Repair Strategy

The Swan Lake Hydroelectric Project is a remote site with steep terrain and a maritime climate. Site access is by floatplane or boat. Access to the reservoir is by road from the project port area. Access to the plunge pool is by a service road in an area above the plunge pool. No road directly leads to the level of the plunge pool. The reservoir fills quickly when there is a storm or high snowmelt runoff. This limits the opportunities for working in the reservoir along the dam and below the dam, as the work sites are affected during spill events by spillway discharges into the plunge pool. Periods of non-spill are relatively short during much of the year. These conditions required a flexible repair strategy to address the non-spill windows that could be as short as 1 or 2 days. In addition, the repair materials and fabricated elements with long-lead time for procurement would require pre-purchase by AEA to provide the maximum flexibility in scheduling the work.

Scheduling was crucial to the success of the proposed leak repair since construction work could not be performed upstream or downstream of the dam during spill periods. In September 1999, it was decided to proceed with an aggressive, fast track, two-phased repair construction schedule. This lead to the selection of corrosion-resistant materials for fabrication of the Leak Closure Bulkhead so as to be able to depend wholly on the bulkhead to stem the leak without grouting, if necessary. The design and procurement of the bulkhead was expedited. The planned phases of construction were:

> *Phase I – Installation of Leak Closure Bulkhead*: This phase was comprised of installing the bulkhead on the upstream side of the dam, closing the flow control valve, and securing it with anchor bolts, thus stopping the leakage. Construction was initially scheduled between November 1999 and January 2000.
>
> *Phase II – Infill of Bulkhead, Conduit 4-165, and Block-Outs*: This phase involved grouting the bulkhead and the void in the leaking conduit, placement of a concrete plug downstream, and any additional work required to improve the condition of the other conduits. Construction was to be scheduled for the period of June through July 2000.

By late September 1999, the leakage flow rate remained stable at about 4 cfs. Because the leakage did not constitute an immediate threat to dam safety, the repair was not classified as an emergency. As such, normal State of Alaska contracting procedures had to be followed that precluded use of expedited, time-saving bidding procurement procedures. However, because the special fabrication of the Leak Closure Bulkhead required 6 to 8 weeks and another 1 to 2 weeks to ship to the site R&M was authorized to design and procure, the Leak Closure Bulkhead as owner-furnished materials for delivery before the construction contractor would begin work.

The revised repair construction schedule maintained the two-phase approach concept of first installing the Leak Closure Bulkhead to stop the leakage and second, performing the permanent infilling repair to the conduit immediately after or later when better weather conditions would be available. The Phase I work was scheduled for the March 2000 period, with the option to complete the Phase II repairs in June-July 2000 if the repairs required additional work and more time or if weather and spillway discharges prevented completion during the March 2000 period.

Flow Net Studies to Address Diver Safety Concerns

To assist AEA in determining the safety parameters of the project, a detailed Activity Hazard Analysis was performed for all anticipated construction activities in the reservoir and plunge pool areas. A numerical hydraulic analysis using FLOW-3D[1] software was performed for the immediate vicinity of the leak and in the reservoir in the vicinity of the dam. The conditions in the vicinity of Conduit 4-165 were investigated for 4 cfs and 8 cfs leakage flow. It was concluded that:

1. For the 4 cfs flow rate, protective grating would be necessary to protect divers working in front of the leaking conduit and in front of the bulkhead with the flow control valve open.

2. Special mechanical means would be required to ensure accurate fit up of the bulkhead as it was put into place.

Although an additional hydraulic analysis of the reservoir and power intake indicated it would have been possible to safely work at Conduit 4-165 while generating power, it was stipulated by AEA that there would be no generation or discharges through the powerplant at any time divers were working. To provide a safe working environment at the plunge pool, all work was to be suspended and equipment moved out if there was any possibility of the spillway discharging. Power production operations would be scheduled for the evening and night hours, only so as to maintain reservoir levels and provide divers access to the work during the daylight hours. In accordance with KPU and AEA safety procedures for operating power facilities, all construction work was performed under daily clearances from KPU Operations and daily Special Work Permits from AEA.

Contract Documents for Fabrication and Repair Construction

R&M and Acres International prepared fabrication drawings and specifications for the repair work, and the documents were issued for bid after AEA and FERC review. The fabrication

---

[1] FLOW-3D software is from Flow-Science, Inc., developed at Los Alamos Laboratories.

Bulkhead installation demonstration.

and supply of owner-furnished materials comprising the Leak Closure Bulkhead system, including installation aides and anchor bolts, was awarded to Industrial Fabrication Corporation (IFC) of Sultan, Washington.

Construction drawings and specifications for the Swan Lake Leak Repair and Resealing Contract (AEA 99-111) were prepared and the contract was advertised for bids on December 15, 1999. A pre-bid conference was held at the IFC shop in Sultan, Washington, on January 5, 2000, at which the installation procedure for the Leak Closure Bulkhead was demonstrated on a test stand. Construction bids were received on January 18, 2000, the Notice Of Intent To Award was issued on February 2 to Ty-Matt, Inc., of Ketchikan, Alaska, and the Notice to Proceed was issued on February 8. A pre-construction conference with Ty-Matt, Inc., was held on February 17 at the site to review contract procedures, site conditions, and coordination of use of project facilities. Physical construction of the leak repair and re-sealing was performed in the period March 7 through April 7, 2000.

Repair Construction

The contractor's first barge arrived at the Swan Lake Hydroelectric project port facility on March 7, 2000, initiating mobilization at the site. Access to the reservoir to assemble the Porta-float diving barge and perform the work was obstructed by ice on the reservoir. The ice in the work area immediately upstream of the dam was estimated to be 14 inches or more in thickness. Personnel access to the reservoir surface and diving barge from the small boat landing was obstructed by shore-fast ice. Personnel safe access to the reservoir work area was provided by using a separate crane mobilized for that purpose. The crane was certified for personnel hoist use and provided with a man-basket to move personnel from the right abutment staging area to a float located adjacent to the power tunnel intake.

Work barge on station above Conduit 4-165.

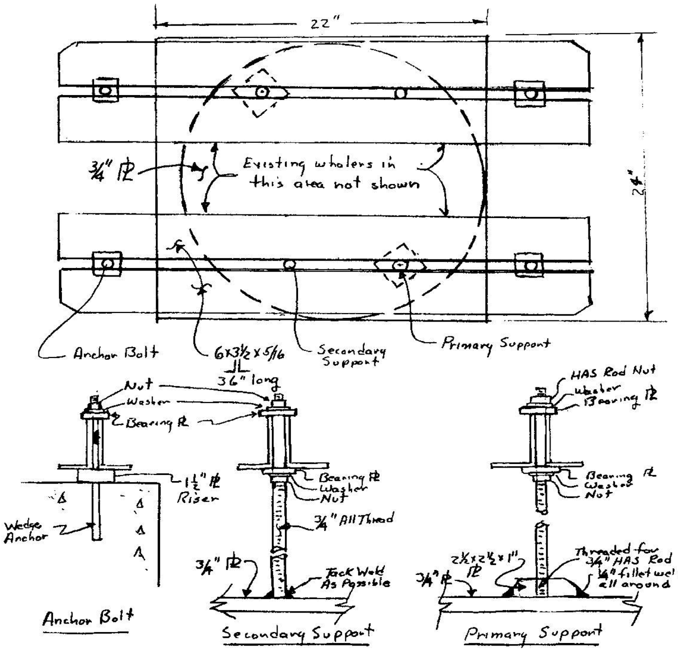
The ice on the reservoir was removed by a combination of impact breaking using a concrete weight hung from a crane, aeration with compressed air, and force applied using a log-boom tug. The bulk of the ice removal was carried out March 10 through 12, 2000. From March 12 to 15, the Porta-float work barge system was assembled on the reservoir, and the equipment for the diving operations was installed on the work barge.

