ally gradual, and information needs to be maintained for future reference. Cost data on completed work should also constitute a part of the record.

Maintenance personnel need to keep abreast of new developments in coating and application techniques to effectively maintain structures for uninterrupted performance throughout the full expected life of the structure.

Selection of Coatings

Selection of coatings requires a specialty study to select the material best suited to the need. A paint manual has been prepared by the Bureau of Reclamation that might well be used by any maintenance personnel (*Paint Manual* 1976). Paint vendors can also supply good information. Finally, there is no substitute for experience of a maintenance superintendent in determining the type of coating to be used for a specific application.

There are many types of coatings, rust-preventive compounds, and accessory materials. Each has a variety of composition and properties available. The person responsible needs to be knowledgeable about thinners, colors, stains, dryers, putties, glazing compounds, waxes, pigments, vehicles, dampproofing, and materials.

Some basic types of materials available include coal-tar pitch, coal-tar paint, vinyl resins, latex paint, boiled linseed oil pigmented paint, epoxy paint, hot-dip galvanized coatings, and red-lead primers. Obviously, a careful study of these materials is needed prior to any application. Regulations governing hazardous materials or environmental compliance may limit or restrict the use of certain protective coatings.

Where rapid deterioration of painted surfaces takes place, either exposed or submerged in water, it behooves supervisory personnel to make thorough on-the-spot investigations to determine cause of failure. In many cases, changing from one type of coating to another may be necessary and beneficial.

Interior Surfaces

Interior surfaces most often employ a semigloss enamel, latex-based paint. No primer is necessary where a dull finish is acceptable.

Boiled linseed oil thinned with mineral spirits or lacquer may be used to retain and enhance the natural beauty of wood grain. Special plastic paint is sometimes used where a speckled or flaked characteristic is desired on interior wallboard and where extra cost is not a problem.

Interior woodwork, properly coated with paint and varnish, should remain in good condition for many years. Deterioration from repeated washings, scratching, and impact chipping will ultimately mean that old coatings must be removed before repainting. Accordingly, added coats of paint should be applied with reluctance to interior surfaces in the interest of overall economy.

Exterior Woodwork

Exterior woodwork will experience much more rapid deterioration of coatings because of the greater effect of sunlight, moisture, and temperature changes. Accordingly, inspections of such surfaces should be sched-

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uled at more frequent intervals, such as annually in the case of extreme exposure.

Again, the pitfall of too frequent repainting with resultant cracking and peeling should be avoided. Generally, surfaces in the northern hemisphere facing north will require less painting than those facing south.

Pigments containing lead are no longer used in exterior coatings, except possibly as tinting colors in minor amounts. Acrylic, polyethylene emulsions, or different types of emulsified resins are the coatings in common use today.

Exterior oil paints are formulated as "self-cleaning" through chalking as the surface of the coating gradually becomes powdery and is washed away by rain. The gradual reduction of film thickness reduces the tendency for cracking and peeling, so that when additional paint is applied, a flexible well-bonded film is usually restored.

In the case of structural timbers that may or may not have been pressure-treated prior to construction, a successfully used technique for coating is the application of shotcrete. This application increases the service life by protecting against rot and mildew.

Concrete

Concrete painting for decoration and dampproofing may be accomplished with a variety of paint choices, including Portland Cement paint, oil vehicle paint, latex paint, and epoxy and silicone materials. The control of algae growth in concrete structures can also be provided with special protective coverings including coal-tar enamel and catalytically blown asphalt. Two coats of copper-base, antifouling paint also have been successfully used to retard algae growth.

Generally, good high-strength concrete is sufficiently waterproof to provide its own protection during its intended service. However, where deterioration due to excessive freezing and thawing occurs, a four-coat linseed oil and paint treatment has generally served satisfactorily. Polyvinyl acetate paint, styrene butadiene paint, and epoxy resin materials have also shown promise for such applications.

Neoprene compounds have been found effective for waterproofing concrete in the upstream faces of older dams. Chlorinated rubber-base paints are less costly, and although not as effective as neoprene, are still considered excellent paints for water tank and reservoir application. Neoprene has also proved very satisfactory in freezing and thawing and waterproofing tests, and has excellent erosion resistance qualities. Another method of waterproofing concrete is to place a protective plastic membrane over the concrete with a bonding agent.

Sometimes painting interior concrete walls is needed to improve appearance. A varnish-base paint may be applied if the surface is thoroughly dry. Latex-base paints have been successfully used for this purpose.

