USE OF EXPLOSIVES IN UNDERWATER SALVAGE

28 FEBRUARY 1956

Gene Slover's US Navy Pages

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OP 2081

USE OF EXPLOSIVES

IN

UNDERWATER SALVAGE

28 FEBRUARY 1956

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DEPARTMENT OF THE NAVY
BUREAU OF ORDNANCE
WASHINGTON 25, D. C.

28 February 1956

ORDNANCE PAMPHLET 2081

USE OF EXPLOSIVES IN UNDERWATER SALVAGE

1. Ordnance Pamphlet 2081 describes the techniqnes for use of explosives and other demolition material in nnderwater salvage activities: harbor clearance, harbor bottom alteration, rock and concrete blasting, steel and timber cntting, and removal of propellers for replacement. The publication also reviews the fundamental characteristics of explosivcs and contains information about demolition equipment.

2. This publication is intended for use by all personnel responsible for planning and performance of underwater salvage.

3. This publication does not supersede any existing publication.

F. S. Withington,

James H. Ward

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Acting Deputy and Assistant Chief,
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Gene Slover's US Navy Pages

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Part 2. Applications of Explosives

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SAFETY PRECAUTIONS

The following listed publications contain safety precautions and other information applicable to underwater salvage work with explosives:

OPNAV 34P1, US Navy Safety Precautions (especially chapters 5, 8, 18, and 20)

OP 4, Ammunition Afloat

OP 5, Ammunition Ashore

OP 1411, Safety in Combat Demolition Installation and Blasting for Underwater Demolition Teams

OCL A3–50, Disposal of Ammunition and Explosives hy Destruction at Naval Shore Establishments.

The safety precautions contained in this publication and in the official publications listed above are mandatory. Following is a list of the safety precautions in OP 2081 and DONT'S adopted hy the Institute of Makers of Explosives, May 5, 1951, which is included for compliance, especially when using commercial explosives.

WARNING

When testing a blasting cap, pull the wires out to their full length and place the cap as far away as possible and behind a barrier. Serious injury can result from failure to observe this warning (page 30).

WARNING

Never enter the danger zone until at least 30 minutes after the last attempt to fire; a hangfire may be in process (page 38).

WARNING

Never work with nonelectric components of a firing system until at least 30 minutes after a misfire; a hangfire may be in process (page 38).

WARNING

The rendering safe of underwater explosive ordnance is outside the scope of salvage operations. Whenever the presence of such explosives is known or suspected, qualified explosive ordnance disposal personnel shall he called upon to clear the area before salvage operations are started (page 42).

WARNING

For above water work, do not place the second charge until the hole made by the first charge has cooled. Artificial cooling with water is suggested to avoid delay (page 59).

WARNING

Never detonate the charge when anyone is in the water within a 2000-foot radius of the charge (page 103).

Terms used in the list are defined as follows:

"Explosives" shall signify any or all of the following: dynamite, black blasting powder, pellet powder, blasting caps, and electric blasting caps.

"Electric blasting cap" shall signify any or all of the following: instantaneous electric blasting caps, delay electric blasting caps, and delay electric igniters with blasting caps attached

1. DON'T purchase, possess, store, transport, handle, or use explosives except in strict accordance with organizational, local, state, and federal regulations.

2. DON'T store explosives anywhere except in a magazine which is clean, dry, well ventilated, properly located, substantially constructed, and securely locked.

3. DON'T allow persons under eighteen years of age to handle or use explosives, or to be present where explosives are being handled or used.

4. DON'T leave explosives lying around where children can get them.

5. DON'T allow leaves, grass, brush, or debris to accumulate within 25 feet of an explosive magazine.

6. DON'T smoke or have matches, open lights, or other fire or flame, in or near an explosive magazine, or have them near by while handling or loading explosives.

7. DON'T shoot into explosives with any firearm, or allow shooting in the vicinity of an explosives magazine.

8. DON'T store any metallic tools or implements in an explosives magazine.

9. DON'T drop, throw, or slide packages of explosives or handle them roughly in any manner.

10. DON'T open kegs or cases of explosives in a magazine.

11. DON'T open kegs or wooden cases of explosives with metallic tools. Use a wooden wedge and wooden, rubber, or fiber mallet. Metallic slitters may be used for opening fiberboard cases, provided that the metallic slitter does not come in contact with metallic fasteners of the case.

12 DON'T store or leave packages of explosives which have been opened without replacing the cover.

13 DON'T use empty explosives cases for kindling.

14. DON'T permit any paper product used in the packing of explosives to leave your possession. Accumulations of fiberboard cases, paper case liners, cartons, or cartridge paper should be destroyed by burning after they have been carefully examined to make sure that they are empty.

15. DON'T use explosives that are obviously deteriorated.

16. DON'T attempt to reclaim or use fuse, blasting caps, electric blasting caps, or any other explosives that have been water-soaked, even if they have dried out.

17. DON'T carry explosives in pockets of clothing.

18. DON'T make up primers of explosives in a magazine or near excessive quantities of explosives.

19. DON'T force cartridges of any explosives into a bore hole or past any obstruction in a bore hole.

20. DON'T allow explosives, or drilled holes while being loaded with explosives, to be exposed to sparks from steam shovels, locomotives, or any other source.

21. DON'T spring a bore hole near another hole loaded with explosives.

22. DON'T load a sprung bore hole with another charge of explosives until it has cooled sufficiently.

23. DON'T tamp with metallic bars or tools. Use only a wooden stick with no exposed metal parts.

24. DON'T use combustible material for stemming.

25. DON'T allow near the danger area of a blast any persons not essential to the blasting operations.

26. DON'T fire a blast until all surplus explosives are in a safe place, all persons and vehicles are at a safe distance or under sufficient cover, and until adequate warning has been given.

27. DON'T return to the face until the smoke and fumes from the blast have been dissipated by adequate ventilation.

28. DON'T attempt to investigate a misfire too soon. Follow all applicable rules and regulations, or, if no rules are in effect, wait at least an hour.

29. DON'T drill, bore or pick out a charge of explosives that has misfired. Misfires should be handled only by a competent and experienced man.

30. DON'T abandon any explosives. Dispose of or destroy them in strict accordance with regulations.

31. DON'T store cases of dynamite so that the cartridges stand on end.

32. DON'T leave dynamite, black blasting powder, or pellet powder in a field or any place where livestock can get at them.

33. DON'T take surplus quantities of permissible dynamite, black blasting powder, or pellet powder into a mine at any one time. These explosives deteriorate rapidly in a damp atmosphere.

34. DON'T use black blasting powder or pellet powder with permissible explosives or dynamite, nor dynamite with permissible explosives, in the same bore hole in a coal mine.

35. DON'T tamp pellet powder in a bore hole hard enough to crush the pellets, because of danger of premature explosion.

36. DON'T store blasting caps or electric blasting caps in the same box, container, or magazine with other explosives.

37. DON'T leave blasting caps or electric blasting caps exposed to the direct rays of the sun.

38. DON'T insert a wire, a nail, or any other implement into the open end of a blasting cap to remove it from a box.

39. DON'T strike, tamper with, or attempt to remove or investigate the contents of a blasting cap or an electric blasting cap.

40. DON'T try to pull the wires out of an electric blasting cap.

41. DON'T connect blasting caps or electric blasting caps to Primacord, except by approved methods.

42. DON'T attempt to fire a circuit of electric blasting caps except by an adequate quantity of delivered current.

43. DON'T use in the same circuit electric blasting caps made by more than one manufacturer.

44. DON'T handle explosives during the approach or progress of an electrical storm. All persons should retire to a place of safety.

45. DON'T make electrical connections without first making sure that the ends of the wires are bright and clean.

46. DON'T allow electrical connections to come in contact with other connections, bare wire, rails, pipes, the ground, or other possible sources of current or paths of leakage.

47. DON'T have electric wires or cables of any kind near electric blasting caps or bore holes charged with explosives except at the time of, and for the purpose of, firing the blast.

48. DON'T use electric blasting caps in very wet work unless they have adequate water resistance and suitably insulated leg wires.

49. DON'T use any means other than a blasting galvanometer containing a silver chloride cell for testing electric blasting caps, singly or when connected in a circuit.

50. DON'T use damaged leading or connecting wire in blasting circuits.

51. DON'T use duplex leading wire except for single shot firing.

52. DON'T tamper with or change the circuit of a blasting machine in any way for any purpose.

53. DON'T spare force or energy in operating a blasting machine.

54. DON'T store fuse or fuse lighters in a wet or damp place, or near oil, gasoline, kerosene, distillates, or similar solvents.

55. DON'T store fuse near radiators, steam pipes, boilers, or stoves.

56. DON'T handle fuse carelessly in cold weather. If possible, it should be warmed slightly before using to avoid cracking the waterproof coat.

57. DON'T use short fuse. Cut fuse long enough to extend beyond the collar of the hole and to allow time to retire safely from the blast. Never use less than six feet.

58. DON'T cut fuse until you are ready to insert it into a blasting cap. Cut off an inch or two to insure a dry end.

59. DON'T cut fuse on a slant. Cut it square across with a clean, sharp blade. Seat the fuse lightly against the cap charge and avoid twisting after it is in place.

60. DON'T crimp blasting caps to fuse with a knife or with the teeth. Use a standard cap crimper and make sure that the cap is fastened securely to the fuse.

61. DON'T use fuse and blasting caps in wet work without having a thoroughly waterproof joint between the fuse and cap.

62. DON'T kink fuse in making up primers or in tamping a charge.

63. DON'T hold the primer cartridge in the hand when lighting fuse.

64. DON'T light fuse in any bore hole until the holes contain sufficient stemming to protect explosives from sparks from the end spit of fuse or a flying match head.

65. DON'T try to light fuse with burning paper, other inflammable refuse, or improvised torches.

66. DON'T light fuse near blasting caps or any explosives, other than those being used in the blast.

Part 1. Fundamentals and Equipment

Chapter 1

INTRODUCTION

Definition

The term underwater salvage used in this publication means constructive underwater demolition by the use of explosives to clear harbors, inland waters, channels, and offshore waters of sunken, capsized or wrecked vessels, or other obstacles. Such salvage demolition is, in general, a short-range emergency operation.

Use

This definition applies to the following operations:

1. Harbor Clearance. The purpose of salvage demolition in harbors or channels blocked by sunken, capsized, burned or wrecked vessels is to remove such obstacles so that these waters may be used by other vessels still afloat, figure 1. A channel is selected through the path of least obstacle density, considering such factors as currents, channel depth, and the desirability of keeping the channel as straight as possible. Obstacles in this path are dispersed by explosives. As time and conditions permit, clearance operations are extended to as wide an area as is considered necessary.

2. Other Obstacle Clearance. Salvage demolition is used to remove such obstacles as rock, concrete, masonry, timber, and piling in the way of shipping.

3. Alteration of Sea Bed. Natural obstacles that obstruct shipping may be present in the form of sand bars, shallow harbor bottoms, or narrow or filled-in channels. Salvage demolition is used to alter the configuration of the sea bed.

4. Propeller Removal. A ship's propeller can be removed while the ship is afloat by the use of a small amount of explosive placed by a diver in the proper location to loosen the propeller from its shaft.

Advantages

The use of explosives in underwater salvage operations has many advantages: speed, economy in labor and materials, elimination of the need for a sizable array of elaborate and specialized heavy floating equipment, and savings in expense. For example, these advantages are apparent in the case of a heavy cargo vessel deliberately sunk by enemy action to block a channel entrance. Depending on its actual condition, action could be initiated to refloat it and tow it away or to dismember the superstructure and hull. Either method would be time-consuming and very costly. The use of explosives as described in succeeding chapters would accomplish the military objective in the most satisfactory manner by dispersing the wreckage.

A further advantage of using explosives is that results are obtained which cannot be obtained by other means. For example, the only practicable method of demolishing a concrete pier is to blow it up.

Disadvantages

The use of explosives requires highly trained personnel and strict and vigorous adherence to safety precautions. However, these disadvantages are far outweighed by the advantages listed.

Scope

Part 1 of this publication reviews the fundamentals of high explosives and information about demolition equipment, accessories, techniques, and tools applicable to underwater salvage operations. Much of this information already is contained in existing publications. OP 1839, Underwater Demolition Team Materials and Their Uses, provides comprehensive and detailed coverage of many of the topics presented in this publication. Review material in Part I is intended as "refresher" information only; it does not supersede

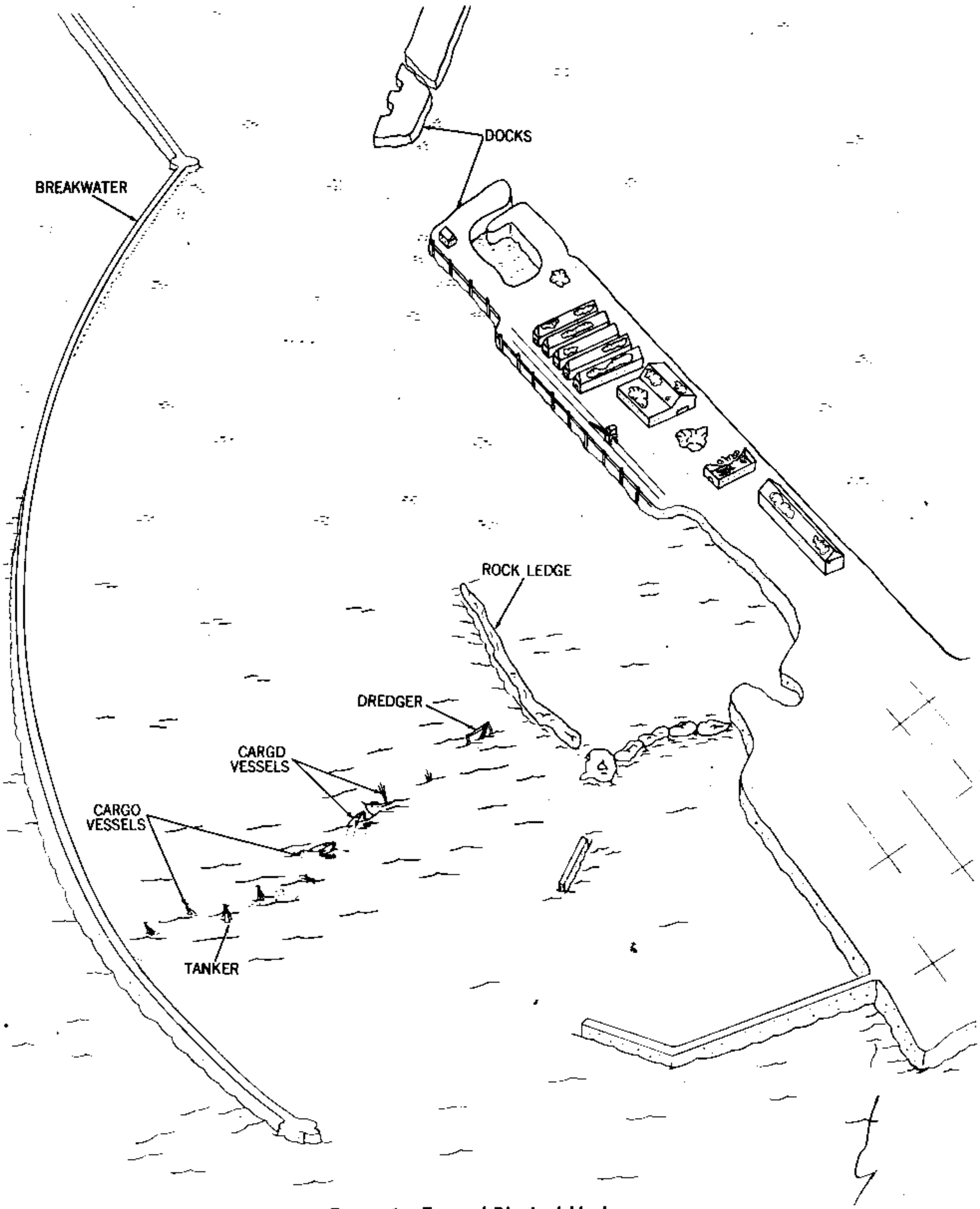

Figure 1—Typical Blocked Harbor.

or replace detailed information in other publications.

Part 2 covers the application of the materials and methods described in Part 1 to such varied underwater salvage activities as harbor clearance, barbor bottom alteration, rock and concrete blasting, steel and timber cutting, and removal of propellers for replacement. Similar underwater activities of groups such as the Underwater Demolition Teams and the Bureau of Yards and Docks are outside the scope of this publication.

OP 2081 is not intended to take the place of training by competent instructors, but rather to provide guidance and information for trained personnel and assistance to instructors. Information on size of charges and techniques employed are furnished for guidance only. The sound judgment and experience of the salvage officer will be the deciding factor in successful underwater ship salvage and harbor clearance work.

References

OP 1178 (First Revision), Demolition Material, 26 June 1946.

OP 1411 (First Revision), Safety in Combat Demolition and Blasting for Underwater Demolition Teams, 14 April 1947.

OP 1839, Underwater Demolition Team Demolition Materials and Their Uses, 8 September 1953.

FM 5–25, Explosives and Demolitions, September, 1954.

FM 5–35, Engineers' Reference and Logistical Data, 4 September 1952.[1]

TM 9–2900, Military Explosives, 29 August 1940.[1]

Translation 208, Introduction to the Theory of Underwater Explosions, David Taylor Model Basin, U. S. Navy, July 1948.[1]

[1] Not available for distribution by the Bureau of Ordnance.

Chapter 2

FUNDAMENTALS OF EXPLOSIVES

Definitions

Explosive. An explosive is a substance or a mixture of substances which, when suitably initiated, is capable of rapid and violent chemical reaction. An explosive reaction always is accompanied by a sudden rise in pressure resulting from the formation of gases and their expansion by the heat liberated in the reaction.

High Explosives. Some substances give rise to explosive reactions characterized by molecular rearrangement which proceeds practically instantaneously. This molecular rearrangement may be combined with burning. Such substances are called high explosives. In these, oxygen is usually, but not always, present with combustible elements such as carbon and hydrogen. The chemical arrangement generally is one of unstable equilibrium; the initiating impulse brings about a breaking down of chemical bonds and a molecular rearrangement which occurs so rapidly that the evolution of heated gaseous products is practically simultaneous throughout the mass.

Propellants. Certain substances give rise to explosive reactions characterized by extremely rapid combustion. These substances, known as burning or progressive explosives, are usually used as propellants. The reaction in these explosives is a true burning, called deflagration, which proceeds from point to point throughout the explosive substance, accelerated by the heat and pressure produced. This type of explosive is not suitable for underwater salvage work.

Deflagration. The explosive reaction of a burning or progressive explosive is called deflagration.

Detonation. The explosive reaction of a high explosive is called detonation. A strong shock is needed to initiate the detonation. This is obtained by exploding a smaller charge of a more sensitive high explosive in contact with or in close proximity to the main charge. The smaller charge is exploded by heat or shock.

Rate of Detonation. The rate of detonation is the velocity, usually specified in feet per second, at which the explosive reaction progresses through the mass of a high explosive.

"Sympathetic" Detonation. Frequently it has been demonstrated that detonation of an explosive mass can be transmitted to other masses of high explosive in the near vicinity, without actual contact. It has been generally accepted that such transmission is caused by the passage of an explosive percussion wave from one mass to the other. The second detonation occurring under these conditions is called a "sympathetic" detonation.

Sensitivity. Sensitivity is a measure of the strength of the impulse required to start an explosive reaction. The less sensitive explosives are difficult to detonate directly and require a booster charge of more sensitive material to set them off. The more sensitive an explosive, the easier it is to start the reaction and the more carefully the explosive must be handled.

Power; Effectiveness. Power, better termed effectiveness, is a general term used to indicate the results produced by the detonation of a high explosive, such as capacity for penetration of steel. Determination of the effectiveness of different explosives is made by conducting comparative tests or equal weights of the different explosives under similar conditions. The effectiveness values of different explosives are useful in selecting the best explosive for a given application.

> NOTE: The effectiveness of an explosive is not necessarily related to its sensitivity. TNT is a highly effective explosive with low sensitivity.

Strength. Strength is a term applied to the dynamites. It is expressed as a percentage that indicates the nitroglycerin content by weight.

Demolition Charges. Demolition charges are defined as follows:

1. INTERNAL CHARGES. Internal charges are those placed in naturally occurring cavities or manmade holes in the object or area subject to demolition.

2. EXTERNAL CHARGES. External charges are those placed on the outside of or secured to the surface of the object or area subject to demolition.

3. SHAPED CHARGES. Shaped charges, also known as cavity or Munroe charges, are so fabricated as to focus the explosive energy to obtain greater penetration for a given mass of explosive. The typical shaped charge has a cavity or air space in the shape of a cone, hemisphere, or V-shaped groove.

Main Filler. A main filler is a high explosive of low sensitivity and forms the bulk of an explosive charge.

Initiator. The most sensitive high explosives are classed as initiators. They are used to start the deflagration or detonation of other explosives.

Booster. A booster is an explosive charge that is sensitive enough to be detonated by a small amount of initiator explosive and powerful enough to cause the detonation of the main filler.

Characteristics of Explosive Reactions

Velocity. The velocity of detonation of high explosives varies within wide limits, depending upon the kind of explosive and upon its physical state. The velocity of reaction of high explosives ranges from about 6,500 to 28,000 feet per second.

Energy. An explosive reaction is always accompanied by the rapid liberation of energy. The amount of energy represents the potential for doing work (damage).

Pressure. The high pressure accompanying an explosive reaction is due mainly to the formation of gases which are expanded by the heat liberated in the reaction. The maximum pressure developed in the surroundings and the way in which the energy of the reaction is applied depend upon the volume of the gases, the amount of heat liberated, the velocity of the reaction, and the density of the surrounding medium.

Comparison of Explosive Reactions in Air and Under Water

The explosive reaction of each of the high explosives discussed in this publication is an almost-instantaneous change from a solid or liquid to an equal volume of gases[1] under extremely high pressure. This change is independent of the surrounding medium within the limits of practical application. That is, detonation of a cubic inch of TNT will produce a cubic inch of gases[1] whether the detonation occurs in air, in earth, or under water; also, the release of energy will produce the same maximum pressure, regardless of the surrounding medium. However, the effects of the reaction are quite different under water from those in air.

In air, the first effect of the completed explosive reaction is the impact of the extremely high pressure of the released gases on the surrounding envelope of air. This impact develops a pressure wave that travels away from the detonated explosive in all directions at supersonic speed, figure 2. The wave rapidly develops into a shock wave (a wave with a vertical front) the amplitude of which diminishes as the distance from the point of origin increases. The high pressure developed by the explosive reaction is quickly dissipated into the atmosphere.

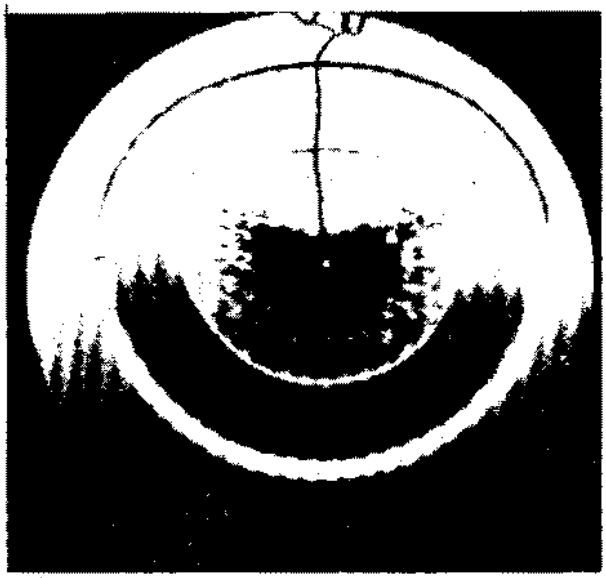

Figure 2—Pressure Wave in Air from Fired Detonator.

Under water, the first effect of the completed explosive reaction is the impact of the extremely high pressure of the released gases on the surrounding envelope of water. This impact develops a pressure wave that travels away from the detonated explosive in all directions at supersonic speed, figure 3. Up to this point, the effect is the same as for a reaction in air except that the pressure wave developed under water does not become a shock wave. From this point on, how-

[1] Certain inert solid particles remain after detonation, but may be disregarded for the purposes of this discussion.

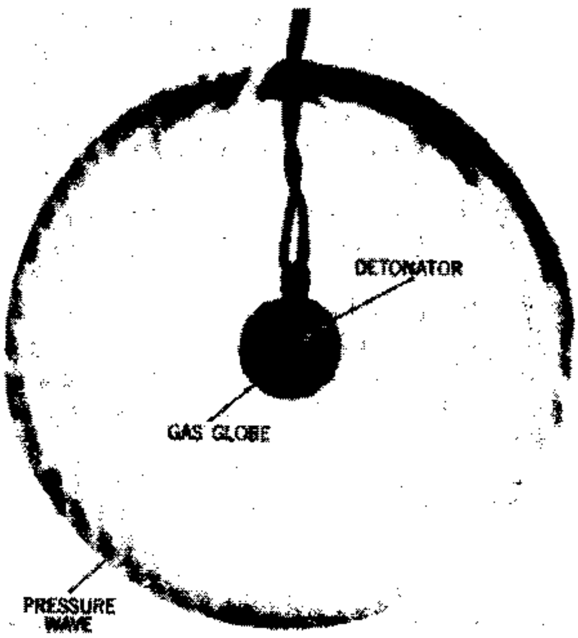

Figure 3—Pressure Wave in Water from Fired Detonator.

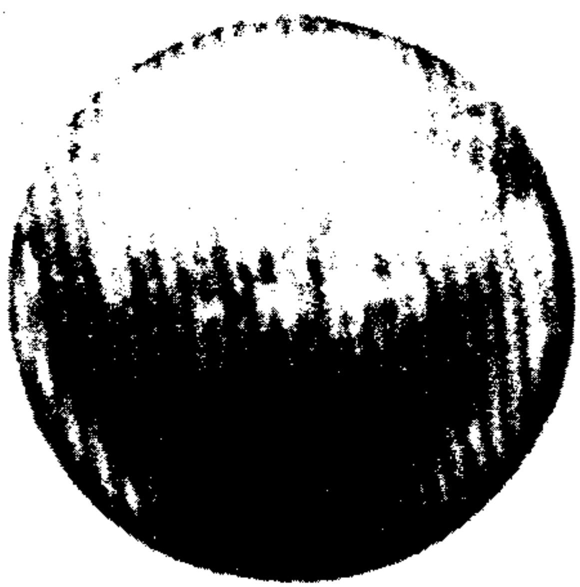

Figure 4—Underwater Gas Globe.

ever, the effects differ. Under water, the gases released by the explosive reaction expand rapidly, compressing the surrounding layers of water and thrusting the water away from the point of origin. The potential energy of the gas pressure is changed to kinetic energy as the water is thrust back. The gases expand enough so that the pressure within the "bubble" drops below that of the surrounding water. Hydraulic pressure then "collapses" the bubble down to a volume approaching that at the instant of detonation. The surrounded gases then start to expand again; at the instant expansion starts for the second time, the impact of the gas pressure against the surrounding water causes a second pressure wave similar to the first. Alternate expansion and contraction of the bubble, figure 4, continues until the bubble breaks the surface of the water and the gases are exhausted to atmosphere. Each expansion causes a pressure wave similar to the first. These successive pressure waves are called bubble pulses. In addition to the effect these pulses have on objects in their path under water, there is a secondary effect on the objects due to the thrust of the water as it is pushed back bodily by the expanding gases.

Figure 5—Fragmentation Effect of a Charge Casing Exploded in Air.

The shattering effects of air and water explosions are different. The fragmentation pattern of a charge casing exploded in air, figure 5, shows innumerable small splinters. The same amount of explosive detonated under water, figure 6, produces fewer, but larger fragments because of the retarding effect of the water.

Figure 6—Fragmentation Effect of a Charge Casing Exploded in Water.

The preceding paragraphs outline the basic differences between explosions in air and under water, figures 7 and 8. Other factors influence the effects of an under water explosion, such as the placement of the high explosive relative to an object or the situation of the object itself. For example, a charge placed against hull plating will have a completely different effect when the compartment behind the plating is a void (filled with air) than when it is filled with a liquid, such as oil or water. Figure 9 shows the wide variation in equal pressure zones produced when equal amounts of an explosive are detonated near the surface, near the bottom, and midway between the two. The contour and type of bottom also modify the effects of an underwater explosion. Within practical limitations, the effects of a specific charge under a specified set of conditions cannot be predicted with accuracy because of the many variables involved.

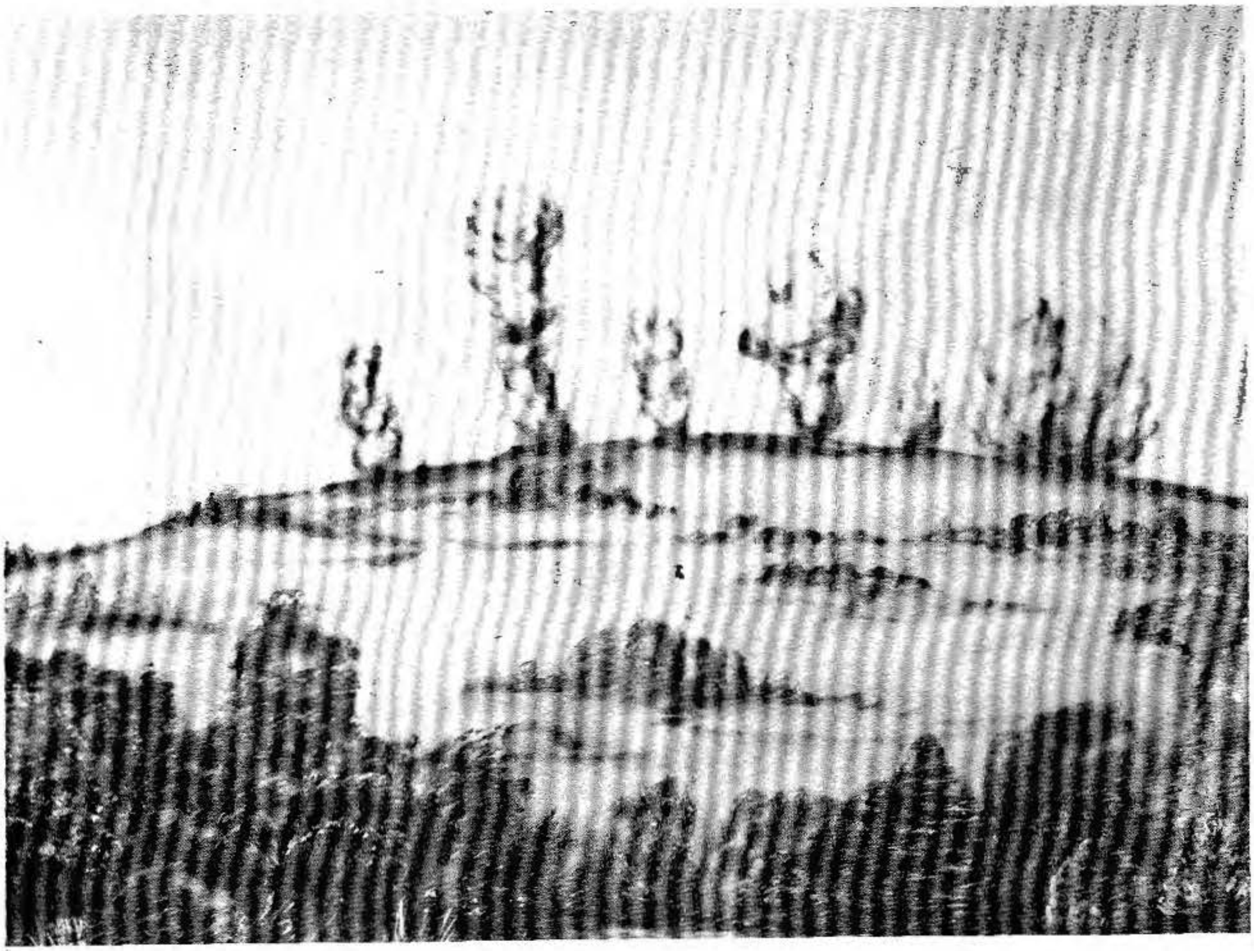

Figure 7—Typical Surface Explosion.

Figure 8—Typical Underwater Explosion.

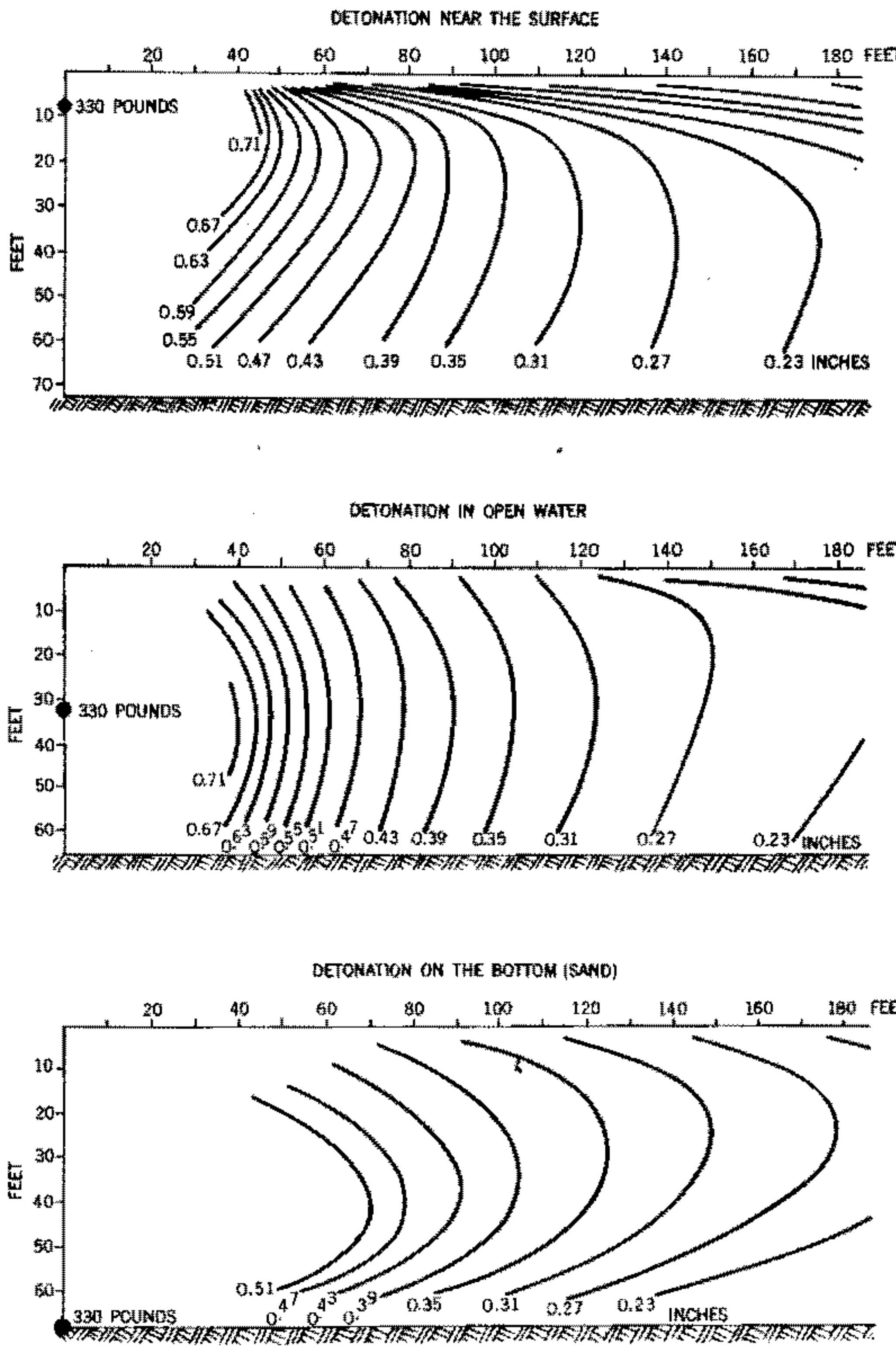

Figure 9—Equal Pressure Zones.

Therefore, the size and placement of a charge for underwater salvage must be determined by the salvage officer based on fundamentals and on his own past experience.

Military and Commercial High Explosives

Basic Characteristics. Tables 1, 2, 3, and 4 give the basic characteristics of domestic and foreign military and commercial high explosives. In general, military high explosives have higher velocities of detonation, greater relative effects (based on the effect of TNT as unity), higher loading densities, and less sensitivity than commercial explosives. Propellants and other burning or progressive explosives are not suitable for underwater use; therefore, such explosives are not listed in the tables.

Magazine Locations. To safeguard other facilities from the effects of a magazine explosion, magazines must be isolated. Table 5 shows the minimum distances required for safety between magazines containing military explosives and other facilities. Table 6 gives similar information for magazines containing commercial explosives.

Table 1—Comparative Effects of Military and Commercial Explosives

Explosive	Use	Relative[1] effect	Loading density	Velocity (feet per second)
TNT (trinitrotoluene)	Military	1.00	1.57	21,000
Ammonium nitrate	do	.42		11,000
Tetrytol	do	1.20	1.60	23,000
Tetryl	do	1.26	1.55	23,000
Composition C-3, C-4	do	1.3	1.59	26,000
Composition C-2	do	1.34	1.57	26,000
RDX (cyclonite)	do	1.50	1.65	25,000
Nitramon[2]	Commercial			20,000
Blasting gelatin[2]	do	.9		20,000
60 percent gelatin dynamite[2]	do	.76	1.34	16,000
50 percent gelatin dynamite[2]	do	.47		9000
40 percent gelatin dynamite[2]	do	.42		8000
60 percent straight nitro-glycerin dynamite	do	.83	1.22	19,000
40 percent straight nitro-glycerin dynamite	do	.65		15,000

[1] Figures based on TNT as unity (1.00).
[2] Used in military operations also.

Table 2—Properties of Dynamite

Grade	Strength (percent)		Loading density[1]	Velocity[2] (feet per second)	Water resistance
	Weight	Bulk			
Straight dynamite	15-35	15-35	102	8200-12,800	Poor.
	40-50	40-50	102-104	13,800-16,100	Good.
	60	60	106	18,200	Excellent.
Ammonia dynamite	15-35	11-29	110	7400-9600	Fair.
	40-60	35-55	110	10,400-12,800	Good.
Gelatin dynamite	20-60	30-59	85-96	10,500-19,700	Excellent.
	75-90	67-79	101-107	20,600-22,300	Do.
Special (ammonium) gelatin	30-30	35-70	88-107	13,100-17,100	Do.
	90	90	109	19,700	Do.
Hi-velocity gelatin	50-80	41-56	100-120	18,000-21,600	Do.
Blasting gelatin	100	100	110	23,000	Do.

[1] Commercial density is given in terms of the number of (1¼ by 8 inches) cartridges per 50-pound case.
[2] Where a range of velocity is given, the rate of detonation of the initiator will determine the velocity of detonation of the charge.

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Table 3—U. S. Military Explosives

Explosive	Physical characteristics	Velocity (feet per second)	Priming	General effects (TNT external charge=1.00)
Composition C-3 (RDX).	Plastic, easily molded at temperatures between −20° and +125° F.; sensitivity about equal to TNT; has good water resistance. Packaged in 2¼-pound blocks (M3 demolition block) and ½-pound blocks (M4 demolition block), fig. 10. Also available in 2-pound blocks as Demolition Charge Mk 20 Mod 0 in Demolition Outfit Mk 135 Mod 0. Gives off poisonous fumes after detonation.	26,000	Detonating cord and/or Bureau of Ordnance special blasting cap. (The Corps of Engineers special cap is exactly the same as that issued by the Bureau of Ordnance.)	Used for general military purposes. Fair value as a cratering charge. External charge 1.26.
Composition C-4 (RDX).	Similar to Composition C-3; is replacing C-3.			
Trinitrotoluene (TNT)	Crystalline substance; light brown color; fairly stable; does not deteriorate; water resistant; packaged in ½-lb. and 1-lb. blocks, fig. 11; gives off poisonous gases after detonation; density 1.58; melting point 80.8° C.; explosion temp. 295–300° C.; very toxic.	21,000	Detonating cord and/or Bureau of Ordnance special blasting cap.	Used primarily for cutting and breaching, but may be used for general demolition work. Good value as cratering charge.
Ammonium (nitrate)	Crystalline powder white to brown in color; insensitive to heat and friction; fairly inflammable; deteriorates fast when exposed to air; not resistant to moisture; packed as 40-pound charge, fig. 12; produces poisonous gases after explosion; density 1.30; melting point 169.5° C.; decomposition temp. 200° C.	11,000	Detonating cord and/or Bureau of Ordnance special blasting cap or Corps of Engineers special electric or nonelectric blasting cap.	Cratering charge value excellent. External charge effect 0.42. Unsuitable for steel cutting charges.
Pentaerythrit tetranitrate (PETN).	White crystal powder; soluble in water; great energy and brisance; can be detonated by bullet; density 1.61; melting point 141° C.; explosion temp. 200–205° C.	26,400		Used primarily in detonating cords; a high-velocity fuse, used for firing a number of charges nearly simultaneously.
Tetryl	Crystalline powder; yellow color; stable at all temperatures encountered in storage; more sensitive to shock and friction than TNT; readily exploded by penetration of a rifle bullet; water resistant; density 1.68; high brisance; melting point 131° C.; explosion temp. 185–195° C.; very toxic.	23,000		Used as a booster explosive.
Tetrytol	Mixture of tetryl (75 percent approximate) and TNT; about twice as sensitive and 1.2 times more powerful than TNT; packaged in chain blocks as M1 (fig. 13), and M2 demolition block. Nonhygroscopic.	23,000 to 24,500	Detonating cord and/or Bureau of Ordnance special blasting cap or Corps of Engineers special electric or nonelectric blasting cap.	Cutting and breaching charge; cratering charge value is fair; external charge effectiveness is 1.20.

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Table 3—U. S. Military Explosives—Continued

Explosive	Physical characteristics	Velocity (feet per second)	Priming	General effects (TNT external charge=1.00)
Amatol	Mixture of ammonium nitrate and TNT. 2 common types are 50/50 density 1.60, and 80/20 (80 percent ammonium nitrate) density 1.57; insensitive to friction; absorbs moisture readily.	50/50 amatol, 23,000; 80/20 amatol, slightly less than 21,000.		Use primarily for cutting and breaching, but may be used for general demolition work. Substitute for TNT.
Ammonium picrate (explosive D).	Crystalline powder; orange yellow color; insensitive to shock and friction; highly inflammable; inferior to TNT on explosive power; poor water resistance.			Bursting charge for armor piercing projectiles.
Nitrostarch	White powder; more sensitive to impact than TNT; highly inflammable; deteriorates when exposed to moisture; produces poisonous gases after explosion. Packed in 1-pound and ½-pound packages.	15,000	Detonating cord and/or Bureau of Ordnance special blasting cap.	Good value as cratering charge. External charge effect 0.86.
RDX (cyclonite)	White crystalline powder; insoluble in water; melting point is 200° C.; added to TNT. High degree of stability in storage.	25,000		External charge effect 1.50.
RDX—composition A	Gray to buff color; contains 91 percent RDX and 9 percent beeswax. Granular in form; insensitive; high brisance.			
RDX—composition B	Contains 60 percent RDX, 39 percent TNT, and 1 percent beeswax; nonplastic; more sensitive than TNT.			
RDX—composition C	Contains 88 percent RDX and 12 percent plasticising oil; buff in color; plastic substance; water resistant; highly inflammable; high brisance; gives off poisonous fumes after detonation.		Detonating cord and/or Bureau of Ordnance special blasting cap or Corps of Engineers special cap.	Demolition explosive.
Torpex [1]	Contains 42 percent RDX, 40 percent TNT, 18 percent aluminum powder, and a fraction of 1 percent of beeswax; hard gray, mortar-like substance; very sensitive to impact; highly inflammable; nonhygroscopic; density 1.70.			External effect, 1.50 in air and 1.70 under water.
Nitramon (commercial)	Extremely insensitive to shock; nonfreezing; packaged in waterproof metal cans 4½-inches to 9-inches in diameter, by 24-inches long, fig. 14.	11,000	Special Nitramon primer with detonating cord or blasting cap.	Good cratering charge (used in powder points).
Blasting gelatin (commercial).	Para rubber substance; absolutely waterproof; sensitivity equal to other gelatins; gives off poisonous fumes after detonation; packaged in ½-pound cartridges 1¼-inches in diameter by 8-inches long, fig. 15.	8600 to 26,000	Detonating cord and/or Bureau of Ordnance special blasting caps.	Excellent for underwater work.

[1] Not currently being procured.

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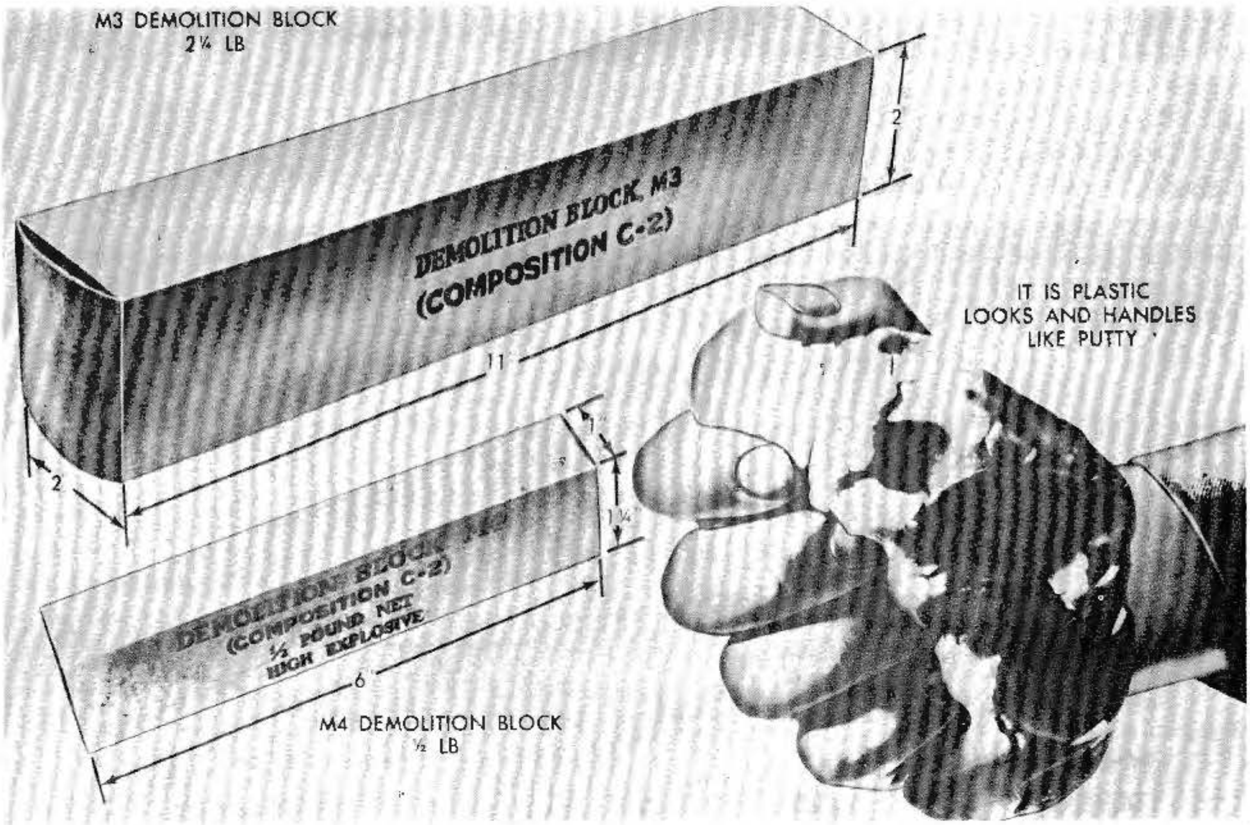

Figure 10—Demolition Blocks M3 and M4.

