used for steel erection certified by the manufacturer and clearly marked to indicate grade and type?
- Are weld filler materials (electrodes) and other welding supplies certified by the manufacturer?
- Are fasteners and welding supplies purchased as quality level materials and certified as such by suppliers?
- Are manufacturers/suppliers of these materials on the project's approved suppliers list and have audits been performed to validate the certifications furnished by these vendors?

- Storage

  - Are qualified and non-conforming materials segregated in storage areas?
  - Is structural steel supported on timber or curbing and not in contact with the ground?
  - Is unpainted structural steel covered when stored outside (Level C storage) for protection from moisture?
  - Are fasteners stored in closed containers and protected from dirt and moisture?

    Note: Manufacturers normally apply a protective coating to fasteners to prevent corrosion and facilitate installation. If fastener components become dirty or rusty,

they are not considered acceptable for permanent installation. Fastener components should not be re-lubricated.

- Are weld filler materials (electrodes) stored in sealed containers, per manufacturer's requirements?
- Are filler materials stored in an oven or otherwise protected from moisture after removal from original packaging?

- Structural Steel Erection

  - Is erected structural steel configured (i.e., correct size, shape, orientation, location and plumb or level) in accordance with design drawings?
  - Are members free of damage?
  - Do fit-up and alignment tolerances, length, depth, and straightness of structural members and alignment of bolt holes meet specification requirements?
  - Are instruments used to control alignment, plumb, and level during erection calibrated?
  - Are joint contact surfaces free of burrs, dirt oil, and contamination, and are they solidly seated?
  - For bolted connections, are connections snug tight prior to final tightening of bolts?
  - Are correct fasteners (bolts, nuts, washers) used?
  - Are washers on correct side of fastener (under turning element)?
  - Do bolts have sufficient thread engagement?
  - Is field welding controlled and is it performed in accordance with requirements of AWS Code?
  - Have anchor bolts, embedded plates, and other hardware used to anchor structural steel to the building structure been properly installed and located?
  - Has installation of anchor hardware been inspected and accepted by QC?
  - Are post-erection activities (e.g., final alignment and plumb checks, base plate grouting, painting) completed?
  - Are inspections of structural steel erection performed when required and by qualified personnel?

- Bolt Installation and Tightening

  - Is each bolt, nut, and washer checked under field conditions, before tensioning, to verify that the pre-tensioning method will develop the minimum required bolt pretension? (AISC 348)
  - Are pre-installation test results documented?
  - Is each joint type (i.e., snug-tightened, pre-tensioned, or slip-critical) clearly identified on the design drawings?
  - Are craft and QC inspection personnel able to identify the joint type and required method for tensioning the bolts in each joint? (AISC 348)
  - Are the correct size and type of fasteners installed and is the correct tensioning (method, sequencing, and torque) applied to each?
  - Do installed bolts have sufficient thread engagement?

- Do inspection and craft understand that bolts cannot be reused after they are tensioned and that bolts used as temporary erection bolts cannot be used as permanent bolts?

- Field Welding

  - Is the welding process qualified by a procedure qualification record (PQR) and is the weld method documented on a written welding procedure specification (WPS)? (AWS D1.1)
  - Do welder qualification records, including results of test assemblies (coupons), which were tested as required by the AWS Code, indicate that welders are qualified per the AWS Code?
  - Are weld filler materials (electrodes) used as specified in the AWS Code and applicable weld procedure?
  - Are storage and handling of welding materials specified in the manufacturer's recommendations and AWS Code?
  - Are weld joints prepared as specified in the WPS (i.e., are they free of paint, oil, dirt scale, rust, moisture and other foreign materials), and are gaps between faying surfaces within specification requirements?
  - Are pre-heat, interpass temperature, and post weld heat treatment controlled in accordance with specification requirements?
  - Are welding process and equipment used as specified in PQR and WPS?
  - Are welds inspected and are NDE inspection personnel qualified in accordance with either AWS D1.1 or SNT-TC-1A?
  - Are weld records maintained to verify welds meet specification requirements? Do these records identify weld location, type and size, identify filler material used, welder identification, materials joined, joint preparation, WPS, thermal treatment, NDE performed and results, and NDE inspector?