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Metalwork

Metalwork painting may be the most important maintenance program for irrigation and drainage structures. This is especially true for underwater and varied exposures of metal surfaces.

Coal-tar enamel and cement mortar coatings provide the best protection for such items as power penstocks, but these coatings are difficult and costly to apply. Two-component materials such as epoxy and coal-tar epoxy offer advantages but require very special care and application.

Two package epoxies, polyurethanes and polyesters, are the most common replacements for multicoat vinyl paints. Metalizing with organic seal is one option, and topcoats is another.

Large underwater metal structures may also be protected by hot-applied, heavy epoxy coating. This material requires special equipment and care in application.

Metal structures exposed to outside atmospheric conditions are no longer protected with red-lead priming paint covered with an aluminum-pigmented varnish or alkyd enamel. Red-lead priming paints have been replaced with lead and chromate-free, anticorrosive primers, many of which are based on phenolated alkyds or cold-cut phenolic varnishes.

Where metal conduits are subject to erosion from silt, sand, or gravel-laden waters, neoprene paint, though more expensive than coal-tar enamel or cement mortar, seems to offer excellent resistance. Elastomeric and other two-package polyurethane coatings are also used for erosion and abrasion-resistant coatings. Neoprene paint is more expensive and is used less often than the urethane coatings.

Quality Control

Quality control in applying a protective coating results from many factors. These include a careful diagnosis of the problem, informed prescription of a remedy, logical but simple specification of materials and methods, rigid inspection requiring conformance, frequent inspection, continual maintenance, and proper records.

Preparations for Painting

Surface preparation is the key to successful protective coating. No coating is better than the foundation on which it rests. Surfaces that are coated with enamel or other nonchalking materials and are in fairly good condition at the time of repainting will require only scraping or sandpapering as surface preparation. Severe cracking and peeling indicates a condition that causes poor adhesion to the old paint, leading to cracking in the new paint. Where this condition is general and numerous repaintings have built up excessive film thickness, satisfactory results can be obtained only through complete removal of the old paint, followed by repainting.

The one method of complete paint removal for large areas is with a paint burner, followed by scraping while the paint is soft and hot. This method requires that safety precautions be taken to avoid fire damage to the structure. Remnants can be removed by scraping or wirebrushing woodwork after the paint has cooled. Corners and edges especially should be scraped clean. Sandblasting is another method and used most often to

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clean coatings from metal surfaces. High-pressure (2,000 psi) washers can also be used to remove old coatings.

It is extremely important that bare metal surfaces are protected immediately. When bare metal surfaces are left exposed overnight, minor rusting of the surface can occur. ***Always sandblast, clean, and prime metal surfaces on the same day.*** Any surface on which a coating is to be applied should be free of all dirt, effluorescence, oil, pits, alkali, moisture, or other conditions that would prevent bonding. This is true of wood, metal, or concrete surfaces.

Special rotating power tools are available for removal of all kinds of hard paints, rust, and scale from steel and concrete surfaces. These tools include power wire brushes, grinders, and chipping tools and are especially effective for touch-up recoating needs. The surface produced is not equal, for painting purposes, to that obtained from sandblasting, but it is free of loose and poorly bonded material and is roughened somewhat. These tools are normally limited to use of flat or large-radius curved surfaces.

Following removal of foreign materials, further cleaning by light wire brushing or wiping with solvent, or with other treatment solution may be necessary to ensure removal of all loose dust and rust from a metal surface before recoating commences. Physical adhesion is enhanced if the surface is roughened while chemical adhesion is sometimes improved for metal surfaces by pretreatment with conditioners.

Mixing

Mixing of coating materials must be done according to manufacturer specification. Obviously, a linseed oil-based paint cannot be thinned with water, nor can a latex base paint be thinned with mineral spirits. Epoxy-resin compounds must be precisely blended with curing agents in a clean working area with good ventilation by trained personnel wearing rubber or vinyl gloves.

Manufactured paint should be vibration mixed if possible and thoroughly stirred to provide satisfactory results. The intent should be to preserve a balance of pigment and thinners by stirring until smooth consistency is achieved. Mechanical mixers are preferred. A stirrer on an electric drill also works well. Some paints require frequent reagitation. Coating materials should be thinned to proper proportions and sometimes heated to yield the specified applied mil-thickness.

