UNDERWATER PHOTOGRAPHY FOR BRIDGE INSPECTIONS

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A photographic technique was developed that will enable divers in the Virginia Department of Highways and Transportation to obtain clear photographs under typical conditions encountered in inspecting bridge components underwater. The equipment selected for the technique is inexpensive, readily available, and uncomplicated. The procedures were kept simple so that the training required would not involve extensive amounts of time.

Once this type of data collection is established, the requirements for obtaining clear photographs in underwater inspections can be written into the performance specifications of contracts.

RECOMMENDATIONS

1. The photographic technique and sampling procedures resulting from this study produced photographs which could be used to evaluate and document the condition of underwater structures. The equipment required is inexpensive and the technique does not require extensive training.

   It is recommended that Department divers be trained in the use of the photographic technique and sampling procedures resulting from this study.

2. It is recommended that the procedures described in this report be adopted as part of the routine inspection procedure for evaluation and documentation.

3. It is recommended that the specification for documenting inspections with photographs be written into contracts for underwater bridge inspections.

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INTRODUCTION

In accordance with the guidelines established by the American Association of State Highway and Transportation Officials, the Virginia Department of Highways and Transportation conducts routine inspections of its bridges. The Department's Policy Memorandum, DPM 3-2 states:

> §1.00 BRIDGE INSPECTION - Each bridge on the State Highway & Transportation System will be inspected at least once every two years and corrective measures to be taken will be noted.

While the procedures for inspecting the superstructures are well known and the expertise to perform them is available within the Department, the inspection of bridge substructures below water presents problems because of turbidity, current, obstructions, extreme cold, etc.

Presently the Department uses commercial divers to inspect the large movable spans and Department personnel for the smaller bridges. The type of data required to be obtained by the commercial divers in their inspections is left to the discretion of the firm awarded the contract. The data compiled by the Department divers are limited to line profiles, sketches resulting from tactile investigation, and soundings, all of which may be deficient in some respect. The data developed from line profiles are evaluated by comparison with data on the design and construction of the structure, which are not always available, and because of adverse ambient conditions, sensory data are not always reliable.

For accuracy in underwater inspections, the diver must have some means of bringing a representation of the structure back to others for interpretation. Since a diver's visual, auditory, tactile, and spatial perceptions are different underwater than in air, he is susceptible to making errors in recording data.(1)

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(1) Schilling, Charles W., M.D., National Plan for the Safety and Health of Divers in Their Quest for Subsea Energy, pp. 6-1 through 6-12.

Aside from the sensory and perceptual processes, the diver's ability to recall information and to make decisions is also affected. The literature on this topic is sparse, but it is generally agreed that cold temperatures decrease the diver's ability to concentrate and the stress of diving and performing tasks underwater results in task fixation. Consequently, information about the overall underwater situation is seldom observed or retained.(2)

There is a need for a data-gathering technique to supplement those now used for underwater inspections of bridges. This technique should be capable of accurately representing conditions, be inexpensive, and be capable of operation by divers without extensive training. Several techniques are available. Among the least expensive in terms of equipment cost and training is photography.

Underwater photography is not a new development, but obtaining clear photographs in turbid water has been a long-standing problem. The Naval Facilities Engineering Command in Washington, D. C., has developed and tested a device which, when attached to a standard underwater camera, will produce the types of photographs needed to document the inspection of underwater structures.

PURPOSE AND SCOPE

The objective of this study was to develop a technique for obtaining clear, underwater photographs under typical inspection conditions, and to transfer the required equipment and know-how to the Department for use by its underwater inspection team.

It was intended that the equipment used or modified and the skills and training required to operate this equipment would be practical and relatively inexpensive.

METHODOLOGY

The methodology for the project consisted of four steps: acquiring design specifications, fabricating the equipment, testing, and technology transfer.

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(2)Ibid.

Design Specifications

Design specifications were obtained from the Office of the Commanding Officer, Naval Facilities Engineering Command. Information concerning the use and maneuverability of the unit under various underwater conditions was also discussed.

Fabrication

The camera attachment was to be fabricated according to the design specifications within the facilities of the Virginia Department of Highways and Transportation or the Research Council.

Testing

Since the unit (camera and attachment) was to give high quality photographs under typical inspection conditions, it was tested to ensure that it was watertight, could function under diminished lighting, would not fog in cold water, and could be operated by divers without jeopardizing their safety. The testing was conducted under three conditions: highly controlled (a pool), the best conditions available in open water (a quarry), and the most typical conditions under which bridge inspections are conducted (rivers, lakes, and streams with limited visibility). The photographs obtained were examined to assure that they were of value to the Department.

Technology Transfer

Assuming acceptance of the technique for use by the Bridge Division, the researcher will hold several training sessions with the Department's underwater inspection team. This training will include techniques for positioning the camera under adverse conditions, maneuvering in current, and diving techniques such as buoyancy control, communications, and emergency procedures. Since the team members already have advanced diving experience, the training needed should require no more than three sessions lasting no more than a total of 24 hours.

EVALUATION

The information developed in the study is presented here in accordance with the steps described in the methodology.

Design Specifications

A visit was made to the Naval Facilities Engineering Command in Washington, D. C., to obtain information on the design specifications for the water box, the type of camera and components used, and the general operation of the photographic unit (see Figures 1 and 2, page 6).

No attempt was made to duplicate the Naval Facilities' unit, but to do as little fabrication and modification as possible. Also, it was decided to utilize a camera that would be available within the typical state transportation agency rather than the Nikonos (an underwater camera produced by Nikon) used in the Naval Facilities' unit.

Based on the previously cited information, five criteria were established for the selection of the camera, lens, and light source:

1. the camera unit must perform underwater,
2. the camera with all other components must be maneuverable under typical inspection conditions,
3. the operation of the camera system must be uncomplicated,
4. the camera system must produce photographs in near zero visibility, and
5. the photographs must represent an area large enough to allow evaluation of a structure.

Camera, Lens, and Light Source

The Minolta SRT 201, 35-mm camera encased in an Ikelite underwater housing was selected for this study because of its extensive availability throughout the Virginia Department of Highways and Transportation and the researcher's familiarity with it. Selected to be tested in conjunction with the housed camera were 28-mm, 50-mm, and number 1 and 3 close-up lenses. Because it was expected that the 28-mm lens would give distortion, both a dome and flat port were selected to be evaluated (see Figure 3).

Because most photography performed for underwater inspections will require artificial light, a Sunstrobe M, an underwater strobe designed by Ikelite to work in conjunction with their underwater housing, was included in the camera system. A small strobe was desired because the area to be photographed was small and framed by opaque plastic (see Figure 4).

Water Box

The water box is used to provide clear water between the camera lens and the object to be photographed. The box should be compact enough that it can be handled under typical water conditions and should be compatible with the camera used in the system. Some apparatus is needed to enable easy filling with clear water and easy emptying. The box should be watertight and have clear plastic or tempered glass lenses.

