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UNDERWATER WORK FUNCTIONS REQUIRED IN SALVAGE

By

G. L. Liffick

February 1971

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43-003

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ABSTRACT

Sixteen past salvage operations have been reviewed and two experienced salvors interviewed to determine the work functions required in underwater salvage. The results indicate seven work functions are compatible with hydraulic systems. These work functions are: rigging and load handling, bolting, mechanical cutting, tunneling/excavating, grappling, drilling and tapping.

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INTRODUCTION

Under the sponsorship of the Supervisor of Salvage, NCEL is developing hydraulic tools and equipment for LOSS (Large Object Salvage Systems) type salvage operations. Prior to the initiation of the hydraulic-equipment development and evaluation program, the work functions that will be the most useful in future underwater salvage were determined. The term underwater work function* is used in this report to refer to a salvage task performed by a diver or an underwater vehicle. For example, the work function Mechanical Cutting refers to all the methods of mechanical cutting used underwater. These include cutting hooks, hacksaws, pipe cutters, hydraulic cutters, chipping hammers and grinders.

The work functions were compiled by reviewing sixteen past salvage operations. These work functions were then discussed with two experienced salvors to determine their future applicability.

All underwater work functions were considered in the literature review and during the salvage conferences. From the complete list of work functions those functions that can be performed with hydraulic tools and equipment were selected for further consideration.

UNDERWATER WORK FUNCTIONS IN PAST SALVAGE OPERATIONS

To determine the underwater work functions utilized in the past, 16 representative salvage operations from 1915 to the present have been reviewed. Brief synopses of these salvage operations are included as Appendix B. The underwater work functions for these salvage operations are presented in Table 1 through Table 3. Table 1 summarizes the underwater work functions used on four surface ship salvage operations. This Table includes the work functions required for the salvage of the U.S.S. LAFAYETTE and the salvage operations after the attack on Pearl Harbor. Each of these operations required a record number of diving hours. Eight submarine salvage operations are summarized in Table 2. Included are the underwater work functions required on the U.S.S. S-51,

*The work functions are defined in Appendix A.

U.S.S. -S-4, and the U.S.S. SQUALUS salvage operations. These three operations are unique in U.S. Navy salvage because of the large amount of deep diving involved. Table 3 presents the underwater work functions used on four salvage operations since 1967. The recovery of the H-bomb at Palomares, Spain and the ALVIN are included.

SALVAGE CONFERENCES

Salvage conferences were held early in 1970 with two experienced salvors. The underwater work functions from the review of past salvage operations were discussed at these conferences to determine their difficulty and their importance in future salvage operations. These conferences are summarized in Appendix C. The conference discussion is organized by work function and contains important details not included in the body of the report.

Based on the conferences a numerical rating has been assigned to each work function to reflect its utility in future underwater salvage operations. The rating for each underwater work function is presented in Table 4. The ratings were selected so that maximum conference totals would be approximately equal to the maximum number of times the work functions were used in past salvage operations. The rating values are:

Very useful in future underwater salvage	6
Useful or potentially useful	4
Questionable usefulness	2
No use	0

The first salvage conference was held with Mr. Earl Lawrence, who is presently with the NAVSHIPS Command Headquarters in Washington, D. C. He is NAVSHIP's Salvage Master and in February 1970 received the Superior Civilian Service Award for his salvage work. He was personally involved in the recovery of the ALVIN and the U.S.S. GUITARRO salvage operation (summarized in Appendix B). For 22 years prior to joining the NAVSHIPS Command, Mr. Lawrence was the Rigger/Diver Supervisor of Diving Operations at Puget Sound Naval Shipyard. Mr. Lawrence was in the Navy from 1935 to 1941. His Navy duty included First Class Diving School, the Submarine Training Tank at Pearl Harbor, and 4½ years aboard the ASR U.S.S. ORTOLAN.

A

Table 1. Underwater Work Function

Salvage Operation Year/Ref	Work Function					
	Drilling	Tapping	Bolting	Mechanical Cutting	Torch Cutting	Explosive Cutting
Scapa Flow 1924 to 1935/2	x	x	x	x	x	x
Pearl Harbor 1941 to 1943/6	x	x		x	x	x
U. S. S. LAFAYETTE 1942 to 1943/7	x		x	x	x	
H. M. S. TRUCULENT 1950/8					x	
TOTALS	3	2	2	3	4	2

B

ions in Surface Ship Salvage Operations

n

Welding	Power Velocity Attaching	Connecting Threaded Pipe Fittings	Operating Small Valves	Rigging And Load Handling	Grappling	Placing Concrete	Tunneling/Excavating
		x	x	x		x	x
x		x	x	x		x	x
		x	x	x		x	x
	x	x		x			x
1	1	4	3	4	-	3	4

A

Table 2. Underwater Work Functions

Salvage Operation Year/Ref	Work Function						
	Drilling	Tapping	Bolting	Mechanical Cutting	Torch Cutting	Explosive Cutting	Weld:
U.S.S. F-4 1915/1			x				
U.S.S. S-5 1920/1			x		x	x	
U.S.S. S-51 1925/3	x	x	x	x	x		
U.S.S. S-4 1927/4	x	x	x	x	x		
U.S.S. SQUALUS 1939/5			x		x		
U-1105 1949/9					x		
SUBSALVEX-69 1969/11			x				
U.S.S. GUITTARO 1969/12			x	x			
TOTALS	2	2	7	3	5	1	

