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Regulation
No. 1110-2-8157

15 June 2009

Engineering and Design
RESPONSIBILITY FOR HYDRAULIC STEEL STRUCTURES

1. Purpose. This regulation defines engineering responsibilities for design, construction and operation of hydraulic steel structures. ER 1110-2-100 requires periodic inspection of completed Civil Works Structures by Engineering Division personnel, but contains only general requirements applicable to all project features. Specific requirements for management and inspection of hydraulic steel structures are described herein.
2. Applicability. This regulation applies to all USACE commands having responsibility for Civil Works projects.
3. Distribution Statement. Approved for public release; distribution is unlimited.
4. References.
 - a. ER 1110-1-12, Quality Management.
 - b. ER 1110-2-100, Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures.
 - c. ER 1110-2-101, Reporting Evidence of Distress of Civil Works Structures.
 - d. ER 1110-2-112, Required Visits to Construction Sites by Design Personnel.
 - e. ER 1110-2-401, Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual for Projects and Separable Elements Managed by Project Sponsors.
 - f. ER 1130-2-500, Partners and Support (Work Management Policies); Chapter 2 Project Manuals.
 - g. ER 1110-2-1150, Engineering and Design for Civil Works Projects.
 - h. EM 1110-2-2105, Design of Hydraulic Steel Structures.
 - i. EM 1110-2-6054, Inspection Evaluation and Repair of Hydraulic Steel Structures.

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j. Federal Highway Administration (FHWA) 1986. Inspection of Fracture Critical Bridge Members, Supplement to the Bridge Inspector's Training Manual. Report No. FHWA-IP-86-26.

k. American Welding Society (AWS) 2008. D1.1 "Structural Welding Code – Steel," Miami, FL 33126.

l. American Welding Society (AWS) 2008. D1.5 "Bridge Welding Code," Miami, FL 33126.

m. British Standards Institution (BSI) 2005. BS 7910:2005 "Guide to methods for assessing the acceptability of flaws in metallic structures," London, England W4 4AL.

5. Background.

a. There have been incidents of significant distress in hydraulic steel structures at Civil Works projects. In some cases the distress has been so severe as to warrant complete replacement of the structure (Ice Harbor Lock, lift gate, 1994, \$6 million) and, in at least one case, to cause collapse of a structure under hydrostatic load, nearly resulting in loss of life (Coffeeville Lock, maintenance stop logs, 1994). Other lift gates have been replaced due to severe cracking (Melvin Price Lock and Upper Mississippi River Lock 27), miter gates have been investigated and repaired due to cracking (Markland Lock), and there has been a failure of a tainter gate (Folsom Dam, Bureau of Reclamation). There have also been a number of failures of operating equipment, including wire rope, machinery anchorage and hydraulic gate-operating systems.

b. In many cases, the primary form of distress has been fatigue damage and fracture. The most common causes of fatigue cracking have been a lack of proper detailing during design, poor weld quality during fabrication and poor detailing and execution of repairs. Recent inspections by districts have indicated that a significant number of stop logs and bulkheads had deficient welds which required repairs. Many of these deficiencies were the result of ineffective quality control during the original fabrication welding of the structures. Corrosion is also a common form of distress, but is often more readily apparent before resulting in failure than fatigue cracking or incipient fracture.

6. Policy.

a. Definition of Hydraulic Steel Structures. Hydraulic steel structures (HSS) are structures which control or regulate water and are typically part of a larger navigation, hydropower or flood control project. Typical HSS are lock gates, dam spillway gates, tainter gates, tainter valves, bulkheads and stoplogs, vertical lift gates, components of hydroelectric and pumping plants, and miscellaneous structures such as lock wall accessories, flood protection gates, lifting beams used for installing other HSS, and outlet works gates. This regulation applies to all HSS being designed, fabricated, operated or inspected by the district with the exception of small size, low head, standard

manufacturer's designs. Many components of the operating machinery are designed and function integrally with the structural components of the HSS. To the extent possible, the provisions of this regulation shall also apply to such components.

