ON THE

CONSTRUCTION OF HOOPED CANNON;

BEING

A SEQUEL TO A MEMOIR

"ON THE PRACTICABILITY OF CONSTRUCTING CANNON OF GREAT CALIBER, ETC.,"

PUBLISHED IN THE

MEMOIRS OF THE AMERICAN ACADEMY, IN THE YEAR 1856.

BY

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FROM THE MEMOIRS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES, 1864.

BOSTON:

LITTLE, BROWN, AND COMPANY.

1864.

Page 1 of Original.

Page 2 of Original.

WINTHROP PRESS: CAMBRIDGE.

ALLEN AND FARNHAM.

ON THE

CONSTRUCTION OF HOOPED CANNON.

[From the Memoirs of the American Academy of Arts and Sciences, 1864.]

ALTHOUGH a great improvement has been made in the construction of cannon by the adoption of the principle, and imperfectly the mechanical form, indicated by me in a Specification of June 19th, 1855, which was immediately afterwards expanded into the Memoir published in the VIth Volume of the Academy's Memoirs;* still, many points in the theory of that construction remain not only unperfected, but almost unexamined.

It is my purpose, therefore, in this paper, to investigate several important properties and laws which are inherent in the materials of which the gun described in my former memoir is constructed; and from this investigation I shall endeavor to draw such instruction as will enable us, if not to perfect,

* The memoir in the VIth Volume must be considered as a sequel to, and a further development of, the principles contained in a publication, in the form of a pamphlet, made by me in 1845. In this pamphlet, not only the principles, but the method of construction since followed by Armstrong and others, are fully pointed out.

at least to understand and improve, the theory of construction. The investigation will be founded almost entirely upon certain peculiarities in the nature, character, and properties of the materials (wrought-iron, cast-iron, and steel) of which the guns, constructed upon the principle heretofore published by me, are formed.

With these preliminary remarks I enter at once into the proposed inquiry, leaving the development of the course to be pursued to appear as I proceed.

In the memoir of 1855, before referred to, in giving an account of the theory of hooping cannon, I inserted the following paragraph (p. 10):

"There may, at the first view, seem to be a great practical difficulty in making the hoops of the exact size required to produce the necessary compression. This would be true if the hoops were made of cast-iron, or any body which fractures when extended in the least degree beyond the limit of its elasticity. But wrought-iron and all malleable bodies are capable of being extended without fracture much beyond their power of elasticity. They may, therefore, be greatly elongated without being weakened. Hence we have only to form the hoops *small in excess*, and they will accommodate themselves under the strain without the least injury."

And again, in a note, I said: "Mr. Barlow does not limit the application of his investigation to any kind of material, but it is evident that his conclusions are not applicable to any *malleable* metal like bronze; for in a cylinder constructed of hoops of this material, the inner hoops may be elongated by the pressure acting as a *crushing* force, and by this means be enlarged without any diminution of tenacity. Perhaps some kinds of soft cast-iron may accommodate themselves to an enlargement in the same way. But with hard crystalline cast-iron, no actual displacement of the constituent particles can take place without fracture; and although the effect of the fluid as a crushing force may act as an auxiliary to the strain, as any estimate of its amount would be a mere guess, I shall not attempt any modification of Mr. Barlow's conclusion, when applied, as in this case, to hard cast-iron gun-metal."

However important I might have considered the effects of the crushing force, and the partial or imperfect malleability of cast-iron, by which the gun may be permanently distended, a further examination of the subject has convinced me, that Mr. Barlow's theory must be in all cases modified and limited by the elongation or yielding from this malleability under the crushing pressure of the fluid; and, in many cases, as where the material is bronze or wrought-iron, the whole theory must be discarded as inapplicable. To show this, I will state the following experiment. I took a ring or hoop of wrought-iron, made up of four concentric rings, one placed over another, after one of the methods practised by me in making my wrought-iron guns in 1840–1843. These rings, when welded together, formed a hollow cylinder 1 inch long, having an internal diameter of