The Swan Lake Reservoir level was lowered to facilitate diving operations. The reservoir level was maintained between El. 280 and El. 301 throughout the work, resulting in dive depths of 115 to 136 feet. The spillway crest, El. 330, provided 30 feet of storage for any storm events. Diving was limited to the period 0800 to 1600 each day. Power generation at night generally passed the day's accumulated inflow to the reservoir, maintaining the reservoir level in a safe working range for the repair operations.

On March 16, 2000, divers inspected the upstream face of the dam where Conduits 3-196, 4-165, 6-226, and 7-231 were sealed during construction. A ROV inspection of the inlet to Conduit 4-165 was conducted before the diver inspection to verify the diving conditions prior to a diver approaching the leakage area. Conduit 7-231 block-out was found to be backfilled with concrete, and the block-out was structurally intact. Conduit 6-226 could not be located within the lift between El. 224.0 and El. 231.5 in Block 6. However, based upon the excellent condition of the Conduit 6-226 downstream block-out patch, it is believed the quality of the upstream block-out patch was also good, so good that it prevented detection. Conduit 3-196, on the upstream side, was found to consist of a 4-foot-wide concrete placement against the dam for about 15 feet along the steeply sloping abutment contact, and two grout pipes were noted in the middle area of the concrete block that encapsulates the upstream end of the conduit. The concrete block was found to be structurally intact, with no cracks evident.

Diver entering water at Conduit 4-165.

The diver inspection of the upstream end of the leaking Conduit 4-165 confirmed that the block-out was 21 inches square and 14 to 16 inches deep, with no concrete backfill. The CMP conduit protruded some 6 inches from the back face of the block-out to within 9 inches from the dam face surface. A 4-inch hole in the upper left quadrant of the CMP provided the leakage inflow source. The divers noted some sort of cement-like infilling below the void in the crown of the CMP. The waler system holding the 3/4-inch circular steel end plate against the end of the 18-inch CMP conduit was found to be shimmed 3 inches out from the dam face, and the walers were measured to be 7-inch channels installed back-to-back. The ROV inspection in September 1999 did not reveal that the walers were set out from the dam face, and that the walers at that time had been estimated to be about 4-inch channels back-to-back.



Sketch of field modification to stabilize Conduit 4-165 inlet end plate.

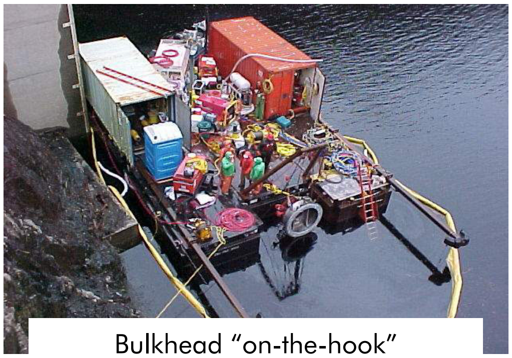
These conditions would not permit installation of the safety rebar cage installation template as fabricated since it would not fit over the walers that extended 10 inches out from the dam face. The safety rebar cage design was modified and re-fabricated on site using straight bars and was installed beneath the existing walers to provide protection to the divers and to maintain the integrity of the bulkhead installation template and centering lugs.

The internal structural support beams in the Leak Closure Bulkhead prevented installation over the existing walers. Because of this interference, it became necessary to remove the existing walers before installation of the Leak Closure Bulkhead. A new structural support system was developed to stabilize the 3/4-inch steel end plate on the CMP before removal of the existing walers. The objective of the design was to prevent shifting of the steel end plate that could present a safety hazard to the divers if leakage flow suddenly increased. A new structural support system was designed, fabricated on site, and installed by divers. Once the stabilizing waler system was in place, the existing 7-inch waler and end plate support pipe were cut away.

The Leak Closure Bulkhead was to be held in place during grouting by a combination of mechanical and adhesive anchors. Test trials of the adhesive anchor installation as recommended by the manufacturer did not provide satisfactory results; therefore, mechanical anchors were substituted. This required additional holes for mechanical anchors and enlargement of other holes in the seal plate. The concrete surfaces against which the bulkhead would seal was not completely flat and contained some minor surface rock pockets.

The protrusions on the surface were ground off and surface rock pockets were filled with “Splashguard.” The surface was checked for flatness using a test ring that comprised a salvaged TV satellite dish antenna base structural ring formed from aluminum channel. Tolerances were achieved, and installation of the Leak Closure Bulkhead over the Conduit 4-165 block-out proceeded as planned.

Flatness testing ring



Bulkhead "on-the-hook"

The Leak Closure Bulkhead was suspended from two hoist lines over an "A" frame at one end of the work barge. Using two separate winches, the bulkhead was lowered into position and mated to the previously installed locating pins on the face of the dam using the two separate winches to maneuver the bulkhead onto the locating pins. Threaded rod jackscrews were used to control the movement of the bulkhead to its mating position on the face of the dam. When the bulkhead was in final position, the butterfly flow control valve was closed, and the leakage through Conduit 4-165 was completely stopped.

In the plunge pool area, erosion and sedimentation control were effected by installation of two silt fences and settlement ponds in the channel downstream from the work area.

The Conduit 4-165 downstream end is located in a bedrock channel at the base of the dam. Access to the conduit outlet was through a very narrow channel leading to the plunge pool that was excavated originally by drilling and blasting. Initial de-watering of the bedrock basin plunge pool produced non-silt bearing water. The small amount of silt in water disposed from construction water control activity was easily managed by the silt fence/settlement basin system.

Conduit 4-165 Downstream Plug

Plunge pool dewatered

The dewatering of the plunge pool and construction of an access road was completed to provide access to excavate and expose the outlet of Conduit 4-165. A back-to-back wale system and 3/4-inch steel plate end cap were used to seal the CMP at the outlet at the time of construction. It was similar to the walers and pipe system used on the upstream end of the CMP.

4-165 downstream end revealed.

The block-out in the dam plug concrete was very shallow and had not been backfilled with concrete. The CMP actually protruded beyond the back of the block-out 6 to 8 inches and was flush with the dam foundation concrete face. The conduit had a ragged hole in the upper right quadrant and a void at the crown of the CMP. See the following photographs.

As described above, the original method used to close the Conduit 4-165 18-inch CMP was to place flat steel plates over the inlet and outlet ends of the CMP and secure the plates in position with short pieces of steel pipe welded to the plate and bearing against a double channel waler placed across the block-out opening. The pipe was welded to the end plate and double channel waler, and the double channel waler was secured to the concrete face with form bolts. It appeared from examination of both the upstream and downstream ends of Conduit 4-165 that the upstream plate was displaced during grouting operations, allowing grout to seep out. The ultimate effect of the upstream leak was that there was a loss of some grout volume from Conduit 4-165.

Original end cap and waler system.

The existing walers and steel end plate were removed, and the damaged conduit wall was removed down to the top of sound grout and replaced with a steel angle-braced steel angle bulkhead and new concrete cap and plug over the CMP with a grout pipe for infilling the void in the conduit.

Conduit 4-165 damaged downstream end.

Steel angle bulkhead.