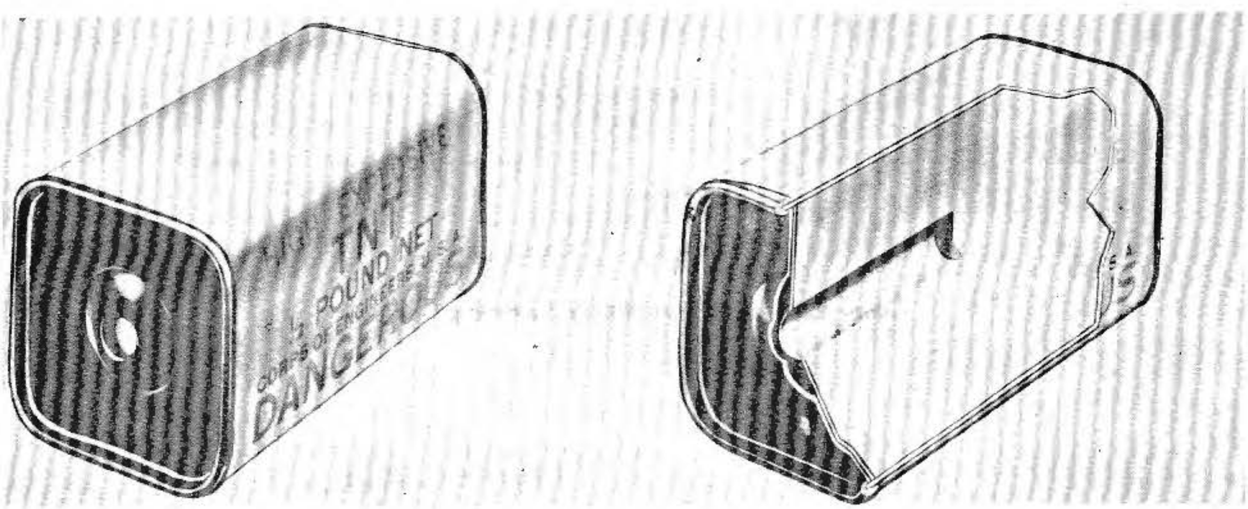

Figure 11—TNT Block, One-half Pound.

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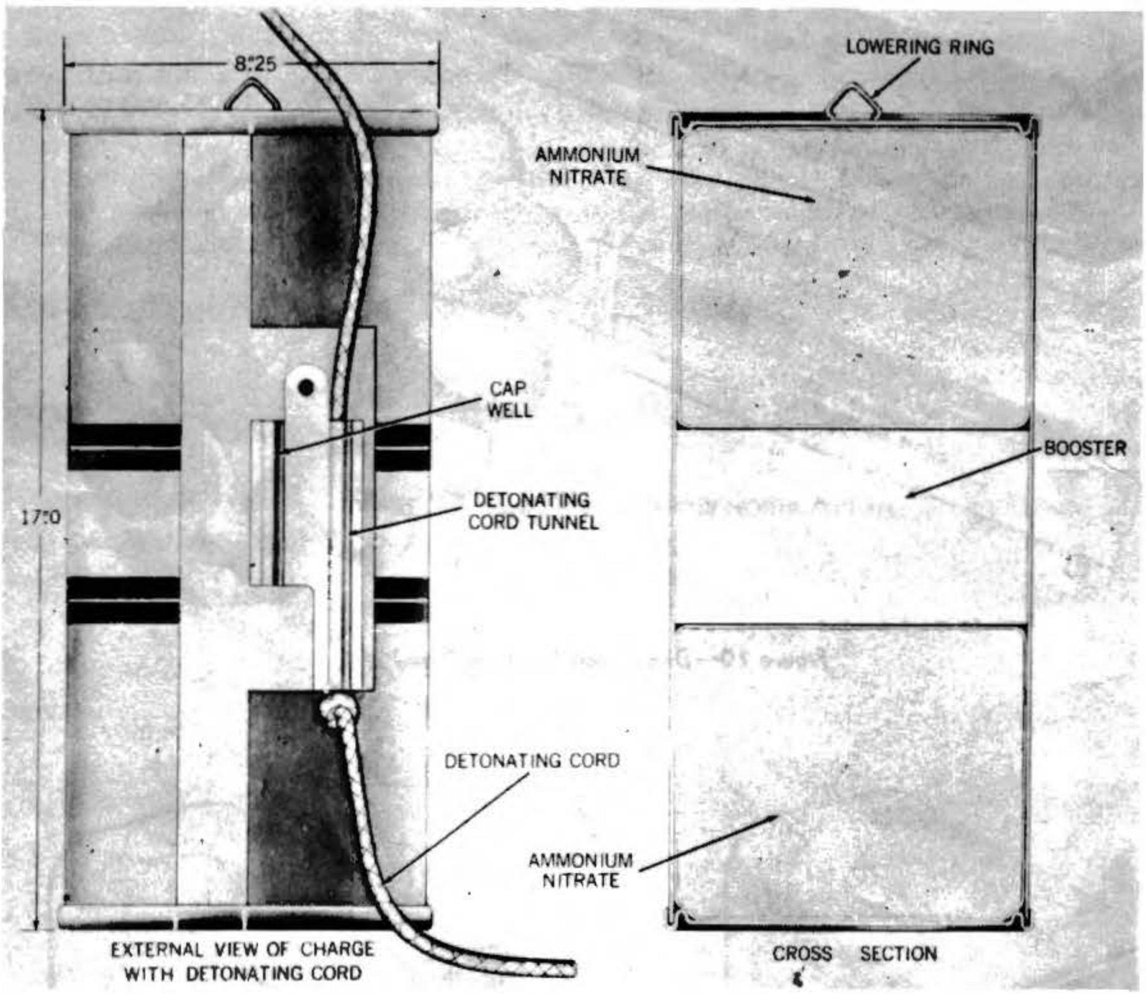

Figure 12—Ammonium Nitrate Cratering Charge.

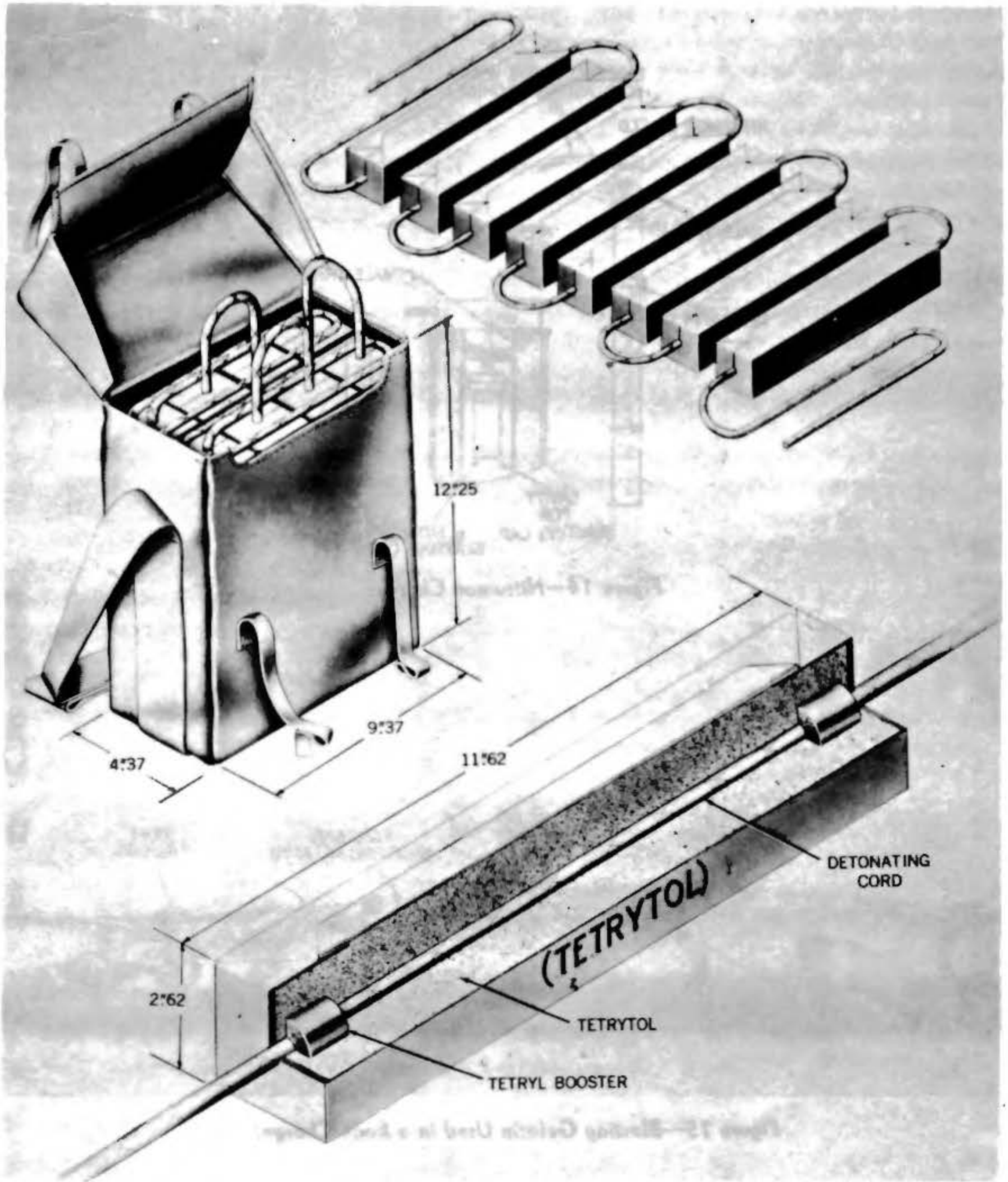

Figure 13—Chain Demolition Blocks M1.

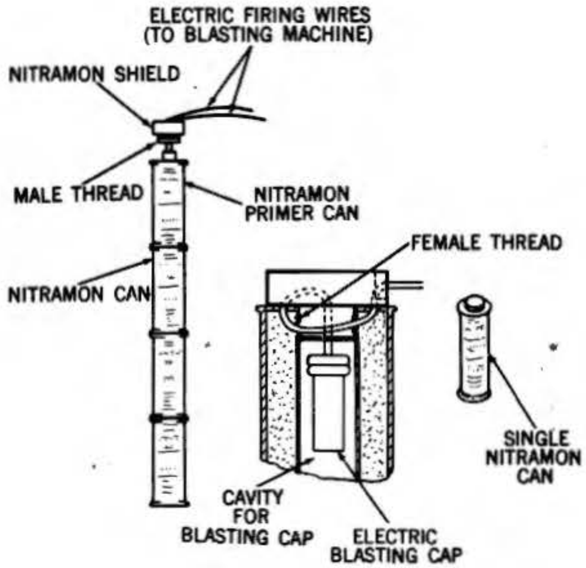

Figure 14—Nitramon Charge.

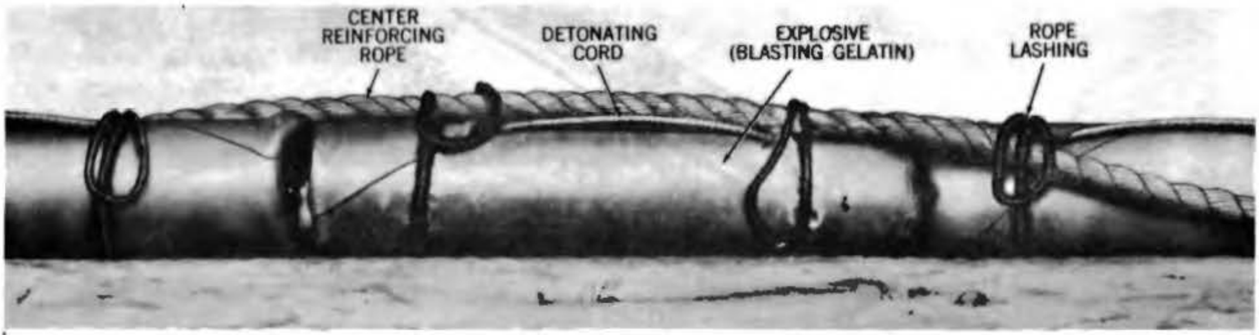

Figure 15—Blasting Gelatin Used in a Rope Charge.

Table 4—Foreign Military Explosives

Great Britain

Explosive	Effectiveness (TNT = 1.00)	Velocity (feet per second)	Value as a cratering charge	Principal uses	Packaging
C. E. TNT demolition slabs	1.16	22,800	Fair (generally not used).	All purpose, except borehole and camouflet charges.	1-pound slabs, 14 slabs in tin box; total weight 26 pounds. 2-pound slabs, 10 slabs in plywood box.
Plastic H. E.	1.3	24,200	Fair	Boreholes, cutting charges, and mined charges.	4-ounce cartridge, 1¼-inch diameter, 4 inches long cellophane wrapped; four 5-pound cartons, packed in wooden box.
808 plastic	1.3	23,800	do	All purpose	4-ounce waxed paper cartridge, 1¼-inch diameter, 3 inches long; four 5-pound cartons packed in wooden box.
Guncotton (obsolete)	Wet, 0.9 Dry, 1.1	16,800 22,100	do	All purpose, except borehole and camouflet charges.	19-ounce slab (including 3 ounces of water), 6 by 3 inches, 1⅝ inches thick; 14 slabs in tin box, packed in wooden crate; total weight 25 pounds.
852 plastic	1.2	23,600	do	All purpose	4-ounce waxed paper cartridge, 1¼-inch diameter, 3 inches long; four 5-pound cartons packed in wooden box.
Ammonal (likely to become obsolete).	.5	11,000	Good (detonation must not be delayed).	All purpose, except cutting. Do not use in damp places or on deferred demolitions.	25 pounds in tin box, 9 by 9 inches 9¼ inches thick; 3 boxes in crate; total weight 114 pounds.
Polar N. S. gelignite	.9	18,400	Good	Boreholes and mined charges particularly suitable in tunneling; dangerous if frozen.	4-ounce paper-wrapped cartridges; ten 5-pound cartons in a 50-pound wood case; total weight 56 pounds.

France

Explosive	Effectiveness (TNT = 1.00)	Velocity (feet per second)	Value as a cratering charge	Principal uses	Packaging
Picric acid (melinite)	1.0	21,500	Good	All purpose	Block demolition charges, model 28, packed in brass case in weights of 135 grams, 1 kilogram, 10 kilograms, and 20 kilograms. Block demolition charges, model 31A, in brass case, 1 kilogram. Small cylinder, 2⅝ ounces in brass case, 1⅛-inch diameter, 4⅛ inches long. Large cylinder, 1 kilogram in brass case, 2¼-inch diameter, 6⅝ inches long.

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Table 4—Foreign Military Explosives—Continued

Germany

Explosive	Effectiveness (TNT=1.00)	Velocity (feet per second)	Value as a cratering charge	Principal uses	Packaging
TNT	1. 0	21, 500	Good	All purpose	Bohrpatrone 28, 3½-ounce waxed paper. Sprengkoper 28, 7-ounce block. Sprengbuchse 24, 2-pound, 3-ounce block. Gebalite ladung, 10-kilogram block in zinc container. 50-kilogram hollow-shaped charge.
Picric acid	1. 0	21, 500	do	do	Bohrpatrone 28, 3½-ounce waxed paper. Sprengkoper 28, 7-ounce block. Sprengbuchse 24, 2-pound, 3-ounce block. Gebalite ladung, 10-kilogram block in zinc container.
RDX/TNT (50 percent RDX and 50 percent TNT).	1. 2	22, 800	Fair	All purpose, good cutting charge.	12.3-kilogram demolition charge. 13.5-kilogram hollow-shaped charge. 3-kilogram magnetic charge.
Plastite RDX/oil	1. 3	25, 000	do	All purpose, cutting and pressure charges.	1-pound 2-ounce.
Penthrite/wax (PETN compressed).	1. 2	24, 200	do	All purpose	400-gram, hollow-shaped charge. 300-gram, hollow-shaped charge.

Italy

Explosive	Effectiveness (TNT=1.00)	Velocity (feet per second)	Value as a cratering charge	Principal uses	Packaging
TNT	1. 0	21, 500	Good	All purpose	100-gram (3½-ounce) block charge. 150-gram (5¼-ounce) block charge. 100-gram (3½-ounce) cartridge charge.
Penthrite (PETN compressed).	1. 2	24, 200	Fair	do	200-gram (7-ounce) block charge. 500-gram (1-pound, 1½-ounce) block charge.

Japan

Explosive	Effectiveness (TNT=1.00)	Velocity (feet per second)	Value as a cratering charge	Principal uses	Packaging
O-Shokuyaku (picric acid)	1. 0	21, 500	Good	All purpose	2-pound, 3-ounce prepared charge. 4-ounce prepared charge. 97 3½-ounce blocks packed in wooden box. 97 3½-ounce sticks packed in a wooden box. 1-kilogram demolition can. 5-kilogram demolition can.
Plastic explosive RDX 80 percent (vegetable oil 20 percent).	1. 3	26, 250	Fair	do	4-ounce charge wrapped in parchment paper.
Ni-go Tan-o-yaku (compressed) RDX 50 percent; TNT 50 percent.	1. 1	22, 800	do	All purpose, cutting and pressure charges.	30-kilogram square blocks. 97 3½-ounce sticks packed in a wooden box.

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Russia

TNT	1. 00	23, 000	Good	
XYLIL	1. 00	21, 700	do	
Picric acid (melinite)	1. 10	23, 300	do	
Tetryl	1. 20	25, 400	Poor	
Ammonium nitrate	(1)	16, 400–17, 700	Excellent	
PETN (ten)	(1)	27, 600	Poor	
93 percent dynamite (93 percent jellied fulminate).	(1)	25, 600	Fair	
63 percent dynamite (63 percent nitroglycerine).	(1)	21, 700	Good	

[1] Information not available.

Table 5—Magazine Location (Military Explosives)

Quantity, pounds of explosive (not over)—	Minimum distance nearest (feet)			
	Inhabited building	Public railway	Public highway	Magazine
50	145	90	45	60
100	240	140	90	80
2000	1200	720	360	230
25,000	2140	1290	640	300
100,000	3630	2180	1090	400
250,000 [1]	4310	2590	1300	800

[1] Maximum permitted in any one magazine.

Table 6—American Table of Distances[1] For Storage of Explosives (Commercial)

Explosives		Distances when storage is barricaded (feet)		
Pounds, over—	Pounds, not over—	Inhabited buildings	Passenger railways	Public highways
2	5	70	30	30
5	10	90	35	35
10	20	110	45	45
20	30	125	50	50
30	40	140	55	55
40	50	150	60	60
50	75	170	70	70
75	100	190	75	75
100	125	200	80	80
125	150	215	85	85
150	200	235	95	95
200	250	255	105	105
250	300	270	110	110
300	400	295	120	120
400	500	320	130	130
500	600	340	135	135
600	700	355	145	145
700	800	375	150	150
800	900	390	155	155
900	1000	400	160	160
1000	1200	425	170	165
1200	1400	450	180	170
1400	1600	470	190	175
1600	1800	490	195	180
1800	2000	505	205	185
2000	2500	545	220	190
2500	3000	580	235	195
3000	4000	635	255	210
4000	5000	685	275	225
5000	6000	730	295	235
6000	7000	770	310	245
7000	8000	800	320	250
8000	9000	835	335	255
9000	10,000	865	345	260
10,000	12,000	875	370	270

[1] Established by the Institute of Makers of Explosives.

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Table 6—American Table of Distances[1] For Storage of Explosives (Commercial)—Continued

Explosives		Distances when storage is barricaded (feet)		
Pounds, over—	Pounds, not over—	Inhabited buildings	Passenger railways	Public highways
12,000	14,000	885	390	275
14,000	16,000	900	405	280
16,000	18,000	940	420	285
18,000	20,000	975	435	290
20,000	25,000	1055	470	315
25,000	30,000	1130	500	340
30,000	35,000	1205	525	360
35,000	40,000	1275	550	380
40,000	45,000	1340	570	400
45,000	50,000	1400	590	420
50,000	55,000	1460	610	440
55,000	60,000	1515	630	455
60,000	65,000	1565	645	470
65,000	70,000	1610	660	485
70,000	75,000	1655	675	500
75,000	80,000	1695	690	510
80,000	85,000	1720	705	520
85,000	90,000	1760	720	530
90,000	95,000	1790	730	540
95,000	100,000	1815	745	545
100,000	110,000	1835	770	550
110,000	120,000	1855	790	555
120,000	130,000	1875	810	560
130,000	140,000	1890	835	565
140,000	150,000	1900	850	570
150,000	160,000	1935	870	580
160,000	170,000	1965	890	590
170,000	180,000	1990	905	600
180,000	190,000	2010	920	605
190,000	200,000	2030	935	610
200,000	210,000	2055	955	620
210,000	220,000	2100	980	635
230,000	250,000	2155	1010	650
250,000	275,000	2215	1040	670
275,000	300,000	2275	1075	690

NOTE 1.—Barricaded, as here used, signifies that the building containing explosives is screened from other buildings, railways, and from highways, by either natural or artificial barriers. Where such barriers do not exist the distances shown in the table should be doubled.

NOTE 2.—The Institute of Makers of Explosives does not approve the permanent storage of more than 300,000 pounds of commercial explosives in 1 magazine.

NOTE 3.—This table applies only to the manufacture and permanent storage of commercial explosives. It is not applicable to transportation of explosives or any handling or temporary storage necessary or incident thereto. It is not intended to apply to bombs, projectiles, or other heavily encased explosives.

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Chapter 3

DEMOLITION EQUIPMENT AND ACCESSORIES

Demolition charges, outfits, equipment, and accessories of standard design and issue are described in OP 1839, Underwater Demolition Materials and Their Uses. Use these stock items whenever practicable as they are particularly suited to salvage operations. However, salvage units may be required to operate in areas remote from supply lines or where the flow of supplies is erratic. Under such conditions, make full use of any suitable explosives and equipment available locally, including foreign military and commercial explosives. Accessories commonly used in underwater demolition work of special interest or not covered in OP 1839 are listed in this chapter.

Blasting Caps

A blasting cap is a detonator used to initiate main charges, boosters, detonating cords, and other initiators. The cap is extremely sensitive and must be protected against heat and shock.

Special NonElectric Blasting Cap. The special nonelectric blasting cap, figure 16, is an openend shell into which is crimped a fuse or the snout of a coupling base. The cap includes a flash charge, a priming charge, and a base charge. The flash from the fuse or coupling base sets off the flash charge; the flash charge then sets off the priming charge which detonates the base charge.

Special Electric Blasting Cap. The special electric blasting cap, figure 17, consists of a PETN base charge, a priming charge, bridge wire, and two 12-foot leg wires sealed into the end of an aluminum or copper shell. When voltage is applied to the leg wires, the current through the bridge wire heats it sufficiently to detonate the priming charge which then detonates the base charge.

Special electric blasting caps are the only caps that positively will detonate all present military explosives. Boxes containing these caps are marked "Will Detonate Composition C." The Bureau of Ordnance issues three different makes,

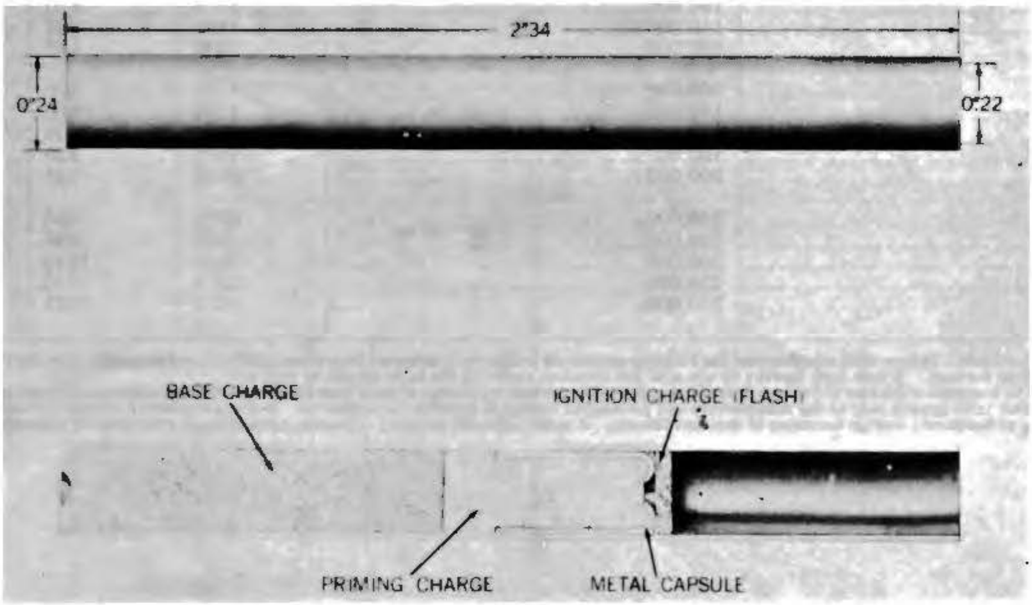

Figure 16—Special Nonelectric Blasting Cap.

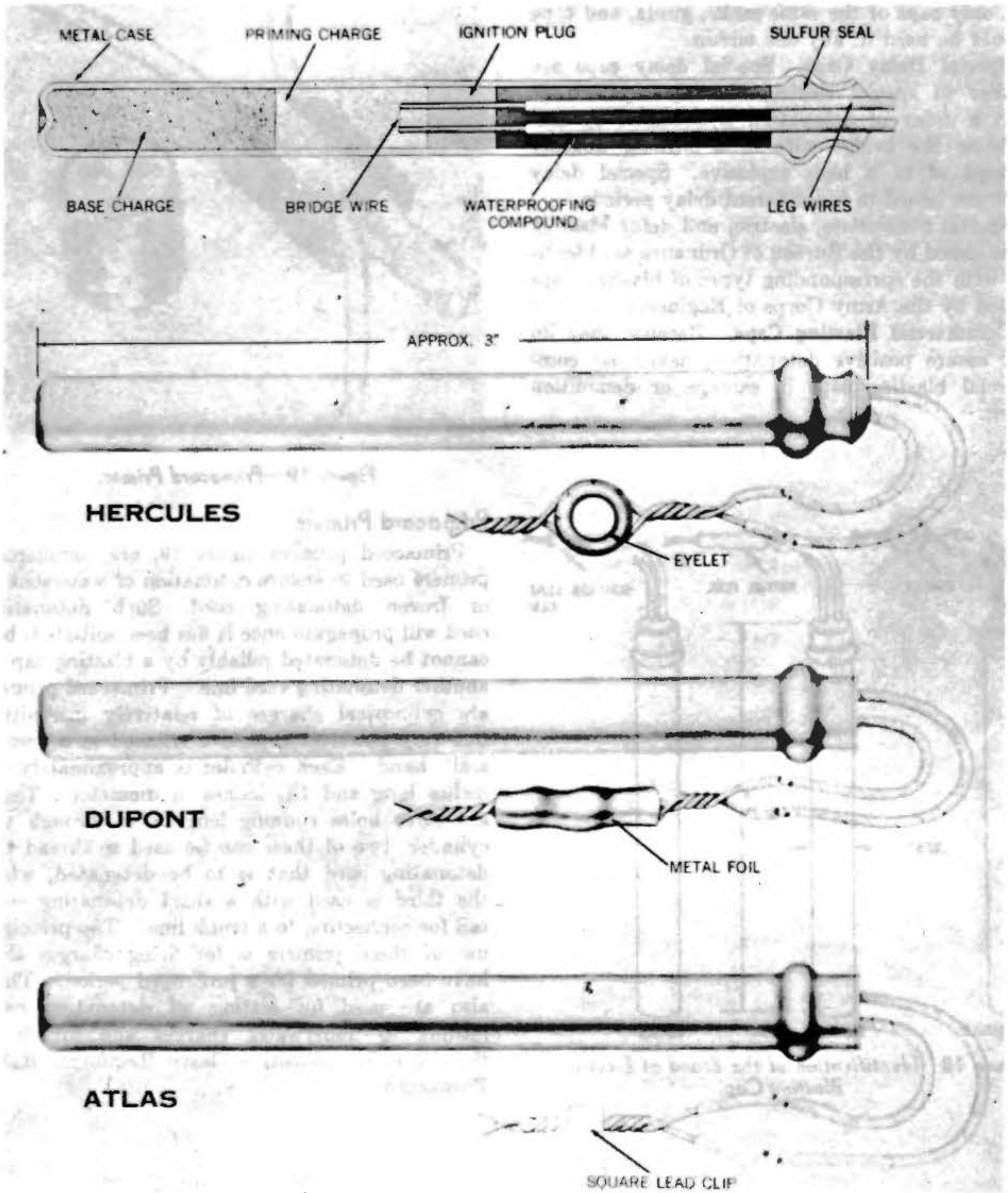

Figure 17—Special Electric Blasting Cap.

figure 18, to naval activities for combat use, but only caps of the same make, grade, and type should be used in any one circuit.

Special Delay Caps. Special delay caps are similar to special electric blasting caps except that a delay in detonation is obtained by embedding the bridge wire in a burning mixture instead of in a high explosive. Special delay caps are issued in ten different delay periods.

Special nonelectric, electric, and delay blasting caps issued by the Bureau of Ordnance are identical with the corresponding types of blasting caps issued by the Army Corps of Engineers.

Commercial Blasting Caps. Because they do not assure positive detonation, never use commercial blasting caps in salvage or demolition work.

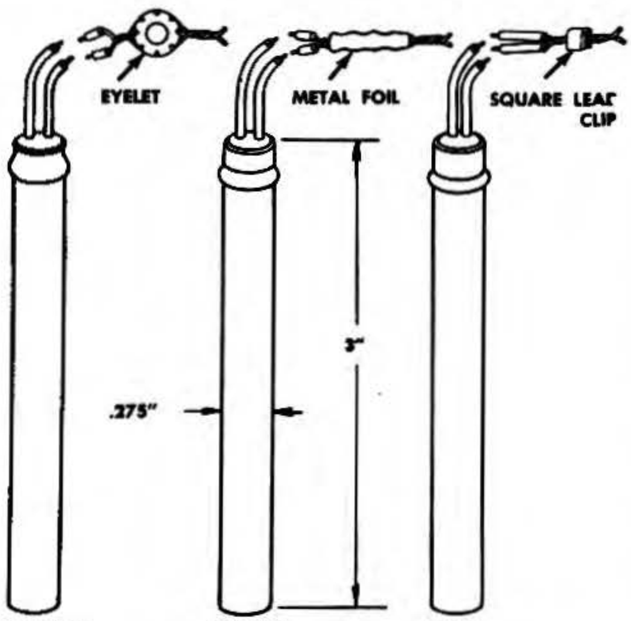

Figure 18—Identification of the Brand of Electric Blasting Cap.

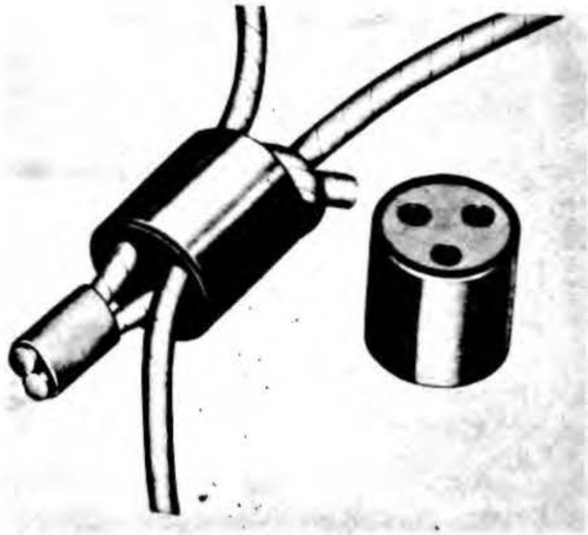

Figure 19—Primacord Primer.

Primacord Primers

Primacord primers, figure 19, are commercial primers used to ensure detonation of watersoaked or frozen detonating cord. Such detonating cord will propagate once it has been initiated, but cannot be detonated reliably by a blasting cap or another detonating cord line. Primacord primers are cylindrical charges of relatively insensitive but very powerful explosive encased in a "cel-o-seal" band. Each cylinder is approximately 1 3/8 inches long and 1 7/32 inches in diameter. There are three holes running lengthwise through the cylinder; two of these can be used to thread the detonating cord that is to be detonated, while the third is used with a short detonating cord tail for connecting to a trunk line. The principal use of these primers is for firing charges that have been primed for a prolonged period. They also are used for setting off detonating cord leading to underwater charges and for firing the relatively insensitive Plastic Reinforced RDX Primacord.

Chapter 4

PRIMING OF CHARGES

A complete salvage demolition charge consists of a main charge, a booster, and an initiator. In some cases, the booster is omitted. The connection of the initiator and booster to the main charge is known as "priming" the charge. Standard military charges and outfits include the necessary booster charges and are equipped with activator wells or detonating cord to facilitate connections with firing accessories.

Salvage demolition charges may be detonated individually or in groups. When charges are to be detonated in groups, they may be connected to detonate successively or simultaneously. Charges may be detonated either by electrical or nonelectrical means or by a combination of both.

Priming Connections

When a series of charges is electrically detonated simultaneously, a firing wire must be connected between the blasting caps and the blasting machine; all blasting caps must be the product of the same manufacturer. If the series is to be detonated nonelectrically, the charges are to be connected by a detonating cord. The detonating cord then is connected for firing by one of three methods: (1) nonelectric blasting cap and time fuse; (2) firing device and detonating cord initiator; or (3) electric blasting cap, firing wire, and blasting machine.

Charges with Threaded Activator Wells

Charges with threaded activator wells are primed with an electric or a nonelectric blasting cap. Priming adapters are designed for use with this type charge as described in the following paragraphs.

Electric Priming. To prime a charge with an electric blasting cap, figure 20, pass the cap wires through the wire slot of the priming adapter, place the wire end of the blasting cap in the larger bore of the adapter, and then screw the adapter into the activator well.

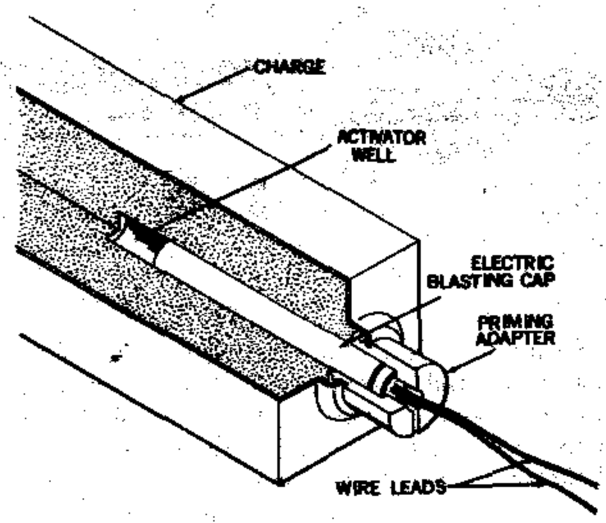

Figure 20—Priming Charges with Electric Blasting Cap.

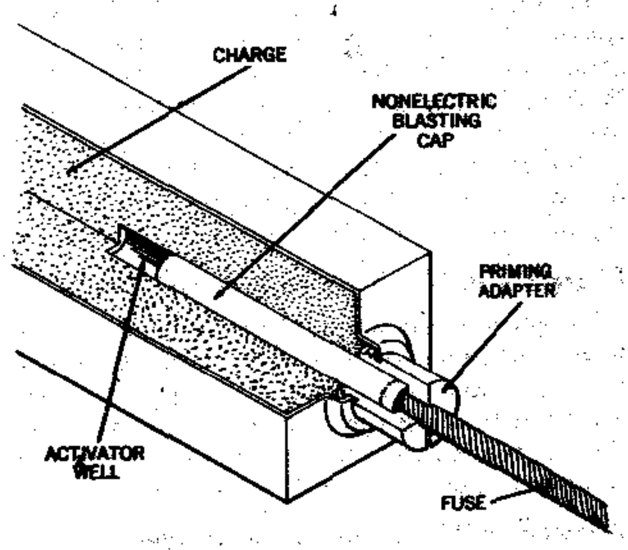

Figure 21—Priming Charges with Nonelectric Blasting Cap.

Nonelectric Priming. For nonelectric priming of a charge with a threaded activator well, use the adapter for priming with time blasing fuse, or use a firing device with a nonelectric blasting cap.

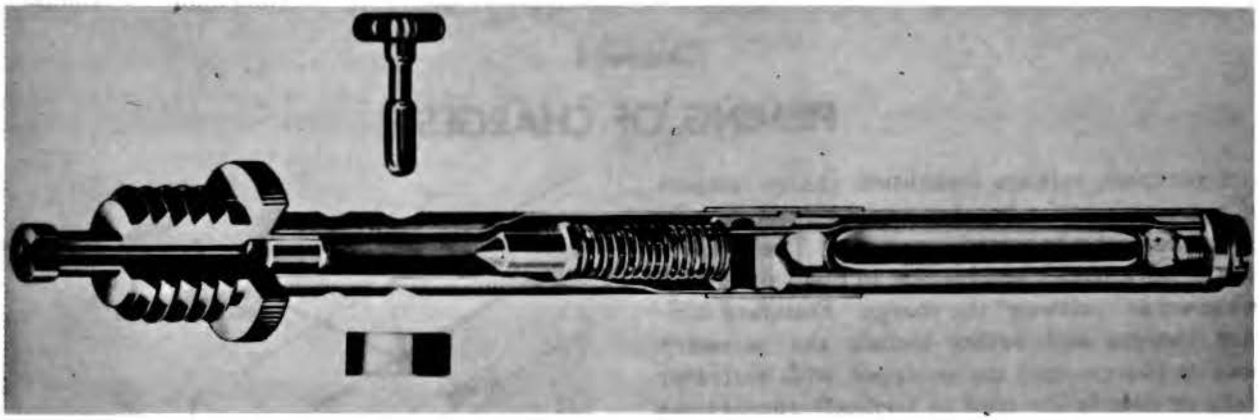

Figure 22—Firing Device.

To prime with a time blasting fuse, figure 21, first cut off and discard about three inches of the fuse to make sure that no absorbed moisture remains at the end of the fuse. Insert the cut end of the fuse through the priming adapter. Crimp a nonelectric blasting cap to the fuse, push the cap into the adapter, and screw the adapter into the activator well.

To prime with a firing device, first screw a coupling base into the firing device. Then place a cap sleeve over the snout of the coupling base. Without forcing, push a nonelectric blasting cap over the cap sleeve and snout. Crimp the cap on the coupling base with a pair of cap crimpers. Screw the assembled firing device and blasting cap into the activator well, figure 22.

Charges with Nonthreaded Activator Wells

No adapters are provided for use with charges having nonthreaded activator wells. To prime this type charge, place the electric cap, nonelectric cap, or detonating cord extender in the well, and then tie the cap wire, cap fuse, or detonating cord securely to the charge.

Ammonium Nitrate Cratering Charges

Electric Priming. To prime a 40-pound ammonium nitrate cratering charge, place an electric cap in the cap well on the side of the can. Wrap the cap wires three times around the cleat above the well. Connect the firing wire to the blasting machine.

Nonelectric Priming. For nonelectric firing of an ammonium nitrate cratering charge, prime the 40-pound can with a nonelectric blasting cap or with detonating cord.

When priming with a nonelectric blasting cap, place the fused cap in the cap well on the side of the can. Tie a string around the fuse and then around the cleat above the cap well to hold the cap in place. This method of priming cannot be used for simultaneous firing of several charges.

When priming with detonating cord, pass the cord through the tunnel on the side of the 40-pound can and tie a knot in the cord six inches from the end. When the charge is to be used in a borehole, prime with detonating cord and connect the cord for firing by a nonelectric cap and fuse.

Demolition Charges

Demolition Charge Mk 8 Mod 0. Prime Demolition Charge Mk 8 Mod 0 (explosive hose, 25 feet long, 2⅛ inches in diameter), figure 23, with electric blasting cap, nonelectric blasting cap, or detonating cord. When priming with electric cap, insert the cap with firing wire attached into the well at the end of the charge. When priming with nonelectric cap, insert the cap with fuse attached into the same well. When detonating cord is used without a detonating cord extender, the cord must be wrapped around one end of the

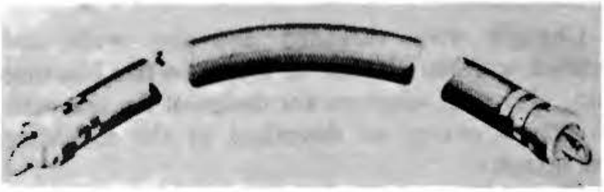

Figure 23—Demolition Charge Mk 8 Mod 0.

charge at least six turns and secured to the charge with sash cord or line of equal strength.

Demolition Charge Mk 14 Mod 0. This demolition charge, figure 24, has a self-contained tetrytol booster and detonating cord. Prime the detonating cord with a blasting cap.

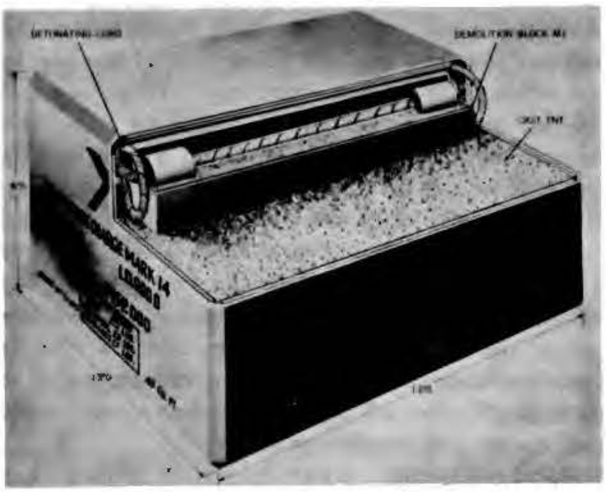

Figure 24—Demolition Charge Mk 14 Mod 0.

Fabricated Charges

Line Charge. A line charge is a chain of charges of blasting gelatin or Composition C–4. To prime a line charge, punch side holes in the ends of each individual charge and weave a detonating cord through the holes, figure 25.

Powder Points. Powder points are fabricated by driving pipes into the bottom of a harbor or channel and then placing charges of blasting gelatin, Composition C–4, or Nitramon in the pipes. Composition C–3 may be used as long as it is in stock; Composition C–4 is being issued to replace C–3 as it is expended. The charges are made above water and then placed in the pipes by a diver. To make up the charges:

1. Tie a series of knots in a continuous length of detonating cord. Space the knots far enough apart to allow each charge to be dropped to the bottom of its corresponding pipe by a diver.
2. Press each knot into one charge of the plastic explosive.
3. Arrange the cord and charges so that the diver can pay the cord out easily as he moves from pipe to pipe to place the charges.

When Nitramon is used for the charges, a special Nitramon primer must be used in conjunction with detonating cord or blasting caps.

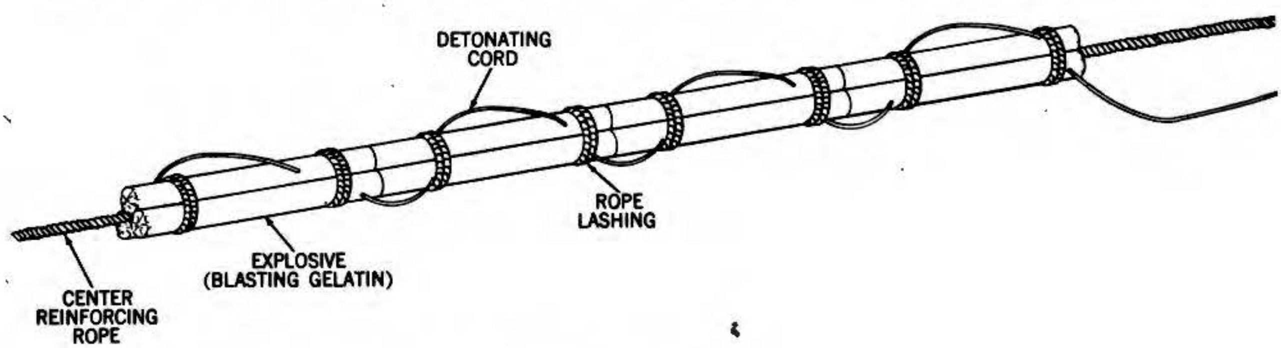

Figure 25—Line Charge.

Chapter 5

FIRING SYSTEMS

A firing system is a group of connected components arranged to permit detonation of a charge from a remote station. The system may be electric, nonelectric, or a combination of both. In air, the system may be a simple fuse that leads from a distant point to a blasting cap, and a match with which to light the fuse. Underwater, the system may be a complex arrangement of electrical wiring, blasting caps, detonating cord, primacord primers, and a blasting machine. In either case, the firing system transmits energy from the point of firing to the main charge to detonate it.

For underwater work, use a combination firing system whenever possible. For best results, detonating cord should be led from the main charge to a point above the surface of the water. An electric blasting cap then is attached to the cord and connected to a blasting machine or other power supply. This combination gives the most positive results because all electric connections are above water.

Electric Firing Systems

An electric firing system is one in which an electric power supply is connected at the instant of firing to one or more electric blasting caps attached to the main charge(s). A single charge or a group of charges can be detonated with such a system. When a group of charges is fired electrically, the charges can be set off simultaneously or in succession; when fired in succession, charges must be fitted with special delay caps. Connections of the firing and connecting wires of the electric circuit may be in series, in parallel, or in series-parallel as the number of charges and available power supply dictate.

Parallel or series-parallel circuits should be used only when absolutely necessary and only by personnel thoroughly familiar with the electrical problems involved. These circuits must be accurately balanced to ensure detonation of all charges. Inaccurate balancing may cause a misfire of one or more charges, with consequent delay and danger. Because most of the charges probably will be detonated, detection and investigation of misfires are usually difficult.

Series Circuit. Use a series circuit for electrical firing by a blasting machine when the number of caps is within the rated capacity of the machine. The simplest series circuit is one in which one side of the cap is connected electrically to one side of the blasting machine and the other side of the cap to the other side of the machine. When several charges are to be set off at the same time, the series circuit, figure 26, is made up by connecting one wire of the first cap to one of the second cap and so on until only one wire of the first cap and one wire of the last cap are free. These two free wires then are connected to the two leads of the firing wire from the blasting machine. The series circuit has a definite advantage over parallel or series-parallel circuits; because it can be tested in its entirety after all connections have been made and it does not require balancing.

Parallel Circuit. A parallel circuit is used when the number of caps to be fired exceeds the rated capacity of the blasting machine or other power supply. In a parallel circuit, one wire of each blasting cap is connected to one side of the circuit and the other wire is connected to the other side so that the same voltage is applied to each of the caps at the same time.

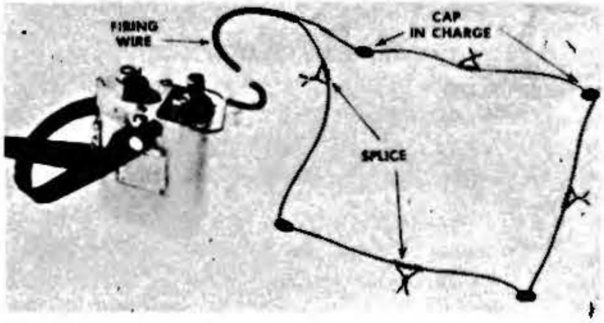

Figure 26—Series Circuit.

Series-Parallel Circuit. Like the parallel circuit, the series-parallel circuit is used to fire a greater number of caps than can be fired in a simple series circuit. The series-parallel circuit, figure 27, is one in which two or more series circuits are connected in parallel. In this type circuit, the number of caps in each series circuit must be the same and must not exceed the number of caps for which the available blasting machine is rated, and in no case may it exceed 30. Although connections are more complicated, this circuit has the advantage that with an adequate power supply the number of caps that can be fired is practically unlimited.

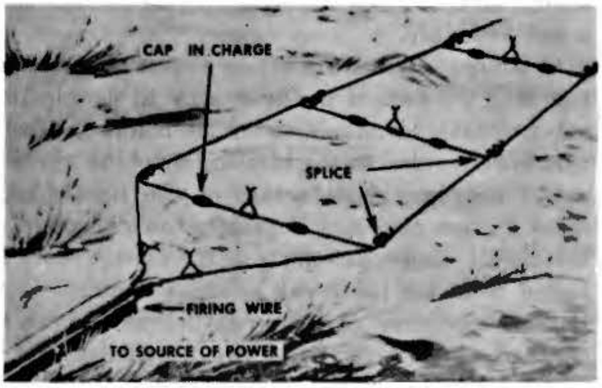

Figure 27—Series-Parallel Circuit.

