NiDI

Nickel
Development
Institute

Nickel-containing materials for water control applications

A Nickel Development Institute
Reference Book
Series Nº 11 010, 1993

NiDI

Nickel Development Institute

The Nickel Development Institute is the market development and applications research organization of the primary nickel industry.

Incorporated and organized in 1984, its headquarters are in Toronto, Canada.

Objective of the Institute is sustained growth in the consumption of nickel.

Through a network of small permanent staff and key international consultants and project contractors, the Institute carries out market development activities, market exploration, and applications-oriented technical research relevant to the achievement of its objective around the world.

Technical service is provided to nickel consumers and others concerned with nickel, nickel alloys and their uses.

Principal marketing efforts of the Institute are directed toward the United States, Western Europe, Japan and the newly industrializing nations in Latin America, the Pacific rim and the Indian subcontinent ... those countries having the greatest current consumption of nickel and those having the greatest potential for growth.

Information services are available to designers, specifiers, and educators as well as to the nickel users.

Enquiries are welcomed from architects, engineers, industrial designers, specification writers, and others responsible for selection of materials for manufacturing and construction.

The Institute co-operates with colleges and universities by furnishing relevant information and material for engineering, materials science, and industrial design education.

Nickel-containing materials for water control applications

Table of Contents

Figures

Tables

Introduction

Nickel-containing materials have established themselves in difficult water control environments such as locks, dams and hydroelectric plants by demonstrating years of economical and trouble-free performance. Data compiled from measurements taken at field sites is presented in this publication together with the physical properties of the materials in use. Satisfactory service, substantiated by evaluations made as much as twenty-six years after project completion, afford a basis for improving existing structures in which lower grade materials are giving less than satisfactory service. The results support the use of various types of nickel-containing materials in new, advanced designs.

Part I reviews the basic reasons that nickel-containing materials furnish corrosion protection and review the types of corrosion encountered in atmospheric, fresh water, and saline water environments. It includes mention of particular properties of alloys used in manufacturing processes such as welding and machining. The discussion extends to pumps and valves where considerable detail is developed regarding cavitation causes, damage, and repair methods. In each topic, it enumerates some key service requirements for specific applications and suggests alloys that are appropriate for use in those applications.

Part II begins with a discussion of the general information which has commonality in its application to water control gates of differing types. This includes such things as material used in gate leaves and skins, seals, and fasteners. The remainder of the treatise reviews construction features and material considerations as they apply to specific types of water control gates and screens. Specifically, the following types of water control gates and screens are discussed: fabricated and cast slide gates, sluice gates, fixed wheel and roller gates, tainter gates, locks, lock mitre gates, and jet flow gates. It discusses the particular areas where nickel-containing materials are used to best advantage. It concludes with a similar treatment of submerged travelling screens, rotating drum screens and rotating cup screens.

PART I

Corrosion

General corrosion resistance

Stainless steels owe their outstanding corrosion resistance to an oxide film, a combination of chromium, iron, and nickel oxide that forms on their surfaces, that prevents further corrosion. This film is very thin, tightly adherent, and self-replenishing when damaged by abrasion. The film forms so rapidly in air, water, or other oxidizing media that it is very difficult to prevent its formation.

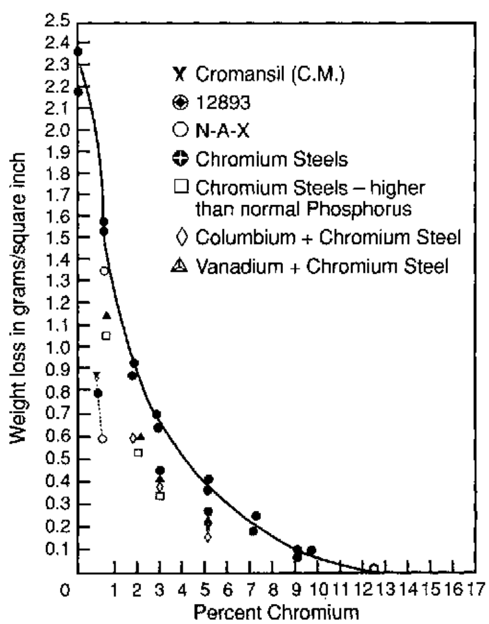


Figure 1 Weight loss versus chromium content for samples exposed 25.1 years to marine atmosphere.[1]

Copper alloys also owe their corrosion resistance to a protective oxide film. Unlike stainless steel, the protective film forms slowly, growing more protective during the first several years of exposure. The film forms more rapidly at summer temperatures and more slowly at winter temperatures. The film is thicker and more easily damaged than the oxide film that protects stainless steels.

The film that protects austenitic Ni-Resist cast iron and Alloy 400 (nickel copper) also forms more slowly and is more easily damaged than the film on stainless steels.

The compositions of alloy materials commonly used in locks, dams and hydroelectric plants are shown in *Table I.* Mechanical properties are given in *Table II.* These alloys are used because they have special properties which render them suitable for application under the service conditions and the particular environments where water control is a design objective.

Atmospheric corrosion resistance

The resistance of steel to atmospheric corrosion increases as chromium is added to it, as shown in *Figure 1* from Faulring's report.[1] Weight loss continues to decrease until, at 12% to 12.5% Cr., it becomes difficult to measure weight loss even after twenty-five years. Since the AISI 300 series stainless steels have even higher chromium, about 18%, weight loss is not useful in

Table I Stainless steels and non-ferrous alloys for locks, dams and hydro plants
Chemical analysis of major elements, %. (Max. except as noted)

AISI Type or common name (UNS)	C	Cr	Ni	Mo	Cu	Fe	Other
302 (S30200)	0.15	17.0-19.0	8.0-10.0	–	–	bal.	–
303 (S30300)	0.15	17.0-19.0	8.0-10.0	–	–	bal.	S 0.15 min.
304 (S30400)	0.08	18.0-20.0	8.0-10.5	–	–	bal.	–
304L (S30403)	0.03	18.0-20.0	8.0-12.0	–	–	bal.	–
308 (S30800)	0.08	19.0-21.0	10.0-12.0	–	–	bal.	–
316 (S31600)	0.08	16.0-18.0	10.0-14.0	2.0-3.0	–	bal.	–
316L (S31603)	0.03	16.0-18.0	10.0-14.0	2.0-3.0	–	bal.	–
17-4PH (S17400)	0.07	1.5.5-17.5	3.0-5.0	–	3.0-5.0	bal.	Cb 0.15-0.45
15-5PH (S15500)	0.07	14.4-15.5	3.5-5.5	–	2.5-4.5	bal.	Cb+Ta 0.15-0.45
Custom 450 (S45000)	0.05	14.0-16.0	5.0-7.0	0.5-1.0	1.25-1.75	bal.	–
NITRONIC 60 (S21800)	0.10	16.0-18.0	8.0-9.0	–	–	bal.	Mn 7.0-9.0 Si 3.5-4.5
2205 duplex (S31803)	0.03	21.0-23.0	4.5-6.5	2.5-3.5	–	bal.	–
CA-15 (J91150)	0.15	11.5-14.0	1.0	–	–	bal.	–
CA-6NM (J91540)	0.06	11.5-14.0	3.5-4.5	0.4-1.0	–	bal.	–
CF-8 (J92600)	0.08	18.0-21.0	8.0-11.0	–	–	bal.	–
CF-8M (J92900)	0.08	18.0-21.0	9.0-12.0	2.1-3.0	–	bal.	–
Ni-Resist D-2 (F43000)	3.0	1.75-2.75	18.0-22.0	–	–	bal.	Si 1.5-3.0
Alloy 400 (N04400)	0.30	–	63.0-70.0	–	bal.	2.5	–
Alloy K-500 (N05500)	0.25	–	63.0-70.0	–	bal.	2.0	Al 2.3-3.15 Ti 0.35-0.85
Waukesha 88	0.05	11.0-14.0	bal.	2.0-3.5	–	2.0	Bi 3.0-5.0 Sn 3.0-5.0

Table II Stainless steels and non-ferrous alloys for locks, dams and hydro plants
Typical mechanical properties (Annealed, except as noted)

AISI Type or common name (UNS)		Tensile Strength Ksi	Yield Strength (0.2% offset) Ksi	Elongation in 2", %	Hardness	Impact Strength Rm. Temp. (ft.lb.)	Coefficient of Thermal Expansion in./in./°F×10^6
302 (S30200)	Bar	85	35	60	150 Bhn	Izod 110	9.6
303 (S30300)	Bar	90	35	50	160 Bhn	Izod 80	9.6
304 (S30400)	Bar	85	35	60	150 Bhn	Izod 110	9.6
304L (S30403)	Bar	75	28	50	70 RB	Izod 110	9.6
308 (S30800)	Bar	85	30	55	80 RB	Izod 110	9.6
316 (S31600)	Bar	80	30	60	78 RB	Izod 110	8.9
316L (S31603)	Bar	75	32	50	72 RB	Izod 110	8.9
17-4PH (S17400)	Bar (H 1075)	145	125	19	33 RC	Charpy V 50	6.0
15-5PH (S15500)	Bar (H 1150)	135	105	16	28 RC	Charpy V 41	6.0
Custom 450 (S45000)	Bar (H 1150)	142	91	23	28 RC	Charpy V 97	6.0
N ITRONIC 60 (S21800)	Bar	100	60	50	95 RB	Charpy V 54	8.8
2205 duplex (S31803)	Bar	90	65	25	290 Bhn	–	7.0
CA-15 (J91150)	Cast	100	75	20	200 Bhn	Charpy Keyhole 20	5.5
CA-6NM (J91540)	Cast	120	100	24	269 Bhn	Charpy V 70	6.0
CF-8 (J92600)	Cast	77	32	55	140 Bhn	Charpy Keyhole 74	9.0
CF-8M (J92900)	Cast	80	42	50	163 Bhn	Charpy Keyhole 70	8.9
Ni-Resist D-2 (F43000)	Cast	59	32	14	170 Bhn	Charpy V 12	10.4
Alloy 400 (N04400)	Bar	79	30	48	125 Bhn	Izod 110	7.7
Alloy K-500 (N05500)	Bar (aged)	150	120	25	300 Bhn	Charpy V 40	7.6
Waukesha 88	Cast	45	38	7	150 Bhn	–	8.0

