Ordnance - Manufacture

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CONFIDENTIAL

Section 7
Envelop 4

Year 1907

No. 66

Author Birnie, Rogers, Lt. Colonel, Ordnance Dept. U. S. Army.

Contents The Construction of Heavy Ordnance. Lecture delivered July 30, 1907 to Conference of Officers.

DECLASSIFIED IAW DOD MEMO OF 3 MAY 1972, SUBJ: DECLASSIFICATION OF WWII RECORDS

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Ordnance

THE CONSTRUCTION OF HEAVY ORDNANCE.

1. In the history of the Construction of Ordnance, this is the era of the built-up steel gun which began in this country twenty-five years ago. This period has been a very remarkable one. Never before, we believe, was the science of gun-making so thoroughly exploited nor was such a tremendous advance in power of the weapon accomplished since gun-powder was first used as the propelling charge. The principles of construction indeed seem to be so well established that they constitute a well marked line of development and enable the true and the false to be distinguished so that we are now enjoying a freedom from that agitation regarding a capable type of gun, which in the memory of many of us seriously jeopardized the national defense. This is not to say that we have reached perfection or that the future may not produce something better, but we congratulate ourselves upon the existing powerful armament of our ships and forts, composed of guns equal at least to those of any other nation, which we are able to build in plenty, and at the present day it appears that in so far as the type of gun alone is concerned the only apparent demand or opportunity for improvement is in respect to quality of metal and especially such as will diminish the erosion due to firing. Also the gun-maker may reasonably look to the powder-maker for assistance in this matter.

2. In 1883 the Navy was testing its first steel gun which, originally designed under Commodore Jeffers, had then been lengthened to 30 calibers, and in that year Commodore Sicard to whose able administration the Navy owes so much for the speedy development of its modern ordnance, presented plans for high-power guns of 5, 6, 8 and 10 inches caliber. These plans were in part for wire and in part for the hooped construction, but the latter prevailed in the subsequent development. In the same year also the Army Ordnance Bureau procured the forgings for the first modern 8-inch steel gun of the sea-coast fortifications, and put out orders for an additional 8-inch and a 10-inch type gun.

3. The difficulties encountered in the inception of the manufacture of the steel guns were many but could be reduced to two principles ones; first, the procurement of a suitable metal for the guns, and, second, the obtaining of the necessary legislation for making them. The second, I believe, applied with more force to the Army than to the Navy. The responsible officers of both services were equally satisfied that forged steel in the built-up construction was the proper metal to use and the convincing argument for the Navy was the limit of weight to be carried on ship-board while for the sea-coast fortifications it was said there is no restriction of weight and you can use cast-iron or cast-steel or combinations of metals which are within the resources of the country. At that time the steel manufacturers in this country had no experience

in making the quality of steel required and were wholly unprepared to undertake the work. The specifications for steel forgings which were put out by the Departments in 1883 happily resulted in establishing the manufacture of a suitable quality of gun steel in this country and presently removed this difficulty, but it was not until 1887 that the best public opinion, that is, of the Mechanical Engineering profession outside of the Departments, became satisfied at least of the reasonableness of the demands made by ordnance officers in respect to the quality of steel best suited for gun construction.

4. One of the most important factors in shaping this professional opinion was the discussion on Mr. Dorsey's paper entitled "Steel for Heavy Guns," before the Naval Institute at Annapolis, which is published in the proceedings, Vol. XIII, No. 1, 1887. Mr. Dorsey's advice to use "the ordinary mild steel of commerce" having a tensile strength of about 60000 pounds per square inch for making guns was ably supported and the great benefit of the discussion was the opportunity it afforded for acquainting the public with the real work then in progress in the Departments and successfully establishing the proposition that a much better quality of steel, possessing a high elastic limit, was required for making guns and moreover that it could be produced by steel-makers in our own country. An echo of this discussion from a prominent steel-maker who opposed the views of ordnance officers at that time was given in a letter written as late as January 1906, in which he said:

"When the built-up steel guns were adopted by the Ordnance Bu-"reaus I opposed them seriously, believing that a steel gun "cast on the Rodman principle would be better and cheaper. I "am satisfied now that I was mistaken."

5. The establishment of our present sea-coast defenses dates from 1888, since in that year, taking as a basis the Report of the Board on Fortifications and other defenses in 1886, popularly known as the Endicott Board, Congress began to make the liberal appropriations for guns for sea-coast defense which have since been continued with the result that the heavy gun armament of all our important home ports on the plans existing prior to the report of the National Coast Defense Board convened by order of the President January 31, 1905, was practically completed several years since.

6. The present scheme for sea-coast fortifications is embodied in the report of the National Coast Defense Board dated February 1, 1906. This was a joint board composed like its predecessor of officers of both services with the Secretary of War (Mr. Taft) as president. The report of the board gives a very succinct and valuable view of the changed conditions of the question of national defense occurring during the period from 1886 to 1906 and of the improvements in means of defense. During this period we had acquired Hawaii, the Phillipine Islands, Guam and Porto Rico, the right to establish naval bases in Cuba and also the care of the Isthmus of Panama and its canal. The Board recommended strong defenses at Guantanamo, Subic Bay, Manila, Pearl Harbor, and entrances to Panama Canal; also de-

fenses at San Juan, Guam and Kiska Island, at all of which places naval bases are included. In the matter of home ports the board attached special importance to an increase in the armament of the existing defenses at the eastern entrance to Long Island Sound and in Puget Sound and the completion of the defenses of Chesapeake Bay entrance. As regards the accessories the board has reviewed the modern system of range finding, fire control and direction, the use of search-lights and the introduction of electrical appliances, which together with submarine mines and torpedoes now form so important a part of the system of sea-coast defense. The calibers of guns recommended as adequate for the armament are 3-inch, 6-inch, 10-inch, 12-inch and 14-inch. It is refreshing to note that the number of calibers has been so minimized with resulting simplification of the service and equipment. The 6-pdr. gun and calibers of 4, 4.7 and 5-inch are omitted. Recognition is properly given, it is thought, to the need of a heavier projectile than the 6-pdr. for use against torpedo boats and in the protection of mine fields and the 3-inch R.F. gun firing high explosive shell and shrapnel of 15 pounds weight is the minimum caliber assigned for the purpose. It will be understood, however, that mobile guns of lighter caliber will be used for land defense of the fortifications, including defense against landing parties.

7. A most interesting feature of the recommendations of this board is the increase of the maximum caliber of gun from

12 to 14 inches. Twenty-seven of these guns are proposed for four localities where wide channels exist to be defended. The board gives the following reasons for adopting the 14-inch caliber:

"A demand for heavier armament and better armor protection "has led to a marked increase in the tonnage of battle ships. "Battle ships of 18,000 tons and upward, mounting twelve to "fourteen 12-inch guns, with a great increase in armor protec-"tion, have been projected. Land guns must keep pace with such "advance.

"Our latest 12-inch coast-defense gun has an initial veloc-"ity of 2,550 feet per second and a muzzle energy of 47,299-foot "tons. With this energy the 12-inch armor of the latest type "of battle ship can be penetrated with normal impact at 8,700 "yards, and the 7-inch armor at all fighting ranges. But in "developing this energy the high temperatures due to smokeless "powder and the great increase in the volume of gas produce an "erosion which materially shortens the life of the gun. There "is little to warrant the hope that any material improvement "will be speedily effected in the manufacture of either steel "for gun construction or in powder to overcome this erosion. "It is considered unwise to tax the 12-inch gun to such an ex-"tent, as the high velocity entails, for the protection of the "wide channels that exist at the entrances to Long Island Sound, "Chesapeake Bay, Puget Sound, and Manila, if by increasing the "caliber of the gun an equal or greater fire effect can be se-"cured by employing a diminished velocity which will not sensi-"bly impair the life of the gun. Such an increase in the cal-"iber means a large increase in weight of gun and carriage, a "consideration of little moment in land defense, but prohibi-"tive for use on battle ships.

