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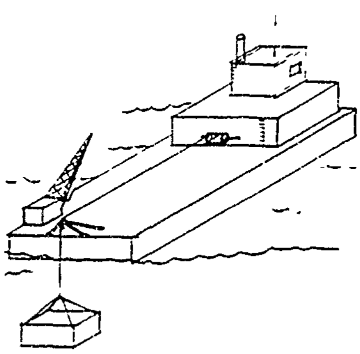

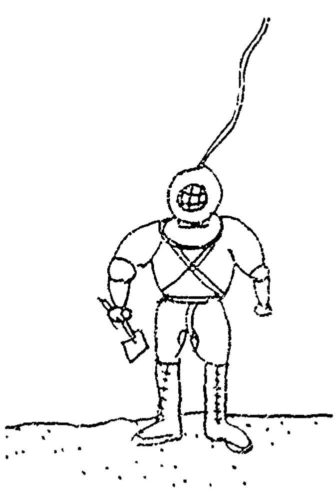

REMR RESEARCH PROGRAM

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-38

UNDERWATER STILLING BASIN REPAIR TECHNIQUES USING PRECAST OR PREFABRICATED ELEMENTS

by

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Commercially available warping tug for surface support

BOTTOM — Hard hat method of working underwater

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The purpose of this study was to investigate methods of repairing stilling basins of hydraulic structures underwater, thereby eliminating costly dewatering operations, and to develop a plan to evaluate products or concepts. The effort focused on methods using precast concrete or prefabricated steel panels. The maximum water depth considered was 70 ft.

This report reviews underwater repairs of the Old River Low Sill Control Structure, Upper St. Anthony Falls Lock, and Kinzua Dam. An overview of the required underwater construction tasks is presented (preplanning, mobilization, surface preparation, installation of field anchors and panel supports, installation of panels, concrete placement, and inspection). Construction methods for underwater repairs are discussed, including the use of divers, wall enclosures, caissons, cofferdams, above-water platforms, and submersibles. Panel design

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factors considered are abrasion resistance, uplift forces, joints, and weight. Other panel considerations include shapes, joints, bond, and supports. Repair schemes, such as large-area, partial-area, small-area, and baffle block repairs, are described.

Several findings evolved from this study: (a) it is feasible to rely on divers in underwater repair projects, because most stilling basins have low-water depths of 40 ft or less; (b) steel panels or composite steel-concrete panels are preferred to concrete panels, because the abrasion resistance of steel is superior to that of concrete and the weight of steel panels is considerably less than that of concrete panels; (c) if steel is selected, design details become important to assure that the steel panels remain serviceable under vibration and uplift forces from high-velocity water flow and impact from rocks in turbulent water; (d) surface cranes can handle larger steel panels than concrete panels because of the lower weight of steel panels; therefore, fewer joints are used between panels, and less work is required of the divers.

Research and development recommendations cover two major areas: surface preparation and panel design.

14. (Concluded).

Precast concrete	Underwater stilling basin repair
Prefabricated steel panels	Upper St. Anthony Falls Lock
Stilling basins	

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program as part of the Civil Works Research Work Unit 32305, "Techniques for Underwater Concrete Repairs." The REMR Overview Committee of HQUSACE consists of Mr. James E. Crews (CECW-O) and Dr. Tony C. Liu (CECW-EG). REMR Coordinator for the Directorate of Research and Development is Mr. Jesse A. Pfeiffer, Jr (CERD-C). The REMR Technical Monitor for this study is Dr. Liu.

This study was conducted by the Naval Civil Engineering Laboratory (NCEL) and was monitored by the US Army Engineer Waterways Experiment Station (WES) under the general supervision of Mr. Bryant Mather, Chief, Structures Laboratory (SL), WES, and the direct supervision of Mr. Kenneth Saucier, Chief, Concrete Technology Division (CTD). Mr. Saucier is also the Principal Investigator. Mr. William F. McCleese (CEWES-SC-A) is the REMR Program Manager, and Mr. James E. McDonald, CTD, SL, WES, is the Problem Area Leader. This report was prepared by Messrs. R. D. Rail, NCEL, and H. H. Haynes, president of Haynes and Associates, Oakland, CA.

Commander and Director of WES is COL Larry B. Fulton, EN. Technical Director is Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	25.4	millimetres
kips (force) per square inch	6.894757	megapascals
knots (international)	0.5144444	metres per second
ounces (US fluid)	0.02957353	cubic decimetres
pounds (force)	4.448222	newtons
pounds (force) per foot	14.5939	newtons per metre
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per square foot	4.882428	kilograms per square metre
square feet	0.09290304	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C + (5/9) (F - 32). To obtain Kelvin (K) readings, use K + (5/9) F - 32) = 273.15.

UNDERWATER STILLING BASIN REPAIR TECHNIQUES USING PRECAST OR PREFABRICATED ELEMENTS

PART I: INTRODUCTION

1. Stilling basins of hydraulic structures can experience considerable abrasion damage. Instances have been reported of local abrasion damage completely penetrating the concrete base slab, which typically ranges from 4 to 10 ft* thick. Steel panels, bolted to an existing concrete base slab in order to prevent further erosion, have been pulled loose and even torn in half. Both types of damage are caused by high velocity, turbulent water, and rocks and other debris trapped in the stilling basin.

2. Repairs are usually required because the entire hydraulic structure can be at risk if turbulent water undermines it. Generally, the method of repair is to dewater the stilling basin and patch the damaged concrete. It is not unusual for half the cost of repair to be associated with dewatering the stilling basin. This cost has approached a million dollars for certain structures. If the need for dewatering can be eliminated and the underwater repair techniques do not result in excessive costs, then an overall net savings can be realized. Also, eliminating the need for dewatering has other benefits including less interference with operations and reduced environmental impact.

Purpose and Scope

3. The purpose of the effort reported herein was to investigate methods that could be used to make repairs underwater, thereby eliminating the dewatering operation, and to develop a plan to evaluate any promising products or concepts. The effort focused on methods using precast concrete or prefabricated steel panels. The maximum water depth for consideration was 70 ft. Methods of placing fresh concrete underwater for in situ repair, other than

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

methods for placing concrete or grout underneath the panels, were not considered in this report since they have been investigated by others (Gerwick 1988).

Background

4. The WES has summarized the repair work on 31 hydraulic structures, of which 30 were stilling basins and one a lock (McDonald 1980). One of the stilling basins, the Old River Low Sill Control Structure, was repaired by5. underwater construction (because the flow could not be cut off) using prefabricated steel panels. The repair is relevant to this study and is reviewed. The Upper St. Anthony Falls Lock structure used steel panels in a test and is also reviewed, along with one other example. Appendix A contains additional examples and information on other underwater repair methods, as well as repair methods adaptable to underwater use.

Old River Low Sill Control Structure

5. The Old River Low Sill Control Structure (Figures 1 and 2) is a reinforced concrete structure 566 ft long between abutments. Eleven gate bays have a clear width of 44 ft between piers. The three center bays have a crest at elevation (el) -5.0 ft, and the eight outer bays have a crest at el +10.0 ft.

6. The stilling basin is a rectangular concrete structure with a width of 566 ft near the piers and flares to a width of 592 ft at the end sill wall. The central portion serving the three low bays is 150 ft wide with a floor elevation of -12.0 ft and terminates with an end sill wall at el -2.0 ft. The outer portions have a floor elevation of -5.0 ft and end sill wall at -2.0 ft.

7. The basin slab is 7 ft thick upstream of the baffle blocks and tapers to 4 ft thick at the end sill wall. Upstream of the baffle blocks, the reinforcement is ASTM No. 11 bars on 12-in. centers at the top and bottom faces. Downstream of the baffle blocks, the reinforcement is No. 9 bars on 12-in. centers. Cover to reinforcement is 12 in.

8. Thirteen years after the structure had been completed, an inspection of the stilling basin disclosed severe abrasion damage between the downstream baffle blocks and the end sill wall. Abrasion 0.5 to 2 ft deep was generally found with isolated areas as deep as 4 ft.

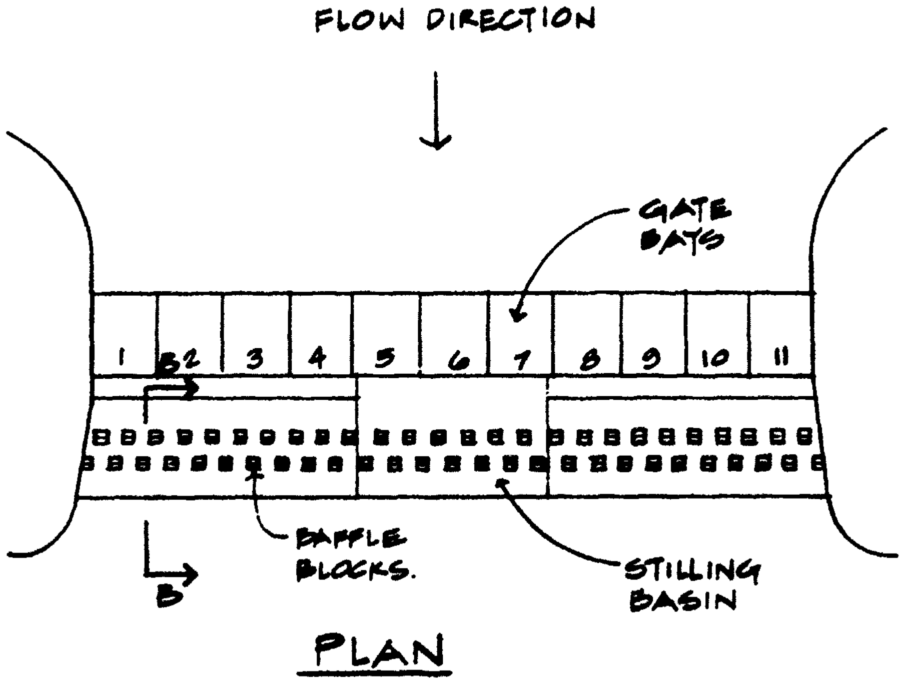


Figure 1. Plan of Old River Low Sill Control Structure

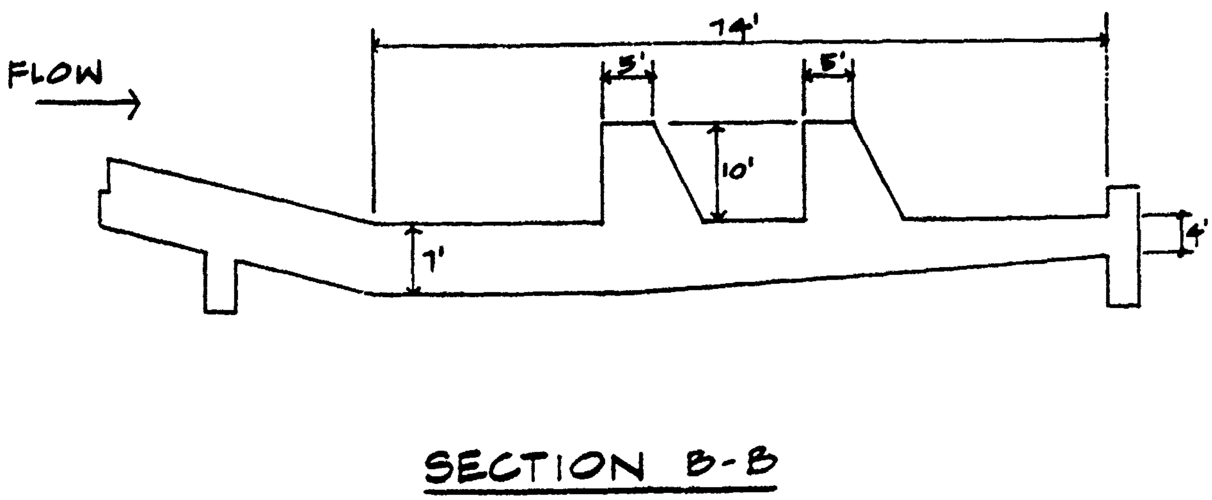


Figure 2. Section of stilling basin

9. The control structure could not be completely shut down; so repairs were made under flow with some gates closed to produce acceptable underwater working conditions. The repair method used steel plates to cover the entire area between the downstream baffle blocks and the end sill wall. The plates sloped up from the basin slab behind the baffle blocks to the top of the end sill wall. The design modification allowed rocks to wash out of the stilling basin. Hydraulic studies showed that the modification was acceptable.

10. Thirty panels 24 ft long and ranging in width from 3 to 22 ft were fabricated of 1/2-in.-thick steel plates. Vertical diaphragm plates were welded to the panels to provide stiffness and to create a form to retain grout (Figure 3). Shear studs of 1/2-in. diam were welded to the plate on 2-ft centers each way.

11. Originally 3/4-in.-diam expansion anchor bolts were used to attach the first panel to the structure. Overnight, the gates directly upstream from the panel were opened, and by morning the panel was gone. The bolts on the upstream edge of the panel had pulled out of the concrete because of uplift forces from the flowing water. The nuts on the bolts in the end sill wall had worked loose from vibration, and the threads were stripped. The number of bolts was increased from 4 per panel to 8 through 16 per panel. Later the expansion anchor bolts were replaced by 1-in.-diam bolts embedded in polyester resin.

12. A fluid cementitious grout reinforced with 1-in.-long steel fibers was pumped under the panels. Typically two panels were grouted during one operation.

13. The grouting plant included an onsite batch plant to supply transit-mix trucks located on the bridge roadway on top of the control structure. A concrete pump was used to convey the grout through a 95-ft vertical pipeline directly to the panels. After the first panel was grouted, an inspection showed a 6-in. void under the panel, and the grout was badly segregated. The grouting plan was altered to provide another pump and two ready-mix trucks on a barge moored in the stilling basin. The grout was pumped from the bridge to the barge, where it was remixed and then pumped to the panels. This procedure was satisfactory.

14. It was decided that a test was desirable to observe whether the grout was filling all the spaces beneath a panel. A full-scale mockup was

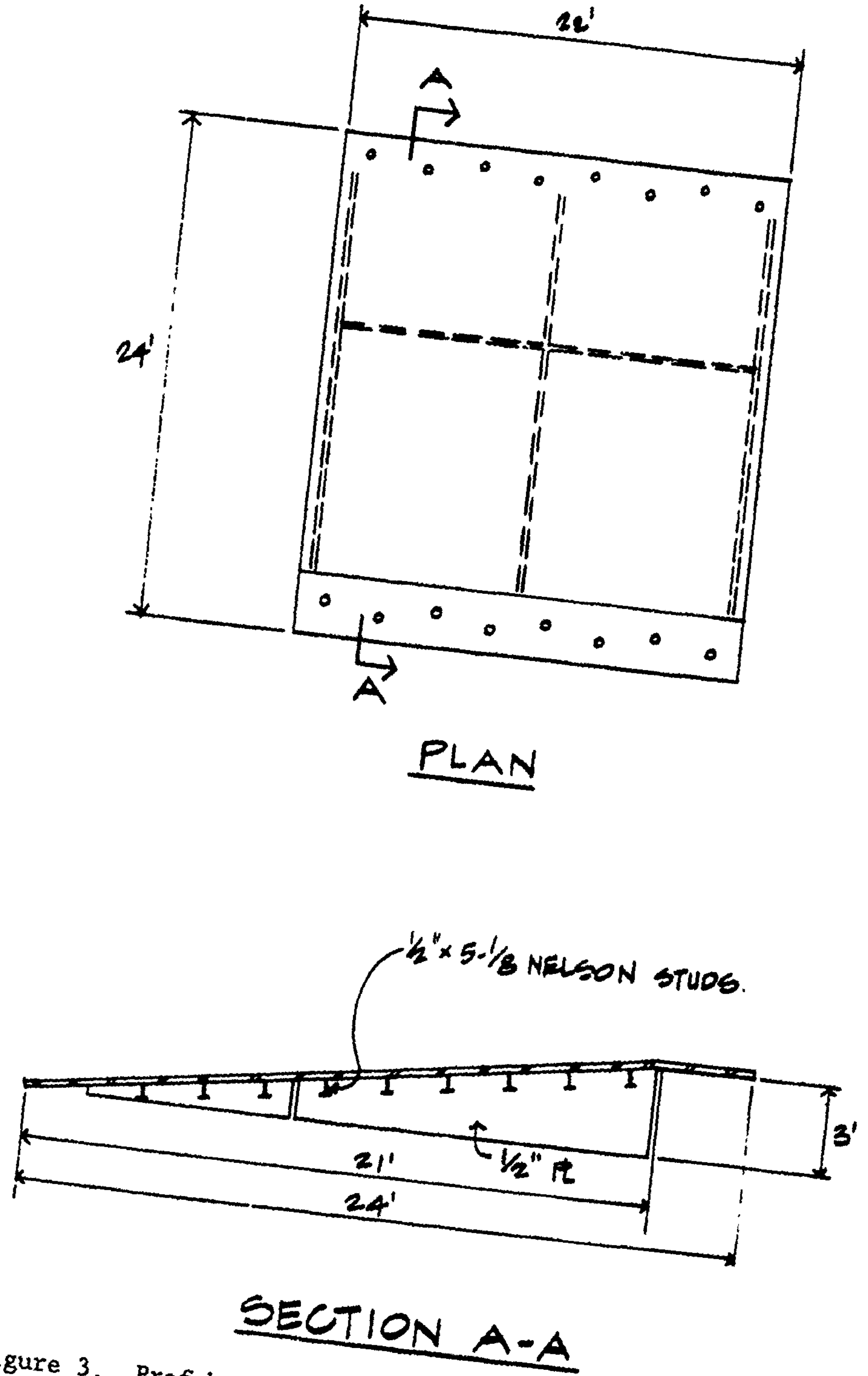


Figure 3. Prefabricated steel panels for underwater repair of Old River Low Sill Control Structure

constructed by using a wooden form placed in a hole that was flooded with water. The test showed that the grout completely filled the form and the steel fibers were being spread throughout the grout. The test also indicated that excessive pumping pressure could lift the panels and cause the holddown bolts to pull out of the basin slab.

15. Uplift forces from high-velocity water also became a concern, so WES conducted model tests to determine the magnitude of the uplift forces. The tests showed a maximum average uplift force of about 3 psi across the panel. Based on the tests, spoilers, which were 12- by 12-in. steel angles, were anchored immediately upstream of the downstream row of baffle blocks in the central portion only. The purpose of the spoilers was to break up the flow of water before the leading edge of the panels.

16. Also based on the tests, additional anchorage for the panels was indicated. Certain panels had 18 additional No. 6 bars installed as anchors. A small drill rig was set up on a tower platform to operate in 16 ft of water and core holes through the panel and into the basin slab to 3 ft. The nuts to the anchor bars remained exposed above the panels.

17. Eight months after the repair had been completed, an inspection showed that all the spoilers were missing, two panels were entirely missing, and several other panels were partially missing. A number of anchor bolts were found broken either flush with the panel, flush with the grout, or pulled completely out. The fiber-reinforced grout was generally in good condition. It was adhering well to the base concrete, and the worst locations showed abrasion to a depth of 6 in.

18. Two years after the repair, an inspection showed 12 more panels either fully or partially missing. The grout was in good condition. Also the stilling basin was free of rocks and other debris; so apparently the rocks were being flushed from the basin.

19. Annual inspections were conducted after the initial repair and appropriate repairs made. In 1984, eight years after the initial repair, the majority of the steel plating and anchor bolts were gone, and there was erosion and spalling of the fiber-reinforced grout surface.

20. In retrospect, the magnitude of the uplift and vibration forces was considerably underestimated. Panel design could not be for the average

uplift, but rather for maximum local uplift pressures. Also, any nuts above the panel surface were not going to last; rocks sheared them off. It is assumed that once a plate had been partially loosened by any means, the failure rate would rapidly accelerate because the amplitude and force of the vibratory motions would progressively increase. It should be noted that some of the anchorages definitely performed well because some of the panels were held in place so that the steel plate sheared instead of being pulled out.

