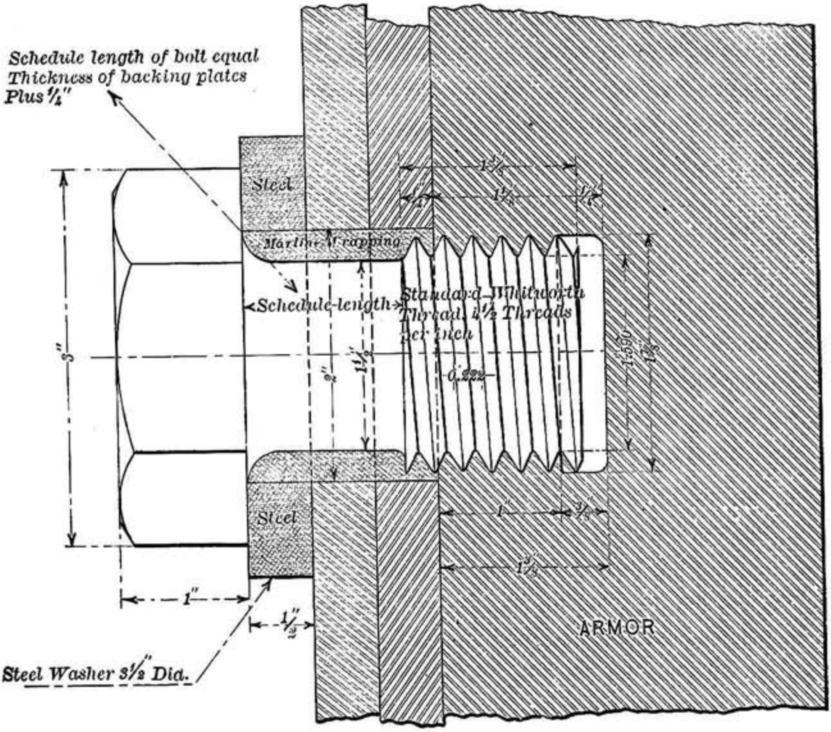

FIG. 1.

1.5-INCH BOLT FOR THIN ARMOR, WITHOUT BACKING.

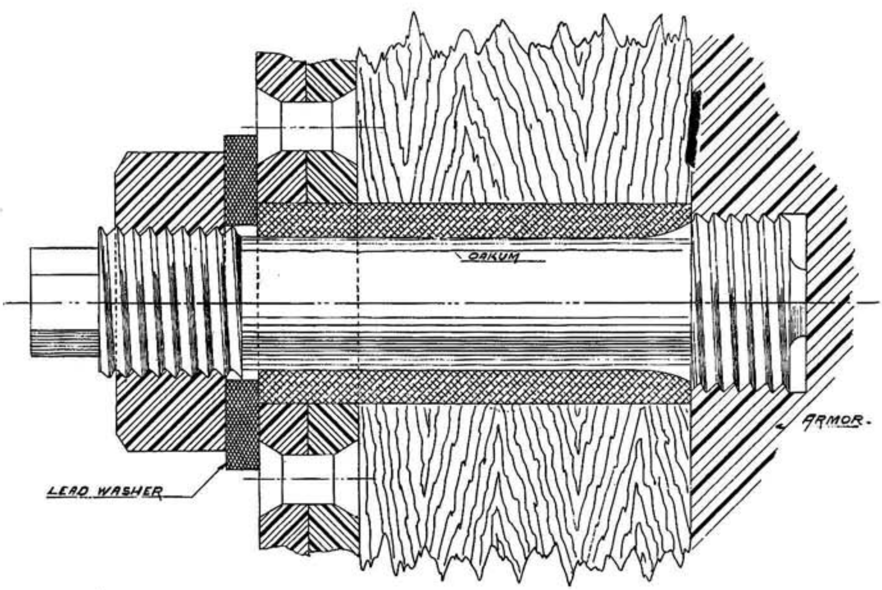

FIG. 2.

STANDARD ARMOR BOLT.

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Plate I, Figs. 1 and 2, show types of bolts for armor with and without wood backing.

The bolts are made of nickel steel of such remarkable toughness that the plate will remain in place even if severely cracked.

6. Specification for Armor 1903.—The following extracts from circular and specifications, etc., 1903, shows the precautions taken by the government to insure as far as possible ballistic efficiency and uniformity of service armor.

The armor defined in these specifications shall, for the purpose of distinction, be classed as follows:

Class A, consisting of armor plates having a thickness greater than 5 inches, to be manufactured, reforged, and face-hardened by the best and most improved process, to be satisfactory to the Bureau of Ordnance.

Class B, consisting of armor plates having a thickness of 5 inches or less, to be manufactured, reforged, and face-hardened by a process satisfactory to the Bureau of Ordnance.

The tests for acceptance shall be made as strictly as practicable in accordance with the following tables, the Department reserving the right to use guns of other calibers than designated for any plate, if it is deemed advisable, the velocities being deduced for Class A armor by the De Marre formula for the perforation of homogeneous steel plates of the thickness of the plates to be tested and increased by the same percentage as that used in establishing the velocities given in the tables.

Class C, consisting of thin plates and hollow forgings, such as turret tops, doors, communication and ammunition hoist tubes, to be oil or water tempered and annealed, but not face-hardened. Class C armor is not subject to ballistic test.

Class D, consisting of armor bolts and nuts.

The ballistic test for acceptance of armor of Class A shall in no case be less severe than the following:

There shall be three impacts with striking velocities as given in the following table, capped armor-piercing projectiles being used:

Caliber of gun. *Inches.*	Thickness of plate. *Inches.*	Striking velocity. *Foot-seconds.*
4	4	1,603
5	5	1,804
6	6	1,658
7	7	1,625
8	8	1,601
8	9	1,739
10	10	1,565
10	11	1,608
12	12	1,506

The first impact shall be located near the central portion of the plate, and on this impact no portion of the projectile shall get entirely through the plate and backing, nor shall any through crack develop to an edge of the plate.

There shall be two other impacts with capped armor-piercing shell to be located as may be directed by the Bureau; no impact, however, to be nearer another impact or an edge of the plate than 3½ calibers of the projectile used. On these impacts no shell or fragment thereof shall get entirely through the plate and backing.

For plates having a thickness not shown in the tables, the striking velocity shall be determined by interpolation, the Bureau to decide whether the caliber of gun next greater or next smaller shall be used.

The velocities for the test of Class B armor shall be those given in the following table, the impacts to be located as for Class A armor and the requirements as to cracking and perforation the same:

Caliber of gun. *Inches.*	Thickness of plate. *Inches.*	Striking velocity. *Foot-seconds.*
4	4	1,394
5	5	1,556
6	6	1,442

7. **Ballistic Tests for Class A Armor.**—The ballistic test is the chief one, and the object of all the other tests of plates is to insure, so far as possible, that the remaining plates of a group

are capable of standing as severe a test as that to which the test plate has been subjected; and the uniformity required among the plates of a group will be only such as may be necessary for this purpose. The plates from each group intended for the ballistic test will be selected by the Department, after all the plates of the group which are subject to ballistic test have received their final treatment and passed satisfactory tests for uniformity. Plates having gun ports or torpedo ports and face-hardened to be excluded from ballistic test after the ports are cut.

8. The bolt holes in the ballistic-test plate will be arranged, when conveniently practicable, in the same manner as for fastening a similar plate to the vessel's side.

9. Ballistic plates will be bolted to a backing of 6 inches of oak and one 5-8 inch ship plate. The backing, including oak and plate and studs for holding in bolts, must be furnished, fitted, and secured by the contractor, but the Department will defray the actual expenses thereof. If the plate is tapered, or otherwise intentionally varied in thickness, the backing will be maintained of full depth behind the thickest part. The whole structure will be braced from the rear, and the bolts will be of the same kind as are to be used on shipboard.

10. In ballistic tests the projectile shall be fired through screens to determine its velocity, when practicable.

11. Steel-capped projectiles of service type in use at time of test shall be used in the ballistic tests of armor. If a new and improved type of armor-piercing projectile should be adopted for service use, such modifications of the striking velocities will be made my mutual consent as shall appear fair and reasonable.

12. Firing at a plate will be stopped whenever, in the opinion of the inspector, the plate has demonstrated its incapacity to stand the full test.

13. If the group represented by the successful test plate has shown a close uniformity in quality, it shall be accepted as far as the ballistic test is concerned.

14. When the plates of a group do not show a close uniformity, if the first plate subjected to ballistic test passes, the Department may test two more before giving a decision as to acceptance of the group, but if all these plates pass, the Department

will pay for them all; if one or both of these plates fail, the successful plate or plates only will be paid for, and the acceptance of the group will be at the discretion of the Department.

15. After a group of plates is accepted, the Department may still test therefrom, ballistically, as many plates as it may desire and only such as pass will be paid for.

This paragraph will only apply when the Department has reason to believe that there is a lack of uniformity in the accepted group, or that defective plates are contained therein.

16. If the test plate shall fail to pass, the contractor may demand that another plate of the same group shall be selected by the Department and submitted to test. Should the second plate fail to pass, the group shall be rejected, unless, for good reason, the Department considers it desirable to continue the test.

If this plate successfully passes the test, the group may, at the discretion of the Department, be accepted; but if the Department so desires, it may select another plate (third) from the group, and on this test the acceptance or rejection of the group will definitely rest.

17. When more than one plate of any group is tested all those that pass the prescribed test shall be paid for at the contract price; provided the group to which they belong is accepted, but not otherwise.

In case of rejection, the contractor must replace the group within a reasonable time.

18. The success of the test plates defines the status of the group in a ballistic sense, but does not secure the individual plates from condemnation for causes which seriously impair their resistance, or which are referred to herein as objectionable.

19. Bolts and Nuts.—A number of nickel-steel armor bolts will be needed. The bolts and bolt holes are to be made and threaded, of dimensions, in numbers, and in the direction shown on the drawings to be furnished the contractor, or as stated by the Department.

20. Both the bolts and nuts will be of the best quality of nickel steel, oil or water tempered and then annealed, to contain about 3.25 per cent nickel.

21. The bolts shall be tested as follows: Two specimens shall be taken from the bolts manufactured from each heat. If more than one hundred bolts are made from a single heat, the inspector shall select two bolts for test after forging and final treatment. If less than one hundred bolts are made from a single heat, the inspector shall select one bolt from which the two specimens shall be taken. The specimens shall be taken longitudinally, and for acceptance shall show not less than 80,000 pounds tensile strength and 27 per cent elongation in 2 inches.

22. The bolts of a heat to be presented for test shall be oil or water treated together and receive their final annealing in the same furnace charge, as far as practicable.

23. The bolts will be required to be of standard dimensions and interchangeable before provisional acceptance. Before shipment the bolt holes shall be packed with waste soaked in white lead and tallow, or protected by other suitable means; the bolts and nuts shall have their machined surfaces coated with white lead and tallow, and they shall be suitably packed for shipment.

24. Nuts shall be treated and tested by heats in the same way as bolts, except that the two specimens shall be taken in the direction of the height of the nut, and shall show for acceptance not less than 80,000 pounds tensile strength and 17 per cent elongation in 2 inches.

25. Arrangement and Disposition of Armor on U. S. Battleships.—The arrangement or armor of various classes is as follows:

1. Plates above 5 inches in thickness consist of cemented or supercarbonized steel plates, face-hardened by the Krupp process, comprising, on battleships, the main side-belt armor, turrets, barbettes, conning tower, casemate, and intermediate-battery protection.