b. **Responsibility.** The District's Chief of Engineering Division (or Engineering function for multi-function Divisions) is responsible for ensuring that new HSS are adequately designed, and that appropriate engineering support is provided for quality control, quality assurance, fabrication, erection, operation, inspection, and maintenance of each new and existing HSS. The District's Chief of Engineering Division will designate a qualified Engineer to be responsible for each HSS activity identified herein. For purposes of this regulation, Engineer shall be defined as the individual designated by and acting on behalf of the District's Chief of Engineering Division on all engineering responsibilities within the scope of this regulation. Funding and scheduling for these actions should be accomplished through normal budgetary procedures.

c. **Qualifications.** The Engineer shall be a licensed professional engineer, be a structural engineer, have continuing education that includes structural steel design, welding, fatigue and fracture analysis, and fabrication methods, and at least five years experience in the design, inspection and evaluation of HSS. Where a particular expertise or experience is lacking in an area of design, inspection, or evaluation, the Engineer shall obtain it from within the District or USACE Regions, or from other agencies or qualified A-E firms. The Engineer is responsible for direct oversight of the design or evaluation. An engineer conducting or leading the team conducting quality control or quality assurance shall have at least the same qualifications as the Engineer.

d. **Required Actions.** Quality management in accordance with ER 1110-1-12 shall be performed to ensure compliance with the requirements described herein during the following phases of the project.

7. Design Phase.

a. **Design Criteria.** Design of HSS shall be in accordance with EM 1110-2-2105. The Engineer shall ensure that the following types of design requirements are satisfied: strength, serviceability, fatigue and fracture, corrosion and wear. Sufficient analyses must be performed to ensure a safe, functional and reliable design. This includes sizing of members, connection detailing and compatibility with adjacent features. Analyses shall be performed and checked as required herein.

b. **Fracture and Fatigue Control.** Fracture and fatigue control requirements are defined in EM 1110-2-2105. The Engineer shall ensure that all cyclically loaded components have been designed to meet the fatigue design requirements. This includes all attachments and connections to cyclically loaded members. The Engineer shall also ensure, as required by the EM, that all fracture critical members (FCM) have been specified to meet minimum material toughness criteria and, for welded structures, the fabrication and inspection requirements follow a Fracture Control Plan (FCP). Fatigue and fracture control are critically affected by the quality of fabrication and

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construction procedures. Therefore, engineering requirements for fabrication and construction procedures should be provided to construction personnel as outlined in paragraph 8.

(1) Fracture critical members or member components are tension members or tension components of bending members (including those subject to reversal of stress), the failure of which would be expected to result in collapse or partial collapse of the structure. The designation "FCM" shall mean fracture critical member or member component. Any attachment welded to a tension zone of an FCM member shall be considered an FCM when any dimension of the attachment exceeds 4 in. in the direction parallel to the calculated tensile stress in the FCM. All welds to FCMs shall be considered fracture critical. Welds to compression members or compression areas of bending members shall not be defined as fracture critical. For new designs, designers should avoid structural systems containing FCMs whenever possible.

(2) Fracture Control Plan (FCP). The Engineer shall develop an FCP for fabrication of FCM. The FCP shall include provisions for controlling parameters that influence fatigue and fracture including: material toughness in base metals and consumables, hydrogen control in consumables, heat input and cooling rates, limits of discontinuities in welds and base metals, welding processes and procedures, repairs of welded connections and base metal, qualifications of fabricators, welders, welding operators, tack welders, and inspectors, and any other parameters that affect embrittlement of materials and introduce discontinuities. The AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members provided in AASHTO/AWS D1.5M/D1.5 was developed specifically for the fabrication of new bridges but provides guidance on process and material controls that can be applied to other types of structures. The Engineer may apply certain or all sections of these provisions as they apply to a particular HSS as long as the Engineer understands fully the development of these provisions and how they apply to the specific conditions of the design.