B

in Submarine Salvage Operations

ing	Power Velocity Attaching	Connecting Threaded Pipe Fittings	Operating Small Valves	Rigging And Load Handling	Grappling	Placing Concrete	Tunneling/ Excavating
		x	x	x			x
		x	x	x		x	
		x	x	x		x	x
		x	x	x		x	x
		x	x	x			x
		x	x	x		x	x
		x	x	x			
		x	x	x			
	-	8	8	8	-	4	5

A

Table 3. Underwater

Salvage Operation Year/Ref	Work funct:					
	Drilling	Tapping	Bolting	Mechanical Cutting	Torch Cutting	Explosive Cutting
Aircraft SALVOPS MED Recommendations 1967/10				x		
PISCES I/TUGBOAT 1969/13				x		
ALVIN 1969/14						
NEKTON/DEEP QUEST 1969/15				x		
TOTALS	-	-	-	3	-	-

Table 4. Future Usefulness of Underwater

Salvage Operation Year/Ref	Work funct:					
	Drilling	Tapping	Bolting	Mechanical Cutting	Torch Cutting	Explosive Cutting
E. Lawrence Conference	0	0	6	4	6	4
B. Badders Conference	2	2	6	4	6	4
TOTALS	2	2	12	8	12	8

B

Work Functions in Recent Salvage Operations

Work Function							
Welding	Power Velocity Attaching	Connecting Threaded Pipe Fittings	Operating Small Valves	Rigging And Load Handling	Grappling	Placing Concrete	Tunneling/Excavating
	x			x	x		
				x	x		
				x			
-	1	-	-	3	2	-	-

Work Functions from Salvage Conferences

Work Function							
Welding	Power Velocity Attaching	Connecting Threaded Pipe Fittings	Operating Small Valves	Rigging And Load Handling	Grappling	Placing Concrete	Tunneling/Excavating
2	4	2	0	6	6	0	4
0	6	4	2	6	4	2	4
2	10	6	2	12	10	2	8

A

Table 5. Underwater Work

Salvage Operation Year/Ref	Work Function						
	Drilling	Tapping	Bolting	Mechanical Cutting	Torch Cutting	Explosive Cutting	Well
Surface Ship Salvage Operations - Table 1	3	2	2	3	4	2	
Submarine Water Salvage - Table 2	2	2	7	3	5	1	
Deep Salvage Operations - Table 3	-	-	-	3	-	-	
Salvage Conferences - Table 4	2	2	12	8	12	8	
TOTALS	7	6	21	17	21	11	

B

Functions Summary

ding	Power Velocity Attaching	Connecting Threaded Pipe Fittings	Operating Small Valves	Rigging And Load Handling	Grappling	Placing Concrete	Tunneling/Excavating
1	1	4	3	4		3	4
-	-	8	8	8	-	4	5
-	1	-	-	3	2	-	-
2	10	6	2	12	10	2	8
3	12	18	13	27	12	9	17

The second salvage conference was held with Mr. Bill Badders, who is presently a salvage consultant. Early in his Navy career, Mr. Badders participated in the salvage of the U.S.S. S-51 and S-4 (Appendix B). Subsequent to these operations he served on the ASR U.S.S. FALCON, the ASR U.S.S. PIGEON, and the submarine tender U.S.S. HOLLAND. In 1936 he was assigned as the Senior Master Diver to the Experimental Diving Unit in Washington, D. C. While at EDU he was involved in perfecting underwater burning and welding and developing helium oxygen breathing gas mixtures. In 1939 he was the Senior Master Diver on the U.S.S. SQUALUS salvage operation and received the Congressional Medal of Honor for his performance during the rescue portion of this operation. Mr. Badders left the Navy in 1940 to become the Salvage Master-Master Diver of the Panama Canal. During his 23 years in the Panama Canal, Mr. Badder's primary duties were keeping the Canal open and performing emergency ship repairs. In addition, he standardized the lock overhaul diving procedures, operated a diving school which trained several hundred second-class divers, and participated in various underwater construction projects.

DISCUSSION

To establish the underwater work functions most likely to be required in future salvage operations, the information in Tables 1 through 4 has been summarized. This was accomplished by adding the number of past salvage operations utilizing the work function and the ratings from the salvage conferences. This summarization is presented as Table 5 and serves the purpose of identifying the relative usefulness of the work functions. Based on the totals in Table 5, the remote and diver salvage work functions are ranked in order of usefulness as follows:

<u>Operation</u>	<u>Total</u>
Rigging and Load Handling	27
Bolting	21
Torch Cutting	21
Connecting Threaded Pipe Fittings	18
Mechanical Cutting	17
Tunneling/Excavating	17
Operating Small Valves	13
Grappling	12
Power Velocity Attaching	12

continued

<u>Operation</u>	<u>Total</u>
Explosive Cutting	11
Placing Concrete	9
Drilling	7
Tapping	6
Welding	3

In this complete list of underwater work functions five functions are not compatible with hydraulic systems. These work functions are: Torch Cutting, Explosive Cutting, Welding, Power Velocity Attaching and Placing Concrete. In addition, the work functions of Operating Small Valves and Connecting Threaded Pipe Fittings were eliminated. These two work functions can usually be accomplished by hand and in the past have been required primarily on the YSP salvage pontoons. The YSP pontoons will not be part of the LOSS Program.

