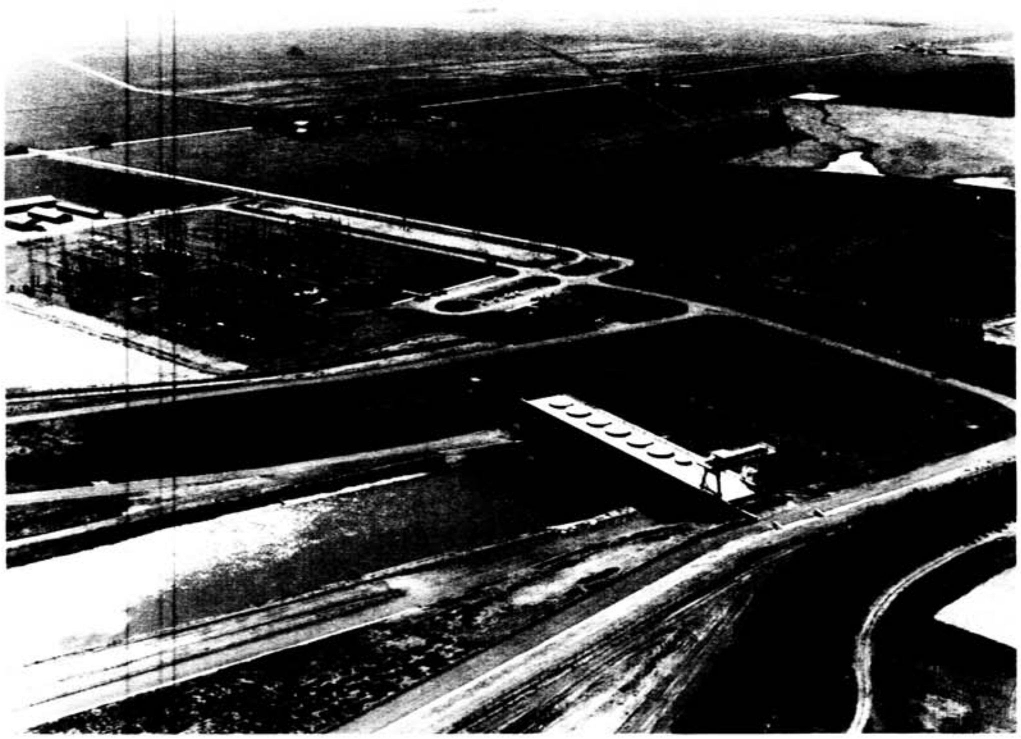
WATER OPERATION AND MAINTENANCE

BULLETIN NO. 157

September 1991



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IN THIS ISSUE

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging information for use by Bureau personnel and water user groups for operating and maintaining project facilities.

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Cover photograph:

Tracy Pumping Plant. Aerial view of pumping plant, switchyard, and control building. San Luis Unit—Delta Division—Central Valley Project, California.
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METHODS FOR THE REPAIR OF CAVITATION DAMAGE TO METAL SURFACES

by Joseph P. Martino[1]

Throughout the history of the Bureau of Reclamation (Reclamation), the prevention and repair of cavitation damage to metal surfaces has been an integral part of ongoing maintenance activities. The loss of material resulting from cavitation costs thousands of dollars in repairs and downtime each year; therefore, new and innovative repair techniques are continually sought after and evaluated that will give better and longer lasting results. Material selection and repair procedures will greatly affect the relative success of a repair and will depend on a variety of factors including accessibility, ventilation, type and condition of base material, weather conditions (temperature and humidity), water conditions (i.e., wetness due to gate leakage), and tolerable downtime. Since many irrigation districts do not operate during the winter months, downtime for repairs is typically not a problem, but weather conditions and the availability of personnel may greatly affect the decision of when and how to perform repairs. On the other hand, in order to maximize power generation revenues, it is desirable to operate hydroelectric units year round, so downtime for repairs can be more difficult to schedule. All of these factors will influence the selection of a repair method.

A survey was sent to Reclamation's regional offices in August of 1990 in order to ascertain what tried-and-true methods, as well as new techniques, were being utilized by Reclamation field personnel in these types of repairs. The regional offices, in turn, distributed this questionnaire to the project and field offices within their jurisdictions. The focus of this article is to summarize the responses to these surveys, provide information on new developments, and provide some general conclusions about cavitation damage repair techniques. A summary of the majority of responses to the survey is contained at the end of this article, and is presented in spreadsheet form.

This article is not intended to be a "how-to" guide on the use of the methods and materials presented here. Much literature is available pertaining to the use and proper techniques involved with the application of these materials. These include manufacturer's literature, the American Welding Society's (AWS) "Handbook" and "Standards"; the Electric Power Research Institute's EPRI AP-4719, "Cavitation Pitting Mitigation in Hydraulic Turbines"; Reclamation's FIST Vol. 2-5, "Turbine Repair"; and other technical publications. Although some of these references deal specifically with turbine repair, the techniques outlined can be extrapolated for use on other metal surfaces.

Methods and Materials

There are two basic categories of materials which are currently being utilized for repairing the voids in metal surfaces caused by cavitation. These can be grouped into the fused and non-fused categories. Other methods include replacement of parts with those made of more cavitation resistant materials and welding of large solid plates in areas of severe damage.

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Fused Repairs

The use of fused material, better known as weld repair, is the most common and, to date, the most successful method of repairing cavitation damage [1][2]. A weld repair would typically include air-arcing out the damaged area to sound metal, filling to within 3/8 of an inch of the original surface with a mild steel weld material (e.g., E7018 electrode), filling the remainder with a 300 series austenitic stainless steel, and grinding to the original contour. The external overlay of stainless steel tends to be more cavitation resistant than mild steel. However, mild steel has been successfully used to completely repair an area, but usually it only holds up well if it is possible to remove the source causing the damage (e.g., a surface discontinuity). It may also be considerably cheaper, depending on the amount of material required, to use only mild steel. New weld materials have recently been developed that are designed to be used in place of the stainless steel overlay. These materials, high-strength cobalt austenitic stainless steels, are claimed to have 2 to 10 times the hardness of stainless steel, as well as superior wear-resistant properties, yet are as easy to grind as AISI Type 308 stainless steel. One such material, Stoody Hydroloy HQ913, has been used to repair turbine runners at Hoover Dam and is holding up well, but repairs were done fairly recently, so the long-term durability is unknown. This material looks promising for use in areas of severe cavitation erosion. Nitronic 60, a manganese-silicon stainless steel, has been used at the J. F. Carr Powerplant with success, but again, repairs are less than 2 years old. Repairs on turbine runners at Hungry Horse Powerplant using this material as an overlay atop mild steel weld have lasted 4-8 years.

Weld repairs are relatively long lasting and normally are effective, on average, for a period of approximately 4 years. If the sources of cavitation are removed from the system, these repairs will last indefinitely. However, many times this is not feasible since the item or discontinuity causing cavitation to occur is typically an integral part of the equipment or operating requirements. Areas adjacent to weld repairs can also be easily repaired using similar methods, without having to remove old repair material, as may be the case with non-fused materials. The increased cost of weld repairs when compared to the use of non-fused materials will usually be made up in the longevity of the repair and decreased downtime for repairs and inspections over the course of several years.

Weld repairs do have some disadvantages, and are generally more complicated to use than non-fused materials. Often, it is difficult to determine the composition of the parent metal unless mill specifications or lab test results are available. The composition will affect such factors as preheat time and temperature, electrode selection, and maximum interpass temperature. Certain materials, such as cast iron and bronze cannot be effectively weld repaired. Other factors such as humidity, dew point, surface preparation, and the experience of the welder(s) will all affect the soundness of the repair. Equipment setup time, adequate ventilation for personnel safety, and difficult access to the area under repair can all limit the use of weld repairs. Warping and cracking can also be negative byproducts of welding. Finally, the heat-affected zone may be annealed during welding causing it to become subject to increased attack by cavitation.

[2] Numbers in brackets refer to References at end of article.

Non-fused Repairs

Non-fused materials are sometimes cheaper and easier to use than welding. Non-fused materials include epoxies, ceramics, metal spraying [2], and neoprene and urethane coatings. By far, the most commonly used are the epoxy compounds with brand names such as Belzona and Devcon. These and many other similar products available on the market today have been used with limited success. Repairs made using epoxies have been known to last less than 1 year under high head applications, although the average duration is approximately 2.5 years. However as with weld repairs, if the source of cavitation is removed, epoxy repairs have been known to last indefinitely. Surface preparation is very important when using these compounds, and manufacturer's instructions must be strictly followed in order to achieve the best possible results. The surface preparation recommended by most manufacturers includes sandblasting the damaged area down to "white metal," cleaning with some type of solvent, and controlling base metal temperature and surface moisture. Ventilation is also required when using epoxies, although the volume and type of fumes produced are not as severe as those involved with welding. Generally, the actual costs associated with the application of epoxies will be less than that of welding. These compounds are mostly used as stop-gap or interim repairs and are often considered to be a sacrificial surface. Epoxies are often used when time constraints, access, or base materials are not conducive to weld repair.

The main disadvantage involved with the use of non-fused material is the relatively low bond strength achieved between it and the parent metal. Although this strength can be maximized by using the recommended techniques, it still cannot achieve that of a weld repair. During a weld repair the interface between the weld material and base metal melts and re-solidifies during the process. On the other hand, the epoxy compounds rely more on a "gluing" action. The bonds formed at the interface are subject to degradation under the extreme forces of cavitation. Epoxies also become hard and brittle after curing, so they should not be used in areas of flexural stress. Epoxies can be troublesome if an area in which they were used is to be weld repaired later. These compounds will burn and produce toxic fumes if exposed to a welding flame and will rapidly gum up grinding wheels, so whatever portion remains will usually have to be chiseled out by hand, which can be a time consuming and frustrating process.

Replacement vs. Repairs

Often, it is cheaper and easier to replace equipment such as small pipe elbows, strainers, and other secondary equipment than it is to attempt to repair it. Yet other equipment parts such as turbine seal rings and slide gate seats are designed to be replaced after the end of their useful lives. If an area of cavitation is severe enough, it can be prepared and a solid plate used to fill the void. It is important to use full strength penetration welds and plug welds in order to hold the plate in place and to reduce any bending stresses in it [1]. Any void left behind the plate should also be filled with an appropriate compound.

Case Studies

Several case studies are presented below in order to illustrate actual field repair methods:

Hungry Horse Powerplant

Maintenance personnel at the Hungry Horse Project Office noted in their questionnaire that they have tried epoxies in the repair of their 105,000-hp Francis turbine runners, but they will not stay on at this high head application. It is for this reason that they use only weld repair on these units. Their normal repair procedure for damage greater than 1/4 inch in depth is to remove the damaged metal and fill to within 1/4 inch of the original surface with E7018 mild steel weld rod. If a significant amount of grinding is expected, the remainder is filled with E309 stainless steel weld rod. In areas of severe damage and/or where not much grinding is anticipated, Nitronic 60 stainless steel is used as the outermost layer. These repairs can be expected to last 4-8 years and are very similar to those presented in FIST Vol. 2-5.