Circuit Connections. For safety, all circuit connections should be made by one man who is thoroughly familiar with electrical firing circuits. He should personally make all splices and insure that all blasting caps are of the same manufacturer and are properly connected into the circuit.

> CAUTION: To short out stray currents that might be picked up by the firing wire and to eliminate the possibility of premature explosions, the two leads at each end of the firing wire must be twisted together and kept that way until final connections are to be made to the blasting caps and the power supply terminals. The firing wire must not be connected to the power supply until the circuit has been checked as described in later paragraphs and until all personnel are clear of the danger zone.

Splices are to be made as follows, figure 28:

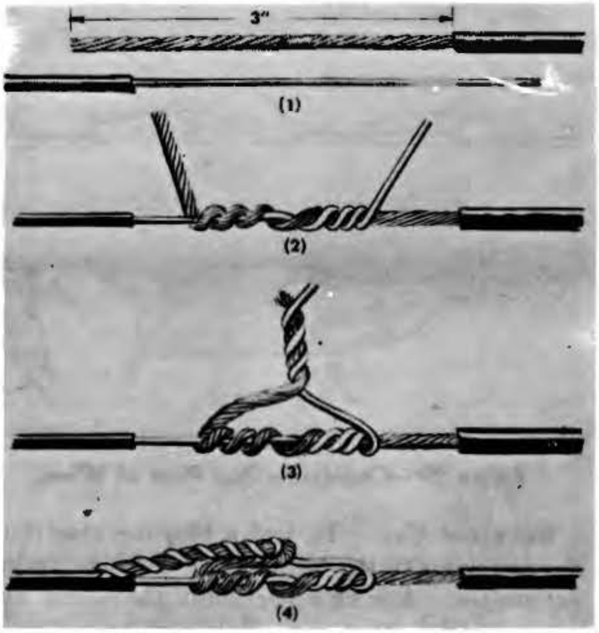

Figure 28—Method of Splicing Wires.

1. Strip about three inches from the ends of the wires to be spliced. Make sure that all insulation is removed.
2. If stranded wire is used, twist the strands of each wire together to form a single lead.
3. Twist together the leads of the two wires to be joined to form a pigtail. Bend the pigtail to one side so that it lies along the wire.
4. Insulate the pigtail by wrapping it securely with electrician's rubber tape.

> NOTE: When a pair of leads is to be connected to a second pair, stagger the splices to prevent a possible short circuit between them, figure 29.

Testing. Test all caps before connecting them into a circuit. Test all series circuits before firing. Parallel circuits cannot be tested safely in their entirety; therefore, parallel circuits require great care in the making of connections.

> CAUTION: Test electric blasting caps and blasting circuits only with a blasting galvanometer (also called a circuit tester) that contains a silver chloride cell. Other types of electric circuit test instruments cause premature explosions.

Blasting machines do not normally require testing unless an unusual number of misfires have occurred.

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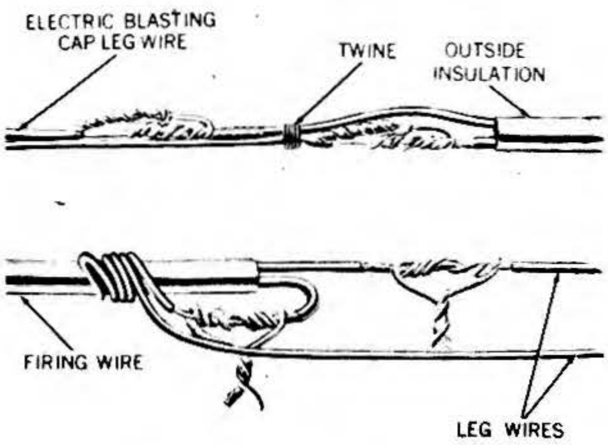

Figure 29—Connecting Two Pairs of Wires.

BLASTING CAP. To test a hlasting cap, touch the cap wires to the terminals of the blasting galvanometer. A wide deflection of the needle indicates a satisfactory cap. Little or no deflection indicates a defective cap.

WARNING

When testing a blasting cap, pull the wires out to their full length and place the cap as far away as possible and behind a barrier. Serious injury can result from failure to observe this warning.

FIRING WIRE. Test firing wire before it is connected into a circuit and then again, when possible, as a part of the circuit. Before connecting into a circuit, firing wire can be tested on or off the reel. To test, twist the two leads at one end together; then touch the leads at the other end of the wire to the blasting galvanometer terminals. A wide deflection of the needle indicates that there are no breaks in the wire; slight deflection indicates a partial hreak or a poor connection at the twisted ends; no deflection indicates a break in the wire. To test for short circuits, separate the twisted leads and again touch the leads at the other end to the galvanometer terminals. If the needle moves, a short circuit exists.

BLASTING MACHINE. A blasting machine may be tested in one of two ways. The preferred method is to connect two or four caps in series with a special test rheostat and then to fire the caps. The rheostat has a series of coils of varying resistance. Each coil has a resistance equal to that of a specified number of blasting caps; this number is stamped between the posts to which the coil is connected. To make sure the blasting machine is performing satisfactorily, the rheostat is set so that its resistance, plus that of the two or four caps in the test circuit, is equal to the resistance of the number of caps to be used in the firing circuit. If the caps in the test circuit fire properly, the blasting machine is functioning properly.

Alternately, the actual number of caps to be fired can be connected to the blasting machine and detonated to check the operation of the machine. Because it wastes caps, this method should be used only when the special test rheostat is not available.

CIRCUITS. An entire series circuit is tested by touching the ends of the firing wire to the blasting galvanometer terminals, figure 30, before the firing wire is connected to the blasting machine or other power supply. A deflection of the needle indicates a good circuit. If there is no deflection of the needle, successive parts of the circuit must be tested to locate the break or short circuit. Only the series portions of series-parallel circuits can be checked as a whole; an entire parallel or series-parallel circuit cannot be checked satisfactorily because a needle deflection results if only one of the parallel circuits is complete.

When a break is indicated by test, proceed as follows: make sure the ends of the wire on the reel are separated and not touching any conductor. Move the galvanometer to the points where the

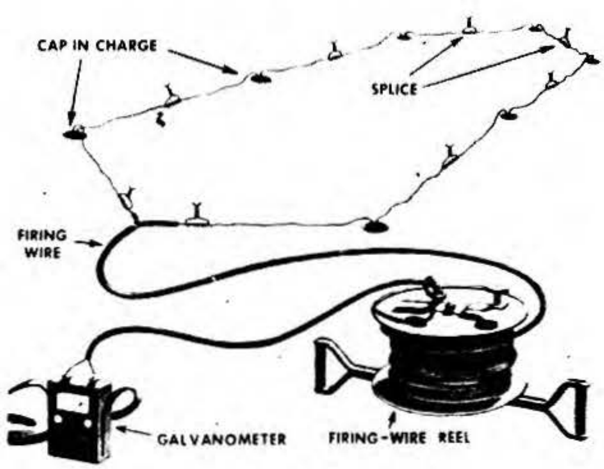

Figure 30—Testing Firing Circuit.

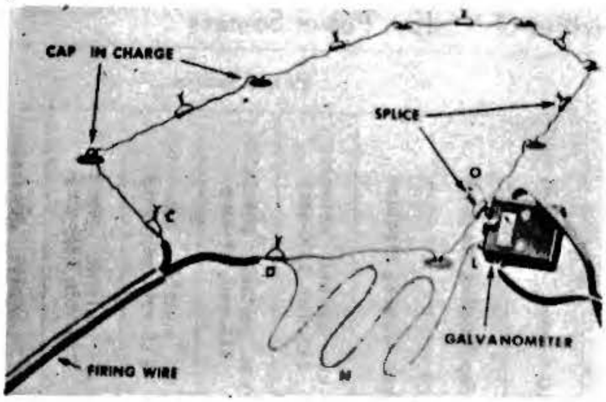

Figure 31—Locating Breaks in Firing Circuit.

cap wires are connected to the firing wire, figure 31. Connect joints C and D to the galvanometer terminals. If the galvanometer needle deflects, the firing wire connections at C or D are faulty. If the needle does not deflect, fasten wire N to joint D and to terminal L. (Wire N must be long enough to reach any joint in the circuit.) Move the galvanometer around the circuit, touching terminal 0 to various points in succession. When a circuit is indicated (by needle deflection) at one point and not at the next, the break lies between these two points. Repair the break by splicing or by replacing the faulty wire. If a cap is found defective and is accessible, replace it. If a defective cap is not accessible, treat it as a misfire. After all breaks have been found and repaired, check the entire circuit again.

Power Requirements. The almost instantaneous detonation of a blasting cap when the firing circuit is closed requires that a minimum current flow through the bridge wire in the cap. The power supply for any circuit must have a voltage equal to the total amperes required by the blasting caps in the circuit multiplied by the total resistance of the circuit in ohms (Ohm's law). Also, the capacity of the power supply must be sufficient to deliver the required current at that voltage. Up to 10 caps in series can be detonated successfully with a 10-cap blasting machine; up to 30 caps in series can be detonated successfully with a 30-cap blasting machine. The number of caps that can be detonated by either machine can be increased by connecting caps in parallel, rather than in series. However, for any circuit that contains the equivalent of more than 30 caps in a single series, a higher capacity power supply is required. Table 7 gives data for calculating power requirements. Table 8 gives circuit arrangements within the capacity of each of several power supplies; no computations are required for circuits connected as listed in this table. Examples of power requirement calculations are given in the following paragraphs.

Table 7—Data for Calculating Power Requirements for Electric Firing Systems

1. Current needed to fire electric caps connected in series = 1.5 amperes.
2. Current needed to fire electric caps connected in parallel = 0.6 ampere × number of caps in circuit.
3. Resistance of one Corps of Engineer electric cap = 2.0 ohms.
4. Total resistance of caps connected in series = 2.0 ohms × number of caps.
5. Total resistance of caps connected in parallel = 2.0 ohms ÷ number of caps.
6. Resistances of copper wire of various B and S gage:

Gage No.[1]	Diameter (inches)	Length/weight (feet per pound)	Resistance (ohms per 1000 feet)
2	3/10	5.0	0.2
4	1/4	7.9	.3
6	1/6	12.6	.4
8	1/8	20.0	.6
10	1/10	31.8	1.0
12	1/12	50	1.6
14	1/16	80	2.5
16	1/20	128	4.0
18	1/25	203	6.4
20	1/30	323	10.2

[1] Sizes 2, 4, and 6 are heavy-duty power lines; sizes 8, 10, and 12 are power lighting circuit lines; sizes 14, 16, and 18 are common lead lines; size 18 is standard 2-conductor firing reel; size 20 is common connecting wire.

Table 8—Maximum Circuit Capacities of Various Power Sources

Circuit design	Total number of caps in circuit	Power source: 10-cap blasting machine	30-cap blasting machine	1½-kw. portable generator, 115-volt, 13½-amp.	3-kv.a. portable generator, 115-volt, 26-amp.	5-kw. portable generator, 115-volt, 43½-amp.	5-kw. portable generator, 230-volt, 13½-amp.	5-kw. portable generator, 22-volt, 22½-amp.
		The circuits below are connected by 1 500-foot standard 2-conductor firing reel.						
10 caps in continuous series	10	x	x	x	x	x	x	x
30 caps in continuous series	30		x	x	x	x	x	x
		The circuits below are connected with 1 500-foot standard 2-conductor firing reel and 200 feet of 20-gage connecting wire.						
2 series with 30 caps each	60			x	x	x	x	x
4 series with 23 caps each	92			x	x	x	x	x
6 series with 16 caps each	96			x	x	x	x	x
4 series with 30 caps each	120						x	x
6 series with 30 caps each	180						x	x
8 series with 30 caps each	240						x	x
15 series with 17 caps each	255							x
9 series with 30 caps each	270						x	x
10 series with 30 caps each	300							x
12 series with 30 caps each	360							x
		The circuits below are connected with 2 500-foot standard 2-conductor firing reels and 400 feet of 20-gage connecting wire.						
4 series with 8 caps each	32			x	x	x	x	x
2 series with 23 caps each	46			x	x	x	x	x
8 series with 13 caps each	104						x	x
6 series with 27 caps each	162						x	x

Series Circuit Calculation. Table 7 shows that a current of 1.5 amperes is required to fire caps in series. Therefore, for any series circuit, the voltage required will be equal to 1.5 times the resistance in ohms of all elements of the circuit.

Example: Assume a series circuit of 20 Corps of Engineers caps to be fired through 500 feet of standard 2-conductor 18-gage firing wire. Cap wires are directly connected, without intermediate connecting wires.

Table 7 shows that each cap has a resistance of 2.0 ohms and that the resistance of the firing wire is 6.4 ohms per 1000 feet.

Total resistance = resistance of caps + resistance of firing wire.
$= 2.0 \times 20 + 6.4/1000 + 1000$ (two 500-foot leads).
$= 46.4$ ohms.

Voltage required = 1.5 amperes $\times$ 46.4 ohms = 69.6 volts.

Thus, the circuit can be fired with a 70-volt power supply rated at 105 watts, minimum.

Parallel Circuit Calculation. A simple parallel circuit can be divided into three parts: the caps themselves, the connecting wires to which the caps are connected, and the firing wire which connects the power supply to the connecting wires. From Table 7, the total amperes required is 0.6 times the number of caps in the circuit. Total resistance of the circuit is the net resistance of the caps plus the resistance of the firing wire plus half the resistance of the connecting wire. (Only half of the connecting wire is considered because it represents the average path of current to all of the caps in parallel.) The voltage required for the circuit will then be the product of total amperes required and total resistance of the circuit.

Example: Assume a circuit of 20 Corps of Engineers caps connected in parallel at 10-foot intervals by 20-gage wire with one 10-foot lead of the same wire from each side of the circuit to the firing wire. The power supply is to be connected to the connecting wires by 500 feet of standard 2-conductor firing wire (18-gage).

Current required = 0.6 × 20 = 12 amperes.

Resistance of caps = 2.0 ÷ 20 = 0.1 ohm.

Resistance of firing wire = 6.4/1000 × 1000 (2 500-foot strands) = 6.4 ohms.

Resistance of connecting wire from caps to firing wire = 2 × 10 × 10.2/1000 = 0.2 ohm.

Resistance of connecting wire between caps = 19 × 10 × 10.2/1000 = 1.94 ohms.

There are 19 intervals of 10 feet each between the 20 caps. There is 1 connecting wire for each side of the circuit for each interval, but only half the length of this wire is considered.

Total resistance = 0.1 + 6.4 + 0.2 + 1.94 = 8.64 ohms.

Voltage required = 12 × 8.64 = 103.68 volts.

Thus, the circuit can be fired with a 105-volt power supply rated at 1¼ kilowatts.

SERIES-PARALLEL CIRCUIT CALCULATION. In a series-parallel circuit, each series circuit requires 1.5 amperes to fire the caps. The total current required is 1.5 times the number of series circuits. Wire resistance is calculated in the same way as for a simple parallel circuit. Cap resistance is equal to 2.0 ohms per cap in any one series divided by the number of series circuits.

Example: Assume 10 series circuits containing 30 Corps of Engineers caps in each series with the series circuits connected in parallel. The firing wire is a standard 500-foot 2-conductor wire. Caps within each series are directly connected to each other without additional connecting wire. Each series circuit is connected to the next by two 20-foot lengths of connecting wire, and the entire parallel circuit is connected to the firing wire by two 20-foot lengths of connecting wire. All connecting wire is 20-gage; a total of 400 feet is required.

Current required = 1.5 × 10 = 15 amperes.

Resistance of caps = 2.0 × 30 ÷ 10 = 6.0 ohms.

Resistance of firing wire = 6.4/1000 × 1000 (two 500-foot strands) = 6.4 ohms.

Resistance of connecting wire from parallel circuit to firing wire = 2 × 20 × 10.2/1000 = 0.4 ohm.

Resistance of connecting wire between series circuits = 9 × 20 × 10.2/1000 = 1.84 ohms.

There are nine intervals of 20 feet each between the 10 series circuits. There is one connecting wire for each side of the circuit for each interval, but only half of the length of this wire is considered.

Total resistance = 6.0 + 6.4 + 0.4 + 1.84 = 14.64 ohms.

Voltage required = 15 × 14.64 = 219.6 volts.

Thus, the circuit can be fired with a 220-volt power supply rated at 3.3 kilowatts or higher.

With a given power supply, such as a generator, nameplate data can be used to determine the maximum number of series for a series-parallel circuit and also to determine the maximum number of caps per series. To determine the maximum number of series, divide the rated amperage by 1.5. To determine the maximum number of caps per series:

1. Divide the rated voltage by the rated amperage or divide the rated power in watts by the square of the rated amperage. This will give the maximum resistance in ohms for the entire circuit.

2. Determine the net total resistance of the firing wire and the connecting wire. Subtract this sum from the total allowable resistance to determine the maximum allowable resistance of the caps.

3. Multiply the maximum allowable resistance of the caps by the number of series to determine the allowable resistance for each series branch. Divide the result by 2.0 (resistance per cap) to determine the maximum number of caps per series branch.

Example: Assume a 3-kilowatt, 220-volt, 13½-ampere generator as a power supply. The proposed circuit is to use one 500-foot standard 2-conductor firing wire and 200 feet of 20-gauge connecting wire.

Maximum number of series = 13.5 ÷ 1.5 = 9.

Maximum resistance = 220 ÷ 13.5 = 16.3 ohms
or = 3,000 ÷ (13.5 × 13.5)
= 16.5 ohms.

Because power ratings are "rounded," the answer may be slightly different when dividing rated power by current squared from that obtained by dividing rated volts by rated amperes. Always use the lower of the two.

Resistance of firing wire=6.4/1000 × 1000 = 6.4 ohms.

Resistance of connecting wire from parallel circuit to firing wire (allowing 20 feet)=10.2/1000 × 20=0.2 ohm.

Resistance of connecting wire between caps (using half the wire because of parallel connections)=10.2/1000 × 180/2=0.92 ohm.

Total wire resistance=6.4+0.2+0.92=7.52 ohms.

Allowable cap resistance=16.3−7.52=8.78 ohms.

Cap resistance per series=8.78×9=79 ohms.

Number of caps per series=79÷2.0=39.

The power supply is capable of firing 39 caps per series in a 9-series circuit, but not more than 30 caps should be used in any series circuit.

Nonelectric Firing Systems

A nonelectric firing system is one in which all components are mechanical or explosive; there are no electrical components in the system. For underwater salvage, the connecting link between the remote firing station above the surface and the main charge(s) underwater is detonating cord, which also may be used for work above water. In a system of this type, the detonating cord is set off by a nonelectric blasting cap, usually as a part of a waterproof detonating assembly, or by a firing initiator.

Detonating Cord. For underwater use and for charges to be left in place above water for several hours before firing, seal all free ends of detonating cord with a reliable sealing compound to keep out moisture. At all connecting points, leave a 6-inch length of cord free to protect the remainder of the cord from moisture. This measure will protect the active part of the cord for 24 hours from seepage through the ends; however, cord subjected to action of surf may abrade enough to admit water into the cord at other points. Pliofilm-wrapped detonating cord, presently issued by the Bureau of Ordnance is the best available cord, but even this cord may develop leaks after being subjected to surf action for more than three hours. Because of this, use waterproof detonating assemblies for underwater demolition work.

When several charges are to be fired together, make the detonating cord main line in the form of a ring and fire from both ends. This will assure firing of all charges, even if there should be a break in the main line.

Use detonating cord double underwater to insure against misfires. Avoid reverse (S) curves, kinks, and sharp bends because they may cause failures. When two cords are connected, tie them securely with a square knot, leaving six inches of each cord free, figure 32, to prevent moisture absorption by the active parts of the cord. Make branch lines and T-connections with a girth hitch, figure 33. The hitch must be tight to prevent sliding of the branch along the main line and the angle between lines must be 90 degrees.

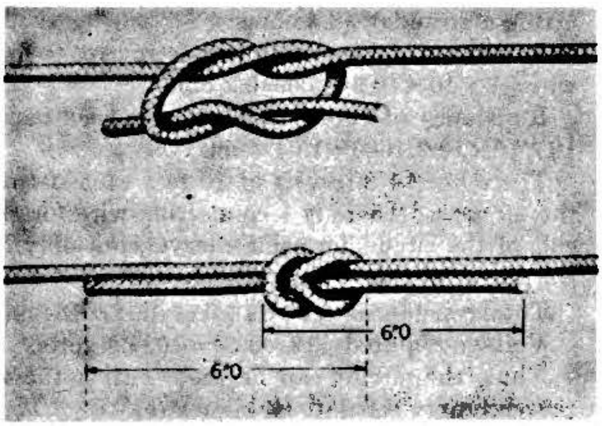

Figure 32—Square Knot for Connecting Ends of Detonating Cord.

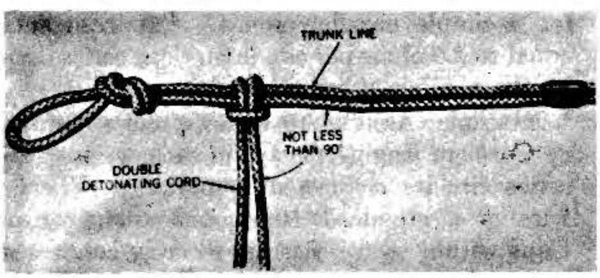

Figure 33—Girth Hitch Used to Connect Branch Line to Trunk Line of Detonating Cord.

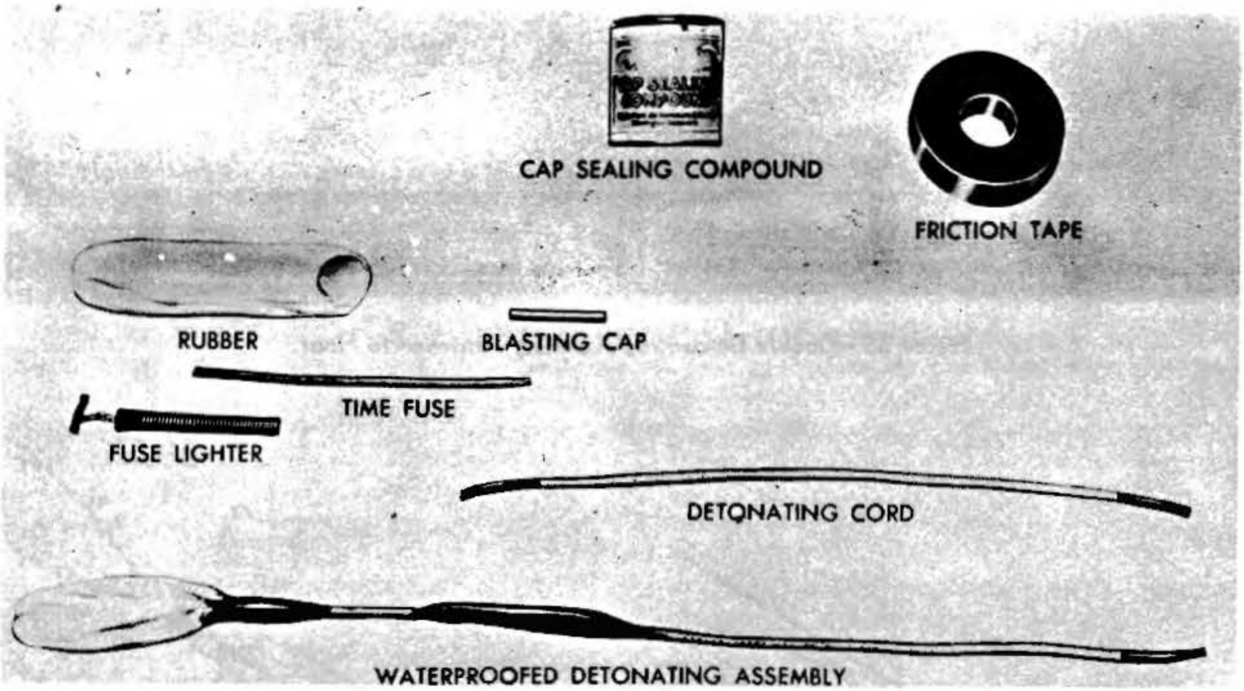

Figure 34—Waterproofed Detonating Assembly.

Waterproof Detonating Assembly. A waterproof detonating assembly, figure 34, can be simply fabricated from the following materials:

Time fuse.	Rubber prophylactic.
Fuse lighter.	Friction tape.
Nonelectric blasting cap.	Detonating cord (2-foot length).
Cap-sealing compound.	

Insert one end of the desired length of the time fuse into the fuse lighter and the other end into a nonelectric blasting cap. Crimp the cap to the fuse. Coat both joints with cap-sealing compound. Place the prophylactic rubber over the fuse lighter; coat the inside of the mouth of the rubber with cap-sealing compound; and tape the open end of the rubber to the time fuse. Dip both ends of the two-foot length of detonating cord in cap-sealing compound. Tape one end of the cord alongside the blasting cap. Coat all friction tape with cap-sealing compound and allow to dry.

NOTE: Cap-sealing compound is the standard issue waterproofing material. Substitutes such as asphalt, shellac, or soap may be used in emergencies, but are not considered entirely satisfactory. Oils and greases will destroy the powder train and must not be used.

Use a double detonating assembly, figure 35, for underwater work. This is fabricated by making 2 waterproof assemblies, as previously described, and taping one to each end of the 2-foot length of detonating cord. The cord then is attached by a girth hitch to the main detonating cord, and to a material that will cause the detonating assembly to float.

Securing Blasting Cap to Detonating Cord. When a nonelectric blasting cap is to be secured to detonating cord above water, it should be placed alongside the cord, figure 36, and fastened securely with tape or twine. When a double-cord is being used, the cap should be placed as shown in figure 37. Before the cap is secured to the cord, the cap should be crimped to the end of a time blasting fuse from which about 3 inches has been cut off and discarded. The fuse is then cut to the desired length. The cap should be secured to the detonating cord at a point about 6 inches from the end of the cord with the time fuse leading in the same direction as the free end of the cord.

Detonating Cord Initiator. Initiator (Detonating Cord) Mk 2 Mod 0 provides an explosive link between a blasting cap or a coupling base and detonating cord. The initiator is snapped onto the detonating cord by gripping the cord firmly

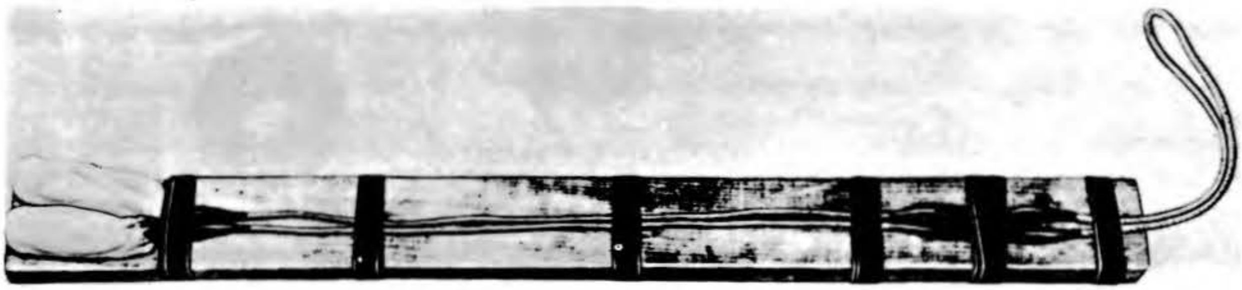

Figure 35—Double Detonating Assembly Attached to Float.

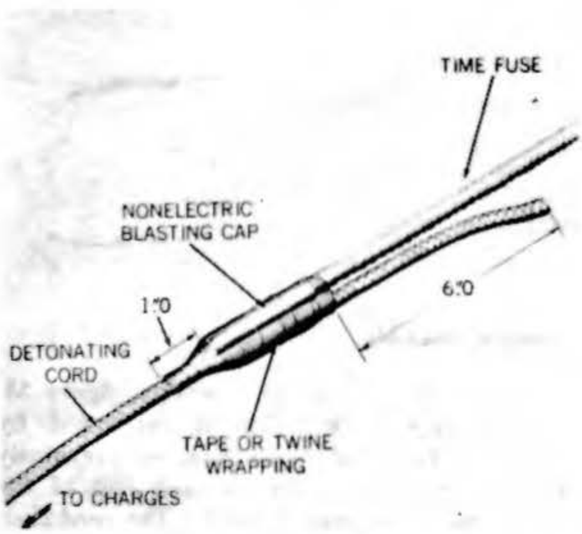

Figure 36—Method of Securing Blasting Cap to Detonating Cord.

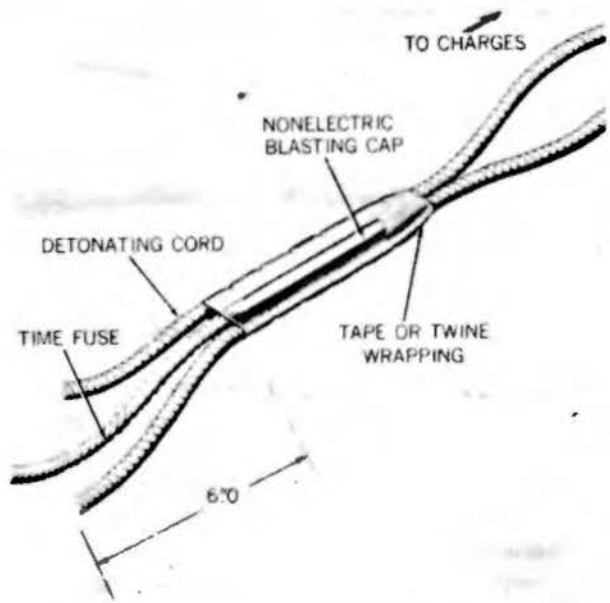

Figure 37—Method of Securing Blasting Cap to Two Lines of Detonating Cord.

and pushing the initiator slot against the cord, figure 38. The detonating cord is compressed slightly as it enters the slot but snaps back into shape after it passes the notch.

Initiator Mk 2 Mod 0 is primed as follows, figure 39:

1. Remove the priming adapter and paper tube.
2. Thread a fresh, square-cut end of time fuse of desired length through the tube and adapter. Insert it as far as possible into a special nonelectric blasting cap.
3. Crimp the cap securely around the fuse near the open end of the cap.
4. Insert the cap into the cap holder.
5. Screw the priming adapter back into place.

   CAUTION: Never try to force time fuse into a blasting cap past the point where it moves easily.

Alternately, Initiator Mk 2 Mod 0 may be primed with a firing device. With most demolition firing devices, such as that shown in figure 40, the following procedure applies:

1. Remove the packing tube and screw the coupling base into the end of the firing device (unless the coupling base is already in place when issued), making sure the flat rubber gasket is in position between the coupling base and the firing device to make a watertight joint.
2. Remove the plastic protective cup (if there is one) from the snout of the coupling base.
3. Detach the initiator head from its cap holder and screw the head over the end of the coupling base, compressing the gasket to provide a water-

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Figure 38—Attaching Initiator to Detonating Cord.

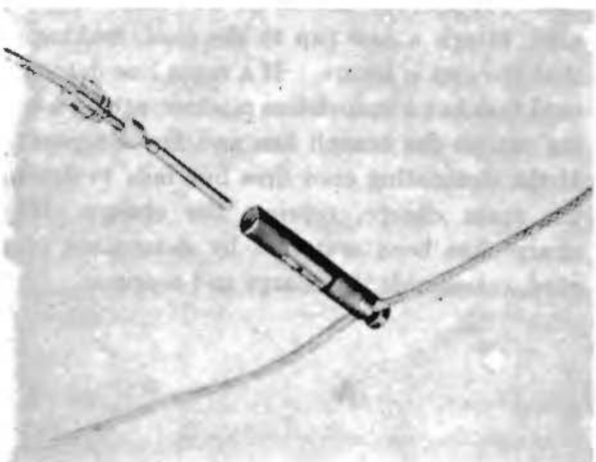

Figure 39—Priming with Nonelectric Blasting Cap and Initiator.

tight seal. (No blasting cap is used in this assembly.)

4. Attach the assembly to the main detonating cord line or lead from the charge by gripping firmly with both hands and snapping the initiator over the detonating cord with the thumbs.

5. Lash the firing device securely with a line through the lashing eye.

> CAUTION: Never leave the percussion cap end of the coupling base unprotected, before assembling it to the firing device.

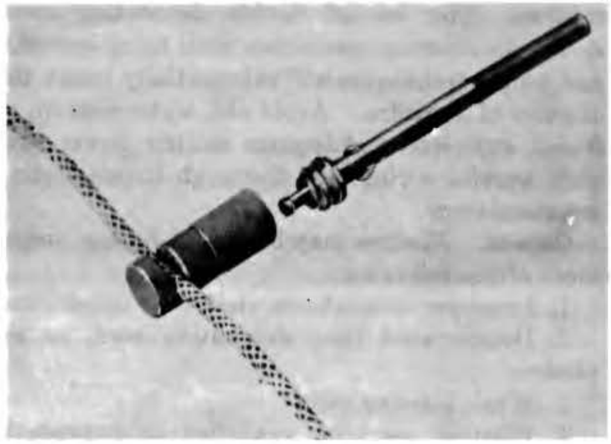

Figure 40—Priming with Other Firing Devices Coupled to Initiator.

Some firing devices, such as the 15-second delay Detonator M1, have self-contained detonators similar to blasting caps. Insert this type firing device into the cap holder without removing the initiator head. The cap holder also will accommodate hand grenade fuses M6A4 and M204.

> CAUTION: Never allow dirt or moisture to get into the initiator head. Always keep it closed with a gasketed cap holder or coupling base.

Combination and Dual Firing Systems

For safety and reliability, the underwater portion of any firing system should be detonating cord doubled. The use of electrical wiring underwater is not recommended. To ensure against misfires, a combination or dual arrangement for the above-water portion of the system is advisable. An electric circuit from the firing point to the main detonating cord may be paralleled by a nonelectric above-water system of time fuse and nonelectric blasting caps. When electric equipment is not available, two separate nonelectric above-water systems leading to the main underwater detonating cord should be used.

Misfires

Because of the possibility of a hangfire, a misfire is a source of danger. When firing a group of charges, a single misfire may easily go undetected; a misfired charge remains a hazard until it is actually detonated successfully. For this reason, it is imperative that every effort be made to avoid

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misfires. The use of double detonating cord, double detonating assemblies, dual firing systems, and proper techniques will substantially lessen the chances of a misfire. Avoid old, water-soaked, or frozen explosives. Adequate electric power supplies, careful wiring, and thorough circuit testing are mandatory.

Causes. Misfires may be caused by any one or more of the following:

1. Improper connections, electric or nonelectric.
2. Deteriorated fuse, detonating cord, or explosive.
3. Weak blasting caps.
4. Blasting machine weakened or improperly operated.
5. Improperly fabricated primers.
6. Failure to light time fuse properly.
7. Damaged electric or nonelectric circuits.
8. Blasting caps of different type or manufacturer used in the same circuit.
9. Inadequate electrical power supply for the number of caps and circuit arrangement.

Procedures. When electrical misfires occur, immediately check the connections of the firing wire to the blasting machine or other power supply and make two or three further attempts to fire.

WARNING

Never enter the danger zone until at least 30 minutes after the last attempt to fire; a hangfire may be in process.

If the circuit still fails to function, disconnect the firing wire from the power supply and check all electrical connections. Test the circuit for short circuits or breaks with the blasting galvanometer. If no breaks or short circuits are found, place additional primed charges near the original charges and detonate.

Misfires in nonelectric systems usually indicate faulty components that require replacement.

WARNING

Never work with nonelectric components of a firing system until at least 30 minutes after a misfire; a hangfire may be in process.

If a charge primed with a nonelectric cap and time fuse misfires, reprime the charge. If a nonelectric blasting cap being used to fire detonating cord misfires, cut the detonating cord between the cap and the charge and attach a new cap to the cord. If the cap detonates but fails to fire the cord, attach a new cap to the cord, making sure that the cap is secure. If a main line detonating cord fires but a branch line misfires, attach a blasting cap to the branch line and fire it separately. If the detonating cord fires but fails to detonate the main charge, reprime the charge. If the charge has been scattered by detonation of the cord, reassemble the charge and reprime.

Chapter 6

SALVAGE DEMOLITION EQUIPMENT

Equipment required for underwater salvage varies according to the conditions encountered. Equipment listed in this chapter is intended as a guide and should be modified to suit the needs of each operation.

Blasting Equipment

For demolition activities incident to underwater salvage, the following may be used as a suggested check-off list:

Main charges—standard issue or in bulk for fabrication.

Blasting caps, electrical or nonelectrical, as required.

Safety fuse, as required.

Fuse lighters and safety matches for non-electric firing.

Firing wire for electric firing, as required.

Blasting galvanometer for electric circuit testing.

Blasting machines (2), for electric firing.

Accessories:

- Baker flag
- Rubber tape (4 rolls)
- Wooden wedges (2)
- Cap crimpers (2)
- 1 pair gloves per man
- Hand shovel
- Marline (200 feet)
- Field first aid kit
- Friction tape (6 rolls)
- Wooden mallet
- Blaster's wooden prod
- Bicarbonate of soda or strong GI soap (1 pound) and bucket
- Sand bags
- Waterproof sealing compound

Salvage Equipment

In addition to the equipment required for actual demolition work, the following major items of equipment will be required for most underwater salvage operations:

- Salvage vessel
- Diving equipment
- Centrifugal pumps
- Air compressors
- Wire rope, chain, cable, and cordage
- Air locks
- Pontoons
- Cutting apparatus
- Pneumatic tools
- Timber, steel plates, and miscellaneous heavy hardware
- Winches
- Cement and aggregate
- Sandbags
- Concrete mixers

Salvage Vessel. The vessel should be a modern ship of sufficient power and size to perform all necessary salvage functions. Salvage operations are often performed under difficult conditions; when time is important, independence from shore installations is imperative. ARS and ARST vessels are recommended, figure 41.

The salvage vessel should be equipped with a workshop with a complete outfit of tools including a smith's forge, engineer's screw cutting lathe, drilling machine, pipe and bolt threading machine, carpenter's benches, circular saw, and vises.

Diving Equipment. Both deep and shallow water diving equipment is needed. Equipment should include air compressors, diving suits and helmets, communication equipment, lights, rigging, and hose.

Centrifugal Pumps. Two 10-inch and two 6-inch portable oil engine-driven centrifugal pumps equipped with an adequate supply of flexible suction hoses with couplings, foot valves, and strainers, discharge pipes, and fittings are recommended. When a power supply is available, electric submersible pumps are of great value.

Air Compressors. Two portable oil engine or electrically driven air compressors each having a capacity of 100 to 200 cubic feet of free air per

Figure 41—ARS Vessel.

minute should be included. These are used for expelling water from ships' compartments, for pneumatic tool operation, for emptying steel pontoons, for inflating nylon pontoons, and for operation of air lifts. Equipment should be portable so that it can be moved from point to point in salvage operations without requiring the salvage vessel to move.

Wire Rope, Chain, Cable, and Cordage. These are required in sufficient quantity for all lifting, slinging, towing, and hauling activities.

Air Locks. Air locks are used to permit entry into non-flooded compartments without opening the compartments to sea.

Pontoons. Steel or rubberized nylon pontoons are usually furnished by support units. Steel pontoons have a lifting capacity of from 25 to 300 tons each. They are elliptical-ended cylinders and are divided into compartments, according to size. Each compartment is fitted with air and water admission and expulsion valves. Channel bars are riveted to the cylinders for attachment of wire ropes or chain. Three-inch fir planking between channel irons protects the cylinder from damage.

Rubberized nylon pontoons (air bags) are placed in the hold or attached to the hull of a sunken ship. A hose connects the pontoon to an air compressor. When in position, the pontoon is inflated for buoyancy.

Cutting Apparatus. Oxyacetylene cutting equipment is used for work above water. Oxyhydrogen cutting equipment is used in all types of underwater cutting operations. When cutting operations must exceed three to four linear feet of ¾-inch steel plate, additional cylinders may be coupled together to speed up the work. Oxyelectric equipment is most adaptable to greater depths, but is not suitable for cutting metals more than an inch thick.

Pneumatic Tools. Pneumatic tools are used for drilling, chipping, and boring, and for driving powder points.

Winches. Winches should he of sufficient capacity for heavy lifts, heaving off ships, and similar operations.

Timber; Steel Plates; Hardware. A good supply of these materials is needed for patching when sunken vessels are to he refloated.

Cement and Aggregate. Provide a supply of cement for patching. Aggregate usually can be obtained at the scene.

Sandbags. Sandbags are used for weighing charges down, tamping, and similar activities.

Concrete Mixers. Concrete mixers are desirable for mixing patching concrete or mixtures of cement and sea water.

Part 2. Applications of Explosives

Chapter 7

UNDERWATER SALVAGE ACTIVITIES

Underwater salvage operations in which explosives are used are primarily harbor clearance operations. That is, they are applied to make a blocked or cluttered harbor useful for ships or vessels of a specified draft. Other underwater salvage operations requiring the use of explosives include rock blasting, alteration of channel or harbor bottoms, concrete and masonry blasting, breaking and cutting steel, ship cutting for dispersal or scrap salvage, timber and pile cutting, and removal of ships' propellers for replacement. These operations may be independent or they may be associated with harbor clearance.

No particular underwater salvage operation is exactly like any other. Rarely does an operation duplicate operations performed in research and development. Many variable factors influence the choice of type and amount of explosive to be used and the placement of charges. For these reasons, no detailed step-by-step procedures can be given that will have universal application. Suggested procedures and methods given in the following chapters must be applied at the discretion of the salvage officer, based on his own judgment and experience and the conditions at the salvage site.

Harbor Clearance Considerations

A harbor may be blocked deliberately to deny its use to an enemy or it may be blocked as a result of bombardment. In the one case, ships and other objects will be positioned and sunk in locations calculated to make harbor clearance particularly difficult. In the other case, obstruction will be haphazard. In intentionally blocked harbors, it is probable that explosives will be placed as hazards for harbor clearance personnel. In harbors obstructed as a result of bombardment, there may be explosives in sunken ships or scattered on the harbor bottom.

WARNING

> The rendering safe of underwater explosive ordnance is outside the scope of salvage operations. Whenever the presence of such explosives is known or suspected, qualified explosive ordnance disposal personnel shall be called upon to clear the area before salvage operations are started.

The type and extent of salvage operations will be determined by many factors such as the size of the area to be cleared, the depth required for channels and anchorages, the character of the bottom, the rise and fall of tide, the types of obstacles to be removed, and the prevailing wind. Much of this information can be obtained from intelligence reports and from standard reference data, such as sailing directions, tide tables, and charts. Such information must be verified and amplified by local observations and by preliminary sweeping, inspection, and sampling of the bottom.

Ship Salvage Considerations

Whether sunken ships are to be dispersed by explosives, converted to mooring or docking facilities, or salvaged for reuse or for scrap must be determined before salvage operations are started. The condition of a sunken ship and the need for it may dictate that the ship be salvaged for reuse. The need for scrap steel and availability of outgoing supply channels may make salvage for scrap the prime consideration. On the other hand, the immediate tactical need for the harbor may make it imperative that all sunken ships be dispersed or flattened so that the harbor will be cleared in the minimum time.

Placement of Charges

As a general rule, charges should be placed to blast against strength rather than against weakness. For example, a charge placed outside a hull should be placed where a plate is riveted or welded to a rib rather than at the center of the plate between ribs. The stronger the structure against which a charge is detonated, the more effective the charge. Blasting against weakness not only requires a greater amount of explosive hut also may result in increased time and effort for completion of a joh. Placement of charges against all the weak points of a ship's hull, for instance, will result in leaving a structure of bare ribs that are harder to disperse or cut than the entire hull would have been had the charges been placed against the strong points in the first place.

A small vessel may be successfully dispersed by placement of a sufficient number of charges so that simultaneous detonation will blow the entire vessel apart. For larger vessels, progressive blasting is used to disperse or flatten tbe vessel in stages. A passenger ship, for example, might have its bow and stern dispersed, the decks cut and dropped, and the sides then cut to fold in on top of the decks. Progressive dispersal and flattening by blasting gives predictable results and uses a minimum of explosives.

Personnel

Qualified personnel only are to be used in all phases of underwater salvage work. Only qualified Explosive Ordnance Disposal personnel are to be used for rendering safe procedures. The use of local pilots and other persons native to tbe area who have knowledge of the barbor or ships sunk therein is encouraged, but information obtained from such persons must be verified before use.

Safety Precautions

OPNAV 34P1, United States Navy Safety Precautions, contains precautions directly applicable to the ammunition and other explosives used in underwater salvage work. Other specific safety precautions are given in the beginning of this publication. These and all other safety precautions issued by competent authority shall be observed in all underwater salvage activities.

Chapter 8

ROCK BLASTING

Types of Rock

Three types of rock are usually encountered in underwater salvage work: (1) Basalt, a tough, dense, fine-grained, dark, igneous stone; (2) gneiss, a conglomerate full of breaks and fissures; and (3) homogenous rock such as limestone, sandstone, and shale. Techniques for blasting these types of rock as well as for blasting coral and lava are given in the following paragraphs.

Charges

Rock blasting requires a fast-acting, brisant type explosive such as composition C-4, TNT, or the higher strength gelatins or dynamites. About one-half pound of explosive per cubic foot rock is required for basalt. Conglomerate (gneiss) requires about one-third pound of explosive per cubic foot; homogenous rock such as limestone, requires only about one-sixth pound per cubic foot.

Explosives with high rates of detonation have been used successfully in demolition of coral, but experience has proved that explosives with slower rates, such as ammonium nitrate, are more effective when powder points are not used.

Charging Methods

Rock is charged for blasting by mud capping, snakeholing, or blockholing. When possible, powder points are used for blasting coral.

Mud Capping. Mud capping, figure 42, is the simplest method of blasting rock but it requires the most explosive and can only be used above water. In mud capping, the charge is placed on top of the rock and covered with mud. The detonation of the charge gives a downward push effect with little scatter of rock particles. Because the mud cap has little confining effect, much of the energy of the explosion is dispersed into the air and lost. Snakeholing requires only about three-fourths as much explosive as mud capping; blockholing only about one-eighth as much.

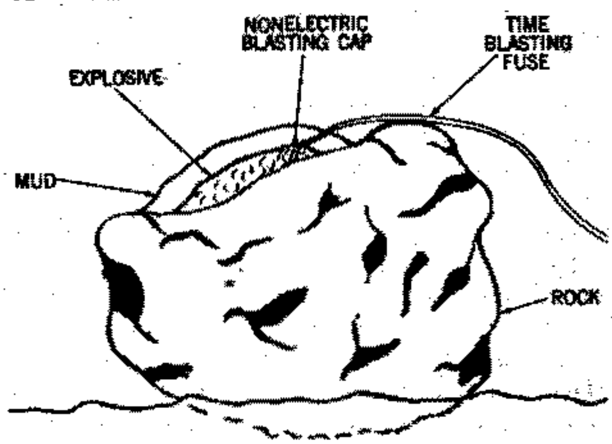

Figure 42—Mud Capping.

Snakeholing. Snakeholing, figure 43, is the removal of material from beneath a rock for the placement of a charge. A water jet can be used to advantage for snakeholing underwater. When using this method, care must be taken to ensure that the lifting effect of the explosion will not move the rock into an existing channel where further demolition work will be necessary.

Blockholing. Blockholing, figure 43, consists of the placement of charges in holes specifically drilled for the purpose. Holes are usually made with hand-operated pneumatic drills. In large operations, a drill barge may be required. Cratering charges should not be used to make the holes because the jagged tapering holes produced are unsuitable. A water jet may be used to keep sand or mud clear of the rock while the charge is being prepared.