Fabrication

The only unit requiring fabrication was the water box. Rather than duplicate the one constructed by the Naval Facilities Engineering Command, an attempt was made to locate some apparatus that was readily available and that could be used with little or no modification.

The Batiscopia distributed by the CRESSI-SUB Corporation appeared to be suitable. The apparatus is compact, cone-shaped, and has a handle that encircles it. It is made of a sturdy plastic that withstands current and pressure at depth. The opaque plastic enabled the simulation of dark water, even in a swimming pool because the box could be positioned next to the object and only the amount of light desired could be allowed (see Figure 5).

With minor modification, the Batiscopia was converted into the water box desired. The length of the box was reduced,* plastic lenses were cut and sealed to each end, an opening covered with clear plastic was fabricated to accommodate a light source, and a capped spout was inserted to enable easy filling of the box with clear water (see Figure 6).

All components were assembled to form the camera system shown in Figure 7.

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*The optimum length was determined from data developed from tests with various camera lenses explained under section entitled Testing.

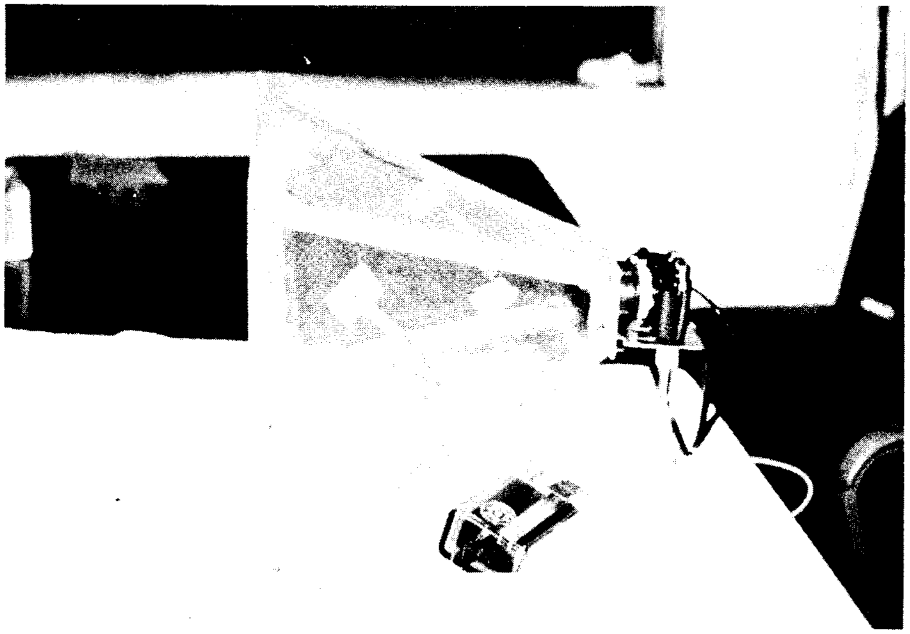

Figure 1. Nikonos camera with large water box developed by the Naval Facilities Engineering Command.

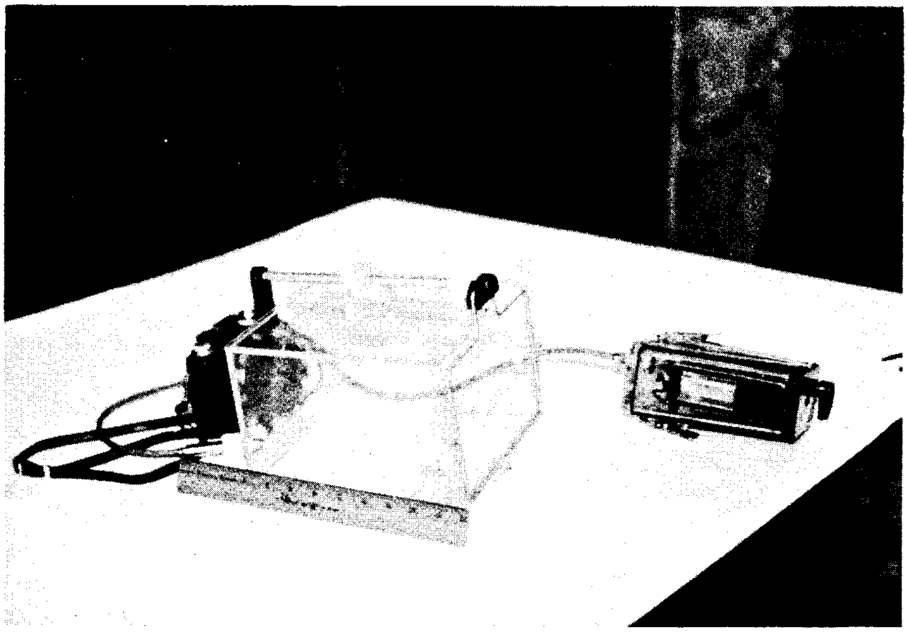

Figure 2. Nikonos camera with small version of the water box.

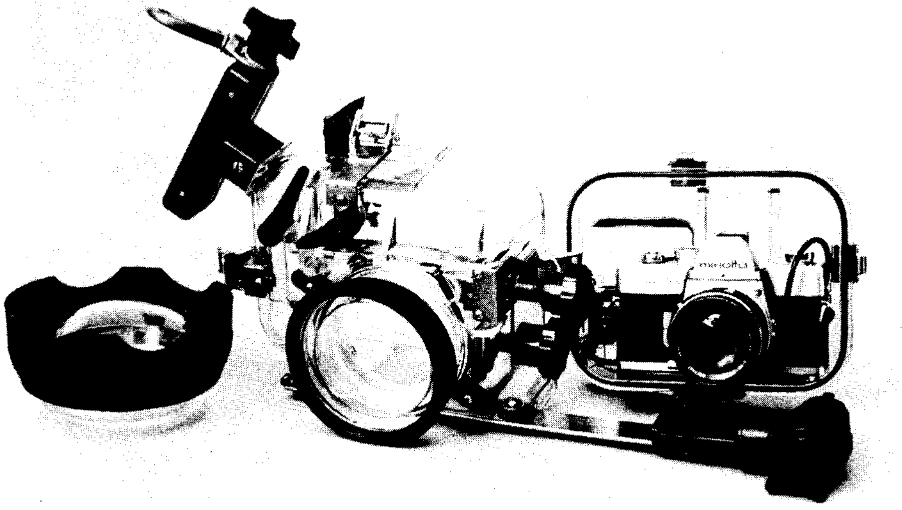

Figure 3. Minolta SRT 201 camera and Ikelite underwater housing with flat and dome ports.