Arrowrock Dam

The steel and bronze seats downstream of the seals on the 52-inch-diameter Ensign needle valves at Arrowrock Dam are repaired annually using the epoxy material Devcon stainless steel (Stock #10270). Weld repairs here are nearly impossible because of the base materials, exposure of the valves to weather, and very poor access for personnel and equipment. Epoxy is used mainly as a stop-gap measure or sacrificial surface to prevent further loss of base material. Although a good bond is usually obtained, the epoxy only lasts a season at this high head (100 feet) application.

Friant Dam

At Friant Dam a resin epoxy (META-LOX by National Chemsearch) is used to repair the 96-inch hollow jet valves. Areas of minor cavitation damage (1/4 to 3/8 inches in depth) in the cast iron ribs and flow splitters as well as dents and cuts in the manganese-bronze seats are repaired using this material. Welding has not been used here because of the base material types and because the high pre-heat temperature required tended to unseat and warp the shrunk-fit bronze ring. The manufacturer's instructions are reportedly simple to follow and generally result in satisfactory adhesion. The valves are overhauled every 4 years.

Seminoe Powerplant

At Seminoe Powerplant vanes had been welded into the fabricated steel draft tubes below the normal standing water line. Extensive cavitation damage resulted to the material surfaces downstream of the vanes due to the discontinuity caused in the flow path. The vanes were removed and the damaged areas air arced out. Rolled steel plates were then cut to fit and welded in place using E7018 electrodes and following AWS standards. Any voids between the new plates and the existing concrete were filled by pumping in Devcon Flexane 80 using grease fittings and a grease gun. Repairs are expected to last indefinitely since the source of cavitation has been removed.

Shasta Powerplant

Generator cooling water is supplied from the tailrace at Shasta Powerplant by six 1,800 gal/min jet pumps. Disassembly of one of the jet pumps revealed extensive cavitation damage to the turning vanes in the inlet and discharge elbows. New vanes will be fabricated from stainless steel to replace the damaged carbon steel vanes. These pumps have been in operation for 50 years, so the replacement vanes are expected to last at least that long.

Lemon Dam

The downstream body of each 2.3- by 2.3-foot high-pressure gate at Lemon Dam showed significant cavitation damage. These areas were cleaned, prepared, and filled with Devcon A plastic steel. Because of the depth of the damage, the epoxy compound was applied in layers and allowed to cure for 24 to 48 hours under heat lamps. After repairs were completed, orifice bars were installed vertically along the side seats, between the gate leaf and damaged area. The installation of the orifice bars allows air to flow down the sidewalls behind them, reducing the chance of cavitation damage [3]. The orifice bars slightly reduce the coefficient of discharge for the gates, but have significantly increased the life of these repairs.

Conclusions

There are many methods and techniques available for the repair of cavitation damage to metal surfaces. Obviously, site conditions, prior experience, and common sense will dictate which method will be the most cost effective and efficient repair. Location, rate and severity of damage, operating conditions, and head are also important factors to consider.

In general it is always a good idea to initially consider weld repair over other methods. If site conditions are proper, weld repair will give longer lasting and more satisfactory results than other methods. Of course, repair costs will greatly affect this decision. If weld repair is not feasible, then other materials such as epoxies should be used as stop-gap measures or sacrificial surfaces to protect the base metal. Since cavitation damage will build on itself, as well as set up anodic and cathodic corrosion cells on a single surface, material loss will progress rapidly the longer it is left alone. It is, therefore, prudent to repair the damaged areas as soon as possible.

Before or during the repair process, serious thought should be given to determining ways of eliminating the source of cavitation within the system. This could range from things as simple as removing surface discontinuities and operating equipment within specified design ranges to recontouring turbine blades and installing vertical orifice bars on high pressure slide gates. Anything which can be done to lessen or eliminate the severity of the damage will, naturally, lower long-term maintenance costs.

References

1. Duncan, William Jr., 1989. "Turbine Repair," Facilities Instructions, Standards, and Techniques (FIST), Vol. 2-5, Department of the Interior, Bureau of Reclamation.

2. Water Operation and Maintenance Bulletin No. 150.

3. Frizell, K. Warren and Brent W. Mefford, 1990. "Experience with Cavitation in High-Pressure Slide Gates," Water Operation and Maintenance Bulletin No. 151, Bureau of Reclamation, pp. 1-5.

SUMMARY OF RESULTS - CAVITATION QUESTIONNAIRE - AUGUST 1990

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
Francis turbine runner		Type 308 SS	Wire-feed welder	3-4 years	Repairs done in accordance with FIST Vol. 2-5	Palisades Dam	Del Sutheimer	208-483-4015
Kaplan turbine runner and Draft tube		Belzona Molecular Ceramic S&R Metals	manufacturer's instructions	1-2 years	Repairs may last up to 6 years, based on location	Minidoka Dam	James Pendegrass	208-436-4393
Francis turbine runner (unit #5)	cast iron	Type 308-16 SS	FIST Vol. 2-5	3+ years		Minidoka Dam	James Pendegrass	208-436-4393
Turbine runners Pump impellers turbine runners pump impellers	mild steel stainless steel	E7018 weld rod E308 or E309 weld rod	All repairs done in accordance with Grand Coulee Project Office cavitation and crack repair procedures.	as needed	General repair methods used for these types of equipment and materials.	Grand Coulee Dam	Mark Albl	FTS 446-9590
Ancillary equip. such as strainers, pipe elbows, etc.		Devcon Devilar Permagile #10	manufacturer's instructions	as needed		Grand Coulee Dam	Mark Albl	FTS 446-9590
Allis-Chalmers 105 khp Francis turbine		E7018 weld rod Nitronic 60 SS overlay	Fill to within 1/4" of surface with mild steel and overlay with stainless steel.	4-8 years	Nearly identical to FIST Vol. 2-5. Notes also that epoxies will not stay on at high head applications.	Hungry Horse Powerplant	D. Christensen	406-387-5241
52-inch dia. Ensign needle valves	steel and bronze seats	Devcon Stainless Steel (#10270)	manufacturer's instructions	Typically < 1 yr. due to higher head (100') application	Epoxies have not been very effective due to low bond strength, but are used because of difficulty accessing area and welding problems with base metal types.	Arrowrock Dam	Steve Jarsky	FTS 554-1465

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
7,100 hp turbines		Devcon Stainless Steel (#10270)	manufac. inst. (applied in thin layers where damage depth is > 1/4-inch)	approx. 1 year	Epoxy works well due to low head. Time involved is minimal and access is easy.	Black Canyon Powerplant	Steve Jarsky	FTS 554-1465
18,500 hp turbines		Type 308 SS weld repair	FIST Vol. 2-5	3-5 yrs. (dep. on reservoir levels)	Repairs hold up very well	Anderson Ranch Dam	Steve Jarsky	FTS 554-1465
Centrifugal pumps		Elastuff 504 (Abrasion res. polyurethane coating)	manufacturer's instructions	5-10 yrs.	Used as a preventative coating prior to placing pumps in service.	Quincy-Columbia Basin Irrig. District	Dale Waggoner	509-787-3591
Turbine runners	SS cladding	Type 309 SS (.035" dia. wire w/ tri-mix gas of argon, CO2, and HE)	Depth < 1/8" use SS weld only. Depth >1/8" fill to 1/8" w/ mild steel & then proceed as before.	3 yrs. min.	Have tested some Devcon epoxies w/ limited success.	Folsom & Nimbus Dams	Bill Jove	916-988-1707
180-MW Francis turbines			FIST Vol. 2-5 EPRI Manual Vols. 1 & 2	as needed	Prefer to stay away from epoxies	New Melones Dam	Bill Nixon	916-978-5296
96" hollow jet valve	cast iron manganese bronze	META-LOX resin epoxy (by National Chemsearch)	manufac. inst. (used only to fill cuts or voids) not used below 50 F.	approx. 4 yrs.	Welding on bronze seats has proven unsuccessful because high preheat tends to warp and unseat shrink fit bronze ring.	Friant Dam	Roy Fronk	209-822-2211

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
High-pressure slide gate		Liquid Steel (epoxy)	manufacturer's instructions	approx. 5 yrs.	Material was used to fill 1" sq. by 1/4" deep cavities in gate seats	Prosser Creek Dam	Bob MacDougal	702-882-3436
Dome valve		Belzona	manufacturer's instructions	as needed	Last repairs were made 1 yr. ago and still look good.	Lahontan Dam	Bob MacDougal	702-882-3436
Slide gates Balanced valves	mild steel stainless st. cast iron cast steel	E7018 & E309 (on mild & SS) Belzona (on cast iron & cast steel)	E7018 to 1/8" below surf. & complete w/ ss rod (309-16 Wash. Alloy) to orig. contour	4-5 yrs. (weld) 2-3 yrs. (epoxy)	Belzona used on cast mat'l. since it is difficult to weld. Does not adhere well to SS. Used mainly as emergency, stop-gap repairs for short term limited use.	Elephant Butte Dam Caballo Dam	Allan Tow	505-894-6661
Hydraulic Francis turbines		E7018 & E309 SS overlay Belzona RC barrier & R metal	Similar to FIST Vol. 2-5	2-10 yrs. dep. on location & res. elev.	Epoxy difficult to remove when preparing an area for weld repair. No distortion or stress cracking with epoxy.	Elephant Butte Dam Caballo Dam	Craig Weisner	505-894-6661
Slide gates		Belzona R metal	manufacturer's instructions	> 2 yrs.	Epoxy used in conjunction w/ orifice bars downstream of slide gate. Appears to be holding up very well. (See Water O&M Bulletin No. 151, March 1990).	Joes Valley Dam	Craig Bott	801-379-1094
Slide gate (downstream gate body)		Devcon A. Plastic Steel	manufacturer's instructions	4 yrs.	Epoxy applied in thin layers and dried w/ heat lamp. Orifice bars installed downstream of reg. gates to lessen cav. damage.	Lemon Dam	D. G. Peden	FTS 323 6573

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
Slide gate (DS gate body same as previous entry)		Devcon ceramic metal	manufacturer's instructions	unknown	Epoxy applied in thin layers and dried w/ heat lamp.	Lemon Dam	Craig Kiar	605-456-2695
Turbine runner	mild steel w/ SS overlay	E308 E7018	Only E308 used if damage penetrates overlay.	3 yrs.	Bead width <= 0.5" and run in dir. of water flow. Sides of area prepared at 45° angle.	Boysen Powerplant	Ralph Carter	307-527-6256
Turbine runners	various matl's.	E308 E309 E7018	FIST Vol. 2-5	varies	Cav. repair to turbine runners is strictly welding. Many damaged areas have not returned.	Eastern Colorado Projects	John Germann	303-667-4410
Turbine draft tube		Epoxylite #203 (by Epoxylite Corp.)	manufacturer's instructions	1 yr. or less		Eastern Colorado Projects	John Germann	303-667-4410
Slide gate liner		Belzona Ceramic R Metal w/ Ceramic RC Barrier topcoat	manufacturer's instructions	unknown		Tiber Dam	Jerry Moore	FTS 585-6417
Turbine runner Draft tube		Arcoloy FR 308 SS weld wire	Cont. wire feed welder	4 yrs.	Air arc out cav. damage 1/8" to 3/16" deep and 1" beyond affected area.	Yellowtail Powerplant	Steve Reimer	406-666-2443
Francis turbine discharge ring		Belzona Molecular Ceramic Metal	manufacturer's instructions	> 5 yrs.	Use of epoxies in areas of flexural stress have proven unsuccessful.	Glendo Powerplant	Gary N. Hagen	307-261-5665
Francis turbine runner	cast steel	Type 309 SS	GMAW & SMAW in accordance w/ FIST Vol. 2-5	6 yrs.	GMAW process: shielding gas 90% He, 7.5% argon 2.5% CO_2. Grinding stones: Norton Norzon III.	Kortes Powerplant	Gary N. Hagen	307-261-5665