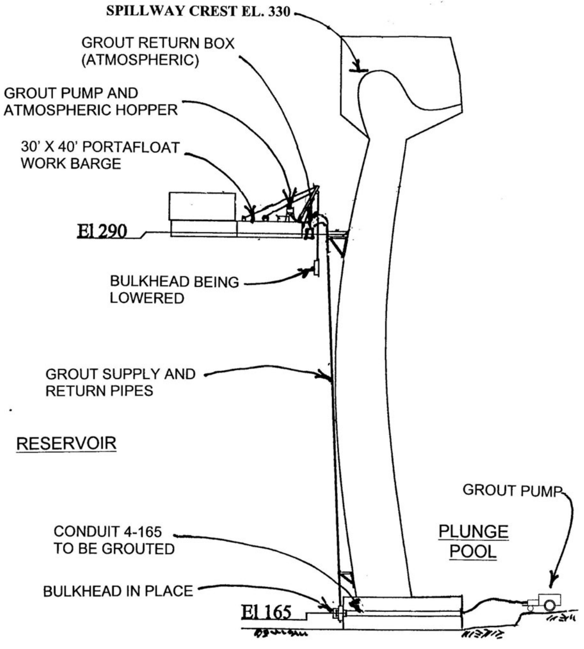
Steel angle bracing of bulkhead.

Concrete cap on Conduit 4-165 downstream end.

Grouting of Conduit 4-165 and Leak Closure Bulkhead

The contractor’s grout program utilized two grout pumps, one setup on the work barge and the other located in the dewatered plunge pool area. A contractor-installed pressure transducer was used to monitor grout pressures in the Leak Closure Bulkhead to avoid excessive pressure buildup.

The grouting of the void in the CMP proceeded from the downstream end until the grout reached the Leak Closure Bulkhead. An anti-dispersant agent, Kelco, was used with the Master Builders 928 grout mix. When grouting from the upstream side of the Leak Closure Bulkhead proceeded, it was not possible to place the grout without it dispersing, as observed from the upstream grout return line discharge. Therefore, the pressure grouting from the downstream side was resumed and was successful in infilling the Leak Closure Bulkhead with non-dispersed grout as the downstream end of Conduit 4-165 was further encapsulated in a concrete placement to provide additional protection from spillway discharges. The grout mix 7-day compressive strength was found to exceed 6,500 psi, and the 28-day compressive strength was found to exceed 7,100 psi.



SECTION THRU DAM SHOWING BULKHEAD INSTALLATION AND GROUTING SETUP

Inspection and Repair to the Downstream End of Conduit 3-196

The downstream end of Conduit 3-196 was exposed by careful removal of all weathered waste grout encapsulating the end of the CMP back to the concrete encasement. Close inspection and sounding with a wrecking bar on the top and sides of the exposed end of Conduit 3-196 showed the downstream end of the conduit to be intact, in excellent condition, and completely filled with grout. The steel end plate used for grouting was found to be held in place with wooden stakes and steel braces tied to the upstream concrete.

Conduit 3-196 exposed, downstream end.

Conduit 3-196 downstream end, new concrete encapsulation.

A new reinforced concrete encapsulation was constructed to protect the downstream end of Conduit 3-196 from weather and physical damage. The new concrete was tied into bedrock and the rock “nose” immediately downstream with grouted-in rebar dowels. The above photograph (right) shows the encapsulation with formwork still in place. This formwork was later removed.

Conclusions

The Swan Lake leak repair was successfully accomplished. The success was due to good coordination and a flexible approach to solving the problem. We have the following conclusions:

- *ROV Inspection*: The use of the ROV allowed the situation at, and around, the leaking conduit to be safely and economically investigated soon after the leak was discovered. It was surprising to find from the later diver inspection that the waler system at Conduit 4-165 projected out from the dam face 10 inches when the ROV video appeared to show a projection of only 4 inches. Use of a ROV capable of taking measurements would have been beneficial and would have helped configure the Leak Closure Bulkhead to better cater for actual conditions and minimize field modifications.

- ☐ *Mechanical Versus Adhesive Concrete Anchors*: Adhesive anchors were specified for the primary anchors to connect the bulkhead to the dam face. The switch to mechanical anchors was due to installation difficulties with the adhesive anchor system working underwater at the depth of the bulkhead and in-situ water temperature.

- ☐ *Hydrophilic Seals and Paste*: The seal system that consisted of two concentric circular seals with hydrophilic paste did an excellent job of sealing the bulkhead to the dam face. This was due in large part to the excellent preparation of the concrete surface on which the seal system bore. Removal of surface form joint sprues and other local high spots, filling low areas with wet patch material, then testing the flatness of the bearing plane with the aluminum angle hoop gage resulted in a surface with a flatness tolerance of about plus or minus 3/16 of an inch. When the bulkhead flow control valve was closed by the divers, the leakage flow through Conduit 4-165 stopped entirely.

- ☐ *Pressure Transducer*: The successful use of a pressure transducer installed in the bulkhead improved the ability to control grout pressures during the grouting operation.

- ☐ The variance from approved shop drawings of the actual Conduit 4-165 closure system used in the original grouting points up the need for careful and complete as-built records for closure and abandonment of any conduits penetrating a dam. Accurate record drawings did not exist for the Conduit 3-196 encapsulation on the upstream side. This lack of accurate information required field changes during the leak repair contract, which resulted in delays in the progress of the work and additional costs.

Acknowledgments

The authors wish to acknowledge the excellent cooperation and support of the Operations Staff of Ketchikan Public Utilities, Electric Division, Swan Lake, and AEA Management during the evaluation and repair of the leak. Also, the authors wish to acknowledge the excellent workmanship and cooperation of Industrial Fabrication Co., Inc., of Sultan, Washington, in producing the Leak Closure Bulkhead on an expedited basis. Lastly, the authors wish to acknowledge the excellent work and cooperative spirit demonstrated daily by Ty-Matt, Inc., of Ketchikan, Alaska, and their diving team from Sound Diving of Bellingham, Washington, in effecting the actual leak repair. The team effort of all parties involved resulted in a very successful project.

◆

For additional information, contact John Magee, P.E., R&M Consultants, Inc., at (907) 522-1707.

UNDERWATER INSPECTION OF WATERFRONT FACILITIES AND BRIDGES: TYPICAL CONSIDERATIONS AND WIDESPREAD ABUSES

by Michael J. Ganas, P.E.

The importance of inspecting the substructures of bridges spanning waterways and waterfront facilities during the development of maintenance programs or prior to preparing rehabilitation or repair designs is often overlooked by public officials and engineering consultants who are ultimately responsible for overseeing such activities.

By its very nature, the substructure of a marine facility is frequently hidden from view since most of the structural elements comprising it are submerged. Therefore, to assess the actual condition of structural members situated below the waterline generally requires the services of divers who possess a basic knowledge of the effects of deterioration on the safe load-bearing capacity of a marine-based structure. However, because submerged components remain visually covert, there is a widespread tendency to allocate relatively low budgets toward inspection of these items within the overall scheme of facility maintenance. Such a scenario lends credence to the age-old adage, “Out of sight, out of mind.” Unfortunately, giving underwater inspection less importance or a lower priority on the budgetary scale with respect to other tasks has often proved to be disastrous, both in terms of facility maintenance costs and, more importantly, safety.

Purpose of Underwater Inspection

In order to fully understand the role of underwater inspection and its relationship to the management of marine facility upkeep, one must consider the goals for which its use has a significant impact. Underwater inspection has four primary purposes:

- ☐ Ensuring public safety
- ☐ Protecting public assets
- ☐ Preventing or reducing facility downtime
- ☐ Initiating proactive maintenance

Many structures situated over water, particularly bridges spanning waterways and waterfront facilities such as marine terminals, piers, wharves, and relieving platforms, are heavily used by the public. While one can logically argue that ensuring the safety of the public of and by itself warrants the implementation of periodic and meaningful underwater inspection aimed at preventing catastrophic failure that could lead to casualties, the reality is that such justification is frequently neglected or diminished by key administrators, decisionmakers, and technical personnel involved with developing budgets for facility maintenance programs.