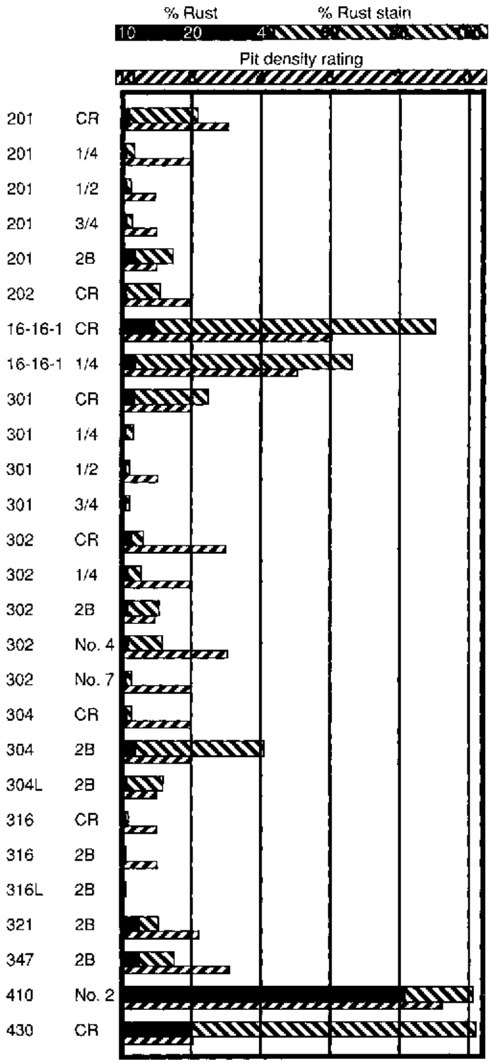


Figure 2 Relative performance of stainless steel exposed 250m from the ocean for 26 years.[2]

differentiating corrosion behaviour. Baker and Lee[2] based their measurements on the percentage of the total area rusted, the percentage with a "rust stain", and the pit density, *Figure 2*. These measurements were made after 26 years of exposure. Although these data are for a marine atmospheric exposure site 820 ft. (250 m) from the ocean, the relative resistance is similar in less corrosive inland sites. In short, Type 410 can be expected to suffer some rusting and light pitting in moist atmospheric exposures, whereas the 300 series stainless steels can be expected to retain their stainless appearance.

Corrosion resistance in water

Table III shows the corrosion behaviour of carbon steel, Type 410 and Type 302 stainless steel in Mississippi River water at Winfield, MO after 8 years[3]. These data indicate that Type 410 is likely to pit in fresh water whereas Type 302 is resistant to pitting. Type 410, and other 400 series stainless steels, not only are subject to pitting, they also develop rust films in fresh waters. This greatly limits usefulness in roller chain and retainer rings where they have been commonly used because of their mechanical properties.

The 300 series stainless steels are inherently resistant to pitting and rusting in fresh water. However, these alloys are subject to crevice corrosion and to microbiologically influenced corrosion in fresh water under certain conditions.

Table III Corrosion behaviour of carbon steel and stainless steels (Based on 8 yrs. of exposure to Mississippi River water at Winfield, MO)

Material	General Corrosion Rate, ipy* (mm/yr)	Pit Depth, in. (mm) Max.	Avg.
Carbon steel	0.0012 (0.5)	0.055 (1.4)	0.040 (1.1)
Type 410 stainless	**	0.027 (0.7)	0.016 (0.4)
Type 302 stainless	0	0	0

*Note: * inches per year*
*** Loss was totally due to pitting attack.* *Source: USACERL Technical Report REMR-EM-6, Dec. 1989, NTIS[3].*

Crevice corrosion in 300 series stainless steels — Crevice corrosion is sometimes referred to as oxygen concentration cell corrosion. Under adherent deposits and in tight stationary crevices, the dissolved oxygen in the water is rapidly depleted resulting in a zone of oxygen depletion within the crevice. The crevice area is linked to the rest of the surface outside the crevice, immersed in water of normal oxygen content, hence the term oxygen concentration cell. Crevice corrosion does not occur in any given crevice until all the conditions necessary for breakdown of the protective film are met. Chloride ion concentration, pH, and temperature, as well as oxygen depletion, all influence the occurrence of crevice attack in any given crevice.

Kain, Tuthill, and Hoxie([4]) report Type 304 stainless steel to be resistant to this type of localized corrosion in tight stationary crevices in waters up to about 200 ppm chlorides and Type 316 to be resistant up to about 1000 ppm chlorides. In many western ground waters where chlorides are greater than 200 ppm, Type 316 is preferred to Type 304 for its greater resistance to crevice corrosion. For waters of several thousand ppm chlorides and coastal saline waters, Alloy 400 and Alloy K-500 are preferred over Type 316 due to their greater resistance to crevice corrosion. Type 904L and the 6% molybdenum superaustenitic stainless steels are alternative materials for highly saline waters.

Other metals in water — Nickel, aluminum, phosphor (tin) and silicon bronzes and austenitic cast irons are quite resistant to localized corrosion and exhibit very low general corrosion rates in the range of 1 to 3 mils per year in most natural waters. Yellow brass, from which small screws and fasteners are commonly made, tends to dezincify and generally has a limited service life in water service. Other brasses and manganese bronze, which contain more than 15% zinc, also tend to dezincify unless inhibiting elements are incorporated into their composition. American Water Works Association specifications are quite clear on the types of water that produce dezincification.

Galvanic corrosion

Two different alloys in contact with each other in a moist atmosphere, water or other electrolyte, form a galvanic couple in which the corrosion of one is increased and the corrosion of the other is decreased. A galvanic series applicable to the materials used in locks, dams and hydroelectric equipment is shown in *Table IV*.

In most applications where stainless steel and Alloy 400 are used in fresh water these alloys are in contact with less noble alloys such as carbon steel, cast iron, aluminum, Ni-Resist, or zinc (galvanized steel). The galvanic effect is favourable for stainless steel or Alloy 400 and unfavourable for the other, less noble, component. In most applications, the galvanic effect is in the direction desired and is beneficial. In cases where the corrosion rate of carbon steel is not acceptable, passive cathodic

Table IV Galvanic series for fresh water

ANODIC, LEAST NOBLE
Magnesium
Zinc
Aluminum
Carbon steel and cast iron
Ni-Resist
Aluminum bronze
Phosphor bronze
400 series stainless steels
Alloy 400
300 series stainless steels
Graphite
CATHODIC, MOST NOBLE

protection by magnesium blocks, rods and ribbons is often used. There are exceptions.

Carbon steel welded to stainless steel — Carbon steel is usually coated up to where it is welded to stainless steel. All coatings tend to break down in the rough area of the weld. Below the water line, galvanic corrosion frequently results in a deep groove in carbon steel parallel to such welds. There is no good remedy other than annual inspection, rewelding and recoating, or by introducing sacrificial anodes when the geometry of the assembly allows.

High strength bolting — The galvanic circuit that exists between fasteners and surrounding structures in water, generates and releases hydrogen at the cathodic stainless steel surface. For most 300 series stainless steels, hydrogen release at the cathode poses no problem. However, when bolting materials of greater than 100,000 psi tensile strength are used, hydrogen has caused cracking in ferritic and precipitation hardening stainless steels and Alloy K-500. Although aluminum-to-high-strength-bolting and zinc-to-high-strength-bolting couples can generate enough hydrogen to cause hydrogen cracking, it is the use of impressed current cathodic protection systems that most often leads to hydrogen cracking. It is best to limit selection of bolting materials to alloys with tensile strengths of less than 100,000 psi when there is any possibility of galvanic coupling with aluminum or zinc. The same practice is recommended when cathodic protection of the whole structure is planned or likely to be installed later.

Aluminum and stainless steel fasteners — While stainless steel is an excellent choice for fasteners in aluminum structures, the galvanic effect tends to enlarge the hole to a point where drop-out of the fastener is possible. To counter the adverse galvanic effect on aluminum, aluminum fasteners are sometimes used despite their lower strength. Filling the hole in aluminum with a silicone or other grease specifically compounded to adhere to, and displace water from the surface, is very effective in preventing hole enlargement in aluminum when stainless steel fasteners are used. Most greases tend to increase corrosion and should be avoided unless they have been specifically compounded for this service.

Carbon or graphite containing gaskets and lubricants — Carbon is quite noble to stainless steel. In saline waters severe galvanic corrosion of stainless steel flanges has occurred where graphite-containing gaskets have been used. Graphitic packing has led to similar corrosion on pump shafts and valve stems in saline waters. As a result, caution should accompany the use of this combination of materials in saline water.

Galvanic corrosion of stainless steel from contact with graphite has not been reported in fresh water service and materials containing graphite are widely used in fresh water applications.

Cast iron pumps — In cast iron pumps with copper alloy impellers, a form of galvanic corrosion is frequently reported that is puzzling to the user. When such pumps are initially placed into service, the iron phase of the cast iron corrodes and, in so doing, galvanically protects the copper alloy impeller, extending the time before the impeller must be replaced. After the first replacement, the second copper alloy impeller sometimes lasts only a few months instead of several years. Findings indicate that the cast iron pump case corrodes in a manner that leaves a uniform layer of graphite on the surface. Once the graphite layer forms, the galvanic relationship reverses and accelerates corrosion of the copper alloy impeller, greatly shortening its life. The remedy is to replace the case, preferably with Ni-Resist or stainless steel.

Cavitation

Cavitation resistance is important in hydro turbines, pump impellers and related equipment. Cavitation damage occurs when the collapse of vapour bubbles, due to low pressure, is severe enough to result in pitting-type metal loss in a localized area. This damage may be referred to as "cavitation pitting", "cavitation damage", or "cavitation erosion": all these terms are equivalent. Cavitation has been a problem to the hydro power industry for several decades and in the last few years has been the focus of surveys, investigations and development work by organizations such as the Canadian Electrical Association[5], the Electric Power Research Institute [6] and a number of power utilities. A typical example of cavitation damage on a pump impeller vane is

Table V Relative cavitation resistance of engineering materials

Material	Cavitation resistance
Cast iron	0.1-0.4
Manganese bronze	0.5
Cast carbon steel	1.0
Carbon steel plate	1.0
Aluminum bronze	3.6
309 stainless steel overlay	5.0
Cast stainless steel (CA-6NM)	5.5
Cast stainless steel (CF-8)	5.5
Stainless steel plate (304)	5.5
308 stainless steel overlay	7.1
Stellite 21 overlay	50.0

Note: Cavitation resistance is relative to carbon steel casting.
Cavitation resistance factors were derived using a number of references.

Source: EPRI Report AP-4719, Vol. 1 & 2[6].

Photo, courtesy of the State of California Department of Water Resources.

Figure 3 Cavitation damage to a pump impeller vane.

shown in *Figure 3*. The impeller is made of CA-15 that was previously repaired with Type 309L stainless steel weld metal. Further cavitation is shown on the weld repair surface. The pump was in service 17 years at the Edmonston Pump Plant, Tehachapi Lift.