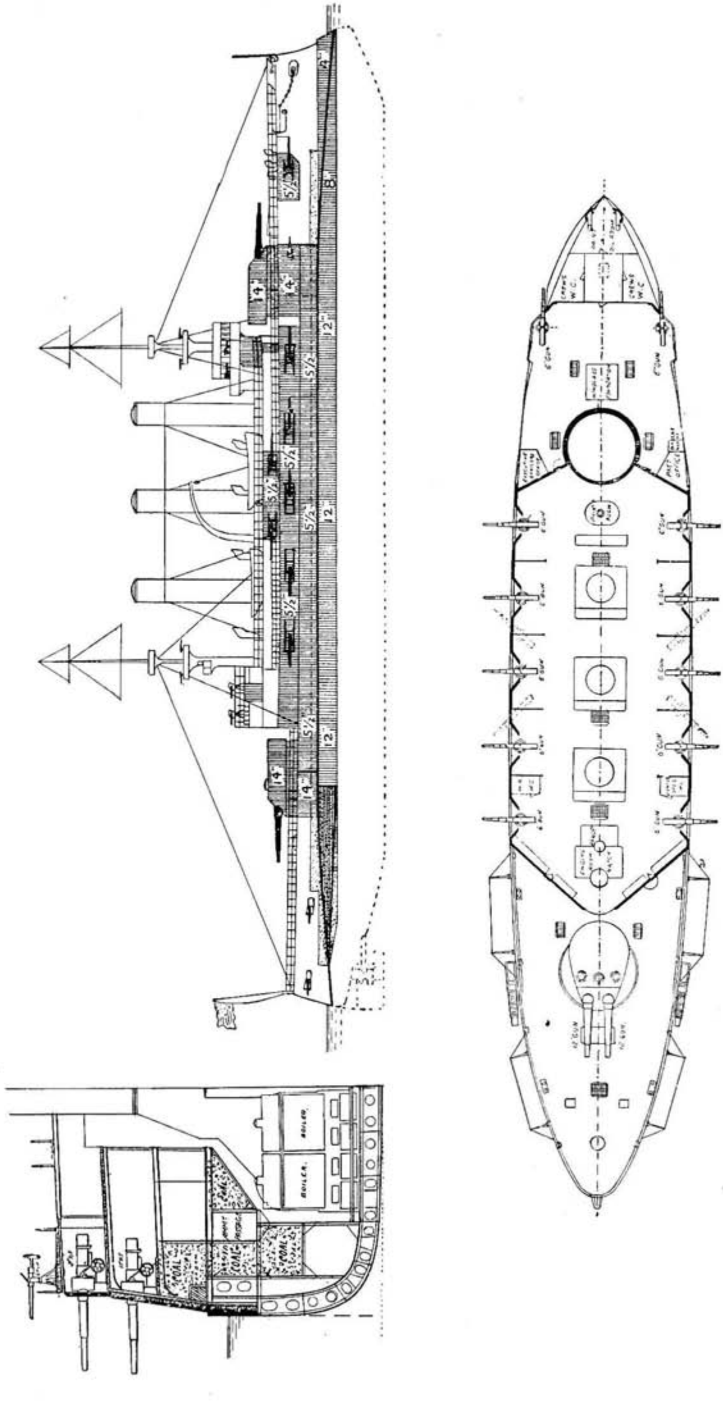
2. Plates not over 5 or less than 3 inches in thickness consisting of steel plates, face-hardened by the Harvey process, comprising the side armor plates forward and aft, when the thickness tapers to 5 inches or less, fore and aft and athwart-ship bulkheads, etc.

3. Thin plates, such as splinter bulkheads, protective decks, protection for minor-caliber guns, turret tops, sighting hoods, signal towers, ammunition and conning-tower tubes are made of homogeneous nickel steel.

4. Small, thick pieces, such as armor doors, strips above gun ports, etc., are made of Krupp noncemented steel.

The thickness depends first upon the importance of the position it is designed to protect and next on the resisting power of the armor. For the purpose of design, it is assumed that Kruppized armor will keep out projectiles of caliber equal to its thickness at moderate fighting ranges. Such, indeed, would be the case were it not for the assistance of the cap on projectiles, which is at once, probably, the simplest and most effective device ever developed in the history of ordnance. At normal impact and up to an angle of about 20 degrees the cap increases the perforating power of the projectile about 15 per cent with respect to velocity, and over 20 per cent with respect to thickness of armor, but it has another very important advantage in that it decreases the tendency of the shell to break up, preserving the latter so that it is well conditioned for exploding after passing through the armor. Its influence on the design of battleships is not yet materially felt, save, perhaps, in somewhat increased thickness and amount of armor carried. It is probable, however, if nothing is developed in armor that will defeat it, that it may induce a tendency to a more extended use of turrets with inclined front plates, so as to present an angle for impact beyond that at which the projectile will bite.

26. Armored Battleships—Oregon.—The evolution of design with reference to armor is brought out by a consideration of the types from the Oregon to the Connecticut class. The former has a very heavy water-line belt, 18 inches in thickness, extending along the machinery, magazine, and boiler spaces. At the ends of this are the barbettes, 17 inches thick, rising on the center line above the main deck. These barbettes protect the turret turning gear, and ammunition supply. Mounted over the barbettes are the turrets for the 13-inch guns, with 15 inches of armor at the sides and back and 17-inch port plates. The casemate armor is 5 inches thick, but is of limited extent, and but poorly protects the two broadside 6-inch guns. The quadrilateral 8-inch turrets have 8½ inches of armor, the barbettes are 10 inches and the ammunition tubes 3 inches thick. The secondary battery is protected by 2-inch armor, and thin gun



TYPES OF BATTLESHIPS MAINE, MISSOURI AND OHIO.

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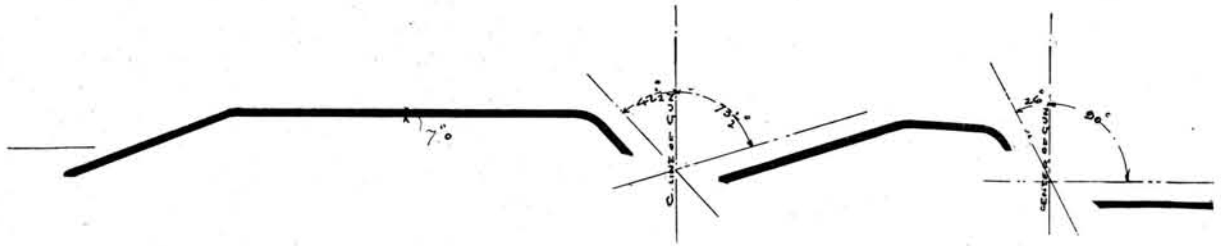
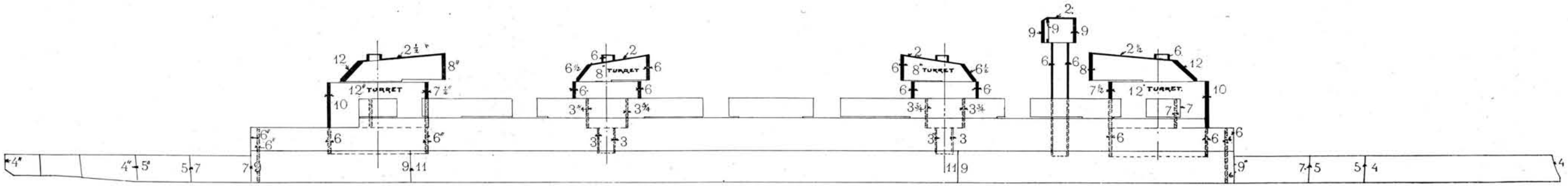


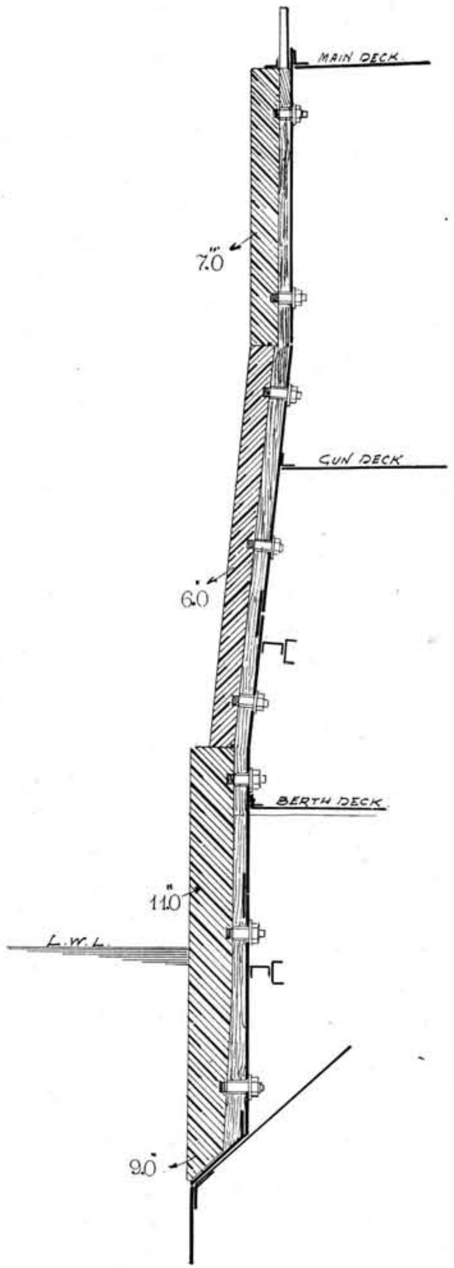
UPPER CASEMATE SIDE ARMOR

ESTIMATED WEIGHTS.

	Thickness.	Tons.
Side belt armor.	11″	686.34
Side belt armor.	9	254.04
Side belt armor.	7	66.36
Side belt armor.	5	52.78
Side belt armor.	4	126.60
Lower casemate side armor	6	505.24
Upper casemate side armor	7	321.06
Triangular athwartship armor	6	13.80
Lower casemate athwartship armor	6	102.94
Upper casemate athwartship armor	7	69.74
Conning tower	9	39.00
Conning tower top	2	2.90
Conning tower shield	9	11.13
Conning tower shield top	2	.85
Conning tower armor tube.	6	38.54
Signal tower	6	17.21
12-inch barbettes	10	318.42
12-inch barbettes	7½	79.72
12-inch barbettes	6	152.86
12-inch turrets	12	35.46
12-inch turrets	8	120.88
12-inch turrets	2½	35.46
12-inch turrets, sighting hoods	6	12.06
8-inch barbettes	6	94.16
8-inch barbettes	4	21.04
8-inch barbette tubes, upper	3¾	93.92
8-inch barbette tubes, lower	3	22.76
8-inch turrets.	6½	33.40
8-inch turrets	6	131.52
S.inch turrets	2	30.02
8-inch turrets, sighting hoods	6	15.98
Total		3505.65 tons



CONNECTICUT AND LOUISIANA.



MIDSHIP SECTION

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shields. There is a conning tower, 10 inches thick and a 7-inch communication tube. These vessels were designed before the Harvey process had been adopted for armor.

27. Iowa, Kearsarge and Kentucky.—The Iowa followed, the armor being distributed on the same general lines, but thinner in corresponding positions. In the Kearsarge and Kentucky we find a slight decrease in thickness to 16 inches and an extension of the water-line belt to the bow, tapering in thickness to 4 inches. The barbette and turret armor were slightly decreased in thickness and more importance given to the casemate armor, 5 inches thick, which was made to cover all the space between the barbettes. The conning tower, tubes, etc., remained practically the same.