In fact, the costs associated with underwater inspection are commonly viewed by many facility owners as negligible in comparison to the total maintenance costs. At the heart of this problem is a substantial contingent of consulting engineering firms that provide services to marine facility owners, often establishing unrealistic and dangerous precedents based on misconceptions about the true nature of underwater inspection. Through association with the engineer, such misconceptions are frequently adopted by the owner. This usually results in past, but improper practices and performances by a predecessor becoming benchmarks for other consultants to follow at the urging of the owner, particularly during price negotiations when previous rates of production and costs are brought into sharp focus, thus proliferating a very risky and perpetual Catch-22, with no end in sight.

Types of Underwater Inspection

Underwater inspections are categorized into six types: Inventory, Routine, Damage, In-Depth, Interim, and Construction. Each is intended to accomplish distinct objectives.

- ☐ *Inventory Inspections*: Inventory inspections are normally performed following new construction, modifications, and repairs of bridge or waterfront facilities. Such inspections are intended to establish as-built or baseline structural conditions and to collect Structural Inventory and Appraisal (SI&A) data. Inventory inspections are often referred to as "**baseline inspections**" since they generally become the benchmark for assessing the results of all future inspections. Baseline and inventory inspections identify potential structural problems such as if the facility is scour critical. They are typically conducted on renovated or newly constructed facilities prior to owner acceptance and/or final payment to the contractor, frequently providing the actual plan, elevations, and section drawings of the structure as opposed to the original design configuration. This type of inspection establishes the time interval for the next inspection.

NBIS mandates that the interval for routine inspections of bridges spanning waterways should never exceed 5 years.

- ☐ *Routine Inspections*: Routine inspections determine the physical and functional condition of the facility, identifying changes from inventory, baseline, or previously recorded conditions. They are intended to assess the overall condition of the structure by assigning condition assessment ratings to the various facility components. They also ensure that the structure continues to satisfy its current service requirements and can include objectives aimed at quantitatively analyzing both local and global structural capacity as a result of damage or deterioration. Routine inspections should be performed on a regular, cyclical basis and are a proactive approach to maintenance since deteriorated elements will be detected and remedied before the deficiencies progress to a level that could jeopardize the structural integrity of the facility. Recommendations for future courses of action usually accompany a report of routine inspection findings, including followup maintenance or repair activities and the time interval to the next routine or other type of inspection.

The frequency interval between routine inspections varies from 1 to 6 years and is a function of material type, age of the structure, the service environment, the economic importance of the facility, the rate of further anticipated deterioration, and other factors. National Bridge Inspection Standards (NBIS), however, mandate that the interval for routine inspections of bridges spanning waterways should never exceed 5 years. Because of the covert nature of underwater inspection, reports containing diver observations and descriptions of findings on routine underwater inspections are generally accepted at face value. If a critical structural deficiency on a marine substructure goes undetected or is misinterpreted by the inspection diver or team leader supervising the inspection, structural failure may result a short time later.

- ☐ *Damage Inspections*: Sometimes referred to as **post-event inspections**, damage inspections are typically unscheduled inspections aimed at rapidly assessing the stability of a structure in the aftermath of a significant, potentially damage-causing event and determining whether further attention to the structure is warranted as a result of the event. Such events as floods, earthquakes of significant magnitude, vessel impact, high concentrations of corrosive chemicals in the water, tidal waves, major runoff caused by a severe storm, and scouring currents induced by the presence of ice floes or debris buildup may all dictate the need for a damage inspection, particularly if significant misalignment of structural members above the waterline is evident, usually an indication of severe section loss on submerged supporting elements or loss of foundation support. The scope of work or level of effort in this type of inspection can vary substantially and is generally determined by the type and severity of the event. However, damage inspections typically focus on the event-related damage only in an attempt to assess the need for immediate or longer-term repairs and often determine whether load restrictions or closure to traffic should be imposed on the structure. They also may determine the need for a more involved followup inspection effort supplemented by testing.

- ☐ *In-Depth Inspections*: Because in-depth inspections are most often performed to record defects requiring repairs, they are more frequently referred to as "**repair design inspections**." In-depth or repair design inspections are normally scheduled when there is prior evidence of structural distress, typically upon the recommendation made after a routine inspection. Although they have no standard scope of work, they are commonly performed when the salvageability of an existing substructure must be determined for supporting a new or modified superstructure and can include a load rating analysis to calculate the residual capacity of the structural members. However, they are predominately performed to keep existing marine-based structures in continuous service. This type of inspection generally involves an extensive close-up, Level II hands-on assessment of structural members identified in the routine inspection as requiring repair or those elements that are anticipated to be modified for supporting a new superstructure. It commonly includes a Level III inspection effort involving non-destructive and/or partially destructive testing of structural components whereby laboratory analysis of extracted material samples are performed.

Although inconclusive results from a routine inspection will frequently dictate the need for an in-depth or repair design inspection, an in-depth inspection may be called for without being preceded by a routine inspection, particularly when the need for repairs is obvious. This frequently occurs following a damage inspection, which recommends that an in-depth inspection be conducted using testing techniques. An in-depth inspection also may be combined with a routine inspection, but the distinction between the two is not always clearly defined.

If improperly performed, an in-depth inspection will invariably result in the preparation of poor quality construction plans and specifications since erroneous or incomplete inspection findings will become the basis of the construction documents. Faulty bid documents will ultimately open the door to unanticipated and costly contractor claims and change orders once the work has begun. Thus, the sins or failings of the underwater inspector will eventually reveal themselves to the owner, assuming that the repair work went out for bid within a relatively reasonable time-frame following the repair design inspection. If the firm that performed the diving inspection was hired on a low bid basis by the design engineer responsible for preparing the construction plans, then the owner's wrath will ultimately befall the engineer for failing to exercise a professional standard of care.

For example, a consulting engineering firm prepares repair documents for the rehabilitation of an active, low-level pier facility, showing that 200 out of 5,000 timber piles averaging 25 feet in exposed length must be posted with treated wood. The posts will average 5 feet in length and will replace the upper portions of those piles that have been damaged by Limnoria, a type of marine borer. The repair plans are based on an in-depth underwater inspection performed by a diving subcontractor that was selected by the engineer with the owner's approval on a low bid basis. The cost of the underwater investigation equates to 10 percent of the consulting engineer's overall fee to perform the work.

Timber pile exhibiting severe section loss caused by Limnoria attack.

Built in 1933, the pier was constructed during a time when pollution levels were high enough in the harbor where the pier is located to completely prevent marine borers from thriving. Thus, there was no need to treat the wood against biodeterioration caused by borers at the time of construction. However, as pollution levels dropped, obvious Limnoria attack began to manifest itself in the timber. This was documented in previous routine inspection reports, which showed some of the supporting piles taking on an hourglass configuration as their load-bearing capacities gradually diminished with advancing section loss. As Limnoria activity increased, pile diameters shrunk. In assessing if the facility can still function up to its required load-bearing capacity, the owner hired the engineer to perform a structural analysis on the pier and to determine the appropriate repairs necessary to restore the structural capacity of the damaged piles. To accomplish this, the engineer developed the scope of work for an in-depth underwater inspection that would provide the information required to perform the analysis and develop the repair designs. Although the scope did not include destructive core sampling of the timber to evaluate covert deterioration occurring within the piles, it did stipulate that penetration tests using an ice pick in conjunction with hammer strikes had to be performed on 20 percent of the timber piles at 5-foot intervals along their lengths to assess the soundness of the wood and would include those portions located at the mudline. The engineer also required that minor cleaning of marine growth had to be performed where necessary for the inspection diver to carryout the work. According to past inspection reports, the piles were heavily coated with barnacles and other marine organisms.