Cavitation damage is influenced by design, by operating conditions, by water velocity and other factors that affect vapour bubble formation and by the resistance of the material to cavitation damage. Cavitation tends to be site and design specific. Laboratory tests of cavitation resistance of materials also tend to be specific for the particular test conditions. *Table V* shows the relative resistance to cavitation of materials commonly used in hydraulic turbines based on both laboratory tests and field experience. *Table VI* shows the relative resistance to cavitation of the weld metals commonly used for welded repair of cavitated areas. *Table VI* is based on field experience.

It is evident from *Table V* that cast iron varies considerably in its resistance to cavitation, in part due to differences in casting quality in ways that have not as yet been well defined. Manganese bronze is less resistant to cavitation damage than carbon steel and more difficult to weld repair effectively. Aluminum bronze is more resistant to

Table VI Cavitation resistance of weld materials, data derived from various sources

Material	Relative cavitation resistance
E7018 Carbon steel	1.0
309 Stainless steel	5.0
316 Stainless steel	6.3
308 Stainless steel	7.0
Haynes 25	9.2
NITRONIC 60	13.2
FERRALIUM 255	14.5
Stellite 21	49.0

Note: The cavitation resistance values should be considered as a guide only. They do not necessarily reflect the true relative cavitation resistance under all operating conditions.

Source: EPRI report AP-4719, Vol. 1 & 2.[6]

cavitation than carbon steel and requires special treatment to weld repair effectively. Information from the manufacturer or qualified experts should be sought when weld repairs of cavitation damage to aluminum bronze must be undertaken. The *Table V* survey shows that stainless steel runners, usually Type CA-6NM, have a superior performance in resisting cavitation pitting.

Repairing cavitation damage

There are two basic repair methods; rebuilding the area with alloy plate, or with weld overlaying. In both methods, the damaged area is machined or ground to sound metal. Cavitated areas repaired with stainless steel are subject to grooving of the carbon steel next to the stainless weld due to the galvanic effect. Such grooves should be ground back to sound metal and welded with Type 309 filler metal. The grooving may continue further out adjacent to the newly repaired 309 to carbon steel junction and will require periodic attention and rework. This is normal and cannot be avoided.

Repairing with alloy plate — When deep cavitation damage occurs, a solid stainless steel plate can be used to cover the area. This is successful when the plate is not subject to vibration. Plug welds are often used for mid-plate attachment in addition to welds around the periphery.

Repairing with weld overlay — Because the weld overlays are applied to a wide range of surface geometries and the extent of damage may vary considerably, only general guidelines can be offered on the welding procedure. They are:

☐Preparation — The area to be overlayed is prepared by chipping, air carbon arc, grinding, or other suitable means to arrive at sound metal. Deep excavations should be bevelled to allow adequate access for welding.

☐Preheat — Since most overlay welding is done in situ (in place), preheat may be impossible or very difficult at best. The base metal composition and degree of weld restraint (metal thickness) strongly determine the need for preheat. When the turbine composition is not known, the manufacturer should be consulted for his preheat recommendations. Thick carbon steel castings with a relatively high carbon equivalent are an example of materials which may require preheat. In any case, it is good practice to bring the metal up to at least 60°F (15°C) to prevent moisture condensation in advance of the weld.

☐Filler metals — Stainless steel has been the long-time standard filler metal, either Type 309 or 308. As shown in *Table VI*, Type 308 appears to have somewhat better cavitation resistance than 309, however, the latter has better weldability as an overlay on carbon steel and is generally chosen for that reason. For deep cavitation repairs, one or more layers of Type 309 may be capped with Stellite 21 or a duplex stainless steel. The same filler metal selections can be used in overlaying CA-6NM castings provided the repair is not so extensive that a weaker weld metal is a problem. These have been the standard filler metals, but there are proprietary weld filler metals that are also being successfully used for cavitation damage repair.

☐Welding process — Overlay repairs are usually made by shielded metal arc welding, SMAW, commonly called stick welding or by gas metal arc welding, GMAW, also known as MIG welding. Each has advantages. SMAW is more portable, faster to set-up for small repairs, and is not affected by air currents that could disturb the shielding gas in the GMAW process. Advantages of GMAW are a faster deposition rate and no slag to remove after welding. Out-of-position welding, particularly overhead, is best done with pulsed arc GMAW rather than other arc transfer processes. With an eye to the future, robotic GMAW overlay repair welding shows promise.

☐Weld sequence — When an appreciable amount of welding is involved, weld bead sequence should be such that minimum residual stresses are imparted to keep distortion to a minimum. Other helpful practices include a limit on interpass temperature, peening all passes except the last, and a continuous check on distortion during welding.

☐Contour grinding — After welding, the overlay should be ground to the proper contour using templates or other aids.

Galling

Alloy materials are used for the sealing surfaces on large dam gates. These sealing surfaces slide over each other when the gates are opened or closed. The sealing surfaces must not only resist corrosion, they must also resist galling and abrasion. Austenitic stainless steels and Alloy 400 tend to gall in like-metal sliding contact and in contact with each other. Neoprene rubber and a variety of nonmetallic materials are therefore used on one of the surfaces. However, nonmetallics have other limitations. When it is desirable to use metallic materials for both faces, it is possible to select materials that are both galling and corrosion resistant. *Table Vll* shows the combinations of metallic materials that are most useful in preventing galling and the combinations that are most likely to gall. The 400 series stainless steels are subject to rusting and pitting in fresh water and for these reasons are omitted from *Table VII*. Nonmetallics are also omitted since *Table VII* is confined to materials for metal to metal seals.

Valves

Alloy usage

Copper alloy trim is standard for the American Water Works Association (AWWA) gate valves. Stainless steel is an optional seating material for ball and check valves and other valve components. Stainless steel is used on the periphery of the disk of butterfly valves. Stainless steel is very resistant to the velocity and turbulence in valves but is susceptible to scoring on seating surfaces.

The two precipitation-hardening grades, 17-7PH and Custom 450 are used for valve stems, bars, and other similar items when material with higher strengths than Type 304 are required.

The duplex stainless steel, Alloy 2205, is increasingly used for shafting and valve stems as well as fabricated equipment in other industrial applications. Alloy 2205 has about twice the yield strength and equal or better corrosion resistance than Type 316/316L. It seems likely that this alloy will find increasing use in fresh water applications.

UNS C83600 (85 Cu, 5 Zn, 5 Sn, 5 Pb), the common cast brass alloy is widely used for small valves and exhibits its low corrosion rates in most waters. Usage of C83600 and other copper alloys with appreciable lead content in potable waters may be limited in the future, because of the lead content.

Fabrication Processes

Welding

The law carbon grades, Types 304L and 316L, are used in sheet and plate form when welded fabrication is required. The lower carbon content of these two grades guards against the possibility of intergranular attack in the heat-affected zone of welds. Type 308L or 316L are used as weld filler metal.

Heat tint and staining

Heat tint on stainless steels is the oxide formed on the surface from heating to a high temperature, such as in the welding operation. The heat tint is often along the side of the weld or the result of welding on the reverse side of a sheet or plate. Staining of stainless steel fabrications during initial service usually results from the presence of iron particles embedded in the surface during fabrication, shipment, or on-site storage. In atmospheric or low chloride water service, such discolouration and stains are more a cosmetic than a technical problem. Both embedded iron and heat tint are easily removed by pickling in HNO_3-HF which is standard practice with quality fabricators.

Pickling can be done by immersion or by locally applying pickle paste followed by a thorough water rinse. Pickling, unlike passivation, is best described as controlled corrosion of the surface. Pickling removes the protective oxide film and 0.001-0.002 in. (0.0254-0.0508 mm) of the surface beneath. In removing a small amount of surface material, pickling also removes embedded iron and other foreign matter. The clean surface rapidly forms a passive film in air and requires no further treatment. Pickling may alter close dimensional tolerances; a factor to evaluate when

Table VII Galling — Metallic material combinations

Alloys	300 Series	PH	NITRONIC 60	Alloy 400	Bronze	Ni-Resist	Waukesha 88
300 Series Stainless Steels	G	G	R	G	R	R	R
PH Stainless Steels	G	G	R	G	R	R	R
NITRONIC 60	R	R	R	R	R	R	R
Alloy 400	G	G	R	G	R	R	R
Bronze	R	R	R	R	R	R	R
Ni-Resist	R	R	R	R	R	R	R
Waukesha 88	R	R	R	R	R	R	R

Note: G =Galls
R = Resistant to galling

surface improvement by pickling is considered.

Heat tint can also be removed by light grinding with clean aluminum oxide abrasive discs. Glass bead blasting with clean glass beads is also effective in removing heat tint. Grinding with a grinding wheel should be avoided as this tends to disturb and reduce the corrosion resistance of the surface to a considerable depth. Abrasives that have previously been used on carbon steel should never be used on stainless steel surfaces. Sand and grit blasting should also be avoided as both processes roughen and tend to embed tramp iron in the surface.

Machining

Machined stainless steel surfaces frequently retain traces of the machine tools used in machining and handling operations. These traces of iron-base materials rust in fresh water and may initiate deeper pitting beneath. Nitric acid passivation treatment, or pickling, is frequently called for after degreasing to thoroughly clean the surface. As noted previously, pickling removes 0.001 to 0.002 in. (0.0254-0.0508 mm) of the metal surface and may alter close dimensional tolerances. Nitric acid does not remove the passive oxide film that forms on stainless steel in air, but it may alter the sheen of the surface finish.

PART II

Introduction

Part II illustrates a variety of gate designs and some screen designs currently used in large hydro systems. It begins by reviewing the many areas where commonality exists among all types of water control gates, i.e., gate leaf and skin materials, seals, and fasteners. It proceeds to describe several types of water control gates along with the construction and materials information which is pertinent to each. The following types of water control gates and screens are discussed: fabricated and cast slide gates, fabricated and cast sluice gates, fixed wheel and roller gates, tainter gates, locks, lock mitre gates, and jet flow gates. It then covers significant details relating to the design and construction features of submerged travelling screens and drum screens and shows specific locations, within the structures, where various types of nickel-containing materials are in use.

General information

Gate leaves and skins

Nickel alloyed cast iron with a minimum tensile strength of 40,000 psi (2812 kg/cm^2) is frequently used for gate leaves and frames. When sizes become too large for casting, they may be fabricated from one of the nickel-copper, high strength, low alloy, HSLA steels. These HSLA steels not only have higher strength than ordinary steel but the rust which forms on weathering is tightly adherent, and more protective than the less adherent rust film on carbon steel. Paint life is also extended by the dense, adherent nature of the oxide formed. The low alloy steels usually are not more corrosion resistant than ordinary steel in submerged applications.

Seals

All water control gates have some type of sealing device to prevent the leakage of water at closures. Seals may involve metal-to-metal contact or metal in contact with a neoprene or other non-metallic gasket. When the gates are being closed, the two parts of the seal may move toward each other and finally be pressed together tightly, or they may slide over one another until a complete seal is effected. In all seals there is need for the use of corrosion resisting materials that will not roughen and abrade the seal surface.