28. Illinois Class.—Next came the Illinois class, including the Alabama and Wisconsin. The principal features of the armor design of these vessels was the abandonment of the 8-inch turrets, a more extensive use of the casemate armor, which was made 5½ inches thick to protect the 6-inch battery, the introduction of splinter bulkheads, and what is very important, the adoption of the inclined port plate for the 13-inch turret guns.

29. Maine Class.—The Maine class followed. The general design of these vessels is similar to that of the Illinois; 5½-inch armor was used for the casemates, and Krupp armor being at this time adopted, the armor protection was considered to be very much superior to the Illinois class. See Plate II.

30. Virginia Class.—In the Virginia class there is a return to the 8-inch turrets, two being superposed on the 12-inch like the Kearsarge and Kentucky and two being placed in broadside. The inclined port plates, however, of the former which permits of a minimum port opening, and at the same time are inclined at a sufficient angle to deflect projectiles, give very much better protection though the thickness is only 6½ inches against 8 inches for the Kearsarge. The 12-inch belt was retained, but was carried all the way aft, tapering to 4 inches at the stern as well as at the bow. The casemate was still further extended, being carried forward and aft with athwartship bulkheads so as to include the 12-inch barbettes.

31. Connecticut and Louisiana.—In the Connecticut and

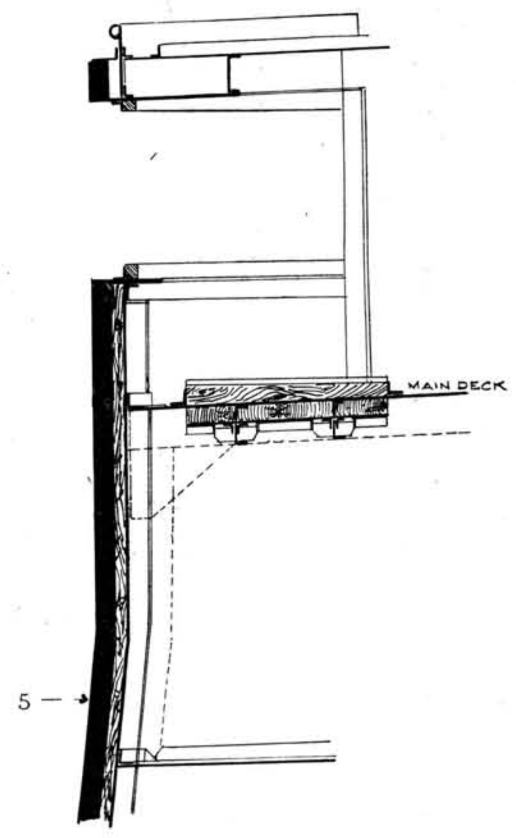
Louisiana, we find a reduction in thickness to 11 inches in the water-line belt, the 8-inch turrets are disposed quadrilaterally, the upper casemate armor is made 7 inches thick to protect the 7-inch guns. The general arrangement and disposition of the armor with the weights of each class are shown in Plate III.

32. Distribution of Armor on Monitors.—It has been demonstrated that such craft are only efficient in smooth water. They are now considered only as a means of harbor defense, and as other methods are more efficient for the purpose, the type has been abandoned. Future design need not therefore be considered. As a matter of fact there has been no change in the principle of design, since the original monitor. The essential features are: A complete water-line belt of maximum thickness in wake of the machinery and magazine spaces, tapering to the ends; a deflective and protective deck, similar to that worked in battleships; turrets mounted on the center line, revolving in heavy barbettes.

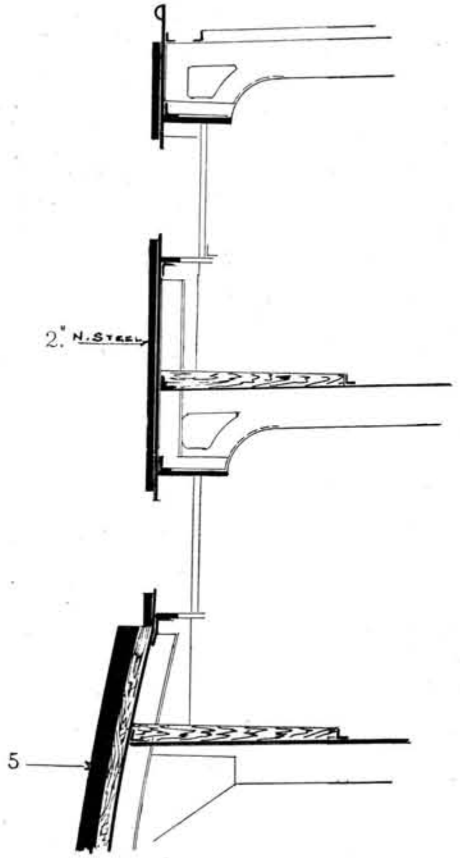
33. Armored Cruisers.—The evolution of the armored cruiser from the New York and Brooklyn to the latest type represented by the Tennessee class, Plate IV, has developed what is in reality a battleship. To compare the Tennessee and Connecticut, for example, we find the same principles applied in the distribution of armor in the one as in the other; namely, a water-line belt 5 inches thick; casemate armor, continuous with the belt and of the same thickness, completely enclosing the broadside battery; protective decks; turrets with 7-inch sides and 5-inch back, and 9-inch port plates; 7-inch maximum on barbettes; splinter bulkheads, conning tower, armored tubes, etc., all being very much lighter.

Many are of the opinion that the limit has been reached in this type and that the logical principles of attack and defense, in war ship design, which means using the most efficient weapon to the end, have not been exemplified in this type.

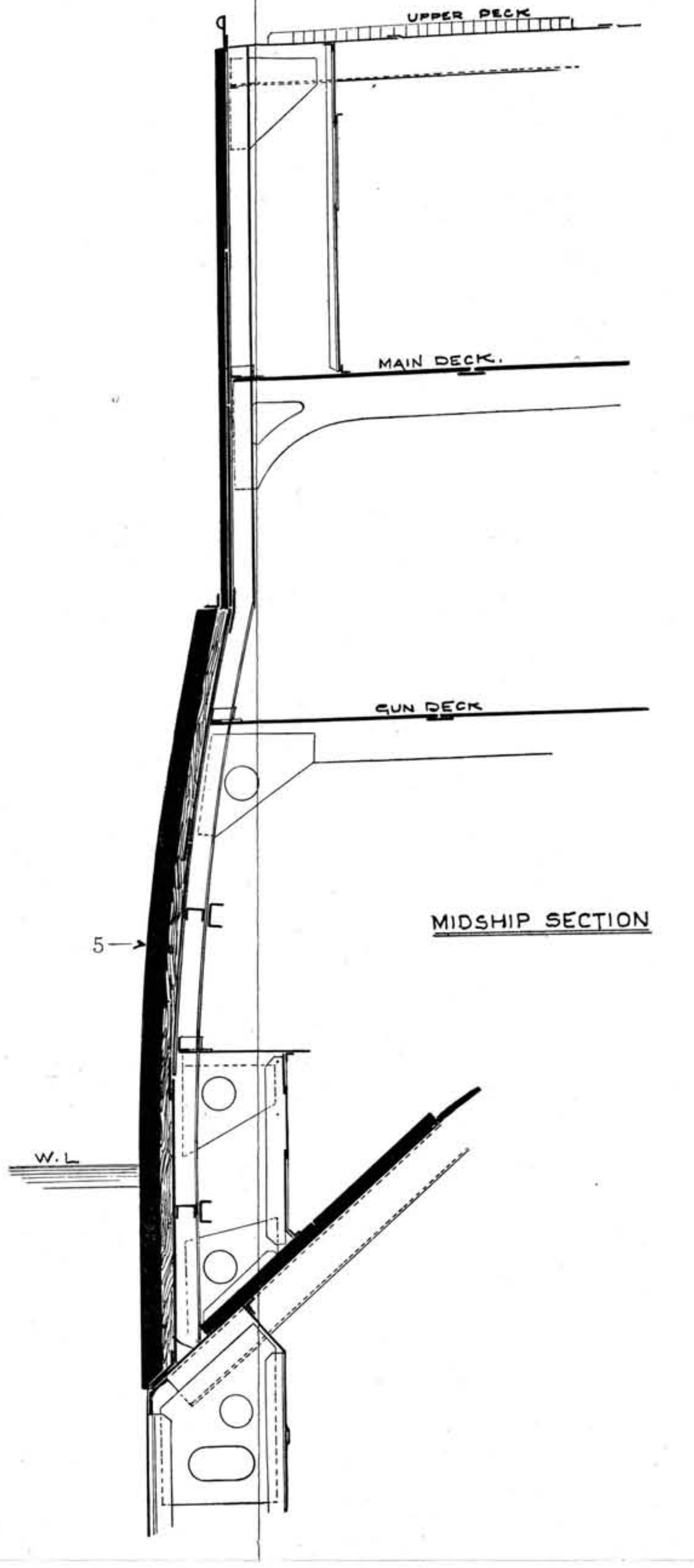
34. Milwaukee Type.—The Milwaukee type, called protected cruisers, but in reality armored cruisers, carry 4 inches of armor to protect the water-line amidships and the broadside battery, and the armor forms in effect a central citadel or casemate of uniform thickness extending from below the water-line to the



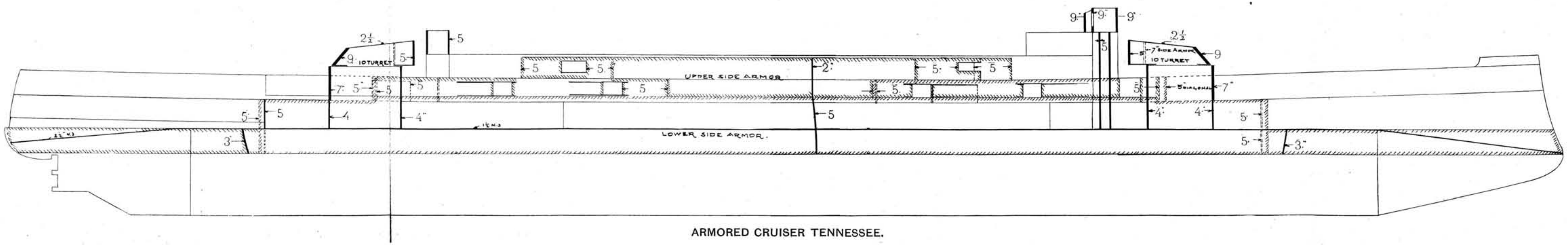
SECTION THROUGH 6IN GUN PORT
— MAIN DECK. —



– SECTION THROUGH 3IN GUN PORT –



MIDSHIP SECTION



ARMORED CRUISER TENNESSEE.

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upper deck and completely enclosing the central portion of the ship. This protection is supplemented by the usual protective deck, cofferdams containing cellulose, and coal bunkers.

35. **Gun Shields.**—Opinion is divided as to the efficacy of gun shields for guns in positions unprotected by armor. On the one hand it is argued that such shields serve merely as means for bursting shell, thus menacing the personnel of the gun's crew, whereas without the shield, the shell would pass harmlessly by. Others maintain that it is better to be certain of defeating smaller calibre projectiles and take chances of being struck by shell that will pierce the shield.

If properly disposed, shields form the best possible protection for the guns. The inclined port plates of turrets are in reality shields. The round shields covering the guns in the reentrant ports of the casemate guns in battleships are absolutely necessary as protection against fragments of shell.

In general it may be said to be good policy to fit shields to all guns where it is possible to make them sufficiently resisting to give complete protection against all shell of the same or less calibre than the gun to which the shield is fitted.