(3) Welding Criteria. The Engineer shall be responsible for, or review and approve, all welding requirements for HSS including welding processes and procedures, weld quality, weld details, material requirements, inspection requirements, weld acceptance criteria, and qualifications of fabricator and fabricator personnel. The Engineer shall apply the provisions of either AWS D1.1/D1.1M or AASHTO/AWS D1.5M/D1.5 as applicable to the weld or member type; i.e., statically or cyclically loaded, FCM, or other critical member or connection. Alternatively, the Engineer can conduct a Fitness For Service (FFS) evaluation (see references h, i, and m) to determine acceptable criteria.

c. Plans and Specifications. Plans and specifications (P&S) shall be prepared in accordance with ER 1110-2-1150. The P&S are the final products of all the preceding design and review efforts. They define legal requirements for the contractor and are the basis for construction bids. The Engineer shall ensure that the P&S include all necessary requirements governing fabrication and erection of the HSS and that submittal requirements are clearly defined. The Engineer will specify design analysis submission requirements for any structural steel components designed by the

contractor such as supplier designed sluice gates, mechanical equipment supports, etc. Generally, all structural submittals for the HSS should be reviewed by the Engineer. Guide specifications may be used as a tool for preparing project specifications, however, the Engineer must ensure that guide specifications are properly adapted to reflect specific project requirements. The following information shall be included in the P&S.

(1) All connections shall be detailed by the designer, not the steel fabricator.

(2) All FCM shall be clearly identified on the drawings, and the material toughness requirements for these members shall be defined in the specifications.

(3) Requirements for weld inspections shall be clearly defined in the P&S. All welds require at least a visual inspection. The Engineer shall also require additional non-destructive testing (NDT) of welds on FCM as required by the FCP. The drawings and specifications should also identify other critical connections (in addition to FCM) that require NDT beyond visual inspection. The specifications should also require NDT of a sampling of other welds on critical connections.

d. Design-Build. When a design-build acquisition strategy is deemed necessary to meet mission requirements, the Engineer shall ensure that the Request For Proposal (RFP) clearly indicates all of the applicable criteria, tasks and controls necessary to design, fabricate, and construct a quality HSS, and that submittal requirements are well defined. The Engineer shall review all submittals necessary to verify compliance with the RFP and recommend approval or disapproval. All relevant documentation shall be maintained in a project file.

e. Technical Review. Technical review is a key element in design quality control plans. The engineer responsible for the HSS shall ensure that an adequate review is performed, in accordance with current USACE policy, and that issues identified by the review are fully resolved.

f. Certification. The Chief of Engineering shall certify that each HSS has been designed, evaluated, and/or repaired in accordance with current USACE policy, received an appropriate technical review by a qualified engineer, and all substantive issues arising during the review have been resolved to meet the provisions of current USACE policy.

g. Operation and Maintenance. Operation and Maintenance (O&M) or Operation, Repair, Replacement & Rehabilitation (OMRR&R) are interchangeable for this paragraph but the regulation for O&M Manuals for projects with Corps O&M is ER 1130-2-500, and the regulation for OMRR&R Manuals for projects operated by non-Federal sponsors is ER 1110-2-401. As a continuation of the design process, or during the construction phase, the District's Engineering Division will prepare information specific to the HSS for inclusion in the appropriate section of the Project O&M Manual. The Engineer should include information in the O&M manual identifying all FCM, and other

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highly stressed tension members, in each HSS. To control fatigue and fracture, the O&M manual will require coordination with the Engineer or his representative, use of qualified welders, and applicable welding specifications and procedures when welding to any HSS element. The information should include recommendations for future inspection procedures and frequency of inspections for the FCM and other critical connections. Where HSS are turned over to local sponsors, the OMRR&R manual must clearly identify and require inspection methods and frequency. Any OMRR&R responsibilities shall be identified to the sponsor throughout the project development process, not just when the project is turned over.