Application

Application of protective coating by brush, dauber, trowel, or spray is obviously important. Painting and coating should not begin unless the surface to be painted or coated is at least 50°F above dewpoint. Inspection should include mil-thickness testing so that adjustments can be made where deficiencies are noted.

Brushing is recommended for the first application of most protective coatings to ensure intimate contact of paint with the surface. Painting skill will produce a reasonable degree of uniformity without brushing the first coat on too thinly. Roller coating and spray painting may be effectively

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used for application of coatings with uniformity and speed. Spraying requires specialized skill and correct equipment in good condition. The spray nozzle should be held perpendicular to the surface and about 8 to 10 in. (200 to 250 mm) away. Uniform application with systematic patterns should be used when coating an area.

With wet techniques, coating will be applied wet, never partially dried, when it reaches the surface. Application should proceed only under suitable atmospheric conditions. To the extent possible, each work area should be started and completed within one continuous timeframe.

4.13.9. Cathodic Protection

Buried and submerged metalwork is subject to electrochemical deterioration (corrosion). This is a major maintenance and economic problem for many irrigation and drainage structures. Corrosion or oxidation on a metal surface submerged in water is an electrochemical reaction in which the electrical current flow from metal surface to water results in metal loss. This phenomena can be eliminated by stopping the flow of current.

Generally, this is accomplished by coating the metal surface to insulate it from the wet environment and by imposing an electric voltage in opposition to the current flow that causes corrosion. Some examples of other structures that can be protected by cathodic protection include underground metallic conduits and underground fuel storage tanks.

Principles Involved

Corrosion and cathodic protection involve the same electrochemical principles at work in a primary battery, of which the common dry cell is an example. In the cell, a direct current flows from the anode (which corrodes), through the electrolyte to the cathode (which does not corrode). By protecting the anode of an electrolytic or galvanic cell with an external anode, natural corrosion currents are neutralized and corrosion does not take place. This can be accomplished by impressing a direct current between the external anode and metal to be protected with a rectifier or other direct-current source.

Cathodic protection can also be accomplished by protecting the anode of a primary battery by proper selection of material for the external anode. Such anodes are called galvanic or sacrificial anodes. When a submerged steel surface is receiving cathodic protection, a protective film of hydrogen, calcium carbonate, and other chemicals forms on the surface of the metal and is constantly renewed by keeping the metal surface charged cathodically.

A common practice in arid areas or where relatively large quantities of current are required is the use of anodes with an impressed current. These anodes are constructed of material that is depleted slowly with current discharge. Examples of impressed current anodes are graphic, cast iron, plutonium, and mixed metal oxides.

In tidal areas, a common practice is to use one or more plates, usually zinc or magnesium, placed on the gate face. The resulting galvanic action on the anode necessitates replacement every 4 to 5 years. An anode

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made of zinc is consumed at the rate of 26 lb (57.2 kg) per amp-year and magnesium at 17 lb (37.4 kg) per amp-year. This method has been used successfully on the downstream side of salinity control structures. A zinc oxide paint, which has excellent steel-adherent qualities followed by a coating of epoxy, is effective in further protecting the gate face as well as extending the life of the anode.

Direct-current power for cathodic protection is supplied by a rectifier where alternating current is readily available. Where electric power is not economically available, galvanic or sacrificial anodes can be used. Magnesium or zinc are two types of anodes commonly used without an external source of power. The magnesium or zinc anode and submerged steel surface to be protected constitute a galvanic cell.

Since magnesium or zinc has a higher solution potential than the submerged steel surface, a driving force of approximately 1 volt and 0.5 volts is obtained from these combinations, respectively, and necessary cathodic protection current flows through the circuit. As this current flows, the anode gradually dissolves at a rate proportional to the amount of current.

In most cases, the use of cathodic protection to supplement regular surface coatings as a means to increase the time between recoatings is desirable. As a coating begins to fail, the area requiring protection increases. Experience has shown, however, that a current of appoximately 1 milliampere per sq ft (11 milliamperes per sq meter) of submerged area to be protected is adequate.

Limitations and Problems

Where water levels vary in a submerged structure, voltage adjustments are necessary to provide adequate protection. The voltage can be adjusted by operating personnel or automatic equipment.

The flowing electric current must be carefully confined to wires and anodes by excellent insulation; otherwise, the wire itself will become an anode and corrode, interrupting the flow of current to the anode.

There are instances in which cathodic protection of one system of underground and underwater metallic structures must necessarily involve the protection of other neighboring structures. This phenomenon is the result of stray current corrosion (electrolysis). These facilities must be accounted for in design and maintenance as one complete system. The corrosive nature of soil will vary from place to place, according to soil propensity to carry electric current. Soil electric resistivity should be measured at the point of installation.