$1\frac{1}{2}$ inches, and an external diameter of 3 inches; consequently its walls were $\frac{3}{4}$ of an inch thick. This cylinder, after being smartly hammered or sledged when cold, was subjected to distension by driving into it a conical plug or pin, by blows with a heavy sledge. By this means the inside diameter was increased to $2\frac{1}{8}$ inches. This distension, from $\frac{12}{8}$ to $\frac{17}{8}$, was far from rupturing the ring, although it produced a great number of minute fissures upon the outside, while the inside did not show the least sign of crack or flaw.

I should remark, that this ring was made of very tough Norway iron; but, although I made several others in the same way, and of common English as well as of American iron, none of them broke under the strain before a distension of $\frac{1}{10}$ of their inside diameter; and, in all cases, the fracture commenced upon the outside and worked gradually inward to the caliber.

Another thing, worthy of all attention, was this: The end of each cylinder or ring showed, after welding, the thickness of each of the several concentric rings of which it was formed; and after the distension, the greater diminution of thickness in the inner and smaller rings was very apparent; thus showing how much greater was their distension or elongation, circumferentially, than that of the rings outside of them; and furnishing an experimental exemplification and corroboration, if such corroboration were required, of the fact first geometrically demonstrated by Barlow, and upon which he founded his theory explaining the weakness of cast-iron hollow cylinders when exposed to an internal pressure. Now, although the fact is to be received as he has demonstrated it, yet it becomes evident that the theory and formulas founded upon it must be limited, rigidly, to unmalleable bodies, and is in nowise applicable to cylinders of wrought metal, like the rings or hoops experimented upon by me. For, to bring a case under the conditions or facts supposed to operate in that theory, the fracture must begin upon the inside, which is supposed to be distended, like a rod strained by a suspended weight. But, in my experiments, not only was the innermost part of the cylinder subjected to the straining force of the conical pin, tending to rupture the whole thickness of the cylinder, but the inner portion of it, to a certain depth outward, was placed between two opposing forces, viz. the pressure of the conical pin in one direction, and the binding strength of the external portion of the cylinder in the other. Between these two forces it was crushed or pressed and extended laterally, and thus made thinner and longer, as a bar or sheet of metal is under a hammer, or between the rollers of a mill. Under these conditions it could not fracture before the external portion; for, to fracture a body, its integrant atoms or molecules must be separated; but in this case they were pressed together. This crushing pressure of the conical plug differed in no essential form from that produced by fired gunpowder. So the fracture commencing upon the outside of the ring is similar to that made in the bursting of bronze guns, which always commences upon the outside. The same fact was observed by me, twenty years ago, in the trial, to extremity, of two 32-pounder wrought-iron guns. In both of these, the fracture began upon the outside and worked slowly inwards.

The preceding statement cannot fail, I think, to convince any one that Mr. Barlow's theory is wholly inapplicable to guns made of wrought-iron, or any like malleable material, and, indeed, is to be applied, in its complete and unlimited extent, only to such materials as highly hardened steel, glass, and those crystalline or wholly unyielding bodies, in which the ultimate particles or molecules are incapable of being made to change place permanently in relation to each other, but in which the limit of elasticity ends in complete separation or fracture. When applied to hollow cylinders made of substances of this latter kind, it is probably true to the letter. But what is cast-iron? And are we to be guided by Barlow's theory in computing the strength of cannon made of this material? Believing, as I do, that most kinds of cast-iron are, to some, though a very limited extent, malleable, or, at least, that they admit of some small permanent change of form without fracture, we ought not, in my judgment, to apply Barlow's theory, without some modification, to express the strength of guns made of such material, as they really possess greater strength than the formula given by that theory assigns them; though for many of the harder and completely crystalline kinds of iron we must consider it applicable, as a safe, if not an entirely accurate, guide for practical purposes.