"The 12-inch gun can now fire two aimed shots in less than "a minute, manual labor being used for loading and operating the "gun and carriage. It is believed that this rate will not be ma-"terially diminished if the 14-inch gun mounted on a disappear-"ing carriage of the same type as that now employed for the 12-"inch gun, loaded and operated by the same means, be adopted. "For the 16-inch gun, however, mechanical devices must be re-"sorted to for loading and operating, a very decided disadvan-"tage. The cost of the 14-inch gun with the required energy is "but slightly in excess of the cost of the 12-inch gun with an "equal energy at 8,700 yards. For these reasons the Board re-"commends the adoption of 14-inch guns mounted on disappearing "carriages for the defense of the channels above enumerated. "The 14-inch projectile will carry a bursting charge of high ex-"plosive more than 50 per cent in excess of the charge of the "12-inch projectile."

8. The 14-inch gun here referred to has been designed for 2150 f.s. initial velocity, with a weight of 49.5 tons or approximately the same as the existing 12-inch rifle. There is good reason therefore in the claim that it can be operated by the same means now employed for the 12-inch, by hand power if desired, and with nearly the same rate of fire. The only reason urged against the 16-inch gun is that mechanical devices must be resorted to for loading and operating. This latter statement may be admitted, although the 16-inch gun can be readily loaded by hand, as has been done. A 16-inch gun has been successfully b built and tested for a muzzle velocity of 2350 f.s. and no doubt is felt as to the practicability of the construction. A comparison of elements for the two calibers based on 2150 f.s. muzzle velocity shows the following:

	14" gun	16" gun	. Increase in favor of -	
			16" %	14" %
Weight of gun - - - - - - - tons	49.5	74.		
Weight of projectile - - lbs	1660.	2400.		
Muzzle energy - - - - - - ft-tons	53260.	77000.	44.6	
Remaining velocity at 8000 yds. f.s.	1510.	1560.		
Energy at 8000 yds - - - ft-tons	26280.	40540.	54.5	
Bursting charge, Explosive D, lbs.	96.	140.	45.8	
Limiting range to perforate 12" Krupp armor:				
Normal impact - - - - - yds.	8700.	12050.	38.5	
35° impact - - - - - - "	5500.	8300.	51.0	
Rate of fire, rounds per hour	36.	30.		20
Probable life of gun, rounds	200.	175.		14
Cost of gun & carriage, $	132000.	192000.		45

The cost of the 16-inch gun including emplacements and ammunition, estimating for the life of the gun, may admittedly exceed that of the 14-inch by 50% or more, but for the limited number of guns involved this is not a serious objection. To offset this there would be, for example, 54% greater striking energy with the 16-inch at 8000 yards (about 4.5 miles) range combined with 46% greater bursting charge of high explosive. The 14-inch has the same measure of penetration at 8700 yards as the 12-inch model of 1900 with 2550 f.s. muzzle velocity which it is designed to supplant. The great majority of hits upon the heavy armor of battleships will be at oblique impact for which the 16-inch gun affords none too much power and it is to be regretted, I think, that advantage was not taken of this opportunity to place it instead of the 14-inch caliber in the sea-coast defenses.

9. The inception of a gun involves first of all a definition of its power, which is usually measured by the penetration it must give in standard armor at a given range. The object of the designer will then be, as a rule, to design a gun of minimum weight for the purpose, compatible with the strength of his available material and the characteristics of the powder to be used for the propelling charge. The penetration will depends upon the caliber and weight of projectile and the muzzle velocity selected. The weight of projectile depending upon the caliber will be proportional to the cube of the caliber based on the weight established for some service caliber. The choice of caliber and velocity allows considerable latitude. Higher ve-

locity and lighter weight of projectile go with the smaller caliber. The advantages of this are a flatter trajectory and greater danger space with a relatively high figure of merit for penetration up to medium ranges. The disadvantages are the diminution of bursting charge and racking effect as compared with the larger caliber and heavier projectile and the relatively greater decrease in remaining velocity and energy with the range. For naval combat it has generally been sought to secure the advantages of a high muzzle velocity (using even a relatively light weight of projectile for the caliber) as best adapted to short and medium ranges, while in the coast guns it is preferred to favor the power of the gun for action at the longer ranges.

10. With respect to the velocity, a year or two since it was the aim of every designer to secure increase of power by increasing the muzzle velocity. The tendency to this was carried so far that in two experimental 6-inch wire-wound guns presented for test in 1905 a velocity of 3500 f.s. was contemplated in the designs. Not only in these guns but in the recent models of service guns designed for more moderate high velocities we have learned that the erosion and wear of the gun produced by these high velocities with their accompanying large powder charges are prohibitive, since the accuracy life of a gun may become so shortened that it would not be good for perhaps more than one prolonged engagement. Therefore, with the best powder and the best gun steel now available it is deemed wiser to revert to lower velocities and use the alternative means of increasing the power

by employing a larger caliber of gun. This does not necessarily increase the weight of gun since the decrease in velocity enables the larger caliber gun to be made proportionally shorter and the same or even a less weight of powder charge may be used in the larger caliber. Length in calibers of bore however has the marked advantage of lowering the maximum pressure required for a given muzzle velocity and it would be well to admit a certain increase of weight for the larger caliber to provide a real amelioration of erosive conditions.

11. The designer will next combine the studies of initial velocity, caliber, length of bore, capacity of powder chamber, powder charge and travel of projectile to lay down the interior dimensions of the gun and construct the curves of velocity and pressure in the bore, using the formulas applicable to interior ballistics. As interior ballistics and powder each constitute a distinct branch of the general subject other than that which I have to discuss, namely, the construction of the gun itself, we will assume that the curves referred to have been established and may proceed to construct the gun around the imaginary bore with sufficient strength to conserve it. I propose then to comment upon some of the features of construction of the built-up steel gun derived from theory and practise which appear to be of current interest.

12. A gun is essentially an instrument of precision which requires at least a sufficient elastic strength in all its parts to resume its original dimensions after the displacement that is produced by the forces engendered in firing. All cal-

culations must therefore be based upon the elastic limit of the metal. The typical structure of the body of the built-up, forged steel gun comprizes a tube, jacket and hoops assembled by shrinkage and with dimension of parts sufficient to give a fair margin of elastic strength. The tube is the core of the structure which extends thru the length of the bore; it has to withstand the strains due to forcing the projectile thru the rifling and affords the main dependencefor longitudinal stiffness in the portion in front of the jacket and its thickness is chiefly regulated by these conditions. The jacket covers the breech portion of the tube, extending forward to or beyond the center of gravity of the gun, thus affording longitudinal stiffness as well as tangential strength; it also extends rearward from the breech end of the tube a sufficient distance to carry the threads that support the breech block and so sustains the pressure on the bottom of the bore, relieving the tube from longitudinal stress due to that pressure. The jacket must have at least sufficient area of cross section to sustain the pressure on bottom of bore; it is also subjected to cross strains in the length between the breech of the tube and the first thread of the breech and to provide ample longitudinal strength the area of cross section of jacket in the critical plane is usually made to give a factor of safety of about 3 on the elastic strength. For guns of 6-in. caliber and upwards it is deemed proper to apply hoops over the whole length of the gun with one or two layers over the powder chamber and portion of bore subjected to the maximum powder pressure, depending upon the caliber of gun. Where two layers of hoops are applied their thickness is determined by the rule that the middle radius shall be a mean proportional between the inner and outer radii of the hoop thickness, as this gives the condition for maximum tangential resistance. The tangential resistance of the gun will be regulated by the powder pressure in the bore, consequently the curve of tangential resistance, for a minimum weight of gun, and in general, will be approximately parallel to the curve of powder pressure and above it depending upon the factor of safety given to the elastic resistance. From this it results with present materials that the thickness of wall of gun over the powder chamber becomes about one caliber or a little more and the least thickness, near the muzzle, about three-eighths of a caliber.

13. Under the specifications of the Army Ordnance Department, the minimum physical qualities now required for gun forgings, determined from tensile test specimens, are:

Caliber of cannon,	Forging	Elastic limit pds.sq."	Tensile strength pds.sq."	Elongation %	Contraction %
	Gun (simple carbon) steel.				
Above 3 and under 8-inch	Tube	50000	87000	18.0	35.0*
	Jacket	50000	90000	16.0	30.0
8-inch and over	Tube	46000	86000	17.0	30.0
	Jacket	48000	90000	16.0	27.0
	Nickel steel.				
Above 5-inch	Tube	55000	90000	16.0	25.0
	Jacket	60000	95000	16.0	25.0
Trunnion hoops - gun steel		55000	90000	16.0	20.0
Cylindrical hoops, gun "		53000	93000	16.0	20.0
Hoops - nickel steel		65000	95000	16.0	25.0

* Specimen 2 inches length of stem, 0.505 inch diameter. All others 3 inches length of stem, 0.564 inch diameter.