The remaining seven (7) underwater work functions can be accomplished with hydraulic-powered equipment. These work functions, listed in order of usefulness in salvage, are:

Rigging and Load Handling: The diver cannot move loads greater than 50 pounds underwater without the possibility of overexertion. Therefore, it is necessary to use the diver as a rigger and an equipment operator. When heavy loads are lowered from the surface it is necessary for the diver to control the final stage of positioning underwater if accurate placement is required. Communication systems between the diver and a topside crane operator are usually not satisfactory for accurate underwater positioning because the response time is too long and the corrections in position are not accurate enough.

Although many types of surface load handling equipment have been used underwater, the life of this equipment is usually limited by corrosion and fouling.

Bolting: Wrenches are among the diver's most useful tools. Impact wrenches are required for large nuts and bolts. Hand wrenches including crescent-type wrenches and socket sets are used for smaller nuts and bolts.

Mechanical Cutting: When small cutting jobs occur in salvage, mechanical cutting devices can often accomplish the task faster than cutting torches. Pipe cutters, abrasive wheels, and various types of wire rope cutters have been used underwater. Most of these tools were designed for surface use and are susceptible to corrosion. Cutting wire rope underwater is always a problem, particularly if the rope is under tension.

Tunneling/Excavating: Tunneling is required in salvage only if lifting wires are placed under the ship. This salvage method is not presently being considered for LOSS type salvage operations. Excavating and tunneling will probably be necessary in future salvage operation, because some ships will probably be buried in the ocean sediments.

Grappling: Present salvage techniques rely heavily on grapnels and snagging equipment for recovery beyond diver depths. Specialized grapnels are required for snagging lines and small objects from underwater vehicles. These grapnels must be designed so that the load cannot be lost as it is lifted to the surface.

Drilling and Tapping: The future of drilling and tapping in salvage operations appears to be limited because of the speed of power velocity tools. However, drill-tap combinations similar to those used on the U.S.S. S-4 salvage operation may be useful for attaching tools.

CONCLUSIONS

1. Rigging and Load Handling Equipment will continue to be important in underwater salvage. This equipment must be controlled in-situ for accurate positioning.
2. Bolting will continue to be a salvage work function.
3. Mechanical Cutting equipment can be a satisfactory substitute for the arc-oxygen torch when small structural members, wire rope, and chains are to be cut.
4. Tunneling in future underwater salvage is dependent upon the use of lifting wires to attach pontoons to sunken ships and appears to have a limited future. Excavating will probably be required in future salvage operations.

5. Grappling is still the primary recovery method, beyond the depth limits of divers.

6. Drilling and Tapping appear to have limited use in underwater salvage operations.

7. Hydraulic Tools and Equipment developed for underwater salvage should be as simple as possible to operate. Divers participating in any salvage operation may not have any salvage experience and may not be familiar with hydraulic equipment.

Appendix A

DEFINITIONS OF THE WORK FUNCTIONS

Drilling: The use of a drill bit to make a round hole in metal or wood by a manual operation or using a power tool.

Tapping: Cutting threads in a previously drilled hole with a tap either by hand or with a power tool.

Bolting: Tightening or removing threaded bolts and nuts.

Mechanical Cutting: All cutting procedures utilizing abrasive wheels, shears, knife edges, saws and chipping hammers.

Torch Cutting: All cutting devices using gases to cut metals including the arc-oxygen torch.

Explosive Cutting: Dynamite and other explosives used to cut metals.

Welding: Joining metals with a consumable electrode process.

Power Velocity Attaching: Tools using a small explosive to shoot a stud through a metal section.

Connecting Threaded Pipe Fittings: Assembling and disassembling threaded pipe fittings and valves.

Rigging and Load Handling: Handling of lines, rigging, and material from the surface or on the bottom.

Grappling: Using grapnels or hook type devices from the surface or from a submersible to recover objects on the ocean floor.

Placing Concrete: Transporting and placing concrete from the surface to an underwater location using a tremie pipe or a pump.

Tunneling and Excavating: Moving the ocean sediments to get to a specified location on a sunken object or to place lifting slings under the object.

Appendix B

SYNOPSIS OF PAST SALVAGE OPERATIONS

U.S.S. F-4

The submarine F-4 sank at 306 feet of water just outside Honolulu Harbor during March 1915. During the first phase of the recovery, divers made inspection dives of the chain lifting slings swept under the hull from the surface. For the second phase of the recovery the submarine was moved to a depth of 48 feet where rigid pontoons were attached for the final lift. During the second phase, divers tunneled under the hull, shackled guide lines for lowering the rigid pontoons to the lifting slings and bolted clamps on the slings to secure the pontoons once they were in place.