Following this property of malleability, from the cast-iron, or body, of the gun to the wrought-iron or steel hoops with which the body is encircled and compressed, let us next see what method of constructing the hoops should be adopted to obtain the greatest strength to the gun.

It is a fact well known to all smiths, or actual workers in the metals, and to many engineers, whose knowledge is often derived principally from books, that all the metals, by being subjected for a considerable time to hammering, rolling, or wire-drawing, acquire a great increase of elasticity and hardness. Indeed, if any of these processes be carried beyond a certain extent, the metal loses its malleability and ruptures or cracks under the continued operation. The hardness and elasticity thus induced are, however, easily destroyed, and the original malleability is restored by simply subjecting the hardened metal to heat, which should be considerably below its melting point. For tin, it is said that the heat of boiling water is sufficient for the purpose. But for gold, silver, copper, and iron, the heat of about 1000° is required to produce this *annealing* effect. For iron, it should be carried to a full red heat, whatever temperature that may be.

Now, for the purpose of ascertaining, with some degree of precision, the difference in hardness, tenacity, and elasticity, between a piece of iron subjected to various degrees of heat from 400° up to that which produces a thoroughly annealed state, that is, a full red heat, and the same iron after having been subjected to some one of the hardening processes before mentioned, I have made a great many experiments upon iron wire of various sizes, and in various states as produced by previous working and heating. I will now relate the mode of making a few of these experiments and the results obtained from them, which results were in accordance with numerous others obtained by the same method of operating.

These experiments were made upon pieces of iron wire about fifteen feet long and of different sizes. The instrument for performing the experiments consisted of a long horizontal frame, to one end of which was affixed a strong steelyard, which was bent into the form of a bell-crank; and the shorter arm of which was vertical, while the longer arm, upon which hung the poise, was horizontal. One end of the wire to be experimented upon was connected with the shorter arm by being turned a few times about a ring which was connected with the arm by a free joint. The other end of the wire was fastened, by similar means, to a strong bolt fixed to the frame at a distance of fifteen feet from the steelyard. Connected by cramping it with the wire, near the end last described, was a stiff wooden rod, which lay upon the frame, and passed, by the side of the wire and parallel with it, to near that end which was connected with the steelyard. To the neighboring end of the wooden rod was fixed a smooth tin plate, about one foot long and five inches wide. This plate lay upon the frame, immediately under the wire and nearly in contact with it; and upon the surface was registered, by a fine needle-point, the changes in the length of the wire under different tensions. To do this, a short straight-edge, or ruler, was firmly cramped to the wire, directly over the register-plate, so that, when a line was drawn upon the register-plate by the needle, which was laterally pressed against the edge of the ruler, its direction would be across the register-plate, or at a right angle with the axis of the wire. The distance from the point upon the wire where the rod connected with the register-plate was cramped to it, to the point where the straight-edge or ruler was cramped, was exactly 140 inches; and it will be seen that, by the arrangement here described, whatever yielding or springing might take place in the frame, in the bolts, in the steelyard, or in the wire itself outside of the 140 inches comprised between the points at which the rod of the register-plate and the straight-edge were respectively cramped, could not affect the accuracy of the measure of any change in the wire between those points, and that the straight-edge could not change its place upon the register-plate in the direction of the length of the wire, unless the length of the wire itself was changed in an equal degree.

The following four experiments, made on wire of ordinary quality, from the same hank, will give sufficient warranty to the conclusions afterwards drawn from them. The results here given are, as I have before remarked, altogether in accordance with other results obtained by the same mode of operating upon other wires.