Upper St. Anthony Falls Lock

21. Twelve years after construction, the Upper St. Anthony Falls Lock was dewatered and inspected. The filling and emptying laterals and discharge laterals showed considerable abrasion damage of the concrete. Abrasion at a 23-in. depth was reported. Rocks up to 18-in. in diameter were found trapped in the laterals (McDonald 1980, McDonald and Liu 1980).

22. Tests were conducted on the concrete to determine if the materials were deficient. All data showed that the concrete was sound and of excellent quality.

23. In one of the filling and emptying laterals, the floor was made a test section for various repair materials. The different materials were conventional concrete, epoxy mortar, fiber-reinforced concrete, epoxy concrete, and steel plate. The steel plate was a 1/2-in.-thick abrasion-resistant steel. Rocks that had caused the original abrasion damage were replaced in the lateral to provide a positive test of the repair materials. Approximately 2 years after the repairs, the lateral was again inspected.

24. The epoxy mortar and epoxy concrete showed little abrasion, except at the corners and edges. The conventional and fiber-reinforced concrete both showed considerable abrasion damage. In places, the abrasion damage was up to 6 in. deep and extended completely through the repair into the underlying concrete. The steel panel showed little sign of wear, although adjacent fiber-reinforced concrete was substantially abraded. A nut on one of the anchor bolts was missing.

Kinzua Dam

25. The stilling basin to Kinzua Dam is about 178 ft long and 204 ft wide. It contains nine baffle blocks, which are 8 ft high, 10 ft wide, and 18.7 ft long. After the dam had been in operation for 4 years, abrasion damage was significant with most of the damage at the transverse contraction

joints and the corners of the baffle blocks. When the stilling basin was dewatered for repairs after another 4 years, some eroded areas were up to 42-in. deep. Cellular cofferdams were required to enclose about 60 percent of the stilling basin for each of two stages so that stream flow was permitted. Water depths were about 23 ft. The cost of the cofferdams was about $734,000 in 1973.

26. The baffles were repaired with steel angles, 8 by 8 by 5/8 in., installed at the vertical upstream corners. Dowels, additional No. 8 reinforcing bars, and fiber-reinforced concrete were also used. Although nine subsequent inspections were reported, mainly to inspect the basin slab, no mention was made of the durability of the repaired baffles.

Stilling water depths

27. McDonald (1980) provided data on the water depths of some of the stilling basins. In many cases, water depths could be estimated by taking the elevation difference between the top of the training wall and the bottom of the stilling basin; however, this depth usually represents high-water levels. Underwater repairs would be conducted when the tailwater level was low.

28. Limited data were available on low-water levels. Where available, these data showed an interesting finding. The majority of low-water depths are 40 ft or less (Table 1). In only one case was the water depth reported greater than 40 ft.

Other related information

29. Appendix B provides information related or applicable to the underwater repair of stilling basins. A summary of the key items is provided here.

30. Precast concrete panels were successfully used in the underwater repair of a portion of the California Aqueduct. Precast concrete panels secured in place with steel dowels have been used to rapidly repair concrete bridge pavements. This technique could be effective in the repair of stilling basins.

31. Steels have been found to resist abrasion much better than concrete. Any readily available steel commonly used for field-welded construction will provide better abrasion resistance than concrete will. Selection of the type of steel is based on design, fabrication, and installation considerations such as strength, formability, and weldability. Underwater weldability

may govern in many cases. Weldability of studs, bolts, and nuts will affect the material choice of any of these items that are to be welded, even "tack welded." ASTM A 36 is the standard steel for general structural uses, but cheaper commercial steels, e.g., AISI 1020, would be suitable in some cases. Harder steels, including the "abrasion-resistant" (AR) alloy steels may provide marginally better wear resistance, but are much more demanding to work with and are not recommended for any field-welded applications. Thus, steel or composite steel and concrete such as that used in the repair of the Mud Mountain Dam are preferred over precast concrete panels. The abrasion resistance of concrete can be increased by using hard aggregate and a low water-cement ratio. Also, admixtures and postcasting procedures (such as polymer impregnation) have been found to increase concrete's abrasion resistance.

32. Surface preparation is a critical step in the repair process. Underwater sandblasting, if done properly, provides a satisfactory bonding surface. This was demonstrated in the repair of the Chief Joseph Dam.

PART II: CONSTRUCTION ASPECTS

Construction Stages

33. Various construction stages will be reviewed as an overview of the required underwater construction tasks.

Preplanning

34. Preplanning is essential prior to writing a construction specification. An accurate underwater survey is most important so that an appropriate construction method can be selected. The more accurate the survey of underwater damage, the more defined the final construction cost.

Mobilization

35. Mobilization is the stage where the contractor gathers his equipment and sets up at the construction site. Typically the construction contract allows a minimum of time for this operation; so the contractor has to immediately implement plans that he developed when bidding the job. It would be to the government's benefit to allow the contractor additional time to rethink the task and perhaps to fabricate some specialized equipment for a better quality end product, savings in diver time, or improved safety.

Surface preparation

36. A key ingredient to the success of any repair job is proper surface preparation of the base concrete. For stilling basins, the process begins by removing rocks and debris. Hydrojet dredges (hydraulic eductors) and airlifts would work well in removing rocks up to several inches in diameter. Larger rocks and debris would have to be removed with a clamshell or dragline bucket.

37. Loose, deteriorated concrete is unlikely to be encountered in the basin slab. More likely, surface preparation would involve removal of concrete to obtain a required elevation for a specific overlay thickness. Rapid concrete removal can be executed by high-pressure water-jet systems with or without an abrasive added to the stream. These methods are well developed for use on land. For concrete removal without an abrasive, higher water pressures are required (anywhere from 15,000 to 50,000 psi), and steel reinforcement is not harmed. With an abrasive, even steel reinforcing bars can be cut.

38. Underwater water-jet equipment exists; however, its application is for cleaning of steel, concrete, and timber surfaces to be inspected or coated (Keeney 1984). Some development work would be required to apply the technology to underwater concrete cutting.

39. As part of surface preparation, deep holes would need to be filled with concrete to bring the basin slab to a relatively uniform elevation. If a surface requires scarifying, water-jet systems can be used.

Installation of field
anchors and panel supports

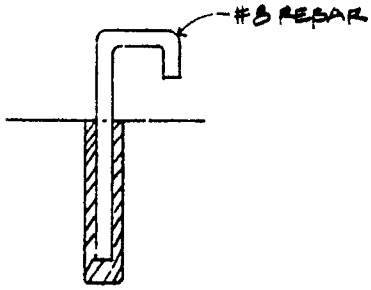
40. Field anchors are typically No. 6 or No. 8 reinforcing bars spaced 3 to 4 ft on-center both ways to assist in bonding the overlay concrete to the base concrete (McDonald 1980). Past repair work, conducted in dry stilling basins, placed concrete overlays that ranged from 5 to 18 in. thick.

41. The necessity for field anchors should be studied. With proper surface preparation, the primary bond holding the repair overlay to the base concrete is the mechanical and chemical interface bond between new and old concrete. Field anchors cannot be of assistance until after the interface bond fails; by then, the life of the overlay will be limited anyway. When good working conditions prevail, underwater placement of concrete to lock a prefabricated panel to the base concrete should produce good bond properties to the base concrete. Overlays up to 18-in. thick should not experience thermal movements from heat of hydration nor movement from shrinkage when the concrete is placed underwater.

42. Naturally, many situations exist where the steel reinforcement will be required to hold repairs to the base concrete, for example, where turbid waters prevent a thorough inspection and muddy or silt-laden water or pockets of mud or sand can interfere with good bond. In cases where field anchors are not necessary, a major cost will be saved.

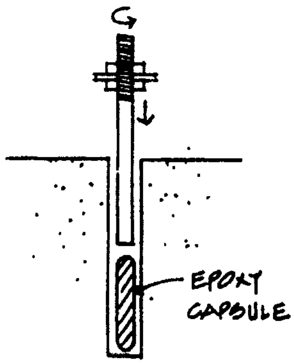
43. Methods to install field anchors are variations of drilling a hole, cleaning the hole, and anchoring a rod in the hole. The holes can be drilled using rotary-percussion or core drills. The rotary-percussion drill is adequate, and this type of underwater equipment is available in both hand-operated (McMullen 1984) and larger sizes. Methods of anchoring rods in the holes are given in Figure 4. The Navy has developed underwater automatic mixing and dispensing epoxy injection equipment (Thompson and Middleton 1984).

GROUTED REBAR



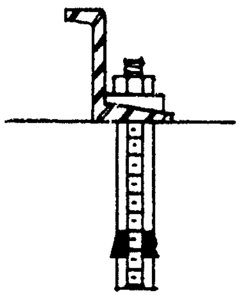
- Cementitious or polymer grout injected in hole before insertion of reinforcing bars
- Hole made with rotary percussion or core drill

EPOXY CAPSULE BONDED ROD



- Polymer capsule is broken and mixed by turning rod
- Not recommended for underwater installation

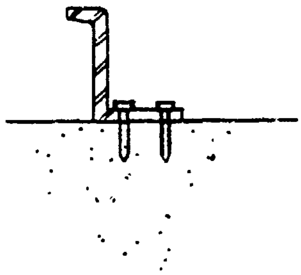
EXPANSIVE ANCHOR BOLT



- Expansive anchor bolts are quick and easy to install for use as temporary anchor
- Vibration can reduce holding capacity
- Failure can be unpredictable

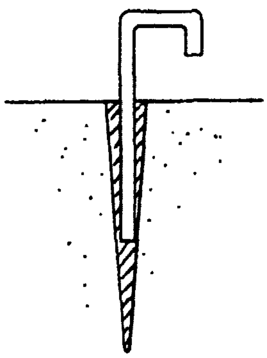
Figure 4. Field anchors in base concrete (Continued)

POWER ACTUATED FASTENER



- Fastener sizes are quite small (1/4 in. diam max)
- Pullout load is low

SHAPE CHARGE HOLE



- Shape charge explosives have the potential of making a hole 2 in. in diameter at top by 18 in. long
- Rapid method, but expensive and dangerous

Figure 4. (Concluded)

Also, the Navy has experience in underwater rock drilling and setting of anchor bolts (Naval Civil Engineering Laboratory (NCEL) 1979). Corps of Engineers guidance on installation of anchors in hardened concrete under submerged conditions is given in ETL 1110-8-2 (FR) (HQUSACE 1991).

44. Panel supports are bottom-installed platforms or seats to provide proper elevation and level to prefabricated panels. The supports may or may not have a means to attach and anchor the panels against uplift forces. Panel support concepts will be presented later.

Installation of panels

45. The panels will be lowered from a surface support vessel or platform. Figure 5 shows some surface support concepts. During lowering, it is most likely that large panels will be handled on edge (vertically, as a wall) instead of flat (horizontally, as a slab). This procedure will reduce added mass loads on the crane due to dynamic motions of the pond. The vertical panels, however, are still susceptible to jerking movements because of water turbulence.

Concrete placement

46. Provisions must be made for placing fresh concrete under the panels.

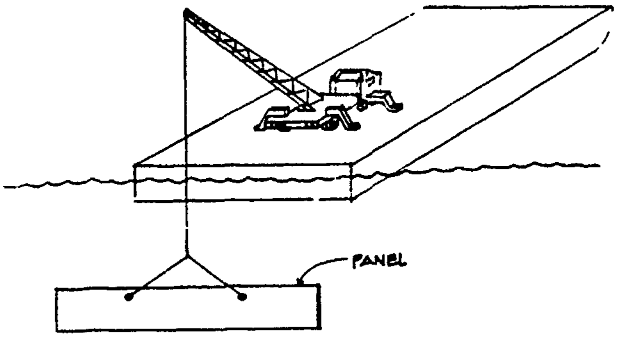
Inspection

47. Inspection of work as it progresses is important. An alternative to the diver-inspector is low-light video that permits engineers located topside to witness work. A diver with two-way communication can carry the video camera and move around at the request of an engineer, who is viewing the video. In some situations, e.g. the Old River Low Sill stilling basin, turbid water may limit the inspection process to that of tactile means. A remotely operated vehicle (ROV) is another tool for carrying the video camera, if the currents or turbulence permit ROV use.

Construction Methods

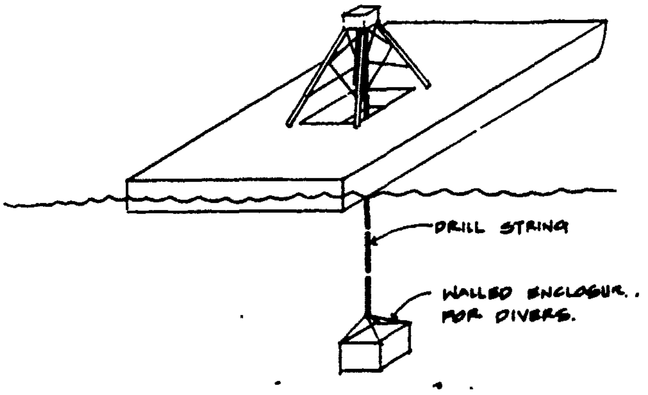
48. Divers are crucial to underwater construction; however, depending on the construction method selected, the use of divers can be minimized. Figure 6 presents some construction methods for working underwater.

BARGE MOUNTED TRUCK CRANE



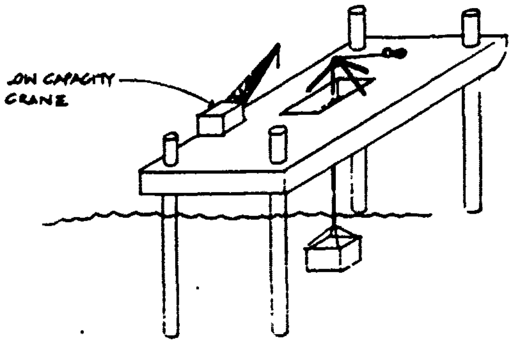
- Mobile truck crane mounted on barge
- Excellent versatility in selecting proper size of crane

OIL WORKOVER RIG.



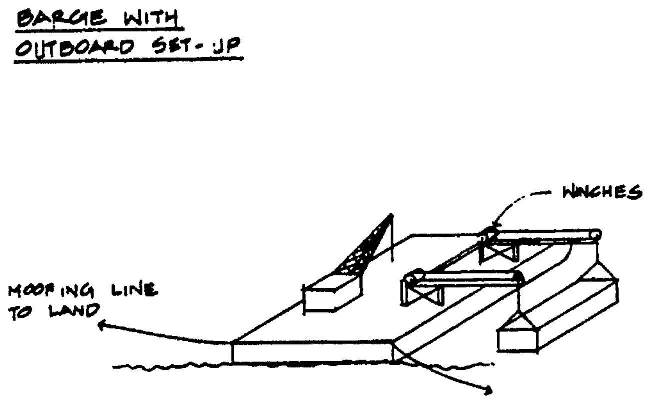
- Mobile workover rigs that can be mounted on a barge are available
- Drill string used to handle loads
- Limited in size of panels that can be handled

JACK - UP BARGE

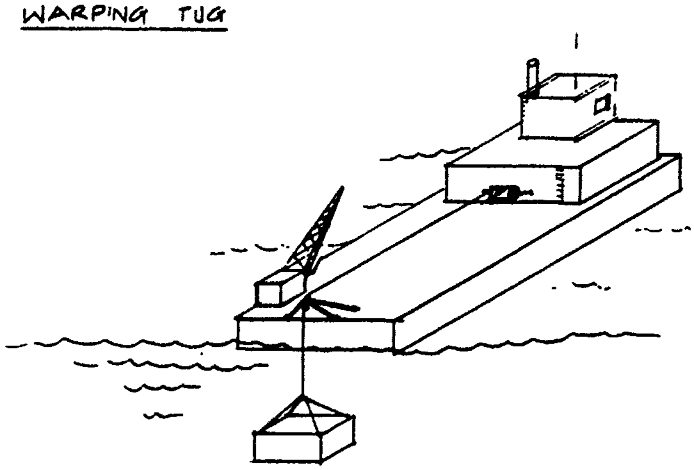


- Stable platform that is good for heavy load handling
- Can work over side or through a center well

Figure 5. Surface support (Continued)



- Barge modified with outboard lifting rig
- Moor barge with lines to land

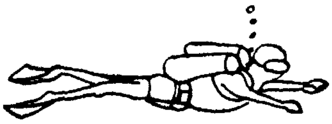


- Commercially available vessel

Figure 5. (Concluded)

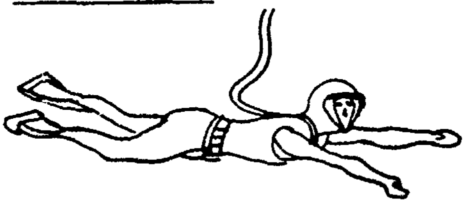
DIVERS

SCUBA



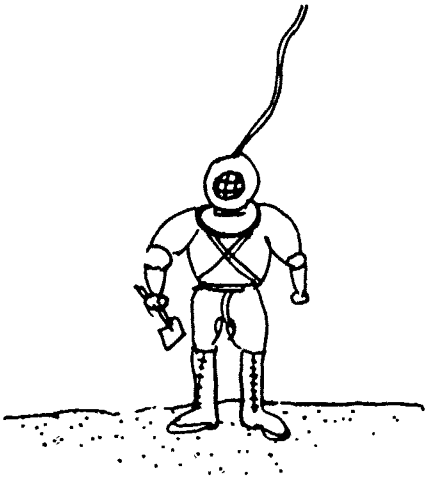
- Scuba not appropriate for construction work

LIGHT GEAR



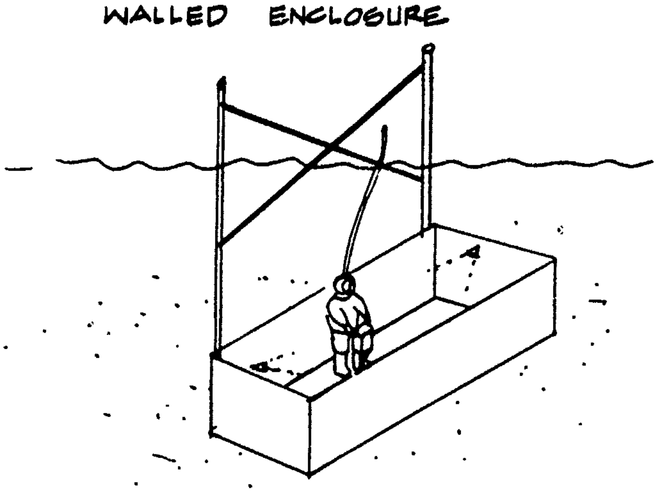
- State-of-the-art method for construction work
- Full head gear with surface supplied air and two-way communication
- Good mobility

HARD HAT

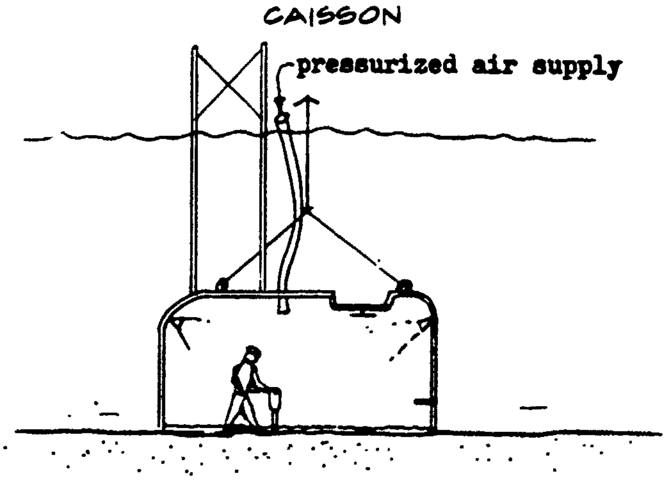


- Commonly used system by commercial dive firms

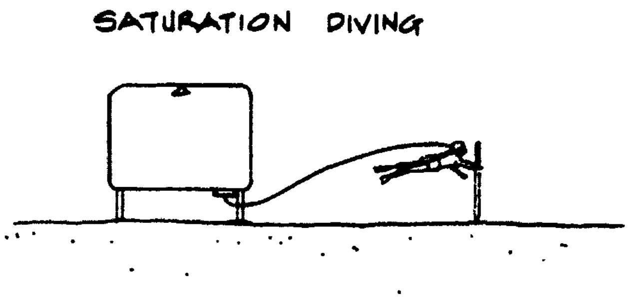
Figure 6. Methods of working underwater (Sheet 1 of 4)