U.S.S. S-5

This submarine sank in 165 feet of water off the Delaware Cape during September 1920. The crew was able to bring the stern to the surface. After the crew was rescued, an attempt was made to tow the submarine into shallow water. While under tow the submarine broke loose and settled on the bottom at 144 feet. In an attempt to raise the submarine 427 dives were made. Divers used explosives to remove hatches and cut holes, sealed valves and hatches with concrete, operated valves, and bolted on salvage hatches and porthole covers. The operation was unsuccessful because the hull was damaged by the explosive cutting.

Scapa Flow, Scotland

The morning of June 21, 1919 in Scapa Flow, Scotland, the German Navy scuttled 72 ships that were to be turned over to the Allies. In 1924 the British firm of Cox and Danks Limited commenced salvage operations on these ships. They and their successor were able to raise 34 of the ships during the following nine years.

Twenty-five destroyer class ships were salvaged from depths of 60 to 100 feet using surface lifts. The messenger lines used to pull the lift lines under the hulls were placed by divers. The larger cruiser and battleship class ships were raised by making them airtight and displacing the water inside the hull with compressed air. On the battle

cruiser HINDENBERG over 800 diver-installed patches were required. On several of the ships, tubular airlocks up to 100 feet long were installed between the hull of the ship and the surface. For each airlock, divers had to drill and tap bolt holes in the hull for 24 pad eyes to anchor the airlock guy wires. Divers also used oxy-acetylene cutting torches, jetted mud, placed concrete, and used dynamite to remove portions of the ships.

U.S.S. S-51

In September of 1925 the U.S.S. S-51 collided with a steamship off Rhode Island and sank in 132 feet of water. The S-51 was salvaged by attaching rigid 80-ton pontoons to her exterior and by pumping air into the hull to displace most of the water in four of the six flooded compartments. The attachment of the pontoons and the airtight sealing of the four compartments required 600 dives. The diving tasks are listed in detail because this was the U.S. Navy's first successful submarine recovery based on the use of divers. The diver tasks included:

1. Clearing of antennas, lines and aerials.
2. Tunneling for pontoon lines.
3. Attaching descending lines to the hull.
4. Operating valves.
5. Removing a 300-pound valve bonnet which included unfastening forty 3/4-inch diameter nuts.
6. Sledging down dogs on watertight doors.
7. Tapping a 3/4-inch diameter air connection into a bolt hole.
8. Installing a 700-pound salvage hatch using a cantilevered support and a chain fall hoist.
9. Cutting wire rope, plate and removing studs in 2½-inch chain with a oxy-hydrogen torch.
10. Unbolting pipe flanges.
11. Caulking hull cracks with lead wool.
12. Sealing valves by filling them with concrete.
13. Making and breaking threaded pipe connections, including air hoses.
14. Handling and making connections to 2½-inch chain, 1-inch diameter wire rope, and 4-inch diameter manila hawsers.

U.S.S S-4

The S-4 sank in 102 feet of water off the coast of Massachusetts in December of 1927. During the following three months 564 dives were made to seal compartments inside the submarine and attach six rigid pontoons. The prior experience of many of the divers and topside personnel on the S-51 recovery significantly contributed to the success of the recovery operation.

The diving tasks on the S-4 were similar to those on the S-51. However, several more sophisticated special tools were used on the S-4 operation. These included an air connection with integral drill and tap, arc oxygen burning torches, and a bit holder for pneumatic chipping hammers.

U.S.S. SQUALUS

The SQUALUS sank during sea trials off the coast of New Hampshire during May 1939 in 240 feet of water. Due to the depth a salvage plan was formulated requiring a minimum of heavy labor by divers.

Diving tasks consisted primarily of (1) clearing lines, air hoses and debris, (2) tunneling using a self-propelled lance and (3) rigging the YSP rigid pontoons.

Pearl Harbor

The underwater work performed by divers during the ship salvage operations at Pearl Harbor was a significant factor in the success of these operations. In fact it is unlikely that the battleships U.S.S. NEVADA, U.S.S. WEST VIRGINIA and U.S.S. OKLAHOMA could have been raised without divers. During the period of salvage operations at Pearl Harbor over 5000 shallow water dives, totaling 20,000 hours underwater, were made by Navy and civilian divers.

The divers at Pearl Harbor performed practically every type of salvage task imaginable. The list below is representative of the underwater tasks:

1. Evaluation of damage.
2. Water jetting and excavating.
3. Metal removal using dynamite.
4. Cutting away damaged metal so that patches could be installed.

5. Drilling holes for the hook bolts used on patches.
6. Placing wood and metal patches secured with hook bolts.
7. Placing concrete with tremie pipes to seal the bottom and sides of patches.
8. Closing watertight doors.
9. Welding patches over small holes.
10. Plugging sanitary drains, piping, ventilating ducts, etc.
11. Operating valves for fuel transfer.
12. Placing YSP pontoon lift chains.
13. Unbolting and removing anti-aircraft guns, and removing ammunition.