The wire used in the experiments now given was $\frac{100}{1075}$ of an inch in diameter, and, consequently, the area of its cross-section contained .006789 of a square inch. Having taken a piece of this wire about sixteen feet long, hard as it came from the draw-plate, I straightened it and fixed it upon the testing apparatus in the manner before described; and, after cramping to it the register-plate and the ruler, I commenced the operation upon it by letting the steelyard draw upon it with a weight of 10 pounds, for the purpose of taking out the sag, and to bring all the bearings into place. I then drew a line, directed by the straight-edge, as before described, upon the register-plate. This line is shown in *Figure* 1, marked *Zero A.* I then placed the poise of the steelyard so as to give to the wire a tension of 40 pounds. This weight elongated the 140 inches of wire, carrying the ruler over the register-plate the distance shown by the interval between the short line and the zero line at the left-hand end of the latter and immediately under it; and this short line (seen above the number 40) was then made by the needle-point, guided by the ruler. The poise was then removed from the steelyard, when the wire returned to its original length, as was shown by the ruler again coinciding with the zero line. The poise of the steelyard was then placed so as to strain the wire with 80 pounds, and the distance of the short line (seen above the number 80) from the zero line, shows the lengthening of the wire under this strain. On removing this weight, the wire again returned to its original length; and, on repeating the operation so as to give the wire the several strains of 120, 160, 200, and 240 pounds, the several elongations, shown in the figure by the distances of the short lines (seen over these numbers) from the zero line, were produced; but from each of these elongations the wire recovered its original length on being released from the strain. On carrying the strain, however, to 280 pounds, the wire became permanently elongated, as was shown, on its release from the strain, by the small quantity denoted by the distance from the zero line of the short line immediately under it; while the permanent elasticity was shown by the distance of the two short lines from each other (as seen over the number 280). The operation was then continued by successively giving to the wire, and again removing from it, the loads of 320, 360, 400, and 440 pounds; and the effects are graphically shown in the figure by the distances between the zero line and the nearest short lines, which distances represent the permanent elongations, while the distances between the short lines themselves represent the permanent elasticity, after the strain of each load.

The register-plate was then moved upwards a little upon the rod, and a new zero line, B, (*Figure* 2) was marked upon it. With this I began as before, by

Fig. 1. Wire, hard, as it came from the draw-plate; 140 inches long, $\frac{100}{1075}$ths of an inch diameter. Area, .006789 square inches.

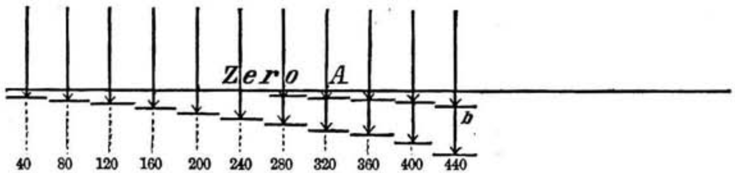

Fig. 2. Same Wire, after the above strain.

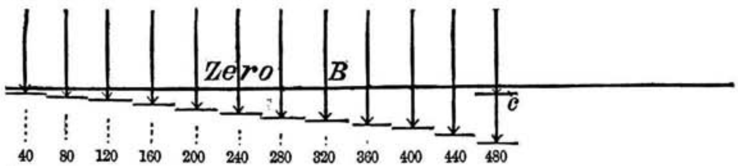

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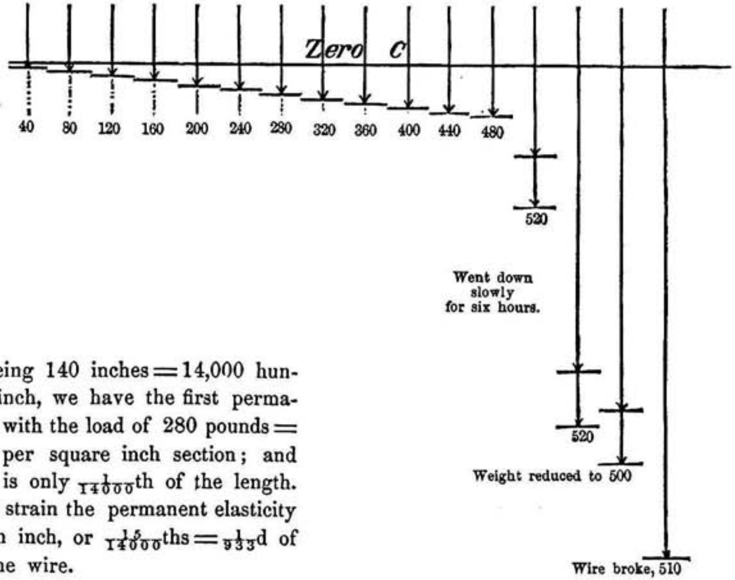
Fig. 3. SAME WIRE, after being heated, when under a strain of 40 pounds, so as to burn oil upon it, through its whole length. Temperature estimated at 850°.