After initiating the repair work, the marine contractor discovers the existence of substantial but hidden Teredo infestation permeating the piles. As it turns out, both types of marine borers, Limnoria and Teredo, are actively destroying the untreated timber comprising the piles identified for posting, with the Teredo actually predominating and being more destructive. The contractor performs a statistical random sampling of the other piles and determines that the damage caused by Teredo is quite extensive and is widespread throughout most of the pile population, causing heavy deterioration in at least 3,000 piles, which are heavily riddled with Teredo tunnels along most of their exposed lengths. By striking the piles with a hammer near the mudline, the contractor was able to expose cavities in the timber with as much as 75 percent section loss. The contractor also notes that water velocity peaks at 2.5 feet per second during maximum tidal flow, making it extremely difficult to work during these periods. The contractor informs the owner that concrete encasement, rather than posting, is the appropriate method of repair and that posting will be a waste of money since it will not restore the hidden but severe section loss that will continue to progress in the piles below the planned postings. In fact, the facility is in imminent danger of collapse and should be closed until effective repairs are completed. This is confirmed when the owner hires another consultant to validate the contractor's claim. Ultimately, the owner blames the original design engineer for failing to note the severity of damage and sues for malpractice.

- ☐ *Interim Inspections*: Also called "**special inspections**," they are used to monitor known or suspected deficiencies that have the potential for compromising the structural integrity of a facility and are performed for the purpose of collecting more detailed information than normally obtained during a routine or repair design inspection. Although they have no standard scope of work, they are conducted for a predetermined purpose. Evidence of or the potential for such occurrences as differential settlement, migrating scour, marine borer attack, or corrosive environments may dictate the need for an interim or special inspection, although they are often scheduled at the discretion of the facility owner and may commonly require the inspection of only one substructure unit or structural element. Interim or special inspections are typically performed on an exceptional basis as a result of a recommendation made after a routine inspection and generally focus on obtaining information necessary to better understand the nature and extent of deterioration prior to determining the need for and type of repairs that will be appropriate.

  For example, measurement of electrical potentials at various points on a steel bulkhead are scheduled to be taken at 6-month intervals to determine the effectiveness of an existing cathodic protection system. In addition, this type of inspection can be used to estimate the remaining useful life of the structure based on deterioration rates of various material components determined from trends established from previous inspection reports. Core sampling of timber elements suspected of hidden biodeterioration as a result of Teredo or shipworm attack is an example of a destructive testing technique that may be used in performing a special inspection. Where appropriate, this type of inspection is sometimes performed concurrently with a routine inspection or an in-depth inspection, making it possible that all three types of inspection can be combined into one in certain cases.

- ☐ *Construction Inspections*: Construction inspections essentially fall into two categories: new construction inspections and repair construction inspections. Both types are intended as quality control measures to ensure that the work of a contractor is carried out in conformance with construction documents. In addition, such inspections serve to verify repair or installation quantities for contractor payment and to develop a list of deficiencies, or a punchlist, for which the contractor is to take corrective action. In general, repair construction inspections should be periodically conducted throughout the repair process rather than at the conclusion of the project to properly interpret and implement the design intent of the construction or bid documents. Not only do they act as a countermeasure against contractor claims, they help keep the project within the established budget and schedule, often resolving field problems and questions.

Underwater construction inspections act as countermeasures against contractor claims.

The scope and frequency of repair construction inspections is typically dictated by the type of repairs specified by the construction documents and also by the repair methods used by the contractor. On more complex projects where there is a sequence of underwater tasks to be performed, some of which would hinder or make impossible the inspection of preceding work items, continuous diving inspections on a daily basis may be warranted to stay on top of the contractor's work. Marine construction projects failing to have sufficient and competent underwater inspection, particularly when a substantial amount of repair work is submerged, will almost always result in at least one, if not all, of the following problems:

1. Poor workmanship by the contractor

2. Costly change orders emanating from unverified contractor claims

3. Hidden construction defects, which may not manifest themselves until years after the project's warranty period has expired, ultimately resulting in expensive repairs that sometimes exceed the original project cost

Unfortunately, there has been an emerging trend in recent years in which the construction documents place the burden of quality control in the hands of the contractor who must make the repairs. This entails subcontracting with an independent party to carryout the construction inspection, with the cost of the inspection services coming out of the contractor's bid price. This is analogous to entrusting the fox with the keys to the chicken coop.

Levels of Effort in Underwater Inspection and Diver Production Rates

Certain inspection types, such as routine and in-depth, focus on the investigation of a statistically representative sample of underwater elements comprising a waterfront or bridge substructure by using a particular effort level of inspection on a percentage of those elements that will adequately define the sample. Three levels of underwater inspection are recognized by both the American Society of Civil Engineers (ASCE) and the National Bridge Inspection Standards (NBIS) and are defined as follows:

Level I

Typically, a Level I inspection effort is conducted on 100 percent of all exposed and accessible components comprising a substructure situated below the waterline with the objective of identifying all severe damage.

This entails a visual or tactile inspection of the entire exposed exterior surface of all accessible submerged components without the removal of marine growth. Commonly known as a “swim-by” inspection effort, it has the dual objective of confirming the as-built condition of a structure and detecting obvious major damage and other glaring deficiencies that could compromise the integrity of the structure, such as discontinuity of structural elements and undermining or exposure of normally buried components. Typically, a Level I effort is conducted on 100 percent of all exposed and accessible components comprising a substructure situated below the waterline. Photographic documentation is often used to record typical and atypical findings. In addition, this level of effort will determine which elements, if any, are to receive a Level II or Level III inspection.

Production rates for inspecting various types of structural elements will vary widely under this level of effort. For instance, as a general rule of thumb, with fairly good underwater visibility (i.e., 8 feet or greater) and little or no current, an experienced diver can inspect anywhere from 200 to 300 timber piles per 8-hour day when piles average 25 feet in exposed length and are spaced within 6 feet of one another. This assumes approximately 5 hours of time spent in the water after taking into consideration other field tasks such as mobilization to the site, dive station setup and breakdown, bent row numbering/stationing, diver changeovers, and demobilization. This equates to an inspection rate of 40 to 60 piles per hour, with each diver averaging 60 to 90 seconds per pile.

Keep in mind that the diver must alternately descend down one pile to a depth of at least 7 feet to be able to observe the pile where it enters the mudline before traversing over to an adjacent pile and ascending. Concurrent with this, the diver must keep verbally communicating his location and observations to the team leader stationed topside. During this process, he will frequently answer questions and clarify observations, often halting his movements while findings and measurements are documented or the surface tender pulls up or slackens his umbilical air hose upon the diver's directives. Very often he will carry a camera for documenting discovered damage and must periodically take photographs. Significant time can be lost if his umbilical hose becomes snagged on an obstruction, in which case the diver must backtrack to unsnag it.

However, as conditions become more adverse in the way of reduced underwater visibility, stronger currents, deeper water, and lower water temperatures, this production rate will drop considerably. For instance, zero underwater visibility in combination with a water velocity of 2 feet per second will frequently result in 70 piles or less being inspected at Level I during 5 hours of water time, assuming an experienced diver is performing the inspection. In zero visibility, a diver must first descend and then ascend along the same pile before swimming to the next pile on which to perform a tactile inspection, otherwise disorientation will ensue. A water velocity of 2 feet per second is about the highest flow most physically fit divers can handle for any extended period before fatigue sets in. In harbors and tidally affected waterways, diver productivity will be greatest during slack flow periods, particularly at low tide when some of the damage may be seen above the waterline. Although the scheduling of inspection dives to coincide with slack tide occurrences are advantageous to a dive team, such events are typically of short duration before water velocity escalates.

