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**MECHANICAL PROPERTIES AND CORROSION  
BEHAVIOR OF STAINLESS STEELS FOR  
LOCKS, DAMS, AND HYDROELECTRIC  
PLANT APPLICATIONS**

by

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**COVER PHOTOS:**

TOP - Mooring bitt at Belleville Lock and Dam.

BOTTOM - Ceramic anodes at Pike Island Lock and Dam.

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mechanical property data, briefly discusses corrosion behavior, and provides general guidelines regarding the use of stainless steels for locks, dams, and hydroelectric plant applications. Carefully selected and properly specified stainless steels are viable options for construction and can result in reduced maintenance costs. Two case studies for rollers and seals for tractor type dam gates are presented to demonstrate the advantages of using stainless steels for Civil Works projects. (SDW)

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## PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as a part of the Electrical and Mechanical Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32338, "Corrosion Resistant Materials for Civil Works Structures" for which Dr. Ashok Kumar is the Principal Investigator. R. Pletka is the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. is the REMR coordinator at the Directorate of Research and Development, HQUSACE; Mr. James E. Crews and Dr. Tony C. Liu serve as the REMR Overview Committee; Mr. William F. McCleese (CECW-OM), US Army Waterways Experiment Station (WES), is the REMR Program Manager. Dr. Ashok Kumar is the Problem Area Leader for the Electrical and Mechanical Problem Area.

This work was conducted by the US Army Construction Engineering Research Laboratory (USACERL) and Mr. James R. Myers, JRM Associates, Franklin, OH, under the general supervision of Dr. R. Quattrone, Chief of the Engineering and Materials Division (EM). The Technical Editor was Gloria J. Wienke, Information Management Office.

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## CONTENTS

|                                                 | <u>Page</u> |
|-------------------------------------------------|-------------|
| PREFACE.....                                    | 1           |
| PART I: INTRODUCTION.....                       | 3           |
| Background                                      |             |
| Objective                                       |             |
| Approach                                        |             |
| PART II: COMPOSITION AND PROPERTIES.....        | 6           |
| PART III: CORROSION AND GALLING.....            | 7           |
| The Problem of Corrosion                        |             |
| General Corrosion Behavior, Pitting Attack, and |             |
| Concentration Cell Corrosion                    |             |
| Galvanic Corrosion                              |             |
| Cavitation                                      |             |
| PART IV: CASE STUDIES.....                      | 12          |
| Oahe Dam, Missouri River                        |             |
| Dam Gate Seal Materials                         |             |
| PART V: MATERIAL SELECTION.....                 | 16          |
| PART VI: CONCLUSIONS.....                       | 46          |
| TABLES 1-8.....                                 | 47          |
| REFERENCES.....                                 | 57          |

MECHANICAL PROPERTIES AND CORROSION BEHAVIOR OF STAINLESS STEELS  
FOR LOCKS, DAMS, AND HYDROELECTRIC PLANT APPLICATIONS

PART I: INTRODUCTION

Background

1. Carbon steels and low-alloy steels have been the primary source for materials used to construct locks, dams, and hydroelectric plants. To a much lesser extent, components for these facilities traditionally have been fabricated from 400-series martensitic stainless steels (e.g., Types 410 and 416) and 300-series austenitic stainless steels (e.g., Types 302, 303, 304, 308, and 316). Although the 300-series stainless steels normally have excellent corrosion resistance in most freshwater environments (Table 1, Kamp and Schmitt 1966) their yield strengths (about 35,000 psi in the annealed condition) are somewhat low for many applications. Further, at a number of locks and dams, bolts and nuts fabricated from the same 300-series material have exhibited serious galling problems in the threaded area. The 300-series stainless steels (including Type 316, which is formulated with a small amount of molybdenum added to resist pitting attack) also have a tendency to pit in waters containing more than about 1000 parts per million (ppm) chloride. They are also susceptible to oxygen differential, concentration-cell corrosion under deposits and in crevices. Fortunately, the austenitic grades of stainless steel do not experience chloride-induced, stress-corrosion cracking at temperatures less than about 150° F (Pecknar and Bernstein 1977). They also exhibit excellent resistance to freshwater erosion corrosion.

2. The yield strength limitations of the 300-series stainless steels for Civil Works projects were originally overcome by using heat-treatable, 400-series stainless steels. Unfortunately, these alloys often do not exhibit the desired corrosion resistance. This is understandable because the metallurgy required to create a martensitic stainless steel allows only limited amounts of chromium (generally, an upper limit of about 14 percent) to be added to these alloys. The martensitic grades of stainless steel have a tendency to pit (Table 1), galvanically corrode, crack due to stress corrosion, and suffer concentration-cell corrosion in many fresh waters. In some cases (Fontana and Greene 1967), heat treated, 400-series stainless

steels have failed due to hydrogen-induced cracking because the components were only slightly overprotected by the cathodic protection systems designed to mitigate corrosion.

3. Traditional stainless steels have certain mechanical property and corrosion behavior limitations for lock, dam, and hydroelectric plant applications. However, carefully selected and properly specified stainless steels, especially some of the newer alloys, can be viably and cost-effectively used. These steels can reduce maintenance costs and improve the availability of equipment and facilities without significant concern for the various forms of deterioration that have been associated with them (e.g., crevice corrosion, intergranular attack, stress-corrosion cracking, hydrogen embrittlement, pitting, wear and galling, and galvanic corrosion).

#### Objective

4. The objective of this work is to present typical mechanical property data, briefly discuss corrosion behavior, and provide general guidelines regarding the use of stainless steels for locks, dams, and hydroelectric plant applications. The unique properties of stainless steels are shown in this report.

#### Approach

5. Researchers selected 14 stainless steels that may reduce maintenance costs and are becoming more available for Civil Works applications. These are: the wrought austenitic alloys NITRONIC 60\* and Types 302, 303, 304, 308, and 316; the wrought martensitic alloys Types 410, 416, and 431; the wrought martensitic PH (precipitation-hardening) alloys 17-4PH and Custom 450\*; the wrought semiaustenitic PH alloy 17-7PH; the cast martensitic alloy CA-6NM; and the cast austenitic-ferritic alloy CF-8.

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\*Nitronic 60 is a brand name of Carpenter Technology, Carpenter Steel Division, Reading, Pennsylvania, 19612.

\*Custom 450 is a brand name of Carpenter Technology, Carpenter Steel Division, Reading, Pennsylvania, 19612.

6. Researchers discussed these stainless steels with U.S. Army Corps of Engineers personnel and obtained additional information from various guide specifications and as-built drawings.

## PART II: COMPOSITION AND PROPERTIES

7. Nominal chemical compositions for the selected stainless steel alloys and their typical mechanical properties are included in Tables 2 and 3, respectively. Austenitic grades of stainless steel cannot be strengthened by heat treatment; they can only be strengthened by cold working. Martensitic and the PH grades of stainless steel can be heat treated to microstructural conditions that provide a wide range of available mechanical properties.

8. Generally, the austenitic grades of stainless steel (e.g., NITRONIC 60 and the 300-series) have better overall corrosion resistance than the other alloys identified in Tables 2 and 3. Typical corrosion resistance, however, depends on heat treatment. For example, the corrosion resistance of 17-7PH stainless steel in both Conditions TH1050 and RH950 is superior to that of the heat-treatable, martensitic alloys. In Condition CH900, the general corrosion resistance of 17-7PH is comparable to that of Types 302 and 304 (Armco, Inc. 1984b). The corrosion resistance of Condition A 17-4PH stainless steel and the alloy when heat treated to its lower (albeit, still relatively high) strength levels is also comparable to Type 304 in more aqueous environments (Armco, Inc. 1983). Similarly, the normal corrosion resistance of Custom 450 is superior to that of heat treated Type 410 and similar to that of Type 304 (Carpenter Technology 1971). NITRONIC 60 is unique in that it has better corrosion resistance to chloride-induced pitting attack than Type 316 (i.e., an alloy specially formulated for pitting resistance to chlorides) and an outstanding resistance to abrasion by suspended solids and to galling, and cavitation when exposed to aqueous environments (Armco, Inc. 1984a).

### PART III: CORROSION AND GALLING

#### The Problem of Corrosion

9. Selecting a material with inadequate corrosion resistance for a particular application can be an expensive mistake. Direct and indirect economic losses that can result from corrosion include:

- a. Failure of equipment and associated damages (e.g., a tainter gate falls because hoisting cable bolts break.)
- b. Replacement of equipment.
- c. Overdesign to allow for corrosion.
- d. Shutdown of equipment.
- e. Loss of a product (e.g., if a hydraulic piping system develops a corrosion-induced leak).
- f. Contamination of a product.
- g. Loss of efficiency (e.g., corrosion products lower heat transfer rates in cooling systems).

10. Some of these indirect losses can cost much more than the difference between a material that would have performed satisfactorily and one that would not. Therefore, it is important to consider potential indirect losses due to corrosion when selecting material.

11. Corrosion can also constitute a significant safety hazard if stress-corrosion cracking occurs in critical parts of transportation media.

12. In addition to these economic and safety aspects, corrosion is also important from the point of view of conserving the earth's supply of materials. The supply of many of the metals and materials used to make conventional steel and low alloy steels is diminishing and these products are being imported into the United States at ever increasing prices.

#### General Corrosion Behavior, Pitting Attack, and Concentration-Cell Corrosion

13. The excellent corrosion resistance of stainless steels depends on the formation and maintenance of an invisible, passive oxide film on the

exposed surfaces. This allows the stainless steels to exhibit potentials that are more noble (electrically positive) than they would have in the active (corroding) condition. In the passive condition, stainless steels have electrochemical characteristics similar to those of a noble metal such as gold. If this passive film is locally destroyed and cannot be readily repaired, pitting attack can be expected to occur in certain environments (especially, chloride-containing, aqueous environments). Similar localized corrosion in the form of oxygen-differential, concentration-cell corrosion can occur in crevices and under deposits (i.e., in occluded cells) where there is insufficient oxygen to maintain the passive film. The absence of oxygen in occluded cells causes the stainless steel to become electrochemically active (i.e., become anodic) and exhibit a negative potential relative to that area where the passive film is still intact. This form of corrosion can be especially deleterious because it is usually facilitated by a large driving voltage between the passive and active regions and an undesirably large cathode-to-anode area ratio.

14. Significant insight into corrosion behavior can be obtained by analyzing data obtained from anodic polarization tests conducted in a laboratory. In general, stainless steels have very negative primary passivation potentials ( $E_p$ ) and small critical current densities for passivation ( $i_c$ ); normally, they passivate quite readily in aerated aqueous environments. Once passivated, the alloys will normally corrode at very low rates in accordance with Faraday's Law and their passive current densities ( $i_p$ ). If the oxidizing characteristics of the environment are overly powerful, alloys can be spontaneously polarized to potentials sufficiently noble that the alloy will be subjected to accelerated corrosion and pitting attack in the transpassive potential region (i.e., corrode at the high current densities associated with the potentials more noble than the transpassive potential [ $E_{tp}$ ]). The desirable anodic polarization characteristics for stainless steels are: low values of  $i_c$ , very negative values for  $E_p$ , low values of  $i_p$ , very positive values for  $E_{tp}$ , and large potential differences between  $E_p$  and  $E_{tp}$ .

