WATER OPERATION AND MAINTENANCE

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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 water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups for operating and maintaining project facilities.

Although every attempt is made to ensure high quality and accurate information, Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

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Cover photograph: Bureau of Reclamation and California Office of Emergency Services Damage Survey Report Inspectors at the Devils Slide caused by flooding in 1995 in northern California.

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RECLAMATION DISASTER RESPONSE

by Jan Henry[1]

In the early 1990's, the Federal Government, through the Federal Emergency Management Agency (FEMA), developed the Federal Response Plan (FRP) to prepare for, respond to, and recover from disasters. Roles and responsibilities for all Federal agencies were identified under this plan, which consists of 12 Emergency Support Functions (ESF). The development of the ESF document and operational coordination of each ESF is delegated to one of the larger Federal agencies as the lead or primary agency. The Department of the Interior, represented by the Bureau of Reclamation (Reclamation), and 11 other agencies were identified as having capabilities to support the U.S. Army Corps of Engineers (Corps), which is the primary agency for ESF No. 3, Public Works and Engineering.

In 1992, Reclamation initiated an agency-wide planning process to identify personnel who were both interested in and had appropriate skills and abilities to participate in disaster response operations. About 500 people volunteered and are now a part of the Reclamation Disaster Response Team computer data base.

Between 1993 and 1995, Reclamation has fielded over 300 personnel in support of disaster response, both for FEMA (under the FRP) and as direct support to the Corps under their Levee Rehabilitation Program. Reclamation aided FEMA and the Corps in the following disasters: the Midwest flooding of 1993; the Northridge California earthquake in 1994; and the Northern California, South Dakota, and Missouri flooding in 1995. Most personnel that have participated in disaster assignments are from engineering, engineering technician, and construction inspector fields. Administrative support personnel, contract specialists, biologists, and survey crews have been on disaster assignments in small numbers.

Several factors point to Reclamation's continued involvement in disaster response. First, Reclamation personnel have demonstrated to FEMA and the Corps that they are a dependable and valuable source of quality technical expertise. This reputation is opening up new opportunities for both the agency and its personnel. Second, a large and expanding pool of enthusiastic and flexible volunteers exists within Reclamation. The willingness of Reclamation's volunteers to participate and to respond in a short period of time has proven to be invaluable. Third, Reclamation's management is developing a better appreciation of the positive impacts of this fully reimbursable disaster work. The disaster work helps balance fluctuations in the staff work load.

Additional factors that contribute to Reclamations participation in disaster response are: (1) as the Federal Government continues to downsize, a smaller pool of personnel is available with technical expertise needed for disaster response; (2) FEMA is now using the FRP as the management framework for all disasters, not just the very large or catastrophic disasters; and (3) more and more of the U.S. population resides in areas such as the west and east coasts, that are susceptible to the disastrous effects of flooding, earthquakes, and hurricanes.

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Damage to Cal-State Northridge Campus from the January 1994 Northridge earthquake in Los Angeles, California.

Flooding from the 1993 Midwest flood.

Reclamation is undergoing a substantial organizational change from its traditional mission as a dam construction agency to a water resource management agency. The Disaster Response Program has tapped the expertise still in the agency from its construction and design days and is directing that expertise in new directions such as providing Damage Survey Report Inspectors to support FEMA.

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DAMAGE SURVEY REPORTS

by Rodney J. Barthel[2]

In the aftermath of a disaster, be it a natural occurrence or manmade, local authorities and individuals request help from private relief organizations and their State Government. If assistance is beyond their capabilities, the Governor of the affected State can request a presidential declaration for a major disaster.

Once a Governor informs the Federal Emergency Management Agency (FEMA) of their intention to request a Presidential declaration for the damage, FEMA dispatches Federal personnel to participate in Federal, State, and local government teams to prepare a Preliminary Disaster Assessment (PDA). The goal of a PDA is to jointly quantify the damage so that the Governor has data to include in the formal disaster declaration request to FEMA. FEMA can use the same data to substantiate their recommendation to the President for denial or approval of a disaster declaration. Bureau of Reclamation (Reclamation) personnel have participated in a limited way on PDA teams.

Bureau of Reclamation and California Office of Emergency Services Damage Survey Report Inspectors at the Devils Slide caused by flooding in 1995 in northern California.

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Upon the President's disaster declaration, FEMA appoints a Federal Coordinating Officer to establish a Disaster Field Office (DFO). The DFO is a centralized facility for Federal and State representatives to coordinate their efforts in support of local governments impacted by the disaster. One of the major disaster programs triggered by a disaster declaration is the Infrastructure Support Program. This program provides Federal funds on a cost-share basis—75 percent Federal and 25 percent State and/or local—to repair or replace damaged public facilities.

The first and most critical step in this program is the estimation of the repair or replacement costs by a joint Federal/State/local Damage Survey Report (DSR) inspection team. For example, in the State of California, the State representative is generally an Office of Emergency Services employee. Reclamation has provided the Federal representative in several DSR disaster operations. A representative of the impacted local government generally accompanies the DSR inspection team. The local representative helps ensure that all eligible work and costs are identified in the teams' site visits to inspect the damage.

Each Federal/State team is deployed to a designated disaster area, assigned a list of applicants, and provided copies of Notifications of Interest (NOI). NOI's are the State and/or local governments' official indication of interest in the program and self identification of the location and categories of damage. Initial contact is made with the local governments' authorized representative, identified on the NOI. Categories of damage are classified "A" through "G," which include, respectively: debris clearance, protective measures, road systems, water control facilities, buildings and equipment, public utility systems, and other (park facilities, recreational facilities, etc.).

The DSR inspection team visits sites and prepares cost estimates for eligible work in accordance with Federal guidelines. At this time, work may or may not have been completed. In the case of completed work, actual costs are preferably used in place of an estimate. Photos are taken to document the site at the time of the inspection. The DSR is prepared and assembled by the team, but the Federal representative has the responsibility to ensure that the document is complete and accurate.

Depending on the FEMA region in which the event occurs, a DSR may contain, but may not be limited to, the following documents:

- Narrative
- Preliminary environmental review
- Maps
- Sketches
- Building survey forms
- Bridge survey forms
- Flood survey forms
- Pumping equipment survey forms
- Levee inspection forms

- Debris worksheets
- Calculations
- Contract labor records
- Force account records
- Force account equipment records
- Rental equipment records
- Contract documents
- Material records
- Insurance documentation
- Photographs
- Hazard mitigation proposals
- Backup documentation

The extent of data in the DSR is a function of both the category of damages and the stage of completion of the work at the time of the inspection.

Once the DSR is assembled, the Federal representatives indicate their recommendation for eligibility. At this time, the State and local representatives have the opportunity to concur or not concur with the Federal recommendation. If the State or local representatives do not concur, then they have the opportunity to provide additional information and clarification justifying their nonconcurrence.