Rock Ledges

Excavation of rock ledges requires blockholing. Holes should be spaced five to ten feet apart. The depth of each hole should be equal to the depth of the desired excavation plus the distance between holes. For example, if an excavation of 12 feet is required and the hole spacing is 5 feet, the holes should be drilled to a depth of 17 feet. The

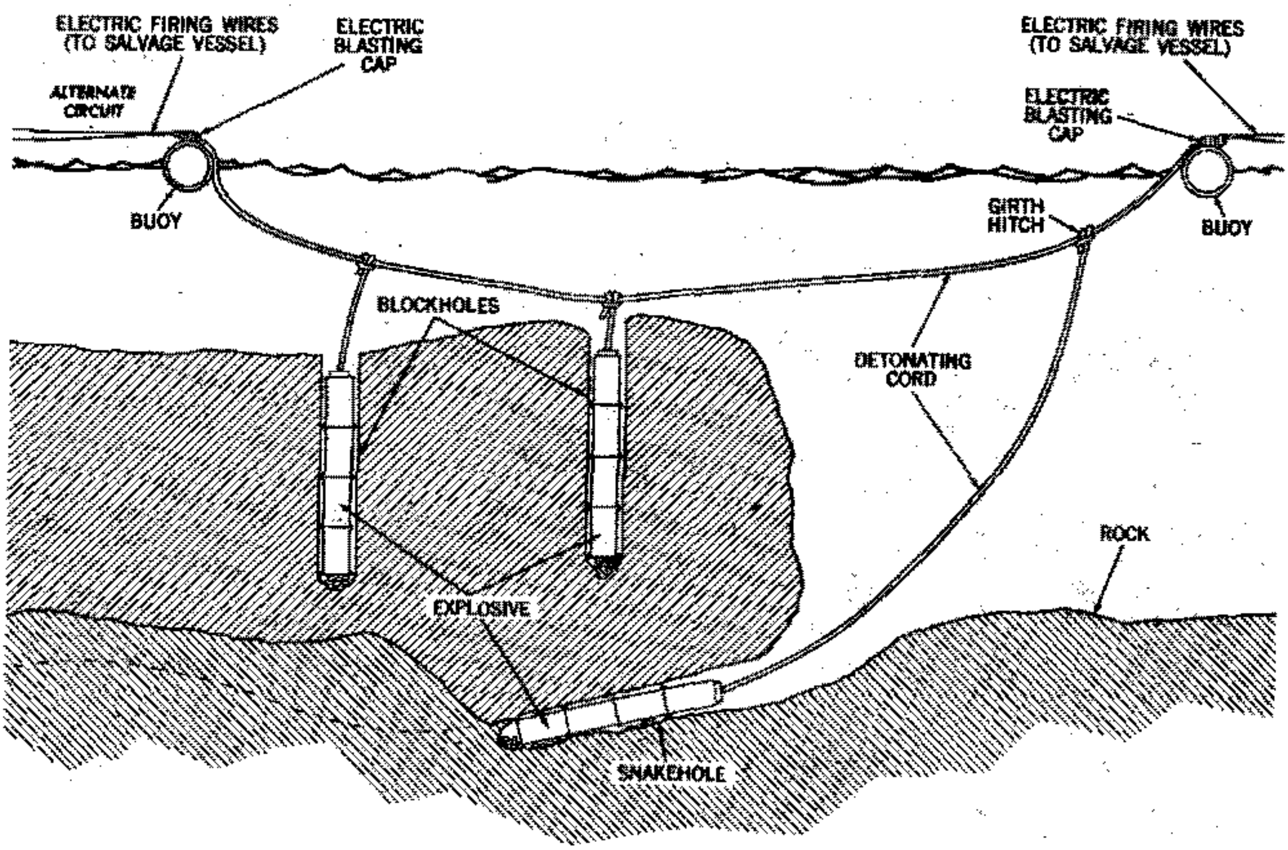

Figure 43—Snakeholing and Blockholing.

amount of charge required will range between one and four pounds per cubic yard of rock. In computing the number of cubic yards, use the depth of the holes, not the depth of the desired excavation.

Boulders

Small boulders that extend above the surface of the water can be dispersed by mud capping. Larger boulders and those completely submerged require snakeholing. Very large boulders should be blockholed.

Coral

Coral is extremely hard and is difficult to blast. The most practical method is with powder points, chapter 4. Blockholing is not practical because the coral particles clog the drill. Water jets can be used to wash away small coral projections, or mud shovels can be used to scoop the coral away; mud shovels are particularly useful when working under ships in tunneling.

For larger masses of coral, where water jets or mud shovels are inadequate and powder points cannot be used, place charges to give a combination of shearing and shattering effects.

Mushroom-Top Head. Place charges around the head itself. Also, place one charge of composition C-4 (or five pounds of TNT or four pounds tetrytol) per cubic foot next to the stem and at least one demolition pack or equivalent on top of the head. By detonating the charges simultaneously, a shearing of the stem and shattering of the head will result.

Solid Head. Place the main charge on top of the head with a few charges suspended around the sides. An average of three demolition packs or equivalent is usually sufficient for the main charge.

Lava

Lava, which is melted rock emitted by a volcano, is solidified by cooling either as a solid or in cinder form. Cinder type lava is easy to blast because it is light in weight, composed of loose

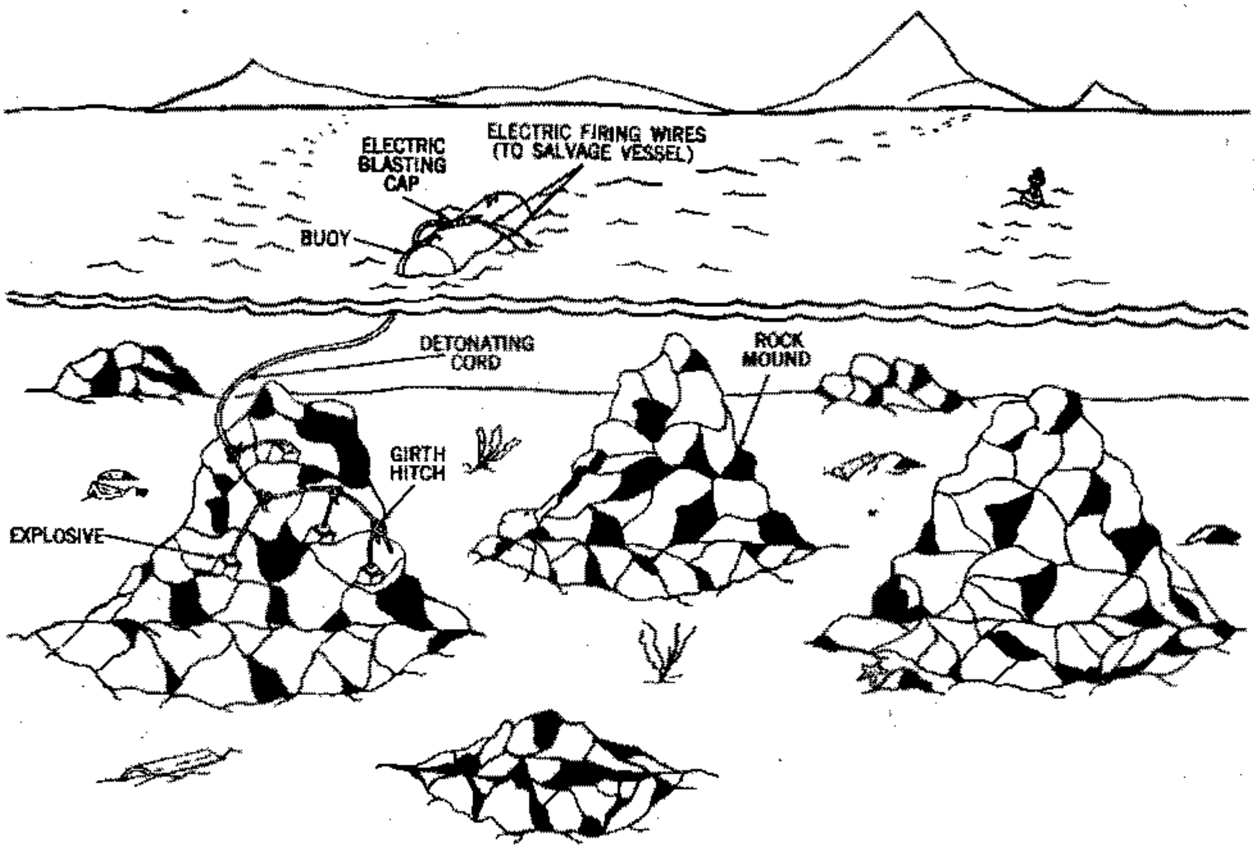

Figure 44—Dispersing Rock Mounds.

particles, and full of cracks. One demolition pack or equivalent, without tamping, will remove about ten cubic feet of cinder lava. Solid lava usually is encountered in the form of boulders. Top loading (mud capping) is preferred to snakeholing for dispersing these boulders because snakeholing has a tendency to crater the earth under the boulder rather than to disperse it.

Rock Mounds

Rock mounds, figure 44, are man-made barriers that are likely to be hidden below the surface of the water. To disperse these rock mounds, charges are placed between the rocks and detonated. Mounds may be dispersed singly or in groups, at the discretion of the salvage officer. If the rock mounds have a large mixture of sand, powder points may be used effectively.

Projections Through Ship's Hull

If a ship that is to be salvaged has been pierced by a rock pinnacle, underwater demolition can be used to help free the ship. The best procedure is to cement the rock to the hull so that it plugs the hole and then break the rock free about two feet outside the hull, figure 45. Steps are as follows:

1. Cement the rock pinnacle to the hull on the outside.
2. Working about two or three feet away from the hull, drill holes circumferentially in the rock.
3. Place small demolition charges in the drilled holes and detonate.
4. Place additional small charges in the craters formed by the first blasting operation and detonate. Repeat this step until the rock is sheared.

If a coral pinnacle has pierced the hull, remove the coral and patch the hole. Coral does not have enough tensile strength to form a part of the patch.

Placement of Anchors

Cratering charges can be used to help set anchors in hard clay, mud, or rock. A charge is placed near an anchor and detonated; the anchor is then lifted and allowed to drop into the crater, figure 46.

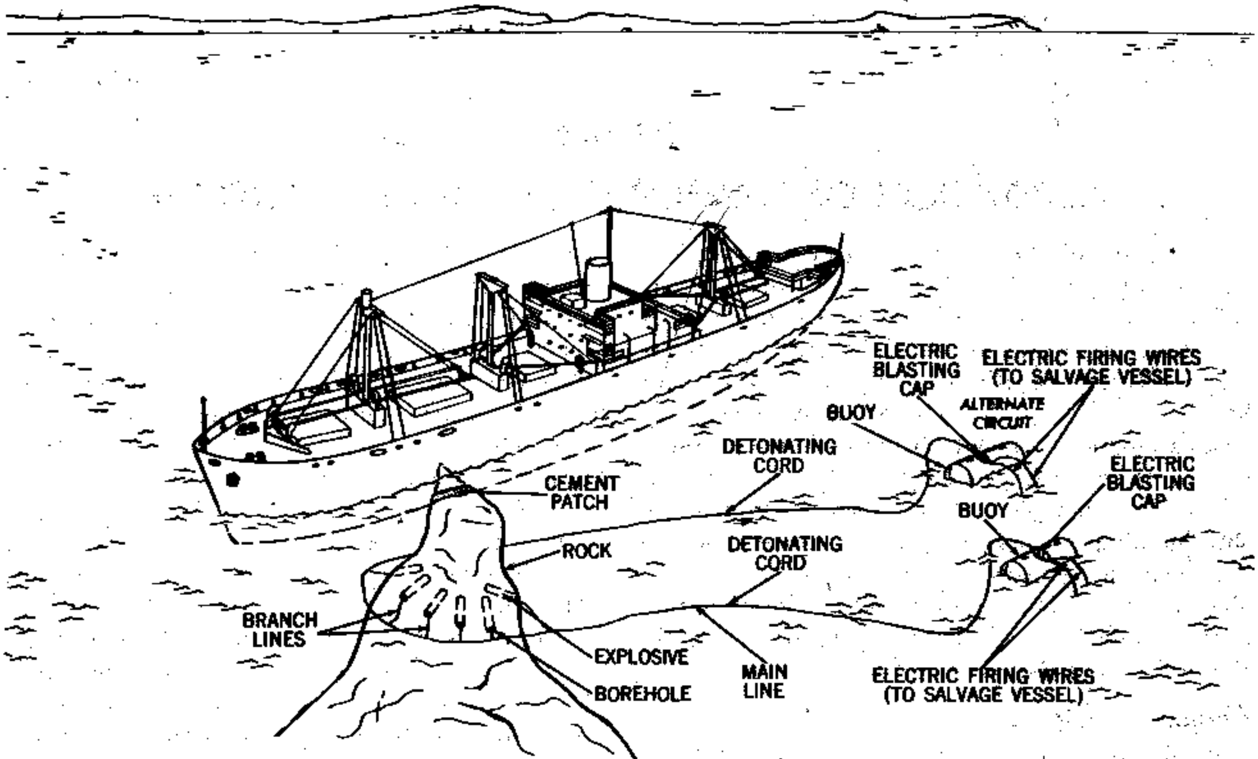

Figure 45—Freeing a Ship from Rock Pinnacle.

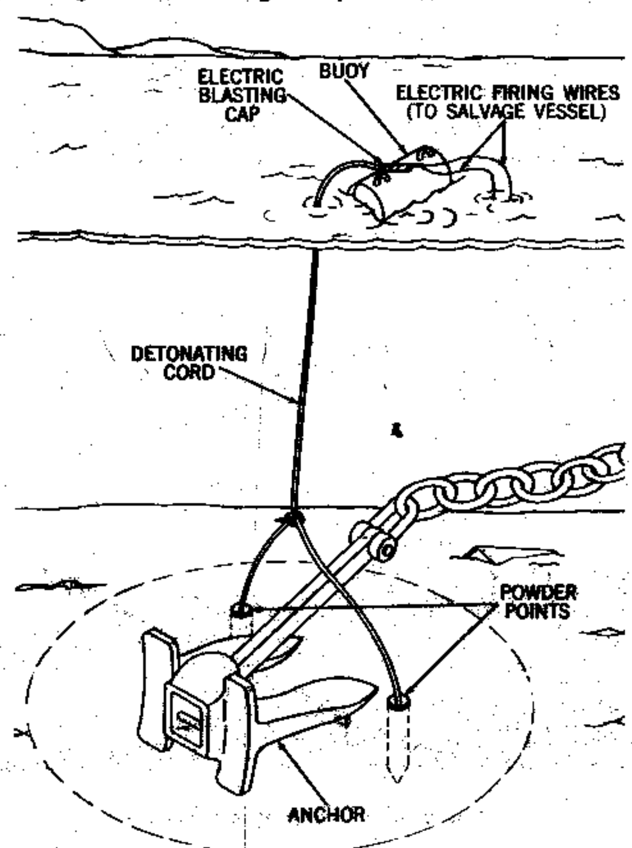

Figure 46—Centering Charge Used for Anchor Placement.

Chapter 9

ALTERATION OF HARBOR AND CHANNEL BOTTOMS

In clearing blocked harbors, heavy dredging and salvage equipment usually is not available, particularly when war conditions make time one of the most important factors. Emergency underwater salvage operations are intended to make a harbor useful as quickly and as easily as possible. Usable channels and anchoring or berthing facilities must be developed rapidly. The convenience of straight channels and free open anchorages for ship handling must be sacrificed to speed and the most expedient means of making the harbor usable. The clearance plan will be based on the minimum obstacle removal and on the minimum change in the harbor and channel bottoms.

Channeling Operations

Preliminary Survey. A sweeping survey, figure 47, is the first step in planning for channeling operations. Standard survey equipment, including fathometers, lead lines, and wire sweeps are used to determine depths, locations of obstacles, and the character of the bottom. All of this information is plotted on a large scale chart of the area; the chart then is studied to determine the best channel for development.

In determining the channel to be cleared, the following factors must be taken into consideration:

1. Existing channels, either natural or manmade.
2. The path of minimum obstacle density.
3. The type of bottom.
4. Interval and range of tide.
5. Prevailing wind.
6. Current conditions.
7. The positions of obstacles that might create eddy currents.

The line for the channel, figure 48, may appear to be "the long way around;" it will probably not be a straight line; but it must be the line that will result in a usable channel with the least amount of time and effort.

Methods. The method used to alter or create a channel must be determined by the salvage officer. Soft bottoms may be more easily worked with air lifts and water jets than with explosives. Both the depth of the water and the character of the bottom must be considered when explosives are to be used.

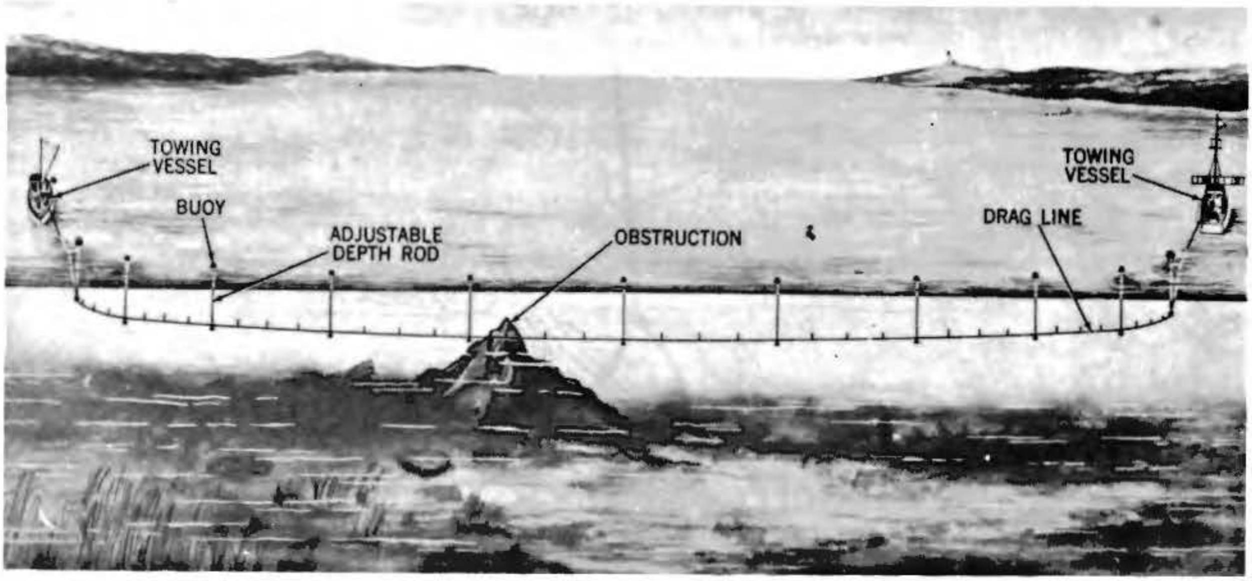

Figure 47—Sweeping a Channel.

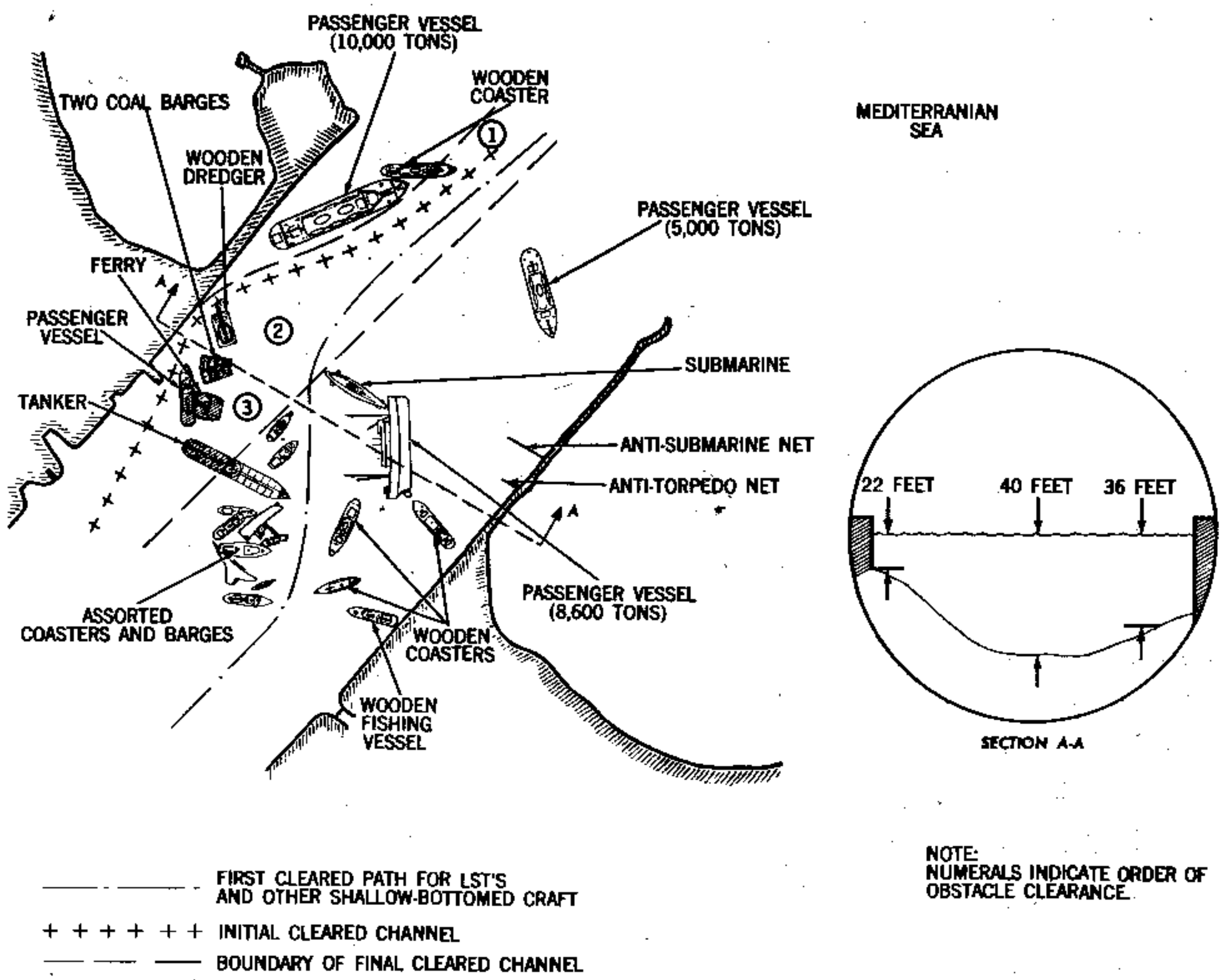

Figure 48—Typical Blocked Channel Entrance.

In loose rock bottoms, for example, about one pound of explosives will displace a cubic yard in shallow water; in rock blasting in deep water, as much as five pounds of explosive per cubic yard is required.

> NOTE: In computing volumes, always use the depth to the bottom of the bore-hole or powder point. This will be greater than the grade-line depth by the distance between charges.

Explosives. For bottom alteration, a 60 percent dynamite is usually satisfactory. For excavation of hard rock, a higher strength dynamite or composition C–4 should be used. In limestone and other soft rocks, a 40 percent dynamite is effective.

Powder Points. In placing powder points, chapter 4, they should always be driven in perpendicular to the material to be moved. Points should be driven in to a depth equal to that of the desired grade line plus the distance between points. For example, if the channel is to be deepened by 10 feet and the powder points are spaced eight feet apart, the points should be driven 18 feet into the channel bottom. Alternate points should contain different charges so that the detonation effects will not cancel each other. That is, if one point contains a 20-pound charge, the next should contain a 10-pound charge, the third a 20-pound charge, and so on. Point positions should also be staggered, figure 49.

Test Charges. To determine the best spacing for powder points or borehole charges, detonation of test charges in the bottom to be altered is recommended. Test charges should be detonated late in the day, when feasible, to allow the silt to settle back to the bottom overnight.

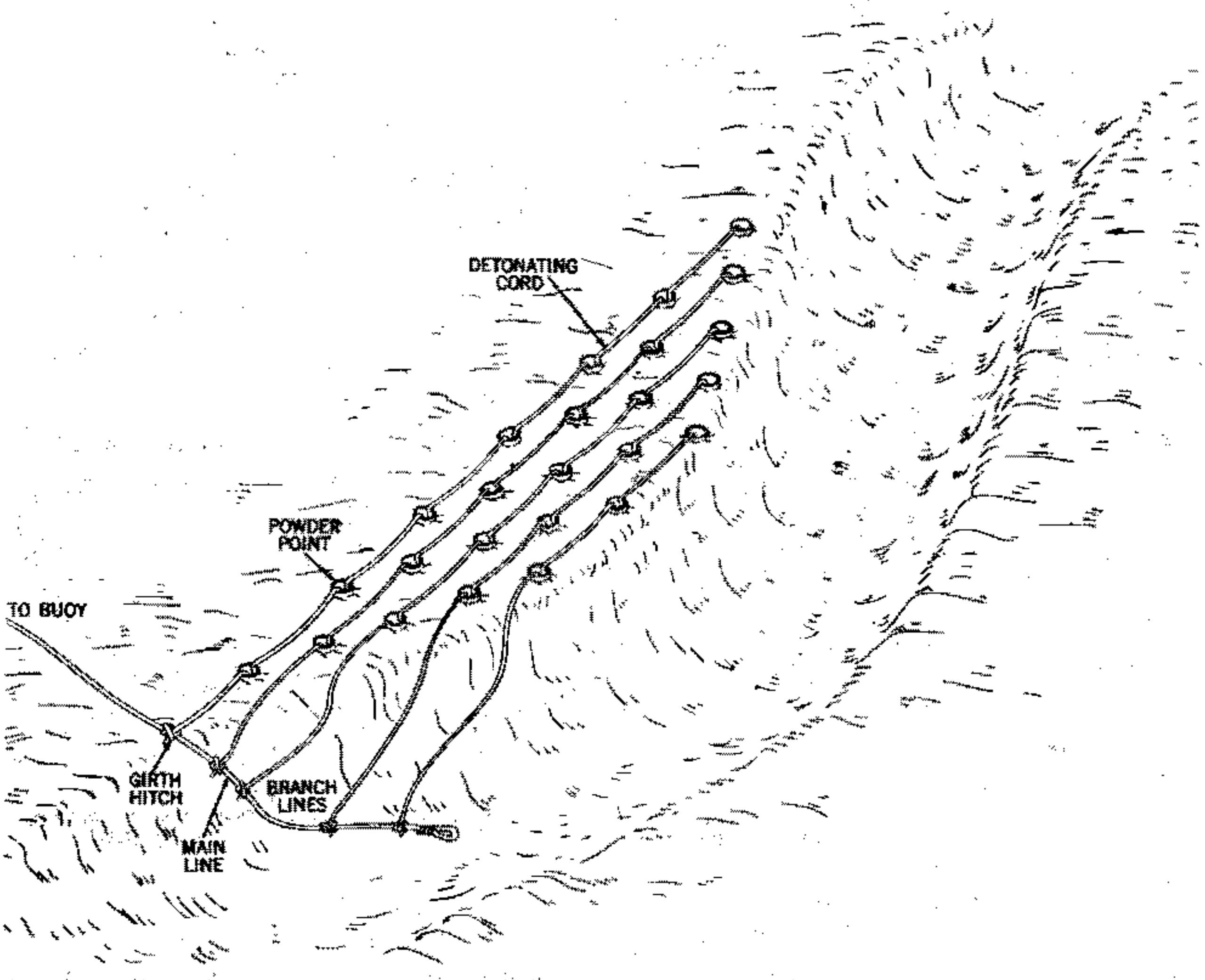

Figure 49—Straightening a Channel.

Channel Alteration. For deepening, figure 50, widening, figure 51, or straightening, figure 49, channels, powder points are recommended. Where powder points cannot be used, charges can be placed in boreholes spaced and staggered in the same way as powder points. When widening or straightening a channel, place a light charge along the bottom of the existing channel to be detonated at the same time as the charges in the side being blasted; this prevents the material blasted from the side from settling in the existing channel.

New Channels. A new channel, figure 52, will usually be required only to clear an obstacle and then only when the work required for the channel is less than that required for removal of the obstacle. The short channel normally required should be blasted in one simultaneous detonation of properly spaced powder points for the best effect. An air lift may be needed to remove the loosened material that is not forced clear of the desired channel.

Channeling Alongside a Ship. When a channel is being altered or created alongside a ship, care must be taken to prevent the ship from moving into the channel. If the ship is to be salvaged, care also must be taken to prevent damage to the hull. If the ship is to be demolished, the hull can be blasted at the same time the powder points are detonated. Charges for hull blasting should be placed on the bottom 5 to 10 feet from the hull, spaced 10 to 15 feet apart.

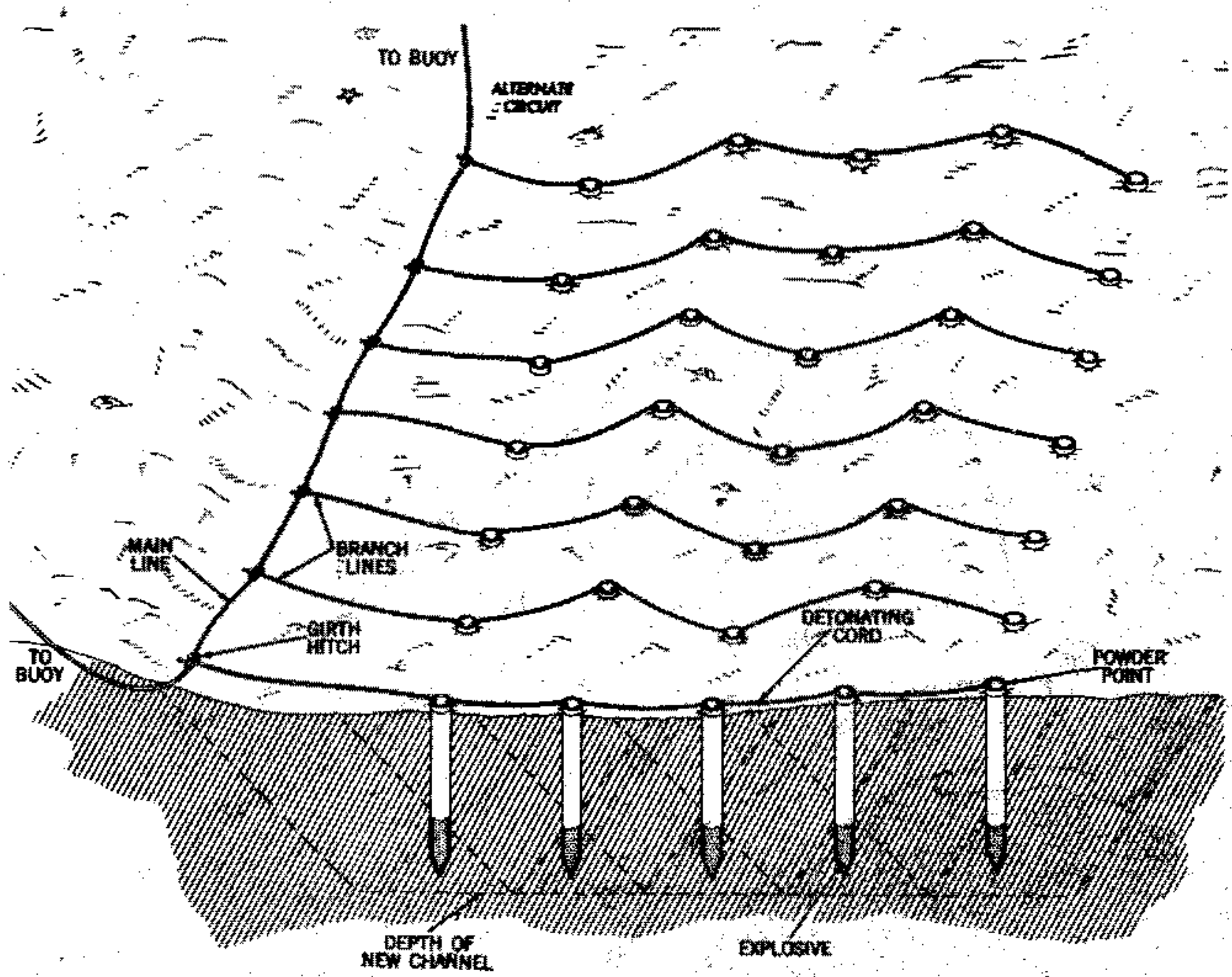

Figure 50—Deepening a Channel.

The completed channel must be clear of all parts of the ship, whether the ship is to be salvaged or flattened.

Trenching and Tunneling

Tunneling and trenching in hard rock bottoms will require the use of explosives. Such operations, adjacent to a ship that is to be salvaged, must be done with light enough charges so that the ship itself will not be damaged, figure 53. Trenching and tunneling in loose rock, clay, sand, or mud are best accomplished with a water jet, an air lift, or a combination of the two. An air lift may be needed to remove material after blasting in rock.

Air Lift. An air lift, figure 54, is a syphon type piping arrangement which lifts mud, sand, and loose rock from one location and delivers it to another. Arranged as shown in figure 55, the lift pipe is 12 inches in diameter. The air pipe, 1 inch in diameter, should enter the lift pipe at least 2 feet above the bottom.

Sand Bar Removal

Sand bars usually can be scoured away with a water jet more effectively than they can be blasted, particularly in narrow channels. When the sand bar covers a large area or the depth of cut makes the use of a water jet impractical, powder points should be used, figure 55. Alternately, TNT blocks (Demolition Charge Mk 14) can be placed 10 feet apart along the bar. A string of these blocks will clear a channel from 10 to 12 feet wide that is 4 feet deep.

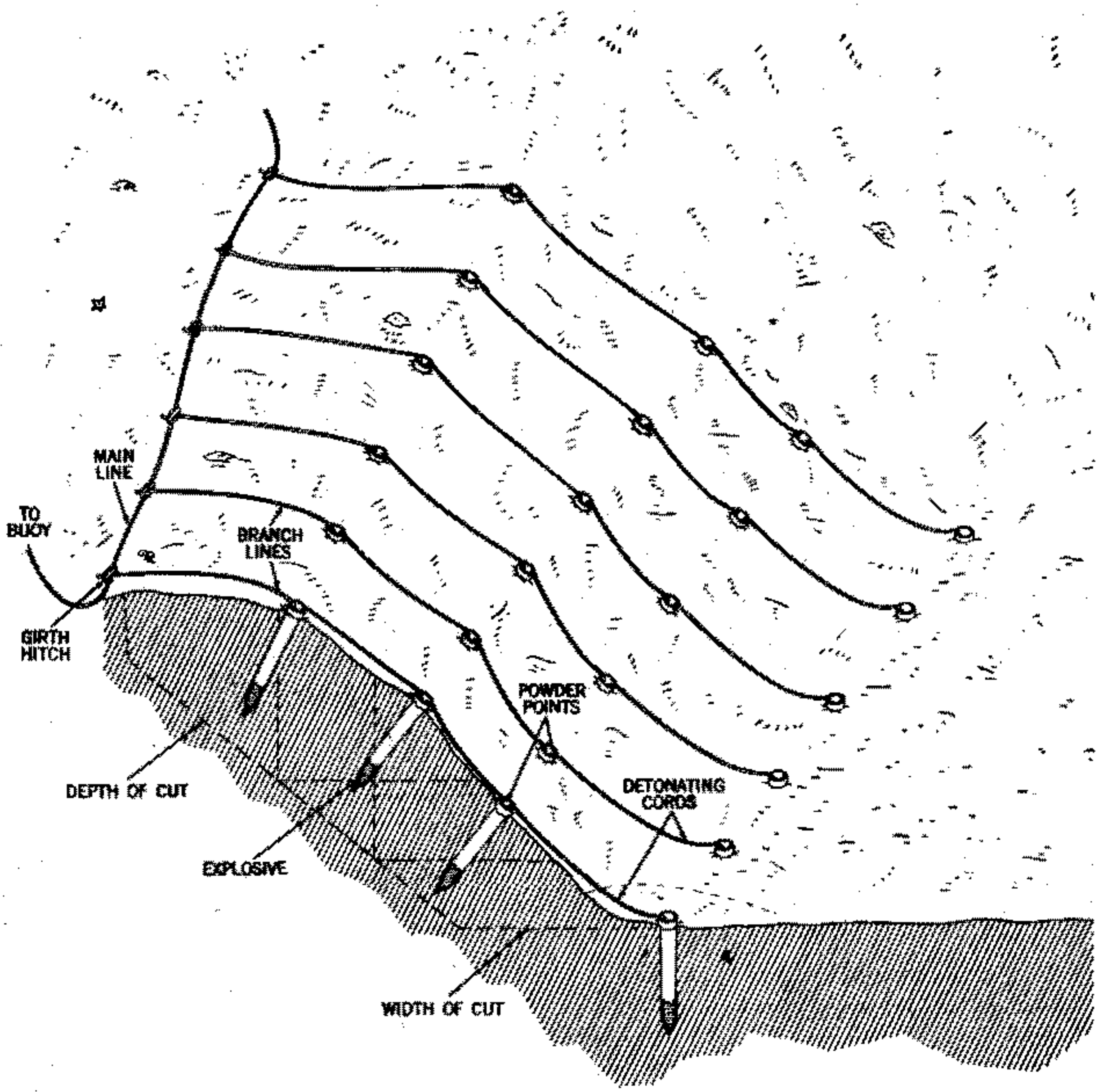

Figure 51—Widening a Channel.

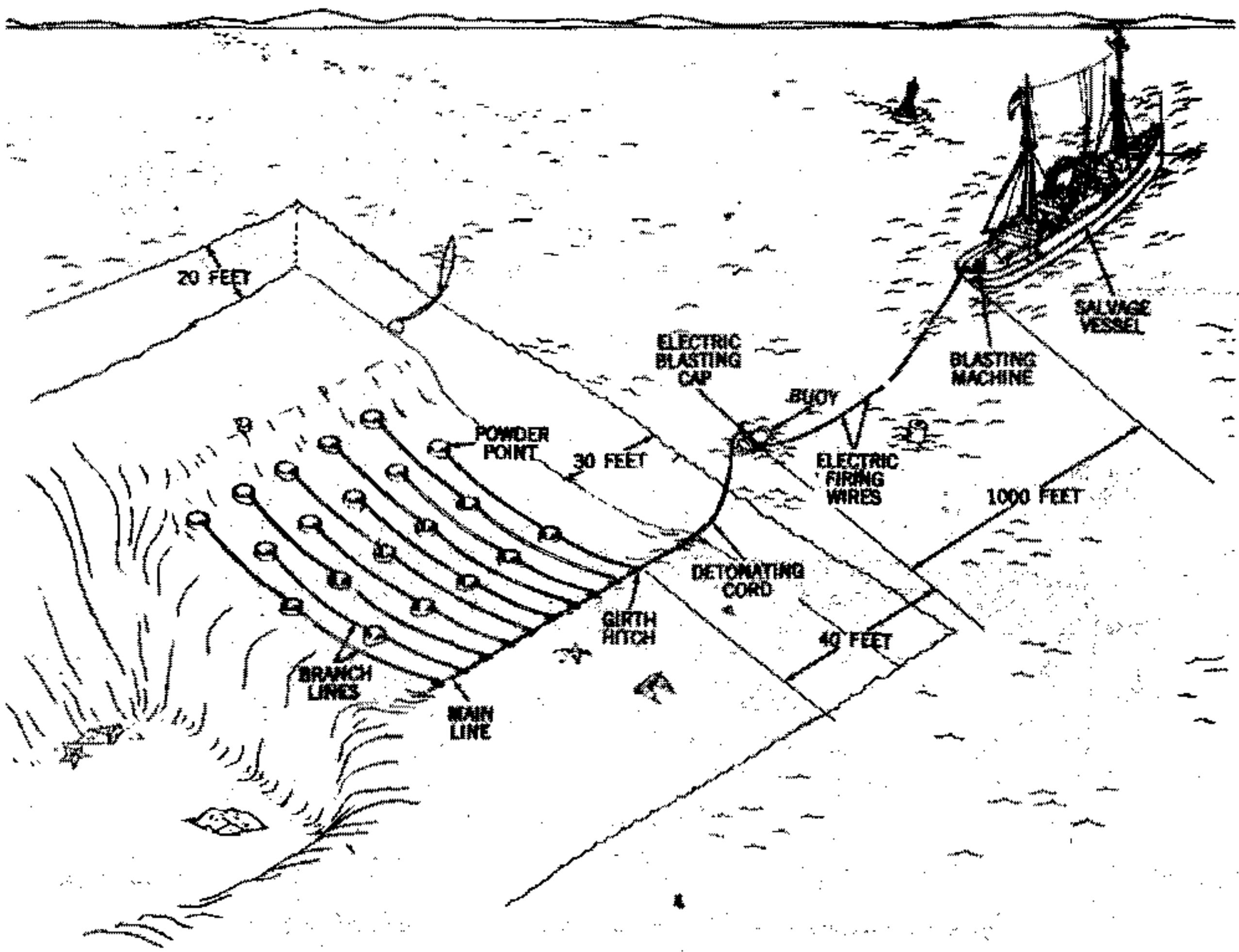

Figure 52—Method of Channel Blasting.

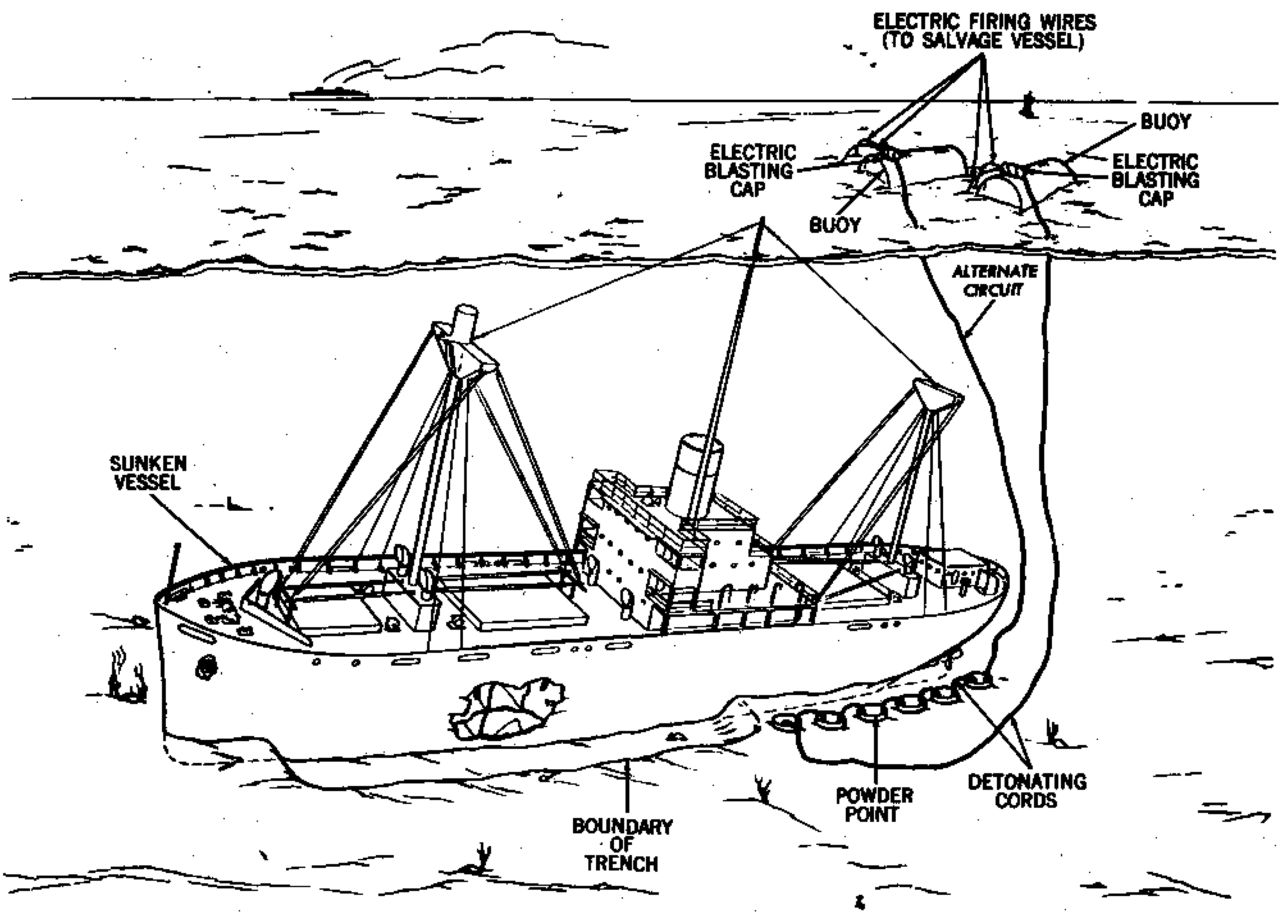

Figure 53—Trenching and Tunneling with Explosives Alongside a Ship.

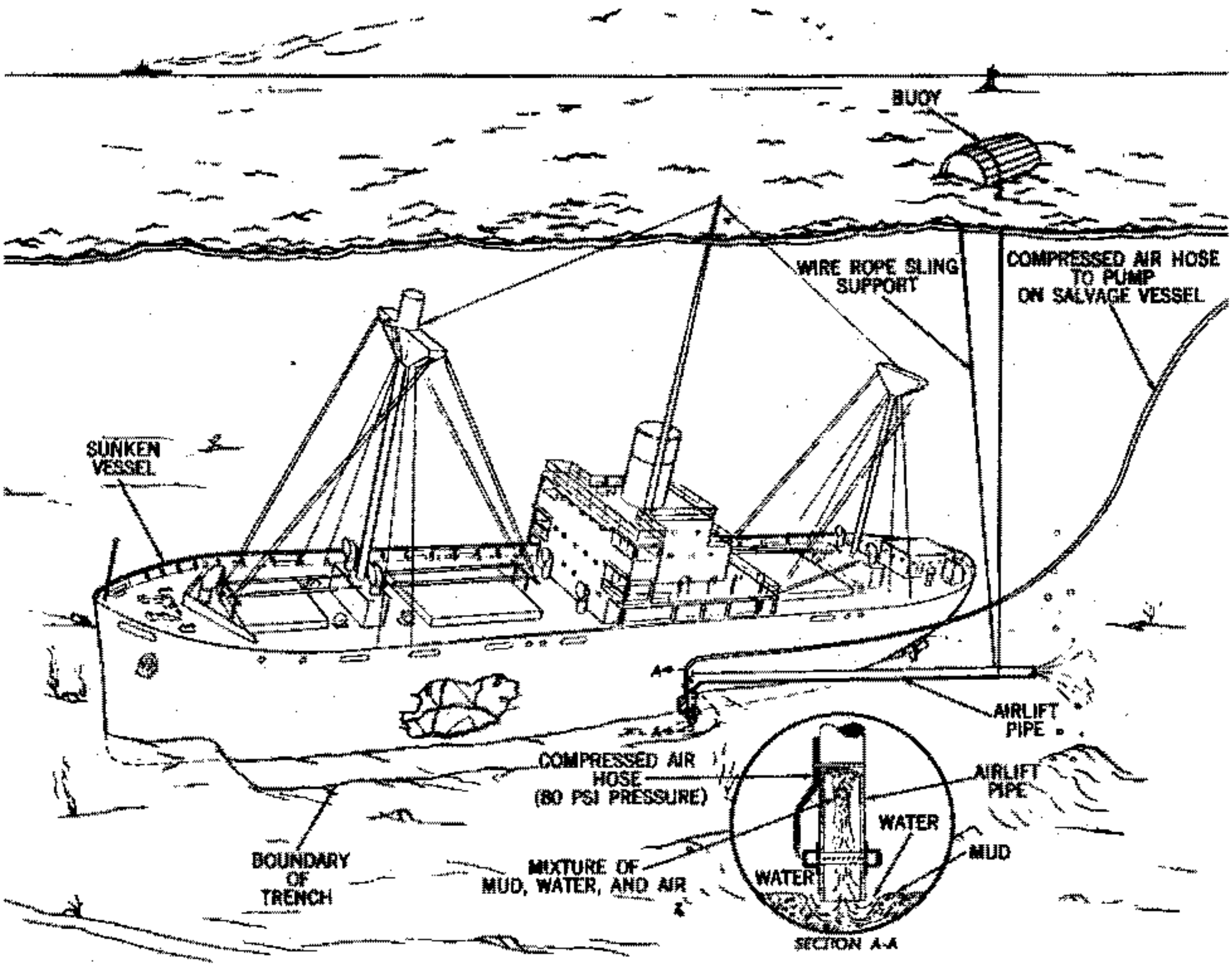

Figure 54—Use of Air Lift During Trenching and Tunneling Operations.