15. Values of  $E_p$ ,  $i_c$ ,  $i_p$ , and  $E_{tp}$  for selected stainless steels in deaerated, 1N sulfuric acid are included in Table 4 (Segan et al. 1982). Adding chlorides to the test environment reduces the passive potential regions

(i.e., the values of  $E_{tp} - E_p$ ) and increases the magnitudes of  $i_c$  and  $i_p$  (Segan et al. 1982). Similar adverse phenomena occur, in general, when the temperature of the environment is increased and/or the pH is lowered. The deleterious effects of high operating temperatures, acidic environments, and the presence of chlorides on stainless steels have been verified and explained through laboratory testing. Additional laboratory testing has also shown that all of the stainless steels listed in Table 4 spontaneously passivate in aerated Columbia River water and corrode in the passive potential region at very low uniform corrosion rates (i.e., corrosion rates associated with  $i_p$  values of  $2.8$  to  $8.2 \times 10^{-7}$  ampere/cm<sup>2</sup>, Segan et al. 1982).

### Galvanic Corrosion

16. The initial driving voltage for corrosion of adjacent dissimilar metals can be estimated when a galvanic series exists for the environment of concern. In general, larger driving voltages increase the initial rate of attack to the less noble alloy when dissimilar metals are metallurgically connected and exposed to a corrosive environment. For example, the galvanic series in Table 5 (Segan et al. 1982) shows that NITRONIC 60 has a potential of  $-0.327$  volt referenced to a saturated calomel electrode (SCE), whereas ASTM A36 steel has a potential of  $-0.574$  volt. If the two alloys were metallurgically connected and exposed to this environment, NITRONIC 60 (i.e., the alloy with the more positive potential) would be cathodic to the ASTM A36 steel which would be the anode in the corrosion cell. The ASTM A36 steel would experience accelerated galvanic corrosion at an initial driving voltage of  $0.247$  volt (the potential difference between the two materials). The NITRONIC 60 would, at least in part, be cathodically protected.

17. The data in Table 5 provides insight regarding the mitigation of galvanic corrosion. Materials should be selected so that those which will be metallurgically connected will have similar potentials in the environment where they will be exposed. Alternatively, the materials can sometimes be electrically isolated from each other. Galvanic corrosion problems can also be reduced by ensuring that the cathodic area is smaller than the anodic area. Large cathode-to-anode area ratios must be avoided if galvanic corrosion is to be avoided. Coatings used in conjunction with cathodic protection have also been effective in mitigating galvanic corrosion.

18. The initial driving voltage for galvanic corrosion will normally decrease with time because of polarization at the anodes and cathodes. This decrease in the driving voltage, in turn, reduces the galvanic corrosion current density at the anodes and lowers their corrosion rates. Table 6 (Segan et al. 1982) lists the galvanic corrosion current densities obtained for equal anodic and cathodic areas of ASTM A36 steel connected to selected grades of stainless steel. Based on these data, galvanic corrosion of ASTM A36 steel is not significantly affected by the chemistry or metallurgical condition of the stainless steel involved. The corrosion current densities for the ASTM A36 steel vary between  $1.4$  and  $2.5 \times 10^{-5}$  ampere/cm<sup>2</sup>.

### Cavitation

19. Tests conducted in accordance with ASTM G32 have allowed stainless steels and a low-alloy carbon steel to be ranked according to their cavitation resistance (Table 7, Segan et al. 1982). Not unexpectedly, NITRONIC 60 had the best cavitation resistance of the materials evaluated. Similar cavitation resistance results have been obtained for stainless steels exposed to jet-impingement by river water. The relative cavitation depth damages for NITRONIC 60, 17-4PH, Type 316, and CA-6NM were reported as being 1.0, 1.9, 3.7, and 6.6, respectively (Schumacher 1986). These data clearly indicate that cast NITRONIC 60 could be a viable alternative for CA-6NM where cavitation is a concern.

### Galling

20. When two metal surfaces are rubbed together under heavy pressure, and without lubrication, it is expected that galling (or even seizing) may result.

21. The "button and block" galling test has been used to evaluate the adhesive wear resistance of various stainless steels under nonlubricated conditions (Schumacher 1977). Specimens were considered galled if deep scoring and heavy surface damage were evident during examination of the surfaces at 10X magnification. The lightest load that caused galling was used to calculate the "threshold galling stress." Threshold galling stresses for

selected stainless steel combinations are included in Table 8 (Schumacher 1977).

22. The data in Table 8 establish that many contacting stainless steel combinations are highly susceptible to galling. Most important, the data show that NITRONIC 60 can be used in contact with many stainless steels without concern for galling. Galling problems associated with the use of Type 304 nuts and bolts could very well be eliminated by fabricating one of the components from NITRONIC 60.

#### PART IV: CASE STUDIES

23. These case studies present two successful examples which indicate that properly selected, corrosion-resistant stainless steels are viable options for roller assemblies on tractor-type dam gates (such as intake gates) and for dam gate seal materials.

##### Oahe Dam, Missouri River

24. The first case study demonstrates the successful use of high strength corrosion-resistant "aerospace" stainless steels for tractor-type dam gate components (Komp and Schmitt 1966).

25. Until about 20 years ago, the rollers for tractor-type dam gates (sometimes referred to as intake gates) were conventionally fabricated from Type 410 stainless steel that had been heat treated to the strength level provided by a hardness of 259 to 307 Brinell. The heavier-than-usual hydrostatic loads (over 4,000,000 lb) on the tractor-type gates for Oahe Dam on the Missouri River necessitated the use of either larger Type 410 stainless steel rollers or rollers of increased strength and hardness. During engineering design, it was quickly established that rollers fabricated from Type 410 would be too large, and the desired size rollers could not be fabricated from any martensitic 400-series stainless steel without some undesirable loss in corrosion resistance. Further, there had been some incidents of cracking in rollers fabricated from Type 410. After serious consideration and evaluation of many candidate materials by the design engineers, they selected corrosion-resistant, martensitic, 17-4PH stainless steel for the rollers at Oahe Dam.

26. The rollers were cost-effectively machined from centerless ground bars of solution-heat-treated 17-4PH. Subsequently, the rollers were given a simple, low-temperature, PH heat treatment that developed a hardness of 385 to 418 Brinell (a hardness considerably higher than the specified minimum of 365). Equally significant, there was no need to final machine the rollers. The 17-4PH has excellent resistance to both oxidation/scaling and distortion during the PH heat treatment.

27. Another advantage obtained by selecting 17-4PH for the roller material was that the width of the individual rollers could be reduced more than 25 percent, permitting the use of a narrower track. This overall decrease in roller size allowed a more corrosion-resistant, higher strength stainless steel (compared to Type 410) to be used without an increase in cost.

28. The 17-4PH rollers and their associated Type 304 stainless steel links and pins and 15-7PH Mo stainless steel retaining rings have been in service, both totally immersed and alternately immersed in the Missouri River since their original installation (1962), without corrosion problems. Similar experience has been reported for the roller assemblies on the tractor-type gates at Gavins Point Dam on the Missouri River.

29. Some districts are considering using round link chain and pocket wheels for tainter gate hoists. These may fulfill the required design and cost criteria better than roller chain. If suitability is proven, round link chain will be used exclusively on dams on the Mississippi River during major rehabilitation, in the interest of standardization of gate operating machinery.

#### Dam Gate Seal Materials

30. The second case study involved an indepth study of the Corps of Engineers' experience with gate seals for 40 dams on the Monongahela, Ohio, Mississippi, Columbia, and Illinois Rivers. Information from this study is significant because it can be useful in selecting the best materials and design options for dam gate seals.

31. Engineer Manual (EM) 1110-2-2702 (Department of the Army, Office of the Chief of Engineers 1966) states that the side seals on tainter gates should be rubber, the side-seal rubbing plates (i.e., the pier seals) should be of a corrosion-resisting steel to ensure permanently smooth surfaces, and the rubber seals should be attached to the gates so as to allow for field adjustment. The same manual also provides guidelines for the bottom seals on these structures. If a small amount of leakage under a closed gate can be tolerated, direct contact between the finished bottom edge of the skinplate and a corrosion-resistant surface on the sill is considered adequate.

However, if a tighter seal is required, it may be necessary to use a rubber seal attached to the skinplate.

32. Examination of the gate seals for the dams included in the study revealed that the guidelines of EM 1110-2-2702 have, in general, been followed with reasonably good performance. The only exception is at Emsworth Dam on the Ohio River where wood was used for seals on the vertical lift gates between 1934 and 1936. They were replaced with rectangular neoprene seals during the major rehabilitation of the dam between 1981 and 1986. Reportedly, personnel at Emsworth Dam do not like rubber seals on the gates because they tend to "bind" and subsequently overload the gate motors. The rubber seals were found to bind in the vertical travel, primarily because the seals are set for the "gate closed" gauge, which over the years has widened due to wear and corrosion, while the gauge of the pier track above the gate closed position is narrower. Rubber seals exhibit a great deal of friction, especially in the dry condition, under even nominal pressure. The problem has been addressed and the solution consists in realigning the lower portion of the pier gate wheels and seal gauge, and providing a relief for the rubber seals above the gate closed elevation. This opinion, however, is not completely shared by personnel at the other dams contacted. For example, nylon-reinforced seals have been used on roller gates for as long as 46 years without the need for replacement (at Dam No. 4 on the Mississippi River). Only about 100 ft of rubber or neoprene J-seals have been replaced on the 15 tainter gates at Dam No. 24 on the Mississippi River during the past 25 years.

33. An unavoidable problem associated with the use of rubber or neoprene seals on the gates is mechanical damage from river debris and ice that collects between the rubber and the seal plates in the piers and spillways. This can be a very serious problem if rubber or neoprene seals are used on the bottom of tainter gates.

34. Based on an analysis of the information collected during this investigation, the most viable materials and design options for the side and bottom seals on tainter dam gates are listed below.

a. Dam Gate Side Seals

(1) Natural rubber or neoprene J-seals for the gates, preferably with fluorocarbon inserts in the seals for the rubbing or contact areas.

(2) Type 304 stainless steel plates for the contacting seal surfaces in the piers.

(3) Type 304 stainless steel bolts and washers with NITRONIC 60 nuts for attachment of the J-seals (to minimize galling or wear and to facilitate removal and loosening of the bolts for field adjustment of the seals).

b. Dam Gate Bottom Seals

(1) Type 304 stainless steel plates attached to the skinplates on the gates.