After this process is complete, the report is forwarded to the DFO where Federal reviewers, and in some regions, State reviewers, review the document for eligibility. At this point, the reviewers incorporate comments and may contact the inspection team to clarify questions or provide additional information as requested. Final approval for eligibility is the responsibility of the DSR reviewers and not the DSR inspection team. Once DSR's are approved for eligibility, emergency assistance funds are forwarded to the State, which serves as the grant administrator. The State processes the paperwork and provides funds to the local government/applicants who are the subgrantee of the State.

If the DSR is denied, in whole or in part, the applicant can submit an appeal to the State. The State then follows guidelines for appeal to FEMA. This completes the Damage Survey Report process.

In general, the DSR process is well organized. Reclamation inspectors are generally committed for 60-day assignments, although some have been on disasters for over 7 months. State and local representative schedules vary depending on the State where the event occurred. At the onset of a disaster, inspection teams may be required to function on a 7-day-week, 12- to 14-hour-day work schedule. Long hours and extended durations away from home and family can take its toll on the inspectors. FEMA, Corps, and Reclamation managers recognize this fact and try to offset inspector burnout by gradually reducing the work schedules and allowing Federal inspectors periodic short, paid breaks to travel home to visit family, take care of personal business, and escape from the pressure of the disaster assignment.

To be successful, a DSR inspector must be flexible both in his personal and professional approach to the disaster assignment and work environment. Inspectors must also recognize that the DSR process is dynamic and that policies and procedures may change in the course of the assignment. The inspector must be able to balance the sometimes conflicting goals and objectives of the Federal, State, and local government interests of the members on this team and still produce an acceptable quantity of high quality DSR's.

DEVELOPMENT OF PERFORMANCE PARAMETERS FOR DAM SAFETY MONITORING

by Jay Stateler, Larry Von Thun, Gregg Scott, and Jim Boernge[3]

INTRODUCTION

To promote efficient and effective monitoring for dam safety purposes, the Bureau of Reclamation (Reclamation) has recently begun developing and documenting performance parameters for each of its dams. These documents are anticipated to be the foundation of the future Reclamation dam safety program. In a nutshell, the performance parameter document addresses the question: "What should be done to properly look after the dam in the future, from a dam safety perspective, given what we know today?" To adequately and appropriately address this question, the following process is followed:

1. Identify the most likely failure modes for the dam.

2. Identify the key parameters to monitor that will provide the best indication of the possible development of each of the identified failure modes and define an instrumented and visual monitoring program to gather the necessary information and data.

3. Define the ranges of expected performance relative to the instrumented and visual monitoring program and define the action to be taken in the event of unexpected performance.

Each of these steps in the process will be discussed briefly below, and then two example failure modes will be presented to illustrate the methodology.

IDENTIFY THE MOST LIKELY FAILURE MODES

The goal is to prevent circumstances where uncontrolled releases from the reservoir cause loss of life or significant economic losses in downstream areas. The most effective initial step toward this goal is to identify potential failure modes for the dam. This initial step is taken in light of the information and analyses that are currently available concerning the dam and damsite and the current state of the art in dam design and evaluation. A careful review is made of the following relative to this effort:

1. Site geologic conditions

2. Design of the dam and appurtenant features

3. Construction methods and records

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4. Performance history, based on instrumentation data and visual observations

5. Current design earthquake and flood loadings

A focused discussion involving all individuals that have had significant involvement with the dam (e.g., had involvement during design/construction, performed analysis work, performed site inspections, reviewed instrumentation data, etc.) can be a very effective means of developing a list of potential failure modes. Synergy during such a session can lead to results superior to those that might otherwise be achieved.

Clearly, the failure mode evaluation is very site specific. The search is for failure modes that are physically possible (or cannot reasonably be ruled out) given the information available. The potential failure mechanisms need to be described as precisely and specifically as possible so that the remainder of the performance parameter process can be effectively carried out. The most probable location(s) for development of each failure mode must be specifically identified along with the manner in which the failure mode would likely initiate.

The identified failure modes are presented in order of apparent threat or likelihood to help establish which modes deserve the most energy, effort, and attention in the monitoring efforts. It is important to understand that the identification of potential failure modes does not necessarily mean they are likely to occur. If the likelihood was viewed to be more probable than "remote," then a dam safety deficiency exists, and dealing with the situation by merely employing future attentive monitoring would not be appropriate. Structural modification of the dam and/or use of a well-designed Early Warning System (EWS), if appropriate, would be indicated in these cases. The concept of being "physically possible, but of low likelihood" may be difficult to accept in some instances, but the fundamental reality is that inherent risk is associated with every dam (generally very low) no matter how apparently well designed and "safe" it may appear, and that reality is being addressed by a continued, vigilant monitoring program for the dam.

IDENTIFY KEY PARAMETERS TO MONITOR RELATIVE TO EACH FAILURE MODE

The next step in the process is to look at each potential failure mode and ask the question: "What clues should we look for to detect the possible development of this failure mode?" The clues can fall into two categories: (1) those that provide early warning of the possible onset of the failure mode and (2) those that indicate the presence of conditions conducive to the development of the failure mode. The monitoring of the parameters can be accomplished by observation for specific visual clues and/or by instrumented monitoring. In addition to specifying what parameter should be monitored, how and where to monitor the frequencies also needs to be established. It is important from the standpoint of efficiency and credibility of the monitoring program that the scale of the program be appropriately balanced with the risks and consequences associated with the potential failure mode. Appropriate explanations of the program should be provided to those who will perform and/or pay for the monitoring so as to give a good understanding of why the program is justified. It is vital that the monitoring program be effective, but efficiency and common sense are also important so as to achieve acceptance and sustainability.

If an instrumented monitoring program is already in place at the dam, it is necessary to determine which instruments should be retained, which are of limited current value and are no longer needed, what additional instruments are needed, and what adjustments should be made to existing reading frequencies. It is typical to use existing instruments in the newly defined monitoring program to the extent possible, both for economic reasons and to take advantage of the existing data base for these instruments that provides a valuable baseline for comparison with future data.

IDENTIFY EXPECTED AND UNEXPECTED PERFORMANCE

This stage of the process is intended to make the work of the "operators" of the routine monitoring program efficient and effective. Regarding routine visual inspections performed by onsite personnel, definition is provided concerning what observations would be in line with expected performance and what needs to be promptly reported and evaluated. Regarding instrumented monitoring, definition is provided concerning what readings are within the bounds of expected behavior and what readings should be promptly checked and investigated further if confirmed. Routine, computerized, real-time comparison of instrument readings to established limits that are a function of reservoir level, tailwater level, air temperature, and/or other relevant parameters is in no way intended to replace necessary human reviews of data, but instead can serve as a valuable "coarse sieve" for the data to allow *much* of the anomalous data to be readily identified.