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
85,000 hp turbines		316 wire electrode	FIST Vol. 2-5	4 yrs.	Difficulty in ventilating fumes caused by welding stainless steel from floor of plant.	Trinity Powerplant	Dave Poore	FTS 450-6214
168,000 hp turbines	cast steel	E7018 and 316 wire electrode	FIST Vol. 2-5	2-4 yrs.(units 1&2) 3-5 yrs.(units 3, 4, & 5)	Crown areas need regul. scheduled repairs. Blade trailing edges often need little or no repair.	Shasta Powerplant	Dave Poore	FTS 450-6214
107,000 hp turbines		316 SS (until 1989) Nitronic 60 (since 1989)	FIST Vol. 2-5	2+ yrs. (interval will likely increase w/ use of new mat'ls.)	Since overhauls in '82-84, bucket leading edges have been progressively recontoured. Has slowed damage significantly.	J.F. Carr Powerplant	Dave Poore	FTS 450-6214
2.75' x 3.75' regulating gates		Belzona	manufacturer's instructions	less than 1 yr.	Epoxy only is as an interim measure until major disassembly can be done. Epoxy fails at adhesive bond.	Whiskeytown Outlet Works	Dave Poore	FTS 450-6214
1800 gal/min. jet pump		stainless steel		indefinitely	Old carbon steel turning vanes will be replaced with new stainless steel ones.	Shasta Powerplant	Dave Poore	FTS 450-6214
8-foot dia. draft tube		Devcon Belzona	manufacturer's instructions	8+ yrs. (still in place)	Half of repair made w/ Belzona and half with Devcon for comparison. Both are performing similarly. Successful epoxy repair, cheaper but not as long lasting as welding and grinding.	J.F. Carr Powerplant	Dave Poore	FTS 450-6214
6-inch dia. penstock filling line				as needed	Short section of pipe replaced because of pinhole leaks caused by cavitation damage.	Trinity Powerplant	Dave Poore	FTS 450-6214

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
Francis turbine Runners	cast stainless steel	Type 308 SS	FIST Vol. 2-5	6 yrs.	GMAW process: shielding gas 90% He, 7.5% argon 2.5% CO_2. Grinding stones: Norton Norzon III.	Seminoe Powerplant	Gary N. Hagen	307-261-5665
Francis turbine runners	cast steel	E7018 & E309	FIST Vol. 2-5	3 yrs.	E7018 used for initial buildup, followed by an E309 overlay.	Alcova Powerplant	Gary N. Hagen	307-261-5665
Draft tubes	fabricated steel	E7018	AWS Standards	indefinitely	Discontinuity causing cav. was removed. New liner plate welded in place. Any voids between liner plate and concrete filled w/ Devcon "Flexane 80".	Seminoe Powerplant	Gary N. Hagen	307-261-5665
Wicket gates Turbine runners	steel stainless steel	E309	AWS Standards	as needed during overhall or uprates	Actual repair holds up well, but heat-affected zone shows considerable cavitation.	Hoover Powerplant	Charles Williams Aaron Martin	702-293-8273
Turbine runners	steel stainless steel	E309 Stoody HQ 913	AWS Standards	as needed	Repairs are fairly new, so no long-term info. is available on repair interval.	Hoover Powerplant	Charles Williams Aaron Martin	702-293-8273
Pump impellers		304 stainless steel welding rod	AWS Standards	as needed	Project has only been in operation about 5 years, so damage has been minor.	Havasu Pumping Plant	Fred Stanek	FTS 765-1727
Ring follower gates		Belzona Ceramic R Metal	manufacturer's instructions	2 years	Repairs were made in summer months when humidity is high. May have affected longevity of repair.	Marshall Ford Dam	James N. Clayton	512-473-3264
Pump impellers	bronze cast iron	Devcon (for bronze) Belzona (for cast iron)	manufacturer's instructions	7-8 yrs. max.	Repairs can last this long if coated with United Coatings Elastuff.	Othello Dam	Jim Pavelka	509-488-9081

EQUIPMENT TYPE	BASE METAL	FILLER MATERIAL	REPAIR METHOD	DURATION OF REPAIR	SPECIAL NOTES	FACILITY NAME	PERSON FILING REPORT	PHONE NUMBER
Wicket gates		stainless steel	In-house methods.	as needed	Gate-to-gate surfaces are repaired during generator rewinds.	Shasta Powerplant	Dave Poore	FTS 450-6214
Turbine wear rings	stainless steel	aluminum bronze	Same as original installation.	25+ yrs.	Stainless steel wearing ring replace with Alum.-Bronze to provide dis-similar metal with turbine wearing ring.	J.F. Carr Powerplant	Dave Poore	FTS 450-6214

WATER-ACTIVATED FOAM USED TO SEAL LEAKS AT TEXAS DAM[1]

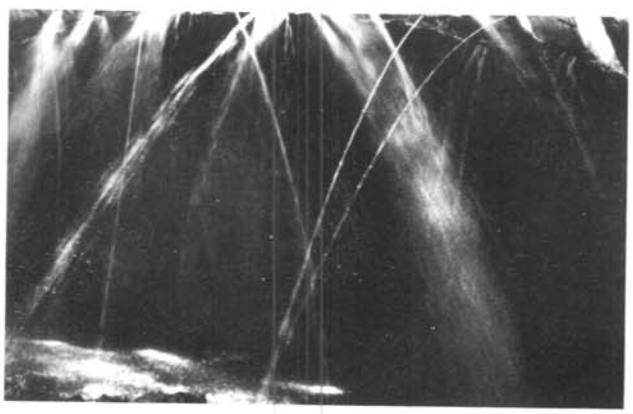
by Troy Ellett[2]

The Lower Colorado River Authority's 36-MW Buchanan Dam near Burnet, Texas, backs up Buchanan Lake, the highest elevation lake in a series of lakes on the Colorado River in central Texas. LCRA, which acquired the project after the original builder went bankrupt in 1932, completed the thin multiple arch dam in 1937.

The area between the original and later construction has leaked continuously since filling of the lake because the older and newer concrete did not bond well. Although the dam is safe, we have sought to stop the leaks because of our commitment to water conservation and dam appearance.

Following numerous attempts to stop the leakage over the years, we have found an effective repair method.

We drill holes into the face of the dam above the construction joint and insert pipes into the holes to divert water from the construction joint (as shown in the photograph on the left). Next, materials are used to temporarily seal the seam, diverting additional water to the pipes. We then inject a water-activated foam under pressure into each pipe to reach the construction joint, where the foam sets and blocks the leak.



At the Lower Colorado River Authority's Buchanan Dam in central Texas, water began leaking from the dam's construction joint after the project was completed in 1937. LCRA has implemented a successful method to stop these leaks. Pipes are installed in holes drilled into the face of the dam to divert water from the joint, as illustrated in the photograph on the left.

With water diverted to the pipes, the flow of water through the joint is reduced, enabling workers to pump foam into the area. In the photograph on the right, pipes to the right of the workers are draining off water while pipes to the left have been pumped full of foam and the leakage stopped. (Courtesy of the Lower Colorado River Authority.)

[1] Reprinted with permission from Hydro Review magazine, HCI Publications, Kansas City, MO, February 1991 issue.

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More than 20 years ago, a similar but more costly method was used to repair one of the dam arches. However, grout used in that repair proved to be ineffective because it became hard and did not move with the dam. We also knew that water-activated foam had been used successfully to repair leaks in underground transportation tunnels and sewer systems in the U.S. By employing elements of the old technique and using a water-activated foam, we have greatly reduced the flow of water in many cases. In cases where we diverted the entire flow of water from the joint during repair, we have stopped the flow entirely.

We began using this permanent repair method in 1985. The foam has performed to our satisfaction, and we have not had to repeat the repairs. We have fixed a total of 600 feet of leaks across several of the arches and plan to make repairs to additional areas.

The copper-sealed construction joint between the two building phases where the leakage occurs is 30 to 40 feet above the foot of the dam. Workers, on occasion wearing wet suits to combat the effects of 60-degree water, use a lift to reach the work area.

The repair process begins with workers drilling holes into the construction joint, or seam. We use 5/8-inch by 24-inch bits to drill holes approximately 12 inches above the seam. The holes are drilled in a horizontal plane to penetrate almost halfway through the arch, which is 3 to 4 feet thick. As a rule, the greater the water volume, the closer together the holes must be drilled along the seam. Drilling for each hole continues until water flows through the hole. A 3/8-inch pipe is then inserted into each hole and driven in with a hammer to assure a secure fit. Next, a valve is installed on the pipe and left open to permit the flow of water through the pipe, diverting water from the seam.

Lead wool, a material similar to steel wool that bonds to itself when compressed, and oakum, a fibrous material, are used to seal the seam. As the seam flow is plugged, the flow of water through the pipes increases. We have experienced some trouble at this point. Sometimes the water pressure increases and pushes the lead wool and oakum back out of the seam. We have had to install more pipes to counter this condition. When all water has been diverted to the pipes, we begin pumping foam into the seam.

A high-pressure pump (capable of pumping up to 5,000 lb/in^2) with a dual cylinder is used to pump the 50-50 mix of chemical foam and water into the seam. The chemical foam and water are pumped through separate hoses, with a mixing manifold connected directly to the 3/8-inch pipe valves installed in the dam. A check valve is also used to prevent back flow of foam or water into the other hoses.

With all valves open and water flowing, one valve on the end of the seam is turned off. A manifold is connected and pumping begins under a pressure of approximately 1,500 lb/in^2. A regulator on the pump is used to control flow pressure of the mix into the seam. The foam mix is pumped until a milky flow is seen from the next pipe. The manifold is then connected to that pipe and the process continues until the flow of water has been stopped. The lead wool helps keep the foam from washing out before it has set. Approximately 40 to 50 gallons of foam are used per seam. We use AV-202 Multigrout, which is supplied by Avanti International of Webster, Texas, for this repair method. The foam is flexible, moving as the dam expands and contracts, keeping the void filled.

In the 5 years since we first used this new material to repair a leaking arch, the foam has performed well. We plan to fix another 1,000 linear feet as time allows, starting this summer. For this next round of repairs, we plan to add another element by depositing cracked kernel corn above the dam. We expect the corn will be pulled into the construction joint, which should make it easier for workers to stop the flow of water before pumping the foam into the seam.

CELLULAR PHONES[1]

New Technology Provides Cost Effect Data Transfer

Recent developments in cellular telephone technology and equipment cost reductions may find this new high technology product in use in more irrigation applications. The applied research and irrigation management groups within the irrigation branch have been using and testing cellulars for some time.

Cellular telephones have now made data collecting even more automated for branch personnel. No longer is a field trip necessary to collect data from their electronic dataloggers, says Svat Jonas, P. Eng., a research engineer with the branch.