In non-sliding seals involving metal-to-metal pressure, the adjoining faces must be accurately machined to ensure a good seal. If either face becomes worn or corroded, leakage occurs and the escaping water under high pressure can cause rapid erosion of the seal; thus, a material having both corrosion and erosion resistance is required. Type 304 and 316 stainless steel and nickel alloys such as Alloy 400 are widely used and have given satisfactory continuous operation in this type of application since 1936.

When seals involve the use of metal-to-metal sliding contact of the sealing members, corrosion resistance is important to prevent the dragging of accumulated corrosion products between the sealing faces. The sealing members must have a low coefficient of friction and must not gall or roughen each other.

When it is desirable to use metallic materials for both faces, it is possible to select materials that are both galling and corrosion resistant. *Table VII* shows the combinations of metallic materials that are most useful in preventing galling and the combinations that are most likely to gall. The 400 series stainless steels are subject to rusting and pitting in fresh water and for these reasons are omitted from *Table VII*. Nonmetallics are also omitted since *Table VII* is confined to materials for metal-to-metal seals.

In fresh water, Type 304 stainless steel is the favoured material for one member. The second seal member may be Type D-2 Ni-Resist, or possibly a tin or aluminum bronze, both of which provide resistance to corrosion and galling. In recent years, NITRONIC 60, a stainless alloy developed to resist galling, has also been used successfully with Type 304 in fresh water.

In brackish or saline water, Alloy 400 is the standard material for one seal member with Type D-2 Ni-Resist as the second member. Waukesha 88 is a proven alternate to Type D-2 Ni-Resist.

When the seals involve a metal component operating against a neoprene gasket, the metal part of the seal must remain smooth to prevent cutting the neoprene. This is especially important when the neoprene wipes against the metal part as it moves into place. Type 304 stainless steel and Alloy 400 have been used successfully for the metal in contact with the neoprene. Since austenitic stainless steels and Alloy 400 tend to gall in sliding contact with each other, neoprene rubber and a variety of nonmetallic materials are used for one surface against these materials.

At times, it is necessary to replace the neoprene gasket. This requires that the seal bars be made of a material which does not clog with corrosion products and can be easily disassembled. Nickel stainless steels again offer advantages in these respects for both bars and bar fasteners.

In some installations the water pressure may be great enough to cause the face of one sealing member to bow away from the mating seal. A seal wedge is commonly incorporated to prevent this. Wedges should be made of corrosion resisting material to prevent binding from corrosion products.

If the thickness of the stainless steel plate required for such applications as sill or foot plates and side seal retainers becomes great, it may be economically advantageous to consider using a clad plate with 20 to 30% of the thickness as alloy instead of a solid alloy plate. A clad plate can achieve the necessary strength and stiffness without sacrificing the needed surface corrosion resistance.

Screws, bolts, nuts, and washers

High strength corrosion resisting materials are important for fasteners in units that may be disassembled for inspection or maintenance. If fasteners of ordinary steel or other non-corrosion resisting materials are used, there is the likelihood that the corrosion products will bind the threaded parts in the holes so tightly, that only cutting can separate the parts. Type 304 is widely used for bolts and washers and a non-galling stainless steel such as NITRONIC 60 for nuts. When higher strength bolting is required, an age hardenable alloy such as Custom 450 may be used. Alloy 400 fasteners are preferred for saline waters.

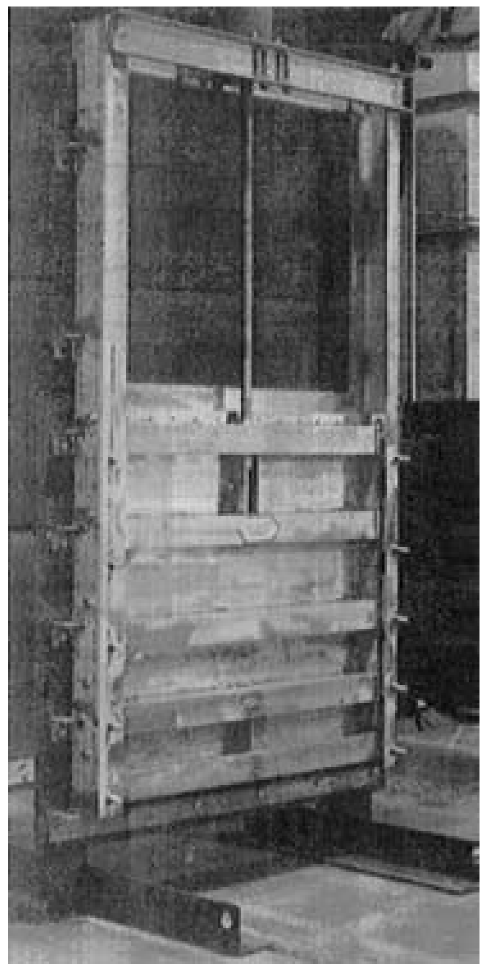
Fabricated slide gates
Cast iron sluice gates

Slide gates and sluice gates are raised and lowered by sliding in vertical guides. Cast iron sluice gates are designed to mount on the face of a wall, either on the upstream or downstream side, but are not suitable for installation in a channel. Fabricated slide gates are ideal for channels because the guides can be fashioned for embedding in the concrete side walls. In a channel installation, the slide gate can be used in either seating or unseating heads because the disc, or sliding member, will take a position to seat in either direction. The slide gate can also be mounted on the face of a wall to cover an opening; however, under these conditions it is not suitable for an unseating head because there are no wedges to hold the disc to the frame.

Guide bars and brackets

Guide bars and brackets that guide the gates into position must be designed with small clearances between the bar and bracket to control positioning accurately. Since gates are frequently left in one position for extended periods of time, the small clearance space between the bars and brackets may become filled with corrosion product if corrosion resisting materials are not used, making it difficult or even impossible to move the gate. Painting, to prevent corrosion, is not reliable because the paint is rubbed off during the operation of the gate. Freedom from galling between bar and bracket is also necessary to prevent binding. The combination of Type 304 solid or hollow guide bars and Type D-2 Ni-Resist for the brackets provides the desired corrosion resistance and freedom from galling.

Fabricated all stainless steel slide gates are often used where the application presents corrosion difficulties with other materials of construction. Type 304 or 304L stainless steel is adequate for most environments but for severe conditions, Type 316 or 316L is a better choice. A self-contained stainless steel gate is shown in *Figure 4.* The entire gate, including the frame and all fasteners, is stainless steel for corrosion resistance. Seals typically use a highly resilient material such as neoprene against a stainless steel face and are held in place with a stainless steel strip and bolts. Designs allow final adjustment in the field.



Photo, courtesy of Rodney Hunt Company.

Figure 4 A self contained stainless steel slide gate.

Cast iron sluice gates are widely used in water, sewage and waste treatment plants for flow control. There are a number of variations of sluice gates and positions in which they are installed. Size can vary from as small as 1 ft. square (0.093m^2) up to 12 by 15 ft. (3.7 by 4.6 m). *Figure 5* is a view of three 72 by 60 in. (1.8 by 1.5 m) sluice gates in the Metropolitan Denver Northside Primary Treatment Plant. Cast iron, such as ASTM A-126, Class B, is usually used for the frame, disc, and guide. A 2% nickel cast iron has higher mechanical strength and is specified by some users. Bronze is commonly used for metal-to-metal seals. It has adequate corrosion resistance in most environments and does not gall or seize. In industrial wastes, it is usually necessary to use stainless steel seat facings.

Stainless steel is the standard material for stems and fasteners in both slide and sluice gates. It is used for stems because of better corrosion resistance and higher strength than bronze. Stems are usually Type 304 but Type 303 may be used for better machinability. The stem thrust nut is usually bronze but when the gates are operated in modulating service, a cast nylon operating nut and a polished stainless steel stem are used successfully. Stainless steel stems have given years of excellent service provided threads are cleaned and lubricated periodically. Type 304 bolts and nuts are commonly used for those applications that are seldom unbolted and where galling is not expected. An excellent combination to resist galling is a Type 304 bolt and NITRONIC 60 nut.

Photo, courtesy of Rodney Hunt Company.

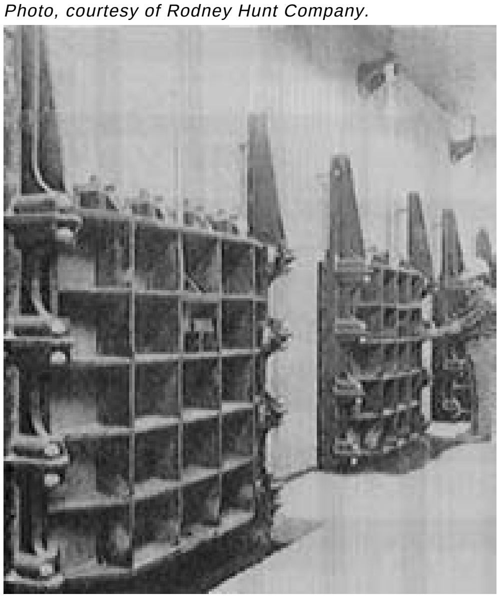


Figure 5 Sluice gates under construction for the Metropolitan Denver Northside Primary Treatment Plant.

Fixed wheel gates Roller gates

On large gates subject to great forces from water pressure, it becomes necessary to roll the gates into position, rather than to depend on sliding mechanisms. Wheel gates and roller gates provide this type of rolling contact.

On fixed-wheel gates, a series of fixed wheels mounted along each side of the gate carry the water load to a vertical track on the downstream side of the gate

Photo, courtesy of U.S. Bureau of Reclamation.

Figure 6 Fixed wheel gate shop assembly, Red Bluff Diversion Dam.

groove. The wheels substitute rolling friction for sliding friction thereby reducing the operating force. In an emergency situation, the gate can close under its own weight.

Figure 6 shows the shop assembly of a 60 by 18 ft. (18.3 by 5.5 m) fixed wheel gate for the U.S. Bureau of Reclamation, Red Bluff Diversion Dam. *Figure 7* shows the same gate installed and modified with a stainless steel flap leaf on the top. Stainless steel is used in the flap leaf for face plate, hinge pins, seal guards, and clamps. Neoprene rubber is the seal material.

The seal and wheels of a fixed wheel gate for the U.S. Bureau of Reclamation Yellowtail Dam, Penstock Intake, is shown in *Figure 8*.

The roller gate, also called a tractor, coaster, or stoney gate, is similar to the fixed wheel gate. This gate is generally larger than the fixed wheel gate and has a train of rollers, instead of wheels, on a track to reduce friction as the gate is moved. The types of seals and structural materials are similar for both types of gates.