For breech block and spindles, steel having 75000 pounds elastic limit is required.

The gain in elastic limit of nickel steel for gun forgings is about 30% over earlier standards.

The modulus of elasticity of the steel is about 30,000,000 pounds, and is so used in computations.

14. The principles applied in the construction of a built-up gun go back to Lamé and Barlow's demonstration of the law of resistance of a hollow cylinder to interior pressure and Rodman's demonstration of the benefit to be derived from initial tension in applying this law to guns made of a single piece with interior cooling. Professor Treadwell's treatise (1843) upon the differentiation of the longitudinal and tangential strains and his proposition to increase the tangential strength by hooping were also very much in point. The modern text-books which treat of this subject very fully are based principally upon the works of Virgile and Clavarino who have been followed by Meigs and Ingersoll, Glennon, Fullam and Hart, and more recently, Professor Alger at Annapolis; Bruff, and Lissak at West Point; and Story at the Artillery School, Fort Monroe. The novel and interesting treatment of this subject by Lt. Comdr. Nulton, entitled "Graphic representation of the relation of pressures and shrinkages of built-up guns for the states of action and rest," published by the Naval Institute, 1906, will be found instructive to the student. My own experience led to the use of Clavarino's work which deals directly with the strains produced in the metal by the forces acting, and by an evaluation

of these strains in the direction of the principal axes of resultant strains or stresses, that is, circumferentially, radially and longitudinally, we are enabled to conserve the primary condition that no part of the gun shall be subjected to strains beyond the elastic limit of the metal. We say that the elastic resistance of the cylinder is reached when the aggregate strain in any one of these directions equals that which would be caused in a free specimen of the metal loaded to the elastic limit under a single stress of tension or compression as the case may be. By modifying Clavarino's formulas in relation to longitudinal stress, as a result of shrinkage experiments made for the Army Ordnance Department at the West Point foundry, a set of relations was secured which produced a most satisfactory agreement in actual construction. The formulas were placed in form (Notes on the Construction of Ordnance No. 35, 1885) to discuss fully the forces engendered in building up a gun with cylinders applied by shrinkage and to enable the fidelity of the work to be verified not only in the completed gun but also in the various stages of construction, by measuring the bore of tube and the diameters of successive cylinders when applied. These formulas were further amplified and applied to the computations for different calibers of guns in Notes on the Construction of Ordnance No. 59, 1891.

15. The existing knowledge of these formulas renders unnecessary any extended discussion of them here but drawings have been prepared to illustrate some important applications. Fig. 1 interprets the formulas for the ~~tangential~~ resistance of a simple homogenous cylinder and of a compound cylinder subjected to

an interior pressure. The formulas are:

Simple cylinder $P = \frac{3(R_1^2 - R_0^2)}{4R_1^2 + 2R_0^2}\theta$

Compound cylinder: Tangential resistance $P = \frac{3(R_n^2 - R_0^2)}{4R_n^2 + 2R_0^2}(\theta + \rho)$

Radial resistance $P = \frac{2(R_n^2 - R_0^2)}{2R_n^2 - R_0^2}\rho$

P = the interior pressure per sq. inch that the cylinder will support without exceeding the elastic limit.

R_0 = Radius of the bore and R_n, R_1 radii of the outside surfaces.

θ & ρ = the elastic limits of the metal under extension and compression respectively.

These formulas involve the condition that the resistance to interior pressure is limited by the displacement of the metal at the surface of the bore, where, within ~~the~~ limits of practise, the strain is the greatest. The simple cylinder will fail by tangential extension only. The resistance of the compound cylinder will be proportionate to its initial compression and failure from interior pressure will occur either by tangential extension or radial compression depending upon certain conditions. If we suppose the bore of the compound cylinder to be initially compressed to the limit ρ, with $\theta = \rho$, the curves may be plotted as shown, where the abscissas represent the thickness $(R_n - R_0)$ of the wall in calibers and the ordinates represent the fractional coefficients of the formulas. The resistance increases with the thickness of the wall, but with diminishing increments which become relatively small beyond a thickness of 1 to 1.25 calibers. The limiting values of the interior pressure for an infinite thickness of wall, making $R_n = \infty R_0$, are: Simple cylinder, $P = .75\theta$. Compound cylinder, tangential resistance, $P = 1.5\theta$; radial resistance $P = \rho$. The formulas for the compound cylinder are equally applicable to the built-up sections of the forged steel gun, a wire-wound gun with tube and a gun composed of a single piece of steel with initial tension produced by interior cooling. In wire-wound guns the tube imposes practically the same restrictions as in the built-up forged steel gun, that is, the maximum resistance is limited by the tube which may not be worked beyond its limit of elastic compression at rest or beyond its limit of elastic extension in action. In applying the formula for tangential resistance of the compound cylinder it will be noted that the value to be substituted for ρ must be the actual compression of bore existing in the structure, and the value of P will be proportionally reduced as ρ is diminished from its maximum value which stands for the elastic limit. In practise, with the built-up forged steel gun, it is found that with the larger calibers where the thickness of wall is sufficient to divide into three or four layers little or no tangential resistance is lost by reason of this curtailment in the compression of the bore.

16. The next plate* shows a cross section through the powder chamber of a 12-inch rifle and illustrates the operation of

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* Taken from a paper read before the Congress of Engineers, Chicago Exposition, 1893.

the shrinkages and the pressures and strains which are produced in the state of rest and also in the state of action by applying an interior pressure which will develop the elastic tangential resistance. In fig. 1 the shrinkages are plotted on the right of the median line. On the left of this line we have the positions of the contact surfaces as each successive cylinder is applied, also the corresponding compressions of the bore, and finally the extension of the exterior of B-hoop. The actual changes are much exaggerated in the drawing. The reference (zero) point for each contact surface is the interior diameter of the applied cylinder. In the completed state of the structure the contact surfaces are in the places marked "final position," and the pressures thereon produced are those required in the state of rest. In these positions, as seen from the drawing, the several shrinkage values are made up as follows: The first by the contraction of the exterior of tube minus the contraction of interior of jacket; the second by the contraction of exterior of of jacket plus the extension of interior of A-hoop; and the third by the contraction of exterior of A-hoop plus the extension of interior of B-hoop. Hence the rule*: At each contact surface <u>the shrinkage is equal to the contraction of the exterior of the inner cylinder increased by the extension of the interior of the outer cylinder; as caused by the action of the pressure pertaining to the complete system in the state of rest</u>. At the first

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* Observe that as regards displacements of exterior surfaces contractions will be considered positive and extensions negative, and for displacements of interior surfaces extensions will be positive and contractions negative.

contact surface the interior of jacket is contracted instead of extended; hence the second term is subtractive.

In fig. 2 the pressures and strains are shown for the inner and outer surface of each layer as usually computed and also for intermediate radii for the purpose of determining a third point in the curves pertaining to each cylinder. In the state of action, which supposes a pressure of 23.66 tons acting within the bore, the interior of each cylinder is tangentially strained to the elastic limit adopted, except the jacket, viz: Tube, 18.5; jacket, 15.08 (limit = 19.5); A-hoop, 22.5; and B-hoop, 20.5 tons.

In the state of rest, with no pressure in the bore, the pressures at the contact surfaces fall to 5.25, 4.55, and 2.18 tons, respectively, whilst the stresses and strains are balanced by compressions in the tube and jacket against extensions in the two hoops, the maximum values being: Compressions of 17.98 tons in tube and 2 tons in jacket, against extensions of 14.63 tons in A-hoop and 14.31 tons in B-hoop.

To utilize the full elastic strength of this section of the gun the tube should be compressed to the limit 18.5 tons. A lower limit is, however, purposely taken to provide for reaming out the gun at a future time to insert a lining tube and prevent overcompression when that is done. The present compression (17.98 tons) will be increased to the limit (18.5 tons) if the completed gun is reamed out to a diameter of 16 inches, as proposed for the exterior of the liner when introduced.