- Walled enclosure protects diver from turbidity currents
- Visibility improved with lights
- Surface markers assist in determining on-bottom location and elevation



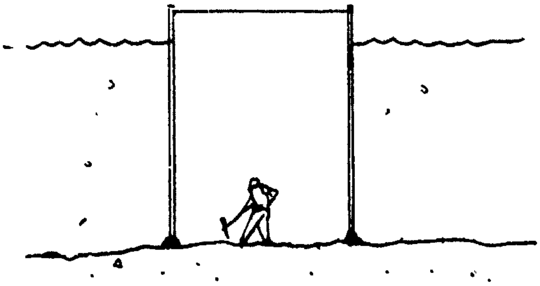
- Laborers must be qualified divers to work inside caisson
- Excellent visibility
- Some water will cover the bottom
- Good method for large jobs



- Applicable for large jobs at water depths greater than 60 ft
- Expensive

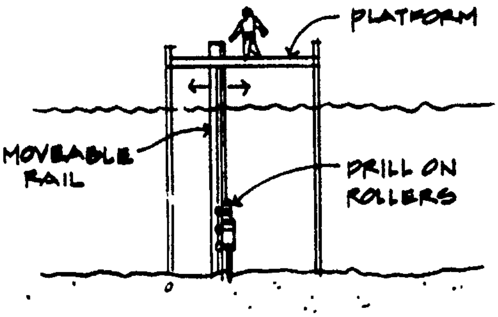
Figure 6. (Sheet 2 of 4)

COFFERDAM

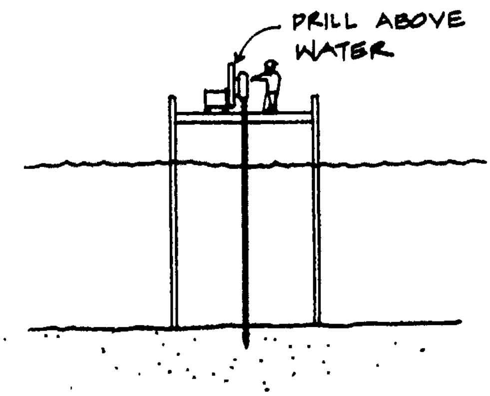


- Laborers work at atmospheric pressure, so qualified divers are not required
- Seal is difficult on rough bottom

ABOVE WATER PLATFORMS

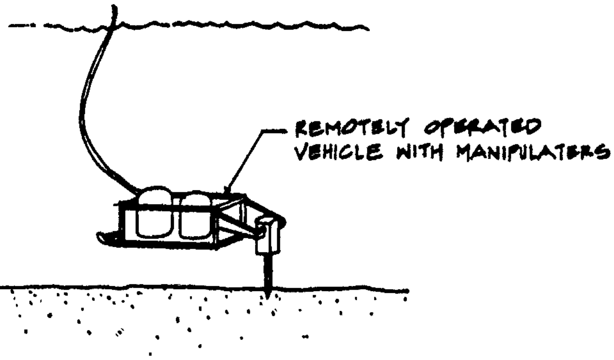


- Work remotely with only tools on the bottom
- Excellent control of bottom location and elevation
- Underwater video inspects work



- Work remotely with tools on the surface

Figure 6. (Sheet 3 of 4)



- Manned or remotely operated vehicles are expensive

Figure 6. (Sheet 4 of 4)

Divers

49. A general guide to work capabilities of divers is that they can perform any work that can be done on land, only it takes longer. For construction work, lightweight diving gear and hard hat gear are the applicable diving systems. Both systems have voice communication, and divers can operate in currents of 2.5 knots. The current capability to do underwater work similar in nature to that needed to repair stilling basins is summarized in Appendix B.

50. In commercial practice a dive team for lightweight gear is composed of three persons: a diver, a standby diver, and a tender-log keeper. If three divers are in the water, the team would be eight persons: three divers, one standby diver, three tenders, and one superintendent-log keeper. Hard hat diving would typically have a dive team of four persons for one person in the water. To have three divers in the water, the team would be eight persons. Corps of Engineers regulations may require different sizes of dive teams and should be followed as appropriate.

51. The labor rate for divers in the San Francisco Bay area is about $400/man/day (1985). A dive team of three persons costs $1,200/day. A dive day can be brief if the water depth is greater than 40 ft.

52. Bottom times are controlled by decompression tables. A brief summary of those used by the US Navy is given in Table 1. From Table 1 it is apparent that the most desirable situation is to keep all depths 30 ft or less because bottom time is not limited by decompression considerations. A depth of 40 ft is still reasonable because a diver can have 200 min bottom time with no decompression stay or 360 min of bottom time with a 23-min stop at 10 ft during the ascent; this is close to a full day. Depths greater than 41 ft limit the bottom time rather severely. In addition, any dives at depths of 61 ft or greater require a decompression chamber at the work site, which adds another person to the dive team.

53. In summary, if the water depth is 40 ft or less, then divers can be a major force in stilling basin repair work. Table 2 shows that most depths are less than 40 ft for stilling basins. For depths greater than 40 ft, the construction method used should require divers only intermittently.

Table 1

Diver Bottom Times for Various Water Depths

Depth, ft	Bottom Time min	Time of Decompression Stay at 10-ft Depth min
30 ft or less	Unlimited	0
31-40 (called a 40-ft dive)	200	0
	360	23
41-50 (called a 50-ft dive)	100	0
	180	29
51-60 (called a 60-ft dive)	6[illegible]	0
	120	26
61-70 (called a 70-ft dive)	50	0
	90	23

54. Saturation diving would permit divers to remain at the greater depths for unlimited time periods (weeks). The equipment is sophisticated and expensive, but the services are commercially available.

Wall enclosure

55. The working conditions in some stilling basins can be difficult because water flow cannot be completely stopped. Both turbidity and currents can disorient divers. The turbidity of the water produces poor visibility. As a guide, divers working in zero visibility require twice the time to perform tasks conducted with visibility. Methods to assist divers in currents and in turbid waters include a walled enclosure or caisson. Extremely cold temperatures also inhibit divers because of the heavier diving equipment.

56. The walled enclosure is an open top and bottom box with walls about 6 ft high. The plan dimensions may be 10 by 20 ft or larger. Inside the walled enclosure, currents are substantially reduced, and lights can be provided to assist with visibility. Also, corner posts extending to the surface assist in guiding the diver to the bottom and, more importantly, allow surface survey techniques to accurately determine the location and elevation of bottom work. The diver has a known frame of reference (the box) from which to take measurements for distance or elevation. This is a valuable asset.

Table 2

Water Depths in Stilling Basins*

Dam	Training Wall Height ft	Estimated Low Water Depth** ft
Old River Low Sill Structure	45	16
Arkabutla Dam	29	-
Enid Dam	30	-
Pomme De Terre Dam	32	-
Pomona Dam	20	-
Tuttle Creek Dam	48	18†
Curwensville Lake Dam	32	28
Lac Qui Parle Dam	23	-
Chief Joseph Dam	-	26
Libby Dam	69	20††
Dworshak Dam	67	49
Ice Harbor Dam	61	33.5
Barren River Dam	31	16
Nolin Lake Dam	35	15
Tionesta Dam	30	10
Folsom Dam	68	-
Conchas Dam	58	30
Somerville Dam	30	-
Waco Dam	53	-
Bull Shoals Dam	67.5	23
Nimrod Dam	35	14
Table Rock Dam	72	18
Oologah Dam	34.5	
Webbers Falls Dam	86	40

* McDonald (1980).

** From either cofferdam dam height, depth during an underwater repair, or some other indication of low-water level in downstream river.

† Low cost to dewater ($37,900 in 1975) indicated that the cofferdam was not required; the stilling basin just needed to be pumped out.

†† Estimated from a photo of dam in operation.

Caisson

57. A caisson is like an open-bottom dive bell. The pressure inside the caisson is equal to the water pressure at the bottom. This keeps water out of the caisson, so the diver can work basically in the dry. His visibility is excellent. He also knows his location and elevation by surface communication. A face mask may be required if dust, epoxy fumes, or other air contaminants are in the environment. Water will still cover the bottom, but it will be shallow.

58. This method has good potential for large repair jobs. A crane can relocate the caisson quickly. The caisson can be fabricated with sufficient dead weight to provide enough negative buoyancy to resist movement by currents.

Cofferdam

59. A cofferdam is a walled enclosure that extends above the surface and is sealed at the bottom. The water within the cofferdam is pumped out so that the laborer does not have to be a diver because he is working in a dry atmosphere. This is a conventional construction method for working in the dry.

Above-water platform

60. This method is useful for all water depths and especially for depths greater than 40 ft. The laborers remain above water on a platform while the equipment has been designed for remotely working on the bottom. Sophisticated hardware development is not required. Straightforward methods of lowering and raising tools need only to be devised so that discrete jobs can be performed. For example, to install a field anchor, use a guide rail to lower a drill; then wash the hole clean with pressurized water; next inject grout, and lastly insert a rod in the hole. Move the guide rail horizontally a few feet and repeat the process. Both bottom location and elevation are controlled accurately.

61. For shallower depths, platforms can be used where laborers work with equipment that stays above water. For example, a drill can remain above water while a long bit is used to drill holes.

Submersibles

62. ROV's or manned submersibles are candidate ideas; however, the equipment is not presently available for production construction work.

equipment is not presently available for production construction work. Development costs for such equipment, or similar equipment like a tracked vehicle with manipulators, is extremely high. It is unlikely that stilling basin repair could economically justify the development of these types of equipment.

PART III: PANEL CONCEPTS

Design Considerations

Abrasion resistance

63. Of major importance is the abrasion resistance of the panel. In addition, for certain flow conditions localized areas of cavitation may occur. From McDonald (1980), various concrete repair materials were all susceptible to abrasion damage to different degrees. Steel plate performed the best.

64. Although many surface treatments and fabrication techniques can be applied to precast concrete panels to impart improved abrasion resistance, the material is still composed of discrete aggregate particles that can be dislodged from a cementing matrix. High concrete strengths relate to high abrasion resistance, and methods are available today for producing extremely high concrete strengths (15,000 psi through 30,000 psi). None of these techniques, however, can compare with the abrasion resistance of steel. Steel would be the preferred material from consideration of abrasion resistance, although other considerations may favor cementitious materials.

Uplift

65. Uplift forces from high-velocity water flowing over a surface is a concern. The Old River Low Sill Control Structure demonstrated the problem of uplift of steel panels. Knowing that these panels failed, an estimate of uplift pressure to cause failure can be made. Assuming that exposed nuts on anchor bolts were sheared off by rocks, only the embedded Nelson studs were considered effective in holding the panel down. Studs of 1/2-in. diam were spaced at 2 ft on-center both ways. Assuming that the stud ultimate stress was 60,000 psi, its ultimate strength was 11,800 lb. The uplift area was 24 in. × 24 in. = 576 in. The uplift pressure to fail a stud was 11,800 lb/576 in. = 20.5 psi. This uplift pressure is considerably higher than the model study estimates of 3 psi. A check was made on the force to pull a stud out of the concrete, and this force is higher than that to fail a stud in tension.

66. The actual uplift pressure was probably less than 20 psi because fatigue or eccentric loading at the stud weld could have caused failure. In turbulent water, pressure fluctuation occurs. If a panel were not bonded well

to the concrete, the pressure fluctuations would be loading and unloading the stud. The weld could fail from fatigue. If the front edge of the panel were lifted and started to peel back, a major eccentric load would occur at the stud, which could also cause premature failure. Once a panel has been partially loosened by any means it can be assumed that the rate of additional damage would rapidly accelerate as the amplitude and force of the vibratory motions would progressively increase and thus increasingly jerk and tear at the anchor bolts and the panels themselves.

67. Concrete panels would be less susceptible to these problems. A minimum thickness of a precast concrete panel would be about 4 in.; the greater panel stiffness, damping, and possibly bond to underlying concrete would reduce the uplift problems. The potential for bonding can be enhanced by roughening the interface surface of the panels during precasting.

68. Both steel and concrete panels, however, would be vulnerable to uplift forces from fresh concrete being placed under the panels. Tremie-placed concrete, pumped concrete, or preplaced-aggregate concrete could be used to tie the panels to the base concrete. During placement of concrete or grout, the pressure needs to be controlled, or the panels can be lifted with a force that exceeds the hold-down anchorage force. Even if the fresh concrete pressure were held to 5 psi, the uplift force acting on hold-down anchors is significant. Over an area of 10 by 10 ft, the uplift force would be 72,000 lb. Anchors should be designed to resist the greater of the uplift forces resulting from either flowing water or concrete placement.

Joints

69. Joints are vulnerable locations. According to McDonald (1980), construction joints in basin slabs produced maintenance problems. In general, it appeared that the joints transverse to the flow created abrasion damage, while joints longitudinal to the flow seemed to have less damage. This observation implied that repair methods using panels should minimize transverse joints. An overall design philosophy may be to minimize all joints by using large size panels; however, a second position would be to minimize transverse joints by maximizing longitudinal joints, if necessary. This will be presented conceptually later.

70. Joint details are an important design consideration. Joints are probably the weakest link in the entire repair process using panels. Once one

panel fails and is torn from its location, adjacent panels are susceptible to failure because their edges are exposed. Rocks moving at high velocity will impact the edges. To increase survivability, each panel needs to be designed as an individual repair unit, unto itself, and not solely reliant on its neighbor for protection.

Weight

71. Weight is important because the panels must be handled by a crane that in all probability will be barge mounted. For a given crane capacity, larger size steel panels can be handled than concrete panels. Larger panels mean fewer joints. Example designs of steel and concrete panels are presented later. It is shown that for panels having the same square footage, concrete panels weigh in air four times that of steel panels. Steel would be the preferred construction material from consideration of load handling. However, once in place, the extra mess and stiffness of concrete panels would be a benefit in resisting uplift forces.

Panels

Shapes

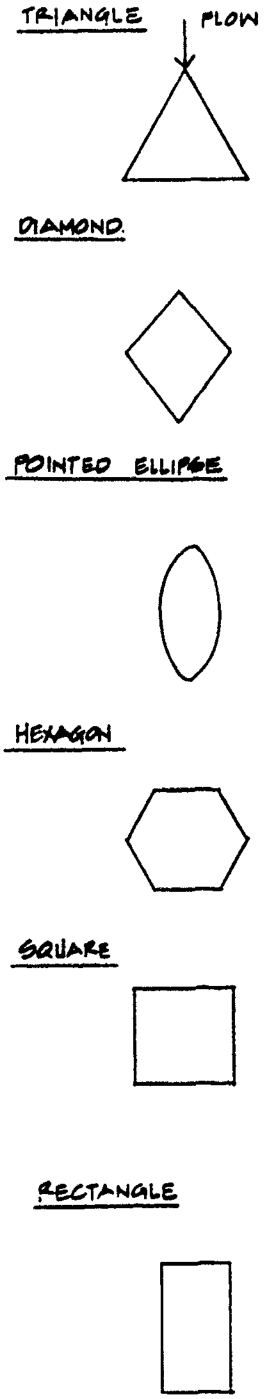
72. Various panel shapes are shown in Figure 7 with their relative advantages and disadvantages. Theoretically, the best shape to minimize joints is the square; however, practically, the rectangle is superior because of stilling basin geometry and the ability to minimize transverse joints by maximizing longitudinal joints. If patches are used to repair localized damage, then the diamond, or perhaps the pointed ellipse, are good shapes because transverse joints can be avoided.

Joints

73. Various panel joints are shown in Figure 8 with relevant comments. The vulnerability of edges can be reduced by providing a stiffened panel edge. An extra measure of protection is provided by recessing the edges so that they are tucked down and out of the way of fast-moving rocks. The recessed and stiffened edge concepts are the preferred choices.

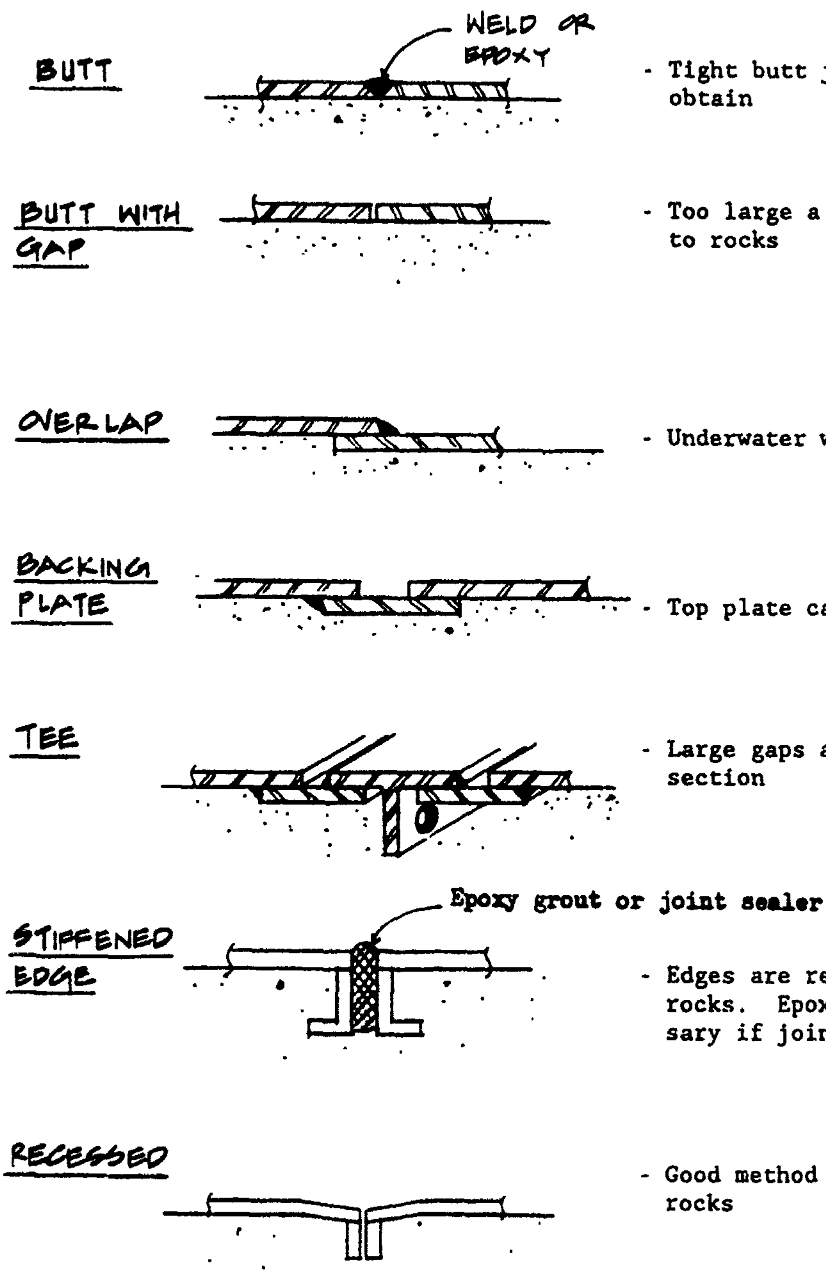
Bond

74. Bond between the panels and the freshly placed concrete is essential. Figure 9 shows various concepts of tying the two elements together.