- Qualifications of QC personnel

  - Do training and qualification records confirm that NDE welding inspection personnel are qualified in accordance with AWS D1.1 or SNT-TC-1A?
  - Do QC inspection personnel demonstrate adequate knowledge of the requirements of their work activities?
  - Is there evidence of an adversarial or intimidating relationship between QC inspection personnel and construction craft?
  - Is the number of qualified QC personnel at the construction site commensurate with the work in progress?

- Quality Records

  - Do records of structural steel erection, installation of bolted connections, and field welding activities indicate the actual conditions encountered in the field and provide adequate documentation of work and inspections?

- Do records include sufficient detail to document the results of inspections and necessary repairs were completed in accordance with design requirements?
- Are records legible, complete, reviewed by QC and/or engineering personnel, and readily retrievable?
- Do receipt inspection records of fabricated steel. Fasteners and weld materials confirm that required material characteristics (physical and chemical), performance tests, nondestructive test, and other specification requirements were met?
- Were hardware/materials supplied by vendors on approved suppliers list?
- Do records confirm that structural steel has been installed in accordance with design requirements and that appropriate inspections have been completed?
- Do nonconformance/deviation records include current status of reported conditions and do they include the status of corrective action or resolution?
- Do training/qualification records establish that QA/QC personnel are adequately qualified to perform their assigned duties and responsibilities and that craft personnel have been trained in their assigned tasks? Are these records complete and current and show which activities inspectors are qualified to perform?
- Do procedures indicate that inspectors who inspect and accept welds are required to meet requirements of AWS D1.1 or SNT-TC-1A?
- Are inspectors who perform inspection of structural steel certified as civil inspectors in the area of structural steel and are they required to pass annual eye exams and be physically able to perform their duties?

**INSPECTION GUIDANCE**

The Construction Authorization Agreement, nuclear facility safety basis documents, and approved Project QA Program specify design, construction, and QA/QC requirements. These requirements are implemented in the construction specifications, drawings, work procedures, and QC/QA implementing procedures.

Subpart 2.5, Quality Assurance Requirements for Installation, Inspection, and Testing of Structural Concrete, Structural Steel, Soils, and Foundations for Nuclear Power Plants, ASME NQA-1 specifies additional QA requirements for structural steel. Industry codes for structural steel design and construction are found in the American Institute of Steel Construction (AISC) Steel Manual and ANS/AISC Standard N690. Structural steel welding requirements are specified American Welding Society (AWS) D1.1, Structural Welding Code. The Editions applicable to the project will be referenced in the specifications and/or nuclear facility safety basis documents. However, the project specifications, drawings, and procedures specify and control the construction and inspection processes. QA/QC inspection and construction procedures should be reviewed and compared with the requirements of the applicable codes and specifications. QA/QC procedures must provide for effective inspections which will ensure that work is performed in accordance with specification requirements. Testing procedures must provide for verification of correct material usage and correct selection of reference standards. Qualified personnel should review test results and determine if results are acceptable. Construction procedures must reference the required inspection hold points and must also address the QA/QC department stop-work authority.

Structural steel construction activities should also be observed to ascertain they are consistent with standard industry practices. Look at the dynamics of the work force, the attitudes in work crews, and relations between construction personnel and QA/QC personnel. Determine whether the construction labor forces also perform their own checks of work as it is completed, or if they rely solely on QA/QC. Look at the level (experience, training, and number) of supervision during concrete-placement activities. Look at how the QA/QC inspectors perform their inspection and check-offs. Is it done sequentially as work is being done?

The construction specifications must translate design requirements into details sufficient to define the technical requirements for structural steel construction activities. The specifications should provide for control of design changes and the issuance of design change notices. The review of procedures, specifications, and drawings should ensure that structural steel construction and inspection activities are controlled and performed in accordance with applicable requirements. QA/QC procedures should specify acceptance-testing requirements and should specify the personnel and interface responsibilities required to define, control, and resolve field problems or design problems that occur during construction. QA/QC procedures must provide for effective inspections that will assure that work is performed in accordance with specification requirements. The procedures should require verification of specified controls and should not be accomplished merely by surveillance. Records must document that work and inspection activities were performed in accordance with all applicable requirements.