8. Construction Phase.

a. General. The Engineer shall provide engineering support for the HSS during construction of the project. Areas of involvement include shop drawing and other construction submittal reviews, contract modifications, value engineering (VE) proposals, construction site visits, consultation with office and field construction personnel on interpreting the P&S, and on procedures to be used for fabrication and erection.

b. Engineering Considerations and Instructions for Field Personnel. As required by ER 1110-2-1150, the District's Engineering Division shall transmit a report to Construction Division, and to the Area/Resident Engineer, to aid them in supervision and inspection of the construction contract. A meeting among designers, district construction personnel and contractor personnel prior to construction is beneficial for identifying and discussing contract requirements and establishing a partnering relationship. As a minimum, the coverage of HSS in the report and meeting should include materials, welding procedures, quality control (QC) testing and quality assurance (QA) that are part of the fatigue design and fracture control plan, any special construction sequences that must be followed, critical tolerances that must be met, and submittals requiring design engineer review including critical structural shop drawings and contractor performed extensions-of-design. Submittals to be reviewed by the Engineer will be so indicated on the Submittal Register. Also, as required by ER1110-2-112, the schedule of field visits by design personnel should be included. This schedule will identify what structural steel details the Engineer should observe during construction, and at what stage of construction the visit should occur.

c. Design During Construction. Typically, during the construction phase, the only design analyses performed by the Engineer are those required to resolve field problems. All design actions during construction are subject to the same technical review requirements as for new designs. The Engineer shall be involved in evaluating contract modifications to assure that both design criteria and construction concerns are satisfied.

d. Review of Submittals. The Engineer must coordinate with Construction Division to receive HSS submittals designated for Engineering review. The Engineer shall be involved in all modifications and deviations to the contract plans.

e. **Contractor Designed Components.** The Engineer shall review and approve the design for these items to assure that they result in a structure that meets functional and technical requirements specified in the P&S.

f. **Contractor Value Engineering Submissions.** VE proposals for HSS that involve changes to the contract P&S shall be reviewed and approved by the Engineer. Review shall ensure that proposed changes comply with the original design criteria established for the project.

g. **Final Inspection of Completed Construction.** The Engineer shall participate in the final inspection of the HSS with construction personnel and shall provide a recommendation on final acceptance.

h. **Permanent Records.** Records that document the materials and quality of construction are important for future evaluation and maintenance of the HSS. Engineering and Construction Divisions shall assemble a copy of items including mill certificates, weld inspection records, welding procedure records, and details of contractor designed items, and shall forward them to the appropriate Project Field Office to be retained as permanent records along with the design documents, as-built drawings and specifications. Copies of all documents shall be stored at a central location, accessible to the Engineer for future reference. Consideration will be given for electronic storage of these documents.

i. **Supply Contracts.** Some of the usual construction contract administration procedures are not applicable when a HSS is procured by a supply contract. For supply contracts, the Engineer must coordinate with Contracting to ensure that appropriate requirements are included in the contract. The Engineer must also coordinate with Construction to define applicable QA/QC requirements, and to determine appropriate USACE inspection actions.

9. Operation Phase.

a. **General.** Communication and a good working relationship between engineering and operations personnel are essential. Operations personnel continuously observe project features and are often the first to become aware of actual or potential problems that may warrant a special inspection. For scheduled inspections, the Engineer must coordinate with Operations Division to develop at least a 5-year inspection plan, including schedule and budget. This plan should be reviewed and updated annually. The Engineer shall coordinate with Operations Division to execute the inspection plan and provide technical support for maintenance and repairs. Where project operation is the responsibility of the local sponsor, the O&M Manual should identify the sponsor's inspection responsibilities.

b. **Modifications/Repairs.** All modifications and repairs to HSS and any modification or repair to a FCM shall be designed by the Engineer and shall conform to the

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applicable requirements of paragraph 7. Execution of the repairs shall be subject to the applicable requirements of paragraph 8, whether contractor or project personnel perform the repair. Repaired groove welds in FCMs shall be inspected by ultrasonic testing (UT). Fillet weld repairs on FCMs shall be inspected by magnetic particle testing (MT). Documentation of the repair shall be included in the permanent project files.