Field Techniques

Most cathodic protection installations are accomplished by contract with suppliers and equipment manufacturers. The maintenance of these facilities is principally one of inspecting, testing, and analysis of the results. Obviously, good records are essential to successful use of cathodic protection. Changes in electrical potential are sometimes very gradual. The anodes are dissipated on a generally straight-line basis, and records are needed to predict when replacements will be required.

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4.14. WELLS AND GROUND-WATER RECHARGE

4.14.1. Wells

The maintenance of wells is important to maintain well efficiency and prolong the life of the well. Well maintenance may also require proper closure and sealing when the well is beyond its useful life in order to prevent accidents.

Removal of encrustations resulting from mineral deposits and/or biological activities is a primary maintenance problem associated with wells. Introduction of properly designed plastic well screens and new metal alloys have greatly reduced the problems associated with corrosion. Periodic treatments with chemicals and/or jetting may be required to properly maintain certain wells.

Regular inspections with well-kept records are essential to good maintenance. Inspections can be completed by means of lighted television cameras. However, the simplest method of determining the well condition is with a hydraulic test for specific well capacity. Efficiency testing should be a routine procedure in the maintenance of wells. Testing is a method to evaluate economics of well performance.

It is occasionally necessary to add gravel to a gravel-enveloped well. A chemical analysis of water pumped from the well is also important in diagnosing well problems.

4.14.2. Ground-Water Recharge Facilities

Other features of irrigation and drainage systems may include ground-water recharge basins or spreading grounds. Maintenance of these facilities includes removal of silt, trapping and removal of gophers, dike sloping, and weed control. Frequent inspection should be made of any corrosion that might occur to flocculation agent dispensers if these are used to facilitate removal of sediment in the water.

Injection wells can also be used in some instances for the purpose of ground-water recharge. Maintenance of injection wells generally is similar to that of production wells. Regular performance records are also important to assess maintenance needs for these wells.

4.15. MAINTENANCE OF MECHANICAL, ELECTRICAL, HYDRAULIC, AND ELECTRONIC EQUIPMENT

The equipment associated with the operation of an irrigation or drainage development generally consists of mechanical, electrical, hydraulic, and electronic equipment. Most of this equipment is highly specialized and vital to operations. Because of its specialized nature, instructions regarding its care and maintenance are difficult to give in a manual such as this. Specific care and maintenance are usually described in bulletins and manuals furnished by manufacturers.

There are five reasons why equipment fails. Failure can be attributed to design faults, manufacturing faults, installation faults, poor maintenance, and lack of operating know-how.

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From time to time, equipment will not meet the specific agency needs. This frequently occurs when designers are not informed sufficiently to understand the function required of the equipment. Manufacturing faults generally occur the least among the five problems encountered. However, it is necessary to be diligent in watching for dangerous defects at the time of installation and during testing of the equipment, which should be done as soon as possible after installation.

Good installation is of utmost importance. The final result is no better than the quality of installation work—excellent design and manufacturing can be nullified by poor installation. On the other hand, a good installation staff can often correct manufacturing errors and often can redeem a poor design situation. Wherever possible, the responsibility of the installers should extend through testing. Equipment should not be officially turned over to operation and maintenance personnel until equipment has been satisfactorily tested and performs as desired.

In this connection, the construction staff should include personnel who are responsible for final correct operation of the equipment, and installation staff should maintain close liaison with both designers and operation and maintenance people.

4.15.1. Recommended Maintenance Procedures

After equipment is installed and operational, manufacturer-recommended maintenance procedures should be strictly followed. Good preventive maintenance is essential for efficient operation of any type of equipment. After equipment has been in service for an extended period of time or usage, teardown and inspection with replacement of necessary components is good practice.

4.15.2. Maintenance Shops, Equipment, and Supplies

Many factors influence the need and extent of the agency maintenance center. The important factors are the geographic location of the operating system, size and machinery, and availability and dependability of commercial concerns. Pipeline distribution systems having a large number of pumping plants may find it advantageous to be equipped with a complete machine shop for both electrical and mechanical work.

Machinery for this type of shop includes hydraulic presses, radial drill presses, shaft alignment bench, impeller balancing machine, milling machine, lathes, a steam cleaner, and bake oven for electric parts. Journeymen machinists and electricians must be a part of this type of organization. Adequate warehousing must also be available for materials and spare parts.