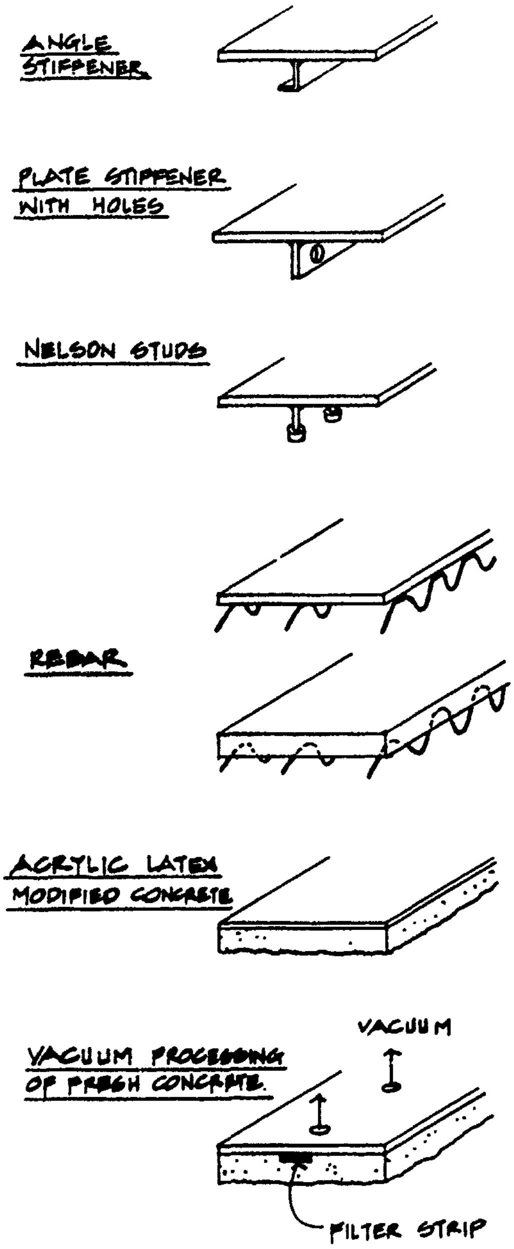
Shape	Advantages	Disadvantages
Triangle	- Only three support points to level	- A lot of edge length - Placement accuracy required
Diamond	- No transverse joints to water flow - Good for local patches	- Placement accuracy required
Pointed ellipse	- No transverse joints to water flow - Good for local patches	- Only appropriate for local patches
Hexagon		- Placement accuracy required
Square	- Minimum total edge length	
Rectangle	- Minimum edge length transverse to water flow	

Figure 7. Panel shapes



- Tight butt joint may be difficult to obtain
- Too large a gap makes edges vulnerable to rocks
- Underwater welding required
- Top plate can be welded or epoxied
- Large gaps are spanned by the tee section
- Edges are reinforced against uplift and rocks. Epoxy grout may not be necessary if joint is tight
- Good method to protect edges from rocks

Figure 8. Panel joints



Advantages	Disadvantages
- Angle is off-shelf item - Automatic welding - Provides bending capacity to plate	- Fresh concrete must flow into corners
- Automatic welding - Provides bending capacity to plate	- Deeper stiffener required than angle
- Automatic welding	- Local attachment point - Plate not stiffened
	- Only a special grade of reinforcing bar is weldable steel
- Easily embedded in concrete	
- Excellent bond properties when cast on land	- May not develop good bond properties when cast underwater because material requires some air drying for high strength
- Removes excess water at steel-to-concrete interface to create good bond	- Extra underwater construction step

Figure 9. Bond between panels and fresh concrete

Fresh concrete placed under the panel may not adhere well to the panel because of a thin layer of cementitious material having a high water-to-cement ratio, called laitance, next to the panel surface. Laitance can be minimized with a properly proportioned concrete mixture.

75. If bond is poor, a mechanical connection becomes important. A flat steel plate will bend upwards due to uplift from water flow. Increasing the stiffness of the plate and at the same time providing a mechanical connection to the fresh concrete would represent a good design.

76. Of the concepts shown in Figure 9, the angle stiffener welded to the bottom of a steel plate is most straightforward. The angle is a stock item, automatic welding is possible, and good interlock with the concrete is provided. The disadvantage is that concrete must flow into corners. Small holes in the plate near corner locations may be desirable to allow trapped water to vent.

77. Normal high-frequency vibration is not appropriate for fresh concrete underwater; however, a method of high amplitude, extremely low-frequency vibration may be appropriate. A thumper device that impacts the top of the steel plate could assist in moving concrete into corners.

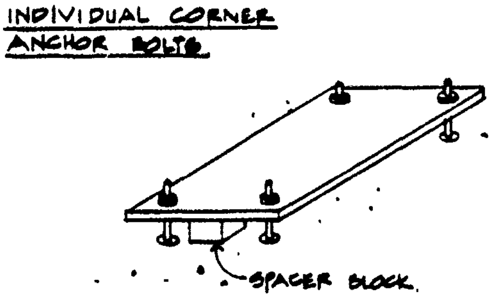
78. Vacuum processing of fresh concrete is an idea that has potential. Through holes in the steel plate, a pressure differential can be created so that excess water in the concrete flows through filter strips on its way out from under the panel. An improved bond between the concrete and the steel would likely result.

Supports

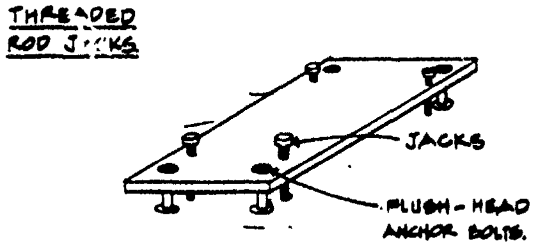
79. Panel supports are required to assist in obtaining proper elevation and levelness of panels. Figure 10 shows support concepts.

80. Considerable work is required in constructing most of the supports. The difficulty is obtaining an easy method to create proper elevation and levelness and providing a means to hold down the panels against uplift during concrete placement. Concrete pads are a potential method that provides flexibility. Figure 11 shows some different types. An advantage with concrete pads is that they can be placed from the surface, as shown in Figure 12.

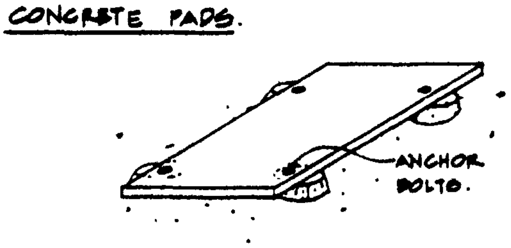
81. Steel tables can be built using high-strength, threaded reinforcing bars. By welding the panels to the tables, adequate uplift resistance can



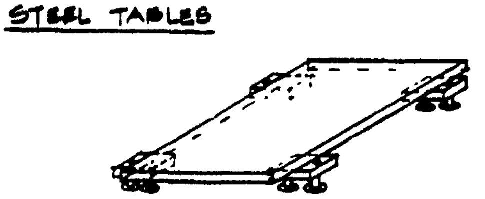
- Individual anchor bolts for each corner are drilled and set after panel is in place
- Blocks are placed to support panel at correct elevation
- Difficult to make elevation adjustments while panel is in place
- After concrete is placed, the tops of the anchor bolts need to be cut off



- Threaded rods function as jacks to obtain the proper elevation
- Anchor bolts provide the hold-down capacity
- After concrete is in place, the tops of the anchor bolts need to be cut off



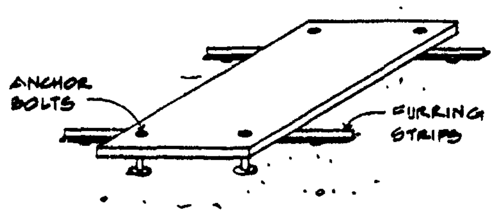
- Concrete pads are cast to proper elevation
- Panels are secured by anchor bolts, or welding if a steel plate were cast in the top of concrete pad



- Steel table supports are set to proper elevation before panel is placed
- Steel table allows welding for hold down

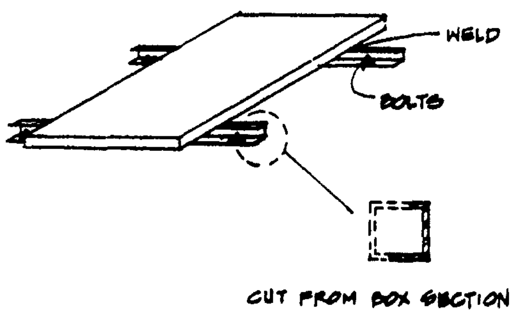
Figure 10. Panel supports (Continued)

SMALL FURRING STRIPS



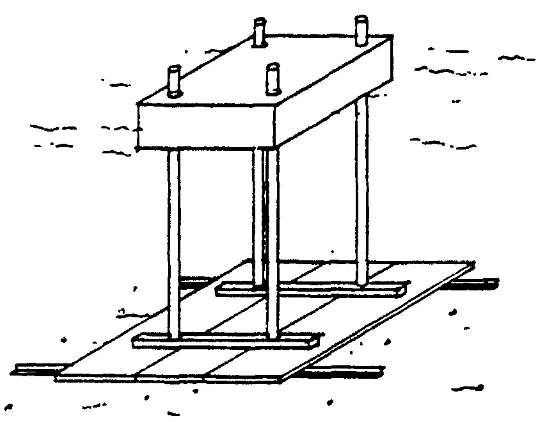
- Continuous furring strips of small steel angle or tee sections are set on the base concrete
- Strips held in place by epoxy resin, power-actuated studs, or clips bolted to the base concrete
- Anchor bolts supply the hold-down force

LARGE FURRING STRIPS.



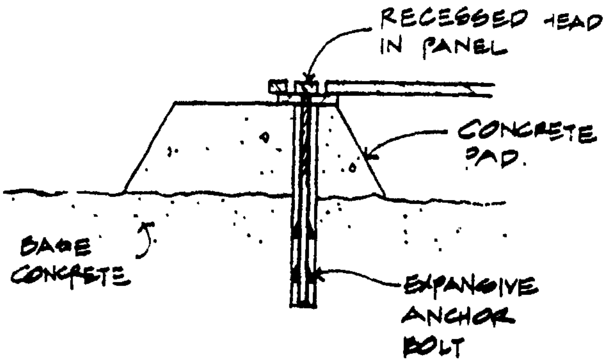
- Large furring strips of channel sections are anchor bolted to the base concrete
- Panels are welded or clipped to the furring strips
- Uplift resistance is low

MINI JACK-UP BARGE FOR HOLD DOWN

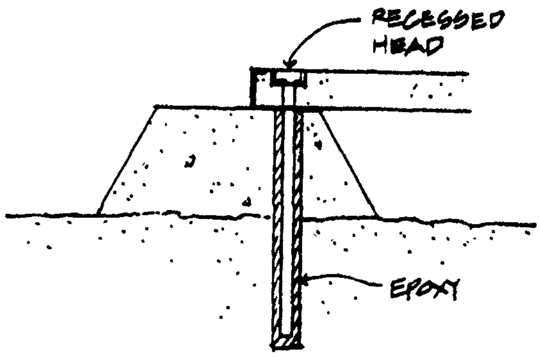


- Live load counters the uplift forces from concrete placement
- Minijack-up barge is one method to apply live load

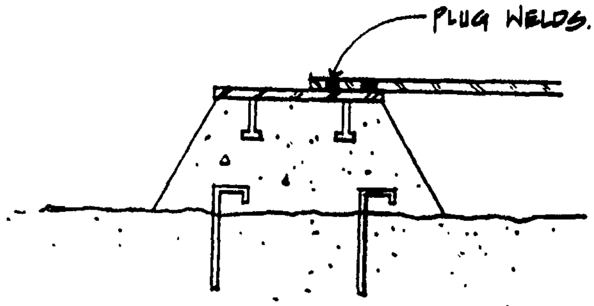
Figure 10. (Concluded)



- Concrete pad cast to proper elevation
- Drill anchor bolt hole after panel is in place

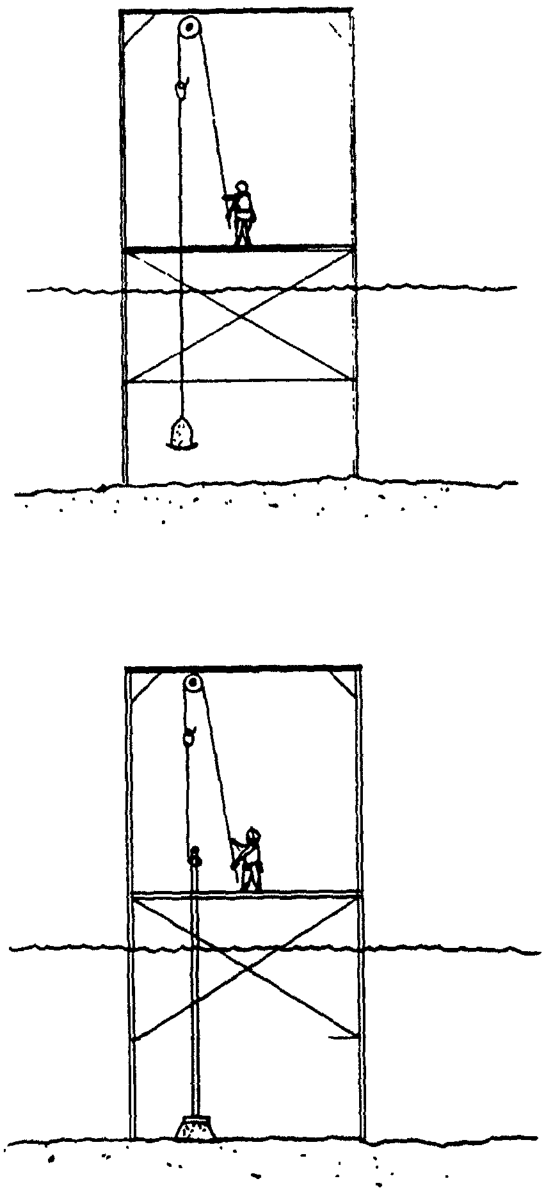


- Anchor bolt holds panel and concrete pad to the base concrete



- Steel plate cast into concrete pad

Figure 11. Variations to concrete pad supports



Steps

A. Equipment and procedures designed so that work can be performed from above water

B. Once location is accurately established, determine the elevation of the base concrete and calculate the required height of the concrete pad. Place fresh con crete of a stiff slump into a bucket and lower to the bottom. Gently discharge the concrete

C. Lower a rod with a flat steel plate on the end to level the concrete pad and obtain the proper elevation. A steel plate could be embedded into the concrete pad and left in place, if desired

Figure 12. Construction steps for concrete pad supports

be obtained. Construction steps for building steel platforms are shown in Figure 13. Much underwater labor is required for this type of support.

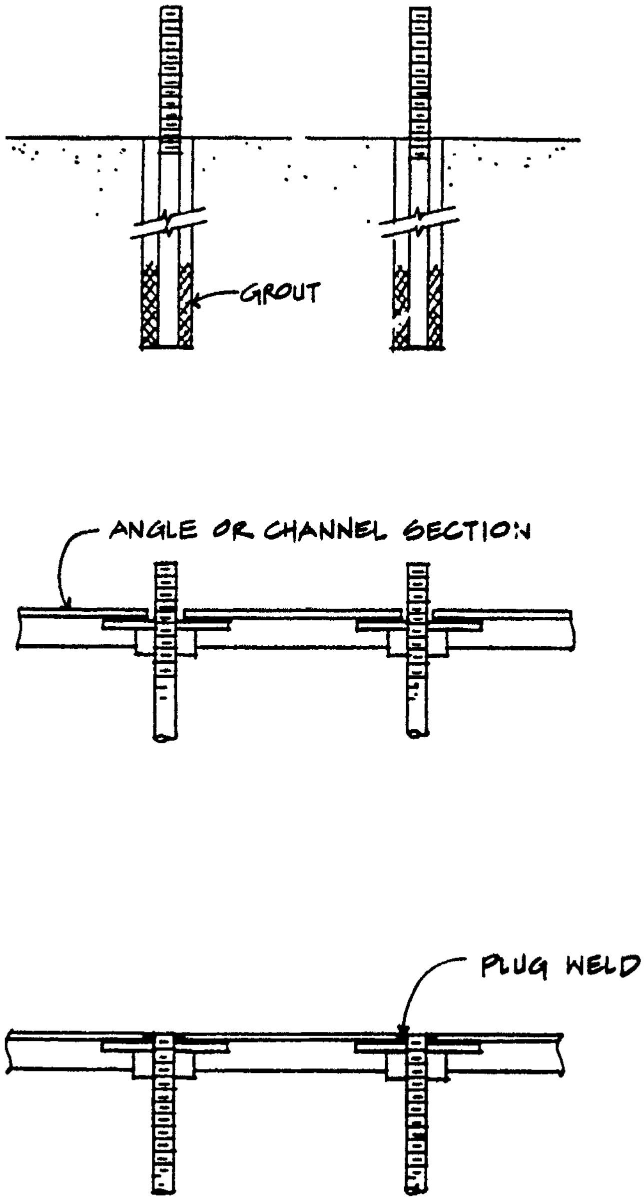
82. The use of furring strips, either large or small, is a practical approach. Long lengths of angle or channel sections, say 60 ft long, can be placed in the transverse direction on the basin slab. Proper elevation may be obtained by shimming certain locations. Some gradual undulation should be acceptable. The strips can be connected to the base concrete either lightly with epoxy resin or powder-actuated studs, or heavily with anchor bolts. The panels could be held down by welding to the strips, which would not produce a high hold-down force, or by separate anchor bolts through the panels and into the base concrete. An alternative idea is to use a temporary live load to counter uplift forces during concrete placement. The live load could be from a minijack-up barge, or even massive weights lowered from the surface.

Panel designs

83. Basic panel designs fall in three categories: monolithic, one-way, or two-way panels. Figure 14 presents the advantages and disadvantages of each design. In summary, one-way panels are suited to rectangular shapes, have good stiffness properties, and are economical to fabricate if welding is involved. This basic design is appropriate to panels for underwater repair.

84. Figure 15 presents design concepts of one-way panels and gives their advantages and disadvantages. Several design concepts are attractive. The stiffened steel plate can be made into large sizes so that joints are minimized. The spacing of the stiffeners can be calculated so that the plate between the stiffeners remains within allowable stresses when uplift pressures from water flow are applied. Figure 16 gives design details and weights for a 1/2- and 3/4-in. steel panel design. Panel design calculations are given in Appendix B.

85. The opposite of large panels is to use numerous long, narrow panels. Transverse joints are still minimized; only the longitudinal joints are maximized. Steel channel sections provide this type of panel. The construction approach would be like that of laying a hardwood floor, that is, one strip at a time. One channel section at a time is placed in the bottom, and divers can manhandle each panel. Versatility in width is provided as stock sizes are available as follows: 8 by 3-1/2, 9 by 3-1/2, 10 by 3-1/2, and 12 by 3-1/2 in.