ILLUSTRATION OF THE METHODOLOGY USING EXAMPLE FAILURE MODES

Two example potential failure modes are discussed in some detail below to illustrate the thought process associated with the three-step approach to developing performance parameters.

Example Failure Mode 1—Piping or Subsurface Erosion of Embankment Core Materials

Historical experience and performance parameter failure mode identification to date show that, by far, the most prevalent potential failure mode for an embankment dam, absent an extreme loading condition caused by an earthquake or flood, is the threat of piping or subsurface erosion of embankment core materials. Current embankment design practice adequately protects against this failure mode, but older embankments generally do not incorporate all the necessary defenses. The following questions can be used to assess the adequacy of the protection against this failure mode:

1. Where embankment core material was placed directly upon bedrock, was the surface of the bedrock treated with slush grouting to seal off all exposed joints and fractures? This treatment would prevent transport of core materials into the bedrock.

2. Where embankment core material was placed directly upon bedrock, was the surface of the bedrock excavated and/or treated with dental concrete to provide a reasonably regular surface upon which to place the embankment (e.g., free of significant "steps")? These procedures would reduce the risk of development of cracks in the core material caused by arching effects and/or differential settlements.

3. Where embankment core material was placed directly upon overburden materials, was the filtering capability of the range of overburden materials to be encountered checked relative to

the core material, and were sufficiently thick filtering zones provided, where needed, to prevent transportation of core material into the overburden materials by seepage flows?

4. In the embankment, was a filter zone provided downstream from all portions of the embankment core, and do all embankment zones downstream from the embankment core meet current filter criteria requirements with the zone immediately upstream?

5. Were properly filtered drains provided to safely intercept and discharge seepage that passed through the embankment?

If these questions reveal that the necessary defenses are not totally present, or if it is unknown or unclear if the necessary defenses are in place, then potential failure mechanisms associated with piping or subsurface erosion need to be addressed by the routine monitoring program. The severity of the threat posed by the identified failure mechanisms may be reduced if one or more of the following conditions are present:

1. The embankment core material has significant plasticity such that it is not easily erodible.

2. The hydraulic gradients are not high in the areas of concern.

3. The seepage quantities are low, such that if erosion of core materials is taking place, failure of the embankment would take a long time, providing ample opportunity for recognition and response to the developing problem.

4. The seepage path involves flow through joints in competent rock, meaning that the cross-sectional area of the flow is effectively limited by the size of the joints and cannot readily increase over time.

5. An exit point for the seepage that permits removal of the material transported by the seepage flow from the site does not exist, *and* areas for possible redeposition of transported material, such as within coarse embankment zones or within coarse foundation overburden deposits, are limited in terms of volume or access. Such a failure mechanism would be self-limiting because, in time, the downstream end of the seepage path would become increasingly obstructed, and no alternative path would be available that has an exit point or large capacity for redeposition of materials.

In addition to the above discussion of general site conditions that could give rise to problems, several special cases relating to this potential failure mode might be encountered.

One special case is for the piping or erosion to occur along the outlet works, spillway, or other appurtenant structures, particularly in the event of differential settlement or movement between the embankment and the structure that produces gaps, areas of lesser seepage resistance, etc. In some instances, cracks or flaws in the appurtenant structure may provide an exit point for seepage flows, though the development of the failure mode typically would be significantly constrained by the available flow area at the exit point. In other rare instances, flaws, cracks, or leaks in an appurtenant structure could lead to the introduction of seepage water *into* the embankment at high pressure, with great potential to move even fairly erosion-resistant materials, because of the high hydraulic gradients involved. When these "special" exit and entrance points are not present, and when a downstream filter zone has been provided (that meets current filter criteria), then the potential for this special case of the failure mode is greatly reduced if not essentially eliminated.

Another special case is that the filter zone immediately downstream from the core material is sometimes not extended all the way to the crest of the dam because the anticipated level of the phreatic surface is far below the dam crest elevation at the downstream edge of the core material. Many such sites could develop transverse cracks near the crest extending to a depth below the maximum reservoir elevation because of desiccation of core materials, differential settlement caused by abrupt changes in embankment/foundation contact elevation, seismic shaking, or other causes. Seepage flow through such transverse cracks could erode core material and carry it into and through the downstream shell materials because these zones rarely meet current filter criteria with the core material.

Yet another special case involves seepage flow through untreated joints in the foundation bedrock or abutment rock at and just beneath the embankment/foundation contact. Such flows could contact and carry core material into the joints in the foundation. Effective foundation grouting could greatly reduce the risks associated with this mechanism, but some ungrouted joints must always be assumed. This "contact" mechanism is a lesser threat than the typical failure mechanism that postulates flow passing from the core material into the joints in the foundation (across, not along the interface). The "contact" mechanism is a lesser threat because it generally would be expected to progress at a slower rate than would the "typical" mechanism.

With a good understanding of the possible failure scenarios associated with this potential failure mode, the locations of prime concern relative to routine dam safety performance monitoring should be clear. Parameters to monitor are as follows:

1. Visual observation for evidence of materials transport with seepage or drain flows. Where natural sediment trap locations are available, such as in manholes and at the stilling pools in front of weirs, they should be carefully monitored (after being cleaned out so as to start with a "clean slate"). General awareness should be maintained for discolored seepage or drain water and for any evidence of material deposits in the vicinity of the flowing water.

2. Visual observation for new seepage areas, for changes in the conditions at existing wet areas or seepage areas that cannot be quantitatively monitored, and for transverse cracks at the crest of the dam. If the failure mechanism involves flow through joints in the bedrock, the visual observations should be extended a significant distance downstream from the embankment because new seepage areas will not necessarily exit near the toe or groin of the embankment.

3. Flow rate monitoring at toe drains, other drains, and known seepage areas that can be quantitatively monitored. Any evidence of increased flows at comparable reservoir elevations would be cause for concern and would need to be promptly investigated.

4. Monitoring of appropriately located piezometers and observation wells for any changes in their historical relationship with reservoir elevation, and for changes in the relative piezometric levels at adjacent instruments. The water pressure data, being representative of conditions over only a limited area, are frequently of lesser value than the information obtained by the three previously noted methods, which are more global in scope.

The monitoring frequencies for items 1 through 3 above generally are all the same because typically they should all be done during the same "tour" of the dam and appurtenant structures. Frequencies can range from four times per year for low risk situations to weekly or several times per week for high risk circumstances. A monthly frequency would be fairly typical. For item 4, monitoring frequencies typically are the same or less frequent than for the other items, with a minimum frequency of three times per year to establish a basic correlation with reservoir elevation. Monitoring frequencies for item 4 may be less frequent than for the other items because the other items typically provide the most valuable information and provide monitoring coverage of the entire dam as opposed to only limited areas as noted previously. Because the risks of this failure mode increase with increasing reservoir elevation, more frequent monitoring is commonly instituted when the reservoir is unusually high.