(2) Type 304 stainless steel plates for the spillway and sills for those gates where water leakage can be tolerated.

(3) Rubber or neoprene wedge seals may be required where leakage cannot be tolerated. See paragraph 33.

## PART V: MATERIALS SELECTION

35. The materials applications presented in this report were, in general, obtained from discussions with the U.S. Army Corps of Engineers personnel. Information was also obtained from various guide specifications and as-built drawings.

36. When comparing materials presented in this report for a given application with those in existing drawings and guide specifications, it should be understood that changes have occurred in the ASTM and Federal Specifications since the drawings and specifications were formulated. The known changes (as of July 1985) include:

|           |                                  |
|-----------|----------------------------------|
| ASTM A7   | Replaced by ASTM A36             |
| ASTM A19  | Discontinued                     |
| ASTM A59  | Replaced by ASTM A689            |
| ASTM A68  | Replaced by ASTM A668            |
| ASTM A129 | Discontinued                     |
| ASTM A232 | Discontinued                     |
| ASTM A235 | Replaced by ASTM A668            |
| ASTM A236 | Discontinued                     |
| ASTM A237 | Replaced by ASTM A668            |
| ASTM A273 | Replaced by ASTM A711            |
| ASTM A296 | Combined with ASTM A743 and A744 |
| ASTM A298 | Discontinued                     |
| ASTM A373 | Replaced by ASTM A36             |
| ASTM B143 | Replaced by ASTM B584            |
| ASTM B144 | Replaced by ASTM B584            |
| ASTM B146 | Replaced by ASTM B584            |
| QQ-C-806  | Replaced by WW-P-405             |
| QQ-S-561  | Replaced by QQ-B-154             |
| SS-P-351  | Cancelled                        |
| WW-P-406  | Cancelled                        |
| WW-P-491  | Cancelled                        |

WW-V-051

Cancelled

WW-V-054

Cancelled

37. The following is a list of suggested materials for components used in Civil Works projects, The materials marked by a bullet (●) are the most recent and preferred options.

## Bulkhead & Tainter Gate Components

|                                                 |                                                                                          |
|-------------------------------------------------|------------------------------------------------------------------------------------------|
| Skin Plate                                      | ASTM A36 Steel<br>ASTM A441 Steel<br>ASTM A514 Steel                                     |
| Diagonals                                       | ASTM A36 Steel<br>ASTM A441 Steel<br>ASTM A514 Steel                                     |
| Horizontal Girders                              | ASTM A36 Steel<br>ASTM A441 Steel                                                        |
| Trunnion Pins                                   | ASTM A668, Class E Steel Forgings                                                        |
| Trunnion Bushings                               | ASTM B148 Aluminum Bronze No. C95400                                                     |
| Trunnion Housings                               | ASTM A27, Grade 65-35 Cast Steel                                                         |
| J-Seals                                         | Natural Rubber*<br>Neoprene*                                                             |
| Bolts for J-Seals                               | • Type 304 Stainless Steel                                                               |
| Nuts for J-Seals                                | • Armco NITRONIC 60 Stainless Steel                                                      |
| Trunnion Girders                                | ASTM A36 Steel<br>ASTM A441 Steel<br>Steel-Reinforced Concrete                           |
| Trunnion Yokes                                  | ASTM A27, Grade 65-35 Cast Steel                                                         |
| st Tension Rods for<br>Concrete Trunion Girders | ASTM A94 Steel                                                                           |
| Bottom/Embedded Seals                           | • Type 304 Stainless Steel<br>Lead<br>Babbitt                                            |
| Ropes                                           | • Type 308 Stainless Steel                                                               |
| Rope to Gate Connections                        | ASTM A27, Grade 65-35 Cast Steel<br>ASTM A36 Steel<br>ASTM A441 Steel<br>ASTM A242 Steel |
| Wear Plates (under wire ropes)                  | ASTM A242 Steel<br>ASTM A441 Steel                                                       |

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\*Preferably with fluorocarbon inserts for rubbing-contact areas.

### Bulkhead & Tainter Gate Components (Continued)

|                           |                                                                                                                                                                     |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rope Sockets              | <ul style="list-style-type: none"><li>● ASTM A276, Type 410 Stainless Steel</li><li>● Type 302 Stainless Steel</li></ul>                                            |
| Keeper Plates for J-Seals | <ul style="list-style-type: none"><li>● ASTM A276, Type 410 Stainless Steel</li></ul>                                                                               |
| J-Seal Heaters            | ASTM A53, Schedule 80 Steel Pipe                                                                                                                                    |
| Trunnion-Hub Pins         | ASTM A668, Class H Steel Forgings<br>ASTM A27, Grade 65-35 Cast Steel                                                                                               |
| Seal Plate on Gate        | <ul style="list-style-type: none"><li>● Type 304 Stainless Steel</li></ul>                                                                                          |
| Gate Arms                 | ASTM A36 Steel<br>ASTM A441 Steel                                                                                                                                   |
| Side Seal/Embedded        | <ul style="list-style-type: none"><li>● Type 304 Stainless Steel</li></ul>                                                                                          |
| Bulkhead                  | ASTM A441 Steel                                                                                                                                                     |
| Bulkhead Dogging Lever    | ASTM A274                                                                                                                                                           |
| Bulkhead Roller           | ASTM A148, Grade 120-85, Steel Casting                                                                                                                              |
| Bulkhead Collar           | ASTM A36 Steel                                                                                                                                                      |
| Bulkhead Bolts            | ASTM A307 Steel                                                                                                                                                     |
| Bulkhead Bushings         | ASTM B148, Alloy No. C95500                                                                                                                                         |
| Bulkhead Axle             | ASTM A291, Class 5                                                                                                                                                  |
| Bulkhead Lifting Bar      | ASTM A148, Grade 150-125 Steel Casting                                                                                                                              |
| Wire Rope Adjusting Bolts | ASTM A564, Grade XM25 Stainless Steel <ul style="list-style-type: none"><li>● Armco 17-4PH Stainless Steel</li><li>● Carpenter Custom 450 Stainless Steel</li></ul> |
| Hoist Bolts               | <ul style="list-style-type: none"><li>● ASTM A276, Type 410 Stainless Steel</li><li>● ASTM A276, Type 416 Stainless Steel</li></ul>                                 |
| Hoist Nuts                | <ul style="list-style-type: none"><li>● Armco Nitronic 60</li></ul>                                                                                                 |
| Flanged-Spiral Segment    | ASTM A36 Steel                                                                                                                                                      |
| Safety Grating            | 6060-T52 Aluminum Alloy Tubing                                                                                                                                      |
| Hoist Frame               | ASTM A36 Steel                                                                                                                                                      |
| Hoist-chain bars          | AISI 3140, class C, ASTM A564 Grade XM-25                                                                                                                           |
| Hoist-chain pins          | AISI 3340, class C, ASTM A564 Grade XM-25                                                                                                                           |

Bulkhead & Tainter Gate Components (Continued)

|                         |                                                                                |
|-------------------------|--------------------------------------------------------------------------------|
| Position Indicator Hand | ASTM A167 Stainless Steel<br>● ASTM A276, Type 304 Stainless Steel             |
| Bolts                   | ● ASTM A276, Type 410 Stainless Steel<br>● ASTM A276, Type 416 Stainless Steel |
| Nuts                    | ● Armco NITRONIC 60 Stainless Steel                                            |
| Shear Pins              | ASTM A434, Class BB                                                            |
| Shims                   | ASTM A36 Steel                                                                 |
| Pinions                 | ASTM A668, Class G Forgings                                                    |
| Pinion/Hoist            | ASTM A291, Class 5                                                             |

## Miter Gate Components

|                            |                                                                                                                                                                                         |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Skin Plate                 | ASTM A36 Steel<br>ASTM A242 Steel<br>ASTM A441 Steel                                                                                                                                    |
| Diagonals                  | ASTM A36 Steel<br>ASTM A514 Steel                                                                                                                                                       |
| Intercostals               | ASTM A36 Steel                                                                                                                                                                          |
| Diaphragms                 | ASTM A36 Steel                                                                                                                                                                          |
| Horizontal Girders         | ASTM A36 Steel                                                                                                                                                                          |
| Gudgeon Pins               | ASTM A668 Steel Forgings                                                                                                                                                                |
| Gudgeon Bushings           | AMPCO 16 Aluminum Bronze                                                                                                                                                                |
| Gudgeon-Pin Hoods          | ASTM A36 Steel                                                                                                                                                                          |
| Gudgeon Rings              | ASTM A36 Steel                                                                                                                                                                          |
| Gudgeon-Pin Barrels        | ASTM A36 Steel                                                                                                                                                                          |
| Link Pins                  | ASTM A688 Steel Forgings                                                                                                                                                                |
| Anchor Bars                | ASTM A36 Steel<br>ASTM A441 Steel                                                                                                                                                       |
| Anchorage Wedge Blocks     | ASTM A688 Steel Forgings                                                                                                                                                                |
| Embedded Anchorages        | ASTM A36 Steel                                                                                                                                                                          |
| Pintle Bushings Sockets    | Cast Steel                                                                                                                                                                              |
| Pintles                    | <ul style="list-style-type: none"><li>● ASTM A473, Type 303 Stainless Steel*</li><li>● ASTM A743 and A/44, CF-8 Stainless Steel</li><li>ASTM A564, Type 630 Stainless Steel**</li></ul> |
| Pintle Socket Grease Lines | <ul style="list-style-type: none"><li>● ASTM A312, Type 304 Stainless Steel Pipe</li><li>● ASTM A269, Type 316 Stainless Steel Tube</li><li>High Pressure Neoprene Hose</li></ul>       |
| Pintle Shoes               | QQ-S-681, Grade 70-36 Cast Steel<br>ASTM A36 Steel                                                                                                                                      |
| Pintle Base                | <ul style="list-style-type: none"><li>● ASTM A27, Grade 60-30 Cast Steel</li></ul>                                                                                                      |

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\*Annealed.

\*\*Brinell Hardness of 390 to 410.