Jonas says, the branch uses mostly Lakewood System dataloggers. Our dataloggers are connected to various water-metering devices. It was necessary, on a regular weekly basis, to send a technologist out in the field to download the dataloggers. The datalogger, explains Brian Cook, an electronics technologist with the branch, is basically a small inexpensive computer without the normal screen and keyboard. It usually has a capacity of about 8,000 data points, but Lakewood's new Ultralogger comes with a 32K RAM memory capable of storing 32,000 data points, he adds.

All dataloggers are programmed for reading connected peripheral devices on a regular time interval. The frequency of reading these devices plus the number of enabled channels determines how quickly memory will fill up, says Cook. Research technicians were downloading the memory of our dataloggers once a week.

In the fall of 1990, Jonas added an additional device to the system—a cellular telephone. This single device has added a whole new dimension to data collecting and datalogger programming, he says. Cellular telephones speed up data transfers and are manpower savers for us, says Jonas. Cellular telephones we purchased cost $400 per unit. The cost for the electronic equipment package as shown in the picture is about $2,000. Peripheral devices are extra says Jonas.

There is an unlimited number of applications for the simple setup described above. Our research group has been using this system for monitoring temperatures of air and water, dissolved oxygen levels in dugouts, and water-level fluctuations in irrigation laterals. The irrigation management group under Robert Riewe, P.Ag., has a weather station hooked up in a similar way, says Jonas.

They have an anemometer, tipping-bucket rain gauge, solar pyrometer, humidity probe, and temperature probe all reporting back through the cellular system. An ideal application, feels Jonas, is a system to monitor magmeters or other water-measuring devices. The SMRID (St. Mary River Irrigation District) has been using a similar system to monitor and collect data from an insertion magmeter. The difference being the district is not using a cellular telephone but a fixed AGT telephone line connected to it. Cellular

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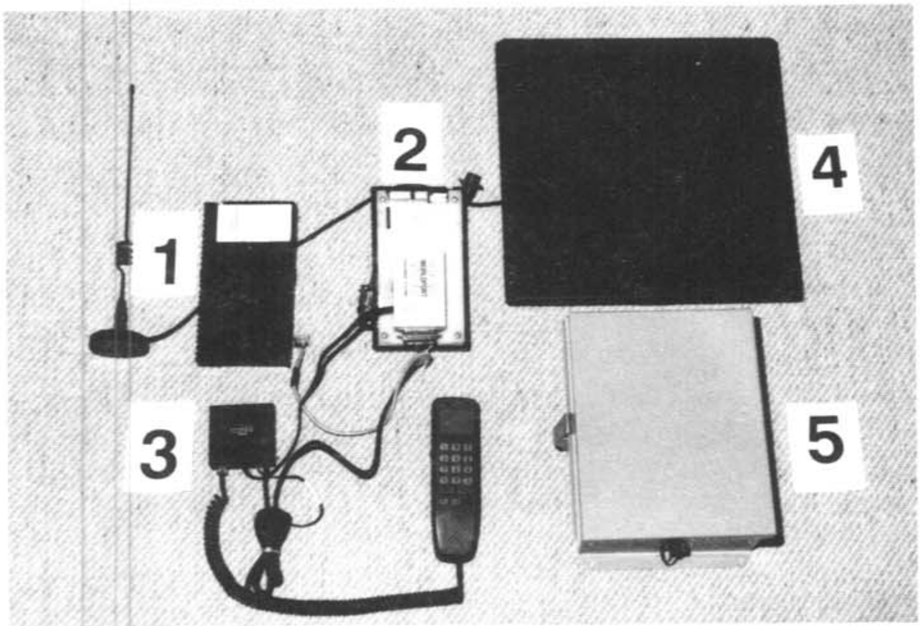
[1] Reprinted with permission from the Editor, Water Hauler's Bulletin, Alberta Agriculture, Lethbridge, Alberta, Canada T1J 4C7, Winter 1991 issue.

telephones cost more money to operate than the ordinary telephone hookup, but in many instances there are no nearby telephones lines, states Jonas.



1. Cellular phone and antenna, 2. datalogger, 3. data interface (allows data to be transmitted through the cellular phone), 4. solar panel, 5. weatherproof instrument case.

"I see a great manpower saving advantage using a telephone hookup," says Jonas. The technician can simply dial the station, check the general status of the station, monitor current field conditions, retrieve stored data, or re-program the station at any time, day or night. Nothing can be much faster than a data transfer via the telephone, he adds.

On the negative side, the remote station and equipment must be protected from vandalism or theft. This can become the most costly part of a station, adds Jonas.

It's all up to the individual user to decide which method of data retrieval is best for their situation. The user has to evaluate the inconvenience and costs connected with a field trip to download the dataloggers or use data transfer via the telephone, says Jonas.

For more information please contact S. Jonas, P. Eng., Research Engineer; or B. Cook, Electronics Technologist; Irrigation Branch; Alberta Agriculture, Agriculture Centre, Lethbridge, Alberta T1J 4C7; telephone (403) 381-5870 or (403) 381-5878.

DIG A HOLE TO DEADEN PUMPING NOISE[1]

It can be annoying, with sleep interrupted and friendships strained or broken from the steady unrelenting pounding of a close-by internal combustion engine of an irrigation pump. "A summer of misery" terms Dr. Vincent Luykenaar, a medical physician, who, with his family, has had to endure this situation. Their home is located inside town boundaries but within 150 m (164 yd) of a farm pump station. Adding mufflers and a sound barrier did help, still the noise remained unbearable.

A similar situation, west of Medicine Hat, has been solved by the ingenuity of two local farmers. Simple, yet highly effective, describes the buried sound-deadening box that neighbor John Mann built, says St. Mary River Irrigation District board member Wayne Schlenker. So impressed was Schlenker that he built a modified version with the financial help of his county residential neighbors.

Sound-deadening box partially uncovered.

The buried sound-deadening box is simple to build says Schlenker. "I had a hole (2 m x 1 m x 1.5 m deep) (approximately 2 yd x 1 yd x 1.5 yd) excavated and lined on the

[1] Reprinted with permission from the Editor, Water Hauler's Bulletin, Alberta Agriculture, Lethbridge, Alberta, Canada T1J 4C7, Winter 1991 issue.

sides only with concrete cinder blocks. The blocks were not grouted in place so cross bracing was necessary to prevent the walls from collapsing. Next, I covered the box with a metal sheet and then backfilled over with 300 mm (approximately 1 foot) of soil.

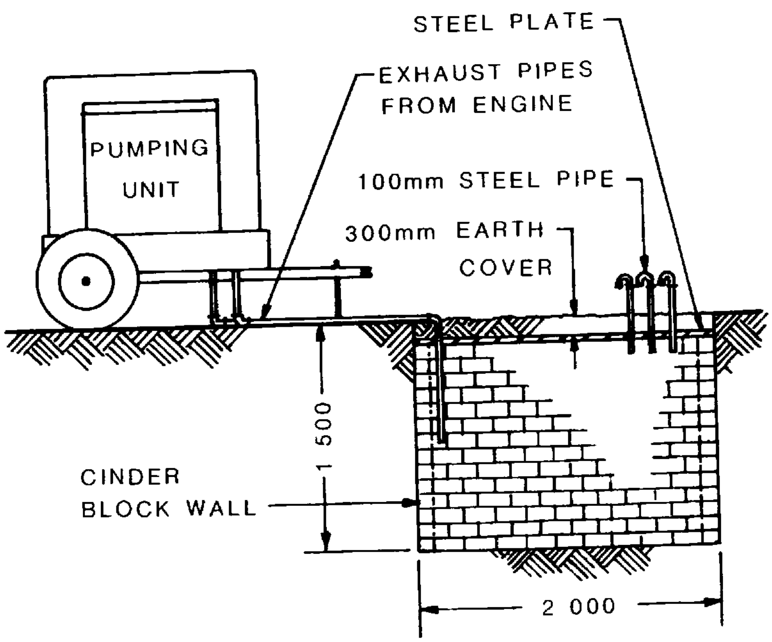
The engine exhaust pipes enter the box at one end and three 400-mm (approximately 1.3-foot) curved vent pipes protrude at the other end," he adds.

INCREDIBLE is the only word one can use when standing beside a fully operational pumping unit and the only sound is the whirl of the fan blades, says Schlenker. "I would never have believed it possible" he adds.

Kenn Blom, senior health inspector with the Barons-Eureka Warner Health Unit, sees no problem from a health perspective, with the buried sound-deadening box. It certainly would alleviate a number of noise problems.

The material cost to build Schlenker's buried sound box was $225. His labor was not included nor was the cost of the backhoe which a neighbor donated.

For more information please contact SMRID Board Member, Wayne Schlenker, 13 Rice Drive SE, Medicine Hat, Alberta T1A 8G8; telephone (403)526-3215.



IF YOU MUST RID AREA OF BATS, HERE'S HOW TO DO IT[1]

by Dallas Virchou[2]

Although they pose few damage problems, bats can be nuisances when inside structures. Bat droppings and urine can produce pungent odors. The squeaking and chirping noises that bats make as they emerge for their evening flights can also be annoying if living quarters are nearby.

What are the best remedies for bat nuisance problems inside structures? "Bat-proofing," or exclusion is the best method for the small number of bats often encountered in Nebraska.

Bat-proofing can involve the same materials used for weather-proofing a building since bats will not chew through soft materials. Insulation, weather-stripping, caulking, putty, screening, and even stainless steel wool can be used.

Possible bat entrance sites are in or around chimneys, behind fascia and cornices, cracks around windows, or holes in loose boards or bricks. Some bats can enter 3/8-diameter holes! Bathroom tissues hung from clothes hanger, candle flames, and small puffs of smoke can be used to detect air currents for locating possible entrance sites in attics.

Bats can also roost on the outside of structures. These sites are often under loose siding or roof tile, behind drainpipes or shutters, in breezeways, patios, and porches.

Bat-proofing can be done as a preventative measure or as part of a management plan once bats have entered the structure. To remove bats from inside, turn off all lights and open all windows and doors. Bats easily detect fresh air movement.

If the bat does not escape, it can be caught in a net, box, or gloved-hand and released. Never handle bats with bare hands.

If a number of bats have become established in attics or unused enclosures, one can seal all openings with the exception of the suspected primary one. Over this opening, a one-way valve device can be used to permit exit but prevent reentry. Home-made or commercial live traps can also be used at such sites. Bats will usually emerge from buildings within 1/2 hour after sunset. Traps or one-way valves should not be used from May through August or if flightless young are suspected inside.

Repellents, such as naphthalene crystals, floodlights, and drafts may be effective. The crystals should be placed in loose mesh-cloth bags and suspended where air can circulate. Two or three pounds will treat an average attic. Fumes from these crystals can cause headache, nausea, vomiting, and anemia; and ingestion can lead to death. Naphthalene should not be used in homes.

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[1] Reprinted by permission from the Nebraska Farmer, March 2, 1991 issue.

[2] Dallas Virchou is an Extension Assistant for Wildlife Damage Control, University of Nebraska Panhandle Research and Extension Center.

Floodlights or bulbs with a minimum of 100 watts can discourage bats from roosting. Breezes can be created by opening windows, doors, and vents.

High-frequency sounds, recorded distress cries of bats, and glue boards have limited value to discourage roosting bats.

Toxicants and fumigants should be used only under specific conditions and by professional pest control operators.