Example Failure Mode 2—Flood-Induced Failure of an Embankment Dam

A flood can lead to the failure of an embankment dam in a number of different ways:

1. The dam is overtopped, and the overtopping flows erode the crest and downstream slope such that breaching of the dam results.

2. Peak water levels are just below the crest of the dam, and "splashover" caused by wind setup and wave action causes erosion that leads to breaching of the dam.

3. Peak water levels are just below the crest of the dam but above the top of the embankment core material that lies more than a foot or two below the dam crest elevation. Flow through pervious materials above the top of the core material erodes the core material, eventually leading to breaching of the dam.

4. High flows through the spillway (or outlet works) lead to damage of the structure, perhaps because of cavitation erosion of the downstream channel undermining the stilling basin and chute structures. The erosion and damage work their way back toward the reservoir until finally the structure is completely lost and uncontrolled release of the reservoir occurs.

5. High flows through the spillway (or outlet works) are not properly conveyed away from the toe of the dam such that erosion of the embankment ensues, leading to undermining and eventual breaching of the dam.

The failure scenarios above may occur in combination during one flood event, increasing the potential for breaching of the dam. It is also possible that the spillway and/or outlet works will not be operated as expected during the flood event because of stuck or inoperable gates, lack of power (and backup power), loss of access to the site, operator error, etc. Abnormal operation may transform a flood that could have been safely handled into a flood that causes dam failure.

The value of performance parameter work relative to extreme events, such as floods and earthquakes, comes largely from steps taken in advance of the event to recognize and deal with possible deficiencies so that the above scenarios can be avoided. Obviously, it is important to be dealing with current crest elevations of structures rather than design elevations because post-construction settlement and camber allowances need to be considered. Crest surveys can identify low spots on the embankment where flood damage may first occur. Embankment areas near the abutments frequently are the low areas because little or no camber was provided. These areas near the abutments would be of particular concern because erosive flows down the groins would be concentrated into a small area.

In some instances, an EWS may be used as the primary defense against loss of life in downstream areas if the reliability of the EWS to minimize loss of life supports such an approach. If an EWS is used, the performance parameters should define a program of periodic operational checks of the EWS to ensure that it functions as designed in the event that it is needed.

Careful visual monitoring during lesser magnitude flood events can identify performance problems that could result in dam failure during a larger flood event. Such "full-scale prototype testing" can provide invaluable information, obtainable in no other way, if appropriate advance preparations have been made to appropriately document performance.

Heightened instrumented monitoring is generally warranted during a flood event because the likelihood of failure mode scenarios involving high uplift pressures, piping, and/or subsurface erosion, etc., increases. Daily visual monitoring for evidence of onset of these failure modes, as well as for the five flood-related failure mode scenarios noted above, typically is warranted. Following the flood event, a thorough inspection of the dam and appurtenant structures should be performed, and all instruments should again be read. If indications of possible settlements or deflections of embankments or appurtenant structures are noted, any measurement points located on them should be promptly surveyed.

PERFORMANCE MONITORING PROGRAM

When all the various failure modes of concern have been identified and appropriate parameters for monitoring have been determined, an integrated program covering all the parameters that need to be monitored for the dam can be defined. Standard elements of the program are as follows:

1. Routine visual monitoring by onsite personnel—A one-page (front and back) inspection checklist form is typically developed specific to the needs of each dam. The form is set up such that any question answered with a "YES" means something unexpected has been noted that needs to be investigated.

2. Routine instrumented monitoring—To the extent possible, provisions should be made so that data can be checked against the limits of expected behavior at the time the instruments are being read.

3. Periodic examination by inspection specialists—This element represents an opportunity for a "fresh set of eyes" to look for anomalous performance, particularly relative to failure modes that are not the current focus of attention. Additionally, this examination represents an excellent opportunity to discuss the failure modes of concern with onsite personnel and assist them with any questions they may have relative to performing the routine visual monitoring.

4. Earthquake response and flood response—Performance monitoring actions that are to be carried out in the event of an extreme loading condition are defined.

The completed performance parameters document includes discussion of the following topics: (1) description of dam and appurtenant structures; (2) site geology; (3) design flood and earthquake loadings; (4) potential failure modes; (5) key monitoring parameters associated with each potential failure mode; (6) discussion of monitoring program, including locations of instruments, discussion of past performance, and documentation of the revised monitoring program; (7) tables specifying limits of expected performance; and (8) action to be taken in the event of unexpected performance. Additionally, a "contact list" is provided to promote open communication among all involved parties, and a two- to four-page "Focused Summary" is provided that briefly presents the key points of the document. Several copies of the summary are laminated in plastic for posting at the dam for quick reference.

LESSONS LEARNED FROM PERFORMANCE PARAMETER WORK TO DATE

1. Reclamation has used a Performance Parameters Team (consisting of the four authors of this paper) to accomplish the majority of the performance parameter work performed to date. For each dam, the team first reviews available information, including a specially prepared notebook summarizing the instrumentation program and data for the dam, and failure mode questionnaires completed by people familiar with the dam. Next, the team has a 2-hour session with people familiar with the dam, where potential failure modes, unusual performance, current concerns, etc., are discussed. The team then has a meeting to agree on the potential failure modes that warrant highlighting and the associated key monitoring parameters. One team member, serving as the "lead author" for that particular dam, then prepares the draft performance parameters document. The draft is first reviewed by the other team members and then by all Reclamation personnel having significant involvement with the dam. When all comments have been appropriately addressed, the document is finalized and distributed. This approach has been effective and efficient, with most reports prepared at a total cost of about 20 to 30 staff days of labor.

2. Reclamation's performance parameter work has opened many eyes to the importance of visual monitoring by onsite personnel. The majority of the key monitoring parameters relate to visual observations. It obviously is preferable that these observations be made frequently by personnel routinely at the dam rather than relying upon infrequent visits by inspection specialists. To promote effective performance of the routine visual monitoring program, the performance parameters document clearly presents the "what" and the "why." Every opportunity needs to be taken to cultivate and foster this routine visual monitoring program when designers and inspectors have a chance to meet or talk with onsite personnel.

3. On several occasions, the performance parameter methodology has identified items that have been overlooked or inadequately addressed by the dam safety analysis/evaluation work done to date by Reclamation, indicating that employing this process at the start of such work would be a good idea. It is striking how often questions, such as whether a particular embankment zone meets current filter criteria requirements with the upstream zone, or what is the clay content of the embankment core material, still exist at dams where recent exploration to obtain foundation samples for liquefaction analyses put drill holes through the zones in question without sampling them.