### Miter Gate Components (Continued)

|                                                                                                                                                    |                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Pintle Bushings                                                                                                                                    | ASTM A564, Type 630 Stainless Steel*<br>ASTM B148 Aluminum Bronze, Alloy C95400                           |
| Miter Contact Blocks                                                                                                                               | Carpenter 450 Stainless Steel<br>• Armco 17-4PH Stainless Steel<br>ASTM A36 Steel**                       |
| Filler Between Miter and<br>Quoin Contact Blocks and End<br>Posts of Miter Gate and Between<br>Contact Blocks and Embedded<br>Steel Wall Retainers | Epoxy such as Nordbak<br>Cast Zinc                                                                        |
| Reaction Bar                                                                                                                                       | ASTM A29, Grade 1020 Steel<br>ASTM A29, Grade 1040 Steel                                                  |
| Quoin Contact Blocks                                                                                                                               | ASTM A27, Grade 70-40 Cast Steel<br>• Armco 17-4PH Stainless Steel<br>ASTM A441 Steel<br>ASTM A36 Steel** |
| Quoin Contact Block Retainer                                                                                                                       | ASTM A 36 Steel                                                                                           |
| Miter Contact Block Retainer                                                                                                                       | ASTM A36 Steel                                                                                            |
| Gate Seals/J-Seals                                                                                                                                 | Neoprene <sup>+</sup><br>Natural Rubber <sup>+</sup>                                                      |
| Sill Plates/Nosings                                                                                                                                | ASTM A36 Steel<br>• Type 304 Stainless Steel                                                              |
| Mitering Device Guide Rollers                                                                                                                      | ASTM A148, Grade 80-40 Cast Steel <sup>++</sup>                                                           |
| Mitering Device Bolts                                                                                                                              | ASTM A668 Steel Forgings                                                                                  |
| Mitering Device Bushings                                                                                                                           | ASTM B584, Alloy C93200                                                                                   |
| Miscellaneous Bushings                                                                                                                             | Aluminum Bronze                                                                                           |
| Bumpers and Fenders                                                                                                                                | ASTM A36 Steel<br>Low Friction Butyl Rubber<br>White Oak<br>Creosote-Treated Pine                         |

\*Brinell Hardness of 270 to 290.

\*\*Preferably with Ceramic/Metal-Filled Epoxy Coating.

+Preferably with fluorocarbon inserts for rubbing-contact areas.

++With provisions for lubrication.

### Miter Gate Components (Continued)

|                                                         |                                                                                                                                                                                                                     |
|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Miscellaneous Bearings                                  | Aluminum Bronze                                                                                                                                                                                                     |
| Miscellaneous Bolts/Nuts                                | ASTM A307 Steel*<br>ASTM A325 Steel* <ul style="list-style-type: none"><li>• Type 304 Stainless Steel Bolts**<br/>Armco NITRONIC 60 Nuts**</li></ul>                                                                |
| Seal Heater Tubes/Pipes                                 | Type K Copper Tube <ul style="list-style-type: none"><li>• Type 304 Stainless Steel Tube<br/>ASTM A53, Schedule 80 Steel Pipe</li></ul>                                                                             |
| Culvert Valve Piston Rods                               | QQ-N-286, Monel <ul style="list-style-type: none"><li>• Type 410 Stainless Steel</li><li>• Carpenter Custom 450 Stainless Steel</li><li>• Type 416 Stainless Steel</li><li>• Armco 17-4PH Stainless Steel</li></ul> |
| Miter Gate Casting for Strut-Pin Connection (Machinery) | ASTM A148 Cast Steel                                                                                                                                                                                                |
| Miter Gate Pin Connection (Machinery)                   | ASTM A668, Class C Steel Forgings                                                                                                                                                                                   |
| Bolts for Attaching Castings to Gate                    | ASTM A325 Steel                                                                                                                                                                                                     |
| Shear Pin Bushing                                       | ASTM A663, Grade 45 Steel                                                                                                                                                                                           |

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\*Where bolts/nuts are not to be removed.

\*\*Where bolts/nuts are to be occasionally removed.

### Miter Gate Machinery

|                                 |                                                                                                                                                                      |
|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Anchor Bolts                    | ASTM A307 Steel                                                                                                                                                      |
| Angles                          | ASTM A36 Steel                                                                                                                                                       |
| Base                            | ASTM A36 Steel                                                                                                                                                       |
| Stud Bolts                      | ASTM A668 Steel Forgings                                                                                                                                             |
| Turned Bolts                    | ASTM A307 Steel<br>ASTM A320, Grade L-7 Steel                                                                                                                        |
| Hold-Down Bolts for Cylinder    | ASTM A307 Steel                                                                                                                                                      |
| Rack Bumper                     | ASTM D2000 Rubber                                                                                                                                                    |
| Piston-Rod Bushing              | ASTM B584, Alloy 2B                                                                                                                                                  |
| Snubbing Bushing                | ASTM A675, Grade 45 Steel                                                                                                                                            |
| Sector Arm                      | ASTM A514, Grade F Steel<br>ASTM A441 Steel                                                                                                                          |
| Sector Arm Wheel Pin            | ASTM A668, Class K Steel Forgings                                                                                                                                    |
| Sector Arm Bushings and Washers | ASTM B584, Alloy C92300                                                                                                                                              |
| Sector Arm Support Wheel        | ASTM A564, Grade XM-25 Stainless Steel <ul style="list-style-type: none"><li>• Armco 17-4PH Stainless Steel</li><li>• Carpenter Custom 450 Stainless Steel</li></ul> |
| Cap Screws                      | ASTM A193, Grade B-3 Stainless Steel <ul style="list-style-type: none"><li>• Type 40 Stainless Steel</li></ul>                                                       |
| Sector Base                     | QQ-S-681, Class 70-36 Cast Steel<br>ASTM A148, Grade 90-60 Cast Steel                                                                                                |
| Cross Pins                      | ASTM A668, Class D Steel Forgings<br>ASTM A668, Class K Steel Forgings                                                                                               |
| Cross Pin Steel Bushings        | ASTM A663, Grade 45 Steel                                                                                                                                            |
| Cylinder Heads                  | ASTM A148, Grade 80-40 Cast Steel<br>ASTM A27, Grade 60-30 Cast Steel                                                                                                |
| Hydraulic Cylinder Base         | ASTM A36 Steel                                                                                                                                                       |
| Hydraulic Cylinder              | ASTM A106, Grade B Steel Pipe*                                                                                                                                       |

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\*With forged flanges.

Miter Gate Machinery (Continued)

|                              |                                                                          |
|------------------------------|--------------------------------------------------------------------------|
| Eyebolt for Sector Pin       | ASTM A668, Class D Steel Forgings                                        |
| Fitted Bolts                 | ASTM A307 Steel                                                          |
| Flanged Spacers              | QQ-S-681, Class 65-35 Cast Steel                                         |
| Strut Follower               | QQ-S-681, Class 105-85 Cast Steel                                        |
| Gate End Castings            | QQ-S-681, Class 105-85 Cast Steel                                        |
| Gate End Seal Retainer       | QQ-S-681, Class 65-35 Cast Steel                                         |
| Gland for Hydraulic Cylinder | ASTM B854 Alloy C92300                                                   |
| Pistons                      | ASTM A48, Class 40 or Class 50*                                          |
| Gland for Piston Rod         | ASTM B584, Alloy 2B                                                      |
| Key for Hydraulic Cylinders  | ASTM A575 and A576, Type 1040 Steel                                      |
| Key for Piston Rod           | ASTM A668, Class B Steel Forgings<br>ASTM A576 and A575 Class 1040 Steel |
| Spring Steel for Strut       | ASTM A689 Steel                                                          |
| Piston Rod Nuts              | ASTM A668, Class C Steel Forgings<br>A668, Class B Steel Forgings        |
| Wedge Nuts                   | QQ-S-681, Class 105-85 Cast Steel                                        |
| Sector Base Plate            | ASTM A36 Steel<br>ASTM A441 Steel                                        |
| Spring Lock Nut              | ASTM A668, Class C Steel Forgings                                        |
| Sector Gear Pin              | ASTM A668, Class A Steel Forgings<br>ASTM A668, Class K Steel Forgings   |
| Sector Top Plate             | ASTM A36 Steel                                                           |
| Spacer (Ring)                | ASTM B148 Aluminum Bronze, Alloy 9C                                      |
| Spanner Bolt (for Strut)     | ASTM A663, Grade 45 Steel                                                |
| Spanner Nut (for Strut)      | ASTM A668, Class A Steel Forgings<br>ASTM A668, Class B Steel Forgings   |
| Springs                      | ASTM A125 Steel                                                          |

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\*Used in Nashville District

### Miter Gate Machinery (Continued)

|                                    |                                                                                                                                                                                                                                                                        |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Spring Cartridge                   | ASTM A148, Grade 80-40 Cast Steel                                                                                                                                                                                                                                      |
| Spring Housing (for Strut)         | QQ-S-681, Class 65-35 Cast Steel                                                                                                                                                                                                                                       |
| Spring Rod                         | ASTM A668, Class C Steel Forgings                                                                                                                                                                                                                                      |
| Strut Pins                         | <ul style="list-style-type: none"><li>• ASTM A276, Type 416 Stainless Steel</li><li>ASTM A668, Class D Steel Forgings</li></ul>                                                                                                                                        |
| Strut Segment Body                 | ASTM A575 and A576 Steel                                                                                                                                                                                                                                               |
| Strut Segment Flange               | ASTM A181, Grade 2 Steel Forgings                                                                                                                                                                                                                                      |
| Strut Segment Clevis               | QQ-S-681, Class 65-35 Cast Steel                                                                                                                                                                                                                                       |
| Studs for Sector Base              | ASTM A193, Grade B6 Stainless Steel                                                                                                                                                                                                                                    |
| Stud Bolts                         | ASTM A307, Grade A Steel                                                                                                                                                                                                                                               |
| Hydraulic Cylinder for Piston      | ASTM A48, Class 50 Cast Iron                                                                                                                                                                                                                                           |
| Piston Ring for Hydraulic Cylinder | Koppers B-19 Bronze                                                                                                                                                                                                                                                    |
| Piston Rod for Hydraulic Cylinder  | <ul style="list-style-type: none"><li>ASTM A564, Grade XM-25 Stainless Steel</li><li><ul style="list-style-type: none"><li>• Armco 17-4PH Stainless Steel</li><li>ASTM A668, Class B Steel Forgings</li><li>• Carpenter Custom 450 Stainless Steel</li></ul></li></ul> |

### Tainter-Valve Components

|                                        |                                                                                                                    |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Skin Plate                             | ASTM A36 Steel <ul style="list-style-type: none"><li>● Type 304 Stainless Steel Clad for Downstream Face</li></ul> |
| Structural Members                     | ASTM A36 Steel                                                                                                     |
| Trunnion Pins                          | ASTM A668 Steel Forgings                                                                                           |
| Trunnion-Pin Bushings                  | AMPCO 16 Aluminum Bronze                                                                                           |
| Anchorage Beams                        | ASTM A36 Steel                                                                                                     |
| Seal Bolts                             | ● Type 304 Stainless Steel                                                                                         |
| Seal Nuts                              | Armco Nitronic 60 Stainless Steel                                                                                  |
| J-Seals                                | Neoprene*<br>Natural Rubber*                                                                                       |
| Trunnion Housings                      | ASTM A36 Steel<br>ASTM A148, Grade 80-40 Cast Steel                                                                |
| Embedded Bottom Seals                  | ● Type 304 Stainless Steel                                                                                         |
| Bottom Seal Plates on Valve            | ● Type 304 Stainless Steel                                                                                         |
| Valve Top Seal                         | Neoprene<br>Natural Rubber                                                                                         |
| Culvert Valve Liner                    | ● ASTM A276, Type 410 Stainless Steel**                                                                            |
| Culvert Valve Side Seal-Embedded       | ● ASTM A276, Type 410 Stainless Steel                                                                              |
| Culvert Valve Connecting Strut         | ● ASTM A276, Type 410 Stainless Steel                                                                              |
| Tainter-Valve Activating System        |                                                                                                                    |
| Strut Arm                              | Schedule 100 Steel Pipe                                                                                            |
| Bell Crank                             | ASTM A53, Grade B Steel Pipe                                                                                       |
| Hydraulic Cylinder                     | ASTM A668 Steel Forgings                                                                                           |
| Fittings for Strut Arms and Bell Crank | ASTM A27, Grade 65-35 Cast Steel                                                                                   |

\*Preferably with fluorocarbon inserts for rubbing-contact areas.