36. **Tendency of Battleship Design.**—Armor serves two purposes; first, protection for the personnel, which involves that of the gun positions and armament, and second, protection for the flotability and interior mechanism of the vessel. The latter includes protection of the hull and machinery. The present system is to protect the water-line area by an armor belt about 8 feet wide, 3½ feet below the water-line and 4½ feet above, extending the whole length of the ship, of maximum thickness in wake of the machinery and magazine spaces, and tapering to about 4 inches at the bow and stern. This belt is supplemented by a deflective or protective deck, sloping from the bottom of the armor belt, the whole length of the ship, flat in the center amidships, and crowned fore and aft as indicated on the type sketch of the Connecticut. There are also cofferdams filled with cellulose, and coal bunkers. The principal function of the coal is to smother fragments of bursting shell, and its value as protection is only incidental. Modern methods of construction have so minimized the effect of a water-line hit that it is doubtful

if it would be possible to seriously affect the stability or even the trim of a battleship by a single impact at the water-line. And the chances of such a hit are extremely small, as witnessed by the recent actions at the Yalu and during the Spanish War. Hence more importance is being attached to the protection of the personnel, so that we see a steady decrease in thickness of the water-line belt, and an increase in thickness of the casemates. It is generally agreed that the best method of protecting the heavy guns is to mount them in turrets rising out of heavily armored barbettes. The casemate method of protecting the intermediate or broadside battery (guns of calibre less than 8 inches) has been used from the beginning of modern construction, but many well-informed officers believe that present direction of development will induce a more extended use of turrets.

Future design as regards armor protection will be influenced by (1) Increase in the calibre of broadside guns (7-inch guns have recently been adopted for the broadside battery of the Connecticut), which will involve a commensurate thickness of armor for protection; and for guns above 7-inch calibre, perhaps mechanical appliances for operating; (2) Improvement in the quality of A. P. projectiles whereby a capped projectile, at any range within 3000 yards, and for the larger calibres than 6 inches at considerably greater ranges, will, if striking normally, perforate the best armor a calibre in thickness and burst inside. This will involve an increase in thickness of armor, or some method of inclining it beyond the biting or efficient angle of the cap; (3) Improved methods of construction that minimize the danger to flotability and stability if struck in the water-line region, and the effect of bursting shell in portions of the ship other than gun positions, which involves a decrease in thickness of water-line armor, and a concentration of protection at the gun positions.

(4) The use of electrical machinery for sighting the guns and supplying ammunition, whereby it is possible to handle the larger calibre guns (above 6-inch or 7-inch), with great ease and nicety, so that it is not too much to hope to get as good results in the matter of rapidity and accuracy of fire as could be obtained from the smaller calibre guns handled by hand.

(5) Possible improvement in the quality of armor. It is doubt-

ful, however, if such improvement will keep pace with the gun and projectile.

All these considerations would, so far as armor protection goes, seem to point to a more extended use of turrets, with inclined port plates. In the matter of armor disposition the present design of turret could hardly be improved upon, having its port plate inclined at an angle beyond that at which projectiles will bite, and with minimum openings for the guns.

37. **Outside Explosions.**—The use of high explosives in the the form of the aerial torpedo in the attack on armor formerly had many advocates, but recent experiments have shown that this method is not efficient. In November, 1901, at Sandy Hook, N. J., a Gathmann 18-inch aerial torpedo was fired from an 18-inch powder gun, especially constructed for the purpose, at an 11½-inch Kruppized armor plate. The projectile weighed 1834 pounds, including 497 pounds of wet gun cotton, and the fuze was so designed as to detonate the mass of gun cotton upon impact. The impact was at a velocity of 1650 foot-seconds, corresponding to an energy of 34,610 foot tons. The gun cotton detonated on striking the plate, and the effect on the plate due to the explosion was nil. The plate was attached to a structure built to simulate a section of the side of a battleship, and the effect of the explosion on the structure seemed to indicate that the detonation of 500 pounds of high explosion against the armored side of a battleship would not seriously affect the structure of the vessel. Two succeeding impacts of projectiles containing the same amount of explosive confirmed the result of the first round.

The result of this test raises the question whether it would not be practicable to armor the bottom of a battleship so as to secure immunity from automobile torpedoes.

38. **Penetrating Power of Naval Guns.**—The following table shows the power of our naval guns with respect to the perforation of modern armor.

TABLE OF ELEMENTS OF NAVAL GUNS (MODELS OF 1899), GIVING PERFORATION OF FACE-HARDENED ARMOR, SERVICE VELOCITIES, AT RANGES UP TO 3000 YARDS, WITH SMOKELESS POWDER, CAPPED AND UNCAPPED ARMOR-PIERCING PROJECTILES, AT NORMAL IMPACT.

Caliber of Gun	Weight in tons	Length in caliber	Total length in inches	Total length of bore	Approximate charge of smokeless powder for maximum velocity	Weight of projectile	Muzzle velocity	Muzzle energy	Perforation at muzzle				Remaining velocity at 1000 yds.	Perforation at 1000 yds.				Remaining velocity at 2000 yds.	Perforation at 2000 yds.				Remaining velocity at 3000 yds.	Perforation at 3000 yds.			
									Harvey nickel-steel Projectiles		Krupp armor Projectiles			Harvey nickel-steel Projectiles		Krupp armor Projectiles			Harvey nickel-steel Projectiles		Krupp armor Projectiles			Harvey nickel-steel Projectiles		Krupp armor Projectiles	
									Capped	Uncapped	Capped	Uncapped		Capped	Uncapped	Capped	Uncapped		Capped	Uncapped	Capped	Uncapped		Capped	Uncapped	Capped	Uncapped
				Inches	*Lbs.*	*Lbs.*	*Foot-secs.*	*Foot-tons*																			
3-inch, Mark I	.87	50	154.3	149.7	5.	13.	2800	709	4.4	3.6	4.4	3.6	2130	3.1	...	3.1	...	1620	...	...	...	...	...	...	...	...	...
4-inch, Mark VII .	2.56	50	204.5	200.	15.	32.	2900	1870	6.7	5.7	6.4	5.6	2380	5.3	4.4	5.2	4.4	1955	4.	3.4	4.	3.4	1605	3.2	...	3.2	...
5-inch, Mark V ...	4.4	50	255.	250.	27.	60.	2900	3503	8.6	7.5	8.4	6.6	2460	7.	6.	6 7	5.6	2085	5.7	4.7	5.5	4.7	1770	4.6	3.9	4.6	3.6
6-inch, Mark VI ..	8.37	50	300.	293.74	46.	100.	2900	5838	10.9	9.3	10.9	7.3	2525	8.9	7.7	8.8	6.8	2185	7.4	6.4	7.2	6.	1895	6.2	5.3	5.9	5.2
7-inch, Mark I	13.33	45	315.	307.	74.	165.	2900	9646	13.2	11.8	13.2	10.5	2580	11.4	10.1	11.4	8.9	2295	9.8	8.6	9.7	7.6	2040	8.5	7.4	8.3	6.5
8-inch, Mark V....	18.	45	343.	335.	115.	250.	2800	13602	15.0	13.6	15.	12.1	2530	13.2	11.8	13.2	10.4	2290	11.7	10.4	11.7	9.1	2070	10.3	9.	10.3	7.9
10-inch, Mark III ..	33.4	40	400.	389.	240.	500.	2800	27204	20.	18.6	20.	17.1	2585	18.3	16.7	18.3	15.	2390	16.5	15.	16.5	13.5	2210	15.	13.	15.	11.5
12-inch, Mark III..	52.	40	493.	480.1	385.	850.	2800	46246	25.	23.4	25.	21.7	2620	23.	21.4	23.	19.4	2450	21.2	19.6	21.2	17.9	2295	19.5	17.9	19.5	16.2

NAVY DEPARTMENT,
BUREAU OF ORDNANCE,
August 20, 1901.

CHAPTER XXX.

PENETRATION OF PROJECTILES.

By Lieutenant Cleland Davis, U. S. Navy.

1. General Discussion.—When a projectile strikes a target, and its motion is destroyed, the motion must be dissipated by (1) heating the target; (2) heating the projectile; (3) changing the form of the projectile; (4) changing the form of the target. All of these but the last are, from the artillerist's standpoint, a waste. The amount of energy which takes the form of heat in the projectile and target is not known, but could be approximately ascertained by the use of bodies which ignited or fused at known temperatures. It is known that the temperature of the shell is sufficiently great to ignite the bursting charge (540° F.), and this indicates an amount of energy which must have been reached or exceeded.

No accurate experiments have as yet been carried out in order to determine the coefficients of resistance for the different materials of projectiles and plates, so that it is difficult to study the subject in a rigidly mathematical way. But practically the amount of penetration, whether for iron or steel plates, masonry, or for earth, has been determined by experiment. A number of formulas have been proposed, based on various hypotheses, and which agree more or less closely with the results obtained in actual firing. The diversity of the formulas proposed testifies to the difficulty of expressing the law of resistance of armored shields to perforation; and it is very doubtful if it be possible to express this law by an exact formula, since the resistance of the plates and the power of projectiles to overcome that resistance depend on so many conditions that escape calculation. Plates vary in different foundries; the same foundry cannot always deliver plates exactly alike, and any single plate is not perfectly homogeneous. The same may be said, to a less degree perhaps, of the projectiles; in addition may be mentioned the variation in shape of the projectile on impact, the possibility of the projectile breaking up, and the amount of heat developed on impact; all of these varying conditions make it practically impossible to apply strictly analytical investigations and deduce a law which will stand the test of general application.

2. **The Penetrative Effect.**—Generally speaking, the penetrative effect depends on the shape and material of the projectile, on its energy, diameter, and the direction in which it strikes the target.

3. **Form of Head.**—Several forms of head have been extensively experimented with, viz., flat, ogival, hemispherical, and conoidal. For piercing plates by shot striking normal to the surface of the plate, the ogival head of two to two and a half diameters is considered to have given the best results.

4. **The Steel Cap.**—A soft steel cap is now being fitted to all A. P. projectiles. This cap is in diameter about half the calibre of the projectile, and is about 4 per cent of the weight. Its action is fully explained in the preceding chapter. It adds about 15 per cent to the efficiency of the projectile with respect to the thickness of the plate and about 20 per cent with respect to the striking velocity.

5. **Material.**—Chilled iron, wrought iron, and steel have been experimented with to ascertain their respective merits for materials to make projectiles for piercing armor plates. Although chilled iron has been used on account of its easier manipulation, its great hardness, and its cheapness, the best material for projectiles to pierce armor is that which will neither break up on impact nor change its shape; this metal is a forged oil-tempered steel of special treatment and of special alloy which fulfills these conditions better than any other metal.

Various elements have been and are used to alloy the steel in order to obtain the requisite qualities for a good armor piercing projectile; these include principally nickel, chrome, manganese, and tungsten, and are combined in various ways to produce the desired results, namely a maximum of hardness combined with a maximum of toughness.

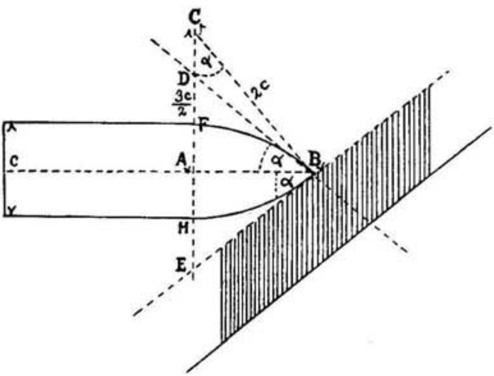
6. **Change of shape** means a loss of energy uselessly expended

ERRATUM.

Page 371, Par. 8; Text-Book of Ordnance and Gunnery, 1903, and the figure on the same page illustrating the *biting angle*.