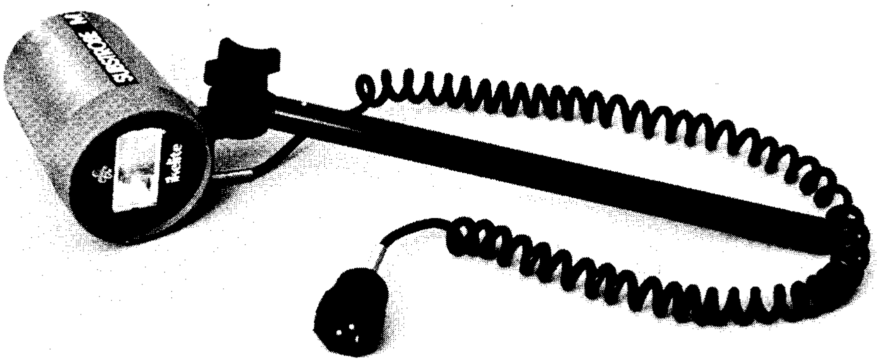

Figure 4. Ikelite substrobem.

Figure 5. Batiscopia before modification.

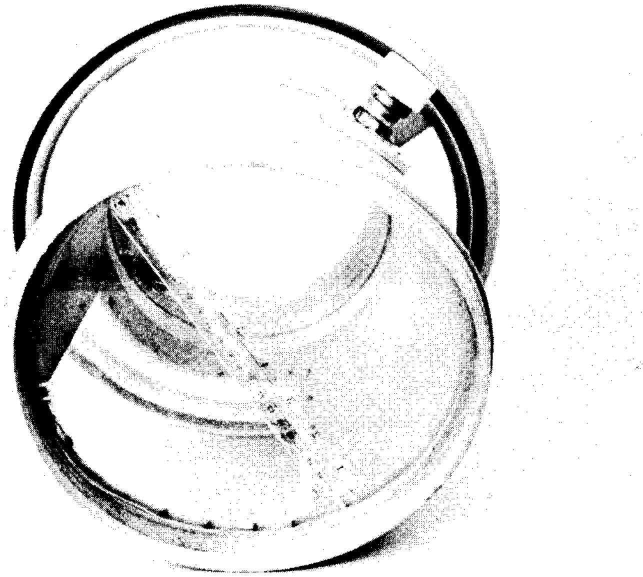

Figure 6. Clear water box resulting from modification of the Batiscopia.

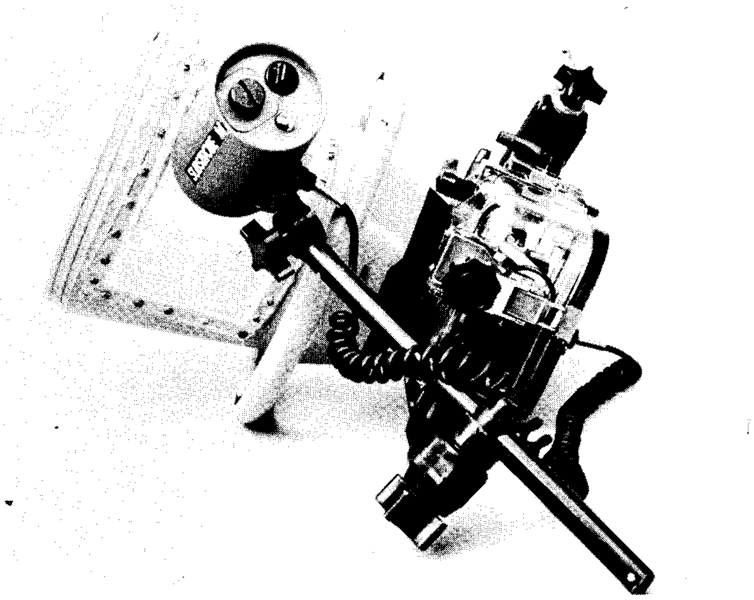

Figure 7. Camera system consisting of Minolta camera, underwater housing, strobe, and water box.

Testing

The camera system developed was tested under the three conditions described in the methodology; i.e., pool, quarry, and typical inspection conditions. The results are described in the following paragraphs.

Pool Test

The facilities at the University of Virginia were used for the initial test of the system. The ease of operation was observed under these ideal conditions. Photographs taken during this test were used for comparison with those obtained under later conditions. The system was observed to ensure that it was watertight as it is important that murky water does not seep into the clear water medium.

The underwater housing was tested without the camera to ensure that it was watertight and to enable the diver to become familiar with the housing mechanisms. When assembled, the unit was watertight, maneuverable, and easy to operate.

Tests were conducted with several combinations of lenses and housing ports (see Table 1) to obtain the best photographic resolution and area coverage at the shortest possible distance from the object being photographed. A 28-mm and 1 and 3 close-up lens gave the best resolution and area coverage at a distance of about 15 inches (38 cm). Both the dome port and the flat port gave good results; however, the picture obtained using the dome port showed the water box as a frame around the object photographed. Including the water box in the photograph is desirable when measurements around the perimeter of the object are desired (see Figures 8 and 9).

Although dome ports are recommended for use with lenses 28-mm and wider to compensate for water distortion, no significant distortion was observed when using the flat port. This lack of distortion is probably due to the closeness of the camera lens to the object.

Because the distance from the lens to the object is constant and a strobe is used,the settings on the camera can be preset. Thus, the only operation the diver needs to perform once in the water is to advance the film and trigger the shutter.

Table 1

Results of Evaluation of Lens and Minolta 35-mm SRT 201 Camera Underwater Housing Ports

Camera Lens	U/W Housing Port	Adequate Representation for Sampling		Image Distortion		Clear Focus	
		Yes	No	Yes	No	Yes	No
50-mm	Flat		x		x		x
50-mm	Dome		x		x		x
28-mm	Flat		x	x		x	
28-mm	Dome	x			x		x
50-mm + close-up	Flat		x		x	x	
50-mm + close-up	Dome		x		x	x	
28-mm + close-up	Flat	x			x	x	
28-mm + close-up	Dome	x			x	x	

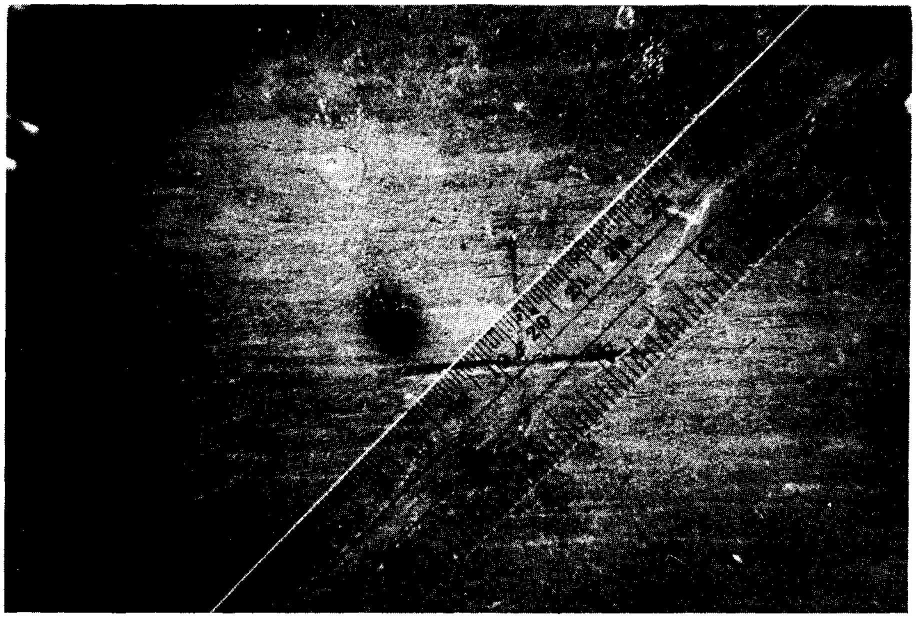

Figure 8. Photograph resulting from use of flat port.