\*\*For high-lift locks.

Tainter-Valve Components

|                    |                                                                                                                                     |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Hydraulic Cylinder | ASTM A668 Steel Forgings                                                                                                            |
| Piston Rods        | Type K Monel <ul style="list-style-type: none"><li>• Carpenter 450 Stainless Steel</li><li>• Armco 17-4PH Stainless Steel</li></ul> |
| Anchorage          | ASTM A36 Steel                                                                                                                      |
| Bushings           | ASTM B148 Aluminum Bronze, Alloy C95400                                                                                             |
| Pins               | ASTM A668 Steel Forgings                                                                                                            |

### Emergency-Gate Machinery

|                                  |                                                                               |
|----------------------------------|-------------------------------------------------------------------------------|
| Anchor Bolts for Wire Rope       | ASTM A307, Grade A Steel                                                      |
| Anchor Bolt Assembly             | ASTM A307, Grade A Steel                                                      |
| Angles                           | ASTM A36 Steel                                                                |
| Axle                             | ASTM A668, Class C Steel Forgings                                             |
| Bearing Block (Roller Bearing)   | ASTM A36 Steel                                                                |
| Bearing Pedestal                 | ASTM A148, Grade 80-40 Cast Steel                                             |
| Bearing Stance                   | ASTM A148, Grade 80-40 Steel                                                  |
| Blind Flange (for Bearing Cover) | ASTM A36 Steel                                                                |
| Shear Bolt                       | ASTM A663, Grade 75 Steel                                                     |
| Roller Support Bracket           | QQ-S-681 Steel Casting                                                        |
| Bull Gear                        | ASTM A27, Grade 60-30 Steel Casting                                           |
| Bull Gear Pinion                 | ASTM A291, Class 4 Steel Forgings                                             |
| Bull Gear Rim                    | ASTM A290, Class D Steel Forgings                                             |
| Sheave Bushing                   | ASTM B584, Copper Alloy C95500                                                |
| Sheave Block Wheel Bushings      | ASTM B854, Alloy C95500                                                       |
| Carriage Wheel                   | ASTM A36*                                                                     |
| Embedded Roller Track            | ● ASTM A240, Type 410 Stainless Steel                                         |
| Drum Plates                      | ASTM A36 Steel                                                                |
| Drive Link for Indicator         | ● Type 304 Stainless Steel                                                    |
| Drum Tie Bolt                    | ASTM A307, Grade A Steel                                                      |
| Machinery Base                   | ASTM A36 Steel                                                                |
| Spacer/Spool                     | ASTM A36 Steel                                                                |
| Sheave                           | ASTM A148, Grade 80-40 Steel Castings<br>ASTM A27, Grade 70-36 Steel Castings |

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\*With Type 304 Stainless Steel Rim.

Emergency-Gate Machinery (Continued)

Cartridge Wheel

ASTM A36 Steel

Rope Separator

- ASTM A743 and A744 CF-8 Stainless Steel

Separator Pins

- ASTM A743 and A744, CF-8 Stainless Steel

### Segmental Valve Machinery

|                                   |                                                                           |
|-----------------------------------|---------------------------------------------------------------------------|
| Anchor Bolt Assembly              | ASTM A307 Steel                                                           |
| Angles                            | ASTM A36 Steel                                                            |
| Arm for Magnet Mounting Indicator | ASTM B584, Alloy C90500                                                   |
| Base                              | ASTM A36 Steel                                                            |
| Bearing Bracket                   | ASTM A148, Class 80-40 Cast Steel                                         |
| Bell Crank Assembly               |                                                                           |
| Pipe                              | Schedule 100 Steel                                                        |
| Bushing                           | Aluminum Bronze                                                           |
| Forgings                          | ASTM A668, Class C                                                        |
| Turned Bolts                      | ASTM A307 Steel<br>● Type 304 Stainless Steel                             |
| Hold-Down Bolts for Cylinder      | ASTM A307 Steel                                                           |
| Bushings                          | ASTM B584, Alloy C90500                                                   |
| Cylinder Bracket                  | ASTM A668, Class C Forgings                                               |
| Trunnion Bushing                  | ASTM B584, Alloy C90500                                                   |
| Struts and Clevises               | ASTM A27, Grade 70-40 Steel Castings                                      |
| Hydraulic Cylinder                | ASTM A106, Grade 2 Steel Pipe                                             |
| Cylinder Heads                    | ASTM A148, Grade 80-40 Cast Steel<br>ASTM A27, Grade 60-30 Steel Castings |
| Cylinder Rocker and Base          | ASTM A441 Steel                                                           |
| Gland for Hydraulic Cylinder      | ASTM B584, Alloy C90500                                                   |
| Hinged Bearing                    | ASTM A27, Grade 70-36 Cast Steel                                          |
| Selsyn Keys                       | ● Type 304 Stainless Steel                                                |
| Spindle Nut                       | ASTM A668, Class H Steel Forgings                                         |

Segmental Valve Machinery (Continued)

|                               |                                                                                                                               |
|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Spring for Strut              | ASTM A689 Steel<br>AISI 5160H Steel                                                                                           |
| Stop Plates                   | ASTM B584, Alloy C90500                                                                                                       |
| Strut Spindle                 | ASTM A148, Grade 90-60 Cast Steel                                                                                             |
| Pillow Block at Fulcrum       | ASTM A148, Grade 90-60 Cast Steel                                                                                             |
| Pistons                       | ASTM A48, Class 40 or Class 50*                                                                                               |
| Piston Rod Hydraulic Cylinder | ASTM A524 Steel Pipe                                                                                                          |
| Piston Rod                    | <ul style="list-style-type: none"><li>• Carpenter Custom 450 Stainless Steel</li><li>• Armco 17-4PH Stainless Steel</li></ul> |
| Piston Rod Connecting Casting | ASTM A27, Grade 60-30 Cast Steel                                                                                              |
| Piston Rod Eyebars            | ASTM A27, Grade 70-36 Cast Steel                                                                                              |

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\*Used in Nashville District

### Emergency Dam (Wicket Type) Components

Structural Steel

ASTM A36 Steel

Link Chain

Ductile Iron

Dogging Device

• Type 304 Stainless Steel

### Gears

|                                                    |                                       |
|----------------------------------------------------|---------------------------------------|
| Drum                                               | ASTM A290, Type G Steel Forgings      |
| Countershaft                                       | ASTM A290, Type G Steel Forgings      |
| Drum Pinion                                        | ASTM A291, Class 6 Steel Forgings     |
| Pinion for Reducer                                 | ASTM A291, Class 6 Steel Forgings     |
| Intermediate for Emergency Machinery               | ASTM A27, Grade 65-35 Steel Castings  |
| Bull (Rim)                                         | ASTM A290, Class 1 Steel Forgings     |
| Intermediate Gear Rim for Emergency Machinery      | ASTM A290, Class G Steel Forgings     |
| Tainter Gate Dogging Device Assembly               | Phosphorus Bronze                     |
| Worm Gear for Tainter Gate Dogging Device Assembly | • Type 304 Stainless Steel            |
| Bull/Tainter Gate Machinery                        | ASTM A148, Grade 105-85 Cast Steel    |
| Tainter Gate Machinery Pinion                      | ASTM A668, Grade G Steel Forgings     |
| Sector Gear for Miter Gate Machinery               | ASTM A148, Grade 90-60 Steel Castings |
| Selsyn Drive for Miter Gate Machinery              | ASTM A711 Steel Forgings              |
| Tainter Gate Machinery                             | ASTM A148, Grade 90-60 Steel Castings |

## Shafts

|                                                                                                                                    |                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Brake Wheel Shaft                                                                                                                  | AISI 1045 Steel                                                        |
| Countershaft                                                                                                                       | ASTM A291, Class 5 Steel Forgings<br>ASTM A668, Class F Steel Forgings |
| Drum for Emergency<br>Gate Assembly                                                                                                | AISI 4140 Steel                                                        |
| Drum for Tainter Gate<br>Machinery                                                                                                 | ASTM A293, Class 5 Steel Forgings                                      |
| Emergency Gate Machinery:<br>Bull Gear Shaft, Inter-<br>mediate Gear Shaft, Bull<br>Gear Pinion, and Inter-<br>mediate Gear Pinion | ASTM A291, Class 5 Steel Forgings                                      |
| Emergency Gate Machinery:<br>Carriage Wheel Shaft                                                                                  | ASTM A291, Class 3 Forgings                                            |
| Reducer Shaft for Emergency<br>Gate Machinery                                                                                      | AISI 4140 Steel                                                        |
| Miter Gate Machinery: Ring-<br>Spring Mandrell                                                                                     | ASTM A668, Class C Steel Forgings                                      |
| Emergency Gate Sleeve Shaft                                                                                                        | ASTM A291, Class 4 Steel Forgings                                      |
| Tainter Gate Machinery:<br>Indicator Hand Shaft                                                                                    | ASTM A276, Type 304 Stainless Steel                                    |
| Bull Gear and Drum Shaft                                                                                                           | ASTM A668, Class C Steel Forgings                                      |
| Emergency Gate Roller<br>Assembly Shaft                                                                                            | Aluminum Bronze, Class 3                                               |
| Torque Shaft for Tainter<br>Gate Machinery                                                                                         | ASTM A108, Grade 60-40 Steel                                           |
| Sheave Shaft for Emergency<br>Machinery                                                                                            | ASTM A668, Class C Steel Forgings                                      |

## Pins

Main Rod and Piston Rod  
for Valve Machinery

ASTM A668 Steel Forgings, Class K

Latch Pins for Tainter  
Gate Bulkheads

- ASTM A473, Type 431 Stainless Steel
- ASTM A276, Type 410 Stainless Steel

Hinge Pin for Valve Machinery

- ASTM A564, Type XM-25 Stainless Steel
- Armco 17-4PH Stainless Steel
  - Carpenter Custom 450 Stainless Steel

Vertical and Horizontal Roller  
Pins for Miter Gate Machinery

- ASTM A276, Type 410 Stainless Steel

### Steel Reinforcements for Concrete

|                     |                                               |
|---------------------|-----------------------------------------------|
| Rods                | ASTM A322, Grade 5160 Steel Bars*             |
| Post-Tension Cables | ASTM A416 Steel; Seven-Strand Wire            |
| Bars**              | ASTM A29 Steel Bars*<br>ASTM A722 Steel Bars* |
| Grout (for bars)    | Portland Cement with Shrinkage Inhibitor      |

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\*Fusion-bonded epoxy coated with seawater service.