The line CB, which is the tangent to the ogival, is *not co-incident with the radius* for this ogival and is *not equal* to 2c in length. And the computation of α for different radii on pages 371 and 372 is incorrect.

Substitute the following figure for that in the book, and the following computation of α for that contained in the last two lines on page 371 and the first four lines on page 372.



The figure shows the shell striking the plate at the *biting angle*, i. e., with the tangent EB in the plane of the plate's surface. Radius of ogival two calibers.

$$CB = 2c = \text{radius of arc } HB \,.\, AC = \frac{3c}{2}.$$

The angle ACB = ABE = the biting angle, α, because its sides are perpendicular, respectively, to AB and BE.

From the triangle ABC, $\cos \alpha = \dfrac{\frac{3c}{2}}{2c} = \dfrac{3}{4} \therefore \alpha = 41^\circ - 24' - 30''.$

From the above it will be seen that the value of α may be expressed as follows:

$\alpha = \cos^{-1} \dfrac{n - \frac{1}{2}}{n}$ where n = radius of the ogival in calibers.

Thus, for $n = 2\frac{1}{2}$, $\alpha = \cos^{-1} \dfrac{4}{5} = 36^\circ - 52'$.

$$n = 2 \;,\; \alpha = \cos^{-1} \frac{3}{4} = 41^\circ - 24' - 30''.$$

$$n = 1\tfrac{1}{2} \,,\; \alpha = \cos^{-1} \frac{2}{3} = 48^\circ - 11', \text{ etc., etc.}$$

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following Page 370,
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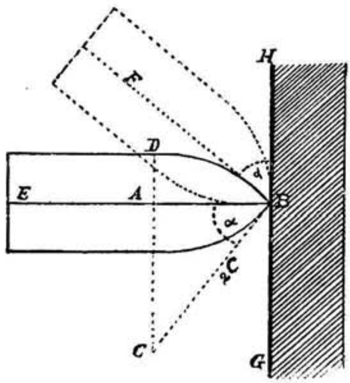
in heating the projectile; and if the projectile breaks up, it generally fails to impress all its energy on the armor plate. Tough steel more nearly answers the requirements for armor-piercing than any other metal. Forged steel is better than cast steel, as it does not break up on impact; and if the power of the armor for resistance nearly equals the power of the projectile for penetration, it is the only metal that will carry a bursting charge through the plate. With nickel steel armor, Harveyized, or with Krupp process armor, it is even more necessary to have forged steel projectiles of special treatment and of special alloy, since experiments show that those constructed of other materials break up on impact.



7. **The best weight** for a projectile of given diameter is generally found by giving a value to the ratio of $\frac{W}{d^3}$, where $W =$ weight of shot, $d =$ diameter. The latest researches give .45 to .5 as the value of this ratio. Thus for a 6-inch gun the weight would be not less than 97 pounds.

8. **The Biting Angle.**—It is evident that the point of an ogival-headed projectile will not bite thick armor at a less angle than that made by the tangent to the projectile at its point and the axis of the projectile. This will be seen from an inspection of the figure, and this angle is called the *biting* angle.

The angle made by the tangent CB with the axis of the projectile is equal to the angle ABC, and when the head is struck with a radius of 2 diam. if c be the diam., we have $\sin a = \frac{3}{4}, \ldots$ $a = 48° \; 30'$, about. Similarly, it may be shown that when the head is struck with a radius of 1½ diam. that the angle will be about 42°. If the plate is of comparatively soft metal, such as wrought iron and low steel, the shot will bite at a slightly less angle, owing to the fact that the plate bends slightly on impact and increases the angle between the tangent and the surface.

It has been demonstrated experimentally at the N. O. P. G., heads of various shapes having been used, that the flat-headed projectile is the superior of all others, at short ranges, against armor inclined at small angles to the line of fire.

9. Biting Angle of the Cap.—Proving ground experiments have demonstrated that the cap is not efficient at angles of impact above about 20° from the normal. In other words this is the biting angle of the cap. Taken in connection with the theory of the cap, the reason of this is susceptible of explanation. Assuming that the normal component only of the total striking energy is useful in smashing in the hard face, there is a point at which this component is not sufficient to give the desired result, so that the effect is the same as if the projectile were not capped.

10. Empirical Formulas for Penetration.—For thin plates which can be easily penetrated, experiment seems to show that the projectile acts as a punch, cracking the plate *circumferentially,* at the same time bulging it on the inside, where it also commences to crack. In this case the method of estimating the resistance per inch of projectile's circumference gives good results, but in cases where the projectile acts as a wedge, and drives the resisting material before it, the method of estimating the resistance per square inch of sectional area gives approximately better results. The truth probably lies between the two, inclining the more to the one or the other according as a punching or wedging action is brought into play.

The following formulas, by Th. Jacob de Marre, Capitaine d'Artillerie de la Marine, France, are those now in use, and have been deduced from the results of experience.

In these formulas,

$v =$ striking velocity in f. s.

p = weight of projectile in pounds.
c = diameter in inches.
E = thickness penetrated in inches.
The quantities in brackets are the logarithms of constants.
For penetration of wood backing,

$$E^{0.6} = [7.79013 - 10]\frac{p^{\frac{1}{2}}v}{c^{0.9}}. \qquad (1)$$

For penetration of wrought iron,

$$E^{0.65} = [7.03838 - 10]\frac{p^{\frac{1}{2}}v}{c^{\frac{3}{4}}}. \qquad (2)$$

For penetration of thin steel plates, not Harveyized, by steel shell from 6-pounder R. F. guns, and smaller calibres,

$$E^{0.7} = [6.86572 - 10]\frac{p^{\frac{1}{2}}v}{c^{\frac{3}{4}}}. \qquad (3)$$

For penetration of thick plates, not Harveyized,

$$E^{0.7} = [6.99066 - 10]\frac{p^{\frac{1}{2}}v}{c^{\frac{3}{4}}}. \qquad (4)$$

To find the striking velocity necessary to penetrate a given thickness of plate and backing, solve the proper formulas for v. If v_1 is the striking velocity necessary to penetrate the plate, and v_2 the striking velocity for the backing, the required velocity is

$$v = \sqrt{v_1^2 + v_2^2}.$$

The use of formula (4):
* " Formula (4) can be put in the form

$$v = K\frac{c^{\frac{3}{4}}}{p^{\frac{1}{2}}}E^{\frac{7}{10}}.$$

It is still used to represent the average resistance to the armor-piercing projectile when it penetrates the armor plate without being deformed, the plate being oil tempered and annealed. The value of K is 1022. for practical purposes.

With a face-hardened plate it has come to be the practice to use this formula with its velocity or the thickness of the plate multiplied by some factor. For some time, for example, our government shot at plates as if they were 1.15 times their thick-

*Discussion by J. F. Meigs, Artillery Engineer of the Bethlehem Iron Co.

ness, but at present it is the practice to multiply the velocity as derived from de Marre's formula, as formula (4) is called, by a factor, which factor has been 1.38 on thin plates of 5 inches and 6 inches in thickness, and about 1.30 on thick plates of 12 inches to 15 inches in thickness. These factors are used only in the case of Krupp process plates. With ordinary hard-faced plates, which were called Harvey plates, the factor could not reach so high a value.

The difficulty of measuring resistance of the hard face plate is much greater than in the case of the soft plates, because it becomes largely a question between the temper of the plate and the projectile.

If the temper and toughness of the projectile could be made perfect they would unquestionably penetrate the existing armor plate, but in existing armor plates the hard face is relied upon to destroy the projectile and thus prevent its penetration. It will be noted that the head and point of the projectile are hard and its base end soft and tough, and that it presents itself in just the same way to the impact as does the plate."

11. **Recent Formulas.**—Other formulas for the penetration of both homogeneous and face-hardened armor have been proposed both in this country and abroad, but the de Marre formula is the one on which ballistic tests are based universally, and this is of value to all governments in that it affords a basis of comparison as to the quality of armor each is getting.

The following formulæ were deduced by Lieut. Cleland Davis, U. S. Navy, from experiments made under the direction of the Bureau of Ordnance, for the perforation of Harveyized Armor:

Projectiles without caps. Capped projectiles.

$$V = \frac{c^{\frac{1}{2}}\,\varepsilon^{\frac{3}{4}}}{p^{\frac{1}{2}}} K \quad (1) \qquad V = \frac{c^{\frac{1}{2}}\,\varepsilon^{\frac{4}{3}}}{p^{\frac{1}{2}}} K^{1} \quad (2)$$

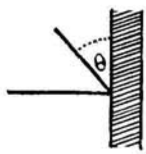
log $K = 3.34512$, log $K' = 3.25312$ using notation as before.

In these, the thickness of armor given just matches the velocity, so that under normal conditions of plate and projectile the latter would just get through, being itself destroyed in so doing. No satisfactory formula has yet been deduced for the perforation of Krupp armor. For capped projectiles, however, a fairly good approximation may be obtained by adding a constant of from 100 to 150 foot-seconds to the velocity obtained from (2).

The velocities for the acceptance test of projectiles by the Bureau of Ordnance are based upon (2).

For uncapped projectiles, a fair approximation may be obtained for plates equal in thickness to the calibre of the attacking gun by adding 200 to 250 f. s. to the velocities given from formula (1).

12. Oblique Penetration.—When a target is penetrated by oblique fire, it is generally found that the projectile turns and penetrates nearly normal to the plate. The normal velocity is then $V \sin \theta$, if θ is the biting angle with the face of the plate. In formulas in which V is used, the value $V \sin \theta$ must be substituted.



13. Kinds of Projectiles.—Three kinds of projectiles are in use in the U. S. Navy for the large calibre guns: Armor piercing, common or semi-armor piercing, and shrapnel. The latter would only be used in the attack of exposed bodies of men on shore. The specifications for the two former require that armor piercing shell shall perforate face-hardened armor plate of thickness equal to the calibre, and remain in a condition for effective bursting. Semi-armor piercing, or forged steel shell, must pass through half a calibre of face-hardened armor and remain in a condition for effective bursting.