The availability of materials or supplies is always an important aspect of an effective maintenance program. In keeping with the type of maintenance program previously discussed, a dependable warehousing program must be established and maintained. Appendix G has examples of

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inventory and material control forms for use as aids to the maintenance superintendent in supplying his field crews with materials.

Useful life of equipment should be estimated and replacement should be programmed. It may be prudent, depending upon availability from the manufacturer, to warehouse some parts and components of equipment that are especially vital to operations.

4.15.3. Gate Control Structures

Manual and automatic control facilities include mechanical, electrical, and electronic equipment. Moving components of the gate should be lubricated periodically, and gate hoists operated throughout their entire operating ranges frequently to assure continued operational reliability. This is particularly necessary for splash systems in order to prevent rust, which can readily occur in humid areas, and to free debris that can accumulate when equipment is not in use. Emulsion-type lubrication oil is standard in these applications because of its ability to absorb condensation.

Gate vibration can be a problem with guide wheels on automatic gates. This can be largely eliminated with sealed bearings that require infrequent lubrication and by case-hardened wearing surfaces.

Periodic inspection of spillway gates and tests of operating equipment should be made by an engineer or a mechanic familiar with the purposes of the equipment. Trashracks should be cleaned of debris and accumulated sediment, and metalwork should be painted to prevent rusting.

Inlet and outlet gates and valves should be tested regularly to make sure gates and valves work freely. Like gates, valves should be exercised periodically to determine that the valves are in good operating condition. All mechanical equipment should be lubricated and serviced in accordance with manufacturer or designer instructions.

4.15.4. Combustion Engines

Detailed instructions for maintaining combustion engines will generally be adequately furnished by the manufacturer supplying the engine. These instructions should be followed and the manufacturer contacted when unforeseen problems arise.

Many agencies make it a practice to periodically operate the engine even though the function for which the engine was installed is under a "no-operation" condition. Such a procedure is recommended to assure operation in an emergency.

4.15.5. General Electrical Maintenance

This is a broad subject and maintenance procedures will depend upon the type of system installed. Manufacturer bulletins and instructions should be included in agency files for reference and guidance. However, maintenance frequently consists of replacement of wiring due to insulation breakdown. In

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the case of motors, it is advisable to have space heaters inside the housing to reduce such insulation problems. Heaters of 25 to 30 watts also can reduce the insulation and moisture problems that cause faults in automatic control housings.

Frequent inspection of electrical equipment and powerlines should be routine on any system, and the agency should be staffed with qualified repair and servicing personnel, or such personnel should be available nearby.

An electrical maintenance program can be divided into three types:

- Corrective or breakdown maintenance—Repairing equipment after an in-service failure.
- Preventive or planned maintenance—Scheduled inspection, lubrication, adjustment, testing, and repair of equipment components to prevent in-service failure.
- Predictive maintenance—Inspections and tests that can predict which components must be repaired or replaced to ensure trouble-free operation of the equipment.

Preventive maintenance has several advantages over breakdown maintenance. One of these advantages is the elimination of many breakdowns when the equipment is urgently needed for service. In addition, it can also be more economical; substituting minor repairs for major ones. This helps keep electrical systems in good operating condition and promotes higher operating efficiency. Performing maintenance on a preventive basis permits orderly budgeting and manpower planning and provides information for a realistic stock of spare parts.

Agencies that propose to establish their own electrical department will find that test instruments such as a digital V-O-M instrument (for extreme accuracy), power driven megger, D-C dielectric test set, portable alternator, A-C volt ammeter, variable frequency generator, portable A-C ammeter, portable A-C voltmeter, portable oil tester, vibrometer, and small portable vacuum cleaner and air compressor should be part of electrician maintenance equipment. Some manufacturers offer special training courses in the use of their instruments. Sending technicians to these schools is certainly a worthwhile investment and a necessity.

A word of caution, however—preventive maintenance can be carried to the point where its cost exceeds periodic replacement of the component. For example, annual cleaning and regreasing of ball bearings in a small electric motor may exceed the cost of replacing the bearings every 2 or 3 years. In fact, small motors on ventilating fans often can be replaced after breakdown for less cost than periodic service.

4.15.6. Servicing, Performance, and Replacement Records

Several forms used by various agencies are included in Appendix G and are self-explanatory. The fact that such forms can be found in most maintenance offices attests to the importance of adapting similar forms for use.

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