Design of Hydraulic Steel Structures

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Chapter 1 Introduction

1-1. Purpose

This course prescribes guidance for (a) designing hydraulic steel structures (HSS) by load and resistance factor design (LRFD) and (b) fracture control. Allowable stress design (ASD) guidance is provided as an alternative design procedure or for those structure types where LRFD criteria have yet to be developed.

1-2. Background

a. **Types of HSS.** Typical HSS are lock 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, local flood protection gates, and outlet works gates. HSS may be subject to submergence, wave action, hydraulic hammer, cavitation, impact, corrosion, and severe climatic conditions.

b. **Types of steels.** Structural grade steels used for design of HSS are as referred to in CW-05502 and American Institute of Steel Construction (AISC) (1986, 1989). High-strength structural steels may be considered where economy, simplicity of detail, or greater safety of design may result from their use. Instability, local buckling, and deflection of members shall be checked regardless of the type of steel used to fabricate the structure. However, these design limit states will generally be more critical for structures fabricated from high-strength steel.

c. **Design policy.** Previously, in accordance with EM 1110-1-2101, ASD criteria were specified for design of all HSS. LRFD is now the preferred method of design and should be used for those structure types for which LRFD guidance is provided (see Appendixes B through I). For HSS where LRFD has been developed, ASD may be used as an alternative design method only with prior approval of CECW-ED. Chapter 4 includes ASD criteria which are required for those HSS where LRFD has not yet been developed. For design of a structure, LRFD and ASD methods shall not be combined; however, use of LRFD and ASD methods for the design of separate structures on large construction projects is allowed.

d. **Structures other than HSS.** Designs for aluminum, timber, and masonry structures, service bridges and highway structures, building construction, cold-formed steel construction, railroad bridges and other railroad structures, and open-web steel joist construction shall conform to the respective industry standards and are not included in this course.

1-3. Supplemental Guidance

Historically, the ASD method has yielded safe and reliable structures; however, the method does not recognize differing variability of different load effects (live load, dead load) and resistances (i.e. bending capacity, shear capacity, fracture, etc.). For this reason, LRFD is the preferred method of design. In the ASD method, an elastic analysis is performed for the structure of interest and the computed stress is compared with an allowable stress. The allowable stress is the yield stress, buckling stress, etc., divided by a single factor of safety (FS). In order to obtain structures with a more uniform reliability and to achieve economy, a limit states design (LSD) approach such as LRFD has been adopted by most specification writing committees. The Load and Resistance Factor Design (LRFD) approach (an LSD approach) recognizes that the loads applied to a structure and resistances of structural members are random quantities. The LRFD method has two main advantages over the ASD method. First, in a limit state analysis, one does not have to assume linearity between load and force, or force and stress. Second, multiple load factors can be used to reflect the degree of uncertainty for different loads (dead, live), while application of multiple resistance factors reflects differing uncertainties in a particular resistance (bending capacity, shear capacity, etc.). Due to these advantages of LRFD, more uniform reliability is attained in the design process and in many cases a more economical structure results.

Chapter 2 General Considerations

2-1. Limit States

All possible modes of failure should be considered when designing HSS. Possible failure modes are: general yielding or excessive plastic deformation, buckling or general instability, subcritical crack growth leading to loss of cross section or unstable crack growth, and unstable crack extension leading to failure of a member. The first two failure modes (general yielding and buckling) are addressed by LRFD and ASD principles while the third failure mode (fatigue) and the fourth (brittle fracture) can be addressed using fatigue and fracture mechanics principles.

2-2. Corrosion

a. **Introduction.** Painting is the primary method of preventing corrosion. It may be supplemented with cathodic protection in severe environments or when other design considerations so dictate. Design considerations for reducing corrosion problems include: (1) In certain cases, very severe environments may warrant an additional thickness added to critical structural members. (2) In general, welded connections are more resistant to corrosion than bolted connections. (3) Intermittent welds are more susceptible to corrosion than are continuous welds. CW-09940, CW-16643, and EM 1110-2-3400 provide guidance for preventing corrosion.

b. **Requirements.** The structural engineer shall consider corrosion effects throughout the design process. Items to consider when designing the HSS include: (1) Detail the members as much as possible so there is access for a sandblasting hose (2-ft minimum bend). (2) Make provisions for sand to escape where member connections form open-ended chambers. (3) Try to avoid lap joints but where used, seal weld the joint. (4) Grind slag, weld splatter, or any other deposits off the steel. (5) Where dissimilar metals are used select the proper material as recommended by Kumar and Odeh (1989), avoid large cathode-to-anode area ratios, use isolators, and paint both surfaces.

2-3. Dynamic Loading

HSS are often subjected to unpredictable dynamic loading due to hydraulic flow. Where dynamic loading is known to exist, but the loading function is not defined, ASD requires an effective increase in the design factor of safety. This increase is to account for unknown dynamic effects. For the LRFD method such loads are accounted for by assigning a higher load factor. The designer should provide proper detailing and structural layout to minimize dynamic loading and cavitation. For example, proper arrangement of seal details minimizes vibration.