U.S.S. LAFAYETTE

The U.S.S. LAFAYETTE caught fire at Pier 88 in New York on February 9, 1942. The next day it rolled over on its side and sank in 40 feet of water. The salvage of this ship required a tremendous amount of diving time. Divers removed approximately 10,000 cubic yards of mud, installed 356 porthole patches, sealed and braced 16 cargo ports and built eight timber and concrete bulkheads inside the ship. The types of diving tasks were similar to those performed at Pearl Harbor.

H.M.S. TRUCULENT

During January 1950, the TRUCULENT collided with a Swedish tanker and sank in 66 feet of water in the Thames Estuary. The submarine was lifted to the surface using two ex-German lifting craft. Although this operation was primarily a surface lift some water was displaced from the interior of the submarine with compressed air. Royal Navy divers assisted in placing the lifting cables, attached power velocity air connections, cut holes with arc-oxygen torches, jettied mud and sand away from the hull, and connected air hoses.

Ex-German U-1105

This decommissioned submarine was made available to the Bureau of Ships and the Bureau of Ordnance for training and explosive testing, respectively. In 1949, subsequent to several underwater tests performed by the Bureau of Ordnance, Navy divers raised the submarine from 95 feet of water in Chesapeake Bay using collapsible pontoons. The recovery was considerably simpler than the raising of an operation submarine since the following modifications were made prior to the tests:

eight 50-ton padeyes with short wire pennants were attached, five messenger lines were placed under the hull, and numerous salvage air fittings were installed. However, the divers did make 277 dives and performed most of the operations required for an actual submarine recovery. These operations included cutting with oxy-hydrogen torches, tunneling, using air lifts, placing concrete, replacing and operating valves, rigging collapsible pontoons and handling air hoses.

Aircraft Salvops Med

The recovery of the nuclear weapon during 1966 in 2800 feet of water off the coast of Palomares, Spain was a grappling-type operation. All three of the attachment schemes were based on snagging the parachute attached to the weapon.

As a result of this operation it was recommended that all underwater vehicles considered for use in deep ocean recovery operations be equipped with the following tool capabilities:¹⁰

1. Line cutting.
2. Placing penetrating attachments, probably explosive types.
3. A detachable claw with an adjustable grab.
4. A latching type grapnel.
5. Provision for attachment of locally improvised special "one time" tools.

Subsalvex-69

The purpose of this Navy training exercise during May 1969 was to "reacquire the ability to salvage a sunken submarine using rigid submarine salvage pontoons (YSP) and train a nucleus cadre of salvage personnel...."¹¹ The exercise did not include any diver work inside the submarine (ex U.S.S. HAKE), resting on the bottom at 108 feet, since the hull has been carefully sealed and pressure-tested prior to submergence. The tasks that divers performed were similar to those on other salvage operations using the YSP pontoons (S-5, S-51, SQUALUS). Diving tasks included: bolting, replacing valves, connecting air hoses and handling lines and chains.¹¹

U.S.S. GUITARRO

During May 19, 1969, while under construction, the GUITARRO sank at Mare Island Naval Shipyard in 34 feet of water. During the successful salvage operation, divers removed service lines and wires, closed watertight doors, installed patches and cofferdams, rigged air hoses, and removed valves.¹²

PISCES I/TUGBOAT

During July 1969 the 51 foot tugboat EMERALD STRAIGHTS was recovered from 670 feet of water near Vancouver, B. C. using the submersible PISCES I. The PISCES first made a comprehensive photographic survey of the tugboat. Based on this survey a successful salvage plan was developed which required the PISCES to cut two anchor chains with a hydraulic actuated cutter, insert toggle bars through the two anchor hawespipes on the tugboat¹³, and guide a lifting sling around the exposed stern of the tug.

ALVIN

The ALVIN was accidentally dropped in 5000 feet of water in 1968. The successful recovery of this submersible during August of 1969 depended on the attachment of a lift line by the ALUMINAUT. The attachment of the lift line consisted of inserting a toggle device into the ALVIN's hatch, tripping the toggle bar release and connecting a snap on the end of the toggle line to a ring in the lift line.¹⁴

NEKTON/DEEP QUEST

During October 1969 the submersible DEEP QUEST became fouled in 3/8-inch polypropylene line at 430 feet. The small submersible NEKTON was sent down to free the DEEP QUEST. This was accomplished by attaching a hunting knife to the outside of the NEKTON to cut the rope.¹⁵

Appendix C

SYNOPSIS OF UNDERWATER WORK FUNCTIONS DISCUSSED AT TWO SALVAGE CONFERENCES

Drilling and Tapping

E. Lawrence: I don't know of any requirements for drilling and tapping underwater in salvage operations. However, I have drilled and tapped in underwater construction. Almost all of the holes were less than $\frac{1}{2}$ -inch diameter in steel plate less than $\frac{3}{8}$ -inch thick.