17. Plate 3† gives a longitudinal section of the first 8

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† Taken from Gun Making in the United States, Military Service Institution, 1887.

inch built-up steel gun made for the Army Ordnance; it shows the curves of powder pressure, velocity and tangential resistance and also the compression of bore measured in the several stages of assemblage. The final measured compression in the section of the powder chamber where the bore was designed to be compressed to the elastic limit is only about 1% more than the anticipated compression. This drawing is interesting in respect to the shortness of the hoops as first employed in these guns. This was soon changed in future constructions when it was found that the steel-makers could readily produce longer hoops. This gun was at first made without chase hooping. After firing 24 rounds the bore at some 15 inches from the muzzle of the tube was found to be enlarged. It was then chase hooped, which remedied the incipient weakness, and chase hooping has since been applied to all the larger caliber army guns.

18. The manufacture of this gun was preceded by building up and dismantling a full size section of the gun, 8 inches long, through the powder chamber, comprizing tube, jacket and two hoops. The details of this experiment are published in Notes on the Construction of Ordnance, No. 32, 1885. The results were important and led practically to the establishment of the formulas we are now using, which as already stated are Clavarino's formulas, modified with respect to the factor pertaining to longitudinal displacements.

19. Plate 4[‡] illustrates the state of strains found to

[‡] Taken from Notes on the Construction of Ordnance, No.70,1896.

exist in a hollow steel forging subjected, experimentally, to interior cooling to develop so called initial tension and to examine the conditions so produced with reference to the capacity of the cylinder to withstand an interior pressure. The forging was prepared in the usual manner for gun steel and treated by annealing, oil tempering and annealing. In the final annealing, while still in the annealing furnace and uniformly heated to redness, water was passed into and through the bore of the forging until it was cool enough to handle. The strains of tension in the outer part and compression in the inner part of the forging were measured by cutting the several sections into thin concentric rings and measuring the changes on the diameter of each ring due to its release from the forging; these changes giving a measure of the strains induced by the treatment. The shaded areas show these strains, and the ordinates of the bounding curve (broken lines) of the lighter area above the median horizontal line represent the tensions produced in the wall due to the calculated interior pressure which will cause the greatest ordinate to equal the elastic limit of the metal, 60000 pounds. The dotted line curves show the stresses or strains of initial tension deduced by theory to compare with the curves (full lines) of actual strains, starting with one point in common. The degree of coincidence of these two curves in each section indicates the regularity of the strains produced by the treatment. The strains produced in the treatment of this forging were too severe for the best conditions. Duplicates of two of the sections were annealed before cutting into rings, with the result of ameliorating the original strains and improving them as shown in the two lower figures. In one of these (muzzle section) the ideal state, nearly, of initial tension is shown since the ordinates showing the strains or stresses throughout the wall when the interior pressure is supposed acting are nearly equal, that is to say the whole thickness of wall would be worked to the elastic limit. This evidently gives the maximum resistance possible for the cylinder. The law of resistance in a cylinder with initial tension produced by interior cooling is the same as for a built-up cylinder. In the one case it is concerned with the infinite number of concentric laminae that make up the thickness of the wall and in the other with the separate cylinders of given thickness in the wall. In the initial state of a gun or cylinder treated by interior cooling, the interior portion of the wall rests in a state of tangential compression which is greatest at the surface of the bore, and the exterior portion in a state of tangential extension which is greatest at the outside surface. The strains of extension and compression are in equilibrium - the aggregate of the two being equal quantities. There is a neutral lamina in the wall where the tangential strain is virtually zero, and from this locality the compression should increase progressively towards the bore and the extensions likewise towards the outer surface. To make the resistance to interior pressure a maximum, the state of initial tension should be such that when the pressure acts from within, the whole thickness of metal through the walls of the piece should be, as nearly as practicable, uniformly strained to the elastic limit of the metal.

20. With a properly regulated initial tension this method of construction, that is, making the gun of a single forging, gives the greatest possible tangential strength in a cylinder of given dimensions and quality ofmetal. The solid construction is also favorable to longitudinal strength and stiffness, and the method is as a whole most promising.

21. The experiment described gave experience for better regulation of the temperature of the forging and of the cooling operations in subsequent work and this method of construction has been applied to a limited extent in the construction of guns. A 3-inch and a 5-inch gun made of single forgings strengthened by interior cooling have been constructed and tested extensively with very satisfactory results. A number of the tubes for 5-inch rapid fire guns have also been made in this way. The outcome of the process in these tubes has not been encouraging for the continuation of this method in view of the trouble experienced and the number of re-treatments necessary to obtain the degree of initial tension desired. Care and experience in manufacture should be able to control this method and apply it advantageously at least to guns of small and medium caliber. The difficulty to be anticipated with guns of large caliber is in procuring a forging for the gun body in one piece of uniform quality. This is, however, also a question of experience and advancement in knowledge of the art, and quite within the limits of future possibility.

22. A novel application of the gun formulas was recently called for in the case of a field gun where in assembling the jacket with shrinkage on the tube the bore of the tube was compressed much beyond that to be anticipated from the shrinkage although the latter had been correctly applied. It was found, however, that the jacket was elongated in place after shrinkage, instead of being contracted in length as required by theory. Moreover, in ten other guns of the same model under manufacture the jacket was contracted in length on shrinkage and the compression of bore in each of these was very nearly the normal value to be anticipated, as usual, from the diametrical shrinkage alone. It appeared that the heated jacket had gripped the tube longitudinally in cooling during the shrinkage operation and had produced an abnormal longitudinal force in the jacket which reacting upon the tube and at the surface of contact between the tube and jacket had caused an increase of the pressure to be anticipated on the exterior of the tube and consequently an increase in the compression of bore. The question presented for solution was, Could the overcompression of bore be accounted for by the measured elongation of the jacket in place which amounted to .009 of an inch on 38.1 inches.

23. The solution is indicated as follows:

(a) Pressure on exterior of tube due to actual diametrical shrinkage alone, - 3.623 tons sq. inch,

(b) Corresponding anticipated compression of bore of tube - - - - - - - - - - - - 0.0024420 inch,

(c) Actual elongation of jacket in place, .009 ÷ 38.1, - - - - - - - - - - - - - 0.0002368 per inch,

(d)

(d) Anticipated contraction in length of jacket due to diametrical shrinkage alone, - - - - - - - - - - - - - - - - - 0.0000836 per inch

(e) Longitudinal extension of jacket is thus greater than should be for normal conditions in the sum, c+d - - - - - - 0.0003204 per inch,

(f) Estimated contraction in length of tube* due to grip of jacket, the two being in contact and acting as one, inverse ratio of cross section of pieces x e - - - - - - - - - - - - - - 0.0010763 per inch,

Note. The effect of longitudinal extension of jacket is to contract the interior diameter and of longitudinal compression of tube is to expand the exterior diameter; hence both of these factors will act to increase the pressure at contact surface on exterior of tube. Circumferential (radial) displacement will be 1/3 of the longitudinal, then:

(g) Circumferential strains at mid-section caused by longitudinal grip of jacket:
Jacket e ÷ 3 - - - - - - - - - - 0.0001068 per inch,
Tube f ÷ 3 - - - - - - - - - - 0.0003579 per inch,

(h) Corresponding increments in normal pressure on exterior of tube,
0.633 + 2.693 - - - - - - - - 3.326 tons sq. inch,

(i) Corresponding increment in normal compression of bore - - - - - - - - - - 0.002242 inch,

(j) Circumferential compression of free bore of tube caused by longitudinal grip of jacket, g(for tube)x2"9 - - 0.0010380 inch,

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* Under normal conditions the tube being acted upon by an exterior pressure only should be <u>elongated</u> 0.0002807 per inch.

Summing the several values for partial compression of bore to get the total estimated, we have:

(b) Anticipated for the diametrical shrinkage alone	.002442	inch
(i) Estimated, for the abnormal increase of pressure at contact surface on exterior of tube, caused by longitudinal grip of jacket - - - - - - - - -	.002242	"
(j) Estimated for free bore, caused by longitudinal grip of jacket - - - - - - - - - - - - - - - - - - -	.001038	"
Estimated compression of bore, total - - - -	.005722	"
Actual compression of bore - - - - - - - - - - -	.0065	
Difference, actual greater than estimated,	.000778	"

The difference between the estimated and actual compression of bore being less than .001 of an inch shows that the overcompression of bore can be accounted for by including the abnormal effect due to the longitudinal gripping of the jacket in shrinkage.