4. Reclamation's experience to date in identifying potential failure modes correlates well with statistical data categorizing the reasons attributed to actual dam failures. For embankment dams, subsurface erosion/piping, flood-induced failure, and earthquake-induced failure are the most frequent modes cited. For concrete dams, foundation support issues dominate, sometimes being related to overtopping flows that may erode the foundation or seismic loadings that trigger failure mode initiation.

5. A central premise of performance parameters work is that "you won't find what you aren't looking for." This approach is the opposite of "let's put in some instruments and see what happens."

6. Efficiency and effectiveness are important in dam safety monitoring work given current fiscal realities. Scribing crisp, thin lines across contraction joints of concrete dams to aid visual monitoring for horizontal and vertical relative movements is inexpensive but very effective. Staking the limits of downstream wet areas is a cheap, effective way to look for significant changes with time. At the other end of the spectrum, routine chemical analysis of water samples obtained at seepage locations is expensive, yet provides information concerning only a specific moment in time. Because sediment transport by seepage flows can be a process that proceeds in "spurts," more effective (and inexpensive) monitoring for sediment transport can be achieved using continuous monitoring approaches such as observing for deposited materials in stilling pools associated with weirs, at sediment trap locations in manholes, in filter socks placed on discharge pipes, etc.

7. Some justifiable monitoring of dams cannot be directly tied to a particular failure mode but instead falls in the category of "general health monitoring." Onsite examination by inspection specialists every few years is an example, as are surveys of measurement points located on the dam and/or appurtenant structures that are performed every few years, or regular seepage monitoring in the galleries of a concrete dam. Monitoring for "general health" opens the door to possible abuse, so a "low-cost, high value" test is applied to such monitoring proposals.

8. In-depth evaluations of instrumentation data can provide not only valuable insight concerning the performance of the dam (such as patterns of seepage flow through an embankment) but also insight as to whether a particular instrument is providing sufficiently consistent, reliable data that it is worthy of being retained in the future monitoring program. Plots of reduced instrument readings versus associated reservoir elevations can be particularly valuable for these evaluations. In some instances, such plots may look discouraging, but in fact may reflect failings of reading and/or maintenance procedures (that can be rectified in the future) rather than failings of the instrument itself.

9. The fact that a dam has experienced many years of apparently satisfactory performance is important information relative to assessing its risks. However, if the monitoring program is not capable of obtaining useful information concerning the key monitoring parameters, the "satisfactory" track record has much less significance. For example, an embankment dam that has significant ponds and swampy areas at its downstream toe may never have given any indication of piping/subsurface erosion problems, but because the key monitoring areas cannot be effectively monitored, who knows what may be going on unseen?

10. In some cases, significant structures in the "shadow" of more significant structures receive less dam safety attention than they deserve. Dikes associated with larger dams and wing dikes associated with concrete dams are examples of structures that might get more attention if they were independent of their associated, more major structure.

SUMMARY

The performance parameters process provides a means of achieving effective and efficient dam safety monitoring programs. Important information can be effectively obtained from and conveyed to onsite personnel and personnel who routinely review instrumentation data concerning: (1) the most likely failure modes, (2) how the monitoring efforts relate to these failure modes, and (3) what constitutes unexpected performance that requires prompt investigation. The justification for the specified monitoring efforts is concisely provided to those who fund the monitoring activities. The experience of Reclamation to date, relative to performance parameters work, has been extremely positive.

Note: This paper was presented at the 1995 Annual Conference of the Association of State Dam Safety Officials in Atlanta, Georgia, on September 19, 1995.

AGRIMET— HELPING TO KEEP THE "LOGIC" IN THE HYDRO-LOGIC CYCLE

by Douglas T. Dockter,[4] *P.E.*

AUTHOR'S NOTE: As discussed in the article below, many agricultural meteorological weather networks are located throughout the Western United States. Although this article focuses on a network operated in the Pacific Northwest, the application of this type of information is universal. Those who reside in different regions are encouraged to read on.

INTRODUCTION

In view of the vital role that water plays to the existence of life on our planet, it is comforting to know that it is a renewable resource. It replenishes itself in a never-ending process known as the hydrologic cycle. The components of this complex cycle are precipitation, infiltration, ground-water flow, surface runoff, evaporation, and transpiration. Together, these components orchestrate a constant, natural recycling and redistribution of water in its various forms while providing life-giving moisture to plants and animals.

Unfortunately, another phenomenon known as the hydro-"illogical" cycle also occurs (figure 1). It is the cycle from relief and apathy followed by concern and panic as the earth's climate continues its vicious circle from drench to drought to drench to drought. During this cycle, we often lull ourselves into periods of relief and apathy when water is plentiful, only to be followed with concern and panic when faced with recurrences of drought and water-short conditions.

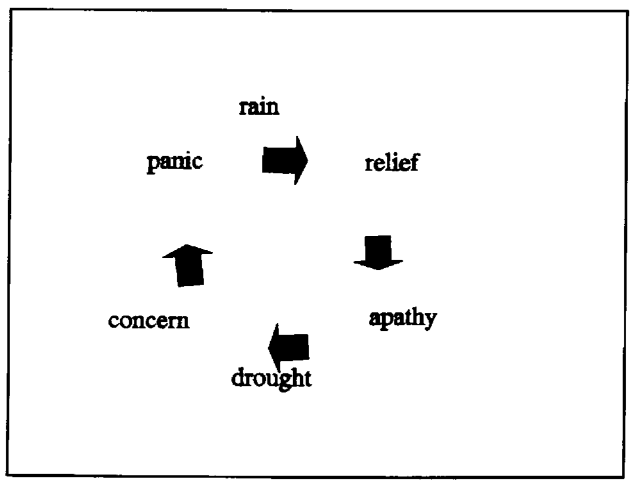

Figure 1.—The hydro-"illogical" cycle.

[4] Mr. Dockter is the acting Pacific Northwest Regional AgriMet Program Manager with the Bureau of Reclamation in Boise, Idaho.

AGRIMET

AgriMet, an agricultural weather station network operating throughout the Pacific Northwest, provides a way for water users to help break this cycle through irrigation scheduling.

AgriMet is the region's meteorological data collection system for agricultural consumptive use modeling. The region is defined by the Columbia and Snake River drainage basins and includes the States of Idaho, Washington, Oregon, western Montana, and portions of northern California, Nevada, and western Wyoming. The system is operated by the Bureau of Reclamation's (Reclamation) Pacific Northwest Regional Office in Boise, Idaho, and consists of 60 agricultural weather stations, including shared data from 11 stations in the Public Agricultural Weather System (PAWS) through Washington State University.

AgriMet was begun in 1983 in cooperation with the Bonneville Power Administration (BPA) in support of regional energy and water conservation programs. The program has since expanded from the original BPA sponsorship to include partnerships with other public and private agencies and organizations.