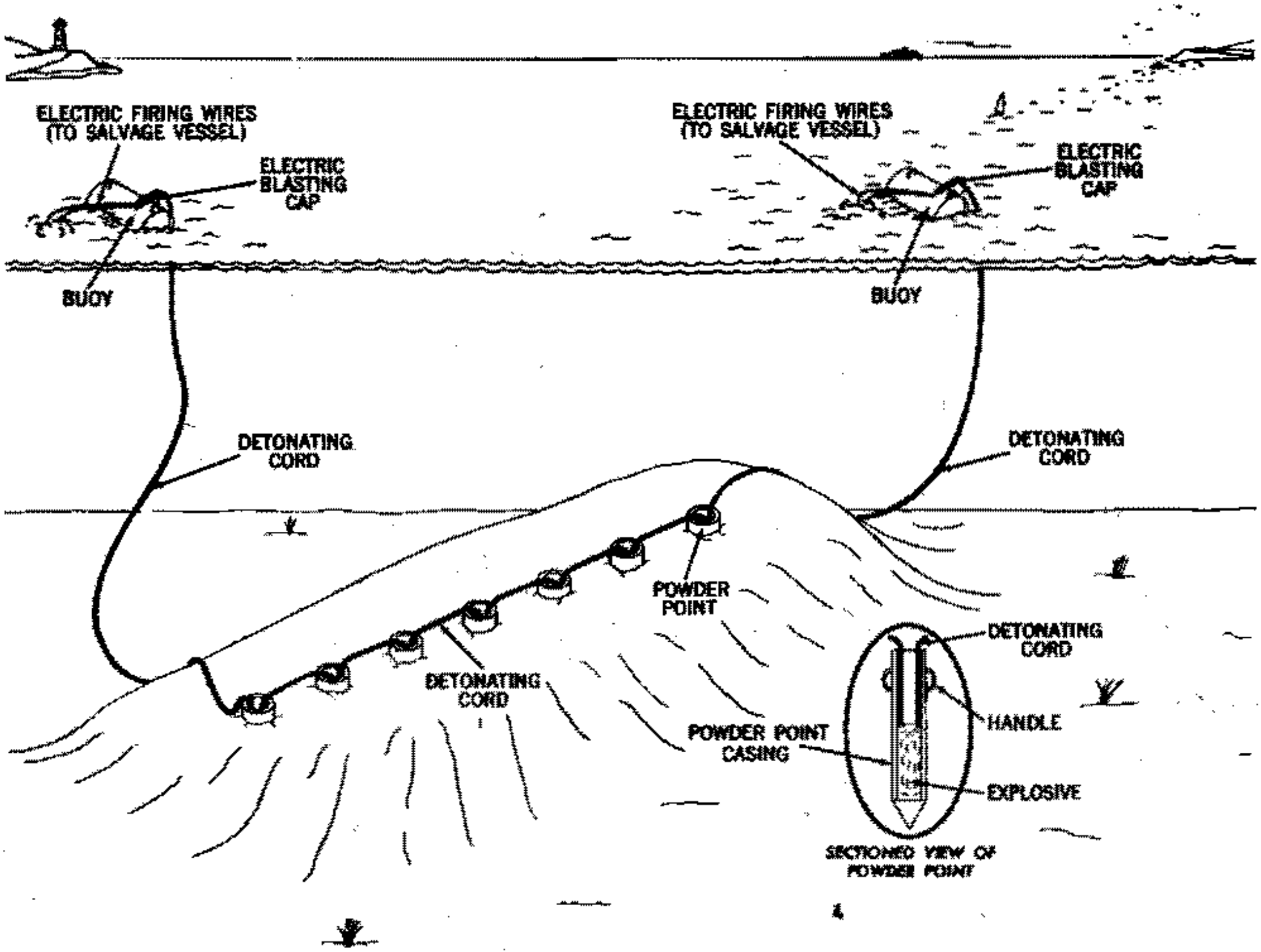

Figure 55—Sand Bar Removal.

Chapter 10

CONCRETE AND MASONRY BLASTING

Blasting of concrete and masonry may be required in underwater salvage work to remove or alter seawalls, retaining walls, or piers and to remove concrete ballast from sunken hulls. Also, harbor or channel blocking sometimes may include concrete obstacles.

Recommended explosives for concrete blasting include TNT, tetrytol, and composition C-4. The formulas given in this chapter are based on the use of any one of these three. In some circumstances, blasting gelatin, dynamite, or ammonium nitrate may be used; if they are, calculated weights should be increased to compensate for the lower effectiveness of these explosives.

The formulas and examples given in this chapter are for blasting concrete in air, except where otherwise noted. Simple concrete requires about one pound of explosive per cubic foot of concrete for dispersal. Reinforced concrete requires approximately twice this amount. For underwater demolition, the amount required in air should be doubled.

Formulas

For simple breaching of a wall (seldom required underwater):

$P=20\ HT$, where P is the weight in pounds of explosive, H is the height of the wall in feet, and T is wall thickness in feet.

For dispersing a section of wall:

$P=R^3KC$, where P is the weight in pounds of explosive, R is the breaching radius, K is a material factor, table 8, and C is a location factor.

The breaching radius, R, is the distance in feet from an explosion within which all material is displaced or destroyed. The material factor, K, is given for different materials for different breaching radii in table 9. For underwater work, C is equal to 1.0 for depths of water above the charge of one-half the breaching radius or less. When the depth of water is equal to or greater than the breaching radius, C is equal to 2.0. For charges in air, consult FM 5-25 for the correct value of C.

Table 9—Material Factors

Material	R	K
Ordinary earth	All values	0.05
Poor masonry, shale and hardpan, good timber and earth construction.	do	.225
Good masonry, ordinary concrete, rock.	Less than 3 feet	.35
	3 to 5 feet	.275
	5 to 7 feet	.25
	More than 7 feet	.225
Dense concrete, first-class masonry.	Less than 3 feet	.45
	3 to 5 feet	.375
	5 to 7 feet	.325
	More than 7 feet	.275
Reinforced concrete (concrete only; will not cut reinforcing steel).	Less than 3 feet	.70
	3 to 5 feet	.55
	5 to 7 feet	.50
	More than 7 feet	.425

Placement of Charges

Walls. Although elevating the explosive above the ground is recommended for all charges, it is not necessary against walls under 6 feet high or thick. However, elevating the charge is necessary for walls over 6 feet high or thick, or for charges greater than 1000 pounds. Elevation of the charge eliminates excessive cratering in front of the wall. For quantities of explosive up to 48 packs (Demoliton Outfit Mk 133 or Mk 135), the charge should be in the shape of a horizontal bar. A charge of 24 packs in this shape is about 9¼ feet long and will produce a gap of about 12 feet.

For walls less than 6 feet high or 6 feet thick, use 8 packs (160 pounds) per foot of thickness placed in a horizontal bar, figure 56.

For walls greater than 6 feet in height or thickness, use 12 packs (240 pounds) per foot of thickness placed as an Army Engineers' Castle Charge, figure 57.

EXAMPLES. The following examples are given to assist in determination of the best placement of explosive charges for breaching or dispersing a concrete obstacle. The effects of an explosion on a particular obstacle encountered will depend

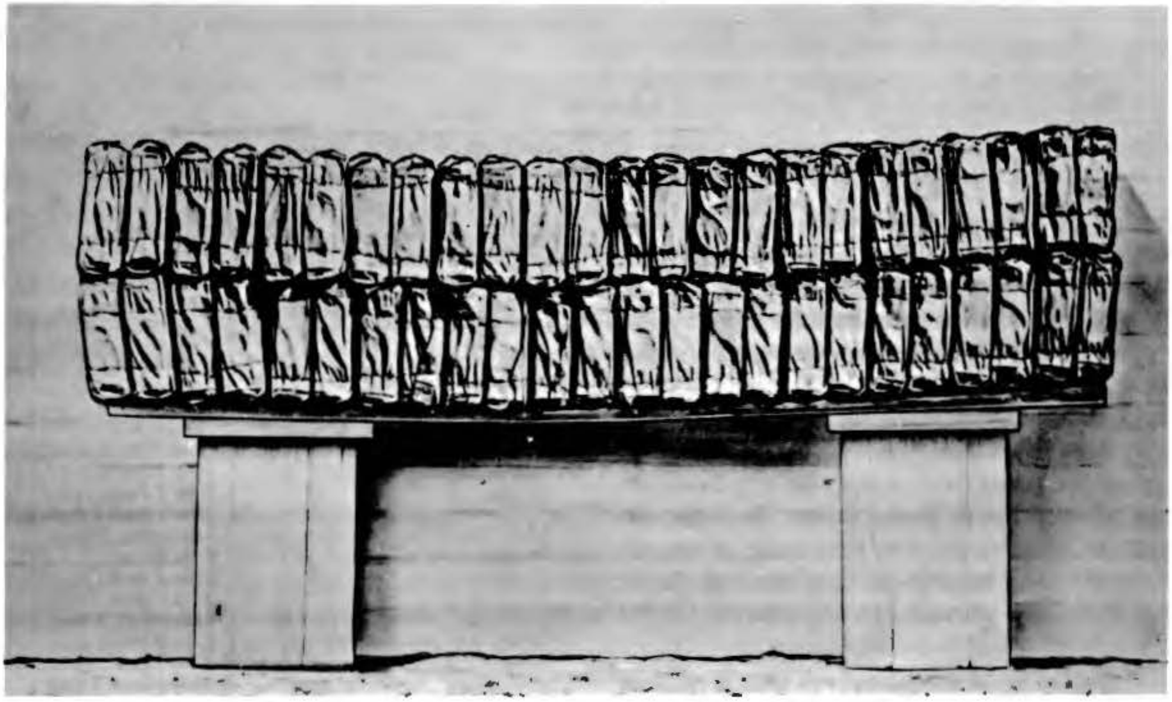

Figure 56—Form of Charges for a Wall Less Than Six Feet High or Six Feet Thick.

upon the material of which it is made, the amount and type of explosive used, the location of the charge, and the confinement of the charge.

A gap 18 feet wide will be opened in a masonry wall with a 30° sloped face by a 24-pack charge detonated on top of the wall. The same charge detonated against the center of the face of the wall will result in a deeper gap about 16 feet wide.

Against a reinforced concrete wall up to 6 feet thick, a bar charge of 56 packs set at least 18 inches above the ground will clear a gap about 13 feet wide by 5 feet deep.

A gap about 18 feet wide by 12 feet high will be cleared in a wall 13 feet high by 3 feet thick at the top tapering to 6 feet wide at the base by a bar charge of 66 packs placed 2½ feet above the ground.

INTERNAL CHARGES. Internal charges are more effective than external charges, but require more preparation time. Boreholes for internal charges, figure 58, may be made with pneumatic tools or with small shaped charges, figure 59. A borehole 2 inches in diameter will hold about 2 pounds of explosive per foot of length. If a single borehole will not accommodate all of the explosive required at 1 point, additional boreholes should be made adjacent to the first.

For dispersing a section of a wall, boreholes for internal charges may be produced by a group of shaped charges placed three feet apart both horizontally and vertically. Adjacent rows of holes should be staggered. The outer line of boles, outlining the desired gap, are cut perpendicular to the face of the wall. All other holes should be cut at an angle 15° downward from tbe horizontal, figure 60.

For walls less than 8 feet high, internal charges may be placed in boreholes 4 feet apart in a horizontal row halfway up the wall. For walls higher than 8 feet, a double row of charges 4 feet apart may be used.

When using shaped charges to make boreholes, it may be necessary to use two successive charges to produce the desired depth of hole. If this is done, the first charge should be secured with the standoff legs in place; the second charge is then detonated directly over the hole made by the first charge.

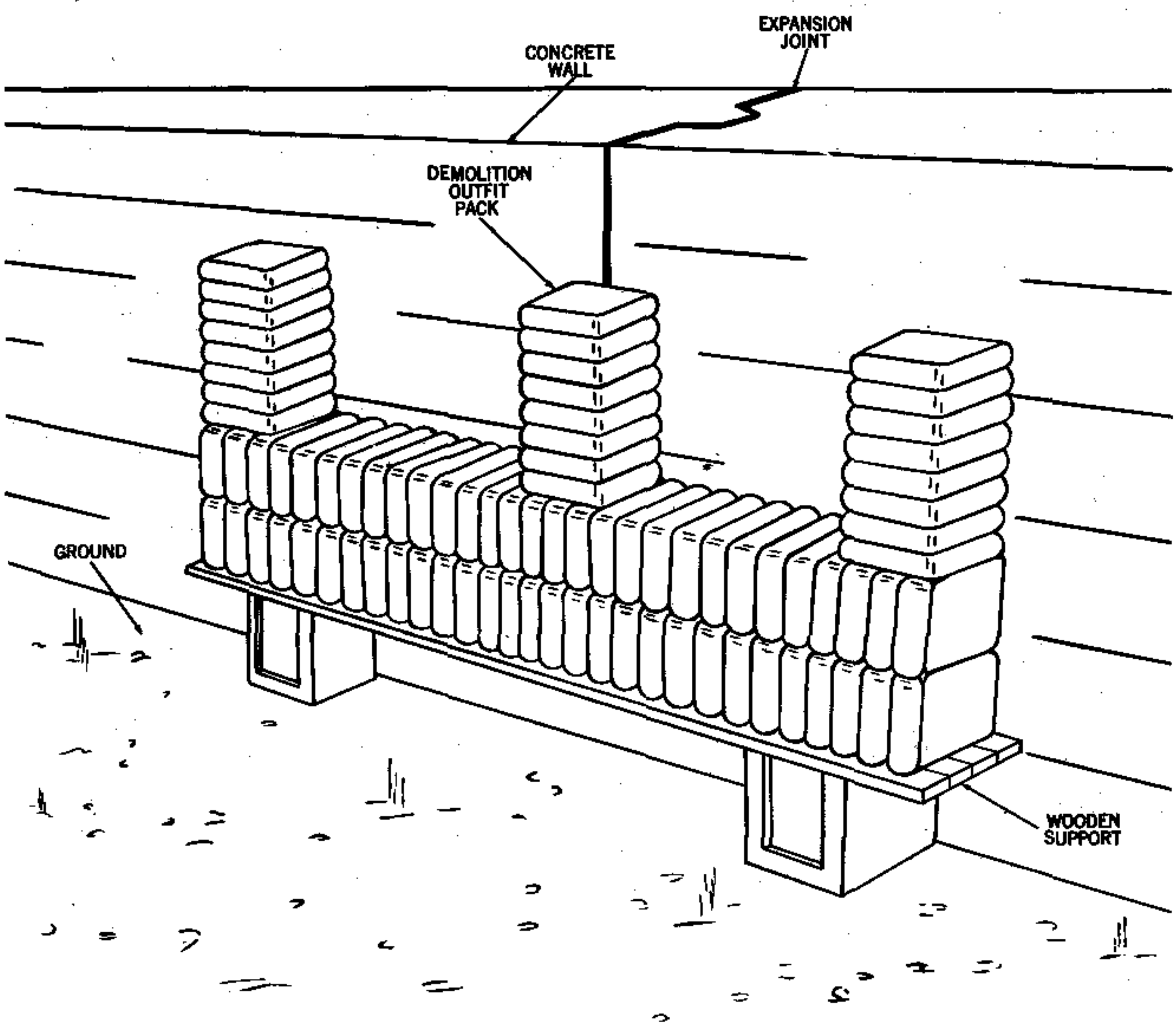

Figure 57—Form of Charges for a Wall Greater Than Six Feet High or Six Feet Thick.

WARNING

For above water work, do not place the second charge until the hole made by the first charge has cooled. Artificial cooling with water is suggested to avoid delay.

Rock-filled Cofferdams. A rock-filled cofferdam is a cribwork of logs fastened together and filled with loose rock. To disperse such a dam, charges should be placed at the intersections of the logs. Main charges should be placed at the foundation with smaller charges about two-thirds of the way to the top; the main charges should comprise about three-fourths of the total charge, which is computed at the rate of 2 pounds of explosive per cubic foot of cofferdam. Charges should be placed about 15 feet apart in tunnels dug into the cofferdam at the base and about two-thirds of the way up. Alternately, the main charges may be placed in holes dug at the base.

Piers. Either external or internal charges may be used for concrete pier destruction. Charges are distributed along the base of the pier and primed for simultaneous detonation; if the pier is small enough so that a single charge will suffice, the charge is placed against the base at the center, figure 61. The effectiveness of charges placed

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against the supports of a pier can be increased by placing pounding charges on top of the pier primed for simultaneous detonation with the base charges.

Removal of Concrete Ballast from Ship's Hull. Concrete ballast in ships is removed from the inside by a nibbling process, figure 62. A small charge is placed in the concrete and detonated. Then a larger charge is placed in this hole and detonated. By successive blasting, the concrete is broken up, without damage to the hull, and can then be easily removed from the vessel.

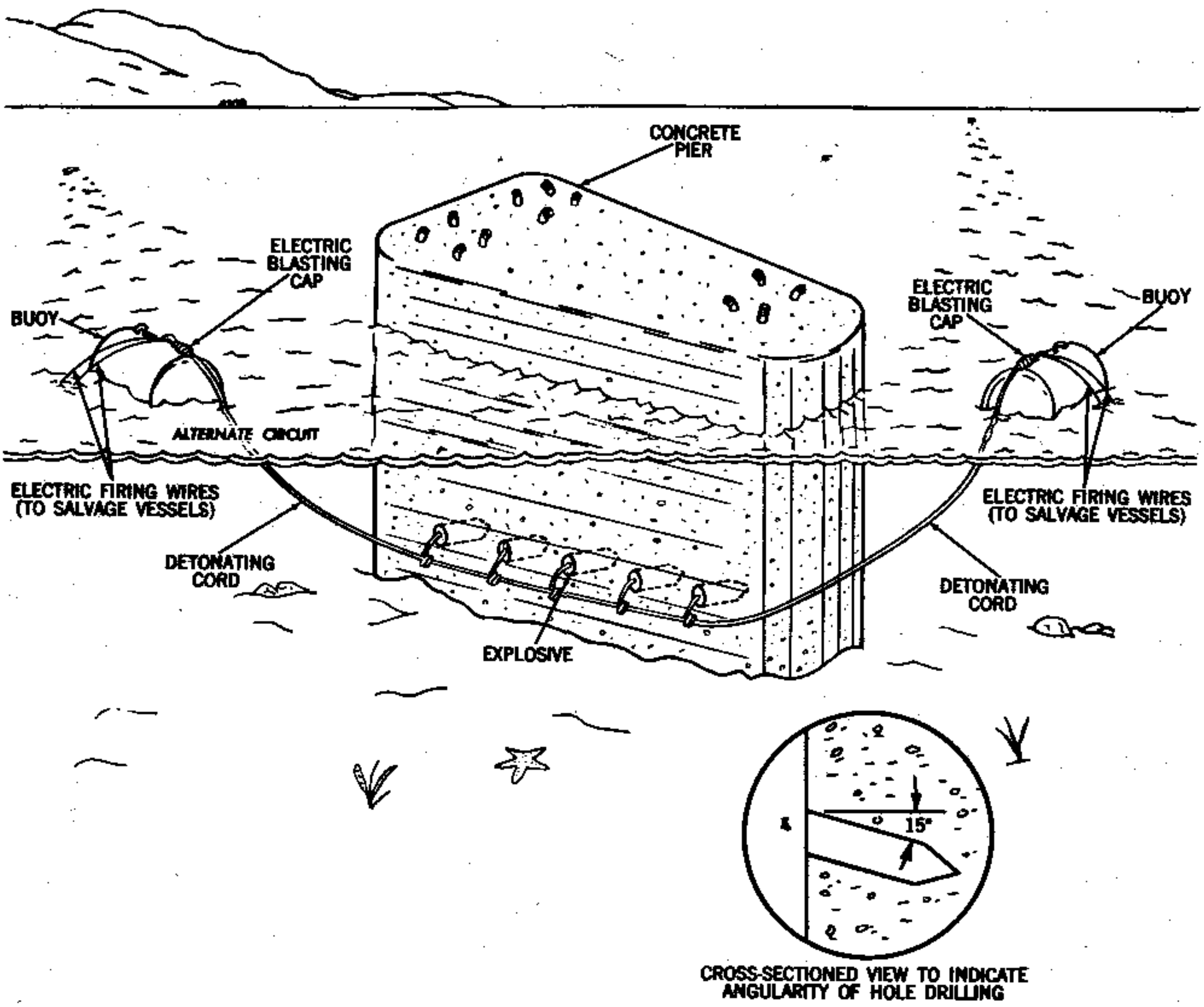

Figure 58—Dispersing a Concrete Pier with Internal Charges.

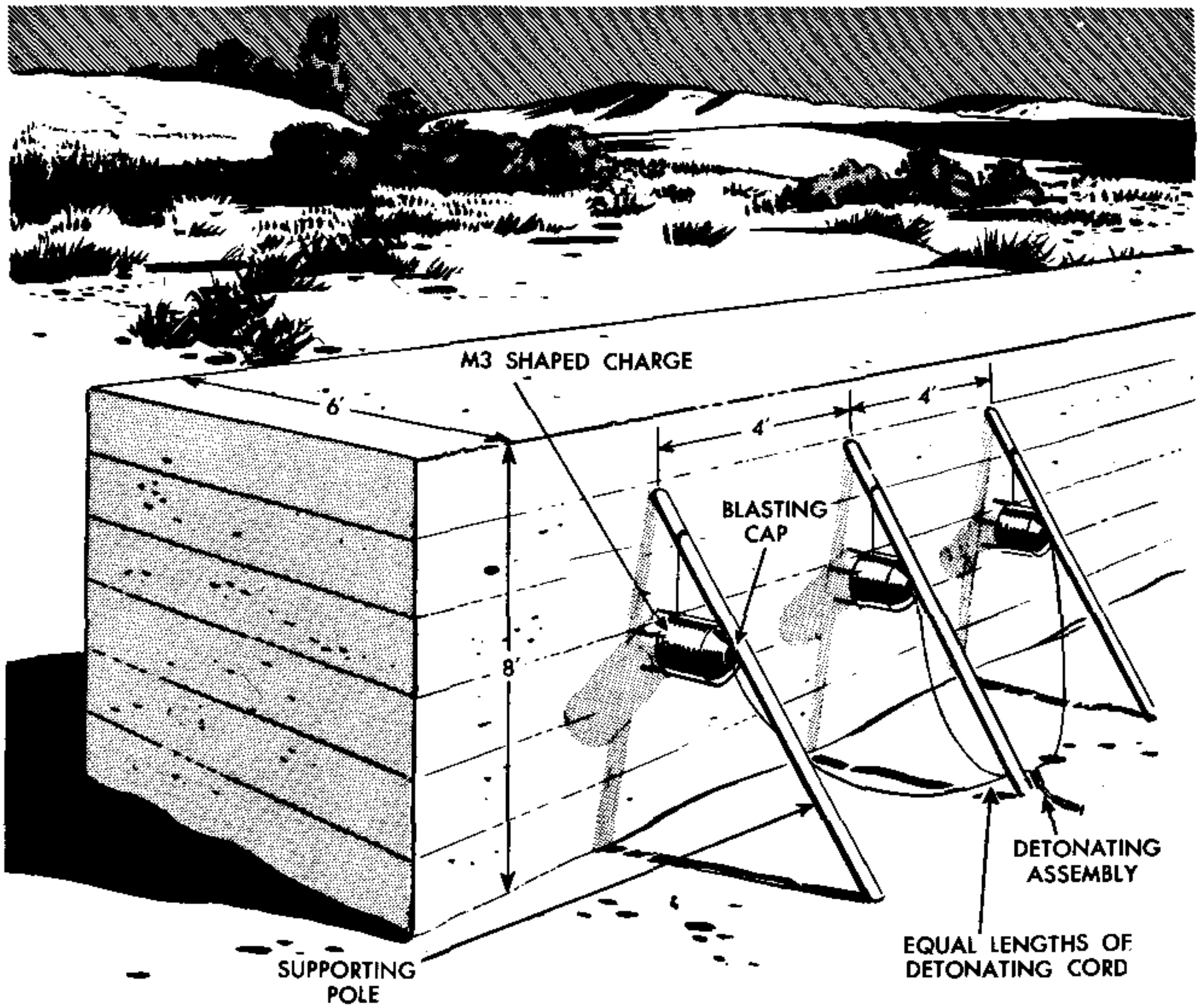

Figure 59—Use of Shaped Charges to Make Boreholes.

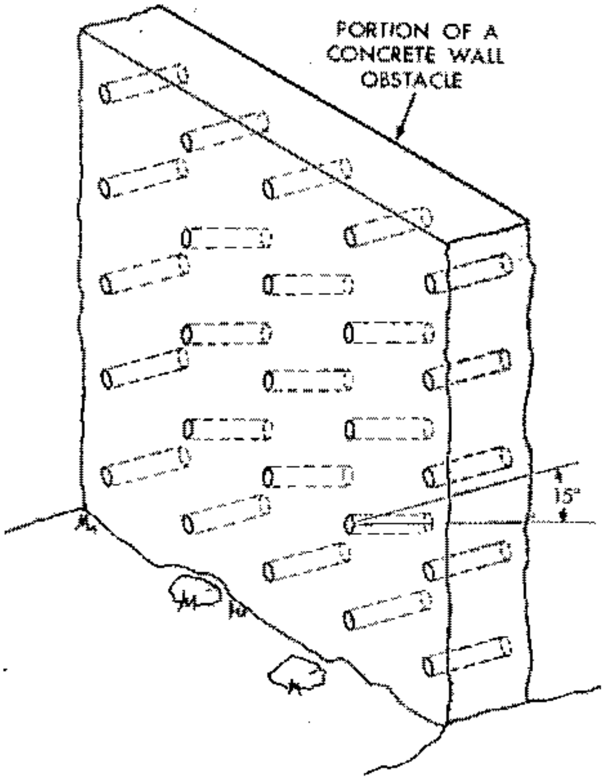

Figure 60—Use of Shaped Charges to Make Boreholes for Dispersing a Section of Wall.

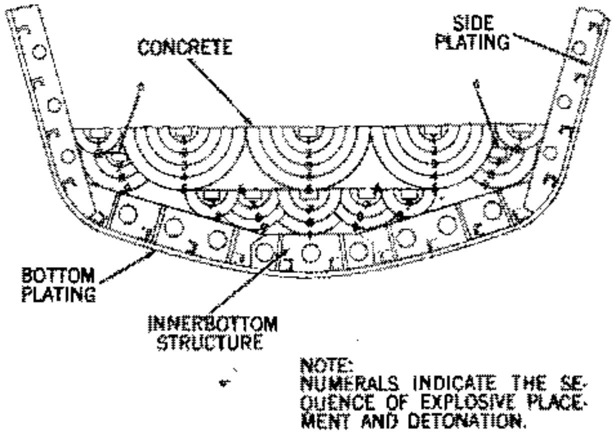

Figure 62—Removal of Concrete Ballast.

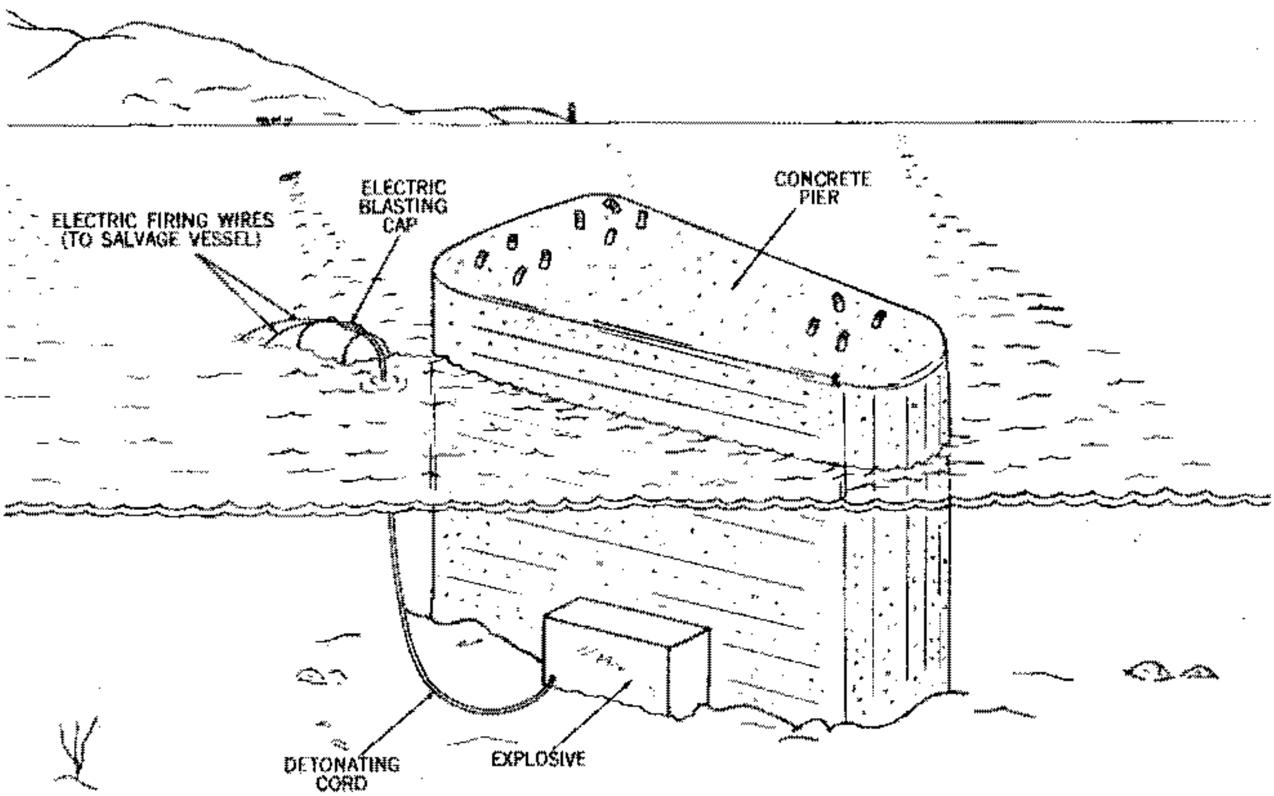

Figure 61—Dispersing a Concrete Pier with an External Charge.

Chapter 11

BREAKING AND CUTTING STEEL

The effects of underwater explosions are influenced by so many variables that no hard and fast rules can be given for the breaking or cutting of steel under water with high explosives. The formulas and methods given in this chapter are intended as a guide; whenever possible, test charges should be placed and detonated to determine the best procedure. In many cases, this procedure only can be determined by trial and error.

Energy released by an explosion is proportional to the weight of the explosive charge. However, the destructive effects on any given steel object will depend on the degree and type of contact of the explosive with the metal. Therefore, it is important that the type of charge and its placement be considered together with the amount of explosive to be used.

Formulas

The following formulas, used to calculate the weight of explosive needed to cut steel, are based on untamped charges in air. Weights must be doubled for underwater use.

For structural steel sections such as I-beams, built-up girders, and steel plates:

$P=3/8A$, where P is the weight of the explosive in pounds and A is the cross-sectional area of the steel section in square inches.

For steel bars, cables, and chains where it is impossible to obtain good contact between the charge and the steel:

$P=A$, where P is the weight of the explosive in pounds and A is the cross-sectional area of the steel in square inches.

Placement of Charges

The charge usually is placed on one side of the steel section along the desired line of rupture, with the largest portion of the charge nearest the greatest cross-section of the member. If the charges must be placed on opposite sides of the desired line of rupture, they should be staggered. Charges placed directly opposite each other have a tendency to neutralize the effects of both. Charges should be primed for simultaneous detonation. Contact between charge and steel should be as close as possible; any air or water space between them results in loss of cutting power. Charges may be secured with rope, tape, canvas, or sandbags.

Structural Members. Structural members may be single solid shapes, multiple solid shapes, single hollow shapes, or hollow shapes fabricated of more than one piece. Single members, such as I-beams, steel rods, or hollow pipes, can best be sheared by staggering charges on opposite sides of the member,

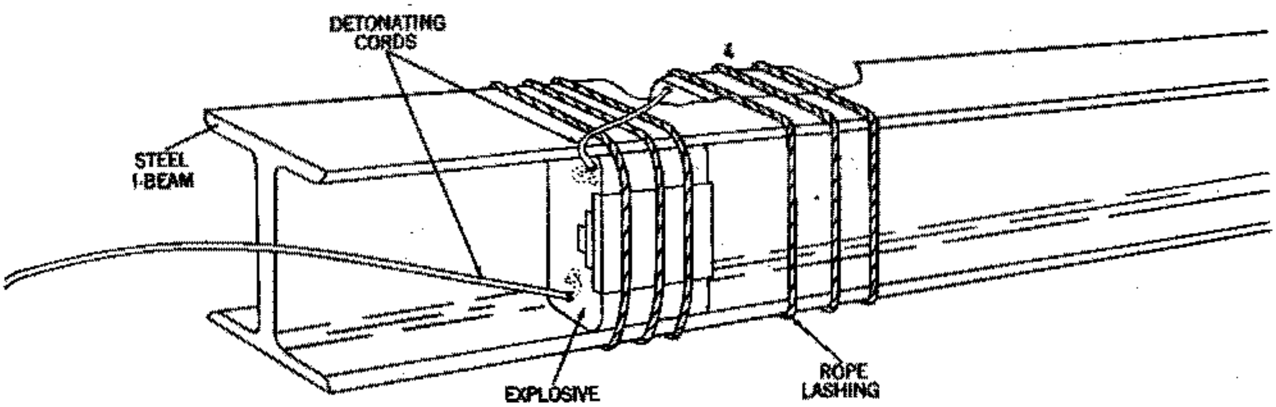

Figure 63—Placement of Charges for Shearing an I-Beam.

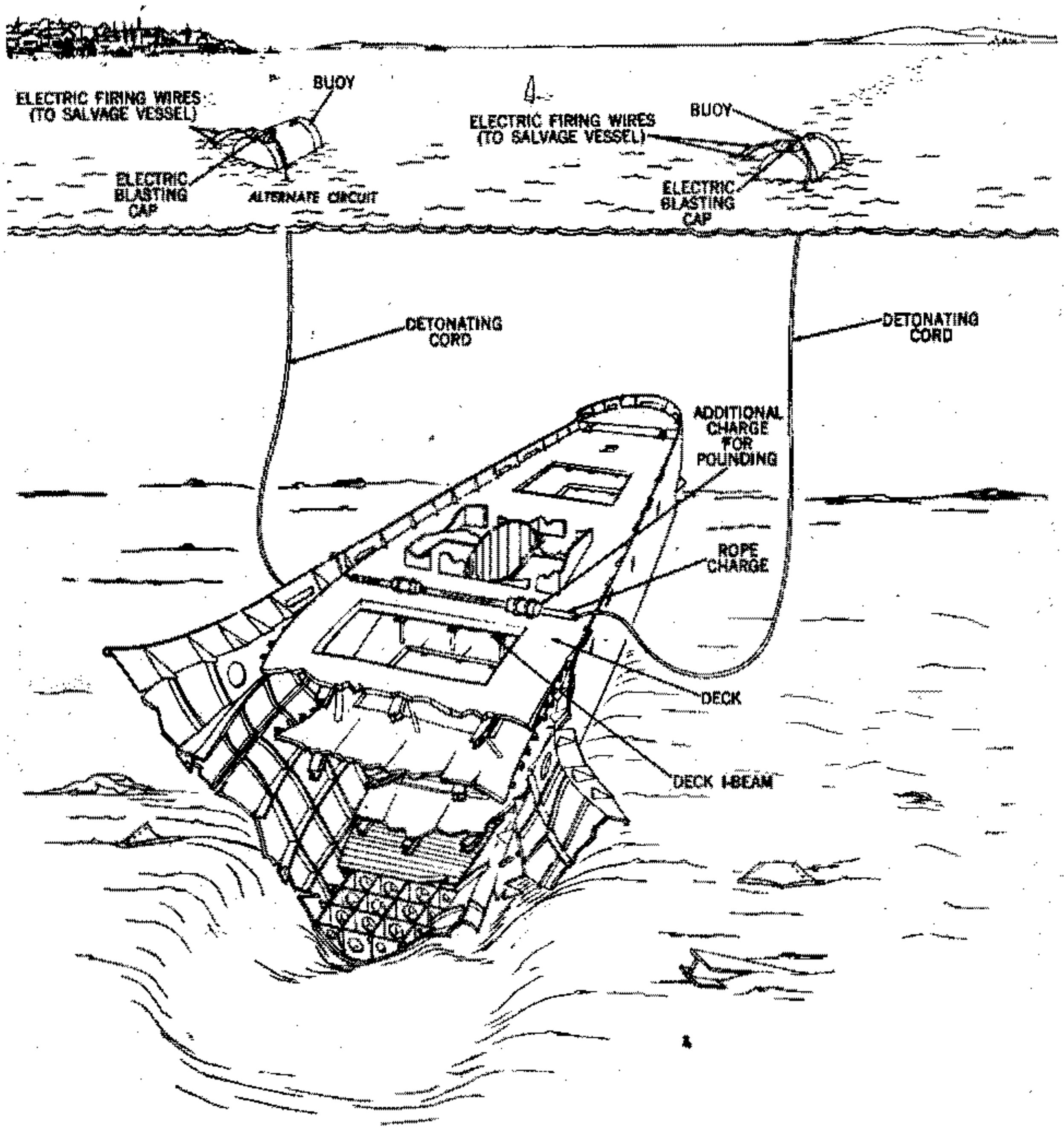

Figure 64—Placement of Charges for Deck Cutting.

figure 63. Charges should be offset slightly more than the diameter or thickness of the member.

The weight of charge for a fabricated shape of more than one piece is calculated for each piece; the total for all pieces is the weight required to shear the entire member. Charges should be placed in the same manner as for single members. For shearing odd-shaped structural members, the largest portion of the charge should be placed against the strongest section of the member.

Steel Plates. Steel plates are cut with a linear-ripping charge placed along the desired line of rupture. Either a rope charge or a cavity charge may be used. The amount of explosive required should be determined by test charges; table 10 gives suggested weights of blasting gelatin. If other explosives are used, refer to table 1 for relative effectiveness values.

Table 10—Rope Charges for Shearing Steel Plates

Thickness of steel in inches	Blasting gelatin pounds per foot
¼	1.5
½	2.0
⅝	2.5
¾	3.5
1	4.5
1¼	6.0
1½	7.5
1¾	10.0
2	

The cavity charge uses only about half the amount of explosive as the rope charge, but no practical method has been found for securing the cavity charge to the plate. Therefore, a rope charge will be required in most cases. The charge can be made up above water in the desired length.

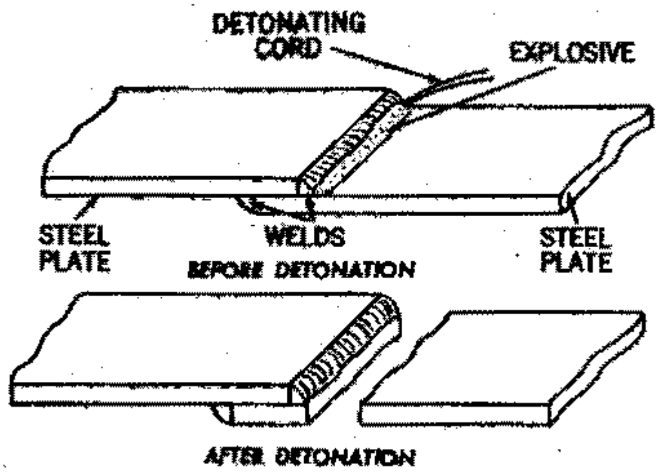

Figure 65—Breaking Welded Joints.

Combination of Plates and Structures. The combination of charges required to cut a combination of plates and structures will usually have to be found by trial and error. Present accepted practice for cutting a deck supported by large and small structural members requires the use of pounding charges in combination with a line charge. The line charge is placed to cut through the deck plate and the small structural members; pounding charges of 20 to 30 pounds additional then are placed at the points of support of the large structural members, figure 64. The line and pounding charges should be primed for simultaneous detonation, but with a one millisecond delay fuse for each pounding charge.

Welded and Riveted Joints. For breaking joints, linear charges are used; when used above water, the charges should be mud capped. For weldments, the charge is placed alongside the weld, figure 65, to shear the plate itself because the weld is stronger than the plate. For riveted joints, the charge is placed along the joint; when the charge is detonated, the rivet heads shear off and the plate buckles, figure 66.

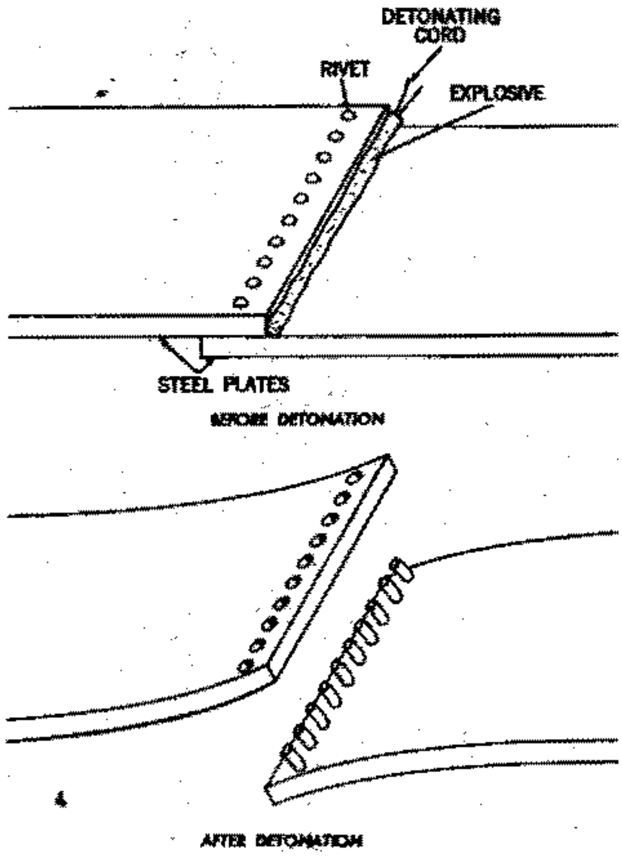

Figure 66—Breaking Riveted Joints.

Wire. For cutting wire up to two inches in diameter, use Cable and Chain Cutter Mk 1 Mod 1, figure 67. Designed for use in air or underwater, the cutter utilizes a composition C-4 cavity charge made up by field personnel. For wire greater than two inches in diameter, use the same procedure as for shafts or masts.

Shafts and Masts. Shafts and masts up to six inches in diameter can be cut with a single staggered charge, figure 68. For greater diameters, an initial charge is placed around the shaft or mast and detonated. This will produce a necked crater around the member into which a second charge is placed and detonated. This procedure is repeated until the shaft or mast is severed. When cutting a mast above water where the direction of fall of the mast is important, the mast can be cut by explosives to control the fall in the same manner in which axe cuts are used to control the fall of a tree.

Anchor Chains. The recommended method for cutting anchor chain is to fill one link with plastic explosive, figure 69, and detonate it. No calculations are required. Link size is dependent on chain size and experience has shown that a link filled with explosive will be severed by detonation of the charge.

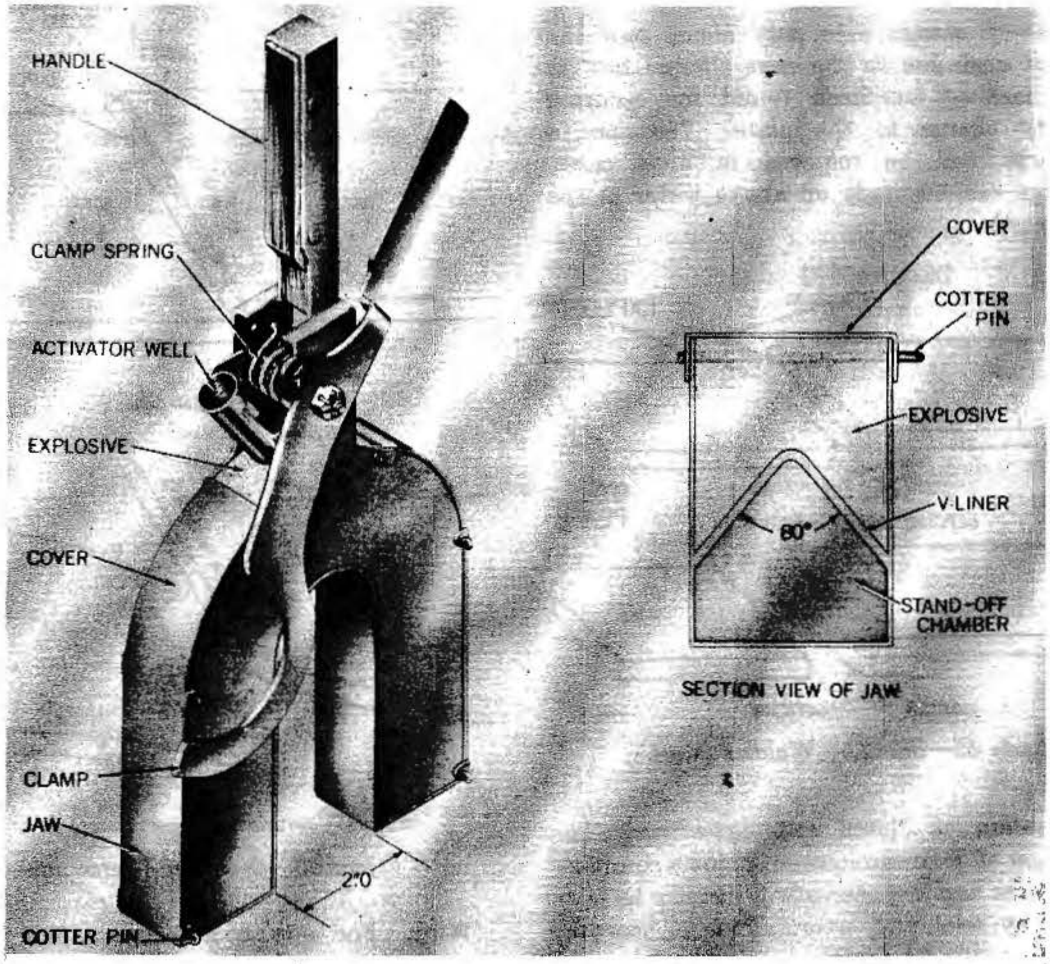

Figure 67—Cable and Chain Cutter Mk 1 Mod 1.