24. The actual compression of bore in this case was so excessive, being .0065 of an inch instead of .0024 of an inch anticipated, as to indicate that the jacket (outer member of the gun) would be strained to its elastic limit of 65000 pounds per sq. inch by a powder pressure of about 20000 pounds in the bore, whereas the normal value for the elastic resistance of the gun is about 50000 pounds - the gun being made of nickel steel. The conditions were considered dangerous and a suggestion to fire the gun in the expectation that the shock of discharge would "shake" it into shape was negatived on the ground that our knowledge and experience of gun construction is sufficient to indicate the danger of putting such guns in service and that while one gun in this condition might be fired some number of rounds without enlarging it, this would be no guarantee of safety for another gun

or warrant for a precedent. An attempt was made to release the abnormal strains by heating the gun to about 500° F. temperature and allowing it to cool slowly. This resulted in very slight easement of the compression of bore, while the elongation of the jacket was increased to .015 of an inch on 38.1 inches by the operation; a set was apparently produced in the jacket due to its existing state of longitudinal strain. The gun was ultimately dismantled.

25. The principal lesson learned from the test of the two 6-inch wire-wound guns recently made at Sandy Hook and closed after firing 98 rounds from each was the rapid erosion of the bore and evident inadmissibility of attempting to use the high velocity for which the guns were designed. The guns have nearly the same dimensions of bore and similar rifling except that in one the grooves were .04 and in the other .05 of an inch deep - the length of bore is 50 calibers and the powder chamber about 3200 cubic inches capacity. The Brown gun has a double tube, the inner made of forged steel and the outer one a segmental tube composed of long steel plates, 0.15 of an inch thick wrapped to form a cylinder. These together have a thickness of about 3 inches over the powder chamber, 3.5 in front of the chamber and 1.4 at the muzzle. Wire is wrapped over the double tube nearly from the breech to the muzzle with a thickness varying from 3 inches to 1 inch. The wire is of square cross section .02 sq. inch area and was wrapped throughout with a uniform tension of 125000 pounds per sq. inch. The breech portion of the gun is covered by a heavy jacket assembled with a light

shrinkage of .005 of an inch on diameters. The wire on the chase of the gun is covered with a sheet steel envelop 3/16 of an inch thick. The inner tube extends the whole length of the gun including the breech recess where it is threaded to support the breech block, with the assistance, however, of locking and threaded rings coupling the rear end of the inner tube longitudinally with the segmental tube and the jacket. This gun has the usual form of cylindrical, slotted breech block with 4 smooth and 4 threaded sectors. The computed elastic ~~limit~~ resistance of the gun was stated by the inventor to be 64500 pounds per sq. inch. The disadvantages of the means provided for longitudinal strength were shown in the tests; the breech threads were stretched rearwards and caused difficulty in operating the block.

26. The Crozier gun has a single tube somewhat thicker than usual for a built-up gun of the same caliber. The rear portion of the tube extending forward from the gas check seat for a length of about 167 inches, is wrapped with wire in sections of thickness varying from 2.8 inches to 0.8 of an inch. Where the wire wrapping terminates and over the remaining length of 134 inches to the muzzle the tube is reinforced by forged hoops only, which are shrunk on in the usual manner. The wire-wrapped portion of the gun is covered by the jacket with a hoop in front of it, and outside of these are the trunnion hoop and a locking hoop which connects the jacket longitudinally with the chase hooping. All of these outer parts are shrunk on and form

a strong protective outer covering for the wire. The breech block is supported in the usual manner by a breech bushing screwed into the rear of the jacket. Longitudinal connection between the tube and jacket is principally afforded by step rings which are embedded in the wire envelop. The trunnion hoop is held in place longitudinally by shrinkage over shoulders. The wire is of square cross section 0.1 inch on a side and was wrapped with a uniform tension throughout of 47400 pounds per sq. inch. The computed elastic resistance of the gun is 66230 pounds per sq. inch for the chamber section.

27. The breech mechanism is a modified pattern of the 6-inch Bofors mechanism. This was the first gun for which this type of mechanism was manufactured in this country. Its principal features comprize the spheroidal form of breech recess which gives a large threaded area and presents a convenient form of opening for loading and place for a simple automatic loading tray. The block has six threaded sectors. It is opened by continuous movement of the operating handle. Rotation of the block in opening or closing is controlled by a geared slide which at one end engages in the "roller" placed on the hinge pin and at the other end in teeth cut upon the stem of the breech block. A friction roller upon a stud on the breech block follows an inclined groove in the roller and controls the swinging movement of the block; the block is positively locked against turning when closed. The firing mechanism is operated by the slide and carried to the right in opening, leaving the vent uncovered for insertion of primer and is automatically returned when the block

is closed; it can also be moved independently by hand to insert a primer. The mechanism is adapted to the service combination electric and friction primer and for firing both by electric circuit and by lanyard. The primer ejector is an independent lever operated by a stroke of the hand; it combines a spring movement which presses against the primer when the latter is inserted and prevents it from being dislodged by pressure of air due to rapid closing of the block. The first mechanism made for the gun gave trouble on account of the softness of the steel parts. This was remedied in the second mechanism provided. This mechanism withstood the high pressures to which the gun was subjected, without deforming the breech threads, in an admirable manner. The original 6-inch Bofors gun with this type of breech mechanism is shown on Plate 5.

28. The guns were first fired 88 rounds each with pressures limited to about 45000 pounds. The test was completed with 10 rounds of excessive, increasing charges designed to give 66000 pounds in the last two rounds, that is, a pressure about equal to the elastic limit of the guns. Some of the results of the firings may be quoted, viz:

In the first 88 rounds:		Brown gun	Crozier gun
Weight of smokeless powder charge with 100-pounds projectile, - -	pounds	71.	72.25
Pressure for 3325 f.s. M.V., about,	pds.sq.in.	42400.	43400.
Weight of smokeless powder charge with 106-pounds projectile, - -	pounds	69.	71.75
Pressure for 3250 f.s. M.V., about,	pds.sq.in.	43500.	44000.

		Brown gun	Crozier gun
Highest pressure in 88 rounds, -		45130.	47069.
Highest M.V. in 88 rounds,	f.s.	3455.	3533.
In the 10 Excessive Charges:			
Highest velocity (projectile 106 pounds) - - - - - - - - - - - - -	f.s.	3740.	3866.
Highest pressure - - - - - - - - -	pds.sq.in.	63415.	61360.
Average pressure for 10 rounds,	" " "	54662.	55490.

29. Erosion of the bore soon became marked. Tumbling of the projectile in the Brown gun was obviated by 5 changes of the rotating band for trial of different forms or to give increased forcing, after rounds 22, 31, 66, 80 and 88 respectively. In the other gun one band was continued in use until tumbling occurred, which was about round 43. After round 62 an enlarged band of the same type was substituted and used, without tumbling, to the end of the test. The erosion of the bore presented the characteristic hour-glass shape, being greatest near the seat of the projectile, decreasing to a minimum somewhat forward of the middle length of the rifled bore and thence increasing again to the muzzle. A peculiar result shown at the muzzle was an unequal wear of the lands, producing eccentricity. In each gun the lands in a certain section of the bore, but differently located in the two guns, were worn much more than the opposite lands. The final comparison by stargaging after 98 rounds showed the following changes from the original measurements of diameters of the bore:

			Brown gun	Crozier gun
Lands:	At origin of rifling, - - - -	inch,	+.231	+.1935
	About 110" from muzzle, - - -	"	+.010	+.010
	At muzzle, - - - - - - - - - -	"	+.0445	+.053
Grooves:	At origin of rifling, - - - -	"	+.189	+.2435
	About 110" from muzzle, - - -	"	-.007	-.001
	At muzzle, - - - - - - - - - -	"	-.0145	-.0025
Powder chamber - - - - - - - - - - - - - -		"	+.04	+.02

The extent of the erosion in the rear portion of the rifled bore after 98 rounds may be better appreciated by stating that in one gun within 41 inches, and in the other within 57 inches, of the original commencement of the rifled bore, there was none of the original rifling left. The ridges and depressions which remained were due entirely to the erosion which deepened the original grooves at the same time that it wore off the lands. As bearing upon one of the disputed points of causes of erosion it will be noted that if escape of gas past the rotating band be one of the primary causes its effects should have been exhibited here. A flat rotating band was used in the Brown gun. After erosion became pronounced daylight could be seen through the rifling grooves around the band when the projectile was seated. On the other hand a rotating band with large rear lip which always insured forcing to fill the grooves from the beginning of movement of the projectile through the bore, was used in the Crozier gun. Yet under these circumstances the increase of erosion was not more marked in the Brown than in the Crozier gun.