\*\*Other than ordinary reinforcement steel.

## Hydroelectric Plant Components

|                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Francis Turbine Wheel                                                                                                                                                                                                                                                               | <ul style="list-style-type: none"> <li>● ASTM A743, CA-6NM Stainless Steel</li> </ul>                                                                                                                                          |
| Packing Box Shaft Sleeve                                                                                                                                                                                                                                                            | ASTM A276, S21800 Stainless Steel<br><ul style="list-style-type: none"> <li>● NITRONIC 60 Stainless Steel</li> </ul>                                                                                                           |
| Interior Wicket Gate Grease Pipe                                                                                                                                                                                                                                                    | ASTM A53, Grade E and S Steel pipe                                                                                                                                                                                             |
| Scroll Case                                                                                                                                                                                                                                                                         | Vinyl Coated Carbon Steel                                                                                                                                                                                                      |
| Intake Gate Hoist Cylinder<br>Piston Rods                                                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>● Carpenter 450 Stainless Steel</li> <li>● Armco 17-4PH Stainless Steel</li> </ul>                                                                                                      |
| Intake Gate Hoist Cylinder Pipe                                                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>● ASTM A312, Type 304 Stainless Steel</li> </ul>                                                                                                                                        |
| Intake Gate Guide Tracks                                                                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>● ASTM A176, Type 410 Stainless Steel</li> <li>● ASTM A276, Type 304 Stainless Steel</li> </ul> ASTM A167, Type 304 Stainless Steel                                                     |
| Wicket Gate Wear Plates                                                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>● Type 304 Stainless Steel</li> </ul>                                                                                                                                                   |
| Intake Gate Roller Chains                                                                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>● ASTM A276, Type 410 Stainless Steel</li> <li>● ASTM A564, Type 630 Stainless Steel</li> <li>● Carpenter Custom 450 Stainless Steel</li> <li>● ARMCO 17-4PH Stainless Steel</li> </ul> |
| Intake Gate Structure                                                                                                                                                                                                                                                               | ASTM A36 Steel                                                                                                                                                                                                                 |
| Intake Trashracks                                                                                                                                                                                                                                                                   | ASTM A36 Steel                                                                                                                                                                                                                 |
| Intake Screens                                                                                                                                                                                                                                                                      | ASTM A36 Steel                                                                                                                                                                                                                 |
| Generator Heat Exchanger Tubes                                                                                                                                                                                                                                                      | ASTM B111, Alloy C70600                                                                                                                                                                                                        |
| Powerhouse Pipe/Tube                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                |
| Up to 125 psig for Generator<br>Cooling, Raw Water Service,<br>Spiral Case Drains, Spiral<br>Case Fills, Draft Tube Drains,<br>Under-watering, Drainage Pump<br>Discharges, Turbine Glands,<br>Water-spray Fire Protection<br>(upstream of deluge valve),<br>and Turbine Air Supply | WW-T-799, Type K Copper Tube for Lines<br>Under 3-Inches (Soldered)<br>ASTM A53 Steel Pipe for Lines 3-Inches<br>and Larger (Welded)                                                                                           |

### Hydroelectric Plant Components (Continued)

|                                                                                 |                                                                                                                                                                                       |
|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Potable Water,<br>125 psig                                                      | WW-T-799, Type K Copper Tube for Lines<br>Under 3-Inches (Soldered)<br>ASTM A53 Steel Pipe for Lines 3-Inches<br>and Larger (Welded); Galvanized                                      |
| Waterspray Fire Protection<br>(downstream of deluge valve),<br>up to 150 psig   | ASTM A53, Schedule 40 Galvanized Steel<br>Pipe for Lines Less than 3-Inches<br>(Threaded)<br>ASTM A53, Schedule 40 Galvanized Steel<br>Pipe for Lines 3-Inches and Larger<br>(Welded) |
| Circulating Water for Air<br>Conditioning, up to 125 psig                       | ASTM A53 Galvanized Steel Pipe for Lines<br>Up to 2.5-Inches (Threaded)<br>ASTM A53 Black Steel Pipe for Lines 2.5-<br>Inches and Larger (Welded)                                     |
| Building and Roof Drains,<br>Sanitary Drains and Vents,<br>and Water Discharges | ASTM A120 Galvanized Steel Where Exposed<br>(Threaded)<br>WW-P-401 Cast Iron Hub and Spigot Pipe<br>Where Underground                                                                 |
| Turbine Vacuum Breaker<br>and Sump Vents                                        | ASTM A120 Black Steel (Welded) Pipe                                                                                                                                                   |
| Battery Room Drains                                                             | Polyvinyl Chloride Schedule 80 Pipe<br>Where Exposed<br>Duriron Pipe Where Underground                                                                                                |
| Pressure Sewage, up to<br>100 psig                                              | ASTM A53 Black Steel Schedule 80 Pipe<br>Where Exposed<br>WW-P-401 Cast Iron Pipe Where<br>Underground                                                                                |
| Piezometer, up to 125 psig                                                      | WW-T-799, Type K Copper Tube for Lines<br>Up to 3-Inches                                                                                                                              |
| Governor, Lube Oil, Circuit<br>Breaker, and Transformer<br>Oil Up to 150 psig   | WW-T-799, Type K Copper Tube                                                                                                                                                          |

### Hydroelectric Plant Components (Continued)

Service Air, Brake Air,  
Draft Tube Air, Depression  
Air and Bubbler Air, up to  
125 psig

WW-T-799, Type K Copper Tube for Lines  
Under 3-Inches (Soldered)  
ASTM A53 Galvanized Steel Pipe for Lines  
3-Inches and Larger (Welded)

Governor Air and Nitrogen,  
up to 600 psig

ASTM A106, Schedule 80 Steel Pipe

Carbon Dioxide

ASTM A53, Galvanized Steel Pipe

Governor Air, up to 1100  
psig

- Type 304 Stainless Steel, Schedule 40  
Pipe\*
- Type 316 Stainless Steel, Schedule 40  
Pipe\*

Hypochlorite

Polyvinyl Chloride Pipe

Floatwells

WW-T-799, Type K Copper Tube for Exposed  
Lines Under 3-Inches (Soldered)  
ASTM A53 Galvanized Steel Pipe for  
Exposed Lines 3-Inches and Larger  
(Welded)

Sleeves

ASTM A53 Black Steel Pipe  
ASTM A120 Black Steel Pipe  
Polyvinyl Chloride Pipe

Basket Strainer Bodies

ASTM A126, Class B Cast Iron

Basket Strainer Baskets

- Type 304 Stainless Steel

Dielectric Unions

WW-U-531

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\*With socket-weld joints.

## Fisheries

Rearing Ponds

6061-T4 Aluminum Alloy

Directional Jets

Schedule 40 Aluminum Pipe

Exit Screens

6061 Aluminum Alloy

5086 Aluminum Alloy

Anodized 5052 Aluminum Alloy

Fish-Handling Equipment  
(Spawning)

• ASTM A276, Type 304 Stainless Steel

### Traveling Fish Screens

|                                          |                                                                                                                                                 |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Chain Pins                               | ASTM A276, Type S21800 Stainless Steel<br>● ARMCO NITRONIC 60 Stainless Steel                                                                   |
| Bushings                                 | ASTM A564, Type 630 Stainless Steel<br>ASTM A564, Type 631 Stainless Steel<br>● ARMCO 17-4PH Stainless Steel<br>● ARMCO, 17-7PH Stainless Steel |
| Rollers                                  | Dupont Delrin 500                                                                                                                               |
| Pin Link and Roller Link<br>Plates       | ANSI B29.4<br>Epoxy-coated C2162H Chain                                                                                                         |
| Cotter Pins                              | ASTM A276, Type 302 Stainless Steel                                                                                                             |
| Sprockets                                | Ultra High Molecular Weight Polymer<br>(e.g., Holstelen Gur No. 413)                                                                            |
| Chair Tracks                             | Ultra High Molecular Weight Polymer<br>(e.g., Holstelen Gur No. 413)                                                                            |
| Structural Steel                         | ASTM A36 Steel                                                                                                                                  |
| Wire Rope                                | ● RR-W-410, Type 302 Stainless Steel<br>● RR-W-410, Type 304 Stainless Steel                                                                    |
| Bolts                                    | ● ASTM A193, Type 304 Stainless Steel                                                                                                           |
| Nuts                                     | Armco Nitronic 60 Stainless Steel                                                                                                               |
| Screen                                   | Polyester Monofilament (PET)<br>(e.g., Trevira, Type 930)                                                                                       |
| Sluice Gates                             | Cast Iron with Aluminum Bronze Seating<br>Surfaces                                                                                              |
| Floating Orifice Gates and<br>Weir Gates | ● ASTM A276, Type 410 Stainless Steel*                                                                                                          |

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\*With stainless steel isolated from structural steel using Oilon Pv80.

### Miscellaneous Components

|                                                                       |                                                                                                            |
|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| R.O. Slide Gate Piston Rods                                           | ASTM A668 Steel Forgings<br>• ASTM A276, Type 410 Stainless Steel                                          |
| Superstructure for Power Houses                                       | ASTM A36 Steel<br>ASTM A441 Steel                                                                          |
| Slide Gate Discharge Line for Temperature Control                     | Cast Iron                                                                                                  |
| Doors                                                                 | 3003-H14 Aluminum Alloy<br>6063-HT5 Aluminum Alloy                                                         |
| Heating/Ventilating Louvers                                           | 6063-T5 Aluminum Alloy<br>3003-H14 Aluminum Alloy                                                          |
| Handrailings                                                          | Aluminum Tube/Pipe                                                                                         |
| Floating Mooring Bitts Posts                                          | ASTM A106, Grade B Schedule 160 Steel Pipe                                                                 |
| Floating Mooring Bitts                                                | ASTM A36 Steel <sup>(1)</sup><br>Filament Reinforced Plastic                                               |
| Grease Lines for Floating Mooring Bitts                               | High Pressure Neoprene Hose<br>• Type 304 Stainless Steel Pipe/Tube                                        |
| Rollers for Floating Mooring Bitts                                    | • ASTM A416, Type 410 Stainless Steel<br>• Carpenter 450 Stainless Steel<br>• Armco 17-4PH Stainless Steel |
| Shafts for Floating Mooring Bitts                                     | ASTM A176, Type 410 Stainless Steel<br>Carpenter 450 Stainless Steel<br>Armco 17-4PH Stainless Steel       |
| Roller Bushings for Floating Mooring Bitts                            | ASTM B148, Alloy C95500*<br>ASTM B22 Bronze*                                                               |
| Floating Bulkheads                                                    | ASTM A36 Steel**                                                                                           |
| Water Supply Conduit Regulating Gate Hoist Piston Rod for Fishladders | ASTM B164 Monel                                                                                            |

\*Lubricated.