FACTS GO TO BAT FOR REAL WORTH OF BATS[1]

by Dallas Virchou[2]

Look up at a yard light some summer night or into the sky at dusk and you might find an erratic flyer. For most people, the immediate impression would be that of a bird. But what you might be witnessing is a bat.

Those strange-looking animals called bats have been maligned and unjustly feared by man for centuries. Much of the fear might be due to the visual appearance of the bat. The specialized adaptations that allow for a mammal to fly, mostly at night, has created a bizarre form. The ears are enlarged for echolocation (navigating by sounds they produce) and the membranous, clawed wings enable the animals to fly and to hang from tenuous perches. The menacing vampire-like teeth are used for crushing the hard shells of insects.

Folklore and falsehoods about bats abound, even in modern societies. Some misconceptions are as follows:

Bats attack people.–Even the thought of a bat flying into one's hair is distressing. However, bats almost never attack people, even when in enclosed areas.

Bats are flying mice.–Bats and mice are both mammals, but bats belong to a special group that contains more than 900 species worldwide, Nebraska, however, can boast of only a few species.

Bats are large.–Bats are actually much smaller than commonly believed. The smaller species can squeeze through openings with the diameter of a dime. Even Nebraska's larger species, such as the big brown bat and the hoary bat, weigh less than 1 ounce!

Echolocation, the ability to fly at night through the use of a type of sonar, is probably the best known characteristic of bats. But also consider the following equally astonishing characteristics:

Bats are some of the longest-lived mammals for their size, 10 years being an average life span for some species.

Migratory species, like the Mexican free-tailed bat, can travel up to 1,000 miles, while other species simply hibernate near summer haunts.

Mating takes place in the fall, but the female does not ovulate until the following spring when fertilization occurs. Pregnant females congregate in maternal colonies where one, two, or sometimes up to four young are born to a litter.

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1 Reprinted by permission from the Nebraska Farmer, March 2, 1991 issue.

2 Dallas Virchou is an Extension Assistant for Wildlife Damage Control, University of Nebraska Panhandle Research and Extension Center.

Amazing amounts of energy are required to keep these small mammals aloft. Studies have shown that bats can consume more than half their body weight or 1,000 insects during a night. Mosquitoes, midges, moths, and beetles are common fare.

Dense bat colonies containing millions of individuals have produced tons of feces called guano. Guano has been used as a fertilizer in parts of Central and South America.

The bat's voracious need for potentially harmful insects should present the bat as a benefactor to humankind. Why, then are bats still so feared and loathed?

Rabies may be one reason. However, fear of this disease has been unfounded. Two California studies revealed that rabies infected less than 0.5 percent and 0.01 percent of those bat populations.

Human deaths attributable to rabid bats seem to support such data. Only eight human deaths in the United States and Canada have been linked to rabid bats during a recent 30-year period. Moreover, recent advances in post-exposure vaccines to the disease make today's treatment much less traumatizing than just a few years ago.

The admirable adaptation of bats and their beneficial consumption of mosquitoes make these animals somewhat less monstrosities to be feared and avoided, and more symbols of the unique denizens that inhabit the night.

TRACY PUMPING PLANT FLOODING INCIDENT

by Bill Nixon, Jr.; Greg O'Haver; and Stephen Herbst[1]

Background

The Tracy Pumping Plant is located on the San Joaquin River in the Central Valley of California.

Tracy Pumping Plant was completed in 1951 to lift water 197 feet from the Sacramento-San Joaquin Delta (Delta) into the Delta-Mendota Canal. There are six pumping units located in the plant that discharge into three discharge lines. A set of two pumping units discharge into one discharge line.

The Delta waters are naturally corrosive and, over the years, have corroded most of the plant piping to the point of needing replacement. The Tracy Office of the Bureau of Reclamation (Bureau) has been in the process of replacing the piping the past several years. This process has been somewhat slow due to the unavailability of funds to procure the necessary materials, lack of manpower, and short amount of time available for unit outages to accomplish the work.

The main activities leading up to the incident that took place on January 16, 1991, included replacing a 10-inch header drain line; portions of all six 4-inch butterfly valve casing drain lines; portions of a 6-inch vent valve drain line on units 5 and 6; replacement of six 8-inch discharge line drain valves; and installation of two new, redesigned 8-inch cooling water lines. Most of this piping is located in the Butterfly Valve Gallery just below the discharge tubes. The work being accomplished required that a temporary stopping point be reached in the piping replacement job prior to starting units 5 and 6. At this temporary stopping point, dresser couplings were installed on the 4-inch butterfly valve casing drain line and 6-inch vent valve drain. The above work required that the discharge line of units 5 and 6 be dewatered.

The present method of filling the discharge lines requires that a full discharge line with its pumping units running be used to fill an empty discharge line. This method of filling is accomplished by using the above-mentioned piping and valves that were being replaced. The original method of filling a discharge line according to the Designers' Operating Criteria (DOC) issued May 1951, was to fill the pump casing, suction tube, and discharge tube to the level of water in the forebay. With the butterfly valve closed, the pump was started. When sufficient head was obtained, the butterfly valve would open and allow the discharge line to fill. This method caused the pumping unit to vibrate and was abandoned years ago in favor of the present method.

On January 16, 1991, after the above work had reached the stopping point, the clearance on units 5 and 6 was released and filling of the discharge line using the units 3 and 4 discharge line commenced at 1:45 p.m. Unit 1 was also pumping at this time.

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[1] Bill Nixon is a Mechanical Engineer and Stephen Herbst is a Civil Engineer employed by the Bureau's Regional Office in Sacramento, California; and Greg O'Haver is a Mechanical Engineer employed by the Bureau's Shasta Office in Redding, California.

Incident

At 7:27 p.m. on January 16, the control room operator, who was on shift alone, received a high-water alarm indicating that there was high water in the Butterfly Valve Gallery. At 7:40 p.m., the operator reported to the Central Valley Control Center (CVCC), located in Folsom Powerplant, that the gallery was flooding. The operator contacted the Tracy Office Mechanical Maintenance Division Chief and the Mechanical Maintenance Foreman to inform them of the situation. At this time, the water was about 4 feet deep and rising rapidly; and the operator, knowing their discharge line was the primary source of the flooding, shut down units 3 and 4. For safety reasons, the operator could not go into the gallery to close the appropriate valves used in filling the discharge line connected to units 5 and 6. At 8:22 p.m., the operator started unit 2 to pump with unit 1 to compensate for shutting down units 3 and 4. Due to the depth of the water in the gallery (6 feet), Tracy Office personnel determined that scuba divers would be needed to close the 8-inch pipe drain valves used in the discharge line filling operation. During this same time, CVCC was attempting to contact the regional emergency official (REO) to discuss the situation. At 8:40 p.m., the Tracy Office personnel determined that the 8-inch discharge line drain valves would have to be closed. By 9:22 p.m., contact with an REO was established and authorization for the use of a regional dive team member was given. The REO followed up on contacting state agencies, the Environmental Protection Agency, the Denver Office, and the Commissioner's Office the following day.

At 9:30 p.m., Tracy Office personnel noticed that the wheel pit of unit 2 was filling with water. The operator was told to shut down unit 2. The butterfly valve for unit 2 failed to close, and unit 2 ran backwards and started to overspeed and vibrate. Unit 1 was shut down at this time. It too started running backwards, but at a much slower speed. After about 15 minutes, unit 1 stopped, signifying that the butterfly valve for unit 1 had closed. Unit 2 continued to run backwards until the discharge line was empty. At 9:57 p.m., all units were down at the plant.

The divers arrived at the plant at 11 p.m. At this time, water in the Butterfly Valve Gallery was over 10 feet deep. After a hazard analysis was performed, two divers entered the water at 1:30 a.m. and closed the 8-inch discharge line drain valves for units 3 and 4. There was considerable turbulence around units 5 and 6, and the closing of the 8-inch discharge line drain valves for these units was held off until the turbulence had subsided. By 11:30 a.m. the next day, the 8-inch discharge line drain valves for units 5 and 6 were closed. This eliminated the last source of flooding, and water started to recede in the gallery.

There was a minor amount of oil released into the forebay. The Tracy Office personnel installed oil booms to handle the oil.

Cause

At 4 p.m. on January 17, Tracy Office personnel entered the Butterfly Valve Gallery and discovered that the 4-inch butterfly casing drain pipes on units 5 and 6 had separated at the dresser couplings. This caused the water intended to fill the discharge line to flood the Butterfly Valve Gallery. The dresser couplings located on units 3 and 4 had not separated, but were very close to separating. The reason that the butterfly valve associated with unit 2 did not close was because the control circuitry shorted, and there was no backup closure mechanism as installed on the unit 1 butterfly valve.

Investigations by the Regional Office and Tracy Office personnel of the site in the days following the incident revealed that there were no additional restraints installed on the 4-inch butterfly valve casing drain pipes or the 6-inch vent valve drain lines at the elbows of the respective pipes to carry the increased loads on the pipes due to the addition of the dresser couplings. There were approximately 200 feet of head on the dresser couplings and pipes just prior to the failure. There were also no restraints on six 4-inch 100 lb/in^2-gauge backflush lines located in the pipe gallery where temporary dresser-type couplings had been installed connecting old lines with newly installed lines.

It has been determined that the above installation of dresser couplings and the vibrations to the pipe associated with the customary procedures of filling the discharge line caused the incident to occur.

It is assumed that water came up through the worn out pump shaft packing box causing the wheel pit of unit 2 to fill with water. The wheel pit sump pump could not keep up with this seepage because the high water in the Butterfly Valve Gallery greatly reduced the efficiency of the pump.

Conclusions

After studying written reports from the personnel involved with the incident and interviews with some of these individuals, conclusions follow.

1. The review team is grateful to all personnel involved in the incident and the subsequent review. Their reports and interviews were very prompt, cooperative, and helpful.

2. The Tracy Office personnel involved in the discovery and response phases of the incident performed in a safe, exemplary manner and should be commended for their efforts.

3. Dresser-type couplings are not designed to hold pipe together. The pipes that slip into the dresser-type coupling must be properly anchored and/or the couplings must be spanned with a restraint fixture. A restraint fixture is essentially composed of bolts that span the coupling and attach to tabs that are welded to the pipes. Dresser-type couplings are used where there is not enough time to install other type couplings. They are also used to provide flexibility and allow for movements such as pipe expansion and contraction. The location and selection of the type of pipe anchors, supports, couplings, and restraint fixtures is the designer's choice and must be indicated on the drawings or in some way communicated to the pipe fitters.

4. The incident could have been prevented by use of restraints on the pipes where the temporary couplings had been installed.

5. There was no adverse effect on the deliveries of water to contractors on the Delta-Mendota Canal.

6. There were several pieces of equipment damaged, and these were either repaired to full operational use or were repaired temporarily until a replacement could be procured.

7. The total cost of the incident, which includes labor, materials, and equipment to get the plant back on line initially and also all replacements to ensure plant reliability is $111,000.

Nos. 8 through 14 are related only to Regional Emergency Operating Procedures.

15. There is no emergency generator setup or backup power at the Tracy Office to ensure that the sump pumps will run uninterrupted.

16. The piping replacement work being done at the Tracy Office is complicated and multifaceted, which becomes even more complicated by budget constraints and lack of manpower.

17. There needs to be a secondary level of review on all modifications and repair work being accomplished at the Tracy Pumping Plant.