All stations monitor precipitation, and many stations monitor additional parameters such as soil temperature. Each station also monitors temperature, humidity, wind, and solar radiation. These parameters are necessary input for computing site-specific evapotranspiration (ET) using the 1982 Kimberly-Penman equation. The 1982 Kimberly-Penman equation is a modification of the original 1948 Penman equation and has been adapted through research performed by Dr. James Wright of the Agricultural Research Service in Kimberly, Idaho.

The equation calculates the theoretical amount of water that a well-watered crop of alfalfa with 30 centimeters of top growth would use. Alfalfa is the "reference" crop and, thus, ET is termed "reference ET" or ET_r. The ET_r is applied to curves for various other crops that translate the ET_r value into inches of water used by the various crops according to their stage of growth. The crop curves are programmed into the crop models for each station location and are updated daily throughout the irrigation season.

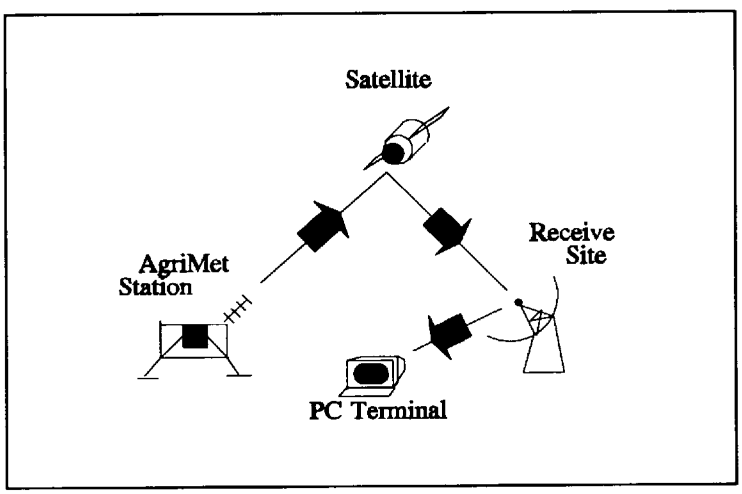

Figure 2.—Data transmission from the AgriMet station to the receive site via GOES.

The data from each sensor are collected on varying intervals and stored in the data collection platform at the station. These data are transmitted from the station every 4 hours via NASA's Geostationary Operational Environmental Satellite (GOES) to Reclamation's satellite receive site in Boise, Idaho (figure 2).

HOW CAN IRRIGATORS USE THE DATA?

Agricultural meteorological data have many uses, such as integrated pest management, power load management, forecasting burn conditions, and urban water conservation programs. The focus here is the application to irrigation scheduling.

To begin scheduling an irrigation, an irrigator should know the amount of moisture in the soil profile occupied by the roots of the given crop. Soil moisture can be determined by the texture of a sample, gravimetric analysis (weight of a sample), tensiometers, gypsum blocks, neutron probes, or time domain reflectometry and is usually reported in inches of moisture per inch of soil. All of these methods have their advantages and disadvantages. Local county extension agents have information on these various methods and will be able to make recommendations as to which method will best suit the operation.

An irrigator who starts with the soil profile at its maximum water holding capacity uses what is termed the "Checkbook Method" to schedule the date and amount of his next irrigation. This scheduling is accomplished by subtracting the daily crop ET values in inches from the soil moisture in the field. By knowing the point at which the crop will begin to be stressed by lack of water, the irrigator can forecast the time and amount of the next irrigation. The irrigator keeps track of the "deposits" or water applied, and AgriMet gives an estimate of the "withdrawals" or water being used by the crop. By also monitoring soil moisture in the field, the irrigator can monitor how the ET values from the station correlate to what is happening in the field. This monitoring may be necessary to correct for differences in the area surrounding a station attributable to microclimatic anomalies. Reliability of the data depends on a field's proximity to the station, how rapidly and to what extent elevation changes as distance from the station increases, and how pronounced the microclimatic effects are in the area of the station. In general, users within a 15- to 25-mile radius should be able to establish a good correlation between the station data and their own field conditions. ***It is important to note that although the daily and seasonal ET values do reflect the actual consumptive use of the plant under optimal growth and production, they do not represent the actual irrigation requirement (IR). IR includes water requirements for differing soil types; onfarm irrigation efficiencies; application uniformities; and cultural practices such as crop cooling, frost protection, and salinity control. Differences in start, cover, and terminate dates among growers and precipitation amounts must also be considered.***

Irrigation scheduling can help growers by increasing crop yields, reducing fertilizer, herbicide, and pesticide costs through leaching, stretching their irrigation supplies through a season, and saving money on their power bills.

USING AGRIMET IS EASY

To start using AgriMet's near real-time ET information in the Pacific Northwest, all you need is a personal computer, MODEM, and communications software. Just contact the Bureau of Reclamation's Pacific Northwest Regional Water Conservation Center in Boise, Idaho, at (208) 378-5283. We will get you a user account on our computer and send you an information packet and a user's manual. This information is currently being supplied without fee, except for expenses incurred through a long-distance phone call to the Boise computer.

The water use information is published in daily newspapers throughout the region and is integrated into onfarm technical assistance programs of local agricultural consultants, the Natural Resources Conservation Service, and the Cooperative Extension System. In the future, AgriMet information will also be available over the Internet.

Other agricultural meteorological weather networks are operating in the Western United States. California has the California Irrigation Management Information System (CIMIS), Washington has the PAWS system, Arizona has the Arizona Meteorological Network (AZMET), New Mexico has a climatic network run by New Mexico State University in Las Cruces, Colorado has a network run by the Northern Colorado Water Conservancy District, Nebraska has AgNet, Utah has the Utah Climate Network, North Dakota State University operates the North Dakota Climatic Network, and Oklahoma has its MesoNet Network. For information on the network in your area, contact your local extension agents, Reclamation office, or the Water Conservation Center number listed above.

CONCLUSION

The AgriMet data are used widely throughout the Pacific Northwest. Various agricultural consultants have reported water and power savings ranging from 15 to 50 percent over varying client bases of 4,000 to 150,000 acres. Many of these consultants are 100-percent grower funded with no cost share, indicating the economic advantage the information provides.

The value of the AgriMet information is apparent and will become more so as the demands on our water supplies increase in the future.

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JUST LINE IT!
(A WATER CONSERVATION PROGRAM FOR CANALS)

A new applied technology effort has been started using shotcrete and geomembranes to reduce canal seepage rates. This new program was developed from work accomplished in the water districts, regions, area offices, and field offices. Economy results from relatively low materials costs, the use of district personnel during installation, reduced design and specifications costs, and the ability to easily make on-the-job procedure changes.

Over one-fourth of the Bureau of Reclamation-constructed canals are earth lined. The total length of the earth-lined canals is almost 2,000 miles, and water loss caused by seepage is estimated to be between 20 and 40 percent. Although a new, high quality compacted earth-lined canal can have seepage rates similar to those for concrete lined canals, earth linings are susceptible to damage, which increases seepage rates as the canal ages.