2-4. Inspection and Maintenance

HSS are often difficult to inspect and maintain due to poor access, particularly at submerged locations. Inspections should be performed in close contact with the inspected part; however, this is not always possible since HSS include submerged components which require dewatering for inspection. Where structures are difficult to inspect and maintain, guidance is provided in paragraph 3-4 for LRFD and paragraph 4-4 for ASD.

2-5. Deviations from Prescribed Design

Where special conditions exist, proposed modifications to the load and resistance factors or allowable stresses specified herein shall be submitted to CECW-ED for approval prior to completing feasibility phase work.

2-6. Supplemental Guidance

a. **Introduction.** (1) Paint systems specified in CW-09940 and EM 1110-2-3400 provide a high degree of protection. For underwater HSS requiring a higher degree of protection, cathodic protection (impressed current or galvanic systems) may be used to supplement the paint system. Impressed current systems for lock gates are often damaged and become inoperative if not carefully maintained; galvanic systems require less maintenance. However, both systems require regular maintenance. If cathodic protection is included as part of the corrosion protection system, it is imperative that a long-term maintenance plan be developed, particularly for impressed current systems. (2) General corrosion occurs uniformly over a large metallic surface. Specifying a uniform increase in design thickness is one means to protect a structure from this type of corrosion damage. However, the total structural cost is increased and the increase in member resistance to tension, compression, and bending effects is not uniform. The primary concern with corrosion damage in HSS is the occurrence of concentration cell corrosion, pitting corrosion, or galvanic corrosion. (3) Concentration cell corrosion occurs at small local areas on metal surfaces which are in contact with water. Concentration cells can result from any number of differences in the environment, but the two most common are metal ion cells and oxygen cells. Either localized corrosion cell causes large tubercles of corrosion products to grow above the surface, generating a weak area in the steel member. Keeping the structure well painted and clean from mud deposits prevents this type of corrosion. (4) Pitting corrosion is a form of extremely localized attack which results in small-diameter holes (in relation to their depth) to appear in the metal. This may be initiated by a material defect in the steel or a chip in the protective coating. Pitting corrosion is highly unpredictable since there is no means to identify where defects may occur. Regular inspection and maintenance practices can reduce the possibility of pitting corrosion. (5) Galvanic corrosion is generally a result of current generated when two dissimilar metals are in contact and the two metals are in water.

a. **Requirements.** (1) Kumar and Odeh (1989) recommend HSS be dry-blast cleaned to a grade approaching white metal grade for surface preparation prior to painting. Therefore, designers should detail the structure to allow sufficient room for the hose. Extra large drain holes located in areas where the sand may be trapped may be appropriate. (2) Most HSS consist of welded construction. Using welded connections in lieu of bolted connections is advantageous when considering concentration cell corrosion. Areas on a surface in contact with an electrolyte having a high oxygen content are cathodic relative to those areas where less oxygen is present. Localized areas where small volumes of stagnant solution may exist include sharp corners, spot welds, lap joints, and fasteners. Using butt welds instead of bolts; seal-welding lap joints; using continuous welds; and grinding weld splatter, slag, or any other deposits off the steel help to prevent concentration cell corrosion. (3) Where dissimilar metals are used (generally carbon steel and stainless steel), the relative areas of each metal exposed are very important because the total amount of current that flows in the cell is dependent on the total area of both metals exposed. If the anode (carbon steel) is large with respect to the cathode (stainless steel), the current is distributed over a large area and the effect at each point will be slight. Conversely, if the cathode-to-anode ratio is large, the current becomes concentrated and severe corrosion can occur. If the carbon steel is painted and there is a small defect in the coating or it becomes damaged, then the relative areas have a large cathode-to-anode area and rapid corrosion can occur. Therefore, it is best to paint both surfaces. If the stainless steel coating has defects or damage, the current will not significantly increase even if the carbon steel has metal exposed. If the distance between the cathode and anode is large, resistance in the circuit will be sufficient to eliminate the galvanic corrosion problem.

2-7. Explanatory Notes

a. Dynamic loading that may occur in HSS is unpredictable in the sense that the dynamic forcing function is unknown. Unpredictable vibrations may be caused by imperfections in the operating machinery and guide slots, hydraulic flow, and load fluctuation due to passing ice. If the forcing function is known, a dynamic analysis can be used for design. At present, it is not feasible to define the load due to the many factors that affect such loadings and therefore special attention must be given to structure details. For example, supporting members of seals should maintain adequate stiffness to limit flexing which results in leakage and flow-induced vibration. The supporting members and arrangement of the bottom seal on a tainter gate can significantly affect its vibration due to flow conditions. Some of the structure types that have experienced vibration due to dynamic loading include tainter valves, vertical lift control gates, tainter gates, and miter gates.

b. Cavitation is also a concern where dynamic hydraulic loading occurs. Cavitation damage is a result of unpredictable dynamic fluid action which causes extreme local negative pressures resulting in pitting and erosion of the surface. As for vibration, proper structure details and good construction practices prevent cavitation from occurring.