The gate leaf or center section of the gate is structural steel but stainless steel is used in a number of working areas where corrosion resistance is needed.

Photo, courtesy of U.S. Bureau of Reclamation.

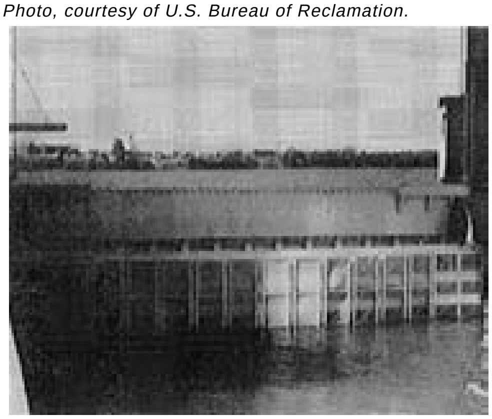


Figure 7 Stainless steel flap leaf installed at Red Bluff Diversion Dam.

Wheels and rollers

Wheels have been made of alloy steel, ductile cast iron, a hardenable stainless steel, or steel with a stainless steel rim. Material selection is based on the number and size of wheels to meet the hydrostatic loads. For rollers and wheels, the corrosion resistant nickel-containing materials provide low resistance between moving parts as well as high strength to prevent deformation of working parts under heavy loads. Age hardening stainless steels have the necessary corrosion resistance that the 400 series hardenable alloys lack in fresh water; thus, when high strength is required in fresh water applications, the precipitation hardening alloys 17-4PH, 15-5PH and Custom 450 are preferred to the 400 series stainless steels.

Type 17-4PH has proven to be an excellent replacement for Type 410 as the pin in roller chain. Type 15-5PH has displaced 410 for the small but vital retainer ring component of many assemblies with much-improved performance and longer service life. Using these materials, compact components can be designed with the desired corrosion resistance combined with the necessary

Photo, courtesy of U.S. Bureau of Reclamation.

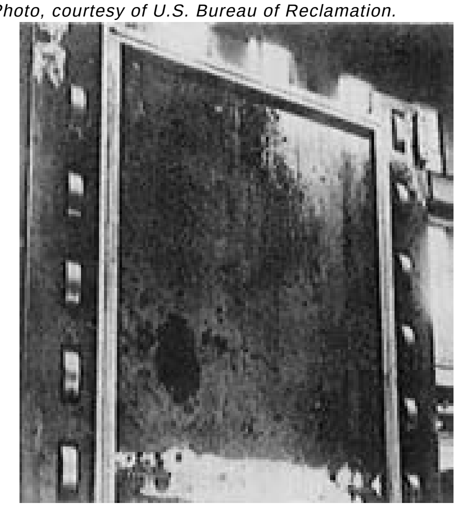


Figure 8 Seal side of a fixed wheel gate, Yellowtail Dam.

strength and hardness to ensure long life.

On roller gates, the U.S. Corps of Engineers has, in the past, used Type 410 stainless steel rollers that can be heat treated to a hardness of 259 to 307 Brinell. The roller gates for the Oahe Dam on the Missouri River demanded a wheel material with greater strength and hardness than Type 410. The age-hardenable Type 17-4PH stainless steel has proved an excellent wheel material for the Oahe Dam and others. After machining, the wheels are given a low temperature 900 to 1150°F (482 to 621°C) precipitation hardening treatment, developing a hardness of 385 to 418 Brinell. These changes allowed a 25% reduction in roller width and better corrosion resistance than is possible with Type 410 stainless steel.

Tracks and seals

Hardenable stainless steel facings such as Type 17-4PH are often applied to a structural steel member to support the wheel track. Type 304 stainless steel plate is used for side seal and sill plate. A high quality rubber seal closes any remaining clearance.

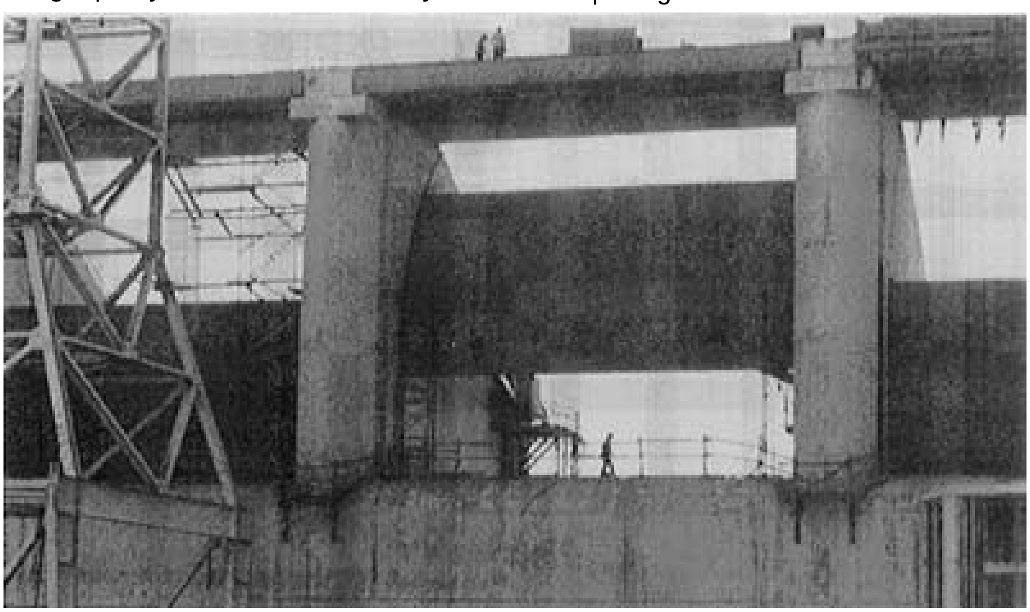
Upstream tracks, end tracks, track guides, and links which are not subjected to high pressure do not require high strength materials; however, resistance to corrosion and freedom from binding are needed. Type 304 stainless steel has proved to be well-suited for such applications.

Passive cathodic protection

Magnesium blocks, rods and ribbons are usually provided to off-set the galvanic corrosion effect on the carbon steel.

Radial gates — tainter gates

Radial gates or tainter gates, as they are most often called, are used as spillway crest gates and in some high-pressure outlet works. They are built in the shape of a cylindrical sector and rotate about a horizontal axis. The leaf, or movable part, consists of a curved face plate supported by vertical side beams which are backed by horizontal wide-flange beams that span the complete width of the opening. Radial arms attach to each



Photo, courtesy of U.S. Bureau of Reclamation.

Figure 9 Radial gates being installed at Brantley Dam.

side of the leaf and extend back to trunnion bearings anchored in concrete piers. *Figure 9* shows a 50 by 25.25 ft. (15.2 by 7.7 m) radial gate being installed at the Brantley Dam, a U.S. Bureau of Reclamation project. The view is from the upstream side and the center of the photograph shows a gate in a partly open position. The gate is lifted by stainless steel wire ropes attached

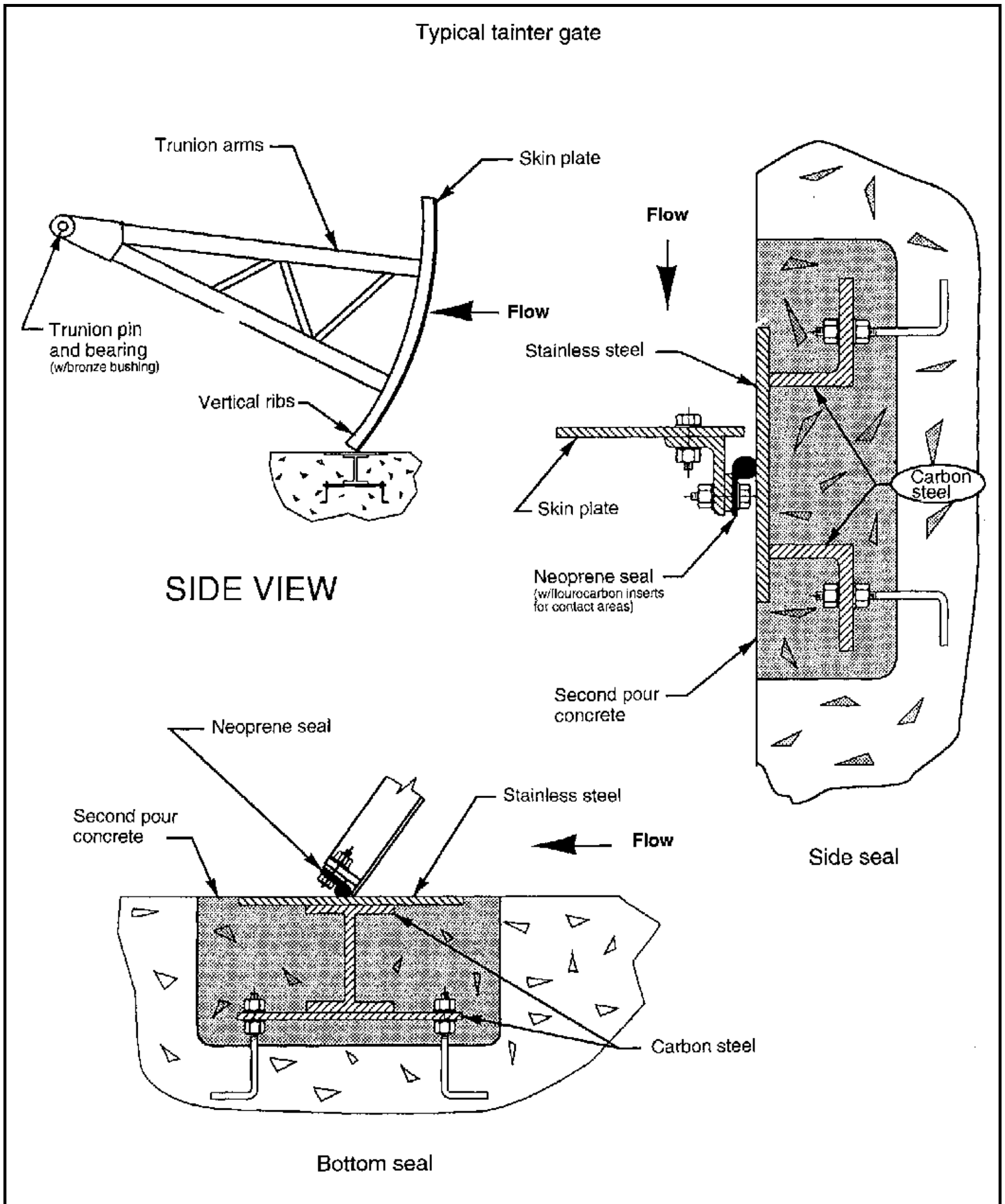


Figure 10. Design features of a typical tainter gate, showing a side elevation and enlarged views of side and bottom seal design.