Fabrication of Structural Steel and Qualification of Materials

The structural steel is typically furnished by a steel supplier who prepares fabrication drawings from the design drawings, purchases structural steel components from an approved vendor, cuts the components to the required length, width, thickness, drill/punches holes for bolts, welds clip angles, stiffener plates and other components to beams and columns so steel can be installed at the construction site with a minimum of field modifications. Each member is uniquely identified using a technique which will permit member identification through the installation and final inspection process. The fabricator may also design connection details, specifying type of joint, number and size of bolts, and any welds. The structural steel fabrication drawings and connection details must be approved by the design engineering organization. The steel fabricator must be on the Approved Suppliers List and should have an approved QA program. Otherwise the General Contractor will be responsible for inspecting and accepting work performed by the steel fabricator.

Requirements for structural steel materials will be specified in the NUCLEAR FACILITY SAFETY BASIS DOCUMENTS and contract specifications. The structural steel materials include structural steel members (beams, columns, plates, and other shapes), fasteners (bolts, nuts, and washers), welding electrodes and other welding supplies, and miscellaneous items such as shims, base plates, and anchor bolts. Chemical and physical tests for all materials used must indicate that specifications have been met. The physical and chemical tests are required to be performed on each lot (batch) of materials. Tests results may be provided by the steel manufacturers via certified materials test reports (CMTR), or may be performed at an independent testing laboratory. Fasteners are certified by the manufacturer, and grade and type

are clearly marked on the bolts, nuts, and washers. There have significant problems in numerous industries with fasteners being supplied with fraudulent documentation indicating the fasteners met various industry standards. These type of fasteners are generally referred to as counterfeit fasteners. Welding electrodes and other welding supplies are also certified by the manufacturers.

The General Contractor is required to audit their suppliers through their vendor inspection program. The contractor's audit of the steel fabricator should verify the fabricator has an adequate QA program and is implementing the program. Key areas are verification that purchased structural steel components were supplied by a qualified steel supplier; documentation that physical and chemical tests were performed to show purchased steel meets appropriate AISC/ASTM requirements (either a CMTR or tests from an independent test laboratory); results of receipt inspection of base steel which should include check of mill tolerances for various size members; results of inspections that show fabricated components meet drawing and specification requirements, fabricator's welder qualification program, shop weld inspection results, audit of steel suppliers; and verification that fabricator's QC inspectors are qualified.

The steel fabricator's shop inspection program should include the following:
- Review of CMTRs from material suppliers.
- An inspection program that verifies dimensions of structural steel shapes received from the steel manufacturer or supplier for assuring structural shapes meet AISC requirements.
- Inspection of shop welds to assure shop welds meet AWS requirements.
- Inspections that verify fabricated beams, columns, and other members were fabricated within specified tolerances, and that bolt holes are properly sized and located, including proper edge distances.

Storage

Structural steel materials need to be clearly identified through use of an adequate marking system. Paper tags are generally not sufficient to maintain identification through installation and final inspection. When structural steel is received onsite, a receipt inspection is performed to assure that documentation is supplied to demonstrate that the steel members comply with project requirements. This documentation includes CMTRs and inspection releases from the vendor. The steel is inspected for damage and verification that it is properly identified. If the steel is damaged, or documentation is missing or inadequate, the item is considered nonconforming. A non-conformance document should be initiated to document and disposition the problem. Non-conforming or unqualified materials are required to be segregated from qualified materials. The CMTRs and inspection documentation which accompanied the shipment should be reviewed in detail by a subject matter expert to assure the materials meet specification requirements.

Structural steel is required to be supported on timber or curbing and not be in contact with ground in the storage area. Painted structural steel requires Level D storage (outside, uncovered). Components which have not been painted require Level C storage (outside and covered) for protection from moisture.

Fasteners are stored in closed containers and protected from dirt and moisture. If the containers are opened or damaged upon receipt or in storage, the fasteners in the damaged/open containers

are considered non-conforming, Containers are required to be stored in a protected shelter, minimum Level C storage area (outside and covered), not in contact with ground. The manufacturers generally apply a protective coating to fasteners to prevent corrosion and facilitate installation. If fastener components become dirty or rusty, they are not considered acceptable for permanent installation and should be scrapped, or used as temporary erection bolts. Fastener components should not be re-lubricated.