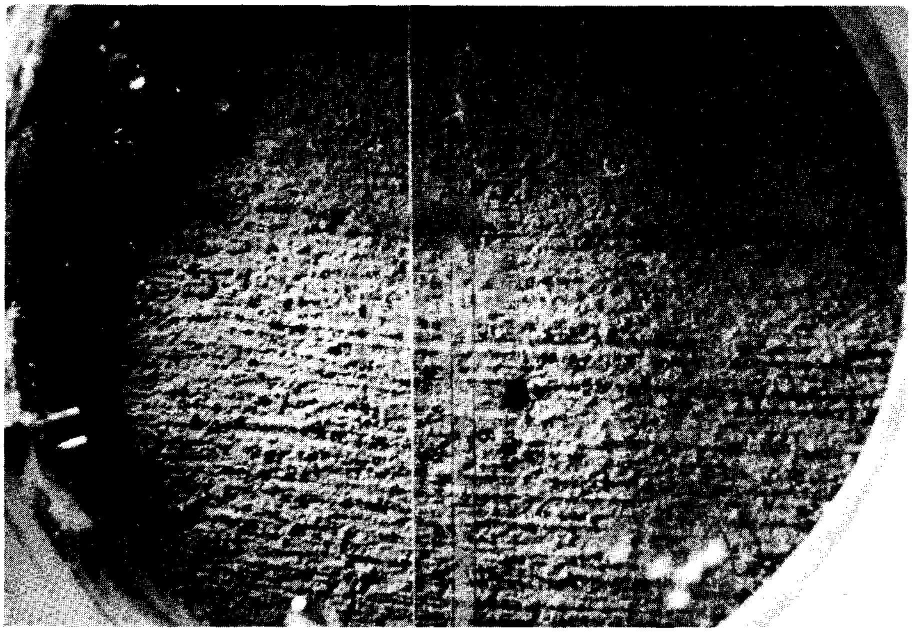

Figure 9. Photograph with dome port showing water box as frame.

The water box was joined to the underwater housing by inserting the housing port into the small end of the water box, which was held firmly with flexible rubber straps. The unit proved maneuverable and easy to operate.

The Substrobe M appeared to illuminate unevenly. The result was distinct over- and underexposed areas in the same photograph. This problem was solved and the desired photographs obtained by covering the strobe lens with translucent latex sheeting to disperse the light.

Quarry Test

The Twenty Fathom's deep-diving facility in Schuyler, Virginia, was used for testing under favorable open water conditions. This facility is a quarry that contains clear water, is approximately 100 ft. (30.4 m) deep, and experiences water temperatures between 45° (3°C) and 75°F (19°C) (depending upon depth and season). Tests were conducted at approximately 34 ft. (10.4 m), 2ATM), 69 ft. (20.7 m) (3ATM), and 100 ft. (30.4 m) (approximately 4ATM).

Several problems were encountered during the quarry tests, including leaks in the housing, moisture in the camera, variation in buoyancy, battery failure, delay in data feed-back, and lack of contrast in the photographs.

Leaks in Camera Housing

Under typical operation, the underwater camera housing is watertight; however, stress can dislodge the port and allow water to leak into the housing. This failure is extremely important when using the water box. Several precautions can be taken to alleviate this problem

1. The housing without the camera should always be checked for leaks prior to use. Since the critical depth at which leaks can occur is shallow, this test can be done in a bathtub.

2. The weight of water required to fill the box causes the system to be difficult to handle on land and places stress on the housing port. However, the weight of the unit is displaced in water, where the unit proved to be maneuverable. Filling and emptying the water box while it is in the water relieves the stress on the port.

3. The camera and water box can be checked periodically to ensure that the clips that hold the port in place are not dislodged.

4. Prior to ascending, the unit should be routinely inspected for proper assembly of critical points where leaks occur in shallow water. This is an important procedure because most leaks do occur in shallow water; at increased depth, the pressure seals the unit.

Moisture in Camera

Although the underwater housing is watertight when properly assembled, constant loading and unloading of film requires care to prevent moisture from entering the housing. Because the camera and housing are often exposed to a variety of temperatures — for example, exposure to water temperatures around 50°F (10°C) and then to air temperatures nearing 90°F (32°C) — the camera should be removed from the housing as soon as practical after photographing is completed to prevent humidity buildup inside the housing. High humidity can cause damage to a camera encased for extended lengths of time.

Buoyancy Control

The buoyancy of the underwater housing is slightly positive (it floats) but with the camera encased and the strobe and water box attached, the buoyancy of the unit on the surface becomes slightly negative. At greater depths, it becomes increasingly negative.

During the tests, divers equipped with automatic inflaters on their buoyancy compensators (BCs) found the unit easy to operate at varying depths, those with unmodified BCs had difficulty.

Because the camera system normally would be used in dark water, a safety line was always attached to the unit at the camera housing to prevent loss.

Battery Failure

A vexing problem associated with using the unit is battery failure. The strobe uses four AA batteries and the shutter in the underwater housing uses one. The manufacturer suggests that either the throwaway carbon battery or the rechargeable nickel-cadmium battery can be used to power the strobe; however, the rechargeable ones were found to be the more reliable. The batteries obviously are very important as they are the sole power source, and many hours of travel and site preparation can go for naught if this small component fails. Several precautions were taken to ensure that the incidence of battery failure was minimized.

1. Only rechargeable nickel-cadmium batteries were used.
2. The date of purchase was recorded and each set of batteries were coded with colored tape to reflect that date. Only batteries with common colors were used together and when one failed, usually because it would not hold a charge, all batteries in that set were discarded.
3. The batteries were charged and checked with a voltmeter before each project, and the frequency of charges was recorded.
4. Spare batteries were always available, the number depending upon length of time expected to be spent in the field and the amount of photographing required.

Availability of Data

Because taking the film back to the laboratory for processing delayed the evaluation of results, a technique for developing black and white film on site was developed. This technique involves minor modifications to the recommended laboratory procedures and is discussed under the heading of "Tests Under Typical Conditions."