The wire being 140 inches = 14,000 hundredths of an inch, we have the first permanent elongation with the load of 280 pounds = 41,241 pounds per square inch section; and this elongation is only $\frac{1}{14000}$th of the length. With the same strain the permanent elasticity is $\frac{15}{100}$ths of an inch, or $\frac{15}{14000}$ths $= \frac{1}{933}$d of the length of the wire.

placing upon it a strain of 40 pounds, and then, in succession, 80, 120, 160, 200, 240, 280, 320, 360, 400, and 440 pounds; removing each in like succession, to see if any permanent elongation would be produced by this repetition of the strain. As might have been expected, none whatever was produced, but the ruler returned in each case to the zero line, as shown in the figure. But, on increasing the strain to 480 pounds, the elongation shown at *c* was produced.

Knowing that the strain had reached nearly the limit of the strength of the material, I then subjected the wire to the heat of two large pieces of iron heated to a glowing red, and passed, one above and one below, in contact with the wire. By this means the wire was heated to such a degree that oil burned freely, on being dropped upon it, through its whole length. The wire was kept connected, in its place, with the apparatus during this heating operation, and it was likewise kept straight by a tension of 40 pounds from the steelyard. The temperature to which it was raised could not have been less than 850°. After it was cold, the register-plate and the ruler, which had been removed, were readjusted upon it, and a new zero line, *C*, was marked. (See *Figure* 3.) The weights were again applied to and removed from the steelyard as before, and the effect produced by each strain was marked, as shown in the figure, above the respective numbers. No permanent elongation was produced up to the strain of 480 pounds, the same result that was before reached. The elasticity, therefore, remained unimpaired by the heating. But, this load of 480 pounds being very near the tensile strength of the wire, on increasing it to 520 the great stretch shown in the figure, above this number and immediately below the zero line, was produced. Still, on taking off the load, the wire exhibited its old elasticity, and this even a little increased. This load, replaced and continued for six hours, carried the elongation much further, as shown in the figure; and so nearly was the breaking-point reached, that the elongation continued even after the load was reduced to 500 pounds, and the wire finally broke after it had been elongated the $\frac{1}{51}$st part of its length under a strain of 510 pounds, thus showing a tensile strength of 75,120 pounds to the square-inch area.* The permanent elasticity had reached, just before the fracture, or when the load was 480 pounds (equal to 70,700 pounds per inch area), $\frac{3}{10}$ of an inch, or the $\frac{1}{466}$th (.00214) part of the length of the wire. Other experiments were made by exposing the wire, which was the subject of them, to the heat of melted lead. Here, in two cases, the wire was passed slowly under the surface of lead which was kept very much above its melting temperature. These wires, when tried afterwards in the testing machine, showed their previous elasticity unimpaired.