Weld filler materials (electrodes) are stored in sealed containers, per manufacturer's requirements. If the containers are opened or damaged upon receipt or in storage, the electrodes in the damaged/open containers are considered non-conforming, After filler materials are removed from original packaging, they are required to be protected or stored in an oven so welding characteristics are not changed.

Storage controls, materials identification, protection, and segregation are required to be maintained until installation in the facility and final inspection and acceptance.

Structural Steel Erection

Structural steel is erected in accordance with design drawings and approved design documents, including design changes. The most significant problems that occur during structural steel erection usually involve alignment and plumbness deficiencies, and fitup problems at joints. Misalignment of bolt holes is also a common problem. These problems need to be as directed by engineering. Unauthorized modifications to steel members to obtain a snug fit at a connection or to correct alignment problems is an unacceptable practice. Joint contact surfaces, also referred to as fraying surfaces, are required to free of burrs, dirt oil, and contamination. Connection parts need to fit up within specification tolerances. Excessive gaps will affect tension in bolts and weld quality.

Bolt Installation and Tightening

A tension calibrator is a hydraulic device that indicates the pretension in a bolt. The tension calibrator must be calibrated. The tension calibrator confirms the suitability of the completed fastener assembly including lubrication of the fastener and the tensioning procedure used by the ironworkers. Before tensioning any bolt, each grade and size fastener of each lot of fastener assembly is required to be checked under field conditions to verify that the pre-tensioning method develops the minimum required pretension. The test methods are discussed in AISC 348. Pre-installation test results must be documented. The joint type must be clearly identified on the design drawings. Joint types include snug-tightened, pre-tensioned, or slip-critical. AISC 348 specifies the requirements for installation and tightening of bolts in each connection type. The joint type must be clearly indicated on the design drawings so that craft and QC inspection personnel can readily identify the joint type and required method to be used to tension the bolts in each joint. QC inspectors should witness fastener tensioning for turn of the nut and calibrated wrench tensioning. For joints with twist-off type fasteners and direct-tension indicator fasteners, the QC inspectors should witness the pre-installation testing discussed above. Refer to AISC 348 for inspection requirements for snug-tightened and slip critical joints. All bolts should have sufficient thread engagement. Requirements for installation of washers are specified in AISC

348. Bolts can not be reused after they are tensioned. Bolts used as temporary erection bolts can not be used as permanent bolts and should be clearly marked so they are not used as permanent bolts.

Field Welding

Welding of structural steel is performed in accordance with the AWS Structural Welding Code, AWS D1.1. Refer to the AWS D1.1 Code for detailed requirements. Supplemental criteria for inspection of welds is contained in NCIG-01, Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants. The following are minimum requirements to insure a good quality welding program. The welding process (type of joint) is qualified in a procedure qualification record (PQR). The weld method is documented on a written welding procedure specification (WPS). All welders are qualified per the AWS Code, which requires preparation of test assemblies (coupons) which are inspected and tested. Weld filler materials (electrodes) used are as specified in the AWS Code and applicable WPS and PQR. Storage, handling, and issue of welding materials are controlled per AWS requirements. Weld joints are prepared as specified in the WPS, are free of paint, oil, dirt scale, rust, moisture and other foreign materials, and gaps between fraying surfaces do not exceed specification requirements. Thermal (reheat, interpass temperature control, and post weld heat) treatment of welding is performed in accordance with AWS requirements. The welding process and equipment used are as specified in PQR and WPS. All welds are inspected by qualified NDE inspection personnel who are required to be qualified in accordance with either AWS D1.1 or SNT-TC-1A. A document typically referred to as a weld traveler is issued to document each weld or group of welds. The locations of welds are shown on a weld map which is a permanent record. The weld traveler identifies the weld location, type and size, identifies the filler material used, the identification of the welder, materials joined, joint preparation, the PQR and WPS, thermal treatment, NDE performed and results, and identification of the NDE inspector.