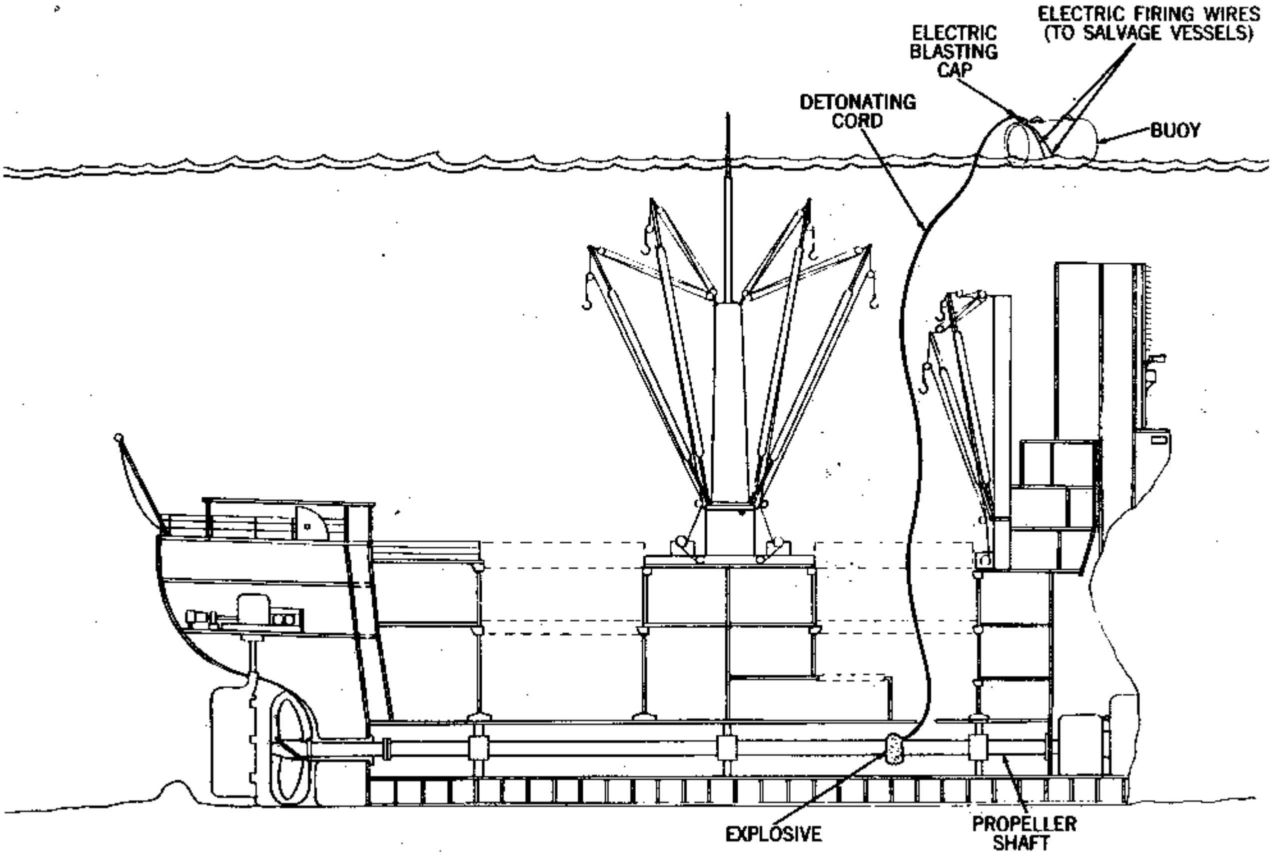

Figure 68—Cutting a Propeller Shaft.

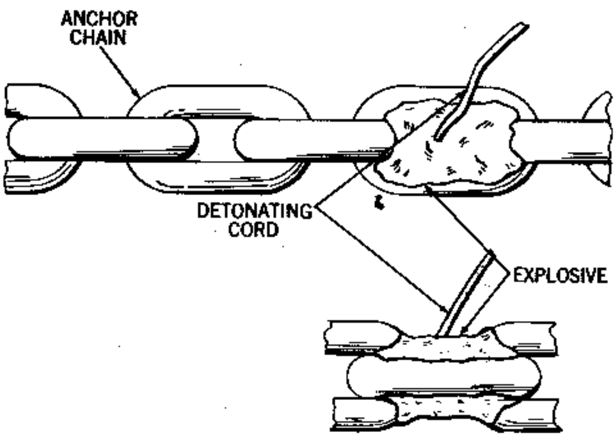

Figure 69—Cutting Anchor Chain.

Chapter 12

SHIP CUTTING, DISPERSAL, AND SCRAP SALVAGE

The time limitation in the emergency clearing of a harbor or channel usually does not permit the salvage of a sunken ship either by raising or by cutting up for scrap. When time is essential, dispersal of the sunken ship by demolition is the most effective way of clearing the harbor or channel. Whether a particular ship is dispersed completely in one continuous operation or whether it is flattened or dispersed in stages is determined by the overall situation at the site. If a well-blocked harbor is made usable first for light-draft vessels and then for deeper-draft ships, the upper portions of several obstacles are dispersed first followed by progressive demolition of the lower portions of the same obstacles, figures 70 through 75. If a channel is blocked by a single sunken ship, the entire ship may be dispersed in a single operation. The methods given in this chapter are the same for either procedure, but they are intended as a guide only. Test shots and the judgment of the salvage officer must be depended on for the best procedure for any particular situation.

In many cases, sunken ships can be made useful as moorings or as additional pier facilities. This is particularly true of a ship sunk alongside an existing pier or close to shore. By removing masts and superstructure and constructing a platform over the hull, figures 76, 77, and 78, a satisfactory pier can be made without the need for the extensive demolition required to flatten the hull.

Cargo Determination and Handling

Before any demolition work is undertaken on or near a sunken hull, it is important to determine the contents of the hull because salvage operations will depend on these contents. If the hull is that of a merchantman, papers may be available that will detail the ship's cargo. Whether a manifest is available or not, divers should be used to investigate the wreck as thoroughly as possible. If there is no other access to cargo spaces, access holes may be cut with explosives, figure 79. Before this is done, however, a pounding charge should be placed against the hull and detonated. This charge is set off to determine whether there are explosives in the hull that will be detonated by demolition activities; the area should be completely cleared by all personnel before this charge is detonated. After this charge, figure 80, has been exploded, cutting the hull with explosives can be considered reasonably safe.

Whether cargo is to be removed or dispersed with the rest of the hull must be determined by the salvage officer. If the cargo is buoyant, large enough holes can be made to allow the cargo to rise to the surface. Ore and similar cargoes can be removed with air lifts. Other types of cargo must be handled with equipment available with regard to the time element and the difficulties of dispersing the hull with or without the cargo.

Ship Settlement

Explosives may be used to prevent further settlement of a ship on the bottom or they may be used to make the ship settle farther into the bottom.

When a ship is to be salvaged, the bottom can be compacted beneath it to prevent further settling. This is done by detonating powder points driven into the bottom around the hull. For this purpose, the powder points should be loaded with an explosive with a low rate of detonation, such as ammonium nitrate. Charges must be light enough so that the ship's hull will not be damaged.

When a ship resting on a sandy or muddy bottom is to be dispersed or flattened, it should be settled as deeply as possible. This can be done by blowing holes in the hull along the bottom, figure 81, to reduce the bearing surface and to allow the bottom material to ooze into the hull. Added settling will result from increasing the weight of the ship by filling voids with sand, mud, or gravel through an air lift.

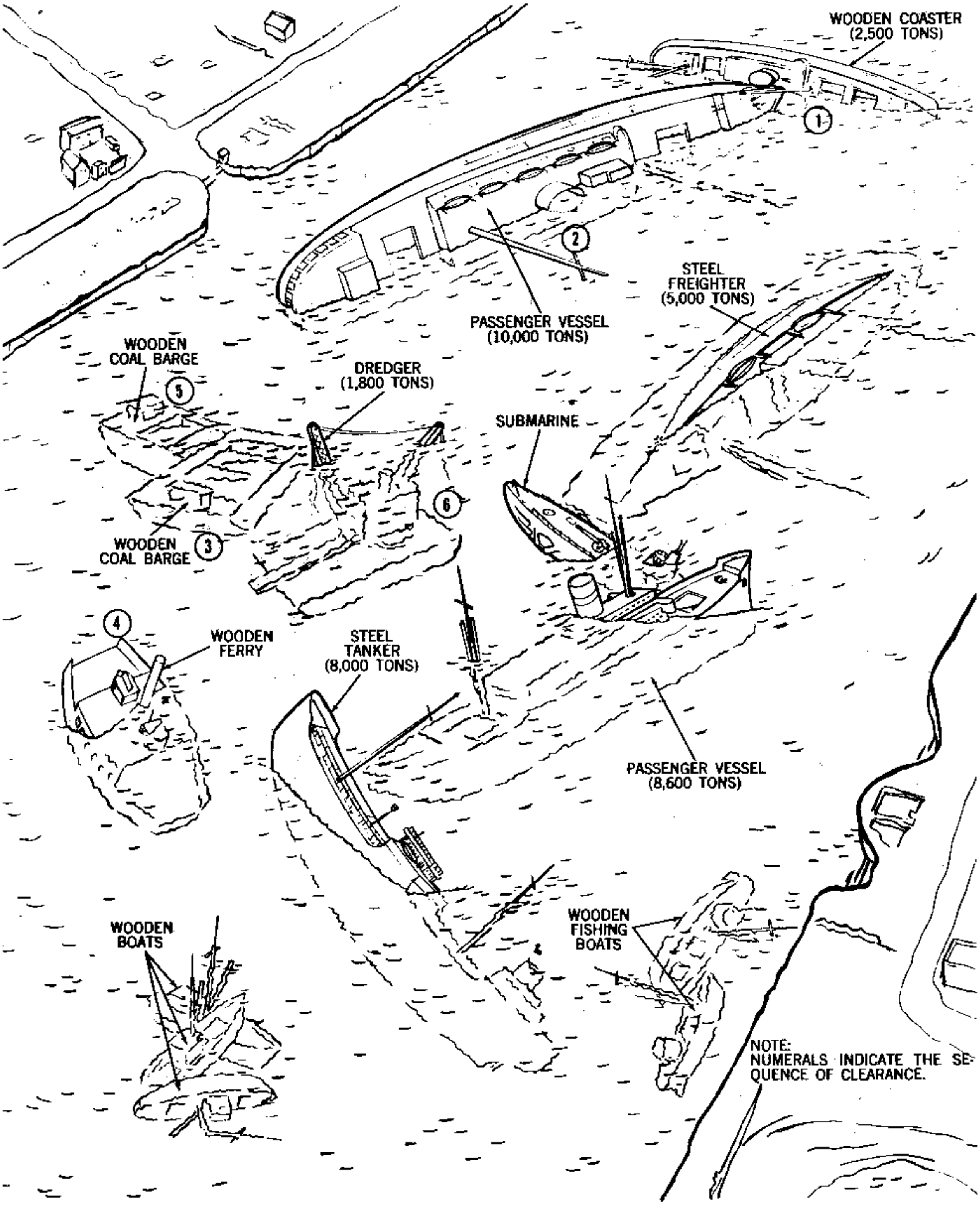

Figure 70—Perspective View of Blocked Channel.

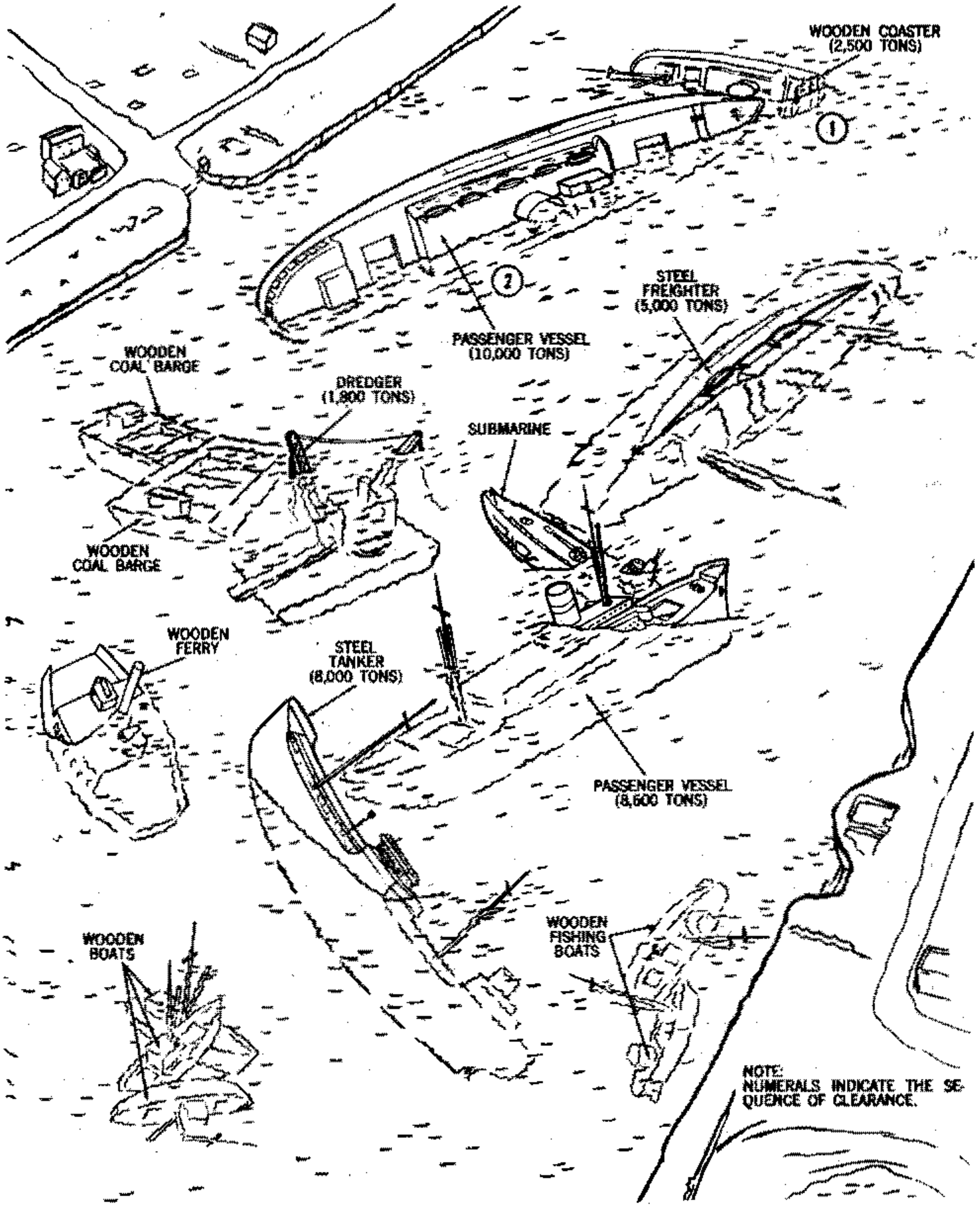

Figure 71—Channel Clearance, First Phase. Bow of Wooden Coaster, and Masts and Rigging of Passenger Vessel are Cut.

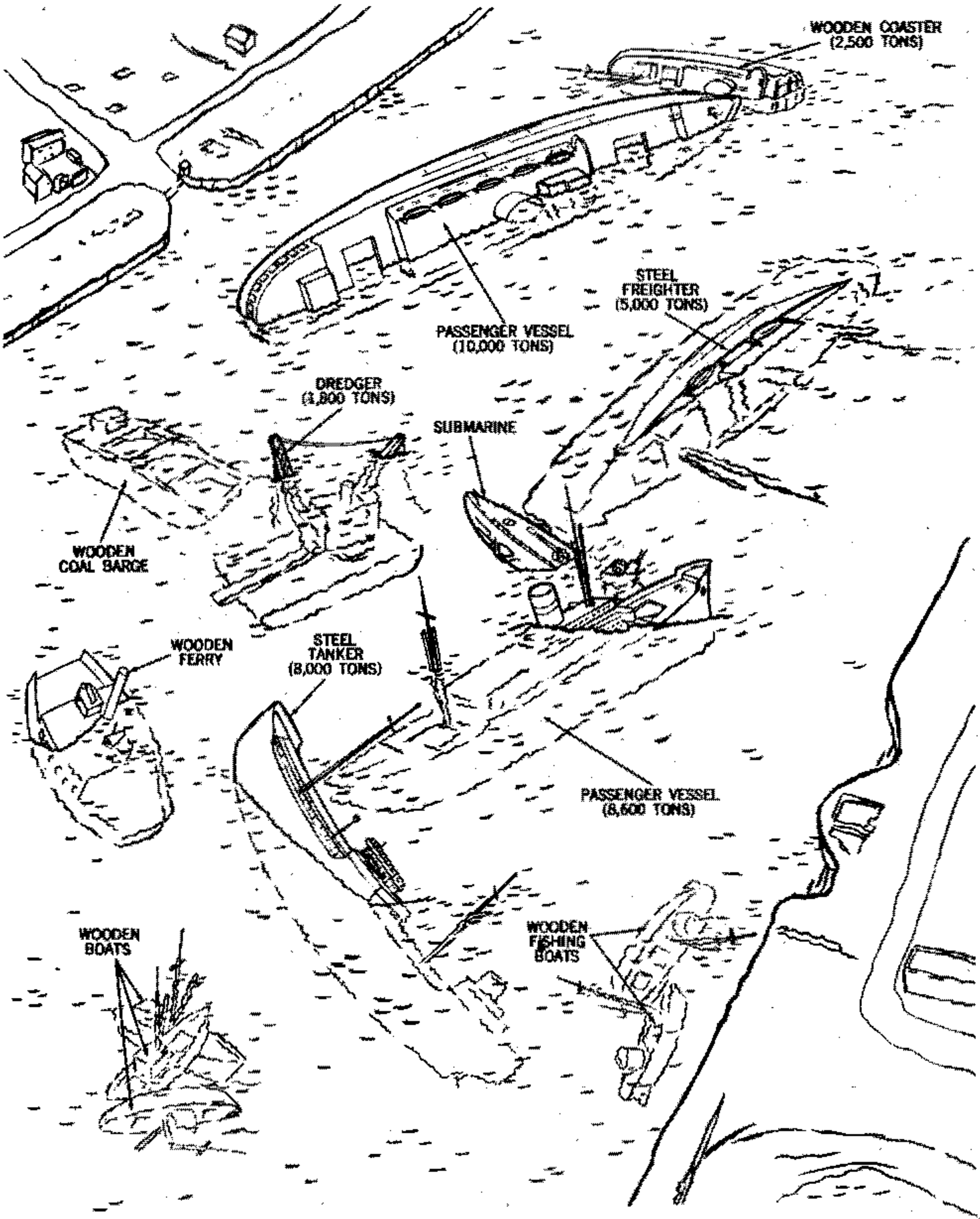

Figure 72—Channel Clearance, Second Phase. Wooden Coal Barge Dispersed.

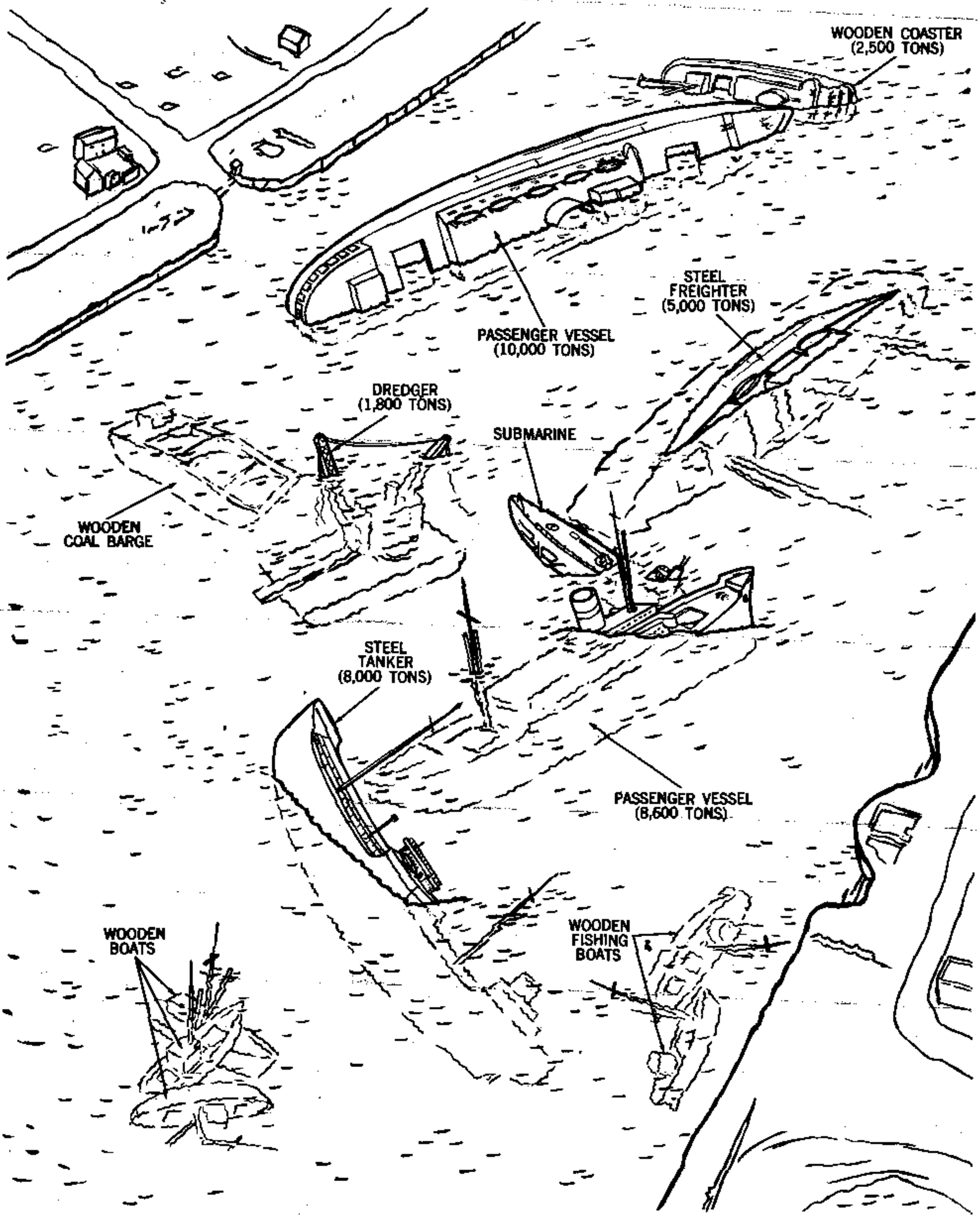

Figure 73—Channel Clearance, Third Phase. Wooden Ferry Flattened.

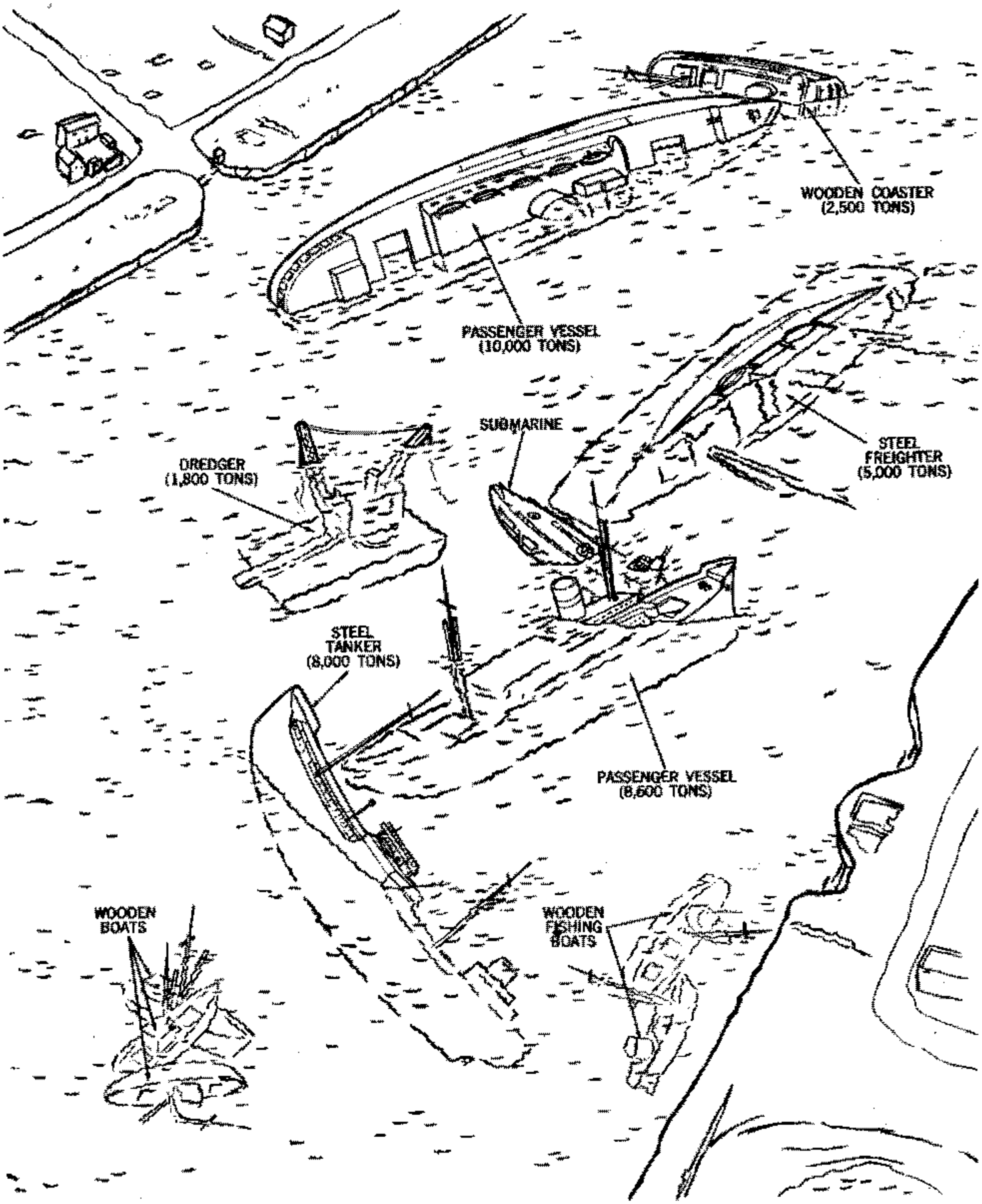

Figure 74—Channel Clearance, Fourth Phase. Remaining Wooden Coal Barge Dispersed.

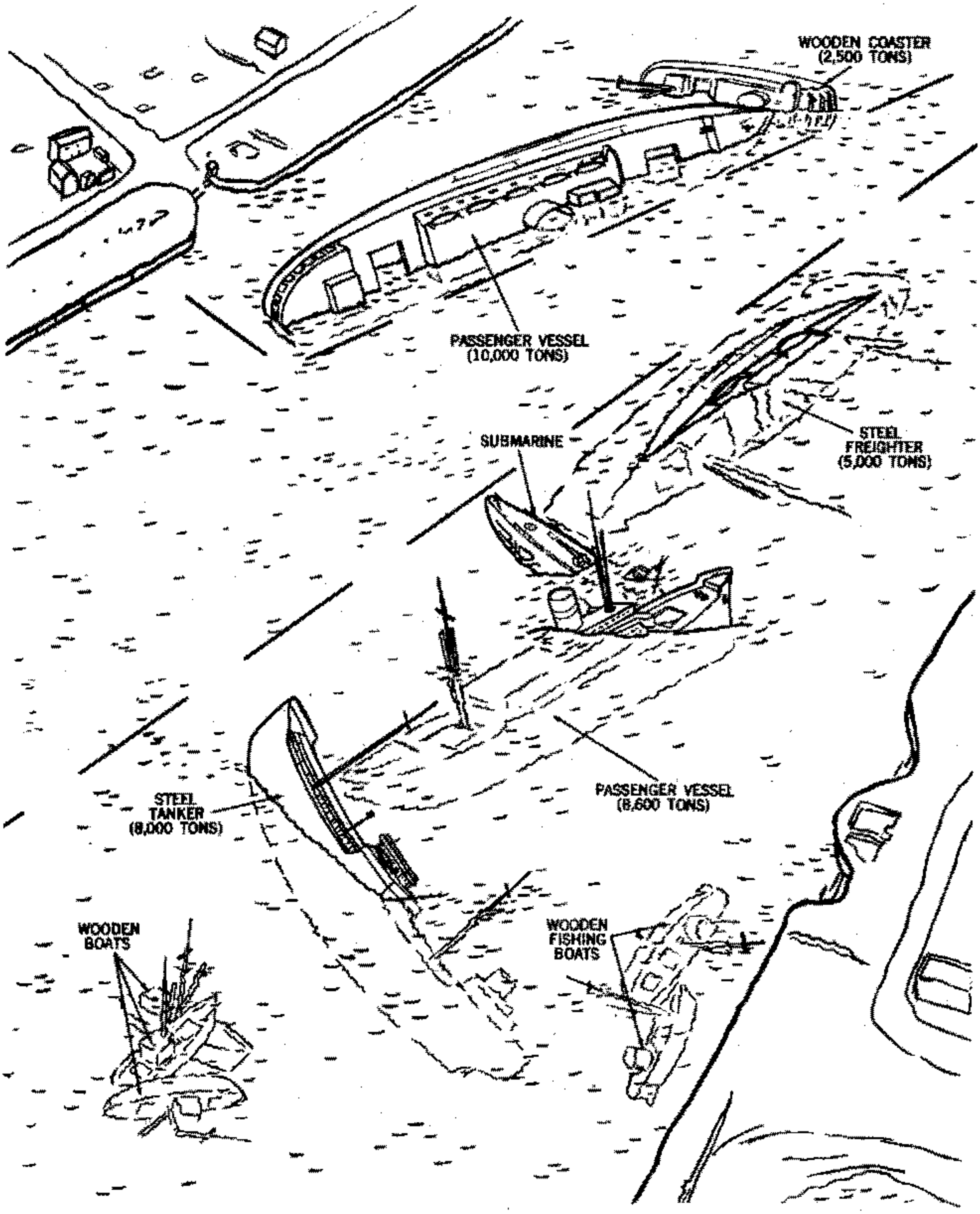

Figure 75—Channel Clearance, Last Phase. Dredger Flattened; Dashed Lines Indicate Cleared Path.

Ship Construction

For salvage demolition purposes, a ship is divided into three major parts: the masts and rigging, the superstructure, and the hull, figure 82. For each part, the principle of blasting against strength should be adhered to in the placement of charges.

The hull is the major component of a ship. Extending from the keel to the main deck, the hull includes the inner and outer plates, bulkheads, compartments, tanks, holds, and machinery and boiler spaces. The superstructure includes all parts of the ship above the main deck except the masts and rigging.

Combat ships differ from others in their heavier construction, armor plate, turrets and gun mounts, and compartments for watertightness. Because of these features, combat ships are much more difficult to flatten or disperse than merchant ships. However, combat ships rarely are used in the intentional blocking of a harbor; normally they will be encountered only when a harbor is blocked by ships sunk by enemy action.

Ship Flattening

The stages in which a ship is flattened will depend to some extent on the position of the ship with respect to the bottom, figure 83. A ship resting on its side presents a different problem from one that is sitting upright on the bottom. In most cases, the masts and rigging are first removed, the superstructure is removed or dispersed, and finally the hull itself is flattened.

Removal of Masts and Rigging. Masts are usually hollow steel cylindrical structures that extend to a height of 40 feet or more above the main deck. They should be cut so they fall clear of all areas in which further work is to be done.

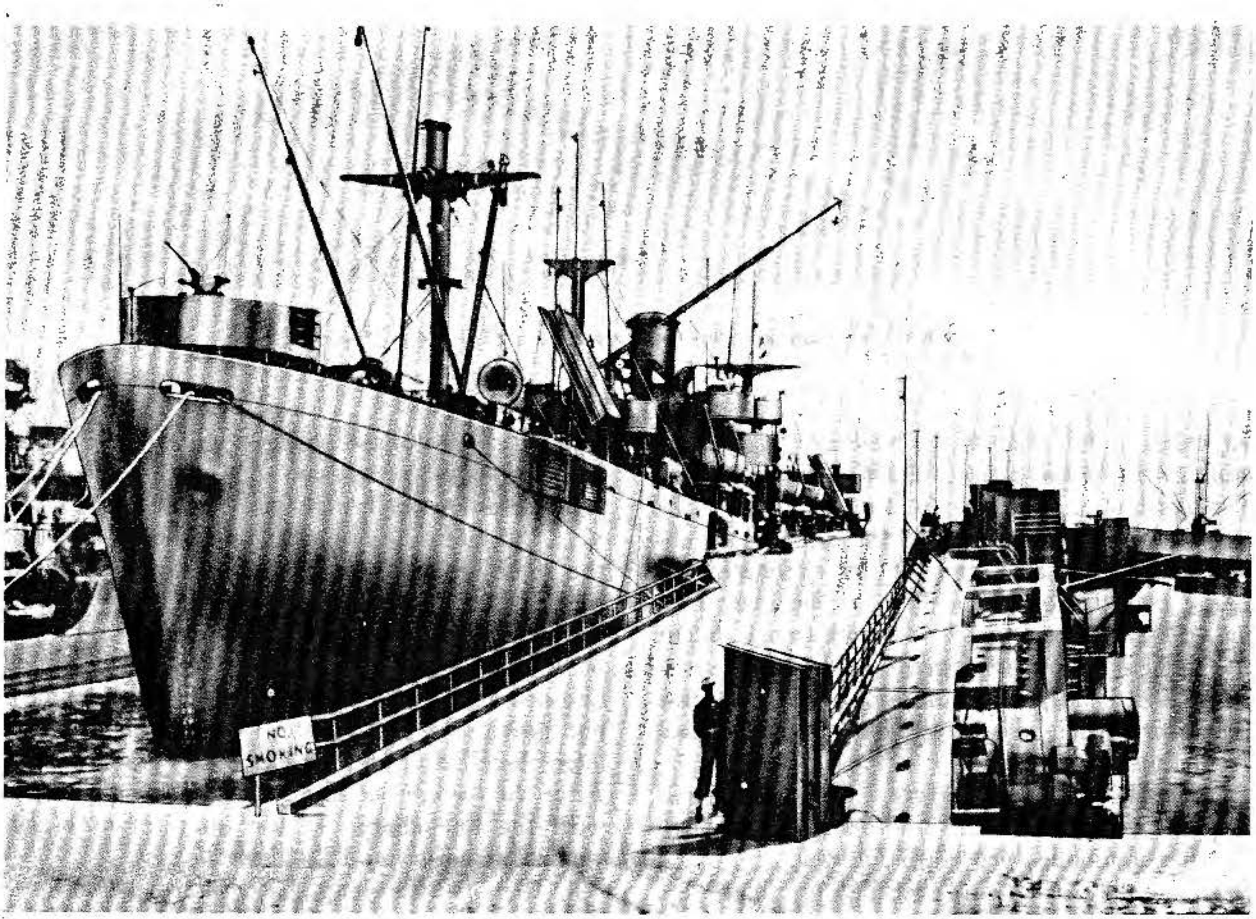

Figure 76—Sunken Ship Converted to a Pier, Front View.

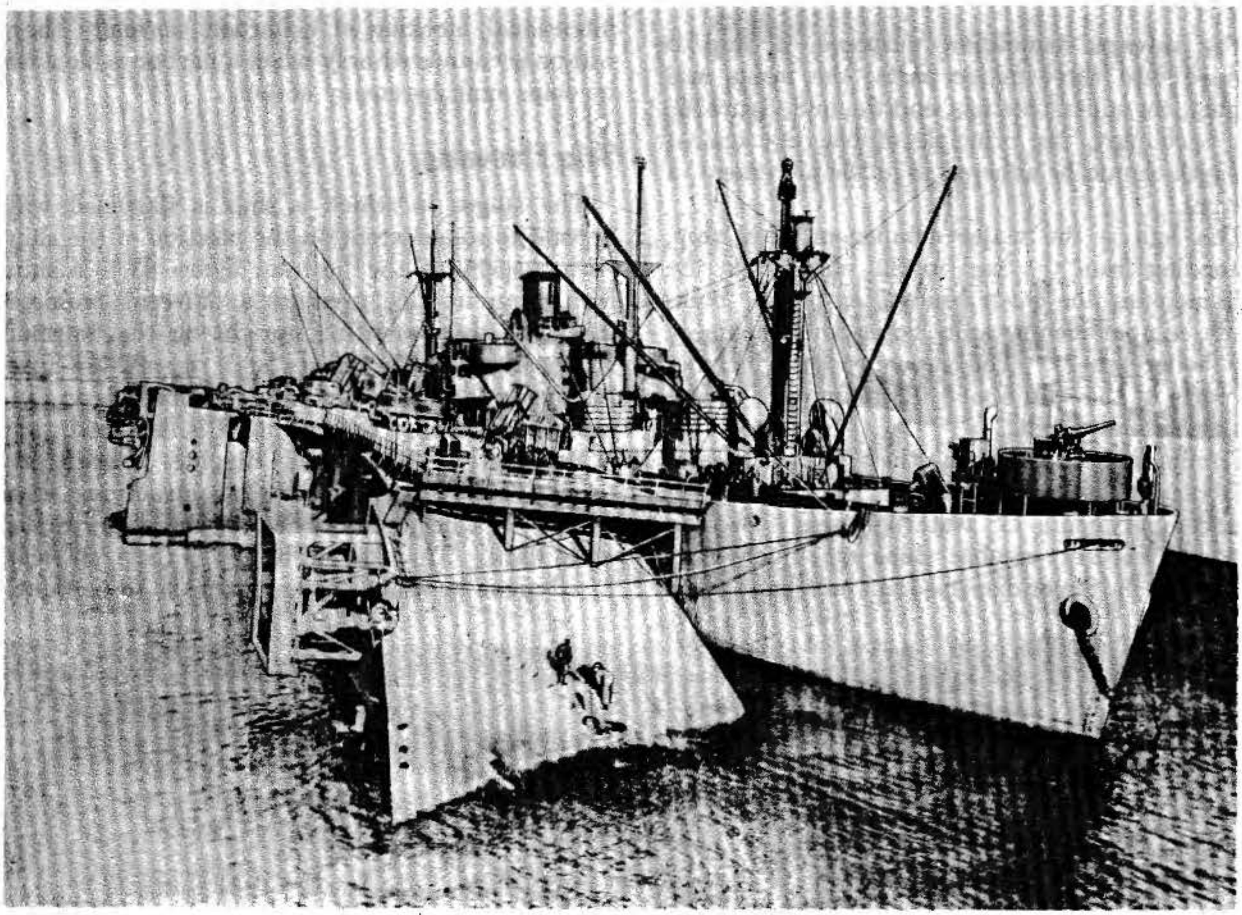

Figure 77—Sunken Ship Converted to a Pier, Rear View.

Direction of fall can be controlled by rigging a hauling wire in the desired direction or by cutting all stays but one, figures 84 and 85, leaving the stay that tends downward in the direction of intended fall. Masts are cut by detonating a charge placed around the base of the mast in a ring. Masts up to 6 inches in diameter can be cut with one charge; masts of greater diameter may require several charges for complete cutting. Cable cutters or formed plastic explosive may be used for cutting the rigging.

Removal of Superstructure. Steps in superstructure removal are shown in figures 86 through 89. Recommended procedure follows:

1. Remove stacks and ventilators, figure 86. Place a linear cutting charge around the base of each about one foot above the deck. Cut stack stays with cable cutters or with formed plastic explosive. Detonate charges individually or simultaneously, as necessary.

2. Remove the bridge and wheelhouse, figure 87. Cut all inside supporting members; then level the structure in three stages. Ring the base of the top section with a line charge heavy enough to shear the plates and all minor structural members; place additional charges, attached to the line charge, against all heavy structural supports not previously cut. Repeat the procedure at a lower level after detonation of the first charge. After the second cut has been made, repeat again with the line charge at the intersection of the vertical structure and the deck.

3. Remove the poop deck, figures 88 and 89. Use a procedure similar to that for the bridge and wheelhouse. If the forecastle is a part of the superstructure, level it also. Simultaneous charges

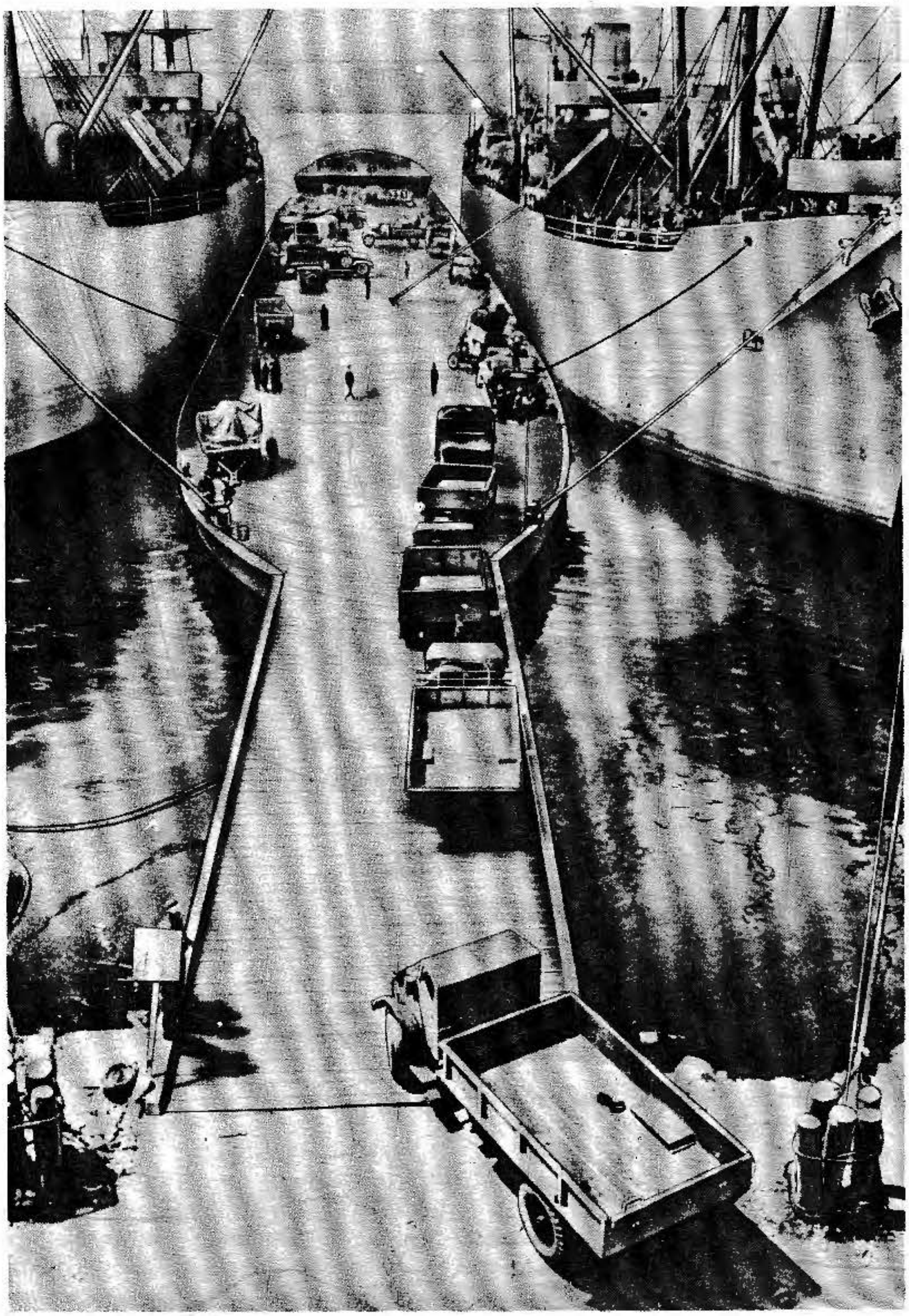

Figure 78—Upright Sunken Ship Converted to a Pier.

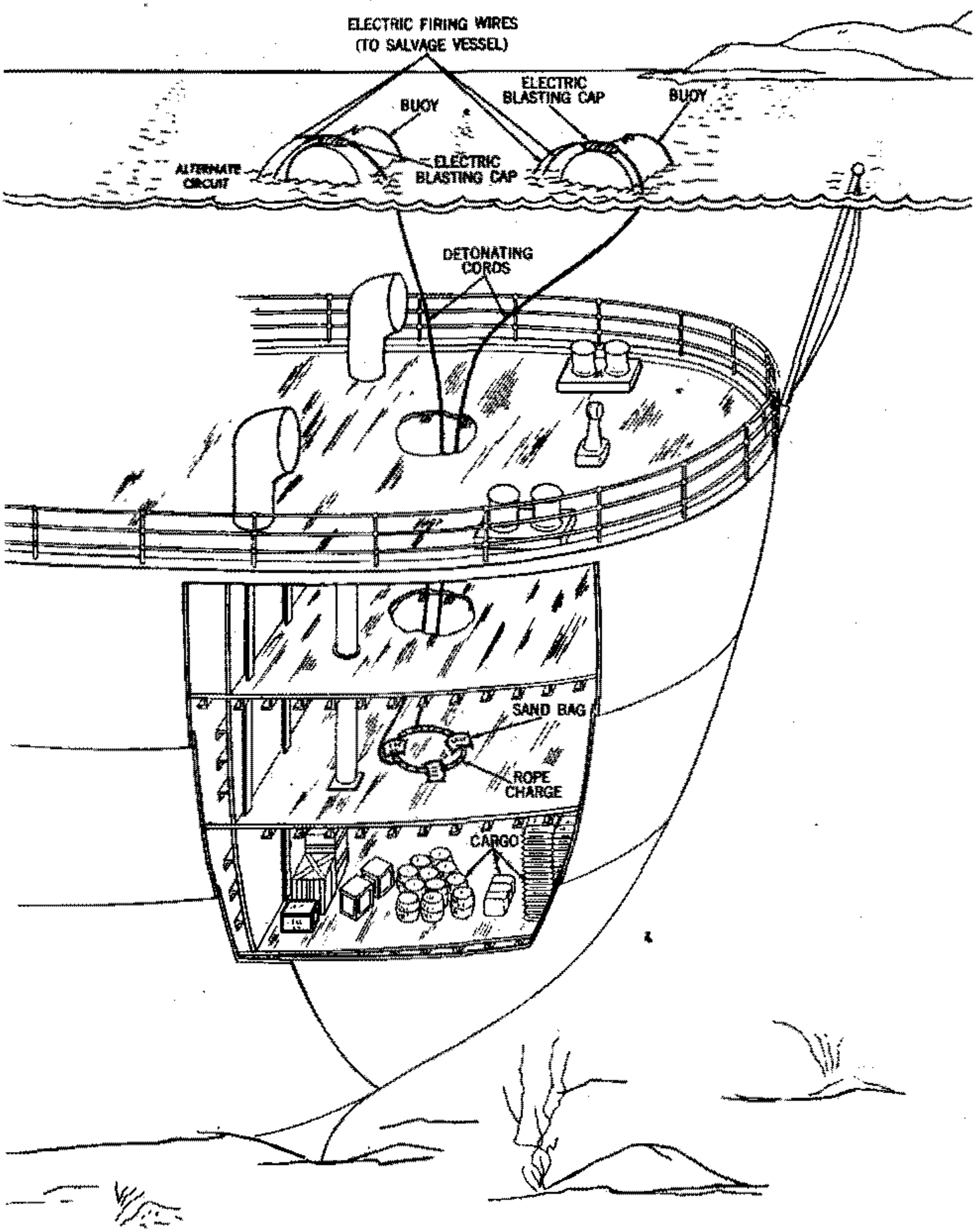

Figure 79—Providing Access to Cargo Spaces.

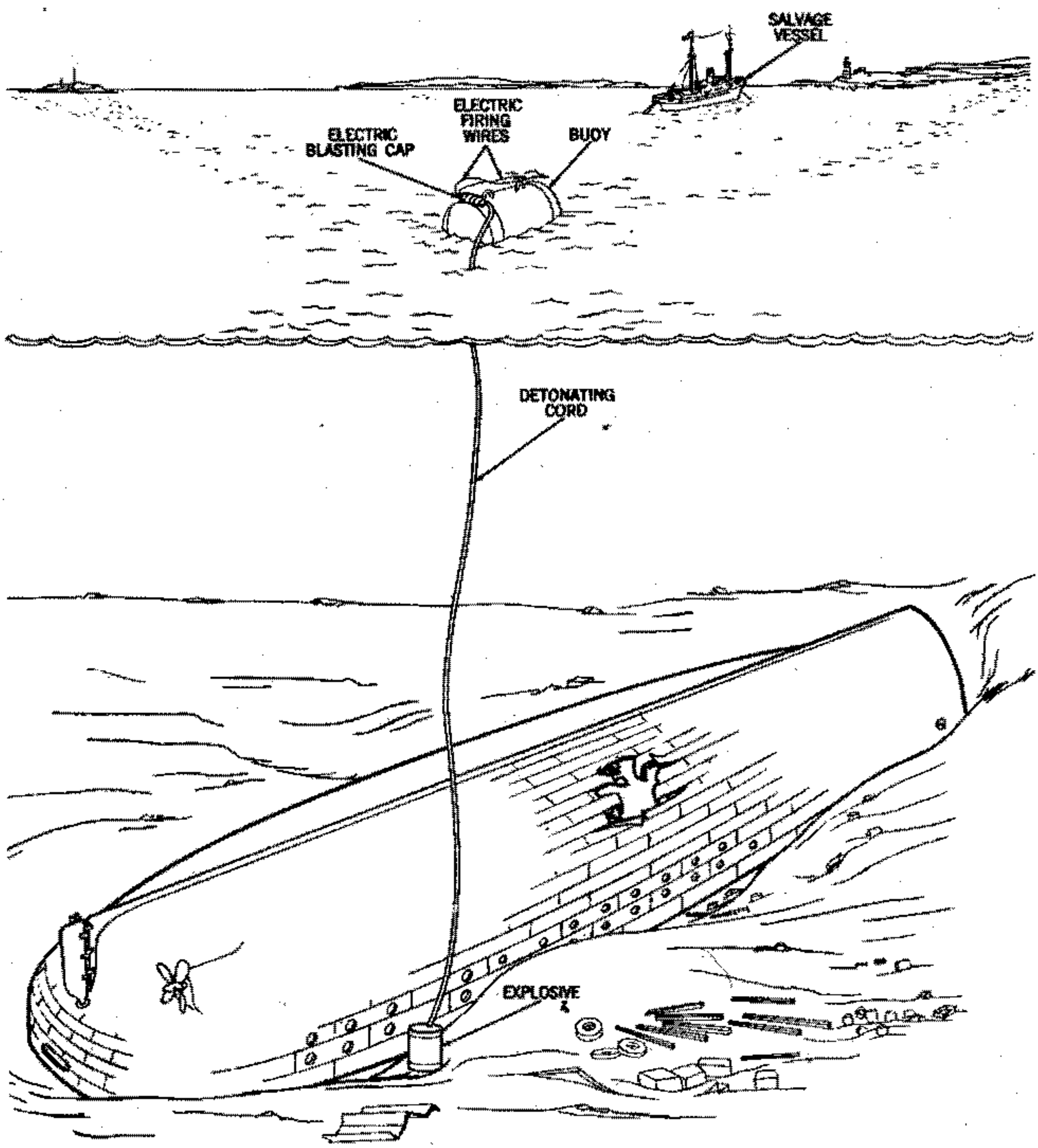

Figure 80—Countermining Against Unknown Cargo.