30. The test of these guns, considering the sustained

high pressures, the large powder charges and the projectile energy developed, is without parallel for severity so far as known. It is a high record for wire-wound guns. It does not, however, establish a record for superiority as regards strength over the built-up construction. Proof of this is afforded in the resistance of the chase of the Crozier gun, where 134 inches or 22 calibers of the length from muzzle is simply the hooped construction, with tube and hoops of nickel steel, which withstood the high chase pressures developed quite as well as the Brown gun with wire-wrapping extending to the muzzle. The enlargement of the powder chambers of the wire guns within the wire construction and where no erosion was produced, amounting to .04 inch in one gun and .02 inch in the other, shows that a material permanent set was produced, and there is no reason to believe that if this portion of the Crozier gun had also been built up of nickel steel forgings there would have been a less favorable record for tangential resistance.

31. The subject of gas check pads is one of recurring interest and it has been asserted by some that the plastic pad is inherently defective and that a metallic gas check would be more satisfactory. I do not agree with this, or at least may say that the difficulties in producing a satisfactory metallic gas check appear very great while the defects of the plastic pad are generally remediable. With the metallic pad attached to the block as it would be for convenience in operating, wear or deformation of the gas tight surfaces will give room for an escape of gas with disastrous scoring effect. The Freyre gas

check wherein the thin edge of a steel ring is forced outward against the gas check seat by the powder pressure in the bore by means of a cone fitting on the rear face of the spindle head is correct in principle and probably the most satisfactory form that has been designed. This has been tried in service but relinquished for the plastic form. The sealing ring ought to be actuated as in the Freyre by the interior pressure so that the ring will be expanded with the diametrical expansion of the bore. This expansion in a 6-inch gun, for example, may amount to .016 of an inch or more and in a 12-inch gun to twice as much. Attempts therefore to hold up the sealing ring by means of spring pressure arranged in the breech block in rear of the sealing ring are not admissible.n In the recent trial of such a device at the Sandy Hook Proving Ground, gas escaped around the ring even with reduced pressure in the gun and the gas check seat was eroded at every round.

32. The plastic pad with its steel split rings at front and rear makes a perfect gas closure when properly fitted. The endurance of these pads in service has been variable; some have lasted a large number of rounds and others required replacement after a few rounds. The principal defects are the cutting of the pad cover by the edges of the rings or by the escape of gas past the front ring, and in rapid fire the softening and bulging of the pad by heat and consequent difficulty in working the breech blcok. The cutting effect in the outside of the pad can in probably every case be traced to insufficient thickness of pad which fails to force the front split ring far enough for-

ward in the conical gas check seat to give it a proper bearing. The split ring should be normally about .01 of an inch larger than its proper seat and be compressed that amount when the block is closed. For this reason it is important that the pad be given its full thickness under the heavy compression used in molding to shape in manufacture and the practise that has been followed at times to press the pads to a thickness of about .02 or .03 of an inch less than shown on drawings, to compensate as stated for swelling or expansion which usually takes place during shipment is to be condemned. It will be seen also that a relatively rapid flare for the gas check seat is objectionable since the greater the slope of the gas check seat the more will variations innthe thickness of the pad affect the proper seating of the front split ring.

33. The undue softening of the pads in use heretofore is a necessary consequence of the use of the tallow mixture. Tallow melts at a temperature of about 120° F., which may readily be exceeded in prolonged firing; it is also objectionable in containing oleic acid which acts to rust the metal parts and rot the pad cover. Two varieties of pad composition have been extensively tried with satisfactory results in firings, either of which obviates these objections to the tallow-asbestos composition and either may be used to replace it in service. One is a mixture of so-called "Non-fluid oil" used in the proportion of about 1 part to 4 of asbestos to make the pad. The non-fluid oil is a patented grease, largely derived from petroleum products apparently, made by the New York & New Jersey Lubricant

Co. The grease has a melting point of about 400° F. The pad composition is sufficiently plastic and remained firm after 6 hours exposure to 190° F. The other is designated Sy-George composition, after the names of the inventors. It is a mixture of asbestos with petrolatum and another ingredient. This composition well preserves its consistency under heat, becoming about like that of dough at 338° F. A pad of this composition was subjected to 25 rounds fired in 10-inch rifle within about 31 minutes total time. The pad was 1.9 inches thick through the body with exposed outer surface 1.28 inches between split rings. Starting with the pad rather tightly adjusted and after 12 rounds fired at less than 1 minute intervals, the pad caused some difficulty in closing the block. It was then loosened and remained loose after the 13 additional rounds. The temperature of the spindle head in contact with the pad, after the 25 rounds, was 160° F.

34. Another means of relieving trouble arising from the swelling of pad has been adopted in the 10-inch rifle model of 1900. The thickness of pad through the body has been reduced from 1.9 to 1.375 inches and the exposed outer thickness from 1.28 to 0.375 inches. This thickness has proved sufficient for obturating purposes; it reduces the bulging surface to an extent that has been found to give excellent practise even with the tallow-asbestos composition. The best material for pad covering so far tried is a specially woven asbestos-wire cloth. Selected asbestos fiber is wrapped on a fine wire core to form a close thread which is then woven into cloth and sized with alum-water,

making a firm, pliable cloth free from protruding asbestos fiber, which in the ordinary asbestos-wire cloth, when used as a pad cover, gave trouble by adherence of the fiber to the metal part of the breech mechanism. By rubbing the special cloth with graphite before placing the pad in the gun, no sticking of the cover occurred. This wire cloth was taken up especially with the view of stiffening the pad against bulging when heated, and as a remedy in connection with the use of the tallow-asbestos pad composition. The cloth is expensive and it is expected that the 10-oz. canvas duck cover will be sufficient for service with the improved pad composition.

35. The propriety of increasing the caliber of gun to gain power rather than to increase the muzzle velocity, by reason of the reduction of the life of the gun due to erosion, has been referred to. This subject has been carefully considered in the report of the Chief of Ordnance, U. S. Army, for 1906 ~~1896~~, page 25 ✓ and in Appendix I of that report. The data there collected with respect to guns that had been fired nearly to or beyond the number of rounds deemed sufficient to develop the accuracy-life of the guns shows the following:

Caliber	Muzzle velocity	Accuracy-life,
6-inch	2600 f.s.	450 rounds,
6-inch	3000 "	150 "
6 "	3300 "	43 "
8 "	2200 "	275 "
10 "	2250 "	250 "
10 "	2500 "	90 "
12 "	2250 "	200 "
12 "	2500 "	60 "

This data can be amended with respect to the 10 and 12-inch guns for 2500 f.s. velocity which were then estimated. The firing of guns of this model has since been continued, the 10-inch to 115 rounds and the 12-inch to 77 rounds, and it is found that they will withstand a still greater number of rounds without material loss of accuracy. The estimated life of large caliber guns, with velocity reduced to 2150 f.s., is then shown on Plate VIII of the report approximately as follows: 8-inch, 350; 10-inch, 315; 12-inch, 280; 14-inch, 245; and 16-inch, 210 rounds. Whether these figures will hold good in practise is perhaps questionable. Based on 350 rounds for the 8-inch, however, and considering the erosion proportional to the time of transit of the projectile through the bore (which for similar guns is directly as the actual lengths of bore), we would have instead: 10-inch, 280; 12-inch, 233; 14-inch, 200; and 16-inch, 175 rounds. These figures for the 14 and 16-inch guns have been entered in the data pertaining to these guns previously discussed.