Lack of Contrast in Photos

Because water filtered out most colors and a monochromatic layer of marine growth covered most structures photographed, evaluation of the photographs obtained was hampered because details were often masked by a lack of contrast. This problem was resolved by preparing the structure prior to inspection by scraping away growth, by always using a strobe when photographing, and by selecting the proper film for the intended task (film selection is discussed below)

Tests Under Typical Conditions

Sites judged to be typical in terms of water current, visibility, and temperature were sought for tests, and the aid of the Richmond District divers was solicited in selecting them (see Table 2).

Photographs taken under typical conditions gave good detail. The example shown in Figure 10 was taken of a concrete plate with a two-inch (5 cm) cross inscribed as a target. Several photographs taken in this series were completely unusable due to mud settling on the lens. A precaution that must be taken is to allow time for any mud that might be stirred up to settle before photographing.

Photographic Sampling Procedure

During these tests, it became necessary to develop an inspection sampling pattern that would provide a correlation between the photographs taken and the areas of the structures they represented.

Using this procedure, a diver can make successive trips to a site to perform follow-up inspections or maintenance operations. To be discussed in the following paragraphs is a procedure for the use of guidelines for outlining a sampling pattern, and making an initial evaluation of a structure using black and white film and a final evaluation and documentation using color film.

The Sampling Pattern. The sampling procedure was developed for bridges constructed with pier stems and footings; some modification is needed for bridges constructed with battered piles. The sampling patterns are set up with nylon lines to provide the diver with a means of stabilizing himself and to provide an aid for orientation under limited visibility.

A 100 ft. (32 m) section of 1/4-inch (.64 cm) nylon line was prepared with a brass clip attached to one end and a 35 lb. (16 kg.) weight attached to the clip. At 10-ft. (3.1 m) intervals from the bottom of the weight, steel rings were attached to the line (Figure 11). From a selected point (recorded for reference) on the bridge deck or pier stem the line is secured and the weighted end dropped into the water. The weight is placed on top of a footing by a diver, and the line is then tightened and made plumb. Two to four lines are set on opposite sides of the pier stem, the number depending upon the size of the structure being sampled and the quantity of data desired (see Figure 12).

Table 2

Testing Conditions

Variables	Pool	Quarry		Typical Conditions		
		Quarry 1	Quarry II	Site I	Site II	Site III
Horizontal Visibility, ft/m	75/22/86 22.86	40/12.19	5 to 10/1.5 to 3.05	5 to 10/1.5 3.04	0	4/1.5
Current	None	None	Very slight	Very slight	None	Moderate
Filming Depths, ft/m	9/2.74	10/3.04, 40/12.19 90/27.43	10/3.04, 10/6.10	10/2.04, 20/6.10 40/12.20, 100/30.40	10/3.04	10/3.04
Lighting	Indoor Artificial	Natural Light	Natural Light	Substrobe M	Substrobe M	Substrobe M
Type Film	Tri-X pan	Tri-X pan	Kodak Ektachrome	Kodacolor 100	Kodacolor 100	Kodacolor 100

Site I = Smith Mountain, bridge on Route 122 over Smith Mountain Lake

Site II = South Hill, bridge on Route 1 over Buggs Island Lake

Site III = Grays Point, bridge on Route 3 over the Rappahannock

Figure 10. Photograph taken under typical conditions. Water depths 15 ft. (4.6 m), visibility about 5 ft. (30 cm), and light very dim.

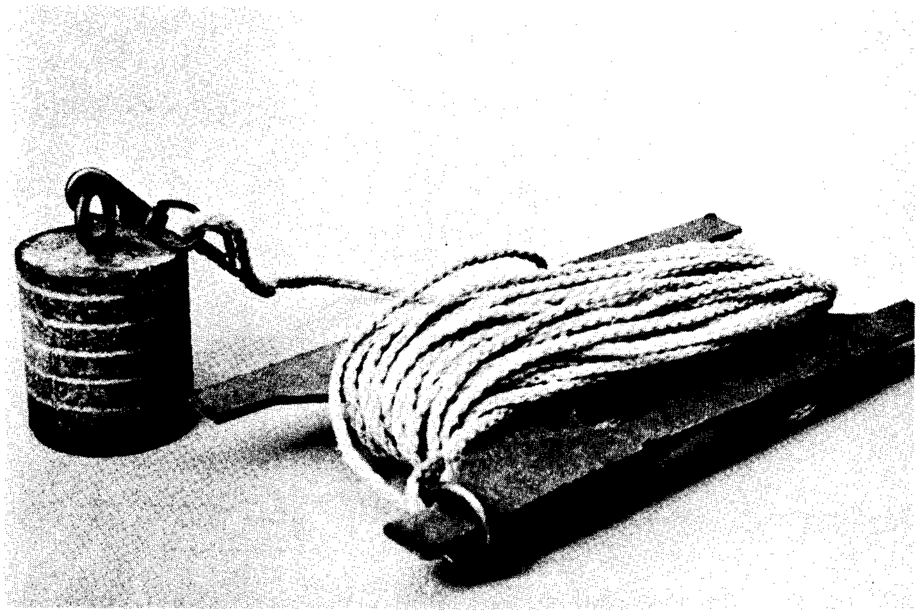

Figure 11. Guideline with brass clip and weight.