Figure 10 Design features of a typical tainter gate, showing a side elevation and enlarged views of side and bottom seal design.

near the gate bottom and extending up to hoisting drums.

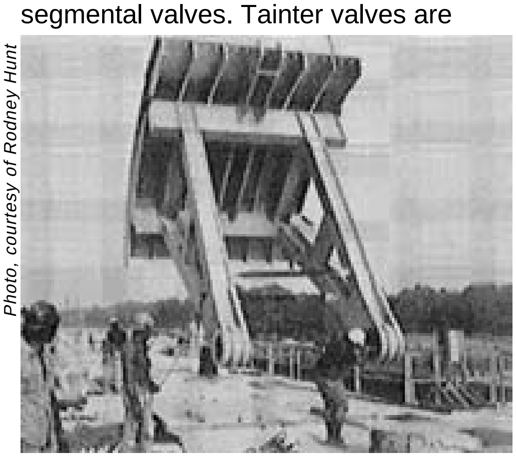
Seals

The U.S. Army Corps of Engineers' standard practice on tainter gates is to use neoprene (preferably with fluorocarbon inserts for rubbing contact areas) side seals held in place by stainless steel bars and fasteners. The side seal rubbing plates are stainless steel. Design of the bottom seal depends on the amount of leakage allowed under the closed gate. If a small amount can be tolerated, the finished bottom edge to the leaf mates against an embedded stainless steel sill plate. If a tighter seal is needed, a neoprene seal is attached to the bottom of the gate. The seal plates may be solid stainless or clad plate with 20% of the thickness as stainless steel. Stainless steel seal plates provide a smooth facing surface against the rubber seals whereas ordinary carbon steels would corrode, producing a surface that would abrade and wear the seals. *Figure 10* shows a typical side and bottom seal design.

Similar in appearance to tainter gates are tainter valves that are often used in large new locks to control water flow into and out of the locks. Other names for tainter valves are reverse tainter or segmental valves. Tainter valves are positioned opposite from tainter gates in that the supporting side arms with trunnions are upstream of the radial skin plate. On high lift locks, a stainless steel skin plate is used to prevent cavitation. Because the valves close off a conduit in the lock, they must seal across the top as well as down both sides and across the bottom when in the closed position. Stainless steel is used for the embedded guides (the seal section when the valve is closed) and extended guides on the conduit when the leaf is raised.

On locks with lifts above 75 ft., the concrete culvert is often provided with a stainless steel liner from just above the valve sides to approximately 15 ft. downstream of the valve in the closed position. The stainless steel liner is needed to prevent erosion damage to the concrete conduit.

Tainter valves in large locks are operated by hydraulic cylinders through a rocker arm assembly. In large units, the piston rods may be 6 in. in diameter and 10 to 12 ft. long. Custom 450 and NITRONIC 60 are often used for the rods. *Figure 11* shows a tainter valve for Tenn-Tom waterway.



Photo, courtesy of Rodney Hunt

Figure 11 A tainter valve being lowered into position for Tenn-Tom waterway .

Locks and lock mitre gates

Lock mitre gates are hinged gates installed at each end of the lock to seal off the lock from either the upper or lower pool, tail water elevation. Lifts may vary between 8 and 110 ft. Each set of gates has two leaves and each leaf is hinged to the lock wall. The leaves are fabricated steel while stainless steel is used in the seal areas described below. A sketch of the seal areas in a typical mitre gate is shown in *Figure 12*.

The bottom seal consists of a sill nosing on the lock mitre sill and a neoprene J-seal on the gate leaf. The design of this seal is similar to that of the tainter gate shown in *Figure 10*.

The seal between each leaf in the closed position is made with mitre blocks which are often stainless steel. Typically the mitre blocks are 8 by 6 in. and 15 to 20 ft. long with splices lining up with the centerline of the horizontal girder webs. Custom 450 stainless steel is often used for blocks. The position of the blocks is adjusted by push-pull bolts to match the mitre blocks

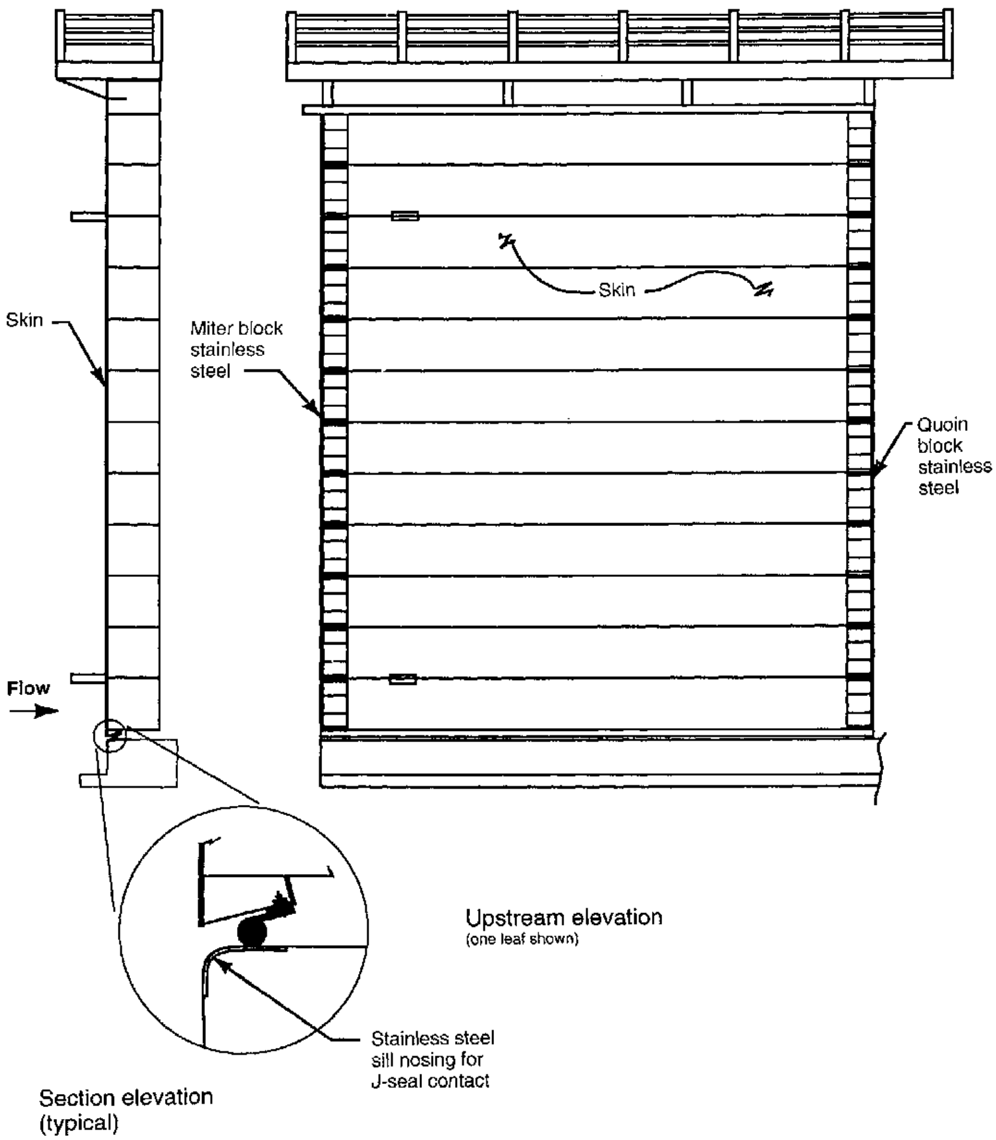


Figure 12. Lock miter gate with bottom seal, miter blocks and quoin contact blocks.

Figure 12 Lock mitre gate with bottom seal, mitre blocks and quoin contact blocks of the adjacent gate. Void areas are filled with an epoxy and transfer the water loads from the mitre gate contact blocks to the lock wall.

Another seal is located where the mitre gate seals to the lock wall. This seal is accomplished by placing quoin contact blocks at the end post leaves of the mitre gates that, in turn, mate with quoin contact blocks mounted on the lock walls. The quoin blocks on the lock walls are essentially the same as the mitre blocks except that the wall quoin has a concave surface and the quoin block on each leaf has a convex surface of the same radius to ensure a good water seal. In addition to making a seal, the wall and mitre gate quoin contact blocks transfer the lockage water loads into the lock's mitre gate monolith. Quoin contact blocks are approximately the same size as mitre blocks and are often made from Custom 450 Alloy.

Photo, courtesy of the U.S. Bureau of Reclamation.

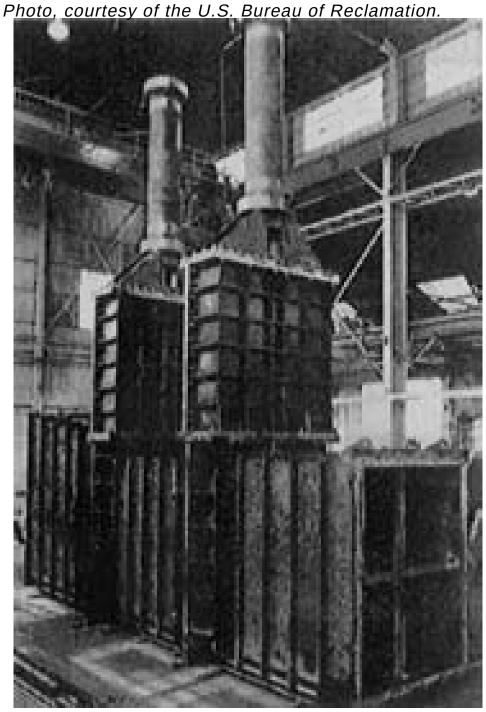


Figure 13 High pressure regulating and emergency gates, Dolores Tunnel.

Experience over many years has shown that the cost of replacing corroded carbon steel contact blocks is many times greater than the initial cost of the stainless steel blocks.

High-pressure control gates Jet flow gates Bonnetted slide gates

The high pressure control gates, jet flow gates, and slide gates are similar in design. They are commonly located in a discharge conduit in the center of the dam to control the outlet. They are embedded in concrete except for the actuator. The head on the gate is often quite high, 300 ft. (91.4 m) or more seating. The gates are usually installed in tandem with the upstream gate as the emergency gate and the downstream one as the control gate.

The gates are fabricated steel with stainless steel used in such areas as:

- gate stems
- seal seats
- selected areas in the steel body and leaf
- numerous fasteners where high corrosion resistance is needed.

Figure 13 shows the U.S. Bureau of Reclamation 5 by 7 ft. (1.5 by 2.1 m) high pressure-regulating and emergency gates for the Dolores Tunnel. *Figure 14* shows the 30 in. (76.2 cm) jet flow gates at the Waddell Pumping-Generating Plant.