A variation of this type of effort is a **surface swim-by inspection** that, as the name implies, keeps the inspector positioned at or within 3 feet of the water surface while examining structural elements. Unless the water depth is shallow and underwater visibility is good, a surface swim-by inspection will not allow the diver to observe all exposed exterior surfaces of submerged elements. Because of this, its use has limited value in locating all of the existing severe damage on most marine structures situated in deeper, murkier water. Although neither the ASCE nor the NBIS would recognize this mode of inspection as an acceptable level of effort if it fails to reveal all major damage that would have been obvious to a diver at depth, many divers will inappropriately substitute a surface swim-by in lieu of a Level I inspection even though the scope of work specified that a Level I effort be performed. While this occurs predominantly out of ignorance as to what a Level I swim-by actually entails, surface swim-by inspections are frequently misused by divers falling behind their inspection schedule and are applied as a means of catching up.

Unfortunately, surface swim-bys are also widely misused by firms low-balling a bid price to perform an inspection. However, unless authorized by the owner as part of the defined scope, a surface swim-by effort should never be employed when the water depth exceeds the underwater visibility. In general, a diver claiming a Level I inspection rate of 100 piles per hour is indicative of a surface swim-by.

A Level II inspection effort requires partial cleaning of marine growth or other fouling encrustations from portions of the substructure to reveal hidden deterioration. Here, a diver used a hand scraper to remove barnacles from a timber pile prior to measuring its circumference.

Level II

More detailed in nature than a Level I inspection, a Level II effort requires partial cleaning of marine growth or other surface fouling encrustations from portions of the substructure to reveal hidden deterioration. Because of the additional expense and time-consuming labor of removing bio-fouling growth or other encrusting substances such as heavy rust, a Level II inspection effort is limited to representative portions of the components on which the inspection is being performed. Often referred to as a **"hands-on" inspection**, it typically includes measurements not only intended to document the type of defect and its size or dimensions, but also its position on the structural element as well as the element's location with respect to the structure. Photographic or video documentation is commonly included in a Level II effort.

As an example, a Level II inspection on steel members may also involve the scraping away of oxidized metal or rust on 2 to 10 percent of their surface area to assess the remaining cross-section obscured by the rust. This information may then be used in determining the appropriate type of repair needed to correct the damage. This type of inspection effort also may involve the technique of tapping and sounding a component with a hammer to identify weakened sections of steel or concrete or hollow areas in members comprised of timber that have been eaten away by marine borers.

In addition, a Level II inspection on wooden elements may frequently employ a simple penetration test using an ice pick or awl to determine if the timber is undergoing soft rot. In particular, timber piles subjected to a Level II examination may often warrant systematic circumferential measurements at specific elevations along their length to ascertain overt section loss caused by abrasion or Limnoria attack. The documented residual pile diameters resulting from the inspection may then be used in a load-bearing analysis of the structure to compute residual capacity and perhaps to determine what structural modifications or retrofits will be required in a repair design aimed at restoring or increasing a pile's original load-bearing capacity.

A Level II effort is typically conducted on at least 10 percent of the submerged components of a structure, particularly during execution of a routine underwater inspection which normally consists of a 100 percent Level I and 10 percent Level II effort. By contrast, repair design inspections will frequently entail a 30 percent or higher Level II effort in combination with a 100 percent Level I, although the number of components requiring a Level II inspection has been known to include all submerged structural elements in some cases.

Production rates for inspecting different types of structural components will vary markedly when performing a Level II inspection effort and will depend on such factors as the structural materials comprising the underwater members, the environmental conditions encountered, the amount of biofouling growth or other encrusting substances that must be removed, the configuration of the substructure, the amount of existing deterioration, and the proficiency level of the diver. However, Level II inspections are generally much more time consuming than a Level I. With fairly good underwater visibility and little or no current, an experienced diver can inspect an average of 14 steel H-piles per hour at Level II while working in water depths of 25 feet. This production rate will lessen as conditions get worse.

Level III

A Level III inspection effort is highly detailed in nature, typically utilizing non-destructive testing (NDT) or partially destructive testing methods to detect covert or interior material section loss and damage. Such techniques are generally focused on suspected areas of representative or critical structural members. Often requiring extensive cleaning, detailed measurements, and the use of ultrasounding technology to evaluate material homogeneity or remaining section for corrosion profiling of steel members, a Level III effort is conducted on a statistically representative sample, normally 5 percent, of a specific population of structural components such as piles or pile caps. It may also involve physical material sampling in which timber or concrete corings are removed for laboratory analysis. Typically, Level III inspections are substantially slower in execution than a Level II effort.

A Level III inspection effort on a timber substructure will often include destructive core sampling of piles to evaluate the extent of marine borer infestation.

For example, a Level III effort conducted on steel H-piles under good conditions would equate to a production rate of roughly 5 piles per hour. This is because more extensive cleaning is performed in combination with the taking of more detailed measurements, noting zones of corrosion and thickness of flanges and webs at various elevations using ultrasonic thickness measuring devices and micrometers.

Minimum Technical Qualifications of Inspection Personnel

A properly conducted underwater inspection goes well beyond the documentation of observed defects, frequently necessitating that sound judgment be applied to decisions made throughout the inspection process. An understanding of load paths, structural redundancy, and the structural significance of observed damage are all important aspects of underwater investigations, particularly when assigning condition assessment ratings to the various components of a structure during a routine inspection. Inspection personnel must not only be proficient in commercial diving techniques to gain access to submerged structural elements, they must also possess a firsthand knowledge of a wide array of deterioration and their causes for the purpose of quantifying the damage and determining the most economical and cost-effective repairs.

The task of measuring and recording section loss along a member of and by itself can be meaningless unless it is determined where the loss has occurred relative to the point of maximum bending moment or shear. For example, conducting an interim or special inspection on a population of timber piles undergoing Limnoria attack may require documenting circumferences at periodic intervals along representative members to evaluate section loss against bending moments at various locations along the piles. Ultimately, the results of the special inspection may recommend that a followup in-depth or repair design inspection be performed. However, the special inspection findings will generally dictate the appropriate levels of followup inspection effort, including testing, to be undertaken based on the repairs that will be most cost effective. Obviously, piles that are to be jacketed to remediate Limnoria-induced biodeterioration will not require the same level of inspection effort as piles on which each defect will be repaired individually by such methods as posting, shimming, and concrete encasement.

A dive team leader communicating with the inspection diver during underwater inspection being documented on videotape.

While the *Underwater Investigations Standard Practice Manual* published by the ASCE recommends that an underwater inspection team shall be led by and be under the direct on-site supervision of a registered professional civil or structural engineer who acts as team leader, the ASCE also stipulates that the team leader should be a trained diver who physically performs at least 25 percent of the diving inspection work. The ASCE further recommends that the team leader should have a minimum of 5 years experience conducting subaqueous structural investigations in combination with a minimum of 5 years engineering experience specifically related to the type of facility being inspected.

Although such recommended requirements typically apply to baseline (inventory), routine, damage (post-event), special (interim), and repair design (in-depth) inspections, the ASCE has less stringent team leader requirements relating to construction inspections, whether they be focused on new construction or repair construction. In such cases, a graduate of a 4-year civil or structural engineering curriculum will suffice as team leader in lieu of a licensed professional engineer as long as the individual has a minimum of 2 years of construction inspection experience. However, the ASCE also concedes that for construction inspections, an individual with a minimum of 10 years construction inspection experience and possessing certification from a nationally recognized building authority such as the National Institute for Certification in Engineering Technologies (NICET Level IV) or the U.S. Department of Transportation's 80-hour course in "Safety Inspection of in-Service Bridges" can also qualify as a team leader.