36. The erosion of bore appears to be chiefly a mechanical result due to high temperature and the rush of gas through the bore following the projectile and it increases with the caliber of the gun chiefly because of the longer time to which the part most affected, that is the choke of the powder chamber and rear portion of the rifled bore, is exposed to the heat of the powder gases. John F. Meigs, of the Bethlehem Steel Company, has contributed an interesting note on this subject, printed in the Journal of the United States Artillery for May-June, 1907. The erosion increases with the pressure and particularly with the large powder charges adequate to produce high velocities in long

guns. It is not serious in short pieces like the 12-inch rifled mortars, although they may be fired with quite as high pressures as the guns, which is another evidence of the relation between heat time-exposure accompanied by high velocity and erosion. The erosion in the rear portion of the bore affects the whole surface, deepening the grooves as well as wearing off the lands. About or beyond the middle length of the rifled bore there is little or no erosion; it then increases again to the muzzle. The wear towards the muzzle, however, is almost entirely confined to the lands and there appears to be the effect of high velocity, rather than heat, of the powder gases and possibly friction of the rotating band, wearing on the lands. In two 6-pdr. guns with 3000 f.s. velocity recently tested at Sandy Hook, by firing 500 rounds, including several series of 45 rounds for rapidity, the lands near the muzzle were completely worn away, leaving the appearance of a smooth bore gun.

37. The rotating band should afford sufficient shearing area in its bearings on the sides of the lands to prevent any shearing movement, not only to insure steadiness of the projectile in flight, but also to prevent openings for the escape of gas over the band in the bore. For this reason a wider band will be required with high velocities. If the band insures this however, and if it also has an enlarged forcing lip which will seal the bore when the projectile is seated, it appears that the essentials for the band will have been as nearly fulfilled as practicable. Placing an undercut in the rear face of the

band to form an expanding lip appears to be an unnecessary refinement as compared with a simple forcing lip since as soon as the projectile has entered the rifling the band will be flattened close on the projectile and the opening of the lip will disappear. A forcing slope in the rear portion of the rifled bore is also a good feature and should be made in the grooves as well as on the lands.

38. Efforts have been made and will be continued, to find a suitable steel or metal for gun tubes superior in erosive qualities to that now used, but the results so far go to show that the simple carbon and nickel steel forgings are nearly equal in this respect and stand nearly if not quite at the head of available metals.

39. After guns have become eroded they may be restored by inserting a lining tube, using a shrinkage adapted to preserve the original tangential resistance. A number of short lining tubes have been placed in field guns to remodel the chamber and gave good service in firings. Two examples of lining tubes inserted in larger calibers will be referred to. The first was a 12-inch rifled mortar, the bore of which was injured in machining and a through liner inserted to restore it, as shown in plate 6. The liner is 1.06 inches thick over the powder chamber and 1 inch thick in front of the longitudinal thrust shoulder which is 89 inches from the muzzle. The location of this shoulder is over the forcing slope in the rifled bore and a few inches in front of the band of the projectile when seated. This lining tube did not prove a success. The very remarkable

fact was observed that after a few rounds were fired the lining tube began to elongate and protrude from the muzzle. After 25 rounds this protrusion was .2 of an inch and the muzzle end of the liner was twisted clockwise, looking at the muzzle, .06 of an inch at its circumference. The twisting evidently came from the driving force on the lands required to rotate the projectile. Four securing pins were then placed in the muzzle to correspond with similar pins originally placed in the breech end to prevent rotation of the liner. Rotation of the ~~tube~~ liner was prevented but the protrusion of the liner continued to increase with firings until after 155 rounds it amounted to .6 of an inch. Accompanying the elongation of the liner the bore was enlarged, showing .008 of an inch enlargement on the groove diameter at muzzle and increasing to .03 of an inch enlargement at 88 inches from the muzzle or just in front of the shoulder on the liner. In rear of the shoulder the bore was less enlarged than in front of it, that is showed a relative contraction indicating a forcing in of the metal due to longitudinal pressure at the shoulder on the outside of the liner. This bunching of metal in rear of the shoulder and the stretching of it in front of the shoulder are not readily explainable by deduction from the effects of the known forces acting. It is presumed that the additional force needed to produce such bodily longitudinal movement of the liner, other than (1) the interior and exterior pressure on the liner, (2) the longitudinal component of pressure on the rifling due to inertia of rotation of projectile, (3) the friction of projectile band, (4) the recoil of piece, and (5) the friction of the gases and unconsumed powder of powder charge (all of which were considered), was produced by what amounted to a mandreling action furnished by the forcing of the rotating band and the wave of powder gas pressure which must produce an elastic enlargement of the bore advancing with the projectile band. It may be said that evaluation of the friction of projectile band and friction of the gases in the bore cannot be made with exactness in the absence of reliable data. The force required to push the projectile through the bore measured in the testing machine at Watertown Arsenal amounts to a radial pressure of 40000 pounds per sq. inch at the surface of contact between the band and the rifled bore. This test, however, of course did not include the expanding effort of the powder gas pressure in the bore which would act to at least partially relieve the friction of the band. On the whole this test showed the decided tendency of the lining tube to be permanently set by longitudinal stretching and indicated the necessity for making them as thick as practicable and giving good longitudinal support.

40. The other lining tube is placed in the type 10-inch rifle which was manufactured in 1890 and laid aside in 1896 after having been fired 292 rounds, whereon the accuracy of fire was so reduced, due to erosion in the rear portion of the rifled bore, that relining was recommended by the testing board. The lining tube, Plate 7, is made of gun steel and is inserted from

the breech by reaming out the original tube for a length of 152 inches and leaving a square abutting shoulder in the bore where the liner ends; the original bore is preserved from this place to the muzzle over a length of 175 inches. The thickness of liner is 0.9 of an inch over the powder chamber and 1.12 inches in the portion in front of the intermediate shoulder; it is assembled with shrinkages that nearly reproduce the original strength of the gun, that is, to support about 54000 pounds per sq. inch powder pressure within the elastic limit of the metal. The means applied to prevent the lining tube from twisting and preserve the alignment of rifling at the junction of the tube with the original rifling, comprize knurling over four inches length of the shrinkage surface at the front end and four securing pins at the breech end which are threaded, one-half in the original tube and one-half in the liner. A clearance of 0.3 of an inch was left, in assembling the lining tube, between shoulders. This was done to insure a close joint in the bore at the front of the liner and that the end should make contact before the shoulder, considering the longitudinal expansion of the gun under the heat used for shrinkage.

41. At the place selected for the termination of the liner the original bore was enlarged by erosion about 0.025 of an inch on the diameters of both lands and grooves. Between this and the muzzle or at about 75 inches from the muzzle, the original diameters were but slightly changed. The finish boring and rifling was done by inserting tools from the muzzle and conse-

quently, although the alignment of rifling was made good, the bore of the liner was not finished flush with the worn bore at the place of meeting and there is left an abrupt enlargement of the bore at the end of the liner amounting to 0.01 of an inch or more on a side. This was at first considered a serious defect as tending to induce rapid erosion at this place and possibly also to impair the accuracy of the fire. These fears have not been realized. The accuracy of the gun is fully up to the normal and after 84 rounds there is no marked erosion of the bore at this place. This is another practical illustration (more in point even than in the case of the Brown 6-inch gun, since this place for gas escape is located where the travel of projectile is about 7.5 calibers) of the slight effect of gas escape past the rotating band in producing erosion.

42. The first program of firings comprized 52 rounds, including 47 fired with full charges, giving 36000 pounds or higher pressure and ending with 10 rounds excessive charges in which the pressure was progressively increased to about 53000 pounds per sq. inch. Ten rounds (Nos. 6-15) were fired for accuracy with 606 pounds projectile at fixed target, 1000 yards range and repeated with rounds 31-40. They gave 2.11 ft. mean deviation from center of impact for the first target and a considerably better figure, namely, 0.825 ft. for the second. The condition of the gun after these firings was entirely satisfactory, except a tendency to contraction of the bore within the front end of the liner, arising apparently from forward flow of the liner metal,

producing excessive pressure at the abutting joint and causing some upsetting of metal on each side of it. For the rest the liner was in good condition; it was not rotated at all to disturb the alignment of rifling or unduly enlarged by pressure the erosion for 52 rounds, with about 2200 f.s. velocity, being of course not material. In the old portion of the bore, forward of the liner, these 52 rounds produced an increased enlargement on the lands amounting only to from .002 to .003 of an inch. After this 32 additional rounds have been fired from the gun, making 84 since relining and a total of 376 for the gun. The 32 rounds were fired with full charges and included 25 rounds fired consecutively in 31 minutes 10 seconds total time.