Photo 1. – Aerial view of Tracy Pumping Plant Complex looking upstream showing office area, switchyard, and pumping plant. Water is lifted by this plant 197 feet into the Delta-Mendota Canal. The plant has six pumps, each powered by 22,500-hp electric motors and capable of pumping at the rate of 767 ft^3/s. Power to run the plant is supplied by Central Valley Project powerplants. 4/12/89

Photo 2. – General view of pumping plant structure from intake side. 4/14/66

Photo 3. - Unit 5—4-inch sleeve coupling, one of two that came apart. Coupling is typical of all. Note also the unrestrained 6-inch sleeve coupling at the right of the photo. 1/18/91

Photo 4. - Unit 5—Same as Photo 3, different view. The 8-inch valve is one of those that had to be turned off under water while high velocity water was coming out of the 4-inch-diameter pipe at the sleeve coupling. 1/18/91

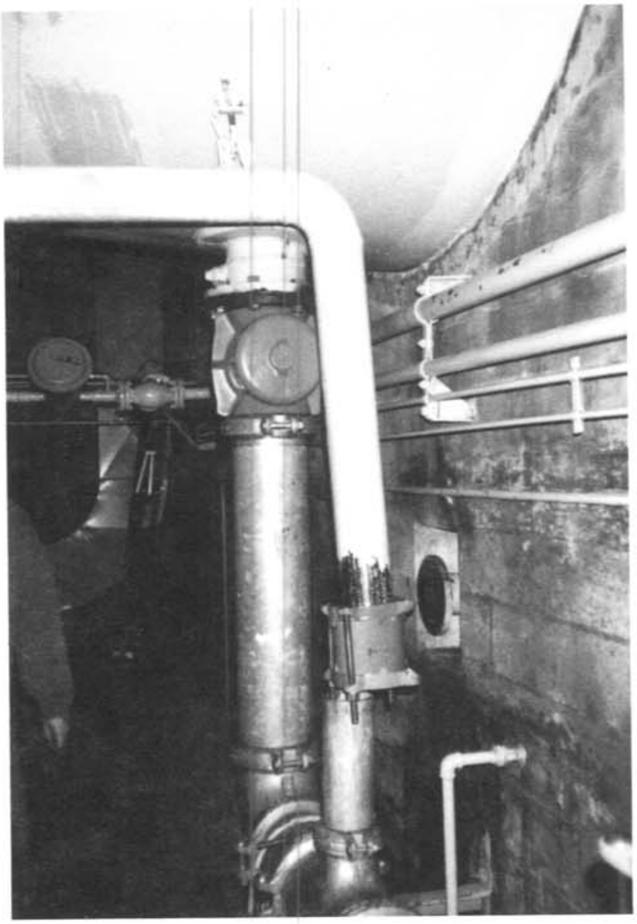

Photo 5. - Unit 6—Second sleeve coupling that separated. Note hanger at elbow does not restrain vertical movement. Vertical restraint was not needed prior to retrofitting because previous pipes had flange coupling at 10-inch pipe. 1/18/91

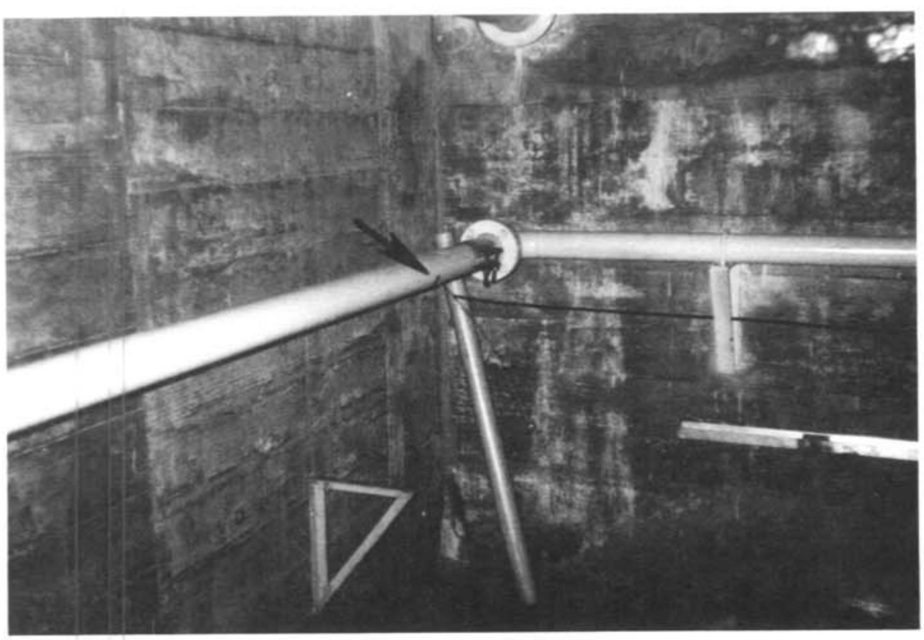

Photo 6. - Unit 5—Arrow points to hole in 3-inch line scheduled for replacement. 1/18/91

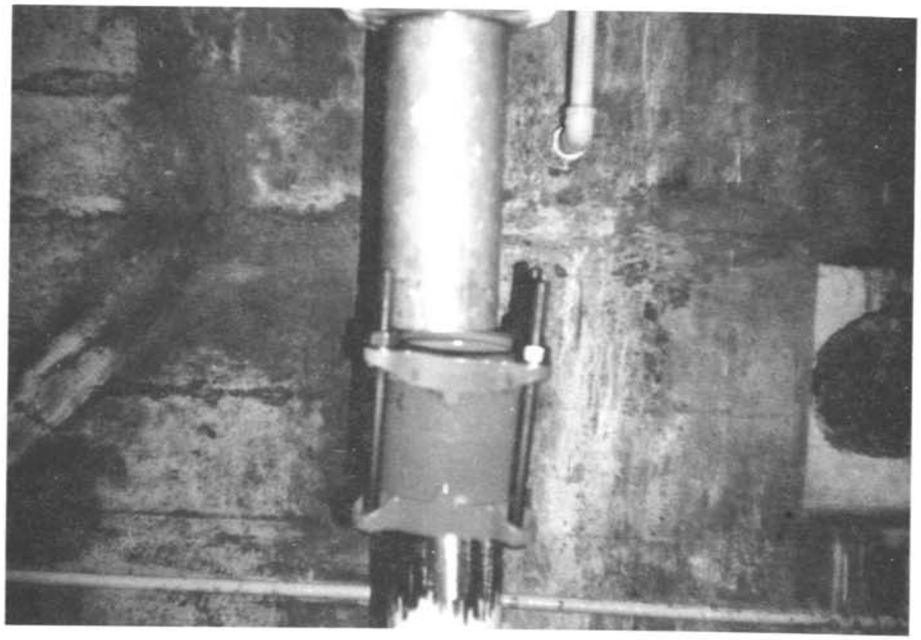

Photo 7. - Unit 5—Closeup of displaced sleeve coupling. 1/18/91

Photo 8. - Unit 5—Water level reached to just above -2 on staff gauge at its highest point. The water level was about 18 inches above the top step in this view. 1/18/91

Photo 9. - Unit 5—Arrow points to oil scum line left behind as the water level receded. 1/18/91