Steps

A. Using a template, drill deep holes in the base concrete for rock bolt type anchors

B. Install threaded steel rods

C. Thread nuts onto rods and obtain proper elevation

D. Mount angle or channel section onto supports

E. Cut off rods at angle or channel and plug weld flush

Figure 13. Construction steps for steel table supports

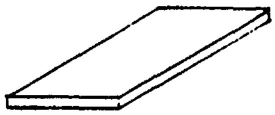
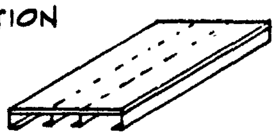
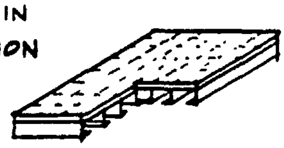
	Advantages	Disadvantages
MONOLITHIC PANEL: UNIFORM THICKNESS 	- Low cost	- Bending stresses during handling limit panel size - Bond to fresh concrete could be improved - Edges of panel are vulnerable
ONE WAY PANEL: STIFFNESS IN ONE DIRECTION 	- Long panels have good handling behavior - Stiffeners provide good connection to concrete - Lowest cost stiffening method for steel panels	- Width of panel is limited
TWO WAY PANEL: STIFFNESS IN TWO DIRECTION 	- Good design for large square panels supported at the corners - Concrete panels fabricated easily (waffle slab)	- Costly to weld stiffeners in two directions - Concrete may not fill the corners

Figure 14. Basic panel designs

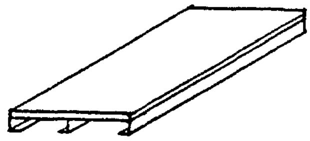
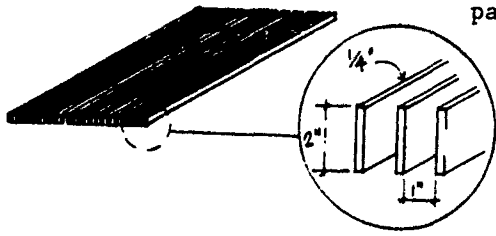
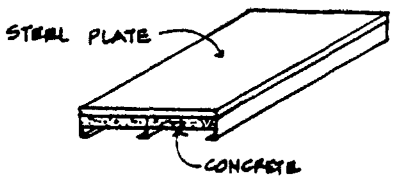
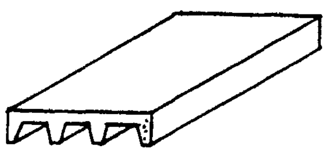
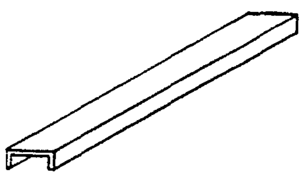
	Advantages	Disadvantages
STIFFENED STEEL PLATE 	- Excellent abrasion resistance - Lightweight for handling large panels - Welding possible	- Plate flexible to uplift forces
STEEL GRATING 	- Lightweight for handling - Minimal uplift forces on panel during fresh concrete placement	- Costly - Impact of stones moving transverse to grating could cause damage
COMPOSITE 	- Stiffened panel resists uplift and pressure fluctuations - Steel exposed to abrasion - Excellent bond between steel and precast latex-modified concrete	- Heavier than plain steel plate
CONCRETE 	- Lowest panel cost - Various surface treatments can be cast into panel top for abrasion resistance	- Abrasion resistance less than steel - Heavy for handling - Panel size limited
STEEL CHANNEL 	- Channels can be laid down like oak flooring, one long narrow piece at a time - Divers can manhandle into position - Off-the-shelf steel sections	- Many small pieces - Divers must do extra work on bottom

Figure 15. Panel designs of difference materials

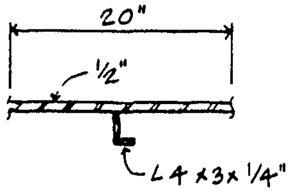
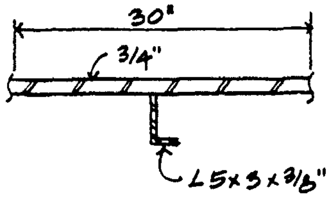
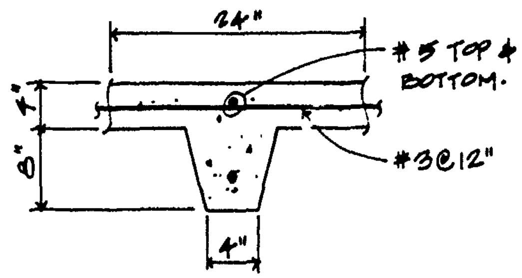
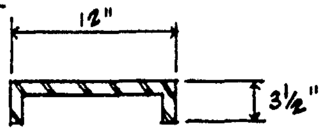
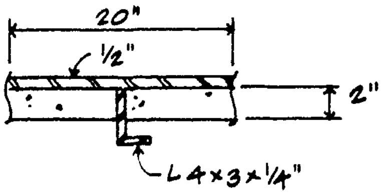
Panel		Avg. panel weight of 12-in. width lb/lin ft	Cost: Unit mat'l cost $/lb	Cost: Panel cost $/ft²
1/2 IN. STEEL PLATE		23.8	0.60	14.28
3/4 IN. STEEL PLATE		34.5	0.60	20.70
CONCRETE		70.8	0.10	7.08
CHANNEL		32.9	0.40	13.16
COMPOSITE		48.0	steel 0.60, conc. 0.06	15.73

Figure 16. Preliminary design and cost of panels

86. The use of steel grating panels placed in their lightweight condition and later filled with concrete has potential. Uplift forces from concrete placement would be minimal. This type of panel shows good abrasion resistance in bridge decks. Tests would be required to investigate their abrasion resistance and long-term serviceability to rocks moving at high velocities. If fresh concrete were placed under the steel grating and rose to fill the spaces, some method would need to be developed to strike-off the concrete and leave a quality surface. An alternative is to place the panel with precast concrete already filling the spaces between steel strips.

87. Composite panels, where both concrete and steel are used, have one significant advantage. A high quality concrete can be precast and bonded to the steel. For steel plate, concrete can be bonded well to the underside to provide stiffness and dampening to the plate in resisting uplift pressures. Acrylic latex modified concrete is known for its tenacious bond to steel. The additional weight, however, is a significant disadvantage (Figure 16).

88. A one-way concrete panel was designed (Appendix A) for comparison to the stiffened steel panels. Figure 16 shows the design. A 10-ft-wide panel does not require transverse ribs to resist handling stresses. The weight of the concrete panel is shown to be about four times that of the steel panels.

89. In summary, concrete panels are at a considerable disadvantage to steel panels. Concrete panels weigh more and abrade more than steel panels. Because of their higher weight, smaller concrete panels would have to be placed. Although the concrete panels would cost less (Figure 16), about half that of the steel panels, it is unlikely that this cost would drive the decision. The additional cost of the steel panels could be offset by faster construction using fewer panels.

PART IV: REPAIR SCHEMES

90. The Old River Low Sill Control Structure was used as a focal project to develop repair schemes. A plan view of a segment of the stilling basin is shown Figure 17.

Large-Area Repairs

91. Large-area repairs imply that the entire flat portion of the stilling basin will be overlaid with panels. Overlaying the entire slab has advantages, notably lack of a vulnerable leading-edge joint between the basin concrete slab and the panels and less surface preparation because the overlay can be placed on top of the basin slab.

92. Figure 17 shows three schemes: large panels to minimize all joints, narrow panels to reduce the weight of each panel for handling purposes, and channel-section panels to permit divers to build with small elements. All schemes attempt to minimize transverse joints.

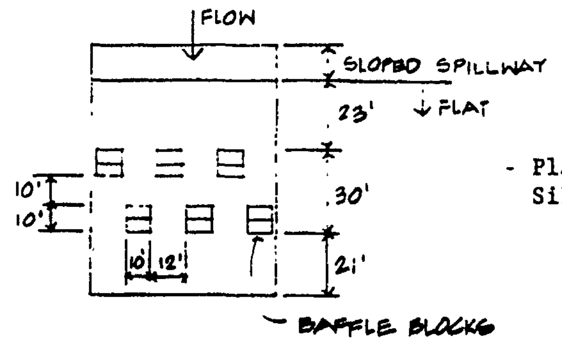
93. A preferred construction approach is shown in Figure 18. Furring strips are used in conjunction with large steel panels. The leading edge of the panels will join with the curved part of the spillway; several concepts for this joint are given in Figure 19. At this joint, high-velocity flow exists without turbulence, so the joint is not as vulnerable as other joints exposed to impact from rocks.

Partial-Area Repairs

94. Partial-area repairs are those that cover a significant portion of the stilling basin slab. The original repair to the Old River Low Sill Control Structure was a partial-area repair. From the performance of that repair, it appears that little or no bonding can be expected between the panels and the underlying grout or concrete. Therefore, inexpensive sacrificial panels as stay-in-place forms may be appropriate for some repairs.

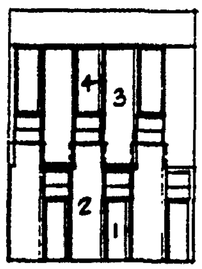
95. Once water flow encounters the baffle area, velocities increase substantially, and turbulent water above the baffles can mobilize any debris that might be present. Therefore, locating transverse joints within the

PLAN



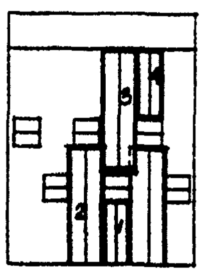
- Plan of stilling basin of Old River Low Sill Control Structure

LARGE PANEL



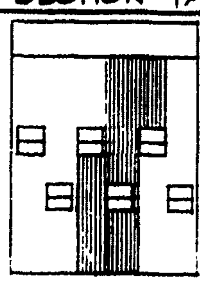
- Fewest transverse and longitudinal joints
- Panels No. 2 must be placed before No. 3
- Largest panel is No. 3 at 12 by 43 ft; approximate weight in air is 12,300 lb for stiffened panel of 1/2-in. plate
- Weight can be handled by large-capacity barge-mounted crane

NARROW PANELS



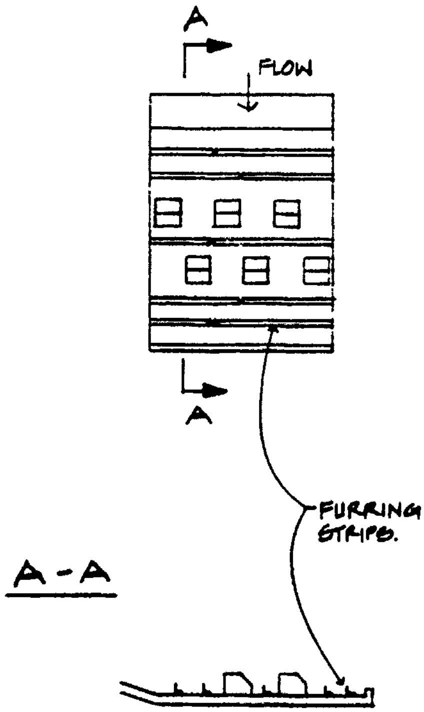
- Panels are half the width of those shown above in order to reduce the weight for handling

CHANNEL - SECTION PANELS



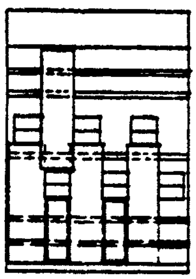
- Transverse joints are a minimum and longitudinal joints a maximum
- Channels are stock steel sections. Weight of a channel section of size 12 by 3-1/2 in. by 43 ft long is 1,400 lb in air

Figure 17. Schemes for large-area repairs



- Place furring strips in transverse direc tion. Bolt or glue strips to the base concrete. Some waviness in elevation, say ±2 in., should be acceptable. Blocking may be required to raise certain areas. Where strips span a hole and excessive deflection is anticipated, place another length of strip across the hole

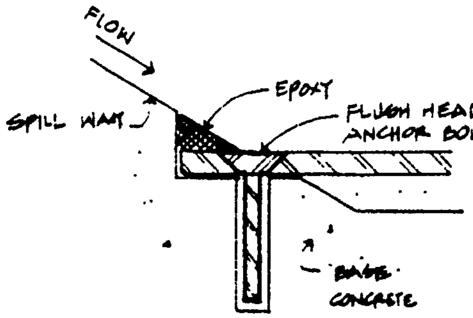
- Lower large stiffened panels to the bottom and anchor in place



- Pump fresh concrete under panels. Perform this operation consecutively with placement of panels or after all panels are in place

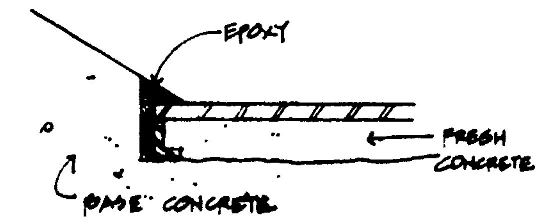
Figure 18. Preferred construction approach for large-area repair

FLAT PANEL



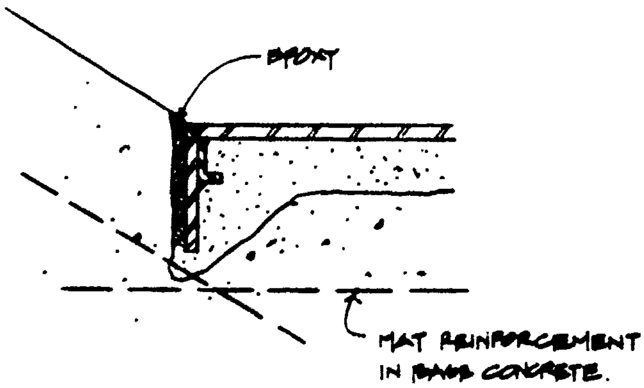
- Cut the concrete spillway. Butt the edge of the repair panel against the spillway. Eventually, front edge is vulnerable to being peeled back by high-velocity water

STIFFENED PANEL



- Butt the stiffened panel against cut concrete face. Stiffened panel will resist front end from being peeled back

PANEL WITH DEEP LEADING EDGE



- Deep front end provides improved holding capacity at upstream edge

Figure 19. Joint concepts for upstream edge of repair panels

baffle area or downstream of the baffles appears to be designing for the worst condition. It may be desirable to place the leading edge of the panels upstream of the baffles as shown in Figure 20.

96. A major difficulty with partial-area repair is that the leading panel edge needs to be recessed slightly below the basin slab. The underwater removal of a significant amount of concrete may be required. If equipment is developed to work remotely in removing concrete, partial-area repairs may become economically feasible. Otherwise, the more economical approach is to lay the panels on top of the basin slab and execute a large-area repair.

Small-Area Repairs

97. Small-area repairs are basically local patches. A concept for patches is to use steel panels of standard sizes. By using standard sizes, templates can be fabricated, remotely operated concrete cutting equipment developed, and training programs for divers produced.

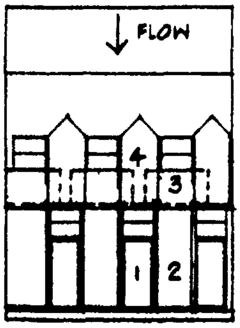
98. Designs for patches can range from deep to shallow. Deep patches have the concrete removed to below the basin slab reinforcing mat. Figure 21 shows a procedure for repairing with a deep patch.

99. Figure 22 shows a few concepts for shallow patches. Shallow patches can be as thin as the steel plate; however, a panel with edge stiffeners and pockets for recessing the bolt heads probably would be a more reliable design.

Baffle Block Repairs

100. Figure 23 shows a method to repair baffle blocks by using steel boxes of various heights. The steel boxes are prefabricated and placed over the existing concrete baffles. Bottom flanges on the box would be placed under new slab panels. The void spaces between the steel and concrete would be filled with cementitious grout or epoxy resin. The tops of baffles are usually unaffected by abrasion, so the partial or full height box would probably be adequate for repair. If bolts are used to anchor the steel boxes in place, then the bolt heads should be recessed. Otherwise, the heads will likely be sheared off by rocks, making the bolts of little value.

ARROW LEADING EDGE

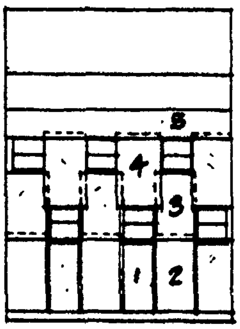


- No transverse joint at upstream edge

- Panels placed in shingle arrangement; order of placement is No. 1, 2, 3, and 4

- Overlapped edges of panels may need to be welded because of high-water velocities

SQUARE LEADING EDGE

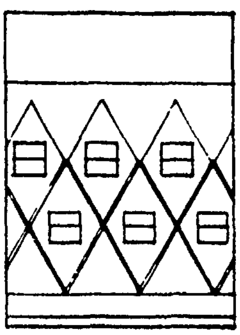


- Upstream edge is transverse to flow; yet, it is located ahead of the first row of baffle blocks

- Shingle arrangement of panels; order of replacement is No. 1, 2, 3, and 4

- Downstream of the second row of baffle blocks, the panels can easily slope to the top of the end sill wall

DIAMOND PANELS



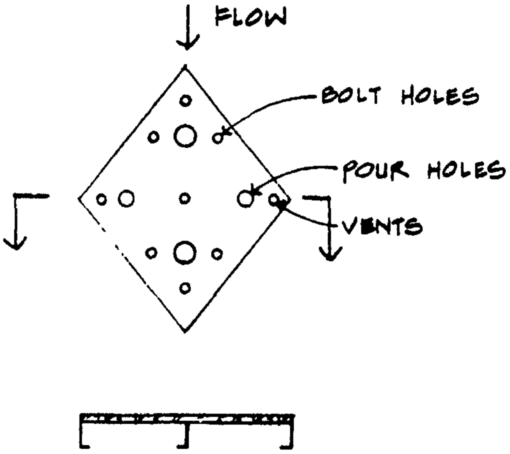
- No transverse joint at upstream edge

- Placement accuracy is required

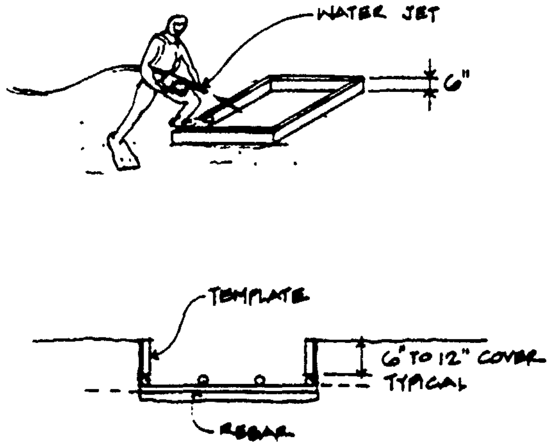
- Water flow between baffle blocks follows panel joints; this could be beneficial

Figure 20. Schemes for partial-area repair

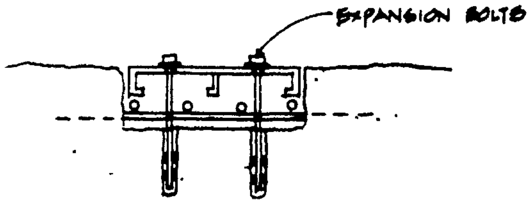
Steps



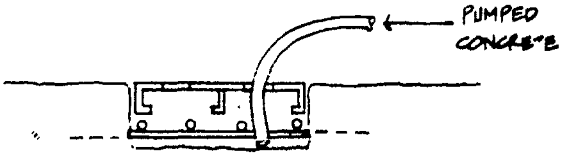
A. Use prefabricated patches of stock sizes



B. Place template over patch area. Template has the same outside dimensions as patch. Cut the outline using a saw or water jet by diver or by remote equipment. Remove the interior concrete by water jetting. Undercut the existing reinforcing bars by 1 to 2 in.