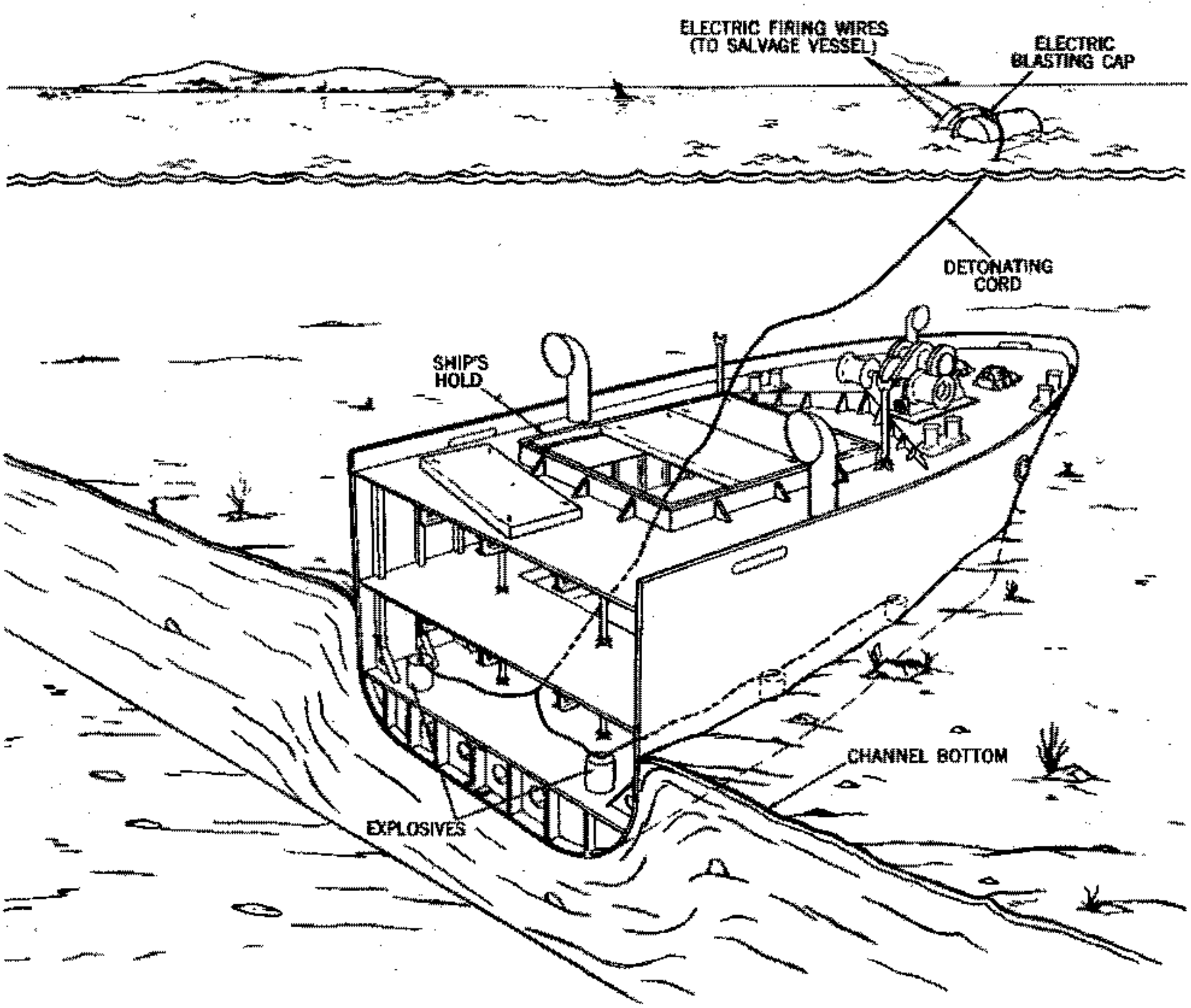

Figure 81—Settling a Sunken Ship.

may be placed for cutting the forecastle and the poop deck at the same time.

Flattening the Hull. In all hull flattening operations, charges should be placed to take advantage of the weights of and existing stresses in structural members. The greater the stress on a member, the less the explosive needed to cut or break it. One recommended procedure for hull flattening is as follows:

1. Remove the bow. Ring the section with a linear cutting charge. Reinforce the linear charge with pounding charges at heavy structural support points. Detonation of the charge will often cut the bow free of the ship, figure 90; in some cases, additional charges must be set and detonated against internal members to free the bow.

2. Remove the stern. Use the same procedure as for step 1.

3. Cut all supports and bulkheads below the top deck of hull.

4. Place a linear cutting charge along each edge of the top deck. The length of deck to be cut at one detonation must be determined by the salvage officer, depending on the length of the hull, the type of supports remaining, and other factors peculiar to the specific hull being flattened. Set several pounding charges at intervals along the longitudinal center line of the top deck.

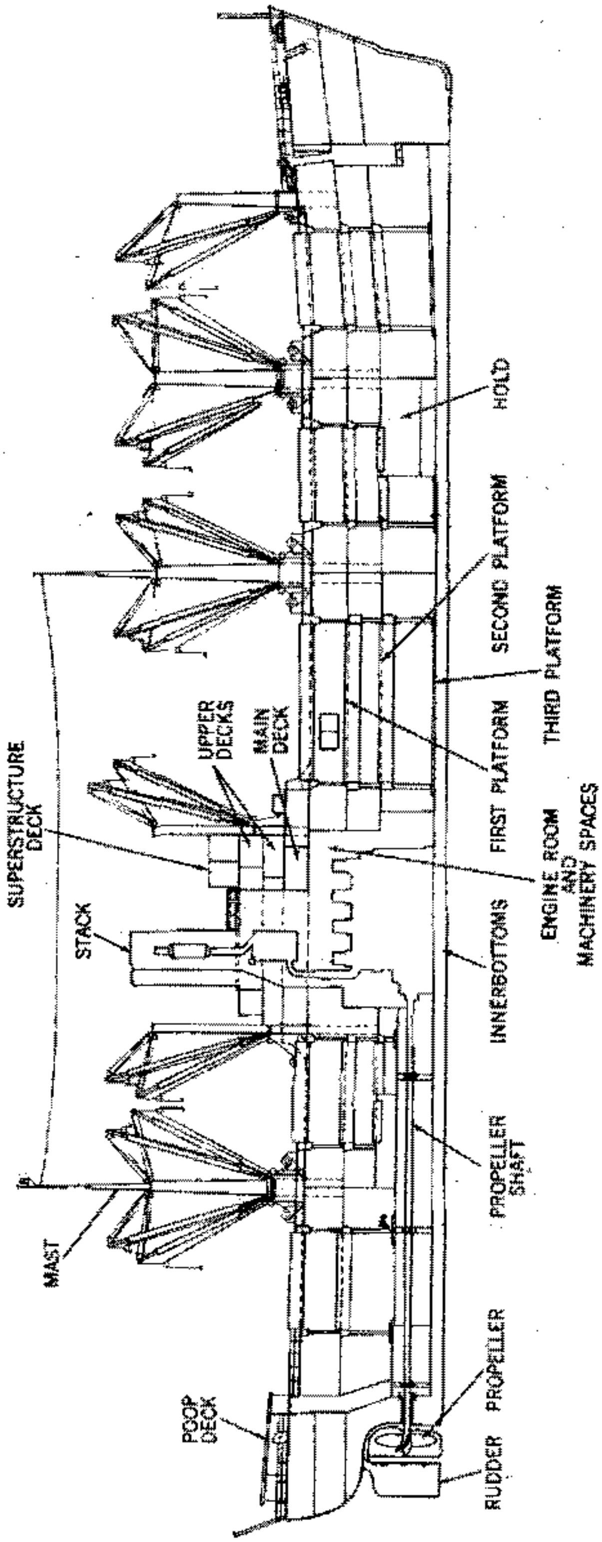

Figure 82—Typical Noncombatant Ship Construction.

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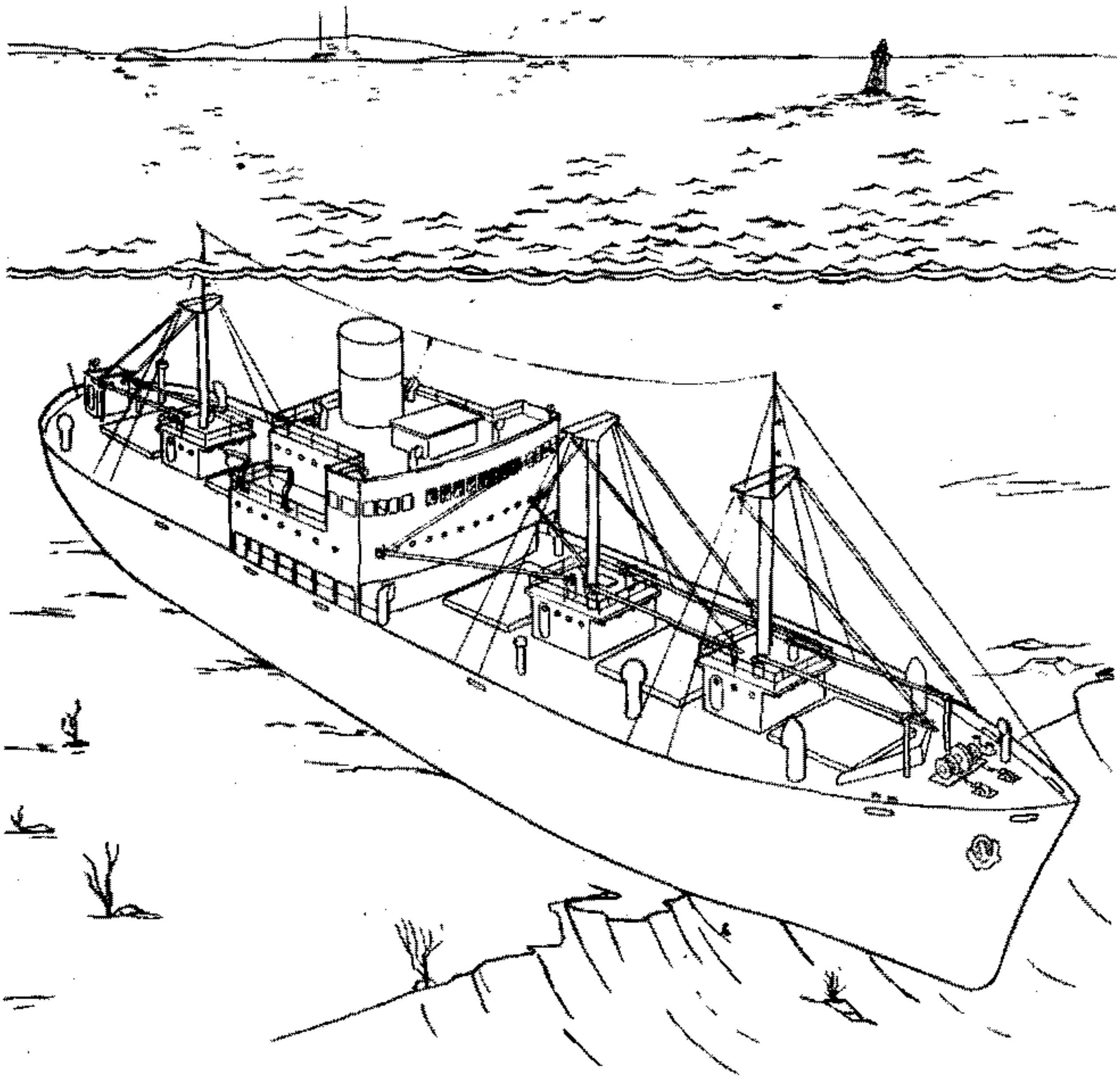

Figure 83—Ship Lying on Bottom.

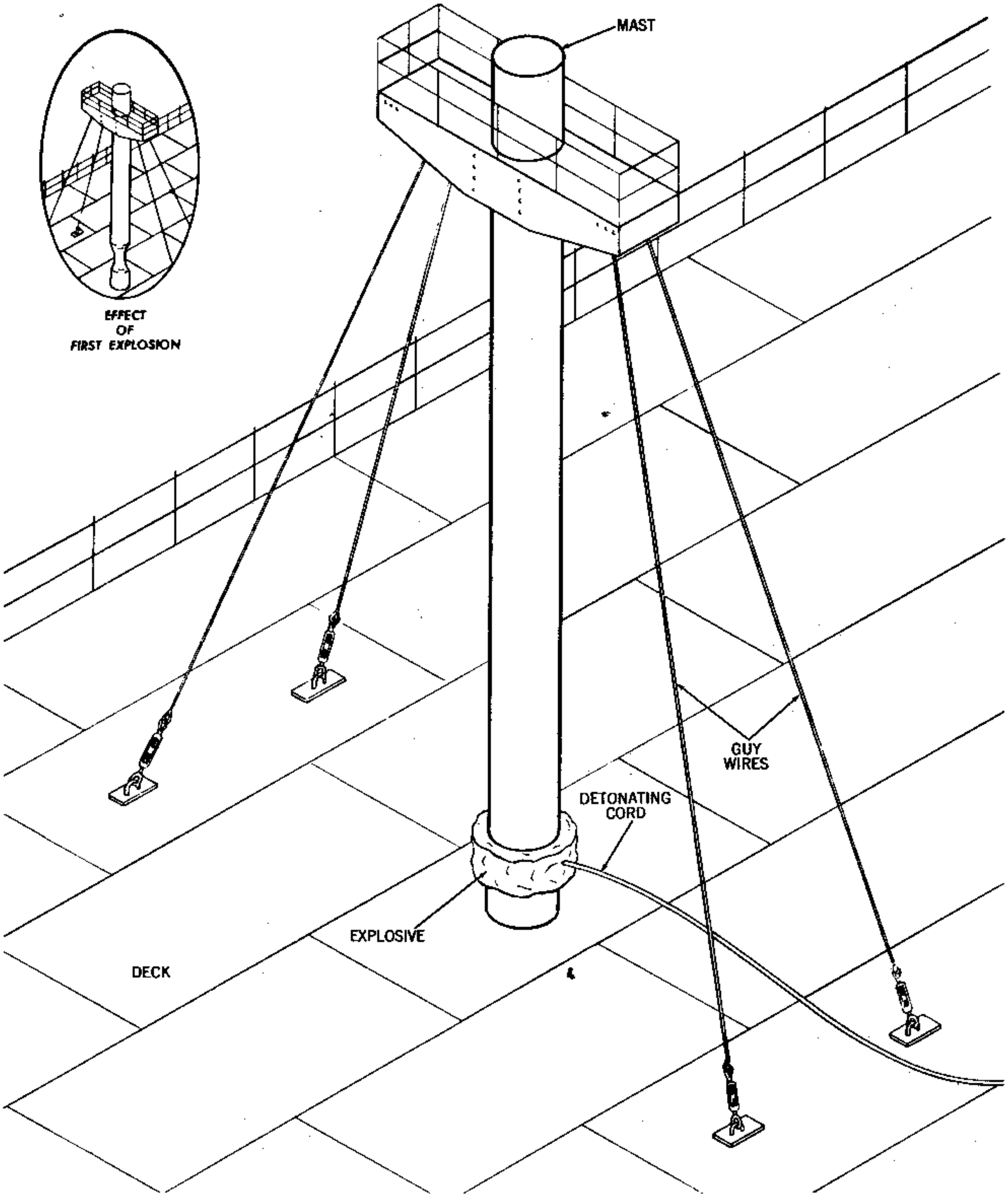

Figure 84—Mast Removal, First Stage.

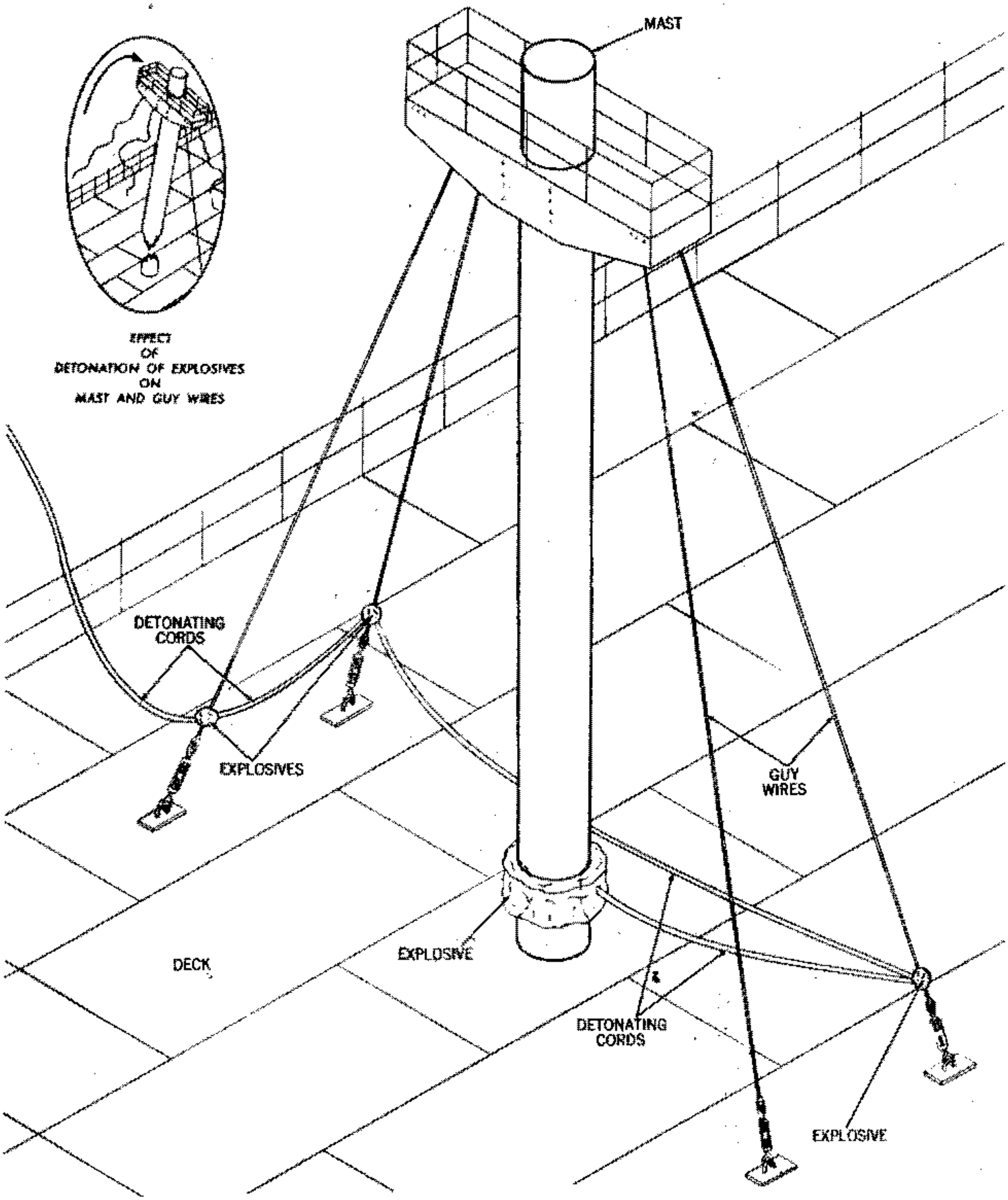

Figure 85—Mast Removal, Second Stage.

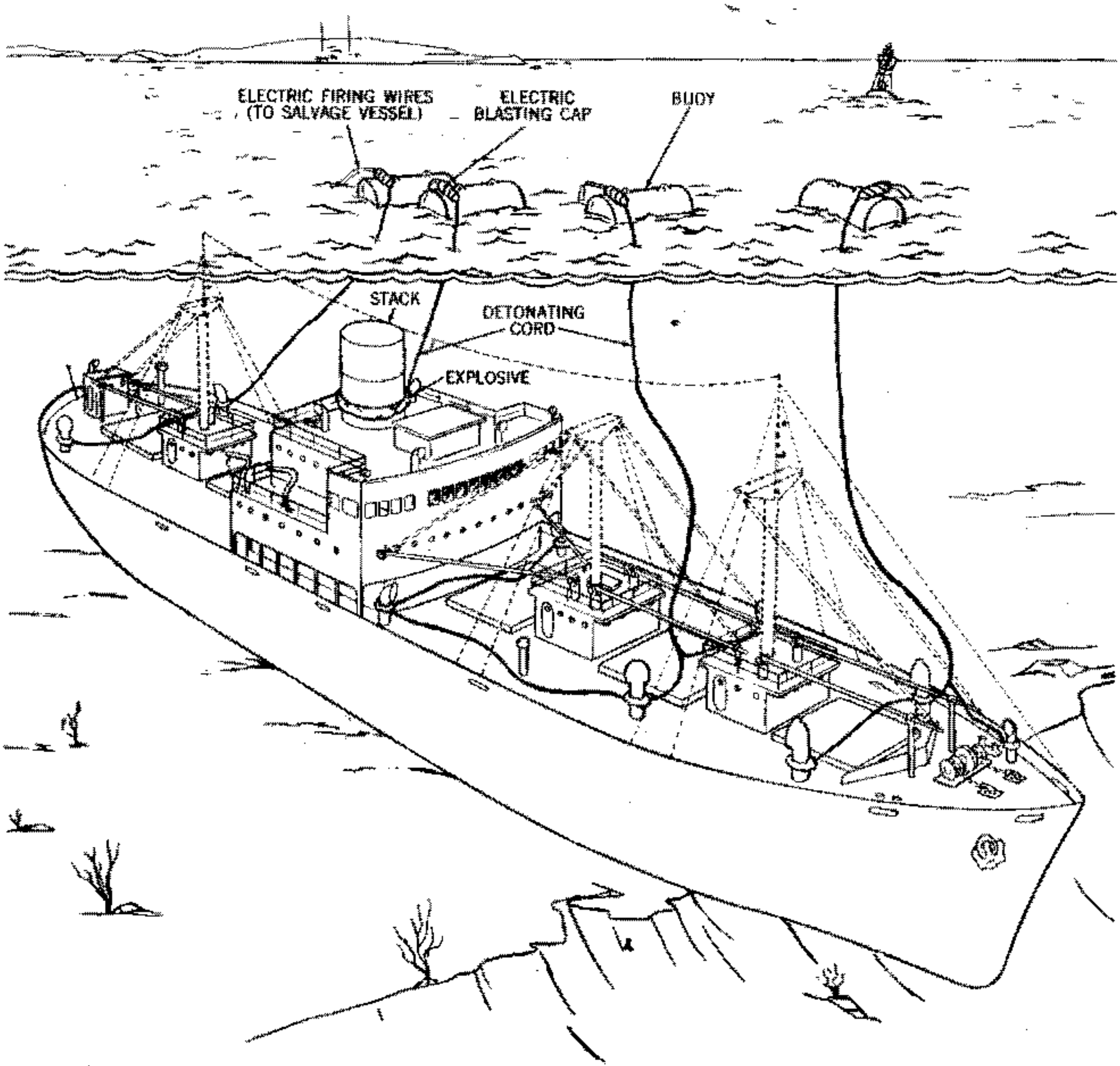

Figure 86—Ship Flattening—Removal of Superstructure, First Stage. Preparation.

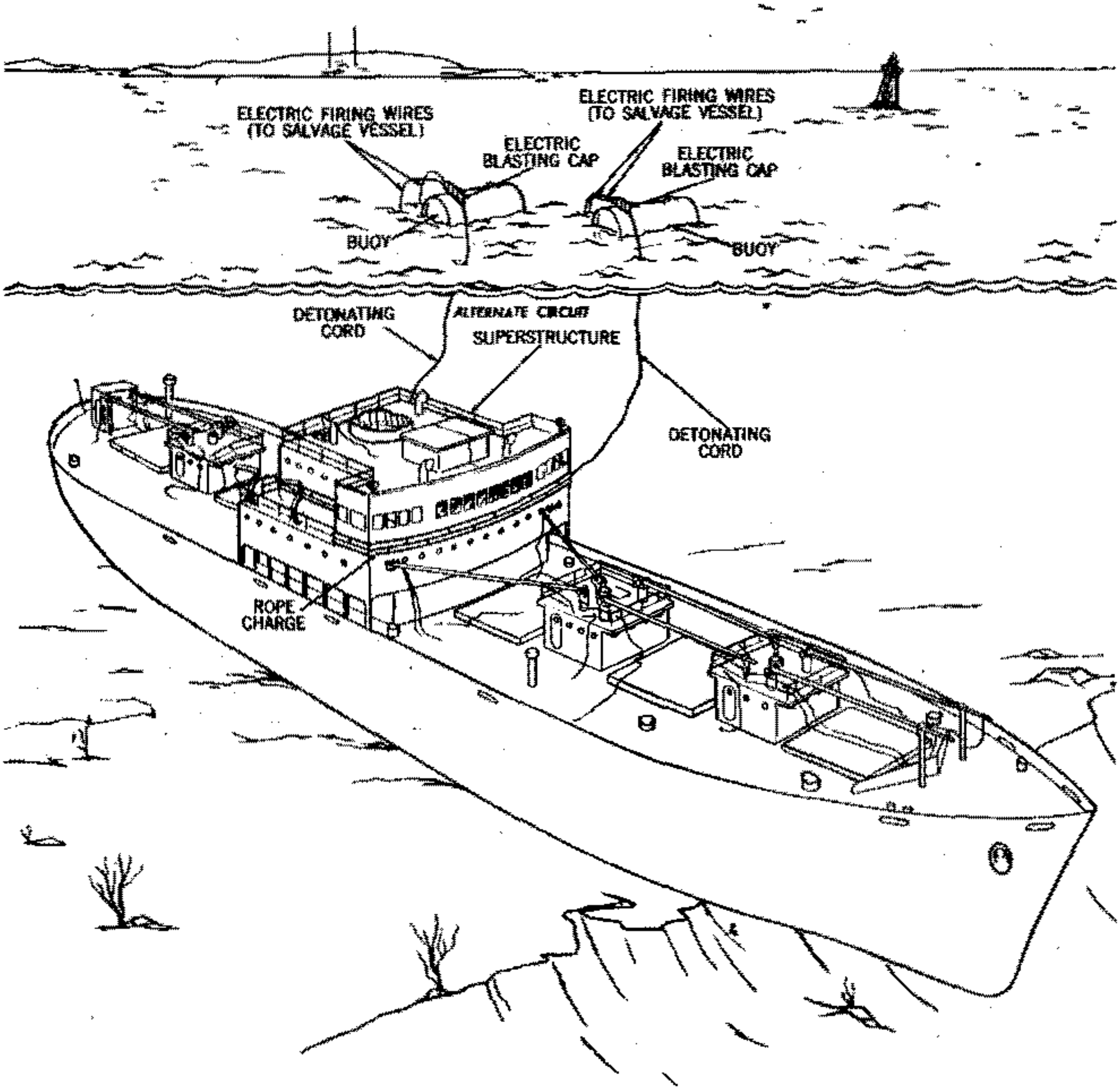

Figure 87—Ship Flattening—Removal of Superstructure, Second Stage. Preparation.

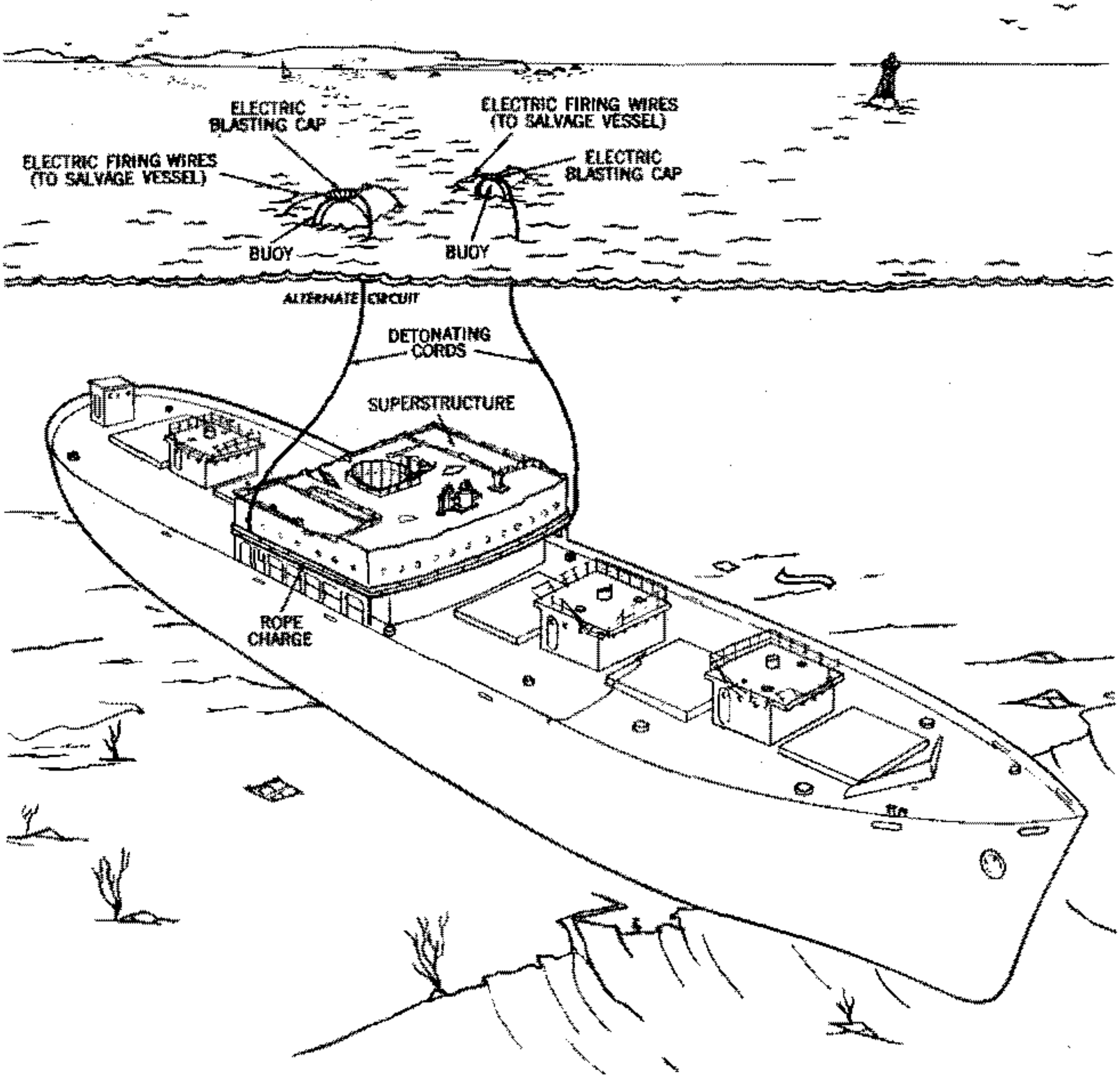

Figure 88—Ship Flattening—Removal of Superstructure, Third Stage, First Step. Preparation.

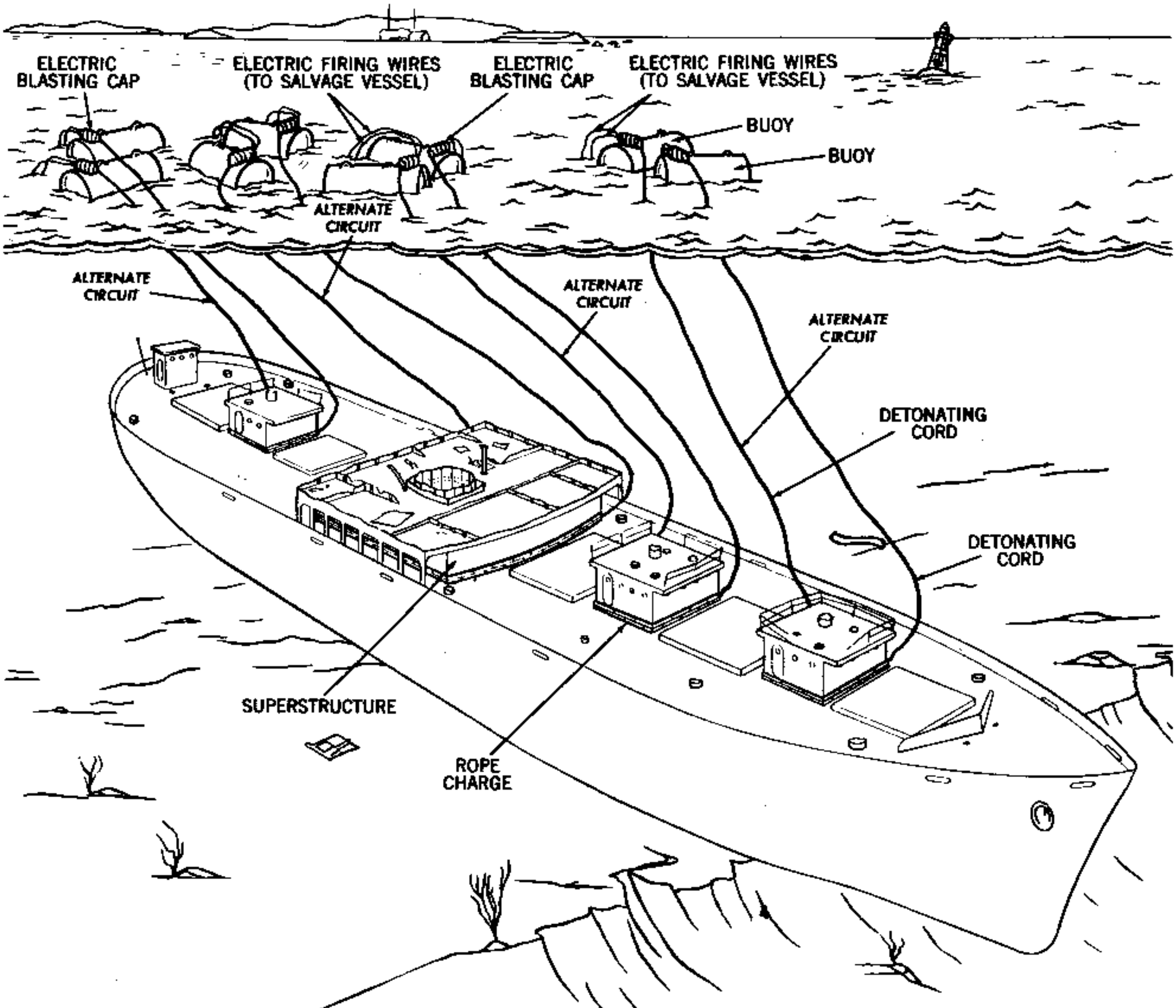

Figure 89—Ship Flattening—Removal of Superstructure, Third Stage, Second Step/ Preparation.

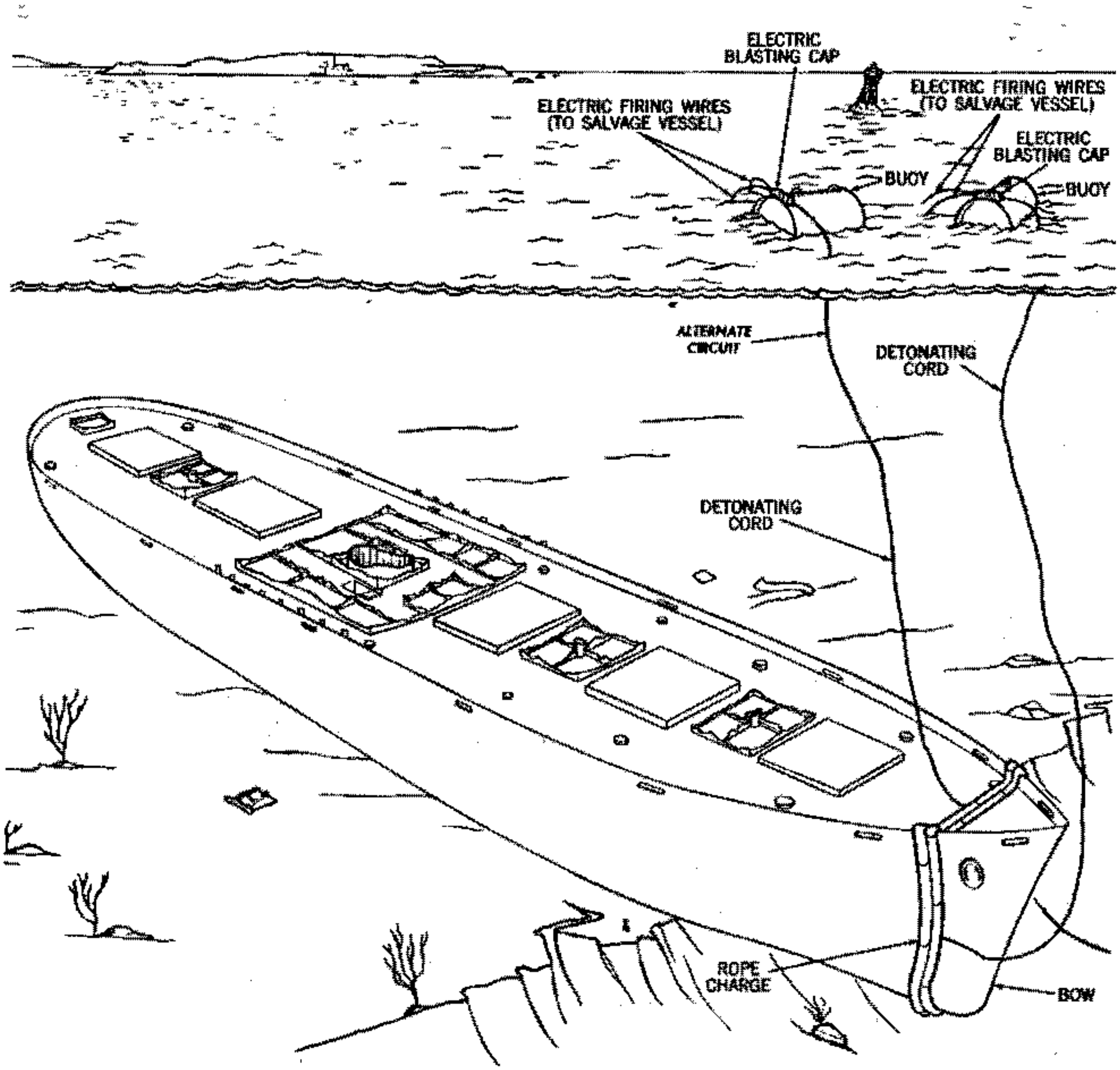

Figure 90—Ship Flattening—Bow Removal. Preparation.

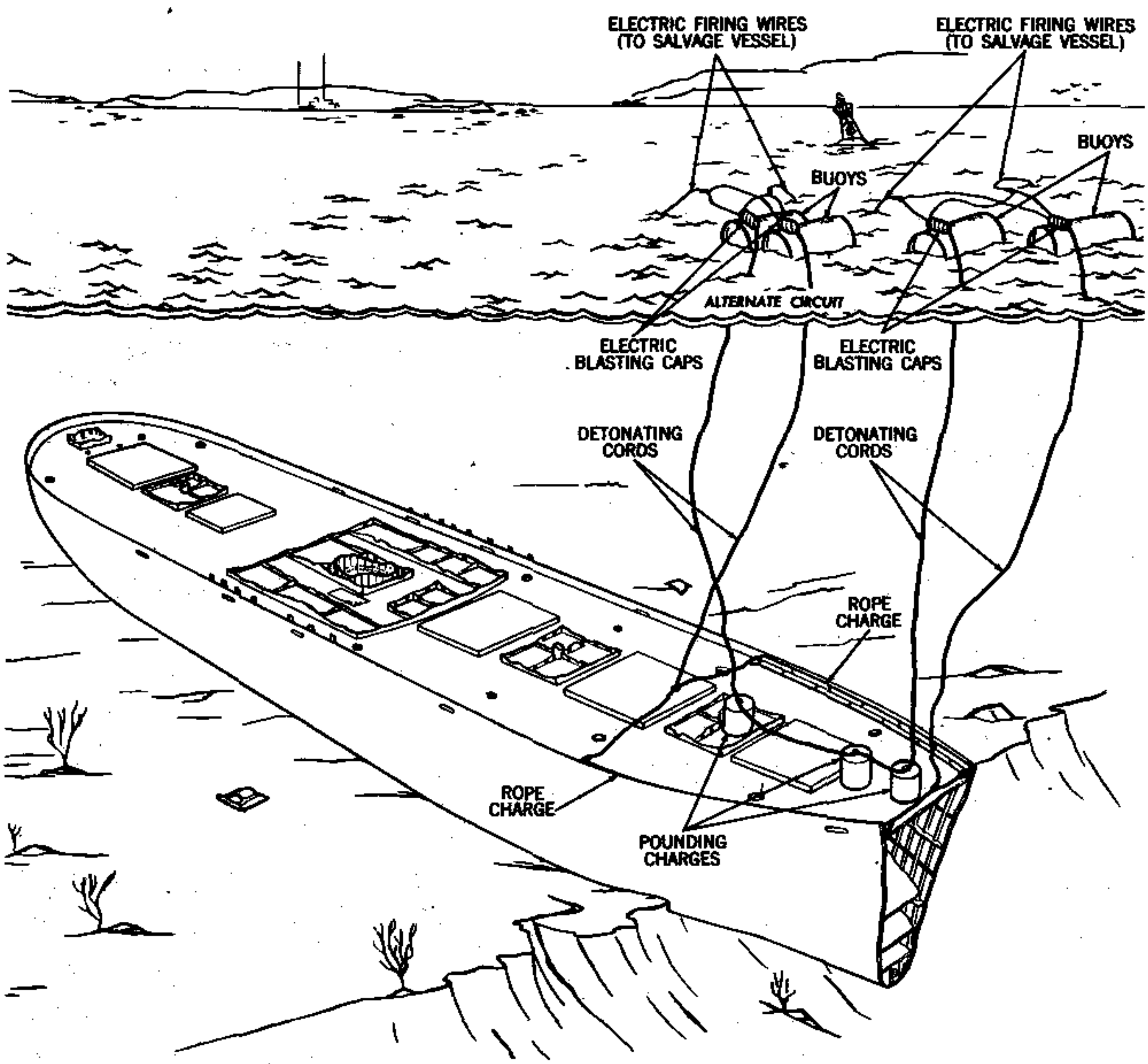

Figure 91—Ship Flattening—Flattening the Hull, First Stage. Preparation.

Connect the pounding charges for simultaneous detonation with the linear cutting charges at the edges of the deck, but prime the pounding charges with delay fuses of one millisecond each, figure 91. This delay allows the cutting charges to cut the deck free of the ship's sides just before the pounding charges force the deck downward and the hull sides outward, figures 92 and 93. Continue this procedure until the entire top deck has been cut away from the sides. Then repeat the procedure for each deck remaining from top to bottom.

If a deck that has been partially cut sags enough to rest on the deck below it, use a linear cutting charge to cut across the deck on a line above the lower deck. When making such a cut athwartships, place pounding charges of 20 to 30 pounds each above the heavy structural beams and connect them to detonate simultaneously with the cutting charge.

Boilers. To flatten a ship's boilers, place several pounding charges inside each and prime them for simultaneous detonation. A single detonation levels the boilers satisfactorily.

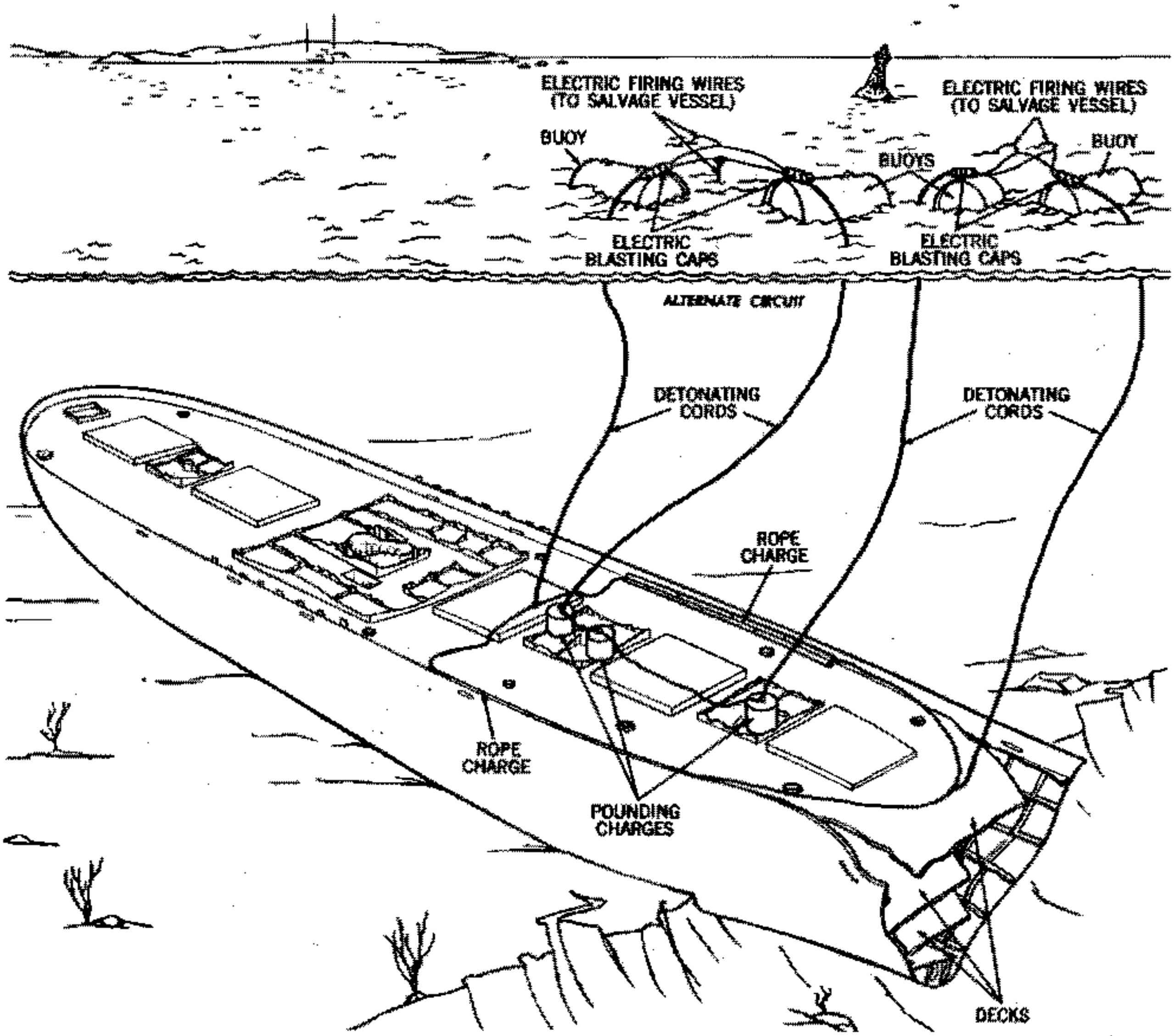

Figure 92—Ship Flattening—Flattening the Hull, Second Stage. Preparation.