c. Inspection Methods. The primary purpose of the engineering inspection of HSS is to evaluate structural adequacy, rather than the general maintenance condition. The focus of the inspection should be on the critical structural members and connections and those most susceptible to various forms of degradation, particularly cracking on critical tension members. Detailed guidance on inspection methods and identification of critical areas is provided in EM 1110-2-6054. Detection of cracks requires a thorough visual inspection, and possibly additional non-destructive testing (NDT) to determine the extent of the discontinuity. Visual inspection involves close physical contact with the member, and may require special access equipment and cleaning of areas with potential cracks. Use of additional NDT beyond visual inspection should also be considered for other critical elements when their failure would result in loss of life or large economic losses. The Engineer shall determine the weld acceptance criteria and weld inspection requirements, in addition to those described in this section, in accordance with paragraph 7.b(3).

d. Inspection Plan. An inspection plan should be developed for each HSS. The plan should be specific to the type of engineering inspection being performed (see paragraph 8.e.) and should identify the members, joints, connections and welds that are to be inspected and the type of inspection (visual or additional NDT) each is to receive. The plan should identify any equipment needed to provide safe access to the members. The extent of inspection will depend upon member importance, the type of HSS and its function and the purpose of the inspection. Drawings, design analyses, inspection reports and O&M records are useful in developing the inspection plan. Those that require additional NDT beyond visual inspection will cost more and take longer than those requiring only a close visual inspection. The plan should prioritize inspection of members, including adjacent joints, in the following order:

- (1) FCMS with life safety impacts;
- (2) Other FCMS;
- (3) Primary tension members or tension flanges;
- (4) Primary compression members or compression flanges;
- (5) Secondary structural members;
- (6) Non-structural items.

e. **Types and Frequencies of Engineering Inspections.** HSS may be inspected at the same time as other project features during a periodic inspection, or may be inspected at times which will maximize the effectiveness or efficiency of the inspection. The Engineer must coordinate each HSS inspection in accordance with the following schedules. To ensure that these schedules are followed, it will be necessary to mark and record a permanent identifying number on each HSS. This will permit identification when HSS are moved or interchanged. When a problem is discovered during an inspection, the Engineer shall determine the need to revise inspection schedules for similar HSS and shall determine the scope of those inspections.

(1) **Periodic Inspections.** A periodic inspection is a regularly scheduled inspection required by ER 1110-2-100. HSS should be included as part of the periodic inspection program. It shall consist of sufficient observations to determine the physical and functional condition of the HSS, to note any changes from previously recorded conditions, to identify any changes in loading or use, to identify any developing problems, and to ensure that the structure continues to satisfy service requirements. For HSS whose failure could result in loss of life, the critical components should be subjected to at least a thorough visual examination during each inspection. NDT shall be done on critical connections where cracks are suspected.

(2) **In-Depth Inspection.** An In-Depth inspection is required for each FCM on all existing HSS where failure of the FCM would result in probable loss of life. In-Depth inspection of stoplogs and bulkheads used for dewatering, and for related lifting beams, shall be completed prior to their next use. The purpose of this inspection is to ensure that there are no defects that could result in failure. This inspection is required to be performed at least once during the life of the HSS. The requirement may be waived if fabrication and inspection of FCMs in accordance with an acceptable FCP is documented. All welds on FCMs shall be visually inspected. Fillet welds on FCM shall be inspected by NDT other than visual. Paint shall be removed from the joint being tested only when a clear indication cannot be obtained through the paint. All butt joints subject to tensile stress in FCMs shall be inspected by ultrasonic testing (UT). All groove welds in "T" and corner joints subject to tensile stress in FCMs shall be inspected by UT. Welds meeting the acceptance criteria of 7.b(3) shall satisfy the requirements of this inspection. Welds not meeting the acceptance criteria may be repaired or evaluated for fitness. In no case shall an HSS with known defects in FCMs be placed into service without repair or an evaluation indicating satisfactory performance for its intended purpose. In many cases, welds with moderate profile defects and volumetric defects such as porosity may be fit for service. Guidance on performing evaluations can be found in British Standard 7910:2005 (BSI 2005) and in EM 1110-2-6054.