Concrete-lined canals generally provide long-term durability against seepage, but localized areas sometimes fail because of frost heave, joint leakage, soil expansion or settlement, and operational problems.

A vast potential exists for saving water and money by providing economical and effective canal treatments that can reduce seepage rates by more than half. Earth-lined canals with high seepage rates and short sections of concrete-lined canals known to have seepage problems offer immediate opportunities for water conservation.

Membrane linings and shotcrete have been used on a small scale throughout the 20th century in various applications to reduce canal seepage. In the 1980's and 1990's, however, the availability of thick, durable geomembranes and the more widespread use of wet-mix shotcrete with its low rebound rates and uniform high quality have presented new options for reducing canal seepage rates. The geomembrane can be placed on soil or existing damaged concrete linings to seal a canal against seepage. The geomembrane can then be covered with shotcrete to protect it from mechanical damage and from solar deterioration. The shotcrete is applied without need for forming and without joints. Although it will develop shrinkage cracks, the geomembrane seals against leakage. All construction seams in the geomembrane can be field tested for air-tightness during construction. In some applications, either a geomembrane or shotcrete is used separately as the only lining.

Research and field trials that evaluate shotcrete and geomembranes have been conducted over the years, and some are currently active. Such efforts will continue because they are extremely valuable in providing data for future operation and maintenance work as well as for new construction.

This program, however, is not a research project. It is an applied technology effort to have an active maintenance program using shotcrete and geomembranes to reduce canal seepage. It is a program of hands-on field operations that improves as it goes by sharing learned practical knowledge and technology among numerous field projects.

The incentive for the program is water conservation and preventing failure of water control structures.

The justification for funding the program is the dollar value of water and structures saved. Funding is provided by the individual projects that need canal lining.

The Materials Engineering and Research Laboratory in Denver provides expertise in geomembranes and shotcrete, provides onsite field assistance, and serves as a clearing house for technical information and technical innovations. Other Technical Service Center experts provide expertise in groundwater hydrology and design.

An essential feature of the program is the flexibility to make construction procedure changes in the field as work progresses. Such changes are for greater economy and effectiveness. Field experimentation is essential to the learning process. Some projects currently over-specify to ensure quality and allow little variation from specifications requirements onsite. Economy will come only from on-the-job procedure changes. Innovative contracts or accomplishing work with operations and maintenance or district personnel can give the needed flexibility.

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A LOOK AT LIQUID FLOOR HARDENERS[5]

Designed to penetrate and strengthen concrete surfaces, liquid hardeners can boost a floor's resistance to abrasion, chemicals, and wear

by John Gill and Cyler Hayes[6]

A dilemma sometimes faced by concrete floor contractors and owners is what to do about a recently installed or existing industrial floor that has a weakened surface. After concrete has been installed, how can contractors most effectively correct the dusting, poor abrasion resistance, and high porosity that characterize such a surface? (Weakened floor surfaces are typically caused by adding excess water to the concrete, poor finishing techniques, and a poor-quality cure.)

Obviously, removing and replacing the concrete is not a favorable option, because it is disruptive, labor-intensive, and costly. A simpler, less expensive option is to use a liquid chemical treatment to harden and densify the concrete surface.

WHAT IS A LIQUID HARDENER?

Liquid floor hardener formulations vary from manufacturer to manufacturer, but they usually contain inorganic compounds that undergo a series of complex chemical reactions with the available lime in mature concrete. Some liquid hardeners also contain special proprietary ingredients to make treated floors more resistant to chemical attack and wear and to improve the aesthetics of the finished surface. Unlike solvent-based, membrane-forming sealers, which usually contain resins and hazardous solvents, most liquid floor hardeners contain inorganic compounds that are water soluble and comply with today's environmental, health, and safety regulations. Wetting agents (surfactants) are usually added to a liquid hardener to help the product penetrate the pores of the concrete substrate. The efficiency of the floor-hardening treatment increases with the depth of penetration, which usually ranges from 1/8 to 1/4 inch.

Though manufacturers of liquid floor hardeners sometimes use the word "sealer" to describe their products, a liquid hardener is actually a treatment, not a surface coating like most membrane-forming organic sealers. A drawback to applying a membrane to concrete is that the membrane tends to wear away in high-traffic areas. Not only is the worn coating unattractive, the unprotected concrete is susceptible to chemical attack by acids and caustics. Liquid floor hardeners not only protect concrete surfaces, they protect the concrete down to the depth of penetration. Also, the hardeners don't form a coating or membrane on the concrete surface, so they don't scratch, peel, show tire marks, or require recoating.

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HOW DO LIQUID HARDENERS WORK?

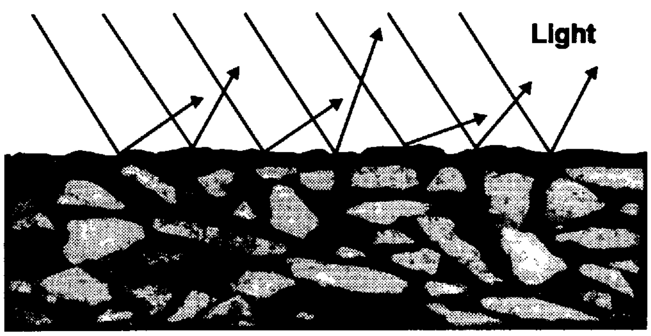
As soon as a liquid floor hardener is applied to a concrete substrate, a chemical reaction takes place between the inorganic compounds and lime (whether hydrated or unhydrated) in the pores of the concrete matrix. The primary product of this reaction is a mixture of dicalcium and tricalcium silicate compounds, which hydrate (react with water) even further to produce a chemical compound called calcium silicate hydrate, or tobermorite gel.

The ultimate strength and binding properties of hydrated portland cement are primarily due to the presence of tobermorite gel in the concrete matrix. Therefore, liquid hardeners increase concrete strength by increasing the concentration of tobermorite gel.

Liquid floor hardeners can also increase concrete's density. When the tobermorite gel forms in the concrete pores, its crystalline growth effectively blocks voids in the concrete, decreasing the pathways for moisture movement. Since chemicals attack concrete by penetrating the matrix, the presence of an insoluble gel in the substrate's pores and on its surface greatly increases the concrete's chemical resistance.