\*\*Vinyl coated.

### Miscellaneous Components (Continued)

|                                                  |                                                                                                      |
|--------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Firehose Cabinets                                | 5005-H15 Aluminum Alloy<br>6061-T6 Aluminum Alloy                                                    |
| Tank Liners for Fish Hauling Trailers            | Type 300 Series Stainless Steel                                                                      |
| Drain Line for Fish Hauling Trailers             | Type 300 Series Stainless Steel                                                                      |
| Circulating Water Pipe For Fish Hauling Trailers | Type 300 Series Stainless Steel                                                                      |
| Waterstops                                       | Natural Rubber<br>Polyvinyl Chloride                                                                 |
| Stainless Steel Wire Rope                        | RR-W-410, Type 300 Stainless Steel                                                                   |
| Wire Rope Sheaves and Drums                      | • Type 304 Stainless Steel*                                                                          |
| Wheel Bushings for Vertical Lift Lock Gates      | ASTM B22 Bronze, Alloy C86300**                                                                      |
| Axles for Vertical Lift Lock Gates               | ASTM A668 Steel Forgings<br>• Carpenter Custom 450 Stainless Steel<br>• Armco 17-4PH Stainless Steel |
| Cables for Vertical Lift Lock Gates              | RR-W-410                                                                                             |
| Seal Heater Pipe for Vertical Lift Lock Gates    | • Type 304 Stainless Steel                                                                           |
| Wheels for Vertical Lift Lock Gates              | ASTM A441 Steel <sup>+</sup>                                                                         |
| Bolts for Vertical Lift Lock Gates               | • Type 304 Stainless Steel<br>• Type 410 Stainless Steel                                             |
| Nuts for Vertical Lift Gates                     | Armco NITRONIC 60 Stainless Steel                                                                    |

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\*For wet locations. Carbon steel drums should be coated with Elastuff 504.

\*\*Avoiding the use of Lubrite.

+Brinell hardness of 200 to 215.

### Miscellaneous Components (Continued)

Shafts for Deep Well Drainage  
Pumps

- Type 303 Stainless Steel
- Type 416 Stainless Steel

Impellers for Sewage Pumps

Bronze

Fasteners for Sewage Pumps

- Type 304 Stainless Steel

Casings for Water Pumps

Cast Iron

Shafts for Water Pumps

- Type 416 Stainless Steel

Impellers for Water Pumps

Bronze

## PART VI: CONCLUSIONS

38. Typical mechanical property data have been presented for 14 stainless steels that are becoming more available for Civil Works applications: the wrought austenitic alloys NITRONIC 60 and Types 302, 303, 304, 308, and 316; the wrought martensitic alloys Types 410, 416, and 431; the wrought martensitic PH (precipitation-hardening) alloys 17-4PH and Custom 450; the wrought semiaustenitic PH alloy 17-7PH; the cast martensitic alloy CA-6NM; and the cast austenitic-ferritic alloy CF-8.

39. While stainless steels are viable options for many lock, dam, and hydroelectric plant applications, no single stainless steel available exhibits the desired mechanical properties and corrosion resistance for all applications. Alloys must be carefully selected and specified for a particular application, and the components must be properly designed and fabricated. General guidelines for selection of materials for specific components are provided in Part V.

Table 1

Corrosion Behavior of Carbon Steel and Stainless Steels\*

| Material           | General Corrosion<br>Rate, mpy** | Pit Depth, mils |      |
|--------------------|----------------------------------|-----------------|------|
|                    |                                  | Max.            | Avg. |
| Carbon Steel       | 1.2                              | 55              | 42   |
| Type 410 Stainless | +                                | 27              | 16   |
| Type 302 Stainless | 0                                | 0               | 0    |

\*Based on 8 years of exposure to Mississippi River water at Winfield, MO.

\*\*Mpy is mils (thousandths of an inch) per year.

+Loss was totally due to pitting attack.

Table 2

Nominal Compositions of Stainless Steels for Lock, Dam, and  
Hydroelectric Plant Applications\*

| <u>Alloy</u>      | <u>Cr</u>       | <u>Ni</u>       | <u>C**</u> | <u>Mn**</u>   | <u>Si**</u>   | <u>P**</u> | <u>S**</u> | <u>Fe</u> | <u>Other</u>                                   |
|-------------------|-----------------|-----------------|------------|---------------|---------------|------------|------------|-----------|------------------------------------------------|
| 302               | 17.00-<br>19.00 | 8.00-<br>10.00  | 0.15       | 2.00          | 1.00          | 0.045      | 0.030      | Bal.      |                                                |
| 303               | 17.00-<br>19.00 | 8.00-<br>10.00  | 0.15       | 2.00          | 1.00          | 0.20       | 0.15       | Bal.      | .060 Mo<br>(optional)                          |
| 304               | 18.00-<br>20.00 | 8.00-<br>10.50  | 0.08       | 2.00          | 1.00          | 0.045      | 0.030      | Bal.      |                                                |
| 308               | 19.00-<br>21.00 | 10.00-<br>12.00 | 0.08       | 2.00          | 1.00          | 0.045      | 0.030      | Bal.      |                                                |
| 316               | 16.00-<br>18.00 | 10.00-<br>14.00 | 0.08       | 2.00          | 1.00          | 0.045      | 0.030      | Bal.      | 2.00-3.00 Mo                                   |
| NITRO<br>(NIC 60) | 16.00-<br>18.00 | 8.00-<br>9.00   | 0.10       | 7.00-<br>9.00 | 3.50-<br>4.50 |            |            | Bal.      | 0.08-0.18 N                                    |
| 410               | 11.50-<br>13.50 | -               | 0.15       | 1.00          | 1.00          | 0.040      | 0.030      | Bal.      |                                                |
| 416               | 12.00-<br>14.00 | -               | 0.15       | 1.25          | 1.00          | 0.060      | 0.15***    | Bal.      | 0.60 Mo<br>(optional)                          |
| 431               | 15.00-<br>17.00 | 1.25-<br>2.50   | 0.20       | 1.00          | 1.00          | 0.040      | 0.030      | Bal.      |                                                |
| 17-4pH            | 15.00-<br>17.50 | 3.00-<br>5.00   | 0.07       | 1.00          | 1.00          | 0.040      | 0.030      | Bal.      | 3.00-5.00 Cu;<br>0.15-0.45 Nb<br>+ Ta          |
| CUSTOM<br>450     | 14.00-<br>16.00 | 5.00-<br>10.00  | 0.05       | 1.00          | 1.00          | 0.030      | 0.030      | Bal.      | 0.50-1.00 Cu;<br>1.25-1.75 Cu;<br>8xC (min) Nb |
| 17-7pH            | 16.00-<br>18.00 | 6.50-<br>7.75   | 0.09       | 1.00          | 1.00          | 0.040      | 0.030      | Bal.      | 0.75-1.50 Al                                   |
| CA-6NM            | 11.50-<br>14.00 | 3.50-<br>4.50   | 0.06       | 1.00          | 1.00          | 0.040      | 0.030      | Bal.      | 0.40-1.00 Mo                                   |
| CF-8              | 18.00-<br>21.00 | 8.00-<br>11.00  | 0.08       | 1.50          | 2.00          | 0.040      | 0.040      | Bal.      |                                                |

\*Values expressed in weight percent.

\*\*Maximum value except where otherwise noted.

\*\*\*Minimum.

Table 3

Typical Mechanical Property Data for Stainless Steel

| Alloy          | Form   | Condition | UTS<br>(ksi) | 0.2% YS<br>(ksi) | % E | % RA | Hard.   | Impact<br>Strength<br>(ft-lbs) |
|----------------|--------|-----------|--------------|------------------|-----|------|---------|--------------------------------|
| 302            | Bar    | Annealed  | 85           | 35               | 60  | 70   | Bhn 150 | Izod 110                       |
|                | Plate  | Annealed  | 90           | 35               | 60  | 70   | Rb 80   | Izod 110                       |
|                | Wire   | Annealed  | 90           | 35               | 60  | 70   | Rb 83   | Izod 110                       |
| 303            | Bar    | Annealed  | 90           | 35               | 50  | 55   | Bhn 160 | Izod 80                        |
| 304            | Bar    | Annealed  | 85           | 35               | 60  | 71   | Bhn 149 | Izod 110                       |
|                | Tube   | Annealed  | 85           | 35               | 50  | 71   | Rb 80   | Izod 110                       |
|                | Plate  | Annealed  | 82           | 35               | 60  | 71   | Bhn 145 | Izod 110                       |
| 308            | Bar    | Annealed  | 85           | 30               | 55  | 65   | Rb 80   | Izod 110                       |
|                | Wire** | Annealed  | 95           | 60               | 50  | -    | -       | Izod 110                       |
| 316            | Bar    | Annealed  | 80           | 30               | 60  | 70   | Rb 78   | Izod 110                       |
|                | Tube   | Annealed  | 85           | 35               | 50  | 70   | Rb 79   | Izod 110                       |
| NITRONIC<br>60 | Bar    | Annealed  | 103          | 60               | 64  | 74   | Rb 95   | Charpy 240                     |
|                |        | 10% CD    | 120          | 91               | 51  | 68   | Rc 24   | -                              |
|                |        | 40% CD    | 195          | 153              | 20  | 57   | Rc 38   | -                              |

\*UTS = Ultimate Tensile Strength, YS = Yield Strength, E = Elongation, RA = Reduction in Area, Bhn = Brinell Hardness Number, Rb = Rockwell B Hardness, Rc = Rockwell C Hardness, CD = Cold Drawn, SA = Solution Annealed, WQ = Water Quenched, AC = Air Cooled; OQ = Oil Quenched. Those associated with 17-4 PH and 17-7 PH refer to special conditions developed by Armco, Inc.

\*\*Soft temper.