C. Install patch. Drill holes in base concrete by working through several bolt holes and insert expansion bolts. Bolt heads can be cut off and welded flush after concrete is placed, or removed if greased bolts were placed inside plastic tubes



D. Use pumped or bucketed concrete to fill the cavity. Let concrete come out of vent holes. Inject epoxy resin around edges

Figure 21. Construction steps for local deep-patch repair

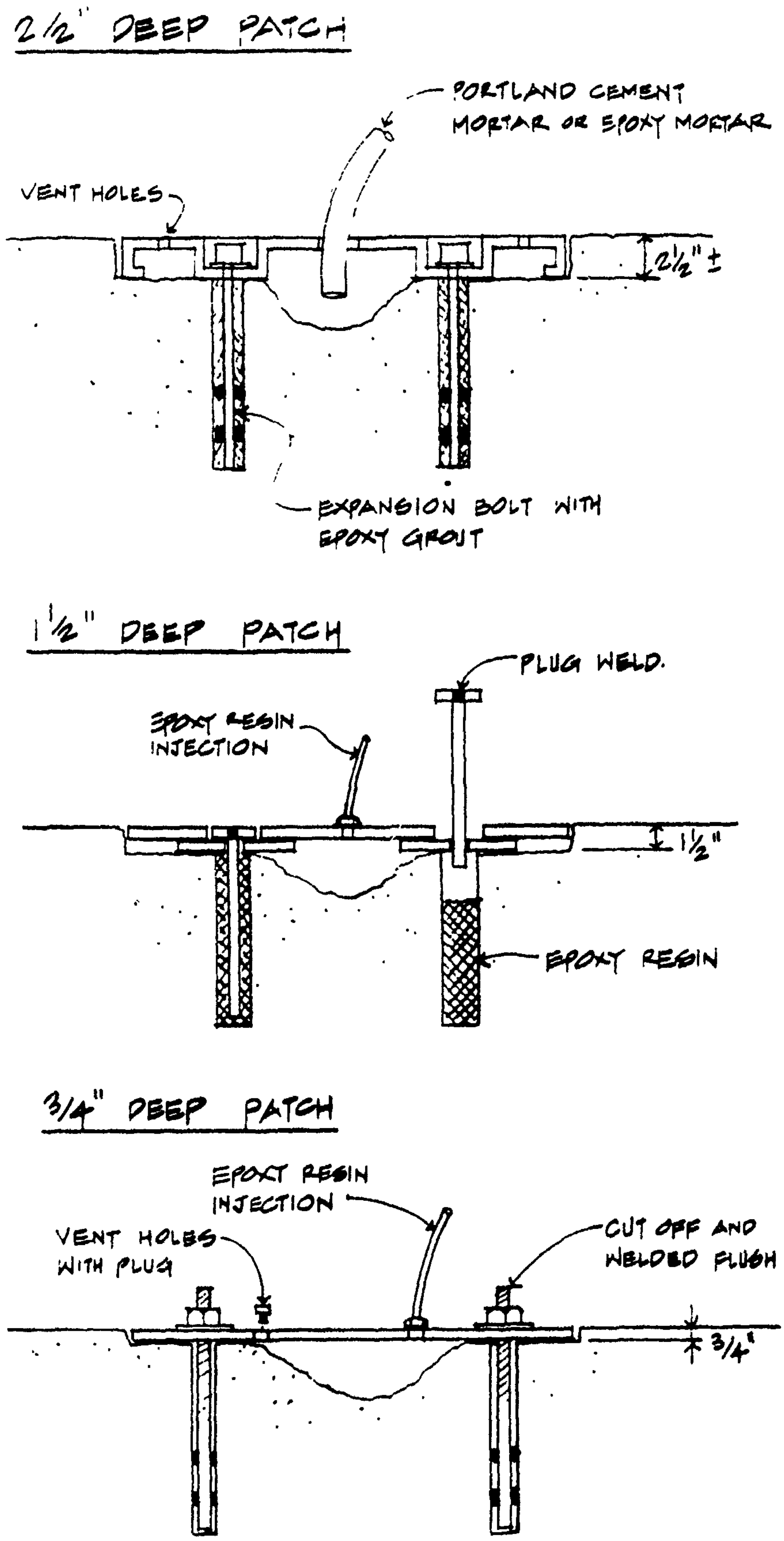
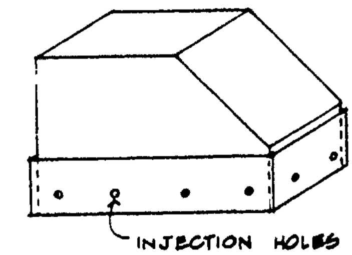


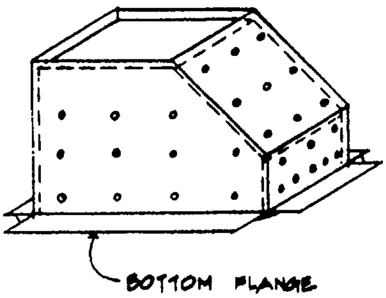
Figure 22. Local shallow patches

PARTIAL HEIGHT BOX



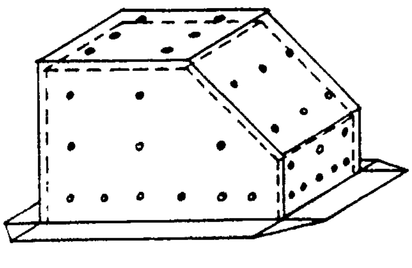
- Steel box is placed over baffle block
- All spaces behind box are filled with cementitious grout or epoxy resin

FULL HEIGHT BOX



- Bottom flange goes under slab panels
- Inject lowest holes first with a rapid-curing epoxy. Then proceed to move upward with injection, only moving to a new hole that already has epoxy coming out

ENCLOSURE BOX



- Having a top on the box allows for higher injection pressures, and the top edges are less vulnerable to damage

Figure 23. Baffle block repair

Concrete Placement

101. Provisions must be made for fresh concrete to be placed under the panels. It is most likely that concrete will be pumped as opposed to tremied or bucketed; however, bucketing may be appropriate for small-area repairs. The size of holes for receiving the pump hose should be as small as possible so that the opening may not need to be capped. A hole diameter of 4 in. or smaller may be adequate.

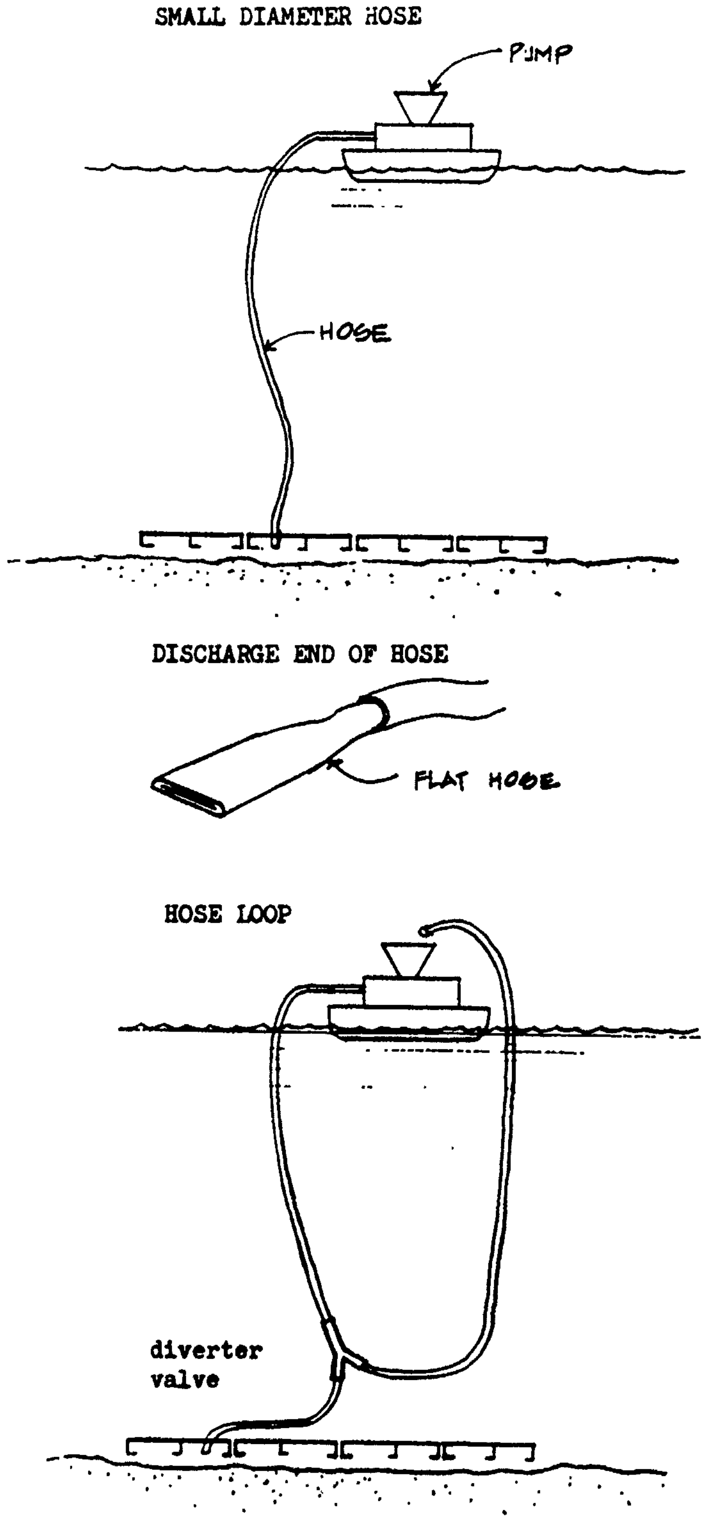
102. Figure 24 shows a concept of a flat hose for the discharge end. As the hose is being moved between holes, the flattening of the discharge end would assist in keeping water out of the hose. When the hose is reinserted into concrete, water should not be trapped in the discharge end.

103. Vent holes are also required, which would probably be about 1 in. in diameter. The vent holes should be located at corners and distant ends.

104. The task of concrete placement requires special attention. The concern of uplift pressures during concrete placement may mean that methods need to be developed for controlling the pressure at the discharge end. Two methods are presented and discussed in Figure 24 for controlling pumped concrete.

105. A relatively low slump concrete would be desirable in controlling the pressure at discharge; however, this is opposite the requirement for flowing concrete once it is placed under the panels. The distance between the base concrete and the underside of the panels may be from 6 to 18 in. At the smaller dimensions, the concrete would be quite confined and would need to be highly workable to flow horizontally at low pressures. An appropriately proportioned concrete mixture is required that flows, yet is cohesive and will not segregate. High-range water-reducing and antiwashout admixtures can be used to achieve the flowable and cohesive properties.

106. Data on the horizontal flow distance of concrete will determine the spacing of the placement holes in the panels. Concrete must appear and fill a new hole before the pump hose can be moved to that new hole. The discharge end of the hose must always be submerged in concrete. If the concrete flows horizontally for, say, 10 to 12 ft, then placement holes need to be located every 8 to 10 ft.



- Use a relatively small-diameter hose to create sufficient friction so that concrete must be pumped to move down the hose

- At discharge end of hose, use a length of flat hose to keep water out of hose when moving locations

- Use a continuous loop of hose so that concrete is always moving in the hose

- Use a diverter valve to discharge concrete on the bottom

Figure 24. Concepts for controlling pumped concrete

107. Methods to create construction joints are also necessary. Concrete will be placed in stages, and form walls are required to contain the flowing concrete so that discrete sections become completely filled. Construction joints can be made by inserting sheet metal between panels. Keyed or doweled construction joints may not be necessary if fresh concrete bonds well to the base concrete.

PART V: PROPOSED RESEARCH AND DEVELOPMENT

108. The use of prefabricated panels to repair concrete structures underwater is an undeveloped area, as evidenced by the few past examples. For stilling basins, the economics of underwater repair appears to be favorable because of the high cost to dewater some stilling basins. Research and development on underwater repair techniques can assist in two ways: ensure that quality repair work can be accomplished and improve further the economics of executing underwater repairs. The following topics for research and development efforts are recommended. The high payoff areas for improving the cost-effectiveness are in design and installation, primarily in surface preparation and large panel design. The thrusts of the proposed research and development in these areas are described below. In addition, there is a need to determine the effectiveness of small-area (spalls and cracks) repair techniques.

Panel Designs

109. Various panel designs should be tested to evaluate numerous parameters: orientation of joints to the direction of flow, joint design, allowable gap spacing between joints, and impact resistance of edges and other parameters. Initially, tests in a tank that simulates high-flow velocities and turbidity with rocks present should be conducted to provide data from a controlled test environment. Later, selected panel designs and construction procedures should be demonstrated in a stilling basin. Long-term performance data should be obtained by field tests. Composite panel designs should be included in the investigation. The composite panels should include a steel grating configuration that would be grouted in place and a composite concrete-steel rail or steel plates on edge.

Surface Preparation

110. Surface preparation is one of the most critical steps in the repair process. If all loose concrete and debris can be removed from the repair site and the sound concrete base roughened, then a strong bond between the new concrete and the base concrete should develop, especially considering

that the concrete is placed and cured underwater. If a high-quality bond can be reliably developed in this manner, then certain benefits may be accrued. For example, field anchors may not be necessary or the number reduced. Mechanical anchorages are used because patches or overlays can debond from base concrete due to volume changes caused by shrinkage or thermal effects. These movements are not present underwater. Thermal movements from heat of hydration, however, can occur if thick sections of concrete are cast (over 30 in. thick). Also, to cut concrete below the existing mat reinforcement may be unnecessary; thus, shallow patches may be acceptable. Furthermore, construction joints may not need to be keyed or doweled. Vertical edges between construction joints would simplify construction.

111. The use of ultra-high pressure (greater than 35,000 psi) water-jetting equipment has significant potential for improving the efficiency of the surface preparation activity and the bonding quality of the repair surface. The effectiveness of this equipment in concrete removal has been demonstrated for above-water applications. This jetting equipment has been effective in removing damaged or weakened concrete without damaging the underlying sound concrete and in removing concrete from around reinforcement steel without damage to it. The latter provides the capability to use the reinforcement in the base concrete to anchor and strengthen the new concrete. The equipment should be effective in preparing both small- (patches) and large-area repairs.

112. Current diver-operated jetting equipment operates at a pressure of approximately 10,000 psi (maximum). Thus, there is a need to adopt and evaluate the ultra-high pressure equipment (e.g. Conjet and JETWAND™) for underwater use. Both operational and safety issues need to be addressed.

113. Additional questions that then need to be addressed are whether inspection can ensure that mud or sand pockets do not exist on the base concrete, that cement fines are not washed out during remote concrete placement, and that adequate bond stresses reliably develop.

Small-Area Repairs

114. Although a variety of materials are available for repairing local spalls and cracks underwater, tests to evaluate their effectiveness are

needed to develop appropriate procedures and guidelines. Epoxy compounds are available for patching small areas. The properties of these compounds, such as elastic modulus, coefficient of thermal expansion, etc., are different from those of the existing concrete structure. If these materials are not adequately bonded or anchored to the base structure, they can loosen and spall off, recreating the damaged area. Tests should be performed using various patching compounds to determine their resistance to spalling when subjected to mechanical and thermal loadings and the need for anchors to the base structures.

115. Underwater crack repair techniques are available but have only been used in a relatively benign environment compared with that usually found in stilling basins. Laboratory tests should be conducted with available compounds to determine their effectiveness--ease of use, depth of penetration, limits on crack size--for both vertical and horizontal surfaces. These tests should be followed by field tests using the most effective compounds. A stilling basin with cracks in both the bed and sidewalls should be selected for the test and evaluation site.

PART VI: CONCLUSIONS

116. In developing underwater repair concepts, both construction methods and prefabricated panel designs require attention. Numerous concepts were developed and presented. Several interesting observations or findings evolved during the study, of which some are summarized below.

117. Divers are likely to be an integral part of repair projects, and it is feasible to rely on divers because most stilling basins have low-water depths of 40 ft or less. For these depths, divers can work underwater for the better part of a work day. For depths greater than 40 ft, severe bottom time limitations are placed on divers.

118. Steel panels or composite steel-concrete panels are preferred to concrete panels for two significant reasons: the abrasion resistance of steel is far superior to that of concrete, and the weight of steel panels is considerably less than that of concrete panels. If steel is selected, abrasion resistance is no longer an issue; however, design details become important to assure that the steel panels remain serviceable under uplift forces from high-velocity water flow and impact from rocks in turbulent water. For equivalent size panels, steel panels weigh about one-fourth that of concrete panels. The lower weight allows larger steel panels to be handled by a surface crane. This is desirable because larger panels mean less work for divers and fewer joints between panels.

119. A design philosophy would be to use as large panels as possible to minimize joints between panels. When joints are necessary, transverse joints to water flow should be minimized. This can be done by using long, narrow panels, if necessary, which would increase the longitudinal joints.

120. Research and development recommendations cover two major areas: surface preparation and panel design. Both topics have the potential of providing quality underwater repairs and reducing costs.

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APPENDIX A: METHODS OF UNDERWATER REPAIR OF ABRASION-DAMAGED CONCRETE STRUCTURES USING PRECAST CONCRETE AND PREFABRICATED STEEL ELEMENTS

1. The purpose of this appendix is to summarize information available on methods for or adaptable to the underwater repair of abrasion-damaged concrete structures using precast concrete or prefabricated steel elements. The first section presents a summary of the salient features of selected hydraulic structure repair projects performed underwater or performed with methods that could be adapted to underwater use. Then, a brief discussion is provided on some repair methods that are used for highway pavements and may be adaptable to underwater use. Lastly, general procedures are described for the underwater placement of preplaced-aggregate concrete and grout.

Hydraulic Structures Repair Projects

2. The following hydraulic structure repair projects used techniques or procedures that can be used directly or adapted to the underwater repair of stilling basins: Mud Mountain Dam, California Aqueduct, Chief Joseph Dam, and Barker Dam.

Mud Mountain Dam

3. The Mud Mountain Dam near Enumclaw, WA, is used primarily for flood control. The water impounded by the dam during runoff contains large quantities of mud, sand, and muck. During nonflood periods, the water is passed downstream through concrete-lined tunnels whose intakes are at the bottom of the impounded lake. Thus, the mud, sand, and rock are passed downstream preventing silt buildup in the lake and limiting downstream erosion. As would be expected, the concrete in the bottom half of the water tunnel eroded severely. Several methods were used to limit this abrasion-erosion of the tunnel invert and lower side walls. The most successful method was the embedment in the concrete of longitudinal steel rails placed closely together. The rails were placed with their top surfaces flush with the concrete or with a concrete cover up to, in one case, about 12 in. thick.

4. The subsequent pattern of erosion was as follows. First, the concrete cover, including high-strength concrete up to 12 in. thick, was rapidly eroded away, as was some of the concrete between the rails. After that, the wear was much slower as, over a number of years, the heads of rails were gradually worn down; then the rail web and base were thinned down. Eventually the head wore away or broke off as the result of web failure, but still the base was left to protect the concrete.

5. Two points are of particular interest: (a) the slow rate of wear of the steel compared with that of the very high-quality concrete and (b) the fact that the steel wore to a very small cross section without being torn out.

6. At Mud Mountain Dam, the original construction and subsequent inspection and repairs were all made in the dry with the tunnels dewatered. However, the concept of resisting abrasion-erosion with mats of closely spaced longitudinal steel rails or steel bars on edge is readily adaptable to underwater placement in stilling basins. An important consideration in such an application would, of course, be the method of attaching the mats to the bottom. If the steel is properly attached to the bottom, it can be expected to outperform even the best concrete and last for many years in a normal stilling basin, which ordinarily would have much less sand and rock debris than that in the Mud Mountain Dam tunnels.

California Aqueduct

7. Three sections of the California Aqueduct had to be repaired without lowering the water level. This required removing damaged concrete from underwater and replacing it with precast reinforced-concrete panels. The techniques used are applicable to the repair of stilling basins.

8. The aqueduct is a concrete-lined open canal with a trapezoidal cross section 30 ft high, sloped sides, and a 24-ft-wide horizontal bottom. The minimum water depth is 20 ft. The existing canal lining consists of 12-ft-square, 4-in.-thick panels that had been cast in place in the dry before the canal was originally filled with water.

9. Most of the precast 4-in.-thick repair panels were also 12 ft square, but subdivided into four 6- by 6-ft, quarter panels, separated by preformed weakened plane joints. This permitted better matching of the heights at the edges of panels to the existing concrete and also accommodated bedding irregularities.

10. Before the panel was placed, a gravel bedding was shaped and graded. Then the 12- by 12-ft precast panel (four quarter panels) was lifted and placed on the bedding material. The joints between panels were then sealed with an epoxy-based gel material.

11. Reinforcement of the repair panels was 4- by 4-in., 10/10 welded wire fabric lapped at least 6 in. at all splices and tied with No. 6 black annealed wire.

12. The preformed weakened plane joint strip was a solid, continuous wedge of polysulfide polymer that conforms to the US Bureau of Reclamation's "Standard Specifications for Elastomeric Joint Sealers," 1 August 1977. The strip was installed flush with the surface using a mechanical device that vibrated the plastic concrete enough to cause an even flow around the strip.