Trash racks and submerged travelling screens

To protect from foreign material entering hydro turbines and cooling systems of power plants, the intake water often is passed through trash racks and submerged travelling screens, STS. A typical arrangement is shown in *Figure 15*.

Photo, courtesy of the U.S. Bureau of Reclamation.

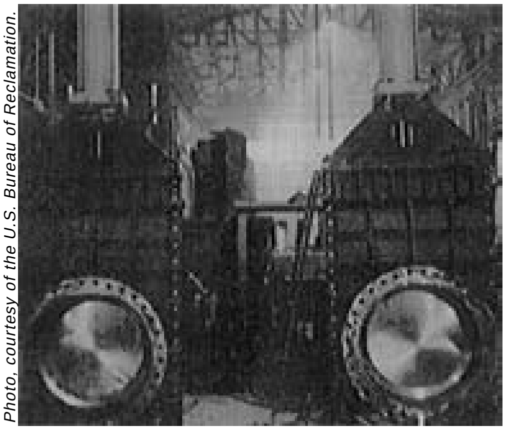


Figure 14 Jet flow gates, Waddell Pumping-Generating Plant.

Photo, courtesy of Envirex Inc. Waukesha, WI.

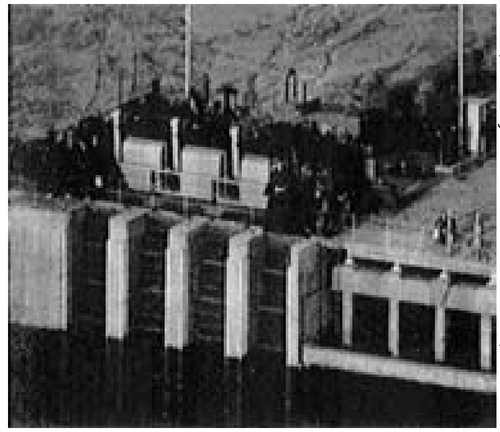


Figure 15 Submerged travelling screens in a typical hydro intake section.

Illustration, courtesy of Envirex Inc., Waukesha, WI.

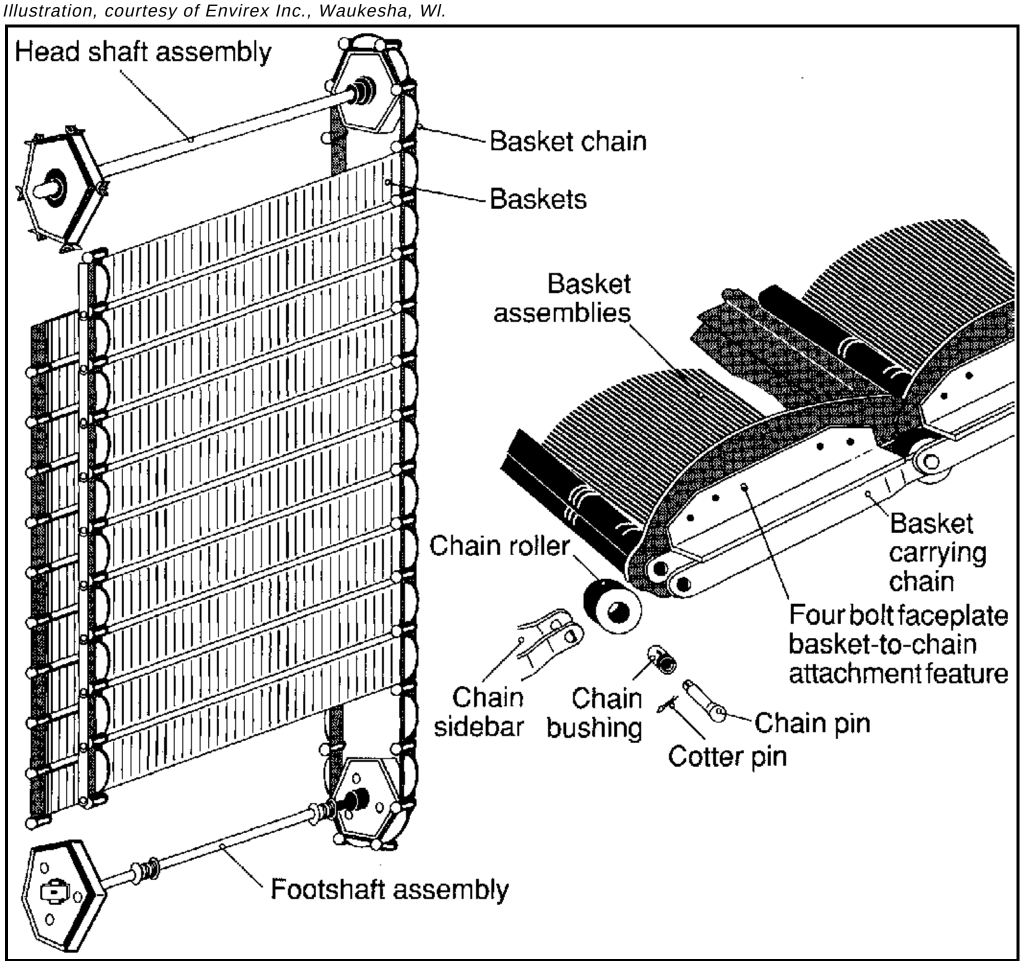


Figure 16 Submerged travelling screen, screen frame assembly and basket assembly.

Trash racks

Typical Materials of construction

The main structure is principally structural steel, ASTM A36. Since the trash rack guides are submerged and not accessible for maintenance, stainless steel is recommended for longer life than is possible with carbon steel. In waters that are quite corrosive to steel, the vertical bars may be stainless steel. Fasteners are usually stainless steel.

Submerged travelling screens

Submerged travelling screens, STS, are made up of a series of horizontal sections called buckets that are mounted to a basket chain. A typical screen section could have a 10 by 20 ft. (3.1 by 6.2 m) face dimension with two or more sections in a large installation. An STS basket chain assembly is shown in *Figure 16*.

Typical materials of construction

- ☐ Main structure — structural steel, ASTM A36, for areas that can be maintained by painting.
- ☐ Screen basket section tracks — Type 304 bar.
- ☐ Roller chain — NITRONIC 60 pins, Type 17-4PH bushings.
- ☐ Wire rope for extending mechanism Type 304.
- ☐ Fasteners — Type 304 bolts and 304 or NITRONIC 60 nuts.

Performance

Stainless steel chain with NITRONIC 60 pins and bushings of Type 17-4PH, outlast hardened alloy steel chain by a factor of at least 5 to 1 in typical applications.

Pictures of a number of submerged travelling screens installed at various sites are shown in the *Figures 17-19* that follow.

Photo, courtesy of U.S. Corps of Engineers, Pacific Division.

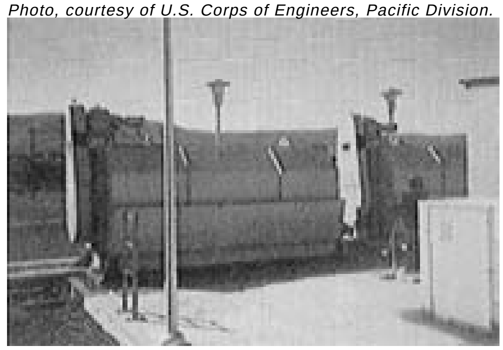


Figure 17 A submerged travelling screen installed at a pump bypass structure, Chandler Canal Fish Facilities, Yakima, Washington.

Photo, courtesy of U S. Corps of Engineers, Pacific Division,

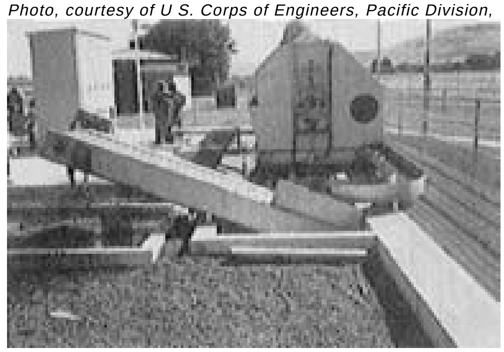


Figure 18 A screen conveyor servicing the debris flushed from a submerged travelling screen.

Photo, courtesy of U S. Corps of Engineers, Pacific Division,

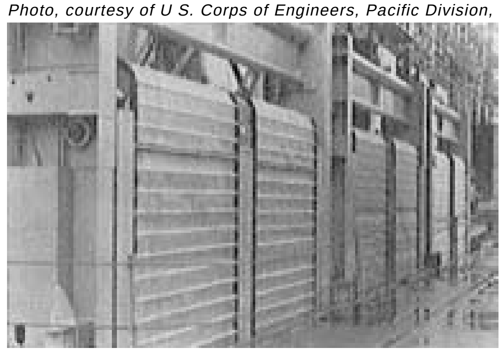


Figure 19 Submerged travelling screens installed at Bonneville First Powerhouse, Columbia River, Oregon.

Drum screens

A drum screen is a cylindrical structure supported from a central shaft located along the cylinder's centerline and mounted horizontally and perpendicular to the water flow in the channel. A series of screen panels covers the outside of the drum screen. The drum receives power through a chain drive mounted at either end of the drum screen or, alternately, it can be driven by a large gear mounted to its exterior surface. Power to turn it is furnished, respectively, by a gear drive with either a sprocket and chain or a meshing gear pinion.

The drum diameter can be as large as 50 ft. (15.2 m) with lengths up to 14 ft. (4.3 m).[7]

Water flow through the drum screen is double entry. It is channelled to enter into the inside surface in an axial direction in the lower portion of the drum screen. The screen surface is equipped with shelves designed to retain the entrapped solids until they are lifted to the top of the drum where they are flushed into a debris trough and allowed to flow axially out of the drum.

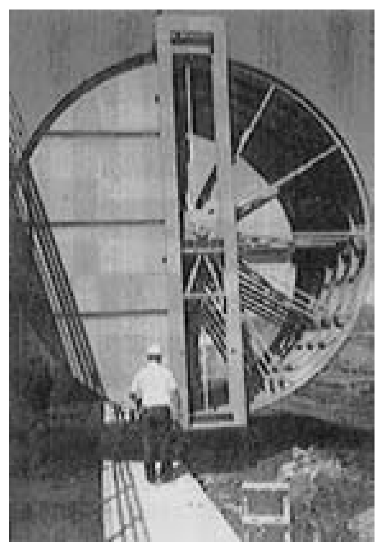
The structure is built up from a fabricated steel hub which becomes the anchor point for a series of spokes fashioned from angle iron. The spokes are welded to the hub at the outer edges of the drum and then are angled in to the center of the drum where they are joined to the central support hoop. From the central hoop, structural members extend either side of center to join and support the two side hoops which form the ends of the drum screen. The stainless steel screens are laid, two courses wide, over the three support hoops.