ASCE guidelines further suggest that other dive team members should either hold a 4-year engineering degree or have completed a course of study in structural inspections such as "Safety Inspection of In-Service Bridges."

Diver Training and Safety

Of equal importance alongside technical qualifications, an underwater inspector should be experienced and proficient as a diver to perform structural inspections under hostile environmental conditions. Commonly encountered factors in the form of swift currents, swirling vortices, poor underwater visibility, cold water, confined spaces, and submerged hazards can often distort an inspection diver's perceptions about the actual condition of a submerged structure, frequently disorienting the diver as well as subjecting him to substantial physical and psychological duress. Even a recreational sport scuba diver with hundreds of

Inspection divers must be sufficiently trained and experienced to perform meaningful inspections in harsh environments.

hours logged underwater may not be fully prepared to adjust to such adverse conditions. As a general rule, sport divers typically restrict their diving to open water settings where warm, clear water and slower currents often predominate. Whereas recreational scuba enthusiasts dive for enjoyment and will usually have the option of selecting a comfortable environment, inspection divers are task oriented and very often must deal with a harsh environment to complete the job. This necessitates that they receive training in commercial diving techniques to learn how to function effectively under more difficult conditions.

OSHA makes a valid distinction between commercial diving and recreational scuba diving. The training and certification a recreational diver obtains is relatively miniscule in comparison to the hundreds of training hours a commercial diver receives. Recreational dive training organizations, such as NAUI, PADI, and YMCA openly acknowledge that diving certification under their auspices is inadequate training for underwater commercial work which, by its very nature, normally utilizes hard hat gear supported by surface-supplied air in combination with diver-to-surface audio communications and frequently employs the use of underwater tools.

The use of scuba equipment in underwater commercial operations has minimal value, particularly when applied to Level II and Level III inspection efforts since its limited air supply and lack of communications render it both impractical and inefficient for subqueous structural inspections. By contrast, diving investigations using surface-supplied air produce far better results. For one, diver measurements and observations can be readily documented by topside personnel, thus providing accurate information on which to base complex rehabilitation schemes and repair designs. In addition, the umbilical air hose used in conjunction with such an investigation not only tethers the diver to a supporting cast on the surface, but also provides him with an unlimited supply of breathable air, making diving much safer and allowing extended underwater operations, both of which contribute immeasurably to the effectiveness and overall quality of the inspection.

Currently, the minimum manning requirement for a commercial diving operation as mandated by both OSHA and Coast Guard regulations is three persons—the team leader, diver, and tender. However, a standby safety diver must be added to the dive team as a fourth member when diving in excess of 100 feet of seawater (fsw), when in-water decompression is necessary, or when underwater hazards exist. Furthermore, an additional diver must be stationed at the underwater point of entry for the purpose of tending the primary diver's umbilical hose whenever diving is conducted in enclosed or physically confining spaces. According to the commercial diving standards put forth by the governing agencies, each in-water diver must be continuously tended from the surface by a separate dive team member. Based on these guidelines, an underwater inspection carried out in a confined space environment would warrant a dive team comprised of six persons—the team leader, primary inspection diver, in-water diver/tender, standby safety diver, and two surface tenders. Such an operation would require three separate umbilical air hose rigs in combination with diver communications, each with a compressed air supply consisting of both primary and backup sources, and if the dive surpassed a depth of 100 fsw or exceeded the no-decompression limits, a recompression chamber should be readily available at the site.

Unfortunately, recreational divers continue to be hired for underwater inspection work in which they are insufficiently trained, experienced, and equipped to undertake. In point of fact, the utilization of recreational divers to perform underwater structural inspections that are clearly commercial in nature is extremely widespread among many public agencies and engineering consulting firms alike. Quite often, this is attributable to an ignorance of the risks involved in this type of work. Such ignorance commonly manifests itself in criteria found in issued RFPs, bid requests, and contracts that nebulously stipulate that the inspector need only be certified as a diver, thus allowing an individual with only basic YMCA sport diver training to qualify for the work.

Based on OSHA and Coast Guard guidelines, an underwater inspection carried out in a confined space environment would warrant a dive team comprised of six persons.

Sometimes this can lead to a tragedy like the one which occurred in March 1997 when two recreationally trained scuba divers hired by a State agency in Washington entered an underground, 104-foot-deep water-filled tunnel with only a limited air supply in the form of scuba tanks strapped to their bodies, no surface tethering, no means of communication, and lacking a stand-by safety diver immediately on hand. After the divers failed to emerge from the murky, 40-degree Fahrenheit water, the agency called in two additional scuba divers, also with limited training and inadequate equipment, to effect a rescue. The end result was that all four divers perished after running out of air. Several times a year, unqualified and poorly trained divers lose their lives in very similar accidents.

In view of this type of catastrophe, it follows that public agencies and engineering consulting firms should take heed of the potentially dangerous liability of hiring recreational divers to undertake commercial diving work since, in the event of an accident, it can be viewed as negligence that significantly contributed to the dire consequence. Even citing recreational diving certification as a prerequisite to qualify for the work can lead to possible OSHA violations since OSHA regulations stipulate that an employer's obligation exists for compliance with all provisions of the commercial diving standards.

The Washington disaster was carried out in a manner that defied commercial diving safety standards on three major counts: insufficient training, undermanning, and inadequate equipment. An undertaking of this scale would have required a minimum of six properly trained and experienced individuals on the dive crew, equipped with surface-supplied diver support gear with primary air and at least two separate sources of backup air, diver-to-surface communications, and a recompression chamber. And while such an operation would have been many times more expensive than the one that ended in tragedy, the lower cost of using recreational divers supported by marginal equipment will ultimately prove to be insignificant when weighed against the staggering liability costs that will surely result once the smoke clears from this debacle.

Sacrificing Safety and Quality in Favor of Reduced Underwater Inspection Costs

Even with an awareness of OSHA guidelines, there are some public agencies and engineering firms that will frequently sacrifice safety in favor of the potential cost savings associated with using recreational divers. As a general rule, correctly performed underwater inspections are expensive and require considerable effort to execute. Associated costs will vary and are sensitive to many factors, including the size and type of submerged structure, the inspection level of effort performed, water depth, water velocity, polluted water, water temperature, the extent of underwater visibility, the existence of confined or enclosed spaces, the amount of obscuring marine growth or other encrustations requiring removal, and the presence and amount of obstructing debris. Special equipment requirements such as workboats, underwater cameras and video systems, waterblasters for removing marine growth, ultrasonic instruments for gauging section loss or remaining thickness of steel members, hydraulically powered coring tools for obtaining timber and concrete samples, and recompression chambers will further contribute to the cost.

The desire to curtail costs at the expense of quality and safety can be a strong motivational force among organizations that are routinely strapped with limited budgets. Most owners of marine facilities will rely almost exclusively on engineering consulting firms either to develop a maintenance program for its facility or to work on some phase of their maintenance program involving underwater inspection, often contracting with the consultant offering the lowest price from among a short-listed field of the most technically qualified firms submitting proposals to perform the owner’s stipulated scope of work. It is not uncommon for the owner to ask the consultant to sharpen its pencil further before an agreement is reached that favors the owner’s budget. If one cannot be reached, the owner will occasionally go to the next firm in the short-list ranking until a reduction in price is achieved without a corresponding modification of the workscope. Sometimes, the owner will select a firm based strictly on technical merit, then enter into negotiations with the chosen firm until a not-to-exceed price or upset limit is agreed upon for the consultant to provide the required services. The riskiest contracting approach, however, occurs when the owner puts the work out for bid without giving any consideration whatsoever to a firm's qualifications. This tactic has occasionally proved to be disastrous, sometimes putting public safety at risk.