B. Badders: I see very little use for underwater drilling and tapping in deep salvage operations.

In shallow water repair work we often drilled and tapped holes from $\frac{5}{8}$ -inch to 1-inch diameter to attach patches with cap screws. Also, when threaded power velocity studs penetrated too far into a hull plate to start the nut that held the patch, we usually drove the stud through the plate and tapped the remaining hole for a cap screw. We always tapped these holes using hand tools because we could not adequately control the speed of the pneumatic drills.

Bolting

E. Lawrence: Bolting is one of the most important salvage operations. In addition to hand wrenches, an impact wrench is a very useful tool for underwater bolting. I have very seldom found nuts underwater that could not be removed with an impact wrench. I believe that this is the result of a soft corrosion film that forms between the threaded surfaces.

B. Badders: Bolting is generally required in any type of diver work. A good ratchet socket set is one of the diver's most important tools. Crescent-type adjustable wrenches are also useful. Impact wrenches are a big help to the diver, particularly for large nuts.

Mechanical Cutting

E. Lawrence: There is a requirement for underwater mechanical cutting devices. These devices are especially useful for cutting small objects. I have used manual pipe cutters underwater and these work as well or better than they do topside. Abrasive-type tools appear to work better underwater. I believe this is because the water lubricates and cleans the abrasive pores and prevents the abrasive from overheating.

There is a definite requirement for better methods of cutting wire rope, particularly when it is under tension. Manual hydraulic wire rope cutters work underwater and, while the cutting mechanism is usually adequate, the hydraulic system is often ruined by salt water. Although wire rope up to 2½-inch diameter is used in salvage, 90% of the wire rope used is 1½-inch diameter or less.

Other cutting tools that I have used underwater include: (1) a hole saw powered by a pneumatic drill, (2) a small sledge hammer and a steel-handled carpenter's chisel for cutting manila and nylon rope, and (3) a chipping hammer for removing small amounts of metal.

B. Badders: There are many small cutting jobs where mechanical cutting methods are easier and faster than assembling the equipment required for underwater burning.

The cutting hook that we used on the S-51 and S-4 jobs worked very well. It was possible to use the heave of the ASR, transmitted through a wire rope, to pull this hook through 3/8-inch thick steel plate. I have used chipping hammers underwater for metal and bolt removal, grinders for preparing surfaces to be welded, and occasionally manual pipe cutters. A good knife is still one of the diver's most useful tools.

Cutting wire rope underwater is always a problem. It would be preferable to have a remotely actuated cutter so that wire rope under tension could be cut without endangering the diver.

Torch Cutting

E. Lawrence: The underwater burning torch is probably the salvage diver's most useful tool. It is essential, however, that the diver has adequate training and continuous practice with the burning equipment. For example, in 1947, a ship sunk in Puget Sound in 135 feet of water. To recover the cargo of canned salmon it was necessary to cut large holes in the side of the ship. The salvage force borrowed my burning equipment from the Puget Sound Naval Shipyard. After six weeks these divers had accomplished almost nothing. Another Shipyard diver and I went up there and we were able to burn an average of 41 feet per hour, on rusty and painted 5/8-inch steel plate. We were able to do this because we spent at least one day per week burning and welding underwater at the Shipyard.

An experienced diver-burner can burn through a 2½-inch chain in three to four minutes. Cutting wire rope underwater with a torch is more difficult. As the stands are cut the ends of the wire rope tend to fly off. This can be dangerous for the diver, particularly if the rope is under tension.

We routinely used the arc-oxygen torch for cutting underwater in wet suits without any problems. I do not feel that there is a shock hazard with this equipment.

B. Badders: The burning torch is the best method of cutting metal underwater. However, I have found that it takes at least three weeks of constant practice for a journeyman welder-burner to become competent at underwater burning.

We accidentally discovered an improved method of burning non-ferrous metals at my diving school in the Canal Zone. When non-ferrous metals are being melted with an arc-oxygen torch, replacing the oxygen or compressed air with water will result in improved cutting performance. The water (1) keeps the torch cooler which results in longer electrode life, (2) is more effective in removing the metal, and (3) improves visibility because almost no bubbles are produced. The EDU did not adopt this burning method because hydrogen is produced and they believed that an explosion hazard could result if the gas was confined. We felt that where the gas could escape, it was a superior method of cutting non-ferrous metals.

Explosive Cutting

E. Lawrence: Explosives are easy to use underwater. I have used explosives to remove ships propellers, and to break up concrete and coral. I believe that some of the present explosives techniques used by the offshore oil industry could be used in salvage operations. Explosives may be useful for removing or destroying classified equipment on a sunken ship.

B. Badders: I see a definite future for explosives in salvage. It is very possible that explosives will be required to remove missiles or the nuclear reactors from submarines.

Although we did not normally use explosives while I was at the Canal Zone, we did test a shock wave screen. This screen was created with air bubbles escaping from 1/8-inch diameter holes drilled six inches apart on a pipe placed at the bottom of the Canal. It required a lot of compressed air, but it completely blocked the shock wave from the adjacent underwater structures.

Welding

E. Lawrence: Welding can be an effective method of joining metals underwater. Although salvage operations usually do not require welding, it has been used to attach padeyes and other lift points.