The hoops and spokes are made from structural steel. Threaded fasteners are typically Type 304 stainless steel with brass nuts. The screens and screen clamp bars are Type 304 stainless steel.

The rolled steel rim of the drum mates up to a similar rolled angle bolted to the concrete walls of the drum chamber to provide a seal. This seal can be improved through use of neoprene to close the clearance gap.

A variation of the drum screen is the single, entry or cup screen which is similar to the drum screen except that the support shaft is mounted parallel with the channel flow. The upstream end of the drum is open and the downstream end is closed by a backplate. The water enters the open end of the drum and then turns through a ninety degree angle to exit through the screen on the drum's periphery. In this type of drum screen, a thrust bearing is incorporated on the downstream end of the support shaft to remove the thrust load imposed by the water on the closed end of the drum. The drive for the drum is located behind the backplate. Sizes of cup screens run from 5 to 25 ft. (1 .5 to 7.6 m) in diameter with widths of 1 to 8 ft. (0.3 to 2.4 m).[7]

Figure 20 shows a view of an 18 ft. 9 in (5.7 m) diameter by 12 ft. (3.7 m) long drum screen being moved along the screen structure prior to being lowered into the screen chamber. There are 32 drum screens of this size in the structure.



Photo, courtesy of the U.S. Bureau of Reclamation, Denver, CO.

Figure 20 Tahoma Colusa Canal, California — 18 ft. 9 in. (5.7 m) diameter by 12 ft. (3.7 m) long drum screen.

Figure 21 Tahoma Colusa Canal, California–Downstream view of the drum screen during installation in screen structure.

Figure 21 shows a view of the downstream side of the Tahoma Colusa Facility drum screen during installation in the screen structure.

Figure 22 shows a view of the seal area of the drum screen at the Tahoma Colusa Facility. Note that the drum screen is supported temporarily on one foot high blocks which are later removed. The drum screen is then lowered to close off the bottom space to incoming flow. The wire cloth is stainless steel Type 304, 5x5 mesh, .092 in. (2.34 mm) diameter wire. The clamp bars at the edge of the screen and at the edge of the structure are Type 304 stainless steel. The retainer for the polyurethane brush which seals the space between the bottom of the drum and the structure is also stainless steel.

Figure 23 shows an overall view of the drum screen being installed at the Chandler Canal Fish Facilities, Yakima, Washington. This installation has 24 13 ft. 6 in. (4.1 m) diameter drum screens.

Photos, courtesy of the U.S. Bureau of Reclamation, Denver, CO.

Figure 22 Close-up of the edge and bottom seals at the Tahoma Colusa Facility.

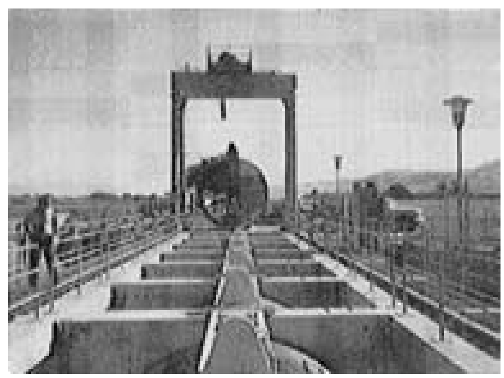


Figure 23 Overall view of the drum screen being installed at the Chandler Canal Fish Facilities, Yakima, Washington.

References

1. Faulring, G.M., “Composition and structure of rust layers and corrosion rate of chromium steels exposed to a marine atmosphere”, *J. Metals*, Vol. 7, N° 4 1972, p. 542.

2. Baker, E. A. and Lee, T. S., “Long term atmospheric behaviour of various grades of stainless steels”, ASTM Symposium on Degradation of Materials in the Atmosphere, May 12-16, 1986.

3. Kumar, A., Myers, J., and Odeh, A., “Mechanical properties and corrosion behaviour of stainless steels for locks, dams, and hydroelectric applications”, USACERL Technical Report REMR-EM-6, Dec. 1989, NTIS.

4. Kain, R. M., Tuthill, A. H., and Hoxie, E. C., “The resistance of Types 304 and 316 stainless steels to crevice corrosion in natural waters”, *J. Materials for Energy Systems*, Vol. 5 N° 4, Mar. 1984.

5. “Metallic overlay materials for the optimum cavitation performance of hydraulic turbines”, Canadian Electrical Association report, CEA N° 135 G 373, June 1987.

6. Cavitation pitting mitigation in hydraulic turbines”, Electrical Power Research Institute report EPRI AP-4719, Vol. 1 & 2.

7. Pankratz, T. M., “Screening equipment handbook for industrial and municipal water and wastewater treatment, Lancaster, PA, Technomic Publishing Company, 1988.

Acknowledgments

The Nickel Development Institute and the authors are grateful to the following organizations and individuals for their photographs, comments and assistance: Bureau of Reclamation, Department of Interior; Corps of Engineers, U.S. Army; Henry O. Dahlinger P.E., formerly Corps of Engineers; Rodney Hunt Company; State of California, Department of Water Resources; Envirex Inc.

Trademarks

Glossary

Gates, Valves and Equipment Used in Water Control Systems
(From International Commission on Large Dams, ICOLD,
Bulletin 31a, and other sources)

Gates

Crest gate A gate on the crest of a dam spillway to control overflow or reservoir water level.

Drum gate A type of spillway gate or barrage-gate consisting of a long hollow drum. The drum is held in its raised position by the water pressure in a flotation chamber beneath the drum. The drum rises with the reservoir and lowers when overtopped by floods, usually automatically. This type is seldom used in the U.S.A. for new construction.

Fixed wheel gate or Fixed roller gate or Fixed axle gate A gate having wheels mounted on the end posts of the gate. The wheels bear against rails fixed in side grooves or gate guides.

Flap gate A gate hinged along one edge, usually either the top or bottom edge. Examples of bottom hinged flap gates are tilting gates and fish belly gates, so called from their shape in cross-section. A check valve is a type of flap gate.

Gate In general, a device in which a leaf or member is moved across the water-way or culvert from an external position to control or stop the flow of water.

Jet flow gate Gate for use in a closed conduit where water velocity is high. When open it produces a contracted jet clear of the gate guides to prevent cavitation. It has a truncated conical nozzle, a floating seal-ring which forms a circular discharge orifice at the down-stream end of the nozzle, and a flat-bottomed gate leaf which is moved across the seal-ring orifice to regulate the discharge.

Mitre gate Gate at each end of a lock to seal off the lock from either the upper pool or lower elevation. Each mitre gate consists of two leaves. They are hinged to the lock sidewall and swing together to close.

Outlet gate A gate controlling the outflow of water from a reservoir.

Radial gate or Tainter gate A spillway gate whose face is a section of a cylinder with radial arms on the downstream side that are hinged to piers or other supporting structure. See *Figure 9*.

Ring-follower gate or Ring-seal gate or Paradox gate A gate for use in a circular conduit where water velocities are high. The lower part of the gate leaf has a circular aperture which precisely matches the conduit diameter so as to allow smooth flow when the gate leaf is raised.

Roller drum gate or Rolling gate A crest gate for dam spillways comprising a long horizontal cylinder spanning between piers. The cylinder is fitted with a toothed rim at each end and rotates as it is moved up and down on inclined racks fixed to the piers. In the U.S.A., this type has largely been replaced by tainter gates.

Roller gate or Stoney gate A gate for large openings which bears upon a train of rollers in each gate guide.

Sluice gate or Penstock (UK only) or Slide gate A gate which can be raised or lowered by sliding in vertical guides. See *Figures 4* and *5*.

Spillway gate or flood gate A gate to control flood release from a reservoir. An example of this type is a tainter gate.

Valves

Hollow jet valve A valve for regulating high-pressure outlets. Essentially it is half a needle valve in which the needle closure member moves upstream toward the inlet end of the valve to shut-off flow. As there is no convergence at the outlet end, the flow emerges in the form of an annular cylinder, segmented by several splitter ribs for admitting air into the jet interior so as to prevent jet instability.

Howell-Bunger valve A valve for regulating high pressure outlets and ensuring good energy dissipation. Inside the valve there is a fixed-cone, pointed upstream, which ensures dispersion of the jet. Outside the valve a cylindrical sleeve moves downstream to shut-off flow by sealing on the periphery of the cone.

Reverse tainter or Segmental valves Valves used to control water flow into and out of locks by closing or opening a conduit in the lock. Tainter valves are positioned with the supporting side arms and trunnions upstream of the face plate.

Valve In general, a device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway so as to control or stop the flow.

Hydoelectric Turbines

Francis turbine This turbine is used in high head power generating plants and operates at medium speed with a radial flow of water in the runner. Francis units differs from the Caplan turbines in that the blades are supported top and bottom.

Caplan turbine This turbine is a low head compared to the Francis turbine. The blades many be fixed or the pitch adjusted during operation to obtain the most efficient angle for power generation. Bulb turbines are a type of horizontally mounted Caplan turbine designed for low head applications.

Pump-turbine This unit is a Francis type designed to provide peak demand electric by pumping water to a high storage area during low demand periods and reversing to become a turbine at peak demand.

Other equipment

Fish pass Any form of artificial passage for fish, such as fish ladder, fish lock or fish lift, to enable migratory fish to surmount an obstruction such as a weir or dam or natural falls.

Trash rack A screen comprising metal or reinforced concrete bars located in the waterway at an intake so as to prevent the ingress of floating or sub-mergeddebris. The term Screen is used in UK. Hence the expressions “fine screen” and “fish screen”.

Gate components

Anchor bolts Hook type bolts that are embedded in concrete to which the gate components are fastened. Anchor bolts are usually steel but may be stainless steel.

Gate leaf Face of various types of gates that withstands the water load and is moveable to allow passage of water.

Mitre blocks Metal blocks placed along the edge of each lock mitre gate leaf that mate to and provides a seal to the adjacent gate leaf when in the closed position.

Quoin contact blocks Metal blocks that make a seal between the end post leaves of the lock mitre gate and the lock wall.

Seals A variety of designs on all gates to prevent leakage where the movable gate seats against the permanent structure. One design is the resilient type in which the mating surfaces are usually neoprene or neoprene with a fluorocarbon insert against metal, such as stainless steel or bronze. Neoprene J-seals are the most widely used. Another design is a metal to metal seal for high head sluice gates where the metals are bronze to bronze or bronze to stainless steel.

Stem A threaded rod used on a sluice gate to raise or lower the gate. Type 304 or 303 stainless steel in the most common stem material with the thrust nuts and coupling a cast manganese bronze.

Wedges A mechanism to hold sluice gates against the seals on the rides, top and bottom. Material is usually bronze with stainless steel for nuts and bolts.