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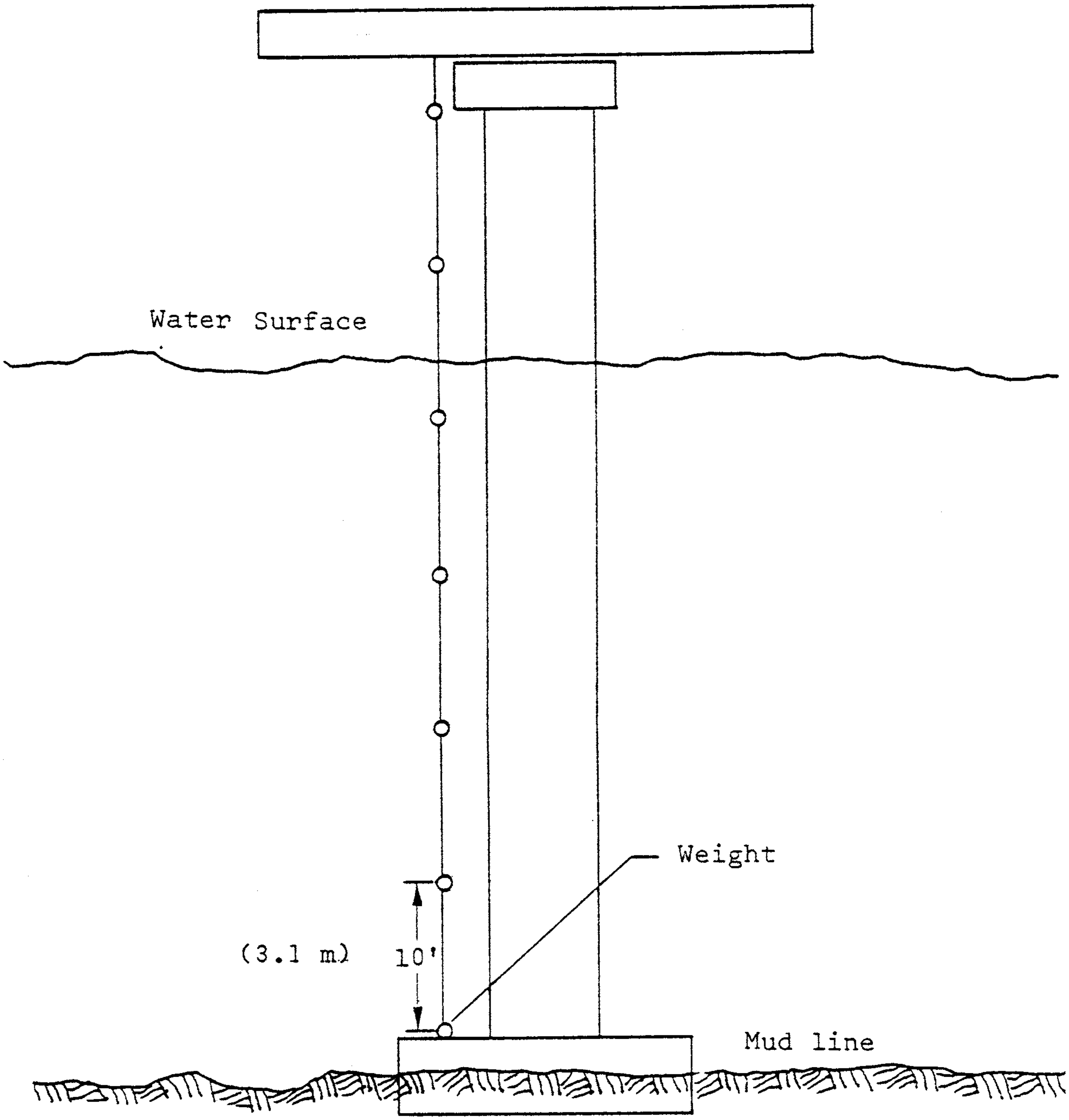

Figure 12. Sampling pattern on bridge pier.

A brass clip is attached to the handle of the underwater housing so that it can quickly be attached to and released from the rings on the nylon line. By attaching the camera to the line with the brass clip and steel rings the diver is assured that the photographs taken are in the area designated for sampling. Photographs are taken at the mud line, at the top of the footing, at each 10-ft. (3.1 m) interval designated by a steel ring, and at the surface (see Figure 13).

Sampling from the mud line or bottom of the structure to the surface was deemed important for accuracy and efficiency and to afford the diver a margin of safety regarding decompression. Any series of measurements taken from the surface would be inconsistent because of the frequent variation in the surface due to changing seasons, tides, weather conditions, etc. However, measurements taken from the footing would vary only in the last increment of measurement to the surface.

To avoid decompression, the diver has only a specific amount of time he can spend working underwater (see discussion on decompression in the Appendix). To minimize the risk of decompression sickness and maximize bottom time, it is common practice when conducting a series of dives using compressed air in SCUBA to progress from the deepest dive to the shallowest. An inspection procedure designed to begin at the bottom of the structure is consistent with this practice. For efficient use of divers' time, it is better to perform the deepest inspections first. Less surface interval is required to enable the diver to perform shallow dives and more time can be spent on these dives without compromising the time available for deep dives, which is already limited.

Evaluation of Data

The data acquired in the form of photographs must be interpreted. To obtain the best contrast and enable the identification of details, the use of color film is recommended. However, having the film processed can take several days from the time the filming is completed. To enable the engineer to evaluate the condition of a structure within an hour of photographing an on-site developing technique was established.

In this technique, black and white film was used and the laboratory procedures for film developing were modified as follows (see Figure 14).

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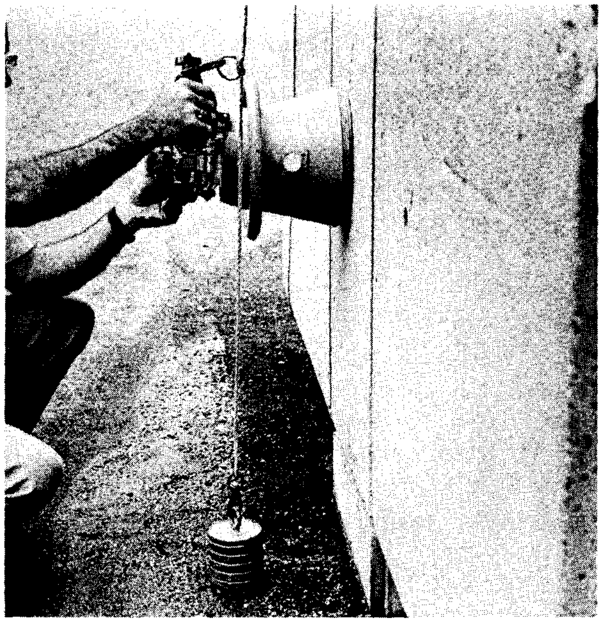

Figure 13. Example of underwater housing, line, and weight used in sampling procedure.

Figure 14. Equipment for on site developing of B/W film.

1. Reusable chemicals were premixed and transported to the field in plastic jars. Exceptions were the direct positive redeveloper (Kodak), which was mixed just before use and then discarded, and the Photo-Flo (Kodak), which was discarded after each use.
2. Ice, a heating unit, metal pan, plastic soaking tub, and thermometer were used to attain the proper temperature of the chemicals by soaking them in a hot or cold bath prior to use.
3. A change bag was used to transfer the exposed film onto a developing reel and into a developing tank.
4. A supply of clean water and a 5-gal. (19 l.) plastic jug were used to rinse and wash the film.
5. A developing tank was used through the process until the final wash.
6. The film was dried in a vehicle when possible.
7. Hypo-clearing agents and any other means suggested in the film processing directions to save time and conserve water were usually followed.

Once the film is developed, the negative can be studied to determine if future work must be performed. In some cases the engineer may desire that color photographs be taken to obtain better resolution and documentation. If direct positive film is used, black and white slides can be made for viewing on site.

Color prints obtained using Kodacolor 100 film provided the best data obtained in the study. Since the photos were taken in an enclosed area, they tended to be overexposed and this film allowed the most tolerance to overexposure.

SUMMARY OF FINDINGS AND CONCLUSIONS

The following findings and conclusions are deemed significant based on the tests and evaluations conducted during this study.