Photo 10. - Unit 4—Cleaning electrical panel that was flooded. 1/18/91

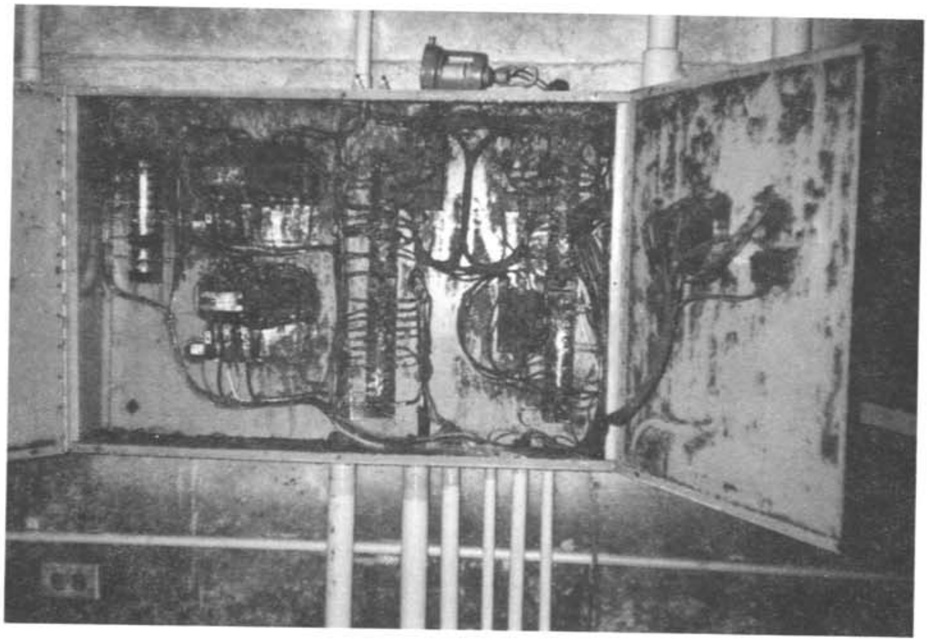

Photo 11. - Unit 2—Flooded electrical panel prior to cleanup. 1/18/91

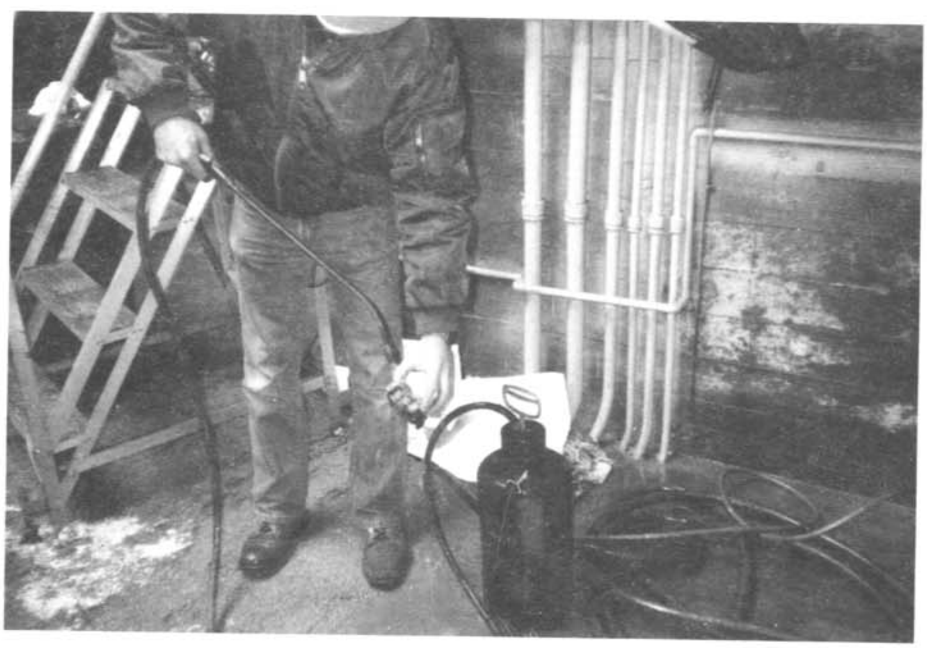

Photo 12. - Unit 4—Cleaning electrical component with water. 1/18/91

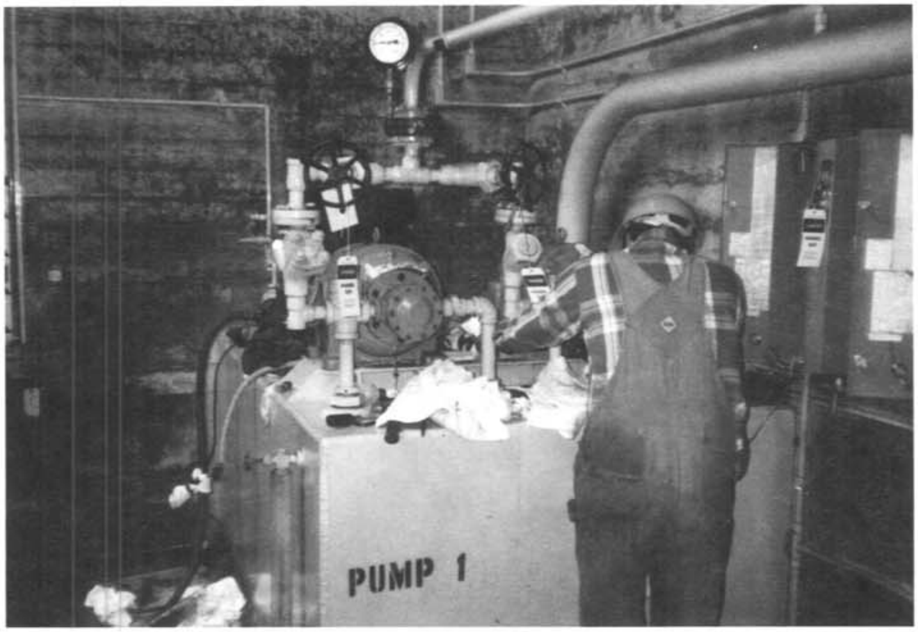

Photo 13. - Unit 4—Butterfly valve hydraulic oil pumps and sump. Motors had to be removed for cleanup and drying. 1/18/91

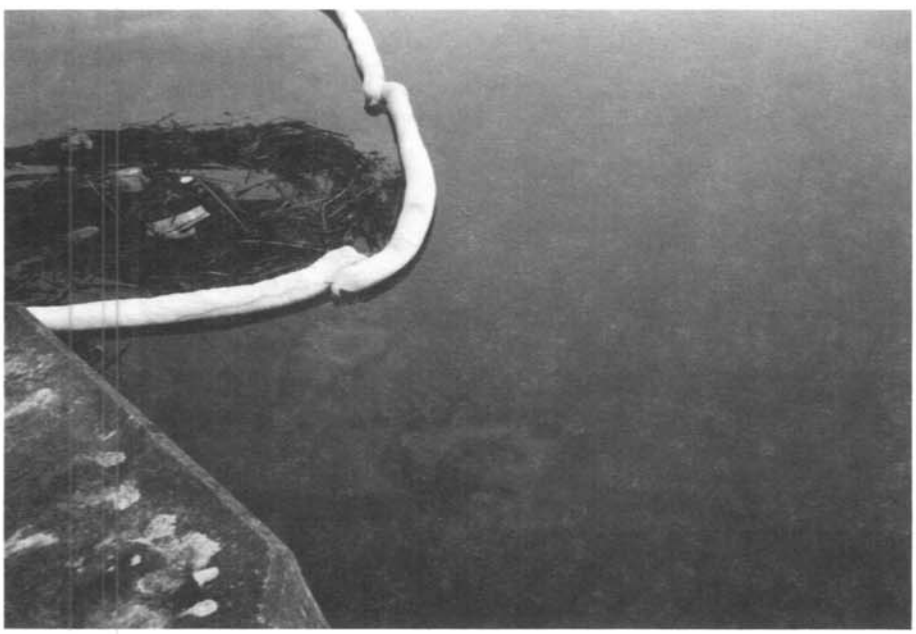

Photo 14. - Intake channel—oil boom, film going under because boom on top of some debris. 1/18/91

BUREAU OF RECLAMATION RESEARCH ON WATER CONVEYANCE FACILITIES[1]

(1946-1989)

By Chester W. Jones[2]

Since the beginnings of irrigation, the need for controlling canal seepage has been apparent. Where soils are pervious, a canal lining or sealant is required to conserve water that could be used for irrigation, avoid building canal structures larger than necessary with resulting extra cost, and avoid waterlogging adjacent irrigable land, which requires either removal of the land from crop production or installation of expensive agricultural drainage to lower the water table so crops will grow. An alternative to a lined canal is a buried pipe with sealed joints.

In 1946, Reclamation officials initiated the first agency-wide research program that became known as the Lower-Cost Canal Lining (LCCL) program. The main thrust of the original program was to improve the quality of linings in use at the time and to develop new types of linings, all within economical limits. In 1967, in order to stress the growing importance of buried flexible pipe in irrigation systems, the Open and Closed Conduit Systems (OCCS) program succeeded the LCCL program. Besides canal lining and pipe, both programs included other research of concern in water conveyance facilities.

Committee members were selected from Reclamation offices in Washington, D.C.; Denver; and the Regions, and guided the LCCL and OCCS programs with approval of the Commissioner of Reclamation. The regional offices of Reclamation contracted with the Agricultural Research Service, Department of Agriculture; irrigation districts; and universities having unique capabilities for supplementing the programs. In 1989, Reclamation terminated the OCCS program. Reclamation's Water Technology and Environmental Research program now performs studies on these concerns.

The LCCL and OCCS research was conducted in the most economical way by starting a new program item, where feasible, by laboratory studies followed by field demonstrations. Research features that were successful were adopted in regular Reclamation design and construction. Although it is possible to calculate cost savings for the research in specific cases, much of the overall savings is intangible. Even small savings accumulate over a long period of time on a large volume of construction. To date, Reclamation has constructed a total of more than 5,000 miles of canal and lateral linings and 7,600 miles of pipelines in water conveyance facilities.

Canal Linings

Concrete.–In 1946, reinforced concrete was judged to be the most permanent type of lining. However, at a cost of $3/yd^2$, widespread usage was considered unlikely because of the prohibitive expense, hence the need for "lower-cost" linings. In 1948, a special board reviewed the design, construction, and performance histories of existing

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[1] This paper condensed from a comprehensive report of the LCCL and OCCS programs.

[2] Chester W. Jones, Civil Engineer, retired in 1986 after 40 years with the Bureau of Reclamation. He has a B.S. from the University of Maine, an M.S. from Purdue University, and is a Life Member of ASCE.

reinforced and unreinforced concrete canal linings. Some of the linings had been in use on operating canals since the early 1900's. Among the findings, the board recommended that steel reinforcement in concrete linings was not needed except for special conditions. Reclamation adopted this recommendation as policy, and it has resulted in 10 to 15 percent savings in total canal lining cost.

The investigation of many industry-developed joint and crack sealants for concrete lining resulted in the use of the most durable and cost-effective materials.

Recent concrete lining research has concentrated on the repair of deteriorated surfaces with polymer and with silica fume concretes. Field evaluation of these repair measures are continuing, and so far, performance has been better than repair by conventional concrete methods.

Soils.–Soil (earth) linings have progressed from fine soil loosely spread on the canal prism to compacted lining 2 to 4 feet in thickness. Guidelines have been established for types of soil suitable for lining and for optimum compaction requirements. The thick-compacted type with the side slope lining placed in horizontal layers has become the preferred type. However, with the modern, large, wide, construction equipment ordinarily used, the linings are sometimes thicker than necessary and result in extra cost. More efficient equipment that could operate to adequately compact soil parallel to canal side slopes (usually 2H:1V) was recognized when the LCCL program was first started and there is still need for such equipment improvement. This would be of value not only for compacting canal lining in a few layers parallel to the slope, but also for some unlined canals in fine-grained soils where seepage could be significantly reduced by just compacting the soil in place.

An early concern was possible deterioration of soil linings in cold climates due to freezing and thawing action. An intermittent 25-year investigation of selected compacted soil linings was conducted. The study concentrated on changes in soil properties which might affect seepage characteristics. Some loss in unit weight of the soil occurred over the years but, in general, performance of the linings has been satisfactory. An important research finding has been that under normal canal conditions, closed-system freezing (freezing of water in the soil voids only) of frost-susceptible soil in compacted linings has a tendency to consolidate the soil and to help maintain unit weight, and sometimes even to increase it slightly.

Asphalt.–In the 1950's and 1960's, extensive laboratory and field research was accomplished on asphalt as a canal lining material. After many types of asphalt linings were tried, the buried membrane with catalytically blown asphalt emerged as a standard in Reclamation's construction. In 1963, 5,839,000 yd^2 of hot-applied, buried asphalt membrane lining had been placed. At that time, 23,690,000 yd^2 of unreinforced concrete; 9,738,000 yd^2 of reinforced concrete; and 14,037,000 yd^2 of compacted soil had been placed. After the oil embargo in 1973, the cost of asphalt increased substantially and this, coupled with the limited sources of supply for the specially refined product, led to the discontinuance of this lining type. Many of the asphalt linings are still serviceable on operating canals.

Plastic membrane.–Following the discontinuance of asphalt membrane linings, buried plastic membrane has become a standard Reclamation canal lining both for canal rehabilitation and for new canals in areas unsuitable for compacted soil or concrete linings. With the cooperation of manufacturers, laboratory and field tests have been conducted on new materials as improvements were made. Samples of the linings have been taken from operating canals for laboratory testing to determine effects of aging. Although polyvinyl chloride (PVC) has been the predominant type of plastic used, low-density polyethylene and other plastic materials have been used to a limited extent. PVC has been the membrane material of choice for the following reasons:

a. PVC remains flexible over a wide range of temperatures, allowing it to be folded to compact shapes for shipping and handling.

b. PVC is available in large sheets (up to 90 feet wide and 300 to 600 feet long).

c. PVC is easily field spliced and repaired using solvent cement.

d. PVC is resistant to puncture, tearing, and abrasion.

Figure 1. – The modern way of placing plastic membrane lining on equipment-trimmed soil subgrade. (Photo courtesy of Alberta Environment, Alberta, Canada.)

A relatively minor disadvantage of PVC is the loss over time of plasticizer, which is a component that governs the degree of lining flexibility. About 10 years ago, the recommended plastic lining thickness was increased from 10 to 20 mils. Since that time, contractors have developed a train of equipment for trimming soil subgrade, laying membrane, and adding a protective soil cover by conveyor belt, which is replacing the older hand-placing and dragline-covering methods.

There has long been a need to have a practical way to line canals that are in continuous operation. In the 1950's and 1960's, attempts to form linings by underwater injection of asphalt into the soil subgrade or submergence of asphaltic mats were unsuccessful. In May 1989, a 1.5-mile field demonstration was started on Coachella Canal in Southern

California while the canal was in operation. The lining consisted of a 30-mil PVC with a non-woven geosynthetic membrane bonded to its surface and topped with a 3-inch protective concrete cover. The field demonstration was preceded by laboratory hydraulic model studies to formulate a concrete mix that would be stable on a 2.5H:1V side slope and not be eroded by flowing water before the concrete had hardened. The lining was placed on one-half of the canal cross section at a time to allow water to continue flowing around the construction. After 1,000 feet was completed on one-half of the canal section, construction was suspended due to summer climatic and canal operating conditions unfavorable to the lining construction and to solve some lining placement problems. The underwater lining demonstration program was finished during March 1991. This large project was funded by the Bureau of Reclamation, the Metropolitan Water District of Southern California, and the Coachella Valley Irrigation District. Much of the expertise for the underwater lining development resulted from the many years of LCCL and OCCS research.