14. Development of High Explosive Shells.—Great Improvements have recently been made in armor piercing shell, and the fact that it is possible to send an armor piercing shell loaded with a high explosive through a thickness of plate equal to its calibre and detonate it behind the plate may result, eventually, in the adoption of but one type of shell for the Navy. The most striking example of this result was in the test of the 12-inch Army rifle in comparison with the 18-inch Gathmann Torpedo

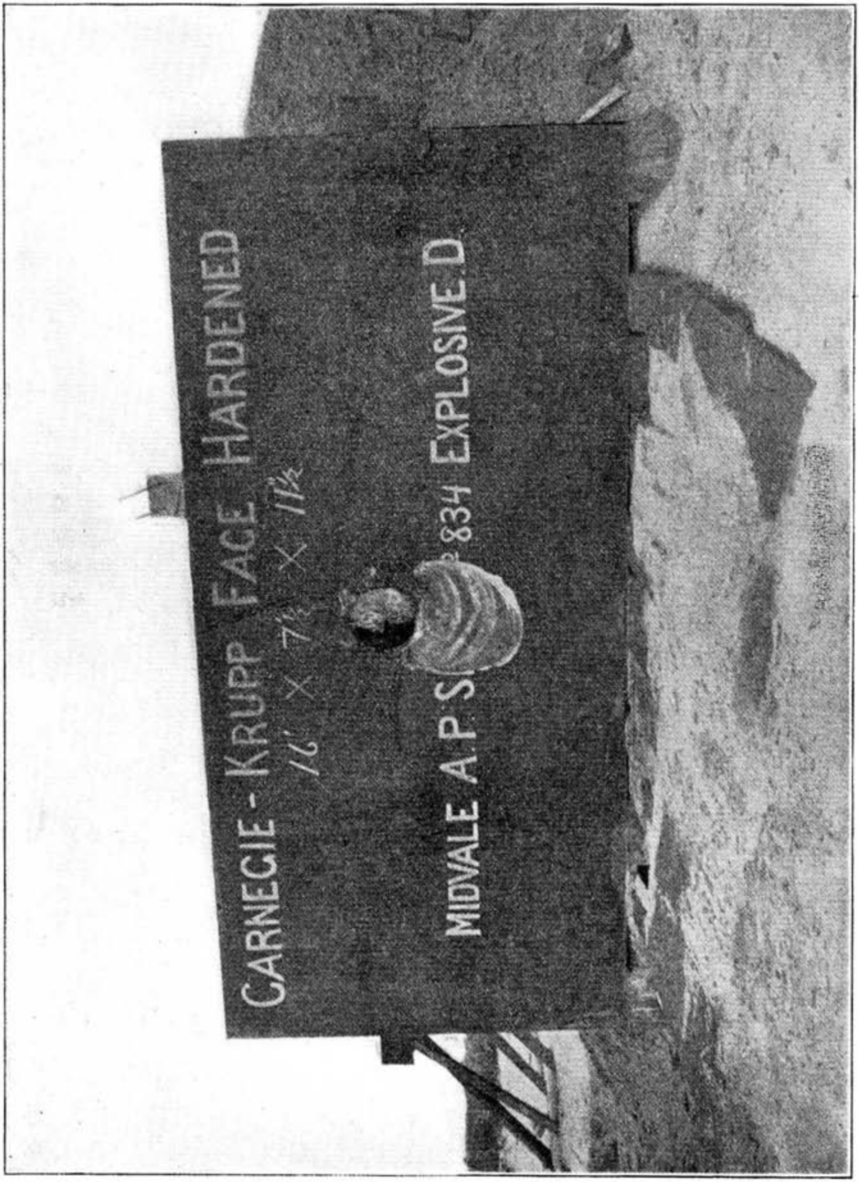
Gun. This test marked such an important advance in the attack on armor that the result is given in full together with photographs. The target was an 11½-inch Krupp plate, 16 feet long by 7½ feet wide attached to a structure which represented a section of the side of the Iowa.

Round one.—An armor piercing shot weighing 1001 pounds and 7 ounces, including 19 pounds 7 ounces of army high explosive, struck the center of the target with a velocity of 1800 feet per second, corresponding to a range of 4400 yards. The striking energy was 22,500 foot-tons. This shot penetrated the plate and was detonated just in the rear. The backing, the skin plates, frames, and cofferdam plates were completely demolished in the line of this impact. The crater formed in the sand butt in the rear of the structure measured 15 feet by 6½ feet. Pieces of the plate and projectile passed through the structure, through the butt, and were recovered at distances of 150 to 200 feet in rear of the butt. The rivets in the top plate were sheared, the side plates of the cofferdam were buckled about 3 inches, and the plate was forced back bodily about three-fourths of an inch. See Plates I and II.

Round two.—An army 12-inch armor piercing shot weighing 1006 pounds, including 23 pounds of Maximite, struck the right center of the plate with a velocity of 1804 feet per second, corresponding to a range of 4400 yards. The striking energy was 22,500 foot-tons. The shot detonated in the plate, completely wrecking the right-hand portion and demolishing the frames behind the armor and the plates of the cofferdam. See Plates III and IV.

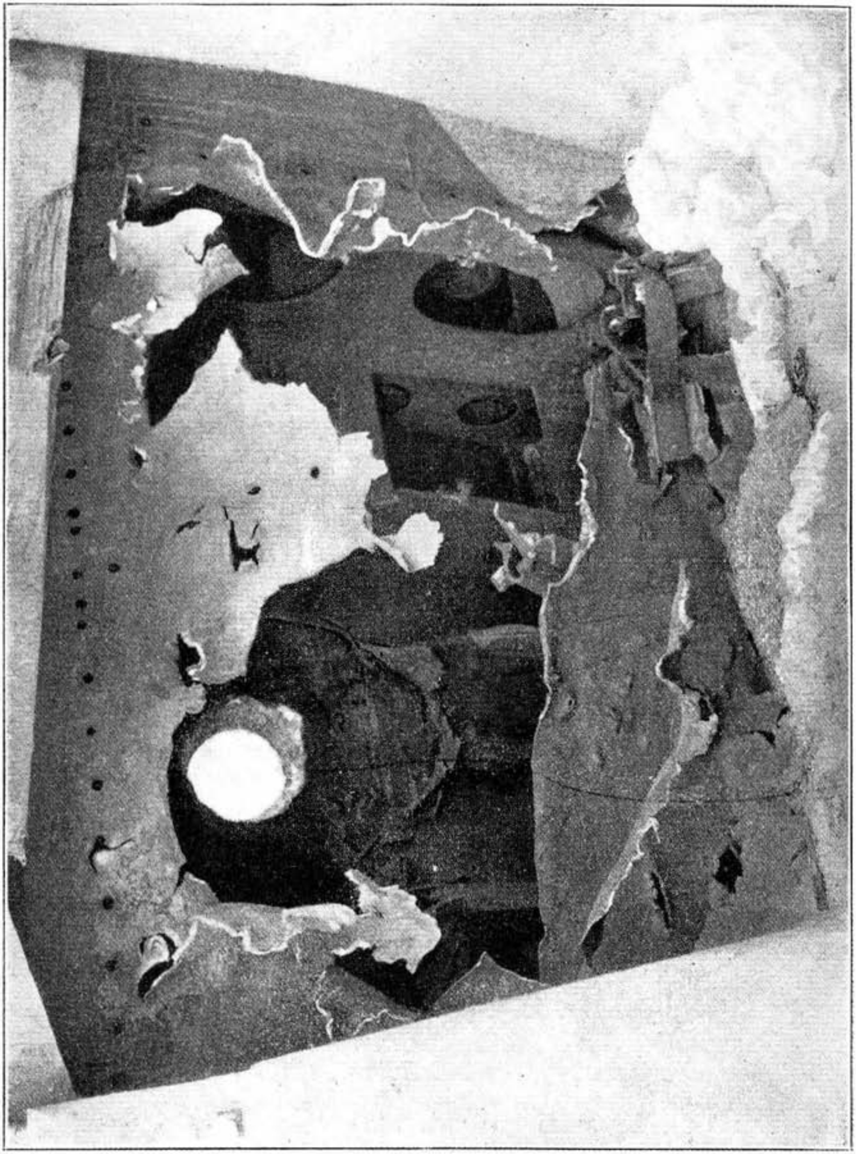
Round three.—A 12-inch armor piercing shell weighing 1045 pounds, including 60 pounds of army high explosive, struck the lower left-hand center of the plate with a velocity of 2073 feet per second, corresponding to a range of 1880 yards. The striking energy was 31,100 foot-tons. The shell penetrated and detonated in the plate: As a result of this impact the plate was totally wrecked and the backing, frames, beams, and cofferdam plates of the structure were completely demolished. An opening was made through the plate 4 feet wide by 8 feet long.

The lower left-hand quarter of the armor plate was broken



12-INCH ARMY SERVICE RIFLE TARGET. FIRST ROUND.

Front of Plate.

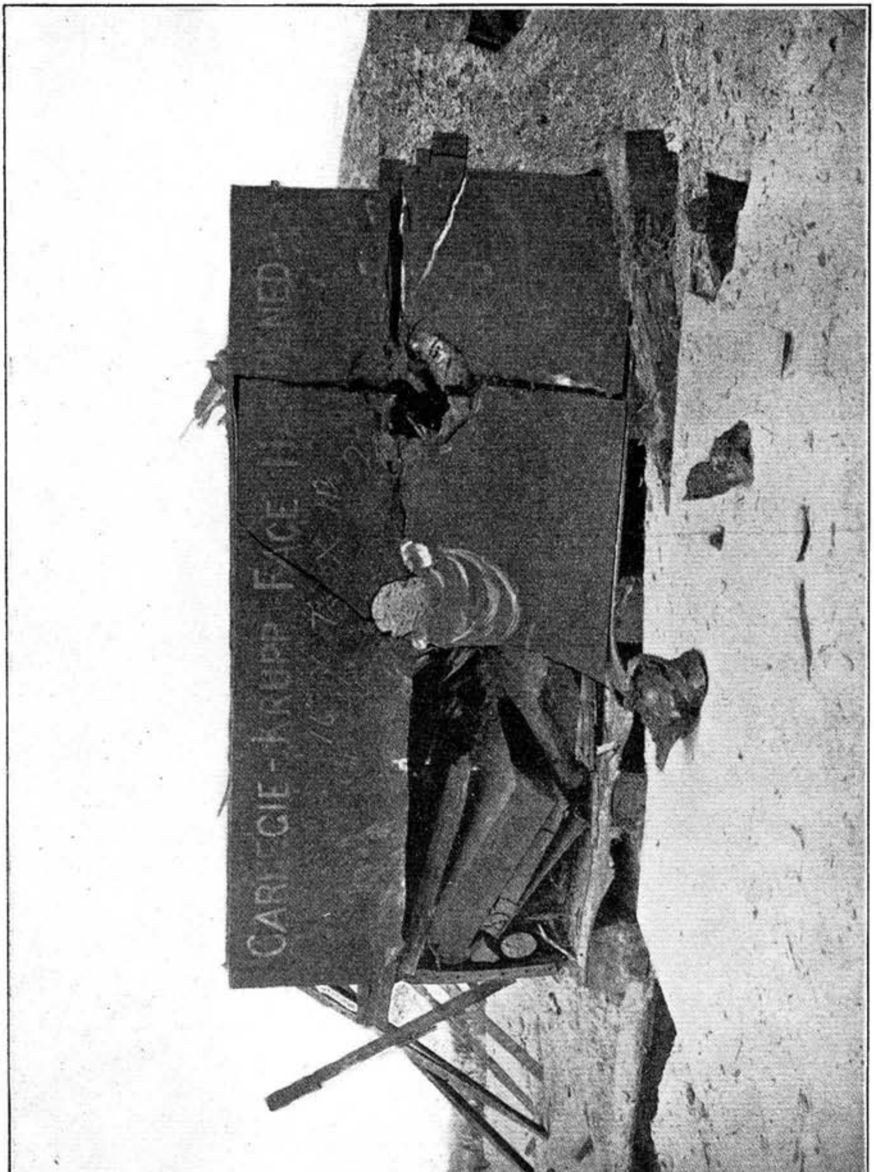


12-INCH ARMY SERVICE RIFLE TARGET. FIRST ROUND. Back of Plate.

12-INCH ARMY SERVICE RIFLE TARGET. SECOND ROUND.

Front of Plate.

12-INCH ARMY SERVICE RIFLE TARGET. SECOND ROUND. Back of Plate.



12-INCH ARMY SERVICE RIFLE TARGET. THIRD ROUND.

Front of Plate.

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into six large fragments and numerous small ones, the largest being about 4½ feet square, which, with the backing and skin plates, was torn loose from the structure and turned inward, so that the left-hand edge of this fragment was in the plane of the original face of the plate. One large fragment about 2 feet by 2½ feet by 11½ inches, and weighing about 2500 pounds, was hurled through the target, through the butt, and was recovered 135 feet in the rear of the butt. Numerous fragments of the plate and projectile passed through the target structure, through the butt, and were recovered in the rear. The effect of this shot would have resulted in serious injury to a battleship. The comparative harmlessness of the Gathmann shell loaded with 500 pounds of gun cotton when exploded against this plate is referred to in the previous chapter. See Plate V.