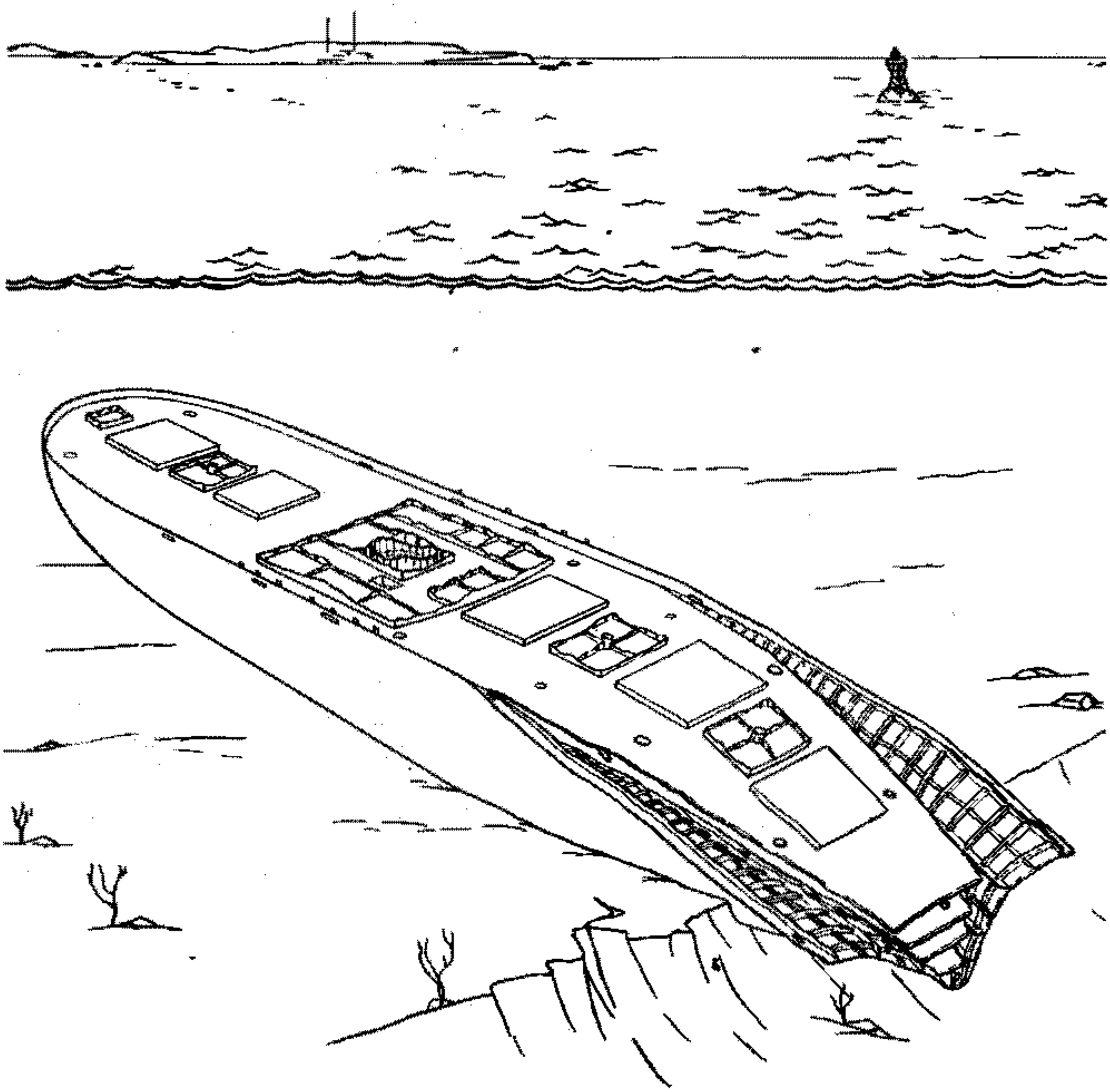

Figure 93—Ship Flattening—Forward Portion of Hull Flattened.

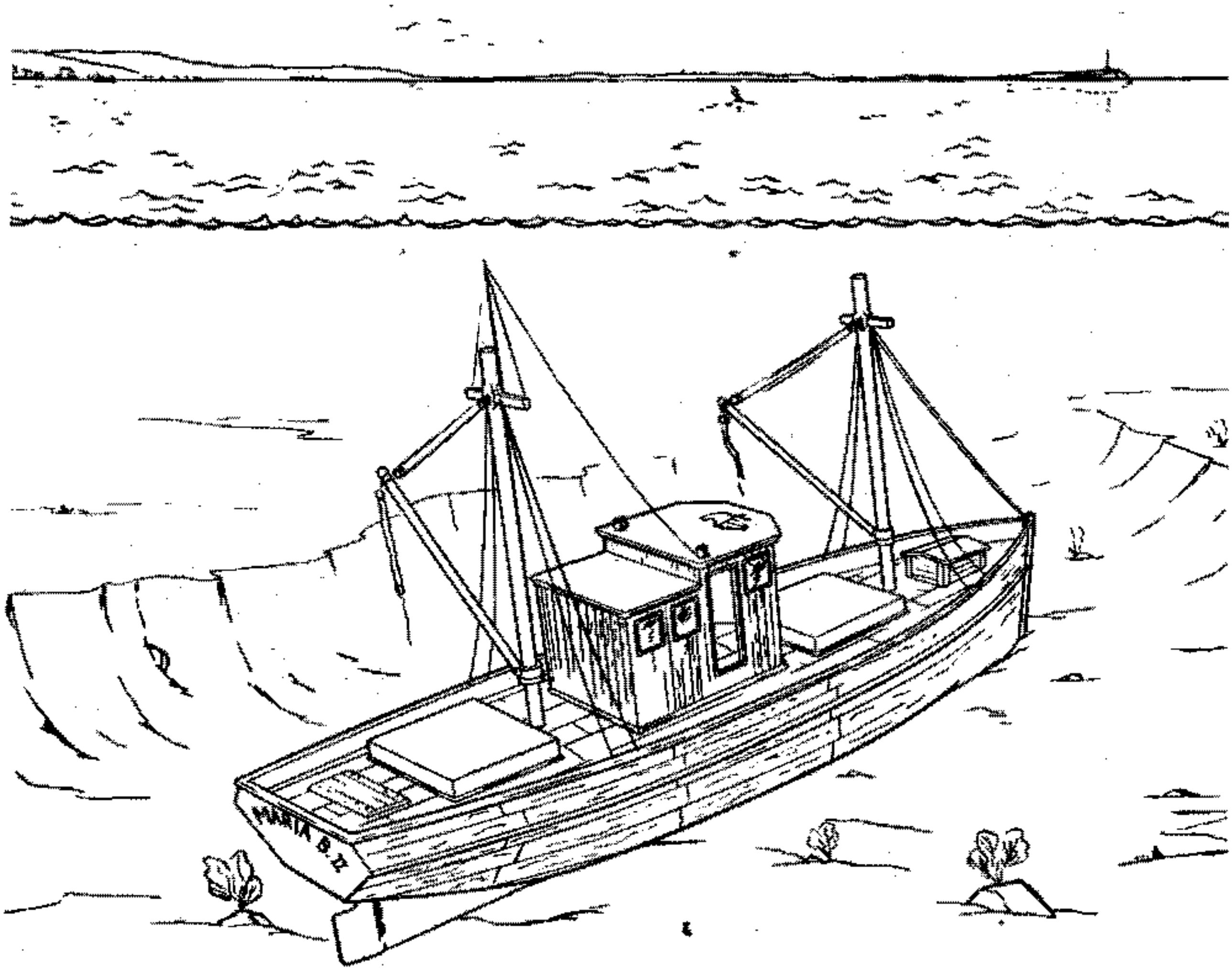

Figure 94—Wooden Ship Lying on Bottom.

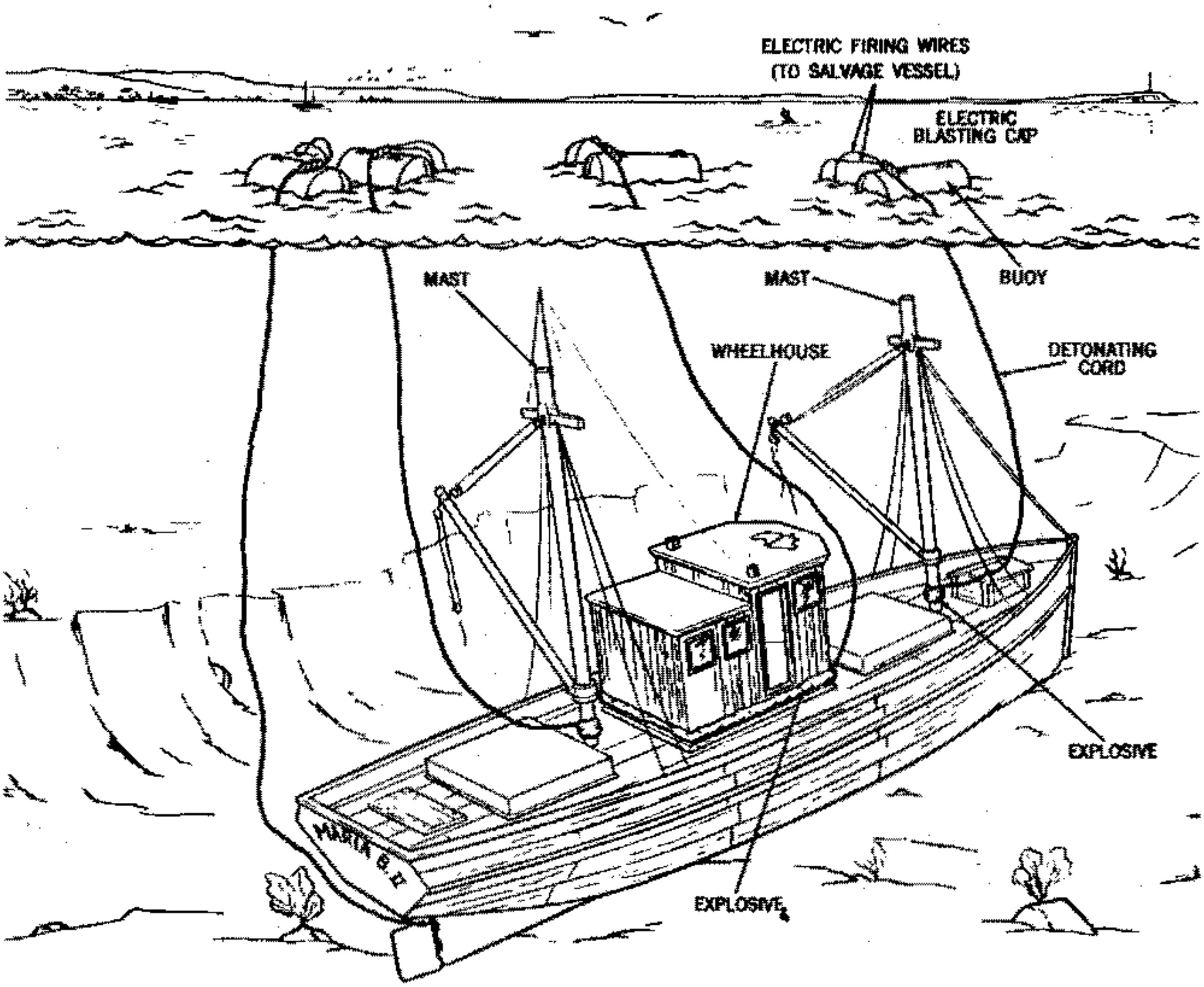

Figure 95—Wooden Ship Dispersal, First Stage.

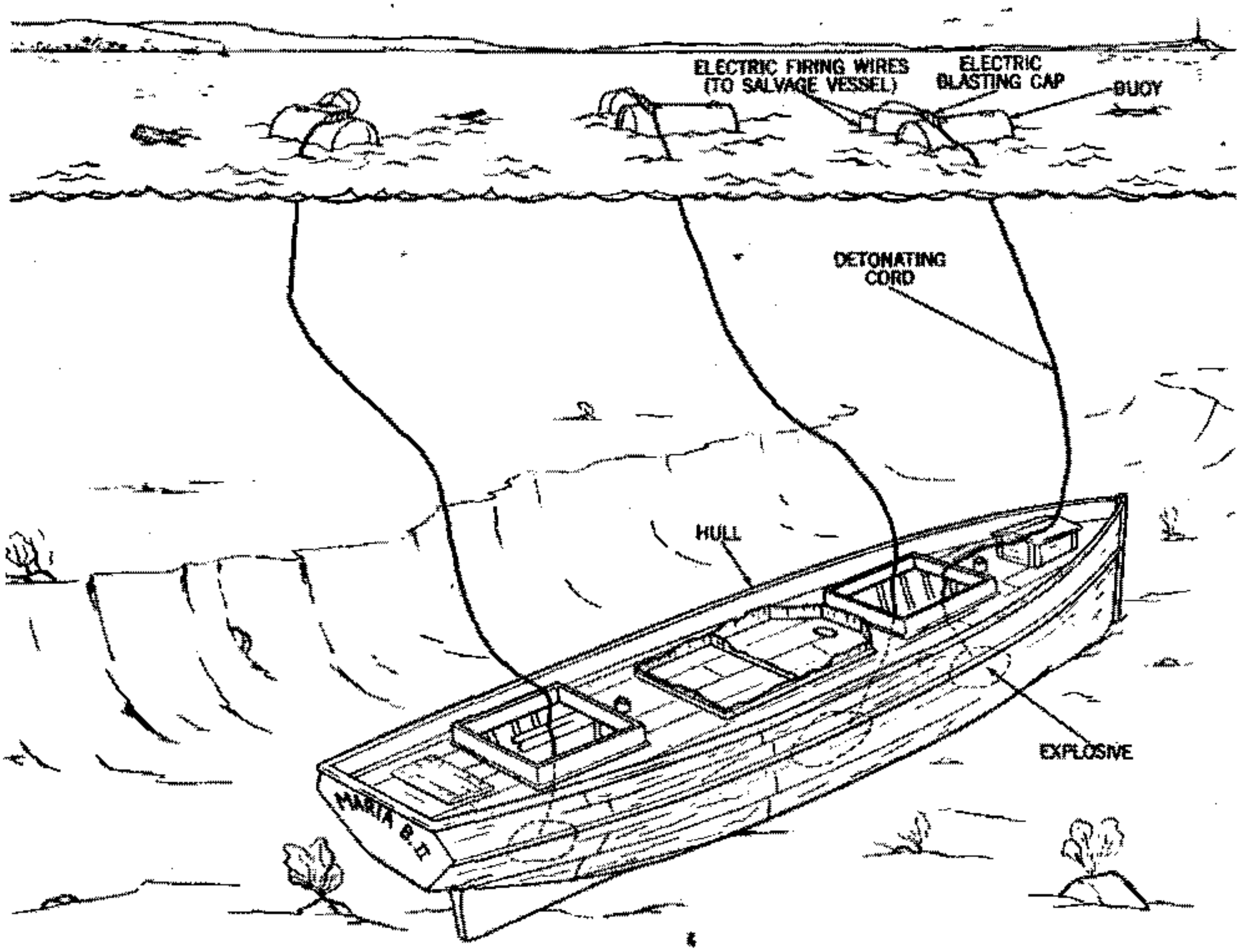

Figure 96—Wooden Ship Dispersal, Second Stage.

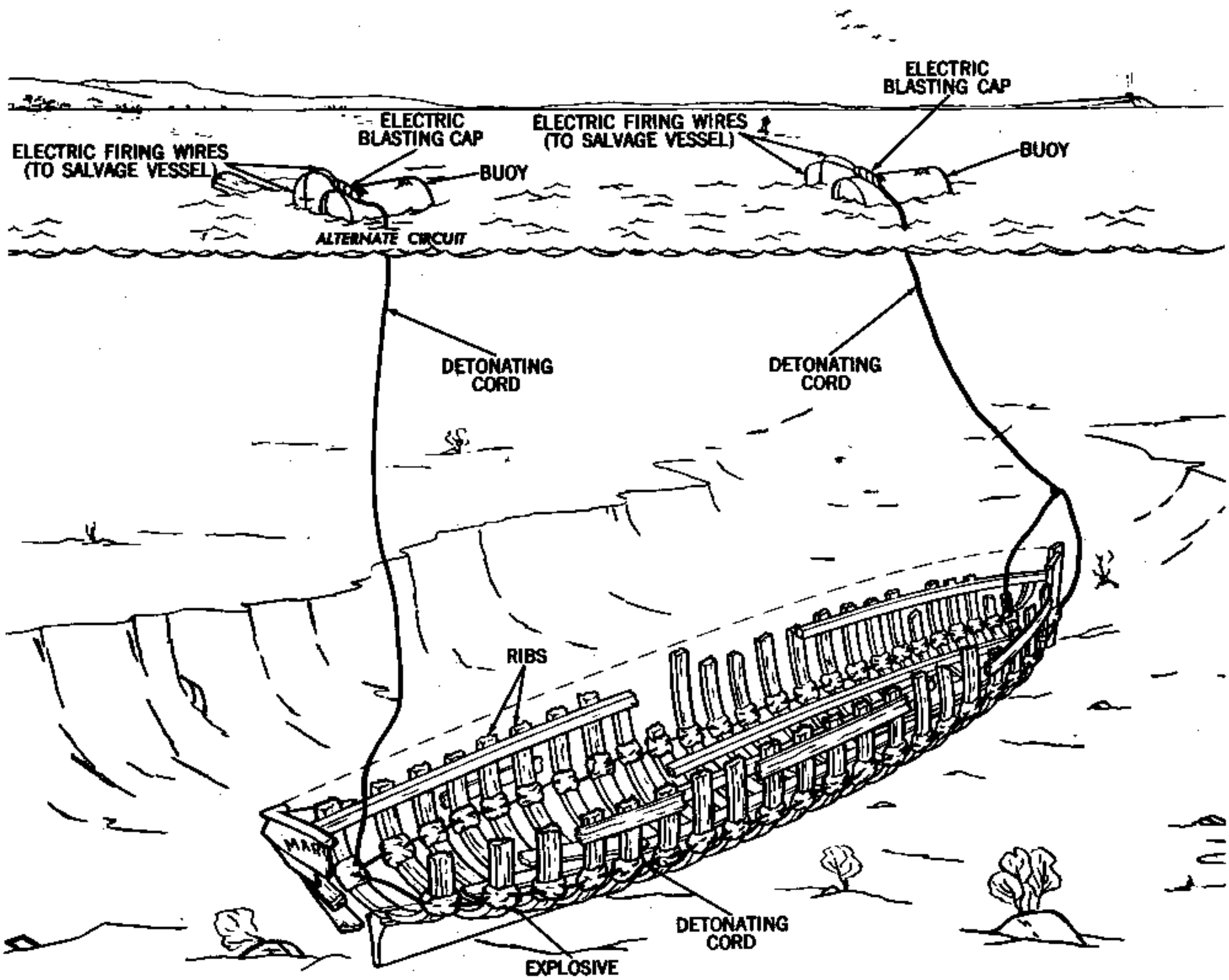

Figure 97—Wooden Ship Dispersal, Third Stage.

Scrap Salvage

When using explosives to cut up a ship for scrap salvage, two general rules must be followed:

1. Cut into parts that can be handled by available lifting equipment.

2. Flatten all parts as much as possible to reduce bulk so that shipping requires minimum space.

Dispersing Wooden Ships

Wooden ships can be cut apart with saw chains or dispersed with explosives, figures 94 through 98. The general procedure for removing masts and rigging and superstructure for steel ships applies; see chapter 13 for calculation of charges required for timber cutting. To disperse the hull, place a heavy charge inside each end of the hull and one heavy charge in the center. Detonate these charges simultaneously. Usually, the heavy planking takes most of the ribs and frames with it as it is forced outward by the explosion. Ribs or frames left standing must be cut individually.

Sawing chains may be used for cutting light wooden vessels, figure 99. A notch is first cut in the bow with explosives. Then each end of a heavy chain is led to a separate winch on the deck on the deck of the salvage vessel; the center of the chain is placed in the notch of the vessel to be cut. The winches are run in opposite directions alternately to give a sawing action to the chain. If the wood clogs the chain repeatedly, the vessel probably can be cut more easily with explosives.

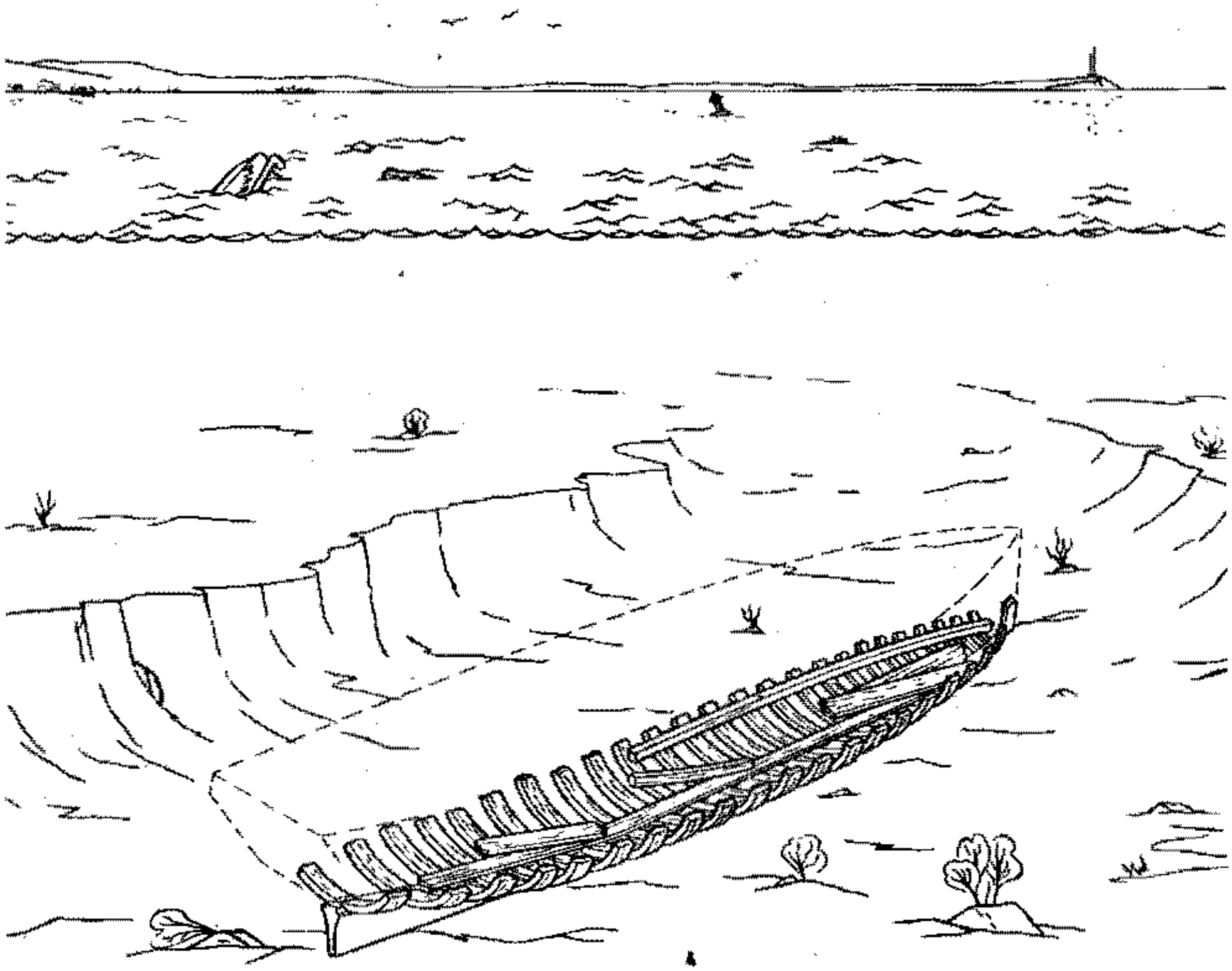

Figure 98—Wooden Ship Dispersed.

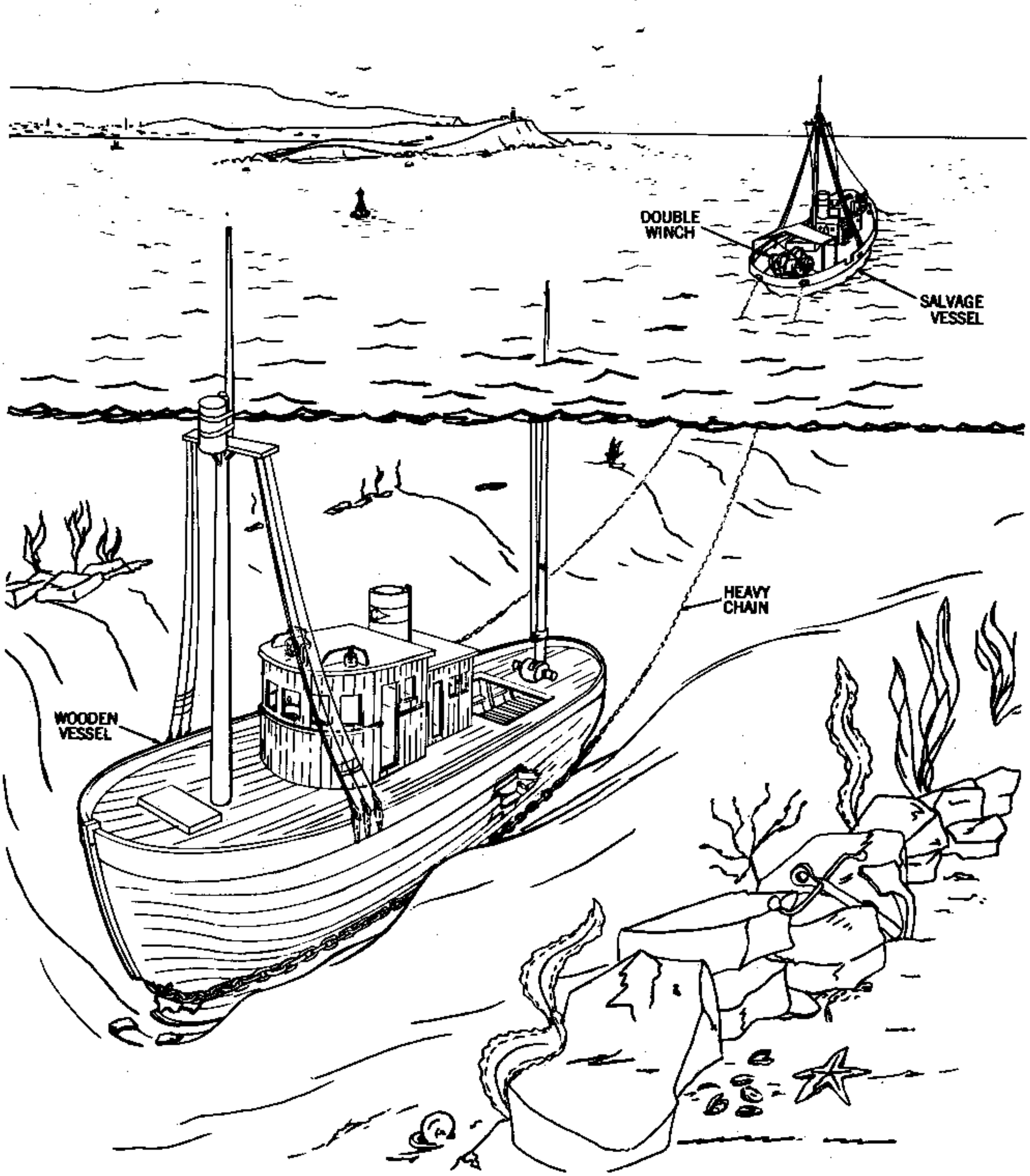

Figure 99—Using Saw Chains to Cut a Wooden Vessel.

Chapter 13

TIMBER AND PILE CUTTING

Harbor clearance may require timber cutting either above water or underwater. In either case, explosives provide the easiest method. Plastic composition C–4 is particularly suited for timber cutting.

Formulas

To calculate the amount of explosive needed to cut timber, use the following formulas:

For external charges, $P=\frac{D^2}{40}$;

For internal charges, $P=\frac{D^2}{250}$;

where P is equal to the weight in pounds of the explosive and D is the smallest dimension in inches of the timber.

Placement of Charges

External charges should be placed in contact with the timber at the level where it is to be cut. The charge should be concentrated as much as possible and should be placed on the widest face of the timber, figure 100. Standing timber, cut with explosive, falls toward the side on which the charge is placed unless influenced by other factors such as wind or lean of the timber. If timber underwater is to be cut below the mud or sand line, a water jet may be used to wash the soil away while the charges are being placed.

Internal charges should be placed in boreholes made for the purpose. Above water, the charges should be tamped with mud or clay; no tamping is required for charges underwater. If the required

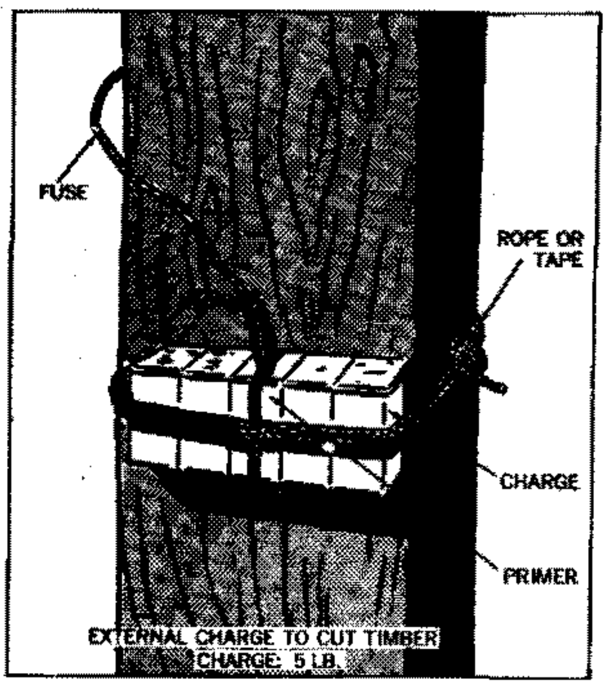

Figure 100—Placement of External Charge to Cut Timber.

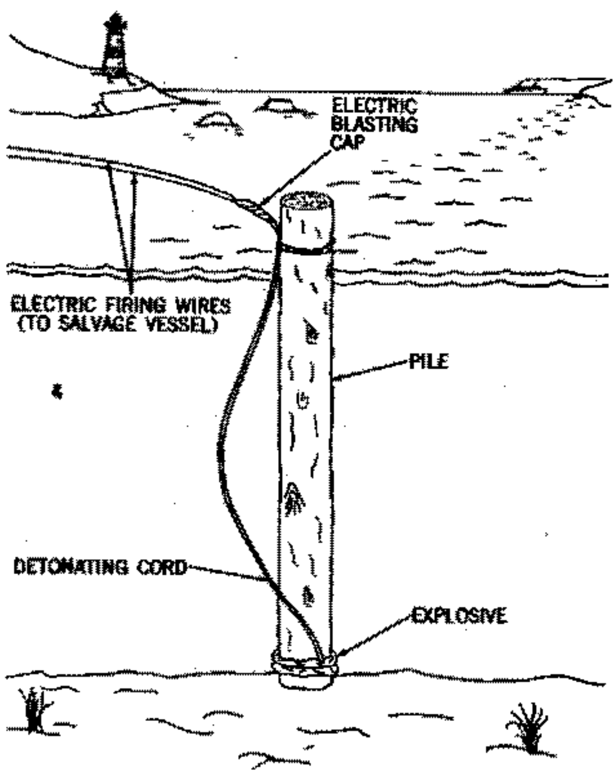

Figure 101—Placement of Charge for Pile Cutting.

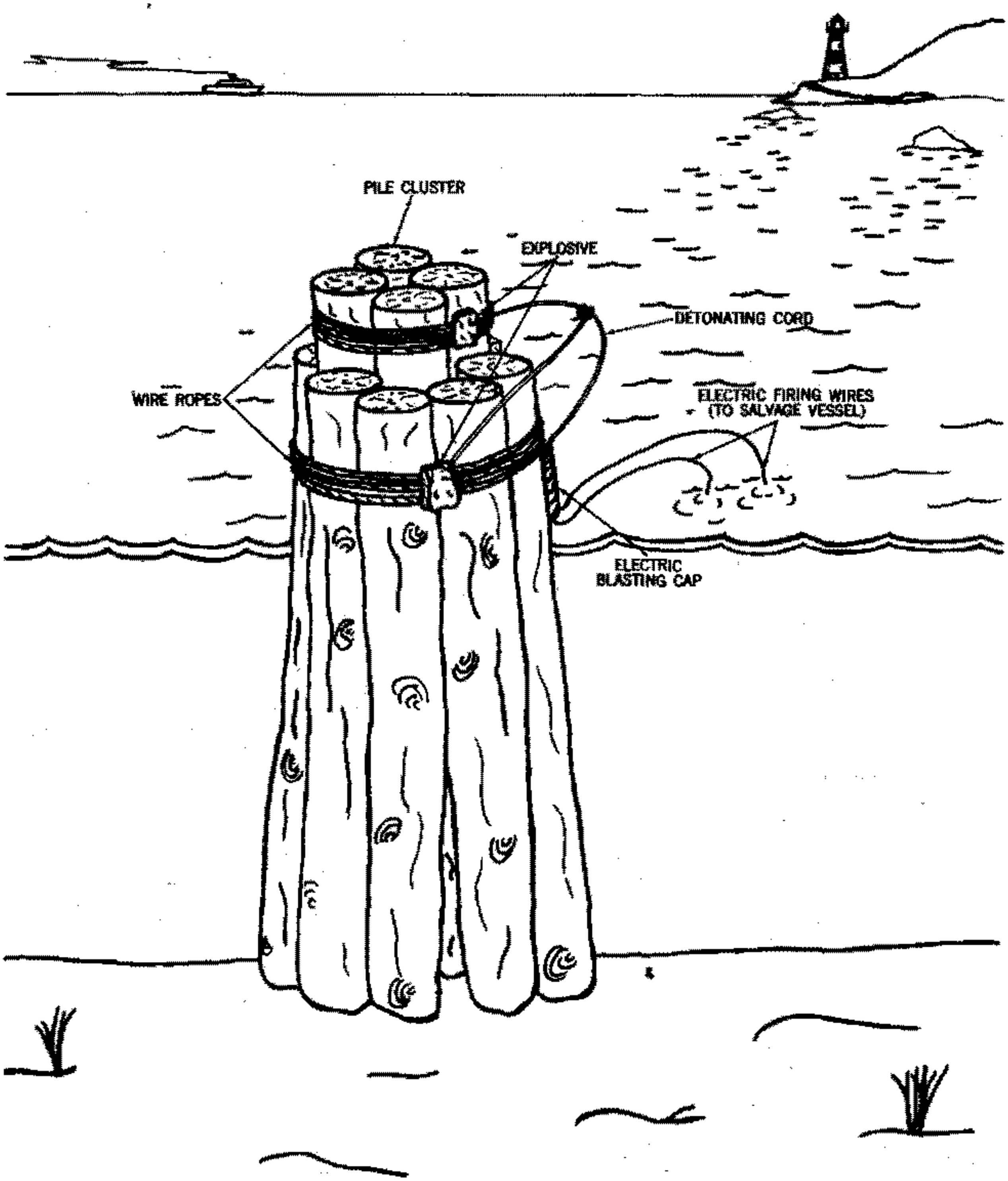

Figure 102—Dolphin Cutting, First Stage.

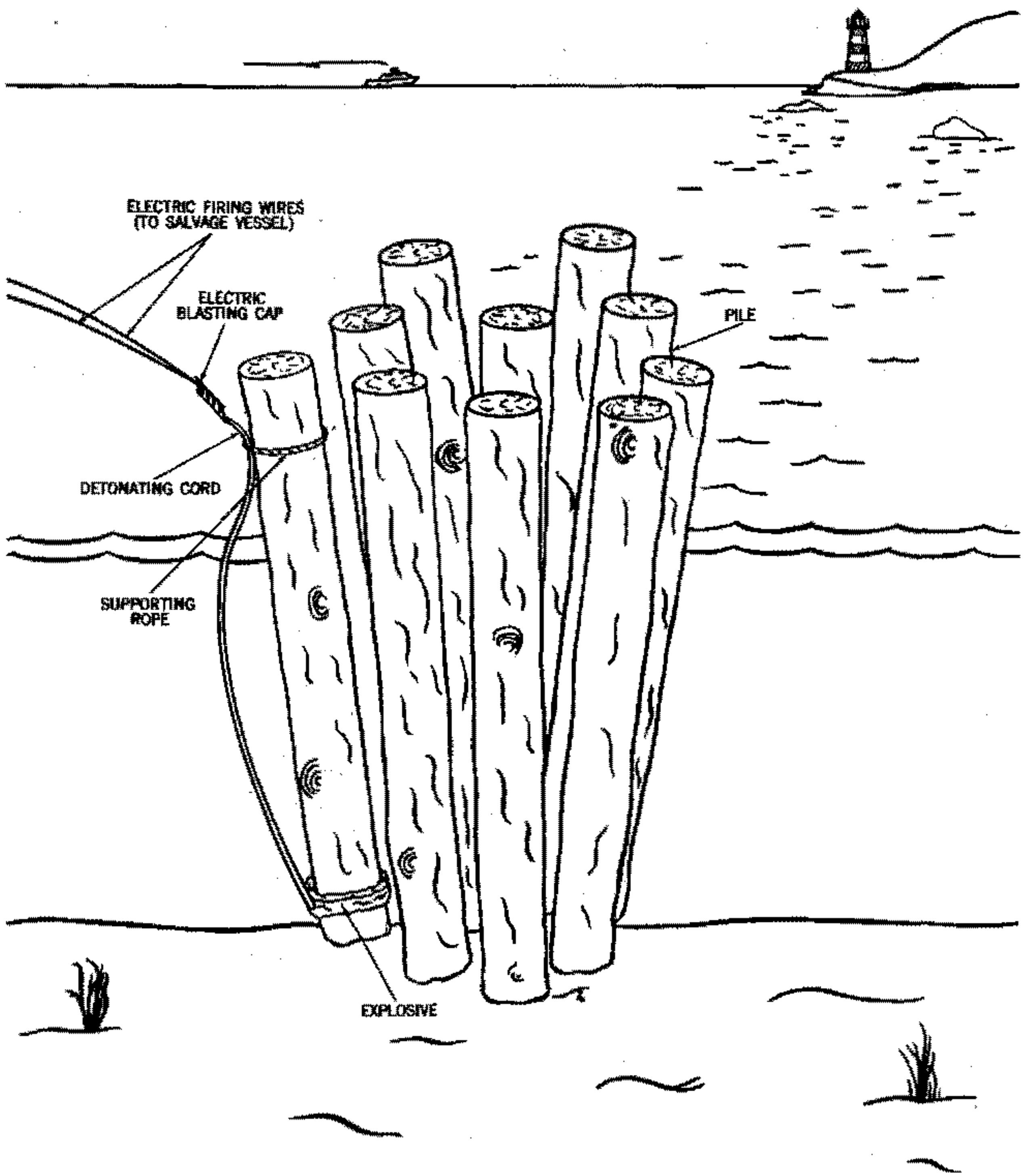

Figure 103—Dolphin Cutting, Second Stage.

charge is too large for one borehole, two or more boreholes should be made as close as possible to each other. When a charge is divided in this manner, all parts should be primed for simultaneous detonation.

Wooden Piers

When a wooden pier is demolished, its own weight should be used to assist in the demolition. By working from the end of the pier toward shore, cutting the supports successively, an increase in unsupported weight is imposed on the uncut supports so that less explosive is needed to cut the inshore supports than the outer supports. When cut free, the pier and all floating debris should be cleared from the area so that they will not endanger shipping.

Piles

Wooden piles can be cut with explosives in the same way as other timber; a charge is placed at the level to be cut and then is detonated, figure 101. When a cluster of piles, or a dolphin, is to be cut, the tie wire is severed first. Each pile then is cut individually at the desired level; outer piles must be cut first to permit access to the inner piles, figures 102 and 103.

Concrete piles are cut in the same manner as other concrete structures, chapter 10.

Chapter 14

PROPELLER REMOVAL AND REPLACEMENT

Without the use of explosives, the removal of a ship's propeller for repair or replacement is a time-consuming and costly task that normally requires drydocking of the ship for accomplishment. The use of explosives to simplify this task is unrelated to the underwater salvage activities discussed in earlier chapters, but it is definitely a function of underwater salvage personnel.

Originally forced onto a tapered shaft, a propeller tends to "freeze" to its shaft after it has been in service for any length of time. This "freezing" makes the starting of the propeller off its shaft the most difficult step in its removal. Effective hammer blows cannot be given underwater with ordinary equipment. However, such blows can be given very effectively with explosives. Furthermore, the work can be done while the ship is waterborne and without damage either to the propeller, to its shaft, or to the ship itself.

Propeller Removal

The following procedure is recommended for removing a propeller from a waterborne vessel, figures 104 and 105:

> NOTE: For all underwater work, two divers should work together.

1. Wrap a few turns of detonating cord around the base of the dunce cap and around the stud nuts. Raise divers. Detonate the cord.

WARNING

> Never detonate the charge when anyone is in the water within a 2000-foot radius of the charge.
>
> NOTE: Detonation of the cord should remove or loosen the cement in the stud nut recess and loosen the stud nuts. Alternately, a pneumatic hammer and ¾-inch side cutting chisel can be used to remove the cement.

2. Remove the stud nuts from the dunce cap and from the gasket retaining ring. Push the gasket retaining ring along the shaft.
3. Remove the lifting pad plugs from the dunce cap and insert the lifting pads.
4. Attach a pennant to the lifting pad; remove the dunce cap and haul it to the surface.
5. Remove the spline nut locking pin.
6. Lower a spline nut wrench to the divers.
7. Back off the spline nut with the wrench and remove the nut; haul the nut to the surface.
8. Cover the shaft threads with several turns of canvas and secure with sail twine. This will prevent damage to the threads when the propeller is removed.
9. Remove the studs from the propeller hub.
10. Attach pennant to the puller lifting pad.
11. Turn the propeller so that the keyway is at 12 o'clock; lock the propeller shaft with the jacking gear so that it cannot turn.
12. Attach the puller to the propeller hub by inserting it into the hub stud holes. Tighten the puller against the shaft. If the propeller does not start (loosen), continue with the following steps.
13. Wrap several turns of detonating cord around the hub. Canvas may be used over the cord to keep it in close contact with the hub. If difficulty is experienced in keeping the cord on the hub, the cord may be woven on the hub between the blades in such a way as to direct the force of detonation against the hub and not against the blades. If detonating cord is not available, two small charges of composition C-4 may be placed on the hub 180 degrees apart. Each charge should be approximately ⅜ inch in diameter by 1¼ inches long. Prime with electric blasting caps for simultaneous detonation.

> **WARNING:** Never detonate the charge when anyone is in the water within a 2000-foot radius of the charge.

14. Fire the charge. If the propeller is not loosened, repeat steps 13 and 14.

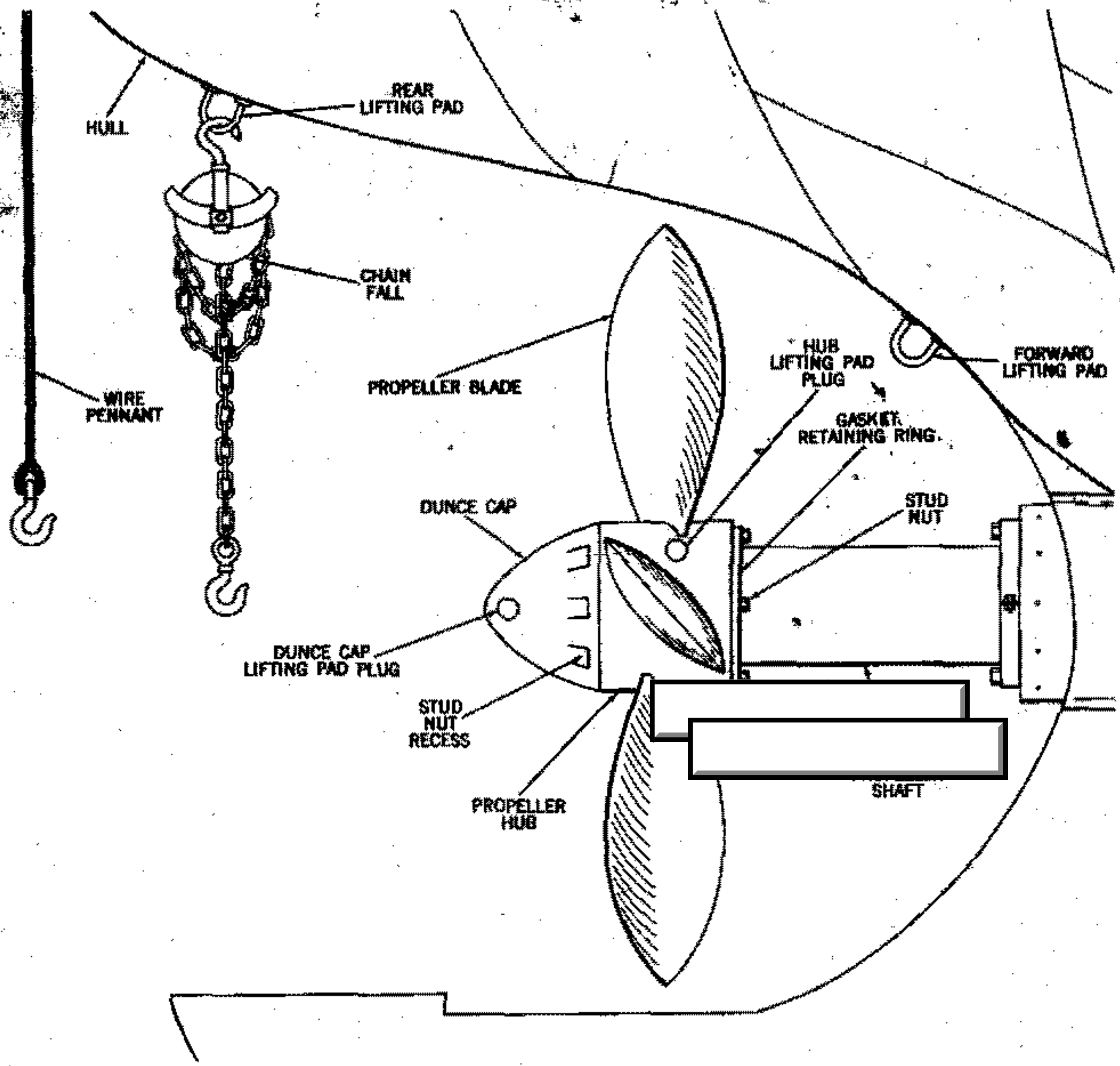

Figure 104—Preparation for Propeller Removal.

15. Attach a chain fall of sufficient capacity to the rear lifting pad on the vessel. Attach the chain to the lifting pad on the puller. Tighten the chain and pull the propeller from the shaft with the chain fall.

16. Remove the chain from the lifting pad; haul the propeller to the surface with a wire pennant. Tie the propeller key to the shaft with sail twine to prevent loss of the key.

Propeller Replacement, figure 106.

Before lowering the propeller for placement on the shaft, clean out all tapped holes with correct size taps. Also, clean the keyway and check it for proper fit of the key.

1. Attach wire pennant to the hub lifting pad.
2. Lower the propeller to the shaft.
3. Attach a chain fall of sufficient capacity to the forward lifting pad on the vessel.

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