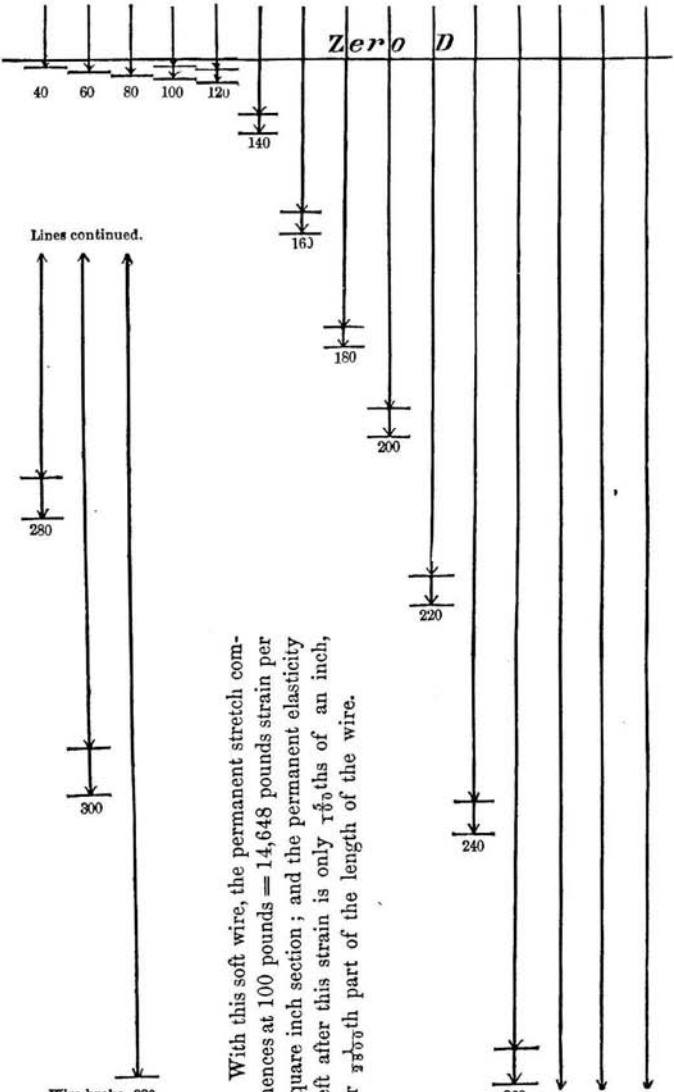
* The following numbers represent the weight upon the wire when reduced, or computed, for a square bar of one-inch section: —

40 = 5,891	200 = 29,458	360 = 53,025	520 = 76,592
80 = 11,783	240 = 35,350	400 = 58,917	560 = 82,433
120 = 17,675	280 = 41,241	440 = 64,808	
160 = 23,596	320 = 47,128	480 = 70,700	

The fourth experiment that I shall relate, was made upon a piece of wire from the same hank with that before used, after it had been annealed to a full red heat. This, after having been straightened, was placed upon the testing machine, and subjected to a succession of strains, commencing at 40 pounds, and increasing by steps of 20 pounds each (instead of the 40 pounds before used) up to 320 pounds, under which strain the wire broke; thus showing an ultimate tenacity of 47,128 pounds per square inch, or, allowing for the diminution of the area of the wire by the elongation previous to breaking, about 51,000 pounds, instead of 75,120 pounds, as given in the former case. The permanent elasticity had reached, just before the fracture, or when the load was 300 pounds upon the wire (or 44,186 pounds per square inch), $\frac{2}{100}$ of an inch, or the $\frac{1}{538}$th part of the original length of the wire. The effects of the various increasing strains are fully exhibited in *Figure* 4 (next page), which (as is also true of the preceding figures) shows a true copy of the lines made upon the register-plate. By this it will be observed that the permanent elongation commenced at a strain of 100 pounds, and increased rapidly, at each successive increase of weight, until it reached a length of $10\frac{1}{4}$ inches, or the $\frac{10}{136}$th part of the length of the wire.

Now, on comparing the results shown in all these figures, we see that these experiments demonstrate with some degree of precision several physical facts, all of which are of high importance in the construction of cannon upon the principle pointed out in the

Fig. 4. WIRE from same hank after it had been fully annealed.



With this soft wire, the permanent stretch commences at 100 pounds = 14,648 pounds strain per square inch section; and the permanent elasticity left after this strain is only $\frac{5}{100}$ths of an inch, or $\frac{1}{2800}$th part of the length of the wire.