15. **The Attack of Armored Ships.**—No academic rules can be laid down as to methods of attacking amored vessels. There are now but two classes of projectiles available, the armor piercing and the common or semi-armor piercing. All the former are now being filled with bursting charges, and the quality is being so much improved that those that will in future be issued to the service will possess the perforating power of the present armor piercing shell and at the same time have sufficient capacity for well-conditioned bursting. Assuming that the object is to explode the shell on the inside of the enemy's vessel, the rule would be to use whatever could accomplish that object. If the enemy is unarmored, semi-armor piercing or common shell should be used. If armored, it may be said in general that the heavier guns with A. P. shell should be used against the most important positions, which would be the most heavily armored, and the lighter calibre guns against the corresponding positions of the enemy. Whether A. P. or S. A. P. shell would be used in the latter case would depend upon the vulnerability of the protection. Of course, if only one type of shell were issued to the service the question would resolve itself into one of choosing what portion of the enemy to attack.

16. **Experiences of Modern Warfare.**—The battles of the Yalu of the China-Japan war, and the battles of the Spanish-American war, afford the only experiences of recent years in which armored vessels have been engaged.

In the battle of the Yalu, the heavy armor of the Chinese battle ships was not materially damaged, and so far as the life of the ships was concerned, they were effective at the close of the battle.

At the battle off Santiago, between the Spanish armored cruisers Maria Teresa, Oquendo, Viscaya and Colon, and the United States fleet, the Spanish cruisers, except the Colon, were totally destroyed, not by the piercing of their side armor, but by the destruction of their unarmored parts by the terrific effects of shell fire and by the fires created by bursting shells. The side armor, so far as is known, was not pierced, but the upper works, battery decks and all unarmored parts were riddled and torn to pieces, by the fire of common shell principally, the wood work being set on fire, fire mains and hose cut, the crews demoralized with great loss in killed and wounded; the ships finally being run ashore. The Colon was run ashore and surrendered after being hit but six times without material damage, in her attempt to escape by flight.

The conclusion reached is that there should be greater protection for the gun positions in armored cruisers than obtained in the Spanish ships, that casemates and splinter bulkheads are a necessity, that the chances of penetrative hits on water-line armor, except in very close actions is small, and that wood and inflammable material must be reduced to a minimum in ship construction.

CHAPTER XXXI.

THE PROVING GROUND.

Prepared by LIEUTENANT JOSEPH STRAUSS, U. S. Navy.

1. All guns, gun carriages, ammunition, armor and new devices in naval ordnance are tested at the proving ground before being accepted for the service.

2. **The United States Naval Proving Ground** is situated at Indian Head, Md., and comprises a tract of land of nearly one thousand acres, on the left bank of the Potomac river, about twenty-five miles below Washington. There is a clear range over the water six and one-half miles long.

3. **The Proof of Guns.**—After a gun is completed it is sent to the proving ground and fired five times, with pressures ranging up to one and one-quarter times the service working pressure it is designed to withstand. Thus, a gun which is to be habitually used with a maximum pressure of sixteen tons will be subjected to a final pressure during proof of not less than 20 tons per square inch. The proof velocities must also be correspondingly high, in order that the chase and muzzle may be tested for their ability to withstand high pressures. After proof the gun is stamped with the letter P and the initials of the officer in charge of the proving ground, after which it is returned to the gun factory at Washington.

Every gun manufactured for the naval service is submitted to this proof; in the case of those guns manufactured by private concerns equipped with a proving ground, the proof is conducted by the Inspector of Ordnance attached to the works.

4. **Proof of Powder.**—An "index" of powder is, generally speaking, the largest lot of a single kind of powder that the capacity of the manufacturing plant is capable of blending. Blending houses are usually large enough to mix from 25,000 to 30,000 pounds, and these figures, therefore, represent the weight

of one index. Small arm and machine-gun powders are usually made up into indices of less weight.

After the index is boxed and ready for shipment, a sample of prescribed weight is sent to the proving ground for proof. A careful chemical analysis of the sample is made at the laboratory in order to ascertain whether the stability, percentage of nitrogen, residual volatiles and solubility are in accordance with the specifications. The powder is then fired in the gun for which it is intended, beginning with small charges and working up to the required velocity, unless the proof is halted by the development of pressures in excess of those permissible. For a required velocity the weight of charge used must not exceed a given amount, nor must the pressure exceed that for which the gun is designed. After fixing the charge, a report of the ballistic and chemical qualities are forwarded to the Bureau of Ordnance, upon which the powder is either accepted or rejected. If accepted, an index number is assigned, and this, with the manufacturer's name, date of manufacture, weight of charge, and manufacturer's lot number, is stenciled on the boxes and the index shipped, to a magazine.

5. Proof of Shell.—Two kinds of shell are at present purchased for the Navy: armor piercing and common. The armor piercing are all capped down to and including the 3-inch. The inspector at the factory selects one shell from every lot manufactured, and this is shipped for test. It is fired with a striking velocity (fixed by the Bureau of Ordnance) at an armor plate which is set up at a distance of about 100 yards from the gun. The conditions for acceptance are, that it must completely perforate the plate, no fragment of it to remain in front of the plate.

Common shell are fired at nickel-steel plates having a thickness of half the caliber of the shell, with just sufficient velocity to get through. They must completely perforate the plate without sustaining any fracture that will open up the shell cavity. After this test, the shell is loaded with fine-grained black powder and exploded in a suitable chamber. If the fragmentation is satisfactory, the lot is accepted.

6. Cartridge Cases.—One case out of every lot of 100 is proved by firing it six times with service pressures, after which it must be in perfect condition. It must enter and extract easily during and at the end of the proof.

7. **Fuzes.**—Minor calibre fuzes are fired against a 3-16-inch plain steel plate and must not have more than a fixed per cent of failures to a lot. Larger calibre fuzes are fired against a ⅝-inch steel plate under similar specifications. Both fuzes must withstand a drop from a height of 30 feet when inserted in blind shell, without arming.

8. **Shell Powder** must be well incorporated, clean and free from dust, and exhibit a proper glaze. It is tested in small-arms for velocity.

9. **Armor.**—Face-hardened armor is tested by firing armor piercing projectiles against it with normal impact. The plate is always backed with 12 inches of oak backing secured to two ⅝-inch skin plates by armor bolts spaced at normal intervals. It is set up against the target structure at a distance of about 100 yards from the gun. The velocity of impact and calibre of shell are fixed with reference to the state of the art of armor manufacture, and the plate must be able to resist a given number of blows without developing through cracks or permitting any shot to penetrate through the skin plates.

Protective deck plates are of nickel-steel and are set up so that the projectile strikes them at an angle of from 7 to 9 degrees from the tangent to their surface. The plate must not fracture under the single blow delivered.

10. **Ranging Guns.**—The powder charge is carefully ascertained a short time before the ranging is to be conducted, in order to eliminate any changes in velocity that may have occurred since the last proof of the powder. The gun is laid at an exact angle of elevation of $1°$ and trained on a fixed mark and fired. The fall of the shot is plotted from observations, with the theodolite and plane table, made by observers stationed at various points down the range. This operation is repeated at $3°, 5°, 7° \ldots 15°$, and back again through the same angles. The height of tide is noted in order to reduce the height of gun above the water to zero. The barometer, temperature, direction and force of wind are also recorded, although, if possible, the ranging is conducted in calm weather. After plotting all of the shots

and reducing the range for each to a normal temperature and barometer, these ranges are plotted on section paper and a smooth curve drawn through the positions. This curve then forms the basis for the range-table. A drift curve is also plotted from the position of the shot on a horizontal plane. The "jump" of the gun on modern carriages is inconsiderable or variable, and is measured by firing the projectile through a paper screen.

11. **Instruments Used at the Proving Ground.**—For velocity work, three Boulengé chronographs are used. A separate circuit and screen are provided for each instrument. The Boulengé chronograph is operated, briefly, in the following manner: Two electro-magnets are each provided with a separate circuit which are cut in turn by the passage of the projectile. The wires that are cut are placed 30 meters apart; when the first circuit is broken a metal rod is dropped from the first magnet and when the second is broken a weight drops from the other magnet, which releases a knife that springs out laterally and cuts a nick in the first rod which is still in the act of falling. Before firing, a datum point is secured by breaking both circuits at the same time with a suitable key; the distance between the datum point and the second nick furnishes a measure of the elapsed time between cutting the first and second circuits. From this time the mean velocity of the shot is calculated, and for all practical purposes represents the remaining velocity at the middle point between screens. A correction which reduces this velocity to the muzzle of the gun is readily taken from the ballistic tables.

12. In order to insure the cutting of the circuits, each wire is arranged in the form of a screen, the mesh being continuous and parallel at a distance apart depending on the calibre of the shot. The triple screens are placed a few inches apart, the first of a set being exactly 30 meters from the first of the second set. The use of three chronographs permits the selection of the most probable result in case the results vary.

13. **Schultz Chronograph.**— Besides the three Boulengé chronographs, a Schultz chronograph is used for time measurements where more exact results must be obtained, such as velocities of recoil and counter-recoil, or in any case where several consecutive intervals must be measured.

This instrument consists, essentially, of a nickel plated cylinder revolving by means of a falling weight, and the rotation of which is controlled with more or less constancy by means of a fan which is in gear with the mechanism: a stylus is fastened to one prong of a tuning-fork and the turning-fork kept in vibration by means of a small electro-magnet, much in the same manner as electric trembler bells are arranged. The breaking of an electric circuit is the means employed to mark successive intervals of the measurement, the break causing a spark to leap across from a point near the stylus on the tuning fork to the metal cylinder, the latter having been coated lightly with lamp black just before the measurement is to be made. As the cylinder revolves and the tuning fork vibrates, a wavy line is traced on the surface and each spark is marked on the line by a small bright dot whenever the current is broken.

The speed of vibration of the tuning-fork is nearly constant and equal to about 250 a second. The distance between two sparks in terms of the vibrations would then measure N.004 seconds. By means of a magnifying glass and micrometer N may be measured quite accurately to $\frac{1}{100}$ thus permitting the determination of time intervals of $\frac{1}{25000}$ of a second.

14. **For the Ranging of Guns** it is necessary to employ the following instruments: 1. A gunner's quadrant, which consists of a level which is hinged at one end, the other end sliding on an arc and provided with a tangent screw and vernier. The movable end is tilted up to the required angle and clamped and the quadrant is then placed on some part of the gun or carriage that is parallel with the axis of the bore. The gun is now elevated until the bubble in the level comes back to the center, and the gun is then at the elevation required.

2. Theodolites or plane-tables for plotting the fall of shot as they strike the water. 3. A stop-clock which measures tenths of seconds to record the approximate time of flight of the projectiles.

15. **Pressure Gauge.**—The pressure gauge consists of a cylinder of steel closed at one end with a screw plug and copper washer, and made strong enough to resist great collapsing pressure. Into this cylinder is loosely inserted a circular prism of

copper, with its base resting against the closed end. Into the other end a solid piston of steel is inserted and just presses against the other base of the copper prism. This steel piston is not packed in any manner, but is made to fit the cylinder with great nicety. A cupped disc of thin copper is gently pressed into the open end of the cylinder and serves to prevent any gases from flowing through beyond the piston. These gauges are of two kinds: those which screw into the mushroom of the breech mechanism, called mushroom gauges, and those which are dropped into the bottom of a cartridge case before the powder charge is put in, called cylinder-gauges. Before inserting the prism, its length is carefully measured by means of a micrometer caliper, and after the gun is fired it is again measured, the diminution of its length furnishing a measure of the pressure it has been subjected to.