Underwater arc welding required even more skill and practice than torch cutting. Techniques have changed very little in the past 30 years. The technology has not advanced because no one is spending enough time and money on its development.

I have done a lot of welding in a wet suit with canvas gloves and have never experienced any electrical shock problems.

B. Badders: We have welded small patches on ships in shallow water, but I do not see a requirement for welding in deep salvage work. Welding underwater is primarily a matter of training. In the Canal Zone our divers were all dual rated. They were diver rated as well as journeyman rated. This worked very well, because when a man was not diving he was performing his underwater speciality, such as welding, topside.

I do not feel that there is a shock hazard in underwater welding. We generally welded in wet suits with surface-supplied helmets and observed two safety rules: first, the diver was not to be between his ground connection and torch when welding, and second, the ground connection was to be as close to the welding area as possible. I never had a man complain, even of a tingle, as a result of underwater welding.

Power Velocity Attaching

E. Lawrence: The power velocity tool, when it is used properly, is an effective method of attachment. Most of my experience was with the old Temple-Cox gun. We always used threaded studs and nuts. These were fired through wood centering plugs in the holes in the patch or padeye to be installed. If you try to fire power velocity studs through one plate into another, each successive stud will vibrate the previously driven studs loose. This is what happened on the BATON ROUGE VICTORY in Subic Bay. They attached a large patch with power velocity studs and it fell off because only the last few studs were holding the patch.

B. Badders: We used threaded power velocity studs to attach most of the patches underwater in the Canal Zone. The studs were driven through holes in the patch and the patch was held on by nuts threaded on the studs. I have experimented with power velocity tools both at the EDU and in the Canal Zone and I have never been able to develop a satisfactory method of shooting studs through a steel plate into another plate. The differences in individual stud penetration and the vibration set up by the successive studs being fired prevent the studs from developing their full holding power. In spite of these limitations, I think that the velocity power tool is the best method available for attaching a lift point to a smooth surface.

Threaded Pipe Connections

E. Lawrence: Threaded pipe connections are used very little in underwater work. Most pipelines underwater are larger than 3-inch diameter and are either welded or connected with flanges. I see very little requirement for the capability of making up threaded pipe connections underwater.

B. Badders: Connecting threaded pipe joints is often required on the YSP pontoons due to accidental damage. A regular pipe wrench works well on the smaller pipe sizes and a chain wrench is preferred for the larger sizes.

Operating Valves

E. Lawrence: Generally a diver can operate valves 6-inches diameter and less without great difficulty. However, valves that require hand operation are rare in salvage operations. The YSP pontoons are the only salvage equipment that I know that require hand operation of valves. Most large valves, such as submarine induction valves, have some type of mechanical operator.

B. Badders: The diver can usually operate small valves by hand without difficulty. If they are frozen shut or must be jammed closed prior to an ocean crossing, the diver must use a pipe wrench or some other means of applying leverage.

Rigging and Load Handling

E. Lawrence: Generally divers do not have difficulty moving lines suspended from the surface. However, the diver may waste a great deal of time looking for a line or trying to find his way back to the attachment point. It is far better to lower a heavy line down a messenger line to the exact location where it will be attached. This is especially important with the larger salvage lines, such as 2½-inch diameter wire rope and 2¼-inch diameter dielock chain, because the fittings on these lines are difficult for the diver to handle if they are lying on a deck or in the mud. The success of any underwater rigging job depends upon adequate planning prior to the time the diver enters the water and good diver to topside communications.

There is a need for better methods of attaching lines to objects underwater. I never use screw pin shackles underwater. It is too difficult for a diver to pull the line into the position with one hand and attempt to thread the pin into the shackle with the other. A safety shackle with the bolt type pin is easier to use because the diver can push the pin through the shackle before he starts threading the pin. Improved quick connecting attachment devices, perhaps like the plate clamps used to lift steel plate, would be a great help underwater.

Divers have a very limited underwater handling capability. A swimming diver may be able to move 20 to 30 pounds (weight in water) a short distance and a diver walking on the bottom could probably carry 100 pounds 50 feet or so. Planning on a diver carrying these weights is not recommended, however, due to the possibility of over-exertion.

The way to go in the future is to provide the diver with handling systems that he can operate underwater. Ratchet-type chain hoists and other surface handling equipment have been used successfully underwater. A good way to move things underwater is with a small collapsible pontoon and a winch. The pontoon provides lift. This prevents possible damage to the object and any reduction in visibility that could occur by dragging the object across the bottom. The winch provides the horizontal force and prevents an uncontrolled ascent if the pontoon is over-inflated. The winch in this system might have the following features: a 500 pound pull and 50 feet of line, a level wind, a method of quick line payout under slight tension to prevent backlash, a wire rope line to allow precise positioning, and a quick and easy method of attaching the winch underwater. An A-frame or a series of snatch blocks could also be used to increase winch versatility.