Memoir to which this is a sequel. These facts are:—

First, That with a piece of iron hardened by compression and tension, in the condition of hard wire, the amount of permanent elongation is far smaller than the permanent elasticity up to near the breaking-point, and also that the permanent elongation does not begin until about one-half of the breaking strain is applied.

Second, That the part of the elongation, or stretch, which is within the elastic power of the wire, increases very regularly under equal increments of strain; thus exhibiting the truth of the maxim, *Ut tensio, sic vis*— As the stretch, so the strain. But the permanent elongations made by the same increments of strain, especially when near the breaking of the wire, are entirely at variance with this maxim. This will be seen in *Figure* 4, where an increment of 20 pounds to an existing strain of 120 pounds, produces a permanent stretch of $\frac{5}{16}$ths of an inch, while the same increment of 20 pounds, when the wire was under a strain of 280 pounds, increased the length, permanently, full $1\frac{1}{2}$ inches.

Third, That, when the material has been subjected to a strain of a given amount (say 440 pounds, as in *Figure* 1), the repeated application of a strain within that amount produces no further permanent elongation.

Fourth, That the subjecting of the same material to a heat sufficient to burn oil in contact with it (supposed in this case to be 800° Fah., at least), will not impair its elasticity.

Fifth, That, when the iron is annealed, the permanent elongation commences at a comparatively low strain, and that its extent is very large in proportion to the elasticity of the iron, which shows how inappropriate is the use, upon a cast-iron body, of a hoop that has been heated to an annealing temperature; as it must be loosened, or suffer the cast-iron to break within its grasp, before a strain upon it up to half its tensile strength shall be reached.

Guided by the conclusions derived from the preceding experiments, I will now proceed to compare, with such precision as the knowledge thus opened to me permits, two guns constructed upon the principles and after the proportions given in the Memoir of 1855, both of these guns being supposed to be of the same size, and made of the same quality of iron throughout, but differing only in this, viz., that, in the one, the hoops are put upon the body in an annealed state; and, in the other, in such a state of hardness, produced by cold hammering and stretching (as hereafter described), as shall bring the iron, as near as may be, to the state of the wire represented in *Figure* 3.

These guns may be shortly described as having a caliber of 14 inches diameter; bodies of cast-iron, 7 inches thick in the reinforce, so as to make the external diameter of the body there 28 inches; and a covering of wrought-iron hoops in two layers, having together an equal thickness of 7 inches. The strength of these cast-iron bodies, as shown in detail in the former Memoir, if made of cast-iron of 30,000 pounds tensile strength, when reduced according to Mr. Barlow's formula (which is recognized as sufficiently perfect for a practical guide), will be 210,000 pounds for each inch in length.

Now, let us suppose one of these bodies to be hooped with two layers of hoops, 3½ inches each in thickness, these hoops being made of wide bars of wrought-iron, coiled like a ribbon wound upon a block, and in this state the coils being welded so as to form one ring, or hollow cylinder, or hoop.* The hoops, being thus formed and properly forged to shape and size, are supposed to be left in an *annealed* state; and, after being bored and finished to .001, .002, or even .003 of their internal diameter less than the part of the body that they are to enclose, we will suppose them to be heated and put in their place, where they cool and compress the cast-iron, being themselves at the same time strained and stretched by the resistance of the enclosed body. Now, whatever proportions this compression and this stretch may bear to each other, it must be evident, from an inspection of *Figure* 4, that, when the strain upon the hoops, from the shrinking, reaches 17,675 pounds per square inch (equal to 120 pounds upon the wire), they will receive a decided permanent

* A more full account of this method of forming rings may be found in the pamphlet published by me in 1845, or in "English Printed Specifications," No. 10,013; enrolled in July, 1844; printed in 1854.