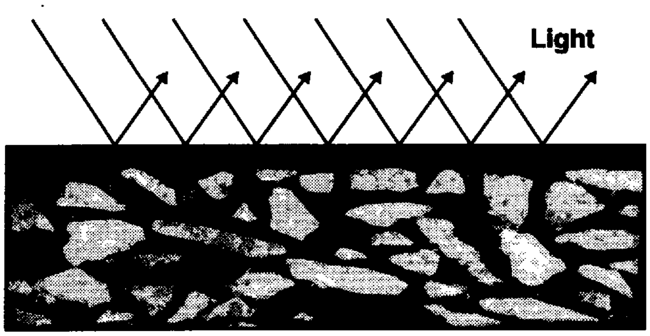
In addition to the benefits of strength gain and chemical resistance, a liquid hardener can enhance the beauty of a troweled floor by giving it a polished look. This high sheen results when the treated floor is polished by mechanical means. Floors treated with liquid hardeners will not dust when abraded or polished.

The drawing below shows a cutaway view of a rough, porous floor prior to floor-hardener treatment. When light strikes the irregular surface, the light is reflected in all directions. This scattering of light



Untreated Concrete Slab

A floor surface prior to floor-hardener treatment scatters light, resulting in a dull appearance. After treatment, a gel-like substance is formed at the surface, which can then be polished to a high sheen.



Treated Concrete Slab With Chemical Floor Hardener

makes the concrete surface appear dull. After a floor has been treated with a liquid hardener, the pores are filled with tobermorite gel and the concrete surface can be polished smooth. When light strikes this smooth surface, it is reflected uniformly, so the floor shines.

Using a buffing machine to polish a floor treated with liquid hardener results in a shiny, low-maintenance surface.

APPLICATION TIPS

Ideally, concrete floors should be treated with liquid floor hardeners at least seven to 14 days after placement, or after the cement has had sufficient time to hydrate. Cement hydration increases the amount of available lime in the concrete, thus increasing tobermorite gel formation. In addition, this waiting time allows the pores of the concrete to dry, so the liquid hardener can penetrate the concrete surface rather than merely lying on it. It is much easier for a liquid hardener to displace air than water in the concrete voids.

True liquid floor hardeners should not be applied to fresh concrete at the time of initial cure, because the concrete is still saturated with moisture. This saturated condition prevents the hardener from penetrating the surface. Also, liquid hardeners should not be applied as curing compounds, since they do not meet the requirements of ASTM C 309, "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete." Always check the manufacturer's recommendations for when to apply its product.

The type of cure used on new floors prior to application of chemical floor hardeners is very important. Liquid hardeners must penetrate the concrete surface to undergo the chemical reaction that imparts density and hardness, but they can't penetrate a membrane-forming curing compound. If a curing compound has been used, be sure to remove it before applying a liquid hardener. ACI 302.IR-89, "Guide for Concrete Floor and Slab Construction," recommends moist curing floors that will later be treated with a liquid floor hardener or other surface treatments.

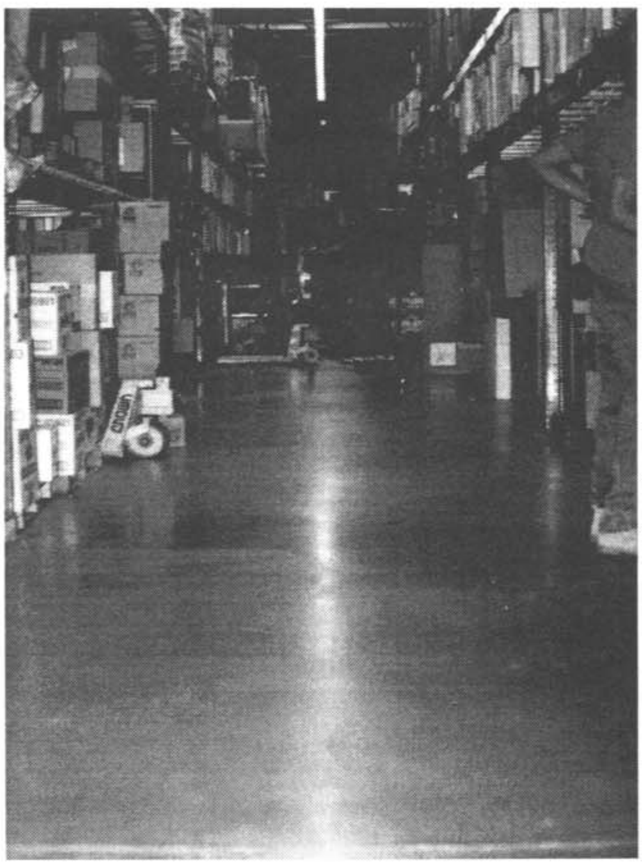
Surface preparation of the floor before hardener application is also important. The surface must be thoroughly cleaned to open the concrete pores and allow for hardener penetration. Typical cleaning methods include chemical cleaners and high-pressure water.

Some chemical floor hardeners contain magnesium fluosilicates, which are low-grade toxic chemicals. When applying these products, be sure to wear protective clothing such as rubber gloves, boots, and goggles. Typically, fluosilicate hardeners are supplied in concentrated form and must be diluted with water before application.

Nonfluosilicate floor hardeners, which are more commonly used today, are colorless, odorless, biodegradable, and VOC-compliant. Many manufacturers offer 10-year warranties with these products. When using a nonfluosilicate floor hardener, apply a slight flood coat to the concrete surface, covering about 200 square feet per gallon. Next, scrub the material into the surface with a stiff-bristle broom or janitorial floor-scrubbing machine for 15 to 30 minutes, until the product begins to gel or become slippery. Wet the material lightly with a water spray, then rework it into the surface for another five to 10 minutes. After this process, rinse the floor and remove any excess material with a mop or squeegee. This final step is important, because residue is more difficult to remove if it is allowed to dry.

WHEN TO USE LIQUID HARDENERS

Typical applications for liquid hardeners include floors in warehouses, industrial plants, shopping malls, stores, schools, food-processing plants, and hospitals. Installation costs vary, depending on the required surface preparation and size of the project. On large projects, installation costs typically start at about 30¢ per square foot.



Because they increase resistance to abrasion and chemicals, liquid hardeners are typically applied to floors in warehouses and industrial plants.

The degree of surface hardness and density that can be achieved with a liquid hardener depends on the quality of the concrete surface. Liquid hardeners can improve the abrasion resistance and reduce the dusting of a lower quality concrete floor. On higher-quality concrete surfaces (those with a lower water-cement ratio and denser finish), the need for a chemical floor hardener diminishes.

Many manufacturers claim that liquid floor hardeners improve the chemical resistance of a concrete floor. This is true to a degree, but you should carefully examine the chemical-resistance requirements of the floor before proceeding with hardener application. Though liquid floor hardeners improve the chemical resistance of a concrete surface, they do not make the surface 100% chemical resistant. Unfortunately, liquid hardeners are sometimes sold as chemical-resistant products meant to replace truly chemical-resistant coatings, such as two-component aliphatic urethanes. For floors exposed to high levels of chemicals, consider using a chemical-resistant coating instead of a liquid floor hardener.

Mission

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