43. The last firings increased the contraction of the bore in the front end of the liner so that it became 9.9875 inches, or 0.0115 inch less than the prescribed maximum diameter of the projectiles which had to pass through it in the later rounds. This contraction extends rearward with diminishing values about 11 inches. For about 3 inches in front of the liner next the abutting shoulder in the older portion of the bore there is also some abnormal contraction. These contractions are attributed, as in the case of the 12-inch mortar liner in the vicinity of its shoulder, to longitudinal flow of the metal of liner produced partly by forces which we are unable to evaluate from known data, namely, the forcing of the rotating band accompanied by the advancing wave of enlargement of bore due to the powder gas pressure. After the rapid firing it was found also that the origi-

nal tube was cracked at the muzzle in four places about 90° apart. The cracks are not open but go through the thickness of the tube on the muzzle face and can be traced 3 to 4 inches in length in the bore. The hoop surrounding these cracks is not injured. Deformation of the rifling near the muzzle indicates that wedging action of a broken cast-iron projectile may have influenced the fracture. Another possible cause will be referred to later.

44. Further examination shows that the lining tube is not expanded or twisted - see plate 8 for photographs of rubber impressions of the bore taken at several stages of the firings. The erosion or wear of the liner is not material and is about the normal to be expected in a new gun of this type after 84 rounds. The only defect observed in the liner is the contraction of the bore at its forward end. This contraction was not sufficient to swedge the projectile after 52 rounds and it may be concluded that this liner has proved satisfactory for say 60 rounds after which (occurring during the rapid fire test) the contraction of bore may have become serious. The liner itself can be restored by passing a reamer through the 11 inches contracted length of bore to take off the top of the lands and it is proposed to try this on the gun in the yard with hand or motor power. If this is successful it can be applied in similar cases that may arise at fortifications in the future and avoid the return of the gun to the factory. Before the reaming is done and in order to test (in deliberate fire) the effect of the

contracted bore on projectiles as well as to observe if this contraction causes any abnormal increase of pressure, it is also proposed to fire one or more rounds with reduced charges into sand butt to recover and examine the projectiles; and finally after reaming to fire with full charges for 10 rounds or less depending upon the development of the cracks in the muzzle of the original tube.

45. Our built-up steel guns have a splendid record for endurance. Citing the number of rounds fired from the type Army guns, we have: 8-inch, 390 rounds; 10-inch, 376 rounds (including 84 since relining); and 12-inch, 265 rounds. A notable circumstance connected with two of these guns is that the 8-inch developed longitudinal cracks in the tube at the muzzle after 388 rounds and the 10-inch, as already noted, at 376 rounds. In neither of these cases was there violent rupture since the hoops remained intact and sustained the cracked tube. Barring possible assistance from a broken projectile in the case of the 10-inch, the similarity of behavior in the two guns and after about an equal number of firings would indicate that the life of these guns is limited by a condition of metal in the tube engendered by long continued firings. The 8-inch gun has been dismantled and cut up for examination. The data is not yet available except as relates to the muzzle piece. The gun was fired two rounds after the cracks were first observed. On dismantling the hoops from the muzzle piece a deposit was found between their interior surface and the tube showing that the powder gas

had been forced through the cracks in the tube on firing. The physical qualities of the tube metal, taken from tensile test specimens, were nearly the same as in the original tests made about 18 years previously, except that the elastic limit was lowered from about 51000 to 47000 pounds per sq. inch; in both the original and the present tests one steel specimen showed a granular fracture but otherwise these tensile tests did not disclose any material weakening of the metal from usage. The most pertinent fact developed was the existence of numerous so-called heat cracks in the surface of the bore of the tube. A plausible theory then to account for the fracture of the tubes appears to be that these cracks gave incipient cause for tangential rupture which finally occurred in the weakest part of the gun; that is, the muzzle, and was caused by the bore pressure assisted by the driving force on rifling required to rotate the projectile; and there is also to be considered that longitudinal force which was exhibited in stretching the lining tubes. We will note here also that the main tube in the Crozier 6-inch wire-wound gun was permanently elongated 0.147 of an inch on the original total length of 303.163 inches in firing the 98 rounds to which the gun was subjected. These considerations may serve in a general way, it is thought, to account for fractures occurring in some Navy guns which were not hooped to the muzzle, even though the pressures sustained were within the estimated factor of safety of the guns; nevertheless it is certain from the reliable performance of so many other similar guns that those which fractured were peculiar in some respect and probably contained more or less defective metal in the tube forging.

46. The recent chase fracture of a 12-inch Army gun at Fort heath, Mass., does not help the difficulty in solving these questions. This gun was hooped to the muzzle. The investigations concerning it have not been completed but it is known that the tube was broken off nearly transversely at about 6 ft. from the muzzle and some 3 feet from the rear end of the muzzle hoop which is 9 feet long. The 3 feet length of hoop was stripped from the stump of tube on the rear portion of the gun and the detached piece, comprizing fragment of tube with muzzle hoop complete, was thrown directly forward upon the outer slope of the parapet to a distance of about 72 feet. Fortunately no injury occurred other than to the gun. The transverse fracture of the tube took place at the front end of a longitudinal crack which extends back into the rear portion of tube and there are other cracks in the tube indicating a very general dissemination of weakness. Evidence of weakness before firing this round existed in the opening of the joint at the rear end of the muzzle hoop and it is surmised that a longitudinal crack existed in the tube before this round was fired. This gun was ruptured at the 27th round. The pressure gage showed about 32000 pounds and the records indicate that the maximum pressure to which this gun had been subjected at any time was about 36000 pounds per sq. inch. It is hoped that the investigation to be made, which will include mandreling tests of rings cut from the tube and hydrostatic tests

also of rings with thickness of wall reduced by turning off metal from the tube, will result in establishing a good reason for the failure of the gun.

47. Before closing this paper reference may be made to some interesting results obtained in firing a very elongated type of 6-inch projectile having 7 calibers radius of head. This is similar in form to the projectile recently tested in the .30 caliber rifle with marked increase of velocity and flatness of trajectory. The trial 6-inch projectiles were made of cast-iron and are shown in comparison with the uncapped common shell having 2 calibers radius of head, on plate 9. The long projectile was first fired with the full point and then a common shell of service type for comparison. Afterwards in order to obtain data for designing an armor piercing shell with cap, the 3 long projectiles were fired with the point truncated to a spherical head with radii respectively 0.75, 1.25 and 1.75 inches. All projectiles weighed 106 pounds and were fired at 7 degrees elevation, with 53 pounds charge of smokeless powder from 6-inch rifle model of 1903. The following are the representative results:

Date	Rd. No.	Muzzle velocity f.s.	Pressure pounds sq.in.	Time of flight seconds	Range - yards	Deduced value of βc	Radius of point inches.
1907							
	Long projectile with full point.						
Apr.19	28	3045	38420	20.72	12738		
	29	3049	39470	21.13	12890	0.53307	
	30	3073	39740	21.10	12893		
	Common shell - service pattern.						
Apr.20	31	2989	38710	15.80	7770		
	Long projectile with truncated points.						
Jun.27	37	3066	38790	20.70	12920	0.50485	0.75
	38	3105	38705	19.24	11940	0.60023	1.25
	39	3034	38790	18.16	10730	0.76211	1.75

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48. Comparing the full pointed projectile with the common shell, the former gave 67 f.s. greater muzzle velocity and 5070 yards greater range; and a comparison of these results with previous firings of service projectiles indicates that the change in form of head increases the range about 60 per cent. The curves on plate 9, plotted for the three rounds with truncated points show the relation of values of βc (coefficient of reduction) and of the ranges to the shape of point. The law is plainly indicated that with a given radius of ogive the range decreases and c increases as the bluntness of point increases. It appears also that the contour of the projectile where the head joins the body has more influence upon the range or ballistic coefficient than the shape of point; for example, the most blunted projectile with 7 calibers radius of head and total length of 19.375 inches, offered less resistance than the common shell (sharp pointed) with 2 calibers radius of head and 20.54 inches length. The former gave 10730 yards range and the latter 7770 yards, an increase of about 38 per cent. It is contemplated in continuing these experiments to use the 0.75 inch radius of point in making capped, armor-piercing projectiles for trial.

Specify explicitly.

Naval War College
Newport. July 30. 1907

R. Birnie
Lt. Col. Ordn. Dept. U.S. Army