B. Badders: Divers can usually move lines and chains suspended from the surface without difficulty. On the SQUALUS I had to move a 2½-inch manila rope suspended from the surface about 40 feet along the deck of the submarine. But, it is poor planning when a diver has to move a line this far. It is better if the line is lowered on a down or guide line. This results in the lowered line arriving at the attachment point with a minimum of diver effort. Of course, as diving goes deeper it is harder to handle lines from the surface, but good planning can simplify most rigging jobs. We often spent more time planning and fabricating the rigging and staging for the divers to work from than performing the actual task. This resulted in the divers being able to complete their tasks in 1/3 to ½ the time required without adequate staging and improved the quality of their work.

We found the standard Navy pin shackle was as good as any other line attaching device available. We always made sure the pin operated freely before sending it down to the diver, and we tried to rig the line to be attached so that any tension in line was not transferred to the shackle while it was being attached. We also occasionally used C-clamps for rigging staging.

Any load lowered from the surface to the salvage site should be placed in the final position if possible. It is necessary that the diver control the lift system if he must precisely locate a load underwater. When it was necessary for a diver to accurately position a load underwater we often used a chain hoist attached to the surface lifting line.

A diver on the bottom can lift 50 to 70 pounds and transport it a short distance. Having a diver lift more than this is dangerous. A diver injured his heart on the S-51 job when he attempted to move a 150 pound hatch cover. Much of my experience has been in shallow water where loads can often be handled from the surface. But, I have used many types of handling equipment underwater including box wedges, hydraulic jacks, chain hoists and blocks and tackle. Corrosion and fouling generally limit the length of time this surface equipment can be used underwater. At the Panama Canal for moving large loads short distances, we used three-piece box wedges and either a chipping hammer or sledge hammer. It was possible to apply a spreading force up to 80 tons. We also used a lot of 5-to 20-ton manually operated hydraulic jacks. There is a requirement for better handling equipment to move large loads underwater.

Grappling

E. Lawrence: Grappling is one of the best methods available for recovering objects from beyond diver depths. Four Gifford grapnels rigged so that there is 90° between each grapnel are very useful for recovering lines on the seafloor. The Hawk anchor can be used to recover chain. There is a definite need for improved grapnels with keepers that can be closed after initial contact to prevent the loss of the salvage object.

B. Badders: I haven't had much experience with grapnels, but I believe that they would be useful beyond diver depths.

Placing Concrete

E. Lawrence: Concrete is easier to pour underwater than topside. But, I don't see any use for it in deep salvage, except perhaps for plugging valves.

B. Badders: With a tremie pipe, concrete is easy to handle underwater. We occasionally used concrete for strengthening and sealing patches in the Canal. I don't believe that concrete will be very useful in deep salvage work.

Tunneling and Excavating

E. Lawrence: Tunneling and excavating will be required as long as slings are the best method of attaching lift lines to a sunken vessel. Slings are preferred if the vessel is to be raised to the surface where it is exposed to wave action. Present tunneling and excavating methods require substantial diver effort and long bottom times which prevents their use in deep water.

The compensated jetting nozzles that have been used in the past are difficult to use because of the rigidity of the fire hose supply line and the forces on the hose from the ocean currents. These problems could be reduced by locating the water pump on the bottom with a power supply from the surface. The tunneling lance used on the SQUALUS is too slow and requires too much operating force. An air lift is a very effective method of moving material. I have used an airlift to transport cans of salmon from 135 feet to the surface. The combination of a jetting nozzle and an air lift to excavate bottom sediment is also effective. Unmanned excavation equipment, I believe, is the way to go in the future.

B. Badders: The future of tunneling underwater depends on the method of pontoon attachment. In any event, some excavation will probably be required in future salvage jobs since it is likely that the snip or submarine will be partially buried in the bottom.

The existing compensated jetting nozzles are too slow and the compensating jets blast the diver with considerable force. In some situations a second diver may be required to handle the 2½-inch fire hose. The lance used on the SQUALUS job worked well once the sections were prevented from twisting, but the lance required surface support. New concepts are required for underwater tunneling. Some of the commercially available equipment that is used to place pipes under roads may be adaptable to deep ocean use. For deep operations the tunneling equipment must not require much diver effort.

Tool Systems

E. Lawrence: I would say that 20 pounds (in water) is the maximum tool weight that a diver can operate for 20 minutes. Future salvage tools should be as simple to operate as possible because it is rare to have experienced personnel on a salvage job. The diver's work position is not too important. He is more effective if he is standing upright, but I have worked in all positions.

One thing that is dangerous for the diver in a salvage operation is the large number of lines, air hoses, etc., that normally run from the surface to the salvage job. With hydraulic tools it is desirable to have as few hydraulic hoses as possible. It is desirable to have tool exchange capability at the end of the hydraulic hoses rather than multiple hoses.

B. Badders: The maximum tool weight (in water) for 20 minutes of diver tasks is 20 to 25 pounds. In the Canal Zone we always tried to rig our staging so that the diver was in a comfortable work position. Usually this was either standing or sitting. But there were a lot of jobs that had to be performed in uncomfortable positions. Salvage tools and equipment should be as simple as possible to operate because of the variety of work positions encountered and because many divers have limited mechanical ability and little or no salvage experience.

I would recommend a separate supply hose for each power tool used underwater to prevent problems of jammed connections and water inclusion.

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Rigging						
Bolting						

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