(Continued)

(Sheet 1 of 3)

Table 3 (Continued)

| Alloy         | Form  | Condition        | UTS<br>(ksi) | 0.2% YS<br>(ksi) | % E | % RA | Hard.   | Impact<br>Strength<br>(ft-lbs) |
|---------------|-------|------------------|--------------|------------------|-----|------|---------|--------------------------------|
| 410           | Bar   | Annealed         | 75           | 40               | 35  | 68   | Rb 82   | Izod 85                        |
|               |       | QQ + 1 hr/300°F  | 195          | 150              | 15  | 55   | Bhn 390 | Izod 35                        |
|               |       | QQ + 1 hr/1100°F | 125          | 100              | 22  | 65   | Bhn 262 | Izod 35                        |
|               | Plate | Annealed         | 70           | 35               | 30  | 68   | Bhn 150 | Izod 85                        |
|               | Bar   | Annealed         | 75           | 40               | 30  | 60   | Rb 82   | Izod 20-64                     |
| 416           | Bar   | QQ + 1 hr/300°F  | 195          | 150              | 10  | 40   | Rc 41   | Izod 20                        |
|               |       | QQ + 1 hr/1100°F | 125          | 100              | 17  | 53   | Rc 26   | Izod 28                        |
|               |       | Bar              | 125          | 95               | 20  | 55   | Bhn 260 | Izod 50                        |
| 431           | Bar   | QQ + 1 hr/500°F  | 198          | 149              | 16  | 55   | Bhn 415 | Izod 40                        |
|               |       | QQ + 1 hr/1100°F | 140          | 115              | 19  | 57   | Bhn 302 | Izod 48                        |
|               |       | Bar              | 147          | 130              | 18  | 59   | Rc 34   | Charpy 47                      |
| 17-4 PH       | Bar   | A                | 147          | 130              | 18  | 59   | Rc 34   | Charpy 47                      |
|               |       | H900             | 200          | 185              | 14  | 50   | Rc 44   | Charpy 15                      |
|               |       | H1025            | 170          | 165              | 15  | 56   | Rc 38   | Charpy 35                      |
|               |       | H1075            | 165          | 150              | 16  | 58   | Rc 36   | Charpy 40                      |
|               |       | H1100            | 150          | 135              | 17  | 58   | Rc 35   | Charpy 45                      |
| CUSTOM<br>450 | Bar   | H1150            | 145          | 125              | 19  | 60   | Rc 33   | Charpy 50                      |
|               | Bar   | SA               | 141          | 118              | 13  | 50   | Rc 28   | Charpy 95                      |
|               |       | Aged at 850°F*** | 196          | 186              | 14  | 54   | Rc 44   | Charpy 20                      |
|               |       | Aged at 900°F    | 195          | 186              | 14  | 55   | Rc 42   | Charpy 41                      |
|               |       | Aged at 1000°F   | 173          | 169              | 17  | 63   | Rc 39   | Charpy 51                      |
|               |       | Aged at 1150°F   | 142          | 91               | 23  | 69   | Rc 28   | Charpy 97                      |
|               |       |                  |              |                  |     |      |         |                                |

\*\*\*Aging time of 4 hrs for all temperatures.

(Continued)

(Sheet 2 of 3)

Table 3 (Continued)

| Alloy   | Form | Condition                                    | UTS<br>(ksi) | 0.2% YS<br>(ksi) | % E | % RA | Hard.   | Impact<br>Strength<br>(ft-lbs) |
|---------|------|----------------------------------------------|--------------|------------------|-----|------|---------|--------------------------------|
| 17-7 PH | Bar  | RH950                                        | 185          | 150              | 6   | 10   | Rc 41   | -                              |
|         |      | TH1050                                       | 170          | 140              | 6   | 25   | Rc 38   | -                              |
| CF-8    | Cast | WQ from above<br>1400°F                      | 77           | 37               | 55  | -    | Bhn 140 | Charpy 74 <sup>++</sup>        |
| CA-6NM  | Cast | AC from above<br>1750; tempered<br>at 1100°F | 120          | 100              | 24  | 60   | Bhn 269 | Charpy 70                      |

<sup>++</sup> Charpy keyhole notch; all other Charpy impact data are for V-notch.

(Sheet 3 of 3)

Note: All of the above are more cavitation resistant than cast iron or structural steel.

Table 4

Values for the Currents in Selected Stainless Steels\*

| Stainless Steel/Condition** | Ep, Volt   | i <sub>c</sub> , amp/cm <sup>2</sup> |                  | i <sub>p</sub> , amp/cm <sup>2</sup> | E <sub>tp</sub> , Volt |
|-----------------------------|------------|--------------------------------------|------------------|--------------------------------------|------------------------|
|                             | vs. SCE*** |                                      |                  |                                      | vs. SCE                |
| Type 304, Annealed + 10% CW | -0.347     | 4.28                                 | 10 <sup>-4</sup> | 3.27 X 10 <sup>-6</sup>              | +0.89                  |
| Type 410/Annealed           | -0.376     | 1.49 X 10 <sup>-2</sup>              |                  | 5.27 X 10 <sup>-6</sup>              | +0.81                  |
| Custom 450/SA               | -0.256     | 3.68 X 10 <sup>-5</sup>              |                  | 1.92 X 10 <sup>-6</sup>              | +0.92                  |
| Custom 450/Aged at 1150°F   | -0.277     | 2.63 X 10 <sup>-5</sup>              |                  | 2.00 X 10 <sup>-6</sup>              | +0.87                  |
| 17-4PH/Condition A          | -0.269     | 1.60 X 10 <sup>-4</sup>              |                  | 2.02 X 10 <sup>-6</sup>              | +0.89                  |
| 17-4PH/H1150                | -0.312     | 8.75 X 10 <sup>-5</sup>              |                  | 2.53 X 10 <sup>-6</sup>              | +0.88                  |
| NITRONIC 60/Annealed        | -0.346     | 3.63 X 10 <sup>-4</sup>              |                  | 1.58 X 10 <sup>-6</sup>              | +0.92                  |

\*E<sub>p</sub> = passivation potential, i<sub>c</sub> = critical current density for passivation, i<sub>p</sub> = passive current density, and E<sub>tp</sub> = transpassive potential

\*\*See Table 3 for condition abbreviations. All samples are deaerated IN sulfuric acid at ambient temperature.

\*\*\*Saturated calomel electrode.

Table 5

Galvanic Series for Selected Alloys

| Alloy/Condition*              | Potential, Volt<br>vs. SCE ** | Initial Driving Voltage<br>of Alloy Coupled to A36<br>Steel, Volt |
|-------------------------------|-------------------------------|-------------------------------------------------------------------|
| NITRONIC 60/Annealed          | -0.327                        | 0.247                                                             |
| Type 304/Annealed<br>+ 10% CW | -0.328                        | 0.246                                                             |
| Custom 450/SA                 | -0.330                        | 0.244                                                             |
| Custom 450/Aged at<br>1150°F  | -0.362                        | 0.212                                                             |
| 17-4PH/H1150                  | -0.384                        | 0.190                                                             |
| 17-4PH/Condition A            | -0.396                        | 0.178                                                             |
| Type 410/Annealed             | -0.488                        | 0.086                                                             |
| ASTM A36/Normalized           | -0.574                        | 0.000                                                             |

\*See Table 3 for condition abbreviations. All samples are 0.5 M sodium chloride solution at ambient temperature.

\*\*Saturated calomel electrode.

Table 6

Galvanic Corrosion Current Densities for ASTM A36 Steel  
When Metallically Connected to an Equal Area of  
Stainless Steel

| Stainless Steel Condition* | Galvanic Corrosion Current<br>Density for A36 Steel,<br>ampere/cm <sup>2</sup> |
|----------------------------|--------------------------------------------------------------------------------|
| NITRONIC 60/Annealed       | $1.4 \times 10^{-5}$                                                           |
| Type 304/Annealed + 10% CW | $2.1 \times 10^{-5}$                                                           |
| Custom 450/SA              | $2.0 \times 10^{-5}$                                                           |
| Custom 450/Aged at 1150°F  | $1.6 \times 10^{-5}$                                                           |
| 17-4PH/H1150               | $1.9 \times 10^{-5}$                                                           |
| 17-4PH/Condition A         | $2.2 \times 10^{-5}$                                                           |
| Type 410/Annealed          | $2.5 \times 10^{-5}$                                                           |

\*See Table 3 for condition abbreviations. All samples exposed to aerated 0.5M sodium chloride solution at ambient temperature.

Table 7

Ranking of Stainless Steels Compared to a Low-Alloy Carbon Steel\*

| <u>Ranking</u> | <u>Stainless Steel/Condition**</u> | Brinell Hardness | Erosion Rate,    |
|----------------|------------------------------------|------------------|------------------|
|                |                                    | <u>No.</u>       | <u>inch/year</u> |
| 1              | NITRONIC 60/Annealed               | 201              | 0.4              |
| 2              | 17-4PH/H1150                       | 388              | 1.2              |
| 3              | Custom 450/Aged at 1150°F          | 320              | 1.3              |
| 4              | 17-4PH/Condition A                 | 321              | 1.6              |
| 5              | Type 304/Annealed + 10% CW         | 197              | 1.7              |
| 6              | Custom 450/SA                      | 270              | 1.9              |
| 7              | AISI 4130 Steel/Normalized         | 286              | 2.5              |
| 8              | Type 410/Annealed                  | 223              | 3.8              |

\*Based on cavitation resistance according to ASTM G32 testing.

\*\*See Table 3 for condition abbreviations.

Table 8

Threshold Gallling Stresses (ksi) for Stainless Steels\*

| Block Material             | <u>Button Material and Threshold Gallling Stress, psi</u> |          |          |          |          |        |             |
|----------------------------|-----------------------------------------------------------|----------|----------|----------|----------|--------|-------------|
|                            | Type 410                                                  | Type 416 | Type 303 | Type 304 | Type 316 | 17-4PH | NITRONIC 60 |
| Type 410**                 | 3                                                         | 4        | 4        | 2        | 2        | 3      | 50+***      |
| Type 416 <sup>†</sup>      | 4                                                         | 13       | 9        | 24       | 42       | 2      | 50+         |
| Type 303 <sup>††</sup>     | 4                                                         | 9        | 2        | 2        | 3        | 3      | 50+         |
| Type 304 <sup>†††</sup>    | 2                                                         | 24       | 2        | 2        | 2        | 2      | 50+         |
| Type 316 <sup>§</sup>      | 2                                                         | 42       | 3        | 2        | 2        | 2      | 38          |
| 17-4PH <sup>§§</sup>       | 3                                                         | 2        | 2        | 2        | 2        | 2      | 50+         |
| NITRONIC 60 <sup>§§§</sup> | 50+                                                       | 50+      | 50+      | 50+      | 38       | 50+    | 50          |

\*Results in psi based on "Button and Block" galling tests.

\*\*Hardened and stress relieved to Bhn 352.

\*\*\*50+ indicates that no galling occurred at 50,000 psi.

<sup>†</sup>Hardened and stress relieved to Bhn 342.

<sup>††</sup>Annealed to Bhn 140.

<sup>†††</sup>Annealed to Bhn 150.

<sup>§</sup>Annealed to Bhn 150.

<sup>§§</sup>Condition RH950 to Bhn 415.

<sup>§§§</sup>Annealed to Bhn 205.

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