13. The joints between the precast panels and the existing panels were sealed with a two-component epoxy-gel product manufactured by either the American Chemical Corp. or Sika Chemical Corp., or an equivalent. This product was to have a tensile strength of 3,000 psi at 14 days, have a minimum elongation of 10 percent at 73° F, and be able to be placed underwater.

14. After the epoxy components were blended and mixed for at least 3 min on the surface, the mixed gel was taken down by divers. They applied the epoxy-gel into joints and cracks using a putty knife, trowel, or caulking gun. The finish of the sealed joint (or crack) was specified to be convex-shaped, at least 1/4 in. high with an overlap of the edges of about 1/2 in.

15. In addition to this repair work, voids were discovered under some of the existing panels, and it was decided to pump cement grout into them. One of the panels was underwater when repaired. The cement grout specified was a 1-part portland cement (Type II, low alkali) to 2-1/2-parts sand by volume and water. The grout was pumped into the voids, keeping the nozzle of the pump embedded in the grout, at a pressure not more than 5 psi.

<u>Chief Joseph Dam</u>

16. In 1966, a pilot repair program was initiated in the stilling basin using preplaced-aggregate concrete underwater. The repair area was a 30- by 42-ft eroded-concrete section with scars ranging in depth from 3 to 16 in. The repair area also included a sloped upstream transition slab.

17. The repairs were conducted in 10- by 20-ft sections at a time (10 by 9 ft for the sloped section). After anchors were grouted and reinforcement

placed, divers emptied concrete buckets containing coarse aggregate into forms. Screeds, placed on the edge forms, leveled the aggregate before placement of the top form. Grout pipes were then driven to the bottom of the aggregate. The grout was pumped into the pipes until it came through adjacent vents located in the top form. The vents were then plugged with corks. This was repeated for succeeding grout pipes until the entire form was completely grouted.

18. In the original repair, the divers used wire brushes, an air-actuated dredge, and a waterjet to clean and prepare the eroded-concrete surface. However, later inspections revealed the preplaced-aggregate concrete was missing in some areas exposing the original eroded concrete. This indicated a bond failure between the preplaced-aggregate repair and the original concrete surface. In an effort to improve the bond, an underwater sandblaster was used on the eroded-concrete surface in future repairs before the preplaced-aggregate concrete was placed. This sandblasting worked well, and there were no subsequent bond failures.

Barker Dam

19. Barker Dam, completed in 1910, is a gravity structure of cyclopean concrete with a maximum height of 175 ft and a crest length of 720 ft. It is located on the Middle Boulder Creek near Boulder, CO, at an elevation of about 8,200 ft.

20. In the 1940's, inspections revealed the dam to be in need of repair. In the original design, the foundation was not grouted. There were also no drainage systems and no allowances for uplift. Excessive leaks were found along contraction joints (which were without waterstops) and through the foundation rock. The dam was not considered safe. The upstream face was also severely deteriorated due to severe freezing and thawing conditions.

21. A restoration program completed in 1947 included: (a) grouting the foundation, (b) installing a foundation drainage system, (c) removing deteriorated concrete from the upstream face, and (d) constructing an upstream face using a continuous lining of preplaced-aggregate concrete faced with precast reinforced-concrete panels. Item (d) is of particular interest because the method is adaptable to underwater repair of stilling basins.

22. The factors that led to the use of preplaced-aggregate concrete and precast concrete over conventional concrete include:

a. The upstream addition had to be completed during the normal emptying (fall) and filling (spring) cycle. This period, being primarily the severe winter months, made the placement of conventional concrete impractical.

b. Concrete precast slabs were less expensive than the heavy wooden forms required for the concrete loads. The precast panels could be constructed during the warmer summer months.

c. Using a preplaced-aggregate concrete with a low temperature rise and continuously grouted eliminated the need for contraction joints and provided a monolithic face to the old dam.

d. Grouting the aggregate behind the precast panels when the reservoir was nearly full provided a favorable compressive stress relationship between the preplaced-aggregate concrete and the dam.

e. Shrinkage due to drying of the preplaced-aggregate concrete was expected to be about half that of conventional concrete. Also, bonding between the preplaced-aggregate concrete and the dam was expected to be about 50 percent higher than with conventional concrete.

23. The precast panels were of various sizes, but the majority were about 6 to 8 ft wide by 12 ft long; all were 8 in. thick and reinforced with a mat of 1/2- and 5/8-in.-diam steel reinforcement bars at each face. Prior to placement, the inside face was sandblasted to ensure a good bond to the preplaced aggregate.

24. When the water receded, the deteriorated concrete was removed from the upstream face, and the face was sandblasted. Anchor bolts for the panels were grouted in holes drilled into the dam. Then, the precast panels were installed.

25. Before the aggregate was placed between the panels and the upstream face, 2-in.-diam grout pipes with 1/4- by 6-in. slots at 30-in. spacing were placed along the dam in the middle of the area to be grouted. These pipes were fed by small distributing pumps that regulated the flow of the grout in the pipes. The pumps were all hooked into a main supply line leading to a central mixing plant. When the water level in the reservoir reached about 15 ft below the crest of the spillway, the grouting started. Ten days later when the water level reached the spillway crest, the grouting was completed.

26. The operation was conducted by zones. In one zone, the grout was pumped up to a few feet. Then, the next zone was pumped up to the same level.

This was continued in succeeding zones until the grout level was the same the full length of the dam. By using this technique along with continuous grouting, no area was left ungrouted for longer than 12 hr, thereby avoiding cold joints.

Repair of Concrete Highway Pavement

27. Concrete highway pavements and bridge decks are sometimes repaired with precast reinforced-concrete panels. Rapid completion minimizing lane closures is the main reason for using this approach. Two examples of this type of repair are provided below. Patching damaged concrete pavements using precast elements may be applied to the repair of concrete stilling basins underwater.

28. In 1977, the Michigan State Highway and Transportation Department experimented with precast repairs of jointed, reinforced-concrete pavements. The precast slabs were matched to one lane width (12 ft) in lengths of 6, 8, 10, or 12 ft. The slab thickness was 1 in. less than the pavement thickness to allow a 1-in. layer of mortar bedding under the precast slab. The reinforcement consisted of two layers of No. 3 reinforcing bars in both directions and spaced 18 in. on centers. Four lift inserts were cast into the slabs for handling. The concrete was regular pavement mix or a high-early-strength mix with a 28-day compressive strength of 3,500 psi. The slabs were cast near the jobsite on casting beds consisting of a compacted sand base and plywood sheets to form the bottom of the slabs.

29. To remove the damaged concrete, a full-depth cut using a circular saw with a diamond blade was made around the damaged area. Each section of concrete to be removed was cut along the joints and transversely across a lane. This facilitated the use of lane-width precast slabs. Once the cuts were made, lift pins were inserted into predrilled holes in the damaged section.

30. The precast slabs were used with doweled and undoweled joints along the transverse edges for load transfer. The doweled joints were constructed by drilling holes into the existing slabs using a drill guide and template. Dowels were then inserted horizontally into these holes, and the

precast slabs were placed on a high-slump, rich sand-cement mortar bed. A steel plate was cast in the edges of the precast slabs. The dowels were welded to this plate. After the slabs were in place, the joints were fille with a preformed bituminous material and sealed with hot-poured rubber sealant.

31. In 1973, the Virginia Department of Highway and Transportation conducted experiments with partial-depth precast repairs of jointed reinforced-concrete pavements. The majority of the slabs were very dense and had high compressive strength because they had been cast by hydraulic press. They were all 2 in. thick and ranged in size from 1 by 2 ft to 2 by 3 ft. The remainder were cast conventionally and contained metal fibers for strength. This type of slab ranged from 1 by 1 ft to 2 by 2 ft and was also 2 in. thick.

32. To determine whether polymer-impregnated concrete (PIC) increased the resistance to road salt, three pressed slabs were treated with a 9 to 1 mixture of methylmethacrylate and trimethylopropane trimethacrylate and 1 percent by weight of vazo 52 solution.

33. To cut the partial-depth holes, a Karcrete machine was used. This machine removed the concrete pavement by hammer strikes at about 1,500 blows per minute. After the hole was cleaned, a layer of epoxy-grout was placed in the hole. Then, the slab was positioned, and the space between the precast slab and the existing pavement was sealed with epoxy-grout. The epoxy-grout consisted of 1/2 gal of catalyst to 1 gal of resin mixed for at least 1 min. Sand was then mixed with the epoxy mixture until the desired consistency was reached. The ratio of the sand to epoxy was about 5 to 10 parts sand to 1 part epoxy.

Methods of Cutting Concrete Underwater

34. In the highway pavement repair, the damaged concrete was removed by cutting around the damaged area and removing the concrete pieces. The Virginia Department of Highways and Transportation case used a partial-depth cut. This concept may be applied to the removal of deteriorated concrete in the repair of abrasion-erosion damaged hydraulic structures underwater. Divers can use underwater tools such as a diamond-bladed circular saw or a high-powered waterjet cutting system to cut out the damaged area.

35. A diamond-bladed circular saw can be used to cut the concrete in the following manner. A steel plate matching the length and width of the precast panel is placed over the damaged area in the stilling basin. Weights can be used to hold the plate down. The concrete basin is then cut along the edges of the plate to the appropriate depth. The saw cuts at the corners should be overrun to ensure a clean and equal-depth cut. After removal of the plate and weights, the deteriorated concrete area within the cuts can be chipped away with an underwater pneumatic hammer. The chipping hammers will give a rough finish to the bottom of the hole that should enhance the bond between the new concrete-grout and the old concrete. The hole can then be cleaned with underwater excavation devices such as air lifts, dredges, and waterjets.

36. Cutting with a high-powered waterjet also makes use of a steel plate as a cutting guide. However, the cut is made within a steel-edged frame or template instead of around a plate. The waterjet can cut into tight corners without any overrun. Within the framework of the template, the concrete is cut to the required depth. This can be accomplished by starting from one end and cutting successive grooves. After all of the concrete is removed, the hole can be cleaned by simply replacing the cutting nozzle on the waterjet with a cleaning-type nozzle attachment.

Abrasion-Erosion Resistant Techniques and Materials for Precast-Prefabricated Elements

37. Liu (1980)* reported the results of a series of tests at the US Army Engineer Waterways Experiment Station (WES) to evaluate the abrasion-erosion resistance of various materials for use in the repair of erosion-damaged hydraulic structures. These materials may be applied to the design and construction of precast concrete panels to enhance abrasion-erosion resistance.

38. The test apparatus used a drill press with an agitator paddle and a cylindrical steel container housing a disk-shaped concrete specimen and

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* This reference may be found in the list of references following the main text.

water. Various sizes of grinding balls (ball-bearings) were also placed in the container to simulate abrasive materials swirling in a stilling basin. Five parameters were studied: (a) water-cement ratio, (b) compressive strength, (c) aggregate type, (d) concrete type, and (e) type of surface treatment.

39. The results of this study were as follows:

a. For a given aggregate, the abrasion-erosion resistance of concrete increased with a decrease in the water-cement ratio.

b. The abrasion-erosion resistance increased with an increase of the compressive strength.

c. Concrete containing soft aggregate was less resistant to abrasion-erosion than similar concrete that contained relatively harder aggregate.

d. The abrasion-erosion resistance of fiber-reinforced concrete was found to be less than similar conventional concrete without steel fibers and of the same aggregate type and water-cement ratio.

e. The polymer-impregnated concrete (PIC) samples had a significantly superior abrasion-erosion resistance compared with the non-PIC samples.

f. The abrasion-erosion resistance of polymer portland-cement concrete (PPCC) was about 34 percent higher than that of comparable conventional concrete.

g. Four types of polymer concretes (PC) were tested. The vinyl-ester polymer was the most abrasion-erosion resistant of the four, followed by methylmethacrylate polymer, polymer-impregnated, and polymer portland-cement concretes.

h. The concrete containing fly ash had a higher abrasion-erosion loss than that of concrete without fly ash.

i. All of the concrete surface coatings (i.e. polyurethane, acrylic mortar, epoxy-resin mortar, furan resin, and iron-aggregate toppings) in general had good abrasion-erosion resistance.

j. The vacuum-treated concrete specimen significantly improved the abrasion-erosion resistance of conventional concrete by increasing the compressive strength of the concrete.

40. The basic recommendations from this study are:

a. Use the hardest available aggregate.

b. Use the lowest practical water-cement ratio (i.e. the highest practical compressive strength).

c. Do not use fiber-reinforced concrete.

d. Consider certain polymer concretes, such as PC, PIC, and PPCC.

e. Consider the use of vacuum-treated concrete for the precast concrete elements.

41. Some of these recommendations have drawbacks. Hard aggregates that performed well are not always readily available at work sites. The highest practical compressive strengths (about 6,000 psi) are not high enough to compensate for unsatisfactory aggregate. Special concretes such as PC, PIC, and PPCC are expensive.

42. Later studies on abrasion-erosion concretes found that very high-strength concretes made with silica fume have a high abrasion resistance. Silica-fume concrete is more economical than concretes using polymers and can be placed using conventional methods for fabricating precast panels in a casting yard.

Preplaced-Aggregate Concrete Underwater

43. Preplaced-aggregate concrete underwater is usually used when the placement of tremie concrete is difficult or impractical. Tremie concrete is usually used where the repair area is easily accessible. Therefore, preplaced-aggregate concrete may be more feasible between precast concrete panels and existing concrete.

44. Preplaced-aggregate concrete involves the placement of forms, grout pipes, coarse aggregate, and then grouting. The forms and grout pipes are first anchored down, and the aggregate is placed around the grout pipes. Grout is then pumped through the pipes, filling the voids in the aggregate and displacing the water upwards.

45. The void ratio of the aggregates should range from 38 to 40 percent. The coarse aggregate should be free of finer material that might tend to impede the flow of the grout. This finer material may result from abrasion of the coarser material during transportation or deposits of mud or silt in and around the repair site. Thus, the repair surface must be kept clean and the grout pumped as quickly as possible after the aggregate placement.

46. Grout is usually a sand-cement slurry consisting of portland cement, a fine sand, mixing water, pozzolanic material, and admixtures to increase fluidity and inhibit segregation and early stiffening.

47. The forms should be watertight and vented at the top to allow control of the grout flow. If they are not properly vented, voids could form in the hardened concrete. The grout pipes should be placed at the lowest possible level in the forms to allow the water to be displaced upwards and out of the forms. Once the forms are filled, a closing pressure of about 10 psi should be maintained until all of the air and water are expelled.

Grout Placement Underwater

48. The following are suggested methods of placing grout underwater for such applications as securing anchor bolts into concrete and sealing joints between precast panels and existing concrete.

49. For underwater applications, two types of grouts are generally used: hydraulic cements and polymers. Different variations of these, depending on the application, are commercially available. For the installation of anchor bolts in concrete underwater, prepackaged polymers (vinylester resin and polyester resin), hydraulic cement, and neat epoxy-resin grouts are usually used.

50. Prepackaged polymer grouts are contained in individual capsules filled with the segregated polymer components. The capsule is inserted into a predrilled hole in the concrete, and the anchor bolt is then screwed into the hole rupturing the capsule and mixing the two-component resin.

51. Hydraulic cement has been placed using either the surface-mix method or the toothpaste-tube method. The surface-mix method consists of a flexible plastic tube, 4 to 5 ft long, about 5 in. in diameter, 6 mm thick, with a knot at the lower end. On the surface, a cement-sand mixture and water are poured into the tube. This mixture is then shaken and kneaded before being taken down by a diver, who squeezes the mixture into a predrilled hole. Anchor bolts are inserted into the hole, displacing the grout. In practice, this method has not always worked well because the mixture has tended to harden too quickly. In the toothpaste-tube method, the cement-sand mixture is poured into a tied-off tube, and the tube is twisted in the middle to seal off the mixture. Then, fresh water is poured into the upper part of the tube, and a knot is tied at the top. This is all done at the surface; a diver then takes this segregated tube underwater, untwists the tube, and mixes the two

components; this procedure eliminates the problem of premature hardening of the cement.

52. Neat epoxy-resin grouts are temperature sensitive and should be used in accordance with manufacturer's recommendations. They can be dispensed by either a caulking gun or grout dispenser. The caulking gun is a pneumatically operated system that dispenses the epoxy grout from disposable plastic cartridges. The grout is premixed at the surface in buckets. This mixture is then poured into the cartridges and taken down to the jobsite by a diver, who loads and reloads the cartridges as he fills the holes with grout. Since the "pot life" of the grout is only about 30 min, the time it takes to deliver the mixed grout to the jobsite is critical. A grout dispenser developed by the Naval Civil Engineering Laboratory (NCEL) is a pneumatically powered tool. The epoxy is mixed at a ratio of 1:1 from 20-fl oz disposable plastic cartridges. As with the caulking gun, the cartridges are loaded and reloaded underwater. However, the NCEL tool simultaneously mixes and dispenses the grout, thus eliminating premature hardening.

Summary

53. Precast reinforced-concrete panels have been used successfully to repair structures above and below water. In the repair of the California Aqueduct, they were used underwater. Because the forces in the aqueduct are not as severe as they can be in stilling basins, no structural joint was needed between the repair panel and the existing structure; the space was filled with a plastic joint material. Doweled joints have also been used in the repair of highway pavements to secure precast repair panels to the existing pavement. A similar approach is feasible for stilling basins.

54. The superiority of steel over concrete in resisting abrasion forces has been demonstrated. The viability of a composite construction, either steel rails or steel plates on edge embedded in concrete, for stilling basin repair was demonstrated in the repair of the Mud River Dam. When concrete is used, the abrasion resistance can be maximized by using hard aggregate and a low water-cement ratio; casting the panel in a hydraulic press also provides a dense high-strength concrete. Adding fly ash to the mix or using a

polymer-impregnated concrete has also been found to increase abrasion resistance.

55. Grouted, preplaced aggregate has been used successfully in both above- and below-water repairs. A clean rough surface on the existing structure is necessary to the development of an acceptable bond between the grout and the old surface. Based on the results of the Chief Joseph Dam repair, an underwater sandblaster provides a better bonding surface than the use of wire brushes and a waterjet. Grouting continuously, from beginning to end, will eliminate cold joints that can develop in discontinuous pours.

56. An array of tools exists for divers to use in preparing (for example, cutting or cleaning) the repair site and completing the repair. Specifications for the grout and preplaced aggregate are available. The technology for using precast-prefabricated panels to repair stilling basins underwater appears to be reasonably well developed. Areas needing investigation are described in the main body of this report.

APPENDIX B: UNDERWATER WORK TECHNIQUES

1. The information provided in this appendix was obtained from the Naval Facilities Engineering Command's manual, NAVFAC P-990, Conventional Underwater Construction and Repair Techniques. This manual provides a guide for the Navy's Underwater Construction Teams (UCTs) in conducting their conventional tasks such as inspecting, maintaining, and repairing cables, pipelines, fleet moorings, piles, cathodic protection systems, and other marine facilities. The underwater work techniques and procedures described in the manual represent the current Navy and commercial practices. Some of the techniques and procedures relate to the underwater concrete repair of hydraulic structures and are described below in general terms to provide a measure of what can be done underwater. The work techniques described include: (a) marine growth removal, (b) preplaced-aggregate concrete, (c) rock drilling, (d) grouting, and (e) weight handling.

Marine-Growth Removal

2. The power tools available for marine-growth removal are described briefly because they represent an effective means for cleaning the surface of concrete in stilling basins prior to repair. Power tools are faster and usually more effective than hand tools for removing marine growth. Three Navy-approved commercially available devices will be described:

a. Cavitation pistol for routine cleaning of concrete and steel structures and cleaning in limited access areas.

b. Reactionless waterjet with variable flow rates and pressures for accessible, heavily fouled concrete and steel structures.

c. Sand injection waterjet to remove all protective coatings from steel surfaces, leaving a bare metal finish.