(3) **Special Inspections.** A Special inspection may be required to assess structural damage resulting from natural causes, accidents, or normal wear. It may follow a specific damaging event, or be a more detailed inspection following identification of distress during a periodic inspection. The scope of inspection must be sufficient to determine whether to continue operation of the HSS, the need for emergency repairs to

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ensure safety, and to assess the level of effort necessary for temporary or permanent repairs. The amount of effort expended on this type of inspection will vary significantly depending upon the extent of the damage and urgency of continued operation. If major damage has occurred, inspectors must evaluate fractured members and section loss and make measurements for misalignment of members. It may be necessary to make on-site analyses and decisions to establish emergency operation procedures. A refined analysis may be necessary to establish or adjust interim operational procedures. NDT may be required where fatigue or other damage is suspected. When documenting Special inspections, the Engineer should be aware of any potential for litigation.

(4) Following the initial in-depth inspection, all FCMs should be subjected to a thorough visual inspection every 5 years. When dewatering is required to perform these subsequent inspections, the Engineer shall decide whether such inspections are required. This decision will be based on an evaluation of the previous condition of the FCM, the number and magnitude of load cycles since the last inspection, consequences of potential failure, and the difficulty and cost associated with dewatering. Each HSS must be thoroughly dewatered (if necessary) and inspected at least every 25 years. More frequent HSS inspections may be required based upon paint system, life expectancy, operational problems (vibration, noise, deflections, damage, etc.), and past performance of similar structures. When several of the same type of HSS exist at a project, at least one of each type of HSS must be inspected as part of each periodic inspection. A different HSS should be selected for each inspection. This selection should be based on the time since the HSS was last inspected, and which HSS has experienced more loading cycles or more severe operating conditions. If the HSS cannot be dewatered for this inspection, the portion above water should be inspected.

(5) If practicable without compromising safety, HSS inspections should be scheduled when the project is already being dewatered for another purpose and activities requiring dewatering should be scheduled to minimize dewaterings. When a HSS cannot be dewatered for a normally scheduled inspection, it should be inspected whenever it is dewatered prior or subsequent to the scheduled inspection. This may occur when Operations Division schedules painting or repairs. The Engineer must coordinate with Operations Division to arrange for such inspections.

f. Inspection Evaluation. Whenever distress of a HSS is noted during inspection or at any other time, the Engineer shall thoroughly evaluate the adequacy of the structure to ensure safety and reliable project function. ER 1110-2-101 defines procedures to be followed when reporting evidence of distress. When a problem is discovered during an inspection, the Engineer shall determine the need to inspect similar project HSS and shall determine the scope of the inspection.

g. Inspection Report. For each HSS inspection, other than operations inspections, a report shall be prepared. The report should identify the structure, inspection date, results of inspection and evaluation, and recommendations. Recommendations should include a description of the problem, budgetary cost to address, potential consequence if not addressed and/or relative priority. Reports should also describe all modifications

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and repairs, including weld inspection results that have been made on the structure since the last engineering inspection. All NDT reports, photographs, and radiographs should be included in the inspection report, so that they may be compared with subsequent NDT reports. The report shall include a certification, by the Engineer, that the inspection and evaluation was adequately performed by a qualified engineer. Copies of completed reports shall be provided to the District's Dam Safety Officer, Dam Safety Program Manager, and the Operations Manager for the project that the HSS is associated with. A summary of findings and deficiencies shall be prepared and included in the next project Periodic Inspection Report. All inspection reports, records, and photographs will be maintained throughout the life of the HSS.

FOR THE COMMANDER:



STEPHEN L. HILL

Colonel, Corps of Engineers
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