Camera System Design

The components of the system described in this report are:

Camera — Minolta SRT 201, 35-mm

Lens — 28-mm & No. 1 & 3 close-up

Housing — Ikelite underwater housing with either dome or flat port

Light Source — Ikelite Substrobe M

Power Source — rechargeable AA nickel-cadmium batteries

Water Box — Cressi-Sub Batiscopia (modified with capped filling spout, light port, plastic lenses, and small diameter end cut to accommodate housing port). Small diameter 6 in. (15.2 cm); large diameter 9½ in. (24 cm); approximate length 9¼ in. (23.5 cm).

Camera System Operation

Several precautions should be taken to ensure that the camera system functions without flaw and produces photographs of the desired quality.

1. The housing should be assembled prior to operation with the camera, the "0" rings cleaned and greased, all retaining devices checked to ensure proper closure, and the housing immersed in water to check for leaks.

2. The water box should be filled and emptied in the water.

3. The underwater housing should be periodically checked for proper assembly, especially before ascending.

4. Safety lines should be secured to the camera housing.

5. Care should be taken to prevent moisture from getting into the camera, especially between film changes.

6. The camera should be removed from the housing as soon as practical after photographing is complete.

7. Divers operating the system should be equipped with automatic inflater devices on their buoyancy compensators.

8. Batteries powering the strobe should be maintained to minimize failure. This includes proper charging, voltage checking, record keeping, and renewal of those with questionable life expectancy.

Photo Sampling Procedure

To correlate the photographs taken and the object they represent, a procedure was established. In this procedure, the area to be photographed is indicated with guidelines paralleling the structure from the footing to a point above the surface. The camera system was attached to steel rings located at 10-ft. (3.1 m) intervals on these lines.

The initial photographs can be taken using black and white film and developed on site to enable evaluation by those on the surface without the delay required when using laboratory procedures for film development.

To give the diver a safety margin in decompression time and to use the diver's time as efficiently as possible, the photographing progresses from the mud line to the surface. This procedure ensures that most work not completed would be at shallow depths and thus require only short surface intervals to complete.

General Comments

The researchers found that wearing their masks with red translucent plastic over the lens prior to diving enabled them to quickly adapt to the diminished light conditions in deep water.

While the flash from the strobe can temporarily reduce the diver's night vision and thus cause momentary disorientation, this can easily be avoided by closing the eyes prior to activating the shutter. This is important for both the photographer and his dive buddy.

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APPENDIX

DECOMPRESSION ASPECTS OF COMPRESSED AIR DIVING

Definitions

Following are definitions of some terms used frequently in discussing the decompression aspects of air diving.

Depth — the maximum depth attained during the dive, measured in feet of seawater (FSW).

Bottom time — the total elapsed time starting when the diver leaves the surface to the time (next whole minute) that ascent begins (in minutes)..

Decompression stop — the designated depth and time at which a diver must stop and wait during ascent from a decompression dive; the depth and time are specified by the decompression schedule used.

Decompression schedule — a set of depth-time relationships and instructions for controlling pressure reduction.

Normal ascent rate — 60 feet (18.5 m) per minute.

No-decompression dive — a dive from which a diver can return directly to the surface at a controlled rate without spending time at shallower depths to allow inert gas to be eliminated from the body.

Decompression dive — any dive deep enough or long enough to require controlled decompression; any dive in which ascent to the surface must be carried out through decompression stops.

Single dive — any dive conducted 12 hours or more after a previous dive.

Residual nitrogen — a theoretical concept that describes the amount of nitrogen remaining in a diver's tissues after a hyperbaric exposure.

Surface interval — the elapsed time between surfacing from the dive and the time when the diver leaves the surface for the next dive.

Repetitive dive — any dive conducted within 12 hours of a previous dive.

Repetitive group designation — a letter that is used to designate the amount of residual nitrogen in a diver's body for a 12-hour period after a dive (in the U.S.N. Diving Manual).

Residual nitrogen time — time (in minutes) added to actual bottom time for calculating the decompression schedule for a repetitive dive, based on the concept of residual nitrogen.

Equivalent single dive bottom time — a hypothetical period of time taken to represent residual gas elimination time, and which is added to the bottom time of one dive to determine the decompression obligation for comparable dives.

Single repetitive dive — a dive for which the bottom time used to select the decompression schedule is the sum of the residual nitrogen time and the actual bottom time of the dive.

Exceptional exposure dives — any dive in which the diver is exposed to oxygen partial pressures, environmental conditions, or bottom times considered to be extreme.

Any diver breathing compressed air underwater risks decompressio sickness. At a depth exerting pressure less than 1 atmosphere,(1) this risk is almost negligible. However, as the depth of dive increases and repetitive dives are performed the risk increases.

The cause of decompression sickness is explained in the following excerpt from NOAA Diving Manual, December 1979, pp. 10-9 and 10-10.

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(1) 1 atmosphere of pressure is equivalent to 14.7 psi, or approximately the pressure exerted by the water upon a diver at a depth of 33 ft. (10 m) in seawater or 34 ft. (10.4 m) in freshwater.

When air is breathed under pressure, the inert nitrogen diffuses into the various tissues of the body. Nitrogen uptake by the body continues, at different rates for the various tissues, as long as the partial pressure of the inspired nitrogen is higher than the partial pressure of the gas absorbed in the tissues. Consequently, the amount of nitrogen absorbed increases with the partial pressure of the inspired nitrogen (depth) and the duration of the exposure (time).

When the diver begins to ascend, the process is reversed because the nitrogen partial pressure in the tissues exceeds that in the circulatory and respiratory systems. The pressure gradient from the tissues to the blood and lungs must be controlled carefully to prevent too rapid an outward diffusion of nitrogen. If the pressure gradient is uncontrolled, bubbles of nitrogen gas can form in tissues and blood, resulting in the development of decompression sickness.

To prevent the development of decompression sickness, several decompression tables have been developed. These tables take into consideration the amount of nitrogen absorbed by the body at various depths for given time periods. They also consider allowable pressure gradients that can exist without excessive bubble formation and the different gas elimination rates associated with various body tissues.

Stage decompression, requiring stops of specific durations at given depths, is used for air diving because of its operational simplicity. The decompression tables require longer stops at more frequent intervals as the surface is approached because of the higher gas expansion ratios at shallow depths.

A basic understanding of the use of these decompression tables is essential to the safety of a diving operation. The constraints proper use of these tables and procedures places upon the conduct of an air diving operation should always be a factor in dive planning.

SPECIAL CONSIDERATIONS RELATIVE TO BRIDGE INSPECTIONS

Several conventions are important when using the dive tables. One especially germane to the inspection procedure is "Plan repetitive dives so that each successive dive is to a lesser depth. This will aid in the elimination of nitrogen and decrease the need for decompression stops. Always keep surface intervals as long as possible."(3)

A typical example of the practical benefit of inspecting the deepest structure first is shown in Figure A-1.

Example 1 represents two dives performed within a 12-hr. period; the first to a depth of 60 ft. (18.5 m) for 30 min.; the second to a depth of 80 ft. (24.5 m) for 30 min. Example 2 represents the same two dives, except the deepest dive is performed first.