Although PVC linings are providing satisfactory service for seepage control, improvements in plastics and other materials for membrane-type linings are expected. Very low-density polyethylene and ethylene interpolymer alloy materials are currently being evaluated as buried membrane lining alternatives. Plastic linings are also being evaluated for special applications such as (1) repair of deteriorated concrete linings; (2) bottom-only linings for soils where seepage is primarily in the vertical direction; and (3) exposed linings, especially in areas where suitable soils are not available for a protective cover. As the nation's infrastructure continues to age and deteriorate, use of plastic linings appears to be a viable repair method, especially under adverse conditions such as limited access; inclement weather; or short downtime.

A long-term study of the stability of protective granular soil covers on membrane linings has resulted in the adoption of guidelines for appropriate soil grading limits to be used. Maximum water velocity in canals with buried membrane linings is restricted by the resistance to erosion of the particular soil cover used.

Canal Sealants

Bentonite.–An old method of temporarily reducing canal seepage was the deposition of water-borne sediment over the canal perimeter. This occurs naturally in some canals which carry sediment or can be accomplished by sluicing fine soil into a canal above a known seepage area. From 1951 to mid-1960, Reclamation and university collaborators made extensive laboratory and field tests with finely ground bentonite as a water-borne sedimenting agent. Bentonite is a form of expansive clay consisting largely of montmorillonite, which occurs naturally in certain areas, particularly in Wyoming and Montana. The fine bentonite particles, fully expanded in water, did not penetrate the soil as expected to form an effective, long-lasting seal. A surface layer was formed that was subject to shrinkage and erosion from flowing water. Petrographic studies showed that although some of the bentonite particles were smaller than the soil voids, they were flat and overlapped one another enough to bridge over the soil voids at the ground surface. Some irrigation districts have used cinders and other material as temporary sealants.

Figure 2. - Conveyor-belt system of adding protective soil cover on membrane lining. Seen following lining placement at far right of previous photograph. (Photo courtesy of Alberta Environment, Alberta, Canada.)

Figure 3. - An old way of spreading plastic membrane. The membrane was covered with soil by a dragline operating from the top of the bank.

Chemicals.–Industry has developed a variety of chemicals that were designed to be introduced into canal water where seepage would draw them into soil to a significant depth and reduce seepage. Although some of the chemical sealants were promising in laboratory tests, field trials showed them to be effective for only a relatively short time, generally up to a single irrigation season. Frequent, repeated applications would not be economical. There is still hope that an economical, more lasting chemical sealant can be developed for seepage control.

In the mid-1960's, a farmer in California discovered that anhydrous ammonia fertilizer flowing through a concrete pipeline appeared to be sealing leaks in his pipeline. Investigations showed this to be true where water carrying the ammonia contained certain chemicals, particularly calcium. The chemicals would cause calcium carbonate to precipitate in cracks in the concrete and seal them. However, the use of this method of sealing concrete has been limited by toxicity of ammonia to handlers, corrosive properties of the chemicals on metals in the irrigation system, and care required in disposal of the chemical solutions after pipe treatment.

Buried Flexible Pipe

In the late 1960's, Reclamation started a comprehensive laboratory and field testing program on buried flexible steel and plastic pipe. Although reinforced plastic mortar pipe was the principal type of plastic pipe tested, polyethylene, PVC, and fiberglass reinforced plastic were also included. An essential part of the research was large-scale laboratory testing of pipe buried in soil in a large steel container, with the soil surface loaded by a testing machine. For each laboratory test, as loading was increased to pipe failure, data were recorded continually from instrumentation installed to measure pipe deflections, soil movement and pressure around the pipe, and strain on the inside surface of the pipe. Of particular concern were the deflections of pipe of different diameters and wall thicknesses under load and soil conditions expected in field installations. Also, the deflections of pipe installed in field tests and in actual irrigation systems were measured at intervals to gather data on long-term performance. From analyses of data, guidelines were formulated for the installation of flexible pipe in various types of soils and degrees of soil compaction so pipe deflections would be within allowable limits. The guidelines, which have been widely publicized in technical society meetings and publications, have been used in pipeline design and construction by Reclamation and other organizations.

Drainage

During the past 25 years, perforated, corrugated plastic tubing has largely replaced open-joint concrete and clay pipe in new agricultural drainage installations. Reclamation has assisted manufacturers in developing plastic tubing by conducting independent tests of tubing in the laboratory and by closely monitoring field installations to determine performance. With encouragement, contractors have adapted machines using lasers for grade control; continuous drain installation, including trench excavation; tube laying; placement of granular envelope around the tubing; and backfilling with soil above it. This has dramatically increased the rate of drain construction and therefore reduced the cost of drainage system installation.

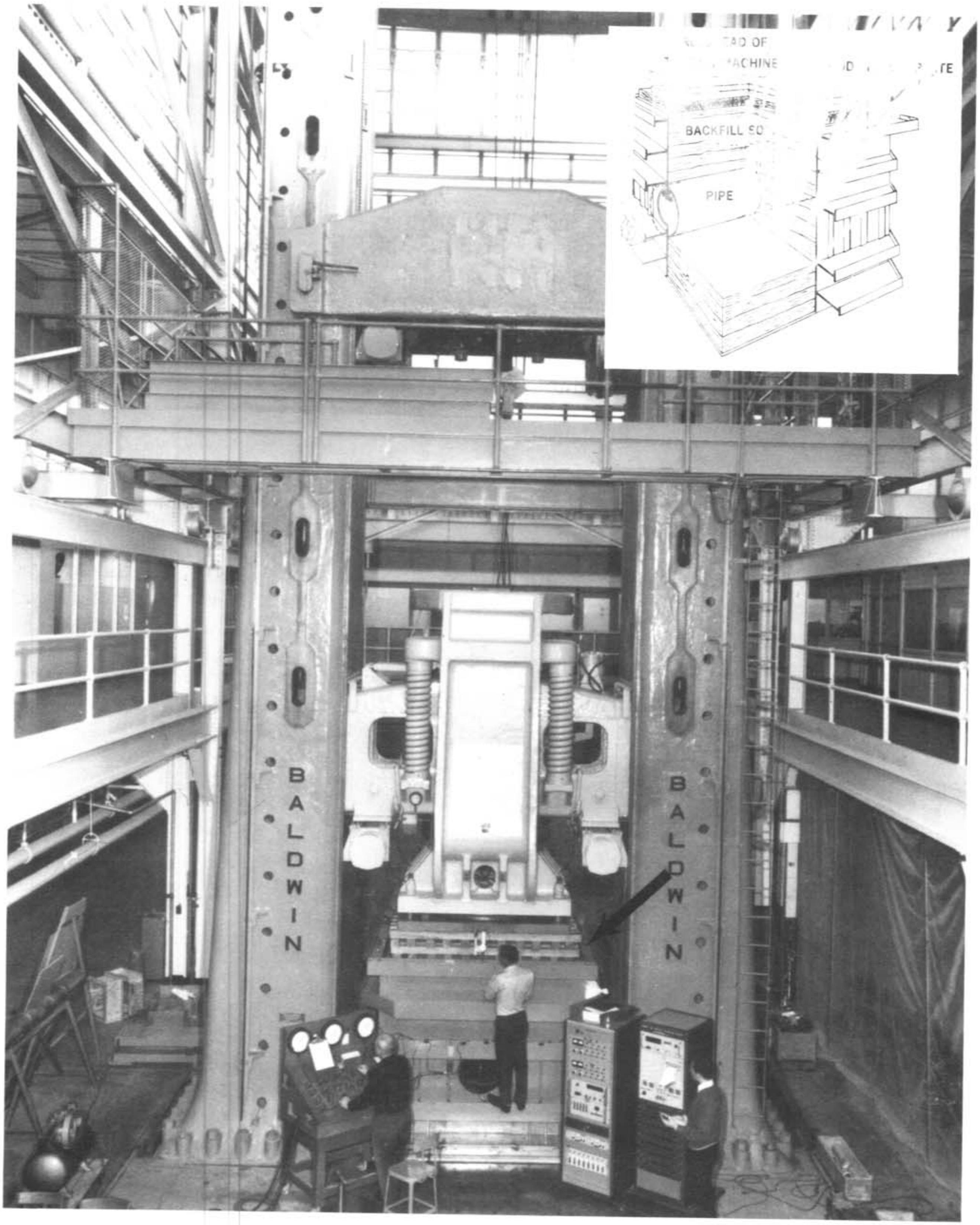

Figure 4. – Large-scale laboratory testing of flexible pipe. Inset illustrates the pipe buried in soil in the large steel container indicated by arrow.

Starting in the mid-1960's, the clogging of pipe or tubing in agricultural drains became a problem because of accumulation of ochre, a gelatinous substance formed by the presence of iron-reducing bacteria. Reclamation conducted laboratory and field tests that revealed that the method of punching and size of the drainage inlet holes affected the ochre problem and that treatment with a solution of sulfur dioxide helped eliminate the ochre. Later, sulfur dioxide was replaced by sulfamic acid in pellet form, which was equally as effective and safer to apply.

<u>Other Research</u>

Under the LCCL and OCCS programs, the following investigations were conducted.

a. The development of procedures for estimating canal seepage and establishing the need for canal lining based on field permeability tests performed prior to canal construction. Also studies were made on various methods (ponding, inflow/outflow, seepage meter, piezometer, etc.) of measuring or estimating seepage in unlined and lined canals.

b. Incorporation of additives in canal soils to reduce seepage and/or stabilize soil to prevent erosion. These have included portland cement, asphalt, fly ash, and various chemicals. Although these materials are not now used in standard practice, the research record is available and some of these additives may be used in the future under favorable conditions. After some laboratory research, lime was successful in stabilizing large quantities of expansive clay in the side slopes and bottom of the Friant-Kern Canal in California.

c. Field and laboratory studies of soil erosion on unlined and soil-lined canals. This has led to canal design and construction with less soil erosion.

d. Studies on the economics of water conveyance facilities. Although the information is not recent, comparisons have been made between construction and operation and maintenance (O&M) costs of canals versus buried pipe with advantages and disadvantages of each.

e. Studies of soil, ground water, and climatic conditions causing frost heave and resulting damage to canal structures, particularly concrete canal linings. Methods of avoiding damage from frost action were proposed.

f. Hydraulic laboratory tests on water control and water measurement devices for irrigation, and models of canal structures to solve special problems.

g. A special study of hazards that canals present and the relative effectiveness and comparative costs of various preventive measures to reduce hazards. This has led to more education and changes in canal design that have improved public safety and preservation of human and animal life (particularly deer).

h. Biological investigations to find safe treatment methods for controlling undesirable plants that grow in canals and on canal rights-of-way, without causing damage to the environment. This has included laboratory and field tests to screen industry-produced herbicides before acceptance for routine use. Also, Asiatic clam populations and methods of controlling them have been studied. In certain canals, the clams have accumulated in sufficient numbers to severely limit canal capacity and require removal.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991—834-927

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

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