Qualifications of QC personnel

The qualifications (education and experience) of inspection personnel must be verified by the employing organization. Personnel qualifications must be supported by documentation. NDE welding inspection personnel are required to be qualified in accordance with AWS D1.1 or SNT-TC-1A. Inspectors who perform inspection of structural steel need to be certified as civil inspectors in the area of structural steel. All inspectors are required to pass an annual eye exam, and be physically able to perform their duties. The minimum education and experience requirements for inspection personnel are specified in ASME NQA-1, AWS D1.1, and SNT-TC-1A.

Quality Records

Sufficient records are required to document that structural steel was erected in accordance with the design drawings and specifications. Records are required to document qualification of materials, installation of steel, connection details, and field welding activities. The records should indicate the actual conditions encountered in the field and provide adequate documentation of work and inspections. Records should include sufficient detail to document

the results of inspections; and repairs, if necessary were completed in accordance with design requirements. Records should be legible, complete, reviewed by QC and/or engineering personnel, and readily retrievable. Training and qualification records for craft and QC inspection personnel are also required to be maintained. Additional records required to be maintained are those that establish that the required audits were performed and that deficiencies identified during audits were corrected.

Prevalent Errors and Recent Concerns

This section is included to provide background for inspectors on past structural steel construction problems that have been identified and on certain areas that should be more closely scrutinized. (Note - These are not listed in order of their perceived importance to safety.)

Inadequate QA/QC records documenting structural steel work activities

- Incorrect bolt type, mismatched bolts and nuts, missing washers, or missing bolts.
- Damaged members or members not fabricated to drawing requirements.
- Missing or defective welds. Defective welds included undersized welds, welds with excessive undercut, excessive porosity, slag or impurities, or incorrect type of weld.
- Improper enlarging of undersized bolt holes, flame cut holes.
- Installation of incorrect members, missing members, or altering members without design approval.
- Materials improperly stored.
- Counterfeit fasteners.
- Fasteners not tightened to specification requirements, e. g. loose nuts. In some cases uncalibrated torque wrenches were used to tighten fasteners, or fasteners were not brought to snug tight condition prior to tightening. Other problems were result of using rusty fasteners, or fasteners where manufacturer applied lubricants deteriorated.

Inadequate design

- Attachment of supports for other equipment to structural steel without design approval, leading to possible overloading of steel structures. Unauthorized use of permanent structural steel for rigging/hoisting of equipment.
- Deficient alignment or fit-up for welded connections.
- Failure to perform pre-installation verification of fasteners.
- Problems with anchorage of steel beams or columns to concrete structures.
- QC inspections not done conscientiously or inspections performed by unqualified personnel.
- Intentional violation of work procedures by craft personnel to avoid rejection of their work or to simplify their work.
- Construction personnel and supervision intimidation of QA/QC inspectors.

**REFERENCES**

Code of Federal Regulations 10 CFR 830.122, Quality Assurance Criteria for DOE Facilities.

American Society of Mechanical Engineers (ASME)

ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Applications.

American Institute of Steel Construction

Manual of Steel Construction

AISC 348, Specification for Structural Joints Using ASTM A325 or A490 Bolts

American Welding Society (AWS)

AWS D1.1, Structural Welding Code - Steel.

American Society for Non-Destructive Testing

SNT-TC-1A, Recommended Practice No. SNT-TC-1A Non-Destructive Testing

American Society for Testing and Materials International Standards

Specific ASTM standards for chemical and physical requirements for structural steel, fasteners, and weld filler materials will be listed in the specifications. These Standards specify the test methods and acceptance criteria for materials testing.

NRC Publications

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.199, Anchoring Components and Structural Supports in Concrete.

Others

Nuclear Construction Issues Group, NCIG-01, Visual Weld Acceptance Criteria for Structural Welding at Nuclear Power Plants

American Concrete Institute (ACI) 349, Code Requirements for Nuclear Safety-Related Structures (code used for design of concrete anchorage and embedments for attachment of structural steel to the building structure).

For information and standards for studs and stud welding (proprietary name: Nelson Studs), which are used to secure embedded plates to concrete structures, refer to Chapter 8, Stud Welding, Volume 2, Welding Handbook, published by the American Welding Society.