Quite often, the owner will have a preconceived but unrealistic expectation of what the engineering services should cost and will use this as a basis for negotiating the price downward to levels that will compromise the quality of the work. When this happens, the risk of reduced safety escalates, not only in terms of the personnel performing the diving inspection, but also in terms of diminished safety to the public since poor quality can easily translate into the potential for impending structural failure conditions to be overlooked. Such unrealistic expectations are typically predicated on previous work performed by past consultants who, eager to get the work, did not adhere to underwater inspection protocol established by the ASCE and OSHA and who either intentionally or mistakenly underestimated the minimum amount of time needed to properly conduct the inspection. In fact, breaches in quality and safety are most often proliferated by consulting engineering firms, making underwater inspection one of the most abused areas within the civil engineering industry. Because of its covert nature, poorly conducted inspection activities taking place below the waterline can routinely go unchallenged, the consequences of which can be extremely costly to an owner over the long term. A diver failing to note relatively minor deterioration that can be remediated at minimal expense in its early stages may ultimately cost the owner millions of dollars in major repairs down the road if left unchecked.

Once the work is awarded, the consultant will normally invoice the owner on either a lump sum or a time and materials basis, depending on the contract stipulations. If the hired engineering firm lacks in-house diving capability, the consultant, in an effort to achieve maximum profitability, will frequently subcontract with the least expensive diving entity to collect information about the condition of the submerged structure(s) requiring inspection. However, there is a widespread propensity among many engineering firms demonstrating an expertise in marine engineering to perceive themselves as having qualified divers on staff simply because some of their engineers happen to possess basic scuba certification. These same firms also have a tendency to believe that basic scuba gear is all that is needed to accomplish an underwater inspection.

Generally speaking, most scuba certified divers are too inexperienced to adequately cope with adverse underwater environmental conditions to perform a meaningful inspection, often spending the majority of their diving time adapting to difficult situations and frequently becoming physically exhausted, hypothermic, or disoriented. The existence of strong currents, poor underwater visibility, and cold water will invariably hamper the quality of an untrained, inexperienced diver's inspection, substantially hindering productivity and causing such work to take longer to complete than originally anticipated. In an attempt to save face with their employers, these same divers may be forced to shortcut an inspection to satisfy allotted timeframes and budgeted man-hours, factors which ultimately determined the firm's final negotiated price or bid. If these same divers carryout the work using scuba gear, the accuracy of the inspection findings may be seriously flawed and incomplete since the documentation of various types and sizes of defects on a relatively large, but deteriorated substructure would be made all the more difficult, to say the least, assuming none of the personnel examining the structural elements were endowed with a photographic memory. Keep in mind that unless SCUBA bottles are used in conjunction with a band mask or diving helmet that incorporates diver-to-surface communication, the diver must keep coming to the surface to report observations and measurements to topside personnel. In addition, a major shortcoming of SCUBA is the limited time it permits the diver to say submerged. On a fairly large substructure, there is always the temptation to rush the inspection to avoid having to change air tanks.

Various types and combinations of diving conditions encountered can directly affect the amount of time required to inspect a substructure in a manner that conforms to ASCE and NBIS guidelines. Swift currents and vortices will dramatically increase inspection time. One must remember that most bridges span the narrowest gap in a channel where water velocity is usually at a maximum and will quickly sap a diver's strength. Cold water can also slow the inspection and will constrain a diver's water time before the effects of hypothermia create mental confusion and drain the diver's energy. Deep water will limit bottom times because of dissolved nitrogen buildup in the tissues. Note that a diver working as deep as 60 feet is limited to 60 minutes in the water without having to undergo decompression. This time restriction becomes more severe with increasing water depth. Additionally, poor underwater visibility can easily cause a diver to become disoriented.

Construction debris in the form of cables, H-piles, pipes, and other items that commonly exist around bridge footings and the base of other types of marine structures are all potential diver hazards. Submerged driftwood and tree limbs can also hamper a diver, catching and entangling an umbilical hose. Ice floes pushed along by tidal and river currents during cold weather can also menace inspection divers.

Overall, the more adverse the conditions, the less time a diver can realistically spend performing an inspection before he becomes ineffectual or endangers himself. For this reason, more frequent diver changeover is needed to continue the inspection. Because of this, one or more additional divers may be required to conduct the inspection in a safe, efficient, and reliable manner. A diver that is easily fatigued or has trouble equalizing the ambient pressure on his eardrums while submerged on an inspection assignment will often become a liability to the success of the project, no matter how skilled he is at recognizing deterioration that can lead to

Frequent diver changeovers are important when adverse conditions exist to avoid burnout and to ensure the quality of the inspection.

structural compromise. To avoid excruciating ear pain or risking personal safety, such an individual may defer going more than a few feet below the waterline altogether, only performing a surface swim-by inspection, at most.

To go a step further, if adverse diving conditions exist but were either unanticipated or disregarded during the bid proposal or price negotiation process, the diving contractor may very likely have insufficient manpower and equipment to execute a competent or meaningful inspection, thus burning out his diver or divers all too quickly. As a rule of safety, and to ensure the quality and completeness of the inspection requirements, all members of the dive team should be qualified inspection divers whenever adverse conditions are present so that frequent diver changeovers are possible.

Cutting Costs Can Cost Lives

Because of these problems, bridges and other water-based structures located in environments where severe conditions preside are often the most likely candidates for a structural collapse due to undetected compromise when award of the underwater inspection work is acquired through unrealistically low bid prices or cost negotiations which overwhelmingly favor the owner. Consulting engineers and owners must come to realize that unrealistic pricing tends to cultivate four primary conditions that can lead to poor underwater inspection and ultimately be very costly to an owner over the long run. These are summarized as follows:

1. The inspection diver is technically unqualified to recognize structural deterioration and deficiencies and their relationship to the integrity of the marine facility

2. The diver is too inexperienced with adverse underwater conditions to give the inspection his full attention and complete all scope requirements

3. The dive team is improperly and/or insufficiently manned and equipped to effectively execute the inspection

4. The diver spends insufficient time inspecting the substructure

While many consulting engineers and owners are cognizant of such problems and have taken steps to avoid them, there remains a substantial contingent that will have to learn about them the hard way – in the pocketbook! Unfortunately, those are the ones that continue to put the public at risk.

◆

Michael J. Ganas, P.E., is the Director and General Manager of Boswell Underwater Engineering, the marine division of Boswell Engineering, located in South Hackensack, New Jersey. He has managed commercial hard hat diving operations aimed at assessing the structural integrity and repair of marine facilities for more than 24 years. Boswell Engineering may be contacted by phone at (201) 373-8914.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

Jerry Fischer, Technical Service Center, ATTN: D-8470, PO Box 25007,
Denver, Colorado 80225-0007; (303) 445-2748, FAX (303) 445-6381;
email: jfischer@do.usbr.gov

Vicki Hoffman, Pacific Northwest Region, ATTN: PN-3234, 1150 North Curtis
Road, Boise, Idaho 83706-1234; (208) 378-5335, FAX (208) 378-5305

Steve Herbst, Mid-Pacific Region, ATTN: MP-430, 2800 Cottage Way,
Sacramento, California 95825-1898; (916) 978-5228, FAX (916) 978-5290

Albert Graves, Lower Colorado Region, ATTN: BCOO-4846, PO Box 61470,
Boulder City, Nevada 89006-1470; (702) 293-8163, FAX (702) 293-8042

Don Wintch, Upper Colorado Region, ATTN: UC-258, PO Box 11568, Salt
Lake City, Utah 84147-0568; (801) 524-3307, FAX (801) 524-5499

Dave Nelson, Great Plains Region, ATTN: GP-2400, PO Box 36900, Billings,
Montana 59107-6900; (406) 247-7630, FAX (406) 247-7898