The area of the prism is, for all guns down to the 6-pounder, 1/6-square-inch; for guns below that calibre, prisms having an area of 1-30 square-inch are used, as the larger gauges would seriously alter the apparent density of loading where the chamber is so small.

For pressure measurements up to 9 tons, copper prisms are made 1/2-inch in length. At the Naval Gun Factory, where they are made, sample prisms of that length are gradually shortened in a testing machine, and the pressure corresponding to a given shortening noted from time to time, from which data a table is constructed which is used with that lot of prisms at the proving ground. For pressure measurements above 9 tons, prisms that have already been subjected to that pressure are used.

CHAPTER XXXII.

SUBMARINE MINES.

NOTE.—Much of the information in this chapter was taken from Bucknill's "Submarine Mines and Torpedoes," and from Armstrong's "Torpedoes and Torpedo Vessels."

1. **Definition.**—A submarine mine may be defined as a charge of explosive confined in a strong case moored beneath the surface of the water in rivers, channels, and sometimes in outer roadsteads for the purpose of preventing or delaying the passage of hostile ships. The charge need not necessarily be so powerful as to completely shatter a ship, but its explosive effect should be sufficient to blow a hole in a double bottom and sink any ship that strikes, or passes near, the mine.

Mines are of several different classes. Each class has its peculiar uses, and the class to be used and the weight of the charge to be employed, depend upon the time and facilities available, the depth of water, the rise and fall of the tide, the strength of the current, and other conditions that may exist at the port to be defended.

2. **History and Development.**—Submarine mines were first used with effect by the Confederates during the Civil War, 1861-1865, and, notwithstanding the crude and imperfect appliances at that time, and the use of gunpowder, which was often rendered harmless by the leakage of mine cases, more than thirty ships were destroyed or seriously damaged by these mines.

Noting this fact, European nations took up the subject and began extensive experiments which have resulted in a steady development and improvement of submarine mines. This auxiliary method of harbor defense is now of great importance.

3. **General Abbot's Experiments.**—General Abbot, Corps of Engineers, U. S. Army, contributed greatly to the knowledge regarding submarine explosions, and his report to Congress giving

the results of his exhaustive experiments at Willets Point is regarded as a classic.

4. The Oberon Experiments.—In England, an important series of experiments was conducted by exploding mines of different sizes, and at various distances, against the hull of H. M. S. Oberon, a large number of crusher gauges being used to record the pressure of each explosion in order to discover a law connecting the pressure with the weight of the charge and the distance of the latter from the ship.

5. As a result of the Oberon and other experiments, various opinions have been advanced as to the pressure necessary to destroy or blow a hole through the double bottom of a modern ship. Some authorities put this pressure as low as 6000 pounds per square inch; but Colonel Bucknill, who was a member of the "Committee on the Experiments against H. M. S. Oberon," expressed the opinion that the pressure required is nearer 12,000 pounds per square inch. Considering the increased strength of modern ships, Colonel Bucknill's rule would be the safer one to adopt.

6. Explosives for Mines.—High explosives have replaced gunpowder, and are now exclusively used for submarine mines. Their explosive action is not seriously affected by moisture, leakage of the mine case is not so liable to render them ineffective, and they are from four to six times as powerful as gunpowder.

Gun-cotton and explosive gelatine are preferred, and the former, being extensively employed for military purposes, is more generally used for submarine mines, though it is not quite so powerful as gelatine.

7. Destructive Radius.—As a result of a careful study of submarine experiments, several formulæ have been proposed to determine the distances at which different charges of the various explosives would be effective against a double bottom. It is evident that such a formula can only be approximately correct; but an approximate rule may be useful. Assuming that a pressure of 12,000 pounds per square inch will be fatal against a modern ship's bottom, the following rule may be used to obtain the distances at which mines containing gun-cotton should be effective:

For distances between 20 and 50 feet from the ship's bottom, multiply the distance in feet by 12 to get the effective charge in pounds; for distances less than 20 feet, multiply by 8. Thus at 30 feet, 360 pounds, and at 10 feet, 80 pounds of gun-cotton would be effective against a double bottom. Or, given the weight of the charge in pounds, to find the distance at which it will be effective, divide the weight by 12. Thus, 480 pounds would be effective at about 40 feet.

It is recorded that in an experiment conducted by Danish naval officers, 660 pounds of gunpowder, exploded at a distance of 24 feet, tore a hole 100 feet square in the outer bottom of a ship and sank the ship. Assuming gun-cotton to be about four times as powerful as gunpowder, 170 pounds of the former would have produced the same result. The rule stated above would give between 200 and 300 pounds of gun-cotton for a distance of 24 feet, and it would appear, therefore, that the rule gives an ample charge.

8. Classes of Mines.—Submarine mines are of two general classes:

(a) Buoyant mines.

(b) Ground mines.

Buoyant mines are moored to the bottom so that they may be held above their anchors a certain distance beneath the surface of the water. Ground mines rest directly upon the bottom, where they should be securely anchored.

9. Buoyant Mines.—There are several kinds of buoyant mines, as follows:

(1) Contact mines.

(2) Electro-mechanical mines.

(3) Electro-contact mines.

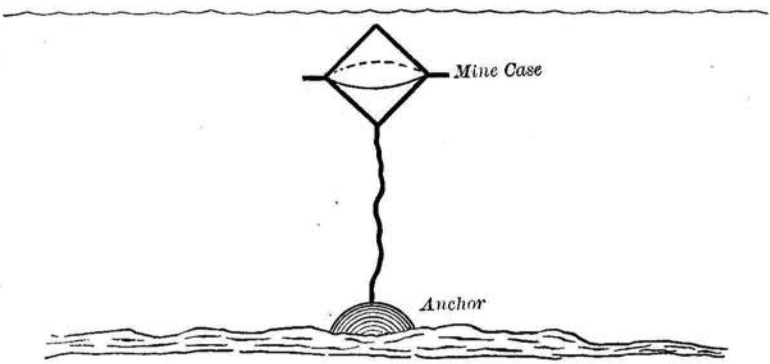
(4) Observation mines.

The different kinds of buoyant mines will be briefly described in the order named, which is the inverse order of their safety and effectiveness.

10. Contact Mines.—The contact mine is the simplest and crudest form of submarine mine. It consists of a strong water-tight case containing the charge, moored at a certain depth below the surface of the water, the case having a number of projecting levers or firing pins, which, if struck by a passing vessel, may be driven in, thus exploding the charge by direct percussion and in immediate contact with the vessel's bottom. Such were the mines used by the Confederates during the Civil War.

It is evident that contact mines are dangerous alike to friend and foe, and should only be used, therefore, where other and safer forms are not available. The firing pins, or levers, have often been rendered ineffective by the adhesion of barnacles, or by other causes, as was the case with the Spanish mines at Guantanamo. Leakage may destroy a percussion primer and thus prevent explosion, even when the firing pin is driven in.

SURFACE OF THE WATER.

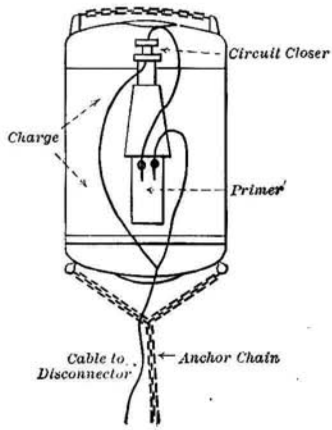


CONTACT MINE. PAR. 10.

11. Electro-mechanical Mines.—The electro-mechanical mine is a modification of the ordinary contact mine in which, instead of firing the charge by a percussion primer, the firing pin (or any other form of circuit closer) completes the circuit of a firing battery carried within the mine case. This form may be rendered somewhat safer in handling, and more certain of action, than the percussion form of contact mine, but when once moored it is equally objectionable in that it is under no control from the shore.

12. Electro-contact Mines.—The electro-contact mine differs from the electro-mechanical mine only in having the firing battery on shore instead of at the mine. This brings the mine under control from the shore and removes one of the great objections to contact mines. When hostile ships are not in the vicinity, the firing circuit may be broken at the shore station so that an accidental blow will not fire the mines, and a friendly ship may pass in safety. When the enemy appears, the firing circuit may be closed at the shore station and the mines will then be operative upon contact.

13. **Laying Electro-contact Mines.**—To reduce the number of firing batteries and electric cables as much as possible, electro-



ELECTRO-CONTACT MINE. PAR. 12.

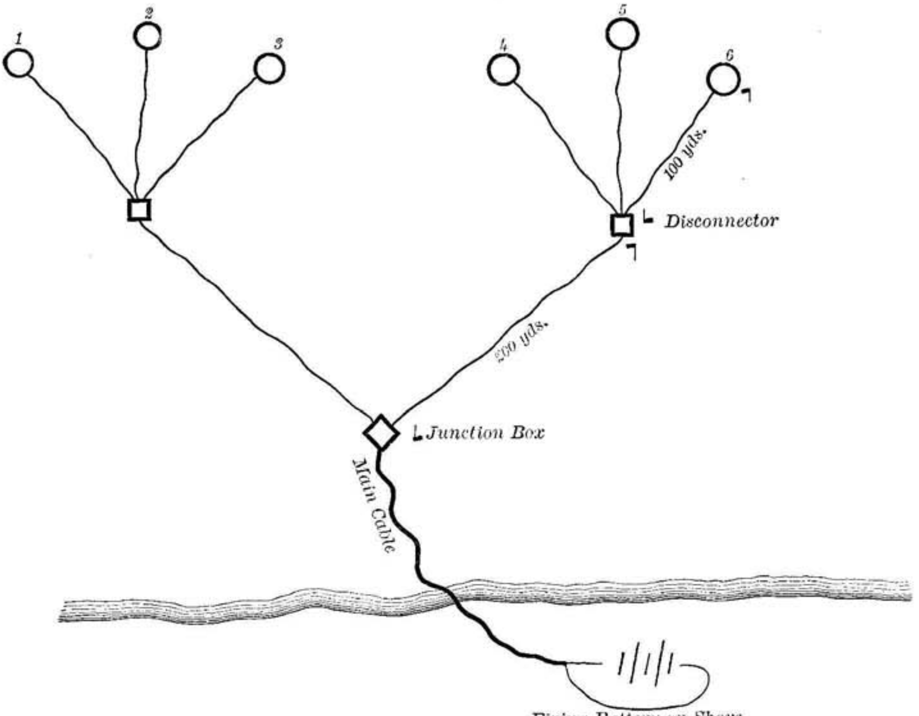
contact mines should be laid in groups of three or more, as shown in the sketch.

Three or more mines may be joined by electric cables to a disconnector box 100 yards distant, and two or more disconnector boxes may be joined by 200-yard lengths to a common junction box, the main or group cable leading from the junction box to the firing battery in the station on shore. By means of the disconnector a mine which has been fired or destroyed may be cut out.

14. **Anchors.**—Mushroom anchors are preferred for all kinds of submarine mines.

15. **Firing Electro-contact and Electro-mechanical Mines.**—Instead of using projecting levers or firing pins to fire electro-contact and electro-mechanical mines, the firing circuit may be

closed at the mine by a rolling ball, or by mercury contained in a cylinder. When the mine is tilted through a certain angle, or is struck with sufficient force, the ball or the mercury will rise in the cylinder, complete the circuit and fire the mine. This form of circuit closer renders electro-mechanical and electro-contact



GROUPS OF CONTACT MINES. PAR. 13.

mines much more certain of operation, because there are fewer holes in the mine case and less chance of leakage than with projecting firing pins or levers; and rust or the adhesion of barnacles will not cause failure.

16. Contact Buoys.—Instead of placing both the explosive charge and the circuit closer in a single case, it is usual and preferable in all forms of electrical mines to place the circuit closer