Comparison between these two examples demonstrates the efficiency of performing the deepest dive first. The diver in example 1 had to remain out of the water 3 hr. and 58 min. to attain surface interval sufficient to enable him to perform the second dive within the no-decompression limits. The diver in example 2 required only a 1 hr. and 16 min. interval, a savings of 2 hr. and 42 min.

Another important consideration relevant to inspection procedures is stated as: "A dive performed within 12 hours of surfacing from a previous dive is a repetitive dive. The period between dives is the surface interval. Excess nitrogen requires 12 hours to be eliminated from the body. These tables are designed to protect the diver from the effects of this residual nitrogen. Allow a minimum surface interval of 10 minutes between all dives. For any interval under 10 minutes, add the bottom time of the previous dives to the repetitive dive and choose the decompression schedule for the total bottom time and the deepest dive."(4)

Example 1 represents three dives, the bottom times of which were calculated as standard repetitive dives. According to this method, each dive is well within the safe no-decompression limits. Example 2 represents these dives calculated according to the rule stated above. According to this rule, the diver has gone into his decompression time by 20 min. and should allow a 17-min. stop at 10 ft. (3.1 m).

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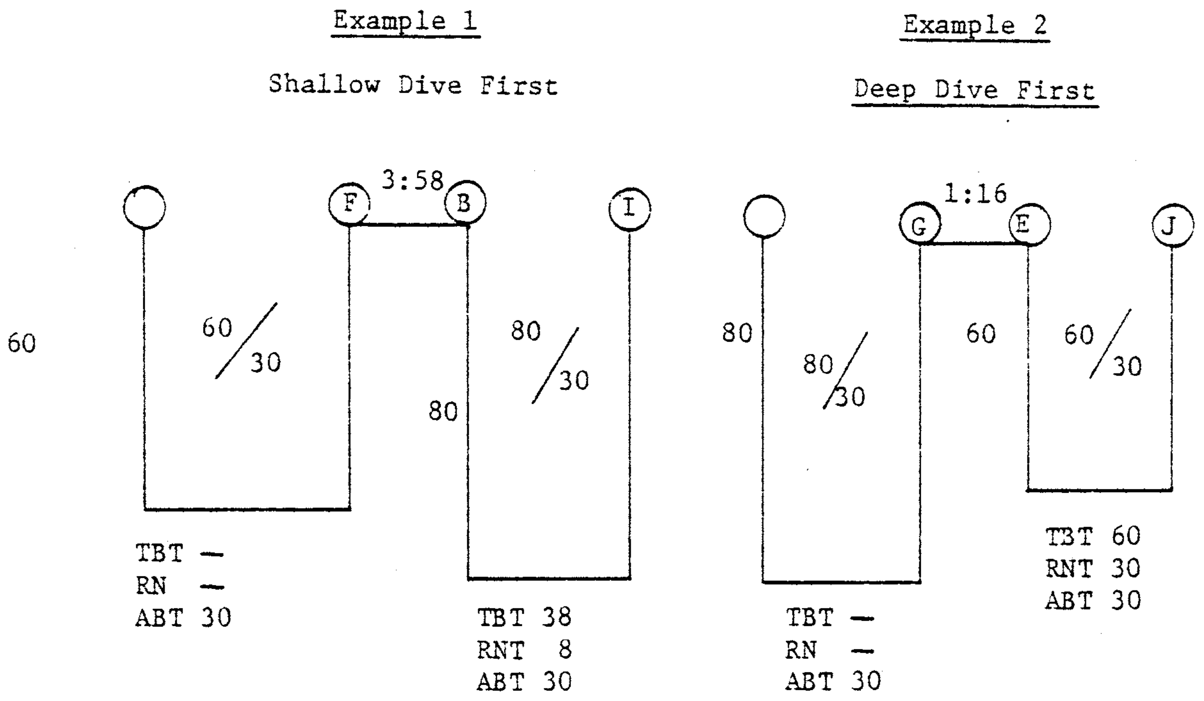
(3) Decompression tables prepared by National Association of Underwater Instructors taken from <u>U. S. Navy Diving Manual</u>, September 1975, pg. 1, No. 10.

(4) *Ibid.*, under "General Instructions for Air Diving".

Example 1 represents an incorrect application of the dive tables and represents a dangerous situation. However, due to the nature of bridge inspections where piers are located close together and surface intervals are short, this type of error would not be uncommon.



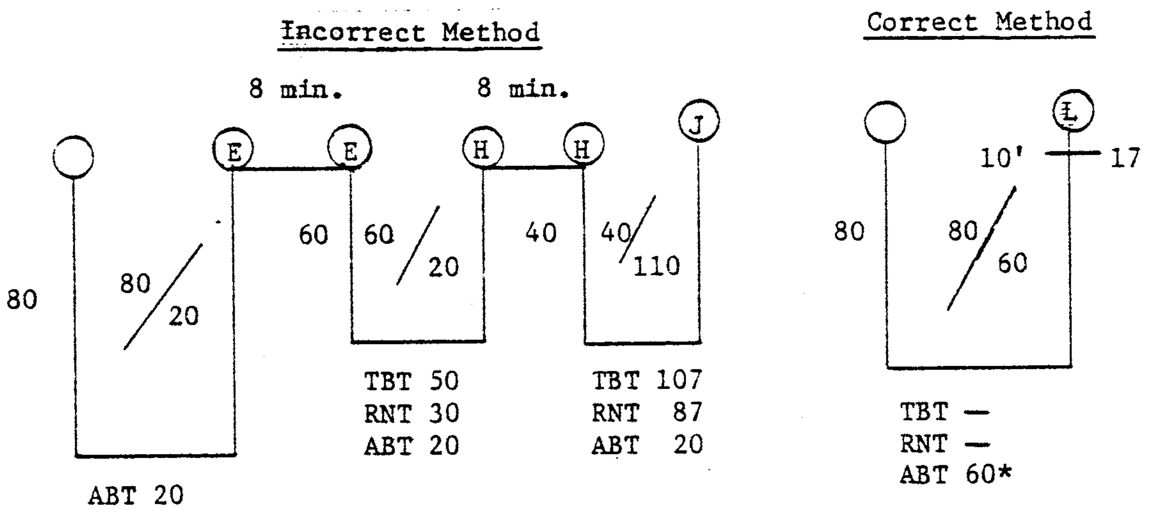
TBT = no decompression limit (in min.) at a given depth. For repetitive dives this may include residual nitrogen limits (total bottom time).

RN = Residual nitrogen time.

ABT = Actual bottom time less residual nitrogen indicator.

○ = Letters A through O inserted above each dive diagram indicate the repetitive group designator taken from the U. S. Navy Standard Air Decompression tables.

Figure A-1. Diagram of repetitive dives.



*No decompression limit at 80 ft. (24.5 m) is 40 min.

Figure A-2. Diagram of repetitive dive calculation.