3. The cavitation pistol is a small hand-held pistol with a cavitation-producing nozzle that operates at a pressure of 10,000 psi and a flow range of 2 to 3 gpm and requires the application of 12 to 18 hydraulic hp. The gun, which does not have a thrust-compensating device, has a maximum reaction force of 8 lb. This device yields the best results with minimum power usage for quick general surface cleaning on concrete or steel. The reactionless, high-pressure waterjet is available with a number of fan nozzles varying in orifice

size and fan angle. The retrojet is surrounded by a diffuser shroud with slots that force the exiting high-pressure water out the side holes to prevent injury if the tool is inadvertently passed in front of the operator. The system operates within a wide range of flows and pressures limited only by the pump capabilities and includes a topside, foot-operated control valve that permits surface personnel to shut off flow to the tool quickly in case of emergencies or equipment malfunction. This device can effectively remove heavy marine growth and corrosion for most situations and satisfies most cleaning criteria and requirements. The underwater counterbalanced sand-injection waterjet entrains abrasive particles in the waterjet and is supplied by two separate hoses. A compressed air line carries the abrasives down to the gun through a dry hose that bypasses the trigger valve to prevent any clogging. The system requires 140 psi and 50 cfm of air. At the gun, the grit particles are accelerated by the water from the high-pressure delivery line, which operates at 6,000 psi, 20 gpm, and 70 hp. It is the only tool that completely removes protective coatings and cleans steel to a bright metal.

4. In addition, a waterjet cleaning system has been developed by the Naval Civil Engineering Laboratory (NCEL) for the routine cleaning of structures, particularly in limited access areas. The system includes a small hand-held waterjet pistol; interchangeable cavitating fan and straight jet nozzles; a diver-operated trigger valve with automatic safety lock; flexible, small-diameter, high-pressure supply hose; a foot-activated shutoff valve; and a high-pressure swivel. The power source, which delivers up to 5 gpm at 12,000 psi, is driven by a diesel engine. The power unit operates on either fresh water or seawater and is capable of powering oil-hydraulic diver tools. A noncavitating high-pressure waterjet without retrojet for surface-subsurface cleaning is commonly used by the UCTs. This device develops more than 40 lb of back thrust and is equipped with a shoulder stock to provide support during operation. It operates at up to 10 gpm and 10,000 psi and is available with a number of standard and fan nozzles. The best operating technique for all high-pressure jets includes a standoff distance of 1/2 to 3 in., an impingement angle of 50 to 90 deg, and quick and agitated translation. Each tool has an optimum operating technique that should be established prior to any actual cleaning.

Preplaced-Aggregate Concrete

5. Preplaced-aggregate concrete is used on large underwater repair jobs where placement of regular concrete would be either difficult or impossible. This method is used also to restore old concrete and masonry structures. Preplaced-aggregate concrete involves placing coarse aggregate in a form and then filling the voids in the aggregate mass with grout. The grout pipes are installed, generally before aggregate placement, and often are fixed to the form or to a reinforcing cage. After the aggregate is placed, grout is pumped into the pipes and flows upward, displacing the water. A typical aggregate gradation is shown in Table B1. The grout should be a sand-cement grout richer than a 1:1 mix. Various admixtures are used to prevent segregation and to act as a wetting agent to promote penetration of the grout. These admixtures are proprietary, and it is essential that the manufacturer's instructions be followed in detail. Bonding strengths of preplaced to regular concrete are between 70 to 100 percent of that attainable in regular concrete.

Table B1

Gradation of Aggregates for Preplaced-Aggregate Concrete*

Aggregate	US Standard Sieve	Percent Passing (by weight)
Gravel**	2 in.	100
	1-1/2 in.	90 to 100
	1 in.	20 to 55
	3/4 in.	0 to 15
	3/8 in.	0
Sand	No. 4	100
	No. 8	80 to 100
	No. 16	50 to 85
	No. 30	25 to 60
	No. 50	10 to 30
	No. 100	2 to 10

* Source: NAVFAC P-990: Conventional Underwater Construction and Repair Techniques.

** Placed separately prior to intrusion of grout.

This makes it possible to restore deteriorated concrete members to nearly their original strengths or to enlarge existing members to take additional loads. Weakened material should be removed to expose sound concrete, and the surfaces of sound concrete should be roughened by either chipping or heavy sandblasting before repairing. Space must be provided for the replacement or addition of at least 3 to 4 in. of new preplaced-aggregate concrete. Forms are then well anchored to the old concrete, the grout pipes are installed, and the coarse aggregate is placed. The grout is injected, and when the forms are filled, a closing pressure of about 10 psi is held for several minutes to drive out all air and water through a vent at the highest point. The forms may be removed 1 or 2 days later. When handling preplaced-aggregate concrete, it is important to:

a. Prevent fines from collecting in the coarse aggregate because they tend to impede the flow of the grout. These fines, which may result from abrasion of the coarse aggregate during handling, collect on the bottom of the conveying barges or trucks.

b. Deposit the aggregate in a clean place that is free of mud, silt, slurry, or other contamination.

c. Pump the grout promptly after aggregate placement.

d. Protect the aggregate from contamination between the times of placement and grout intrusion.

Rock Drilling

6. Drilling holes in seabed rock is usually done with hydraulic rock drills. Pneumatic rock drills were used in the past, but have proved undesirable because of high maintenance requirements and the percussion waves produced by the exhaust gas. Also, in cold weather the pneumatic equipment tends to freeze up. Two types of hydraulic rock drills have been developed by NCEL for use on rock and coral. The hand-held drill is capable of drilling holes from 1/4 to 1-1/2 in. in diameter up to 18 in. deep. The heavy-duty rock drill produces holes between 1-1/2 and 4 in. in diameter to a depth of 4 ft. Commercially available underwater hydraulic rock drills are also extensively used by the UTCs. These tools come in three models: a light-duty hammer drill, a heavy-duty hammer drill, and a sinker drill. They are capable of drilling holes up to 3 in. in diameter and up to 20 ft deep. Hydraulic rock

drills should be powered by sources capable of 10 gpm and pressures up to 2,000 psi. It is recommended that the tool be cleaned after each use in water. Drilling rates vary with the type of drill, diameter of the hole, hardness of the rock, skill of the diver, and the working conditions. Average drilling rates for sound rock for the various model drills and drill diameters, assuming good working conditions and an experienced diver/operator, are given in Table B2.

Grouting

7. Grouts for underwater use can be generally classified as either a hydraulic cement or an epoxy. Several variations of both the hydraulic cement and the epoxy are commercially available for use in different applications. A hydraulic cement is a single-component cement that is capable of setting and hardening underwater because of the interaction of water and the constituents of the cement. Admixtures are available from hydraulic-cement manufacturers for obtaining specific performance goals (i.e., accelerate or slow down the reaction rate). Epoxy is a resin compound used for bonding different surfaces or filling thin voids. It consists of a resin, hardener, and sometimes an aggregate. Epoxies are commercially available in different formulations, each having a specific performance or physical characteristic (i.e., strength, mixing ratio, pot life, moisture sensitivity, etc.). Neat epoxy resin refers to an epoxy mixture containing only the resin and hardener component. Oven-dried aggregate is sometimes used to "extend" the epoxy mixture or alter the performance characteristics. Table B3 lists the materials for several grouting applications.

8. For repairing deteriorated underwater concrete surfaces, either epoxy-resin/oven-dried aggregate grout or hydraulic-cement grout is used. The concrete surfaces to which the grout is to be applied are cleaned by sandblasting or waterblasting to allow for good bonding action. Loose concrete is chipped out, and corroded reinforcing bars cleaned and supplemented by new bars if necessary. The hydraulic-cement grout or epoxy grout should be mixed and applied in accordance with the manufacturer's directions, either by hand or tool smearing.

Table B2

Rock Drilling Production Rates*

Tool	Bit Size (in.)	Penetration Rate (in./min)
NCEL hand-held	1/2	4.5
	1	2.0
	1-1/2	0.5
NCEL heavy-duty	1-1/2	6.5
	2-1/2	2.2
	4	0.5
Commercial light-duty	1/2	7.9
	1	5.1
	1-1/2	0.8
Commercial heavy-duty	1/2	9.1
	1	5.5
	1-1/2	2.7
Commercial sinker drill	1-1/2	5.5
	2-1/4	1.8
	3	1.1

* Source: NAVFAC P-990: Conventional Underwater Construction and Repair Techniques.

Table B3

Grouting Applications and Materials*

Procedure	Material
Securing U-bolts or rock anchors to seabed	• hydraulic-cement grout • neat epoxy-resin grout
Repairing deteriorated concrete surfaces	• epoxy-resin/oven-dried aggregate grout • hydraulic-cement grout
Repairing cracks in concrete	• neat epoxy-resin grout
Installing anchor bolts in concrete structures	• prepackaged epoxy grout • hydraulic-cement grout • neat epoxy-resin grout

* Source: NAVFAC P-990: Conventional Underwater Construction and Repair Techniques.

9. The best method for repairing small to medium cracks in concrete piles or structures is pressure injection of neat epoxy grout. The epoxy selected should be a low-viscosity formulation suitable for wet surfaces and underwater application. In choosing the appropriate resin, it is very important to confer with the manufacturer to ensure that the resin is compatible with the crack size and depth, temperature variations, characteristics of the concrete, and the equipment to be used to apply the resin. Holes should be drilled into the crack every 6 in. to 3 ft along its length, and small tubes, or one-way polyethylene valves, should be installed. The area around the tube or valve and the entire surface of the crack should be sealed with a quick-setting epoxy paste adhesive. The low-viscosity epoxy grout is then injected into the lowest tube or valve until it reaches the level of the next tube or valve. The epoxy is then injected in that tube or valve, and the procedure repeated until the crack is filled.

10. Using prepackaged epoxy grout in glass tubes is an extremely efficient method of installing anchor bolts in existing concrete structures. The action of screwing the anchor into the tube breaks the glass, which then acts as a coarse aggregate, and mixes the resin to start the setting action. This type of grouting system is very cost-effective for small projects. Alternatively, hydraulic-cement grout or neat epoxy grout can be used. With these materials the grout is squeezed or injected into the drill hole so that the hole is almost full. The anchor bolt is then inserted into the hole, forcing some of the grout out and ensuring that the hole is completely filled.

Load Handling

11. In UCT operations, it is sometimes necessary to move heavy and bulky objects underwater. This can be achieved underwater by the diver using lift bags and float balloons and from the surface using cranes and winches. Several lift bag systems can be used: open- and closed-bottom commercial lift bags, variable-buoyancy zipper lift bags, and fixed-displacement Kevlar lift bags. The lift capacities and sizes of the open-bottom bags are presented in Table B4. Considering the water depths and conditions in stilling basins, the preferred procedure would be the use of surface support for the load handling.

Table B4

Open-Bottom Lift Bag Available Sizes*

Model	Lift Capacity lb	Overall Width ft	Overall Length ft	Shipping Weight lb
Minor range				
M2	220	1.48	3.44	9
M5	550	1.97	4.26	10
M10	1,100	2.46	5.25	16
Professional range				
Pr1	2,200	3.28	8.20	31
Pr1V	3,300	3.94	8.86	44
Pr2	4,400	4.43	8.86	57

* Source: NAVFAC P-990: Conventional Underwater Construction and Repair Techniques.

APPENDIX C: PANEL DESIGN CALCULATIONS

STIFFENED STEEL PANEL DESIGN

TRY 1/2" PL., FIND STIFFENER SPACING

$f = \frac{M}{S}$ $M = \frac{w\ell^2}{8}$ $S = \frac{bh^2}{6}$

f allowable = 27 Ksi mild steel

W = 20 psi uplift pressure

$\ell^2 = fS\frac{8}{w}$

$= 27{,}000 \left(\frac{0.5^2}{6}\right)\left(\frac{8}{20}\right) = 450$

$\ell = 21"$

USE 1/2" PL W/STIFFENER @ 20"

TRY 3/4" PL, FIND STIFFENER SPACING.

$\ell^2 = 27{,}000 \left(\frac{0.75^2}{6}\right)\left(\frac{8}{20}\right) = 1013$

$\ell = 31.8"$

USE 3/4" PL W/STIFFENER @ 30"

FIND STIFFENER SIZE

ASSUME 10'x45' PANEL

1/2" PL

PL wt. = 20 psf.

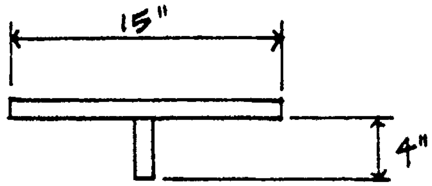
ASSUME STIFF. wt. = 10 psf.

TOTAL wt. = 30 psf. $\times \frac{20}{12}$ = 50 #/ft on RIB.

ASSUME 9' CANTILEVERS, 27' SPAN

$M = \frac{50 \times 9^2}{2} = 2025'\# = 24'^{K} \times 1.25$ (IMPACT) $= 30'^{K}$

TRY 1/2" x 4" PL



$A = \frac{15+4}{2} = 9.5 \text{ in}^2$

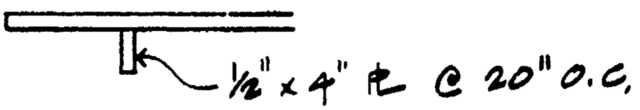
$NA = \frac{7.5 \times 0.25 + 2.0 \times 2.25}{9.5} = 0.7"$

$I = 7.5 \times 0.5^2 + 2.0 \times 1.5^2 + \frac{0.5 \times 4^3}{12} = 9.0$

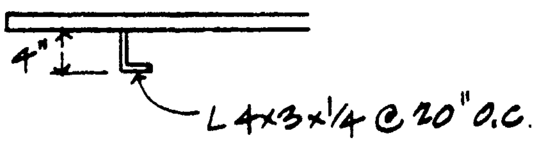
$f = \frac{30 \times 3.8}{9.0} = 12.6$ ksi ✓ O.K.

ALT. DESIGN. :

1.)



2.)



3/4" PL

PL wt. = 30 psf.

ASSUME STIFF. wt. = 10 psf.

TOTAL wt. = 40 psf $\times \frac{30}{12}$ = 100 #/ft ON RIB.

$M = \frac{100 \times 9^2}{2} \times 1.25 = 61'^K$

TRY 1/2" x 5" PL

$A = \frac{22.5+5}{2} = 13.8 \square''$

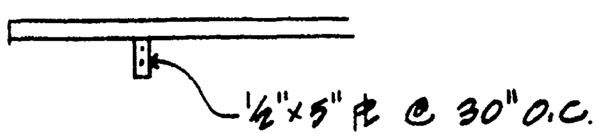
$NA = \frac{11.3 \times 0.25 + 2.5 \times 2.75}{13.8} = 0.7''$

$I = 11.3 \times 0.5^2 + 2.5 \times 2.0^2 + \frac{0.5'' \times 5^3}{12} = 18.0$

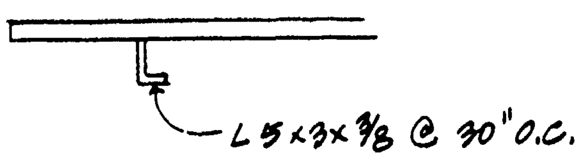
$f = \frac{61 \times 4.8}{18.0} = 16.3$ Ksi ✓ O.K.

ALTERNATE DESIGNS:

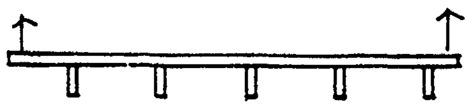
1.)



2.)



CHECK ½" PL BENDING TRANSVERSELY UNDER OWN. WT. WHEN PICKED



$\ell = 10' = 120"$

$w = 30\#/\square' = 0.21\#/\square"$

$M = \frac{0.21 \times 120^2}{8} \times 1.25 = 469"\#$

$S = \frac{0.5^2}{6} = 0.042$

$f = \frac{469}{0.042} = 11.3\ ksi$ ✓ O.K

NO TRANSVERSE STIFFENERS REQ'D.

SAME FOR 3/4" PL.

CONCRETE PANEL DESIGN

ASSUME 4" PANEL, CHECK RIB SPACING:

TRY #4 @ 12" @ PANEL ℄

$$P = \frac{0.20}{2 \times 12} = 0.83\% \ \checkmark \ O.K$$

$$M = 0.90 \times 0.0083 \times 60 \times 12 \times 2^2 \left(1 - 0.59 \times 0.0083 \frac{60}{6}\right)$$

= 20.5"K / Ft. WIDTH / 1.7 = 12.0"K WKG. STRESS

$$\frac{w l^2}{8} = 12.0 = \frac{12 \times 0.020 \, l^2}{8}$$

l = 20" CLR. - USE 4" WIDE RIB 24" O.C

DESIGN OF RIB:

PANEL wt. = [(4×12 + 2×8)/144] 150 = 67 #/'

$$67 \times \frac{24}{12} = 133 \ \#/' \ \text{ON RIB.}$$

$$M = \frac{133 \times 9^2}{2} \times 1.25 = 6750'\# = 81"K$$

USE $d = 11"$ $b = 4"$. $a = 1"$

$$A_s = \frac{81}{54\,(10.5)} = 0.14\,\square" \times 1.7 = 0.24\,\square"/'$$

CHECK TRANSVERSE BENDING UNDER SELF WT.:

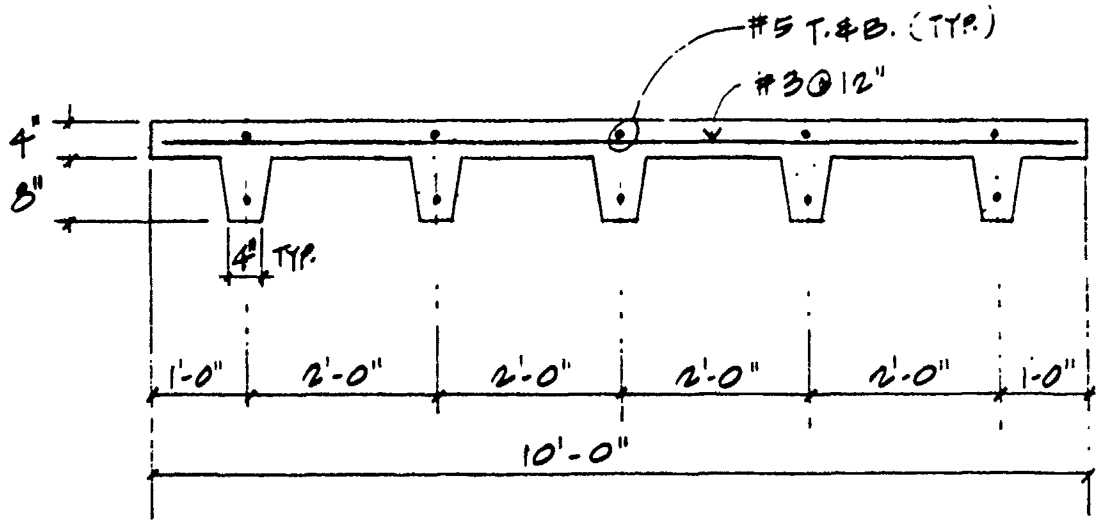
$$w = 67\#/\square' = 0.47\ \#/\square"$$

$$M = \frac{0.47 \times 120^2}{8} \times 1.25 = 1047"\# = 1.05"K/"$$

$$= 12.6"K/' \ \checkmark \ O.K$$

∴ NO TRANSVERSE RIBS REQ'D.

CONCRETE PANEL



APPENDIX D: ENVIRONMENTAL IMPACT

1. This technical report has been reviewed for environmental and water quality aspects. No significant concerns were raised concerning water quality or environmental impacts due to the repair methods discussed. However, the following items should be considered when evaluating site specific conditions:

   a. Surface preparation may result in significant increases in the levels of suspended solids in the water column. In areas of environmental concern, the impacts of these increased concentrations should be evaluated in the project planning and design phase.

   b. The health and safety aspects of using synthetic grouts should be evaluated. This is an area of increasing concern. Unfortunately, there is little, if any, data to support a definitive statement on the impacts of these materials on the environment or water quality.

   c. If dewatering of the stilling basin can be eliminated, implementation of underwater repair techniques should result in an overall positive environmental impact.