elongation. Let us suppose, then, that the hoops are grasping the body with this force of 17,675 pounds per square inch, at the instant when the fired gunpowder has distended the cast-iron to its normal diameter. We see by the *Figure* 4, that by a further distension of the body the resistance of the hoops will be very slowly increased. What will this resistance amount to, when the cast-iron is distended to its breaking point? Although we cannot determine with any great accuracy how far the cast-iron can be distended before fracture, we may, I think, be very certain that a fracture would be produced by repeated firing under an enlargement of $\frac{1}{1000}$ part of its external diameter. But it will be seen by the figure, that a strain upon the wire of 160 pounds, or 23,596 pounds per inch section, produces an elongation of the wire of .9 of an inch, or $\frac{1}{155}$ part of its length; and it must be evident, that, long before this elongation and distension in the hoops are reached, the cast-iron must give way and the gun be destroyed. But, even allowing the gun to hold together up to the strain of 23,596 pounds per square inch upon the cross section of the hoop, we have the following computation of the strength of the gun, for each inch in the length of the reinforce: Cast-iron body, 210,000 pounds per square inch; wrought-iron hoops, 23,596 pounds per square inch, and, as both sides give 14 inches thickness, $14 \times 23{,}596 = 330{,}344$ pounds for each inch in length, and $210{,}000 + 330{,}344 = 540{,}344$ pounds for the strength through each inch in the length of the reinforce of the gun of these dimensions and proportions.

Let us next suppose a gun to be constructed, in size and material, like that just given, but having this single difference in the method of preparing the wrought-iron hoops: that instead of placing them upon the gun in an annealed state, such as is represented by the wire from which *Figure* 4 was formed, they shall be subjected to a process of cold hammering and stretching, so as to bring them into the same condition, as near as attainable, with that of the wire used in making *Figures* 2 and 3.

Computing the strength of a gun covered with hoops brought into this state of hardness and elasticity, we have the diameter of the body, as before, 28 inches. Let the hoops be .001 part of their diameter less than the body, or 27.972 inches.

The hoops thus made, and expanded by heat, and placed upon the body, will, when cold, compress the body to a diameter somewhere between 28 and 27.972 inches, — the exact degree of compression depending upon the power of the body to resist compression, and that of the hoops to resist distension; but, when the force of the fired gunpowder is exerted upon the caliber, and the external diameter of the body is distended to its normal dimension of 28 inches, the power of the hoops to resist further distension will become 35,350 pounds for every inch area of their cross-section (this being equal to 240 pounds' strain upon the wire).

From this point the distending force of the gunpowder will be resisted, both by the hoops and by the body; and, if we suppose the cast-iron body, in this as in the last case, to be fractured only after a distension of $\frac{1}{1000}$th part of its normal external diameter, we shall find that that point will not be reached until a strain of more than 70,700 pounds per square inch (shown by 480 pounds upon the wire) has been exerted upon the hoops. Then, taking the body, as before, to resist with a force of 210,000 pounds per inch in length, we have, as the whole strength of the gun: Body 210,000, and hoops $14\times70{,}700=989{,}800$, making together 1,199,800 pounds for each inch of its length, — decidedly more than twice the strength shown in the former case, where the hoops were annealed before being put in place.

In this statement, I have taken the comparative diameters of the body and the hoops at 28 and 27.972 inches. Now this difference is so small, that it cannot be produced in practice with geometrical precision; nor is this necessary; all that is required being, that the difference shall not be *less* than that here given, though a deviation by which the difference of diameters shall be twice, or even thrice, as great as this, will not affect injuriously the construction.

Thus, suppose the hoops, instead of being 27.972 inches, be made 27.916 inches, in diameter. A heat of 800°, to which the hoops may be heated without affecting their elasticity, will expand them to 28.064 inches, thus giving a margin of .064 or about $\frac{1}{16}$th of an inch, for play, and imperfect workmanship, when the hoops are run on to their places. In this case, although the first compression of the body would be greater than if the hoops were made of the exact size assigned, yet the first discharge of the powder would, by a little permanent elongation of the hoops, bring them to the true diameter, without enlarging them beyond their elastic limits.

In the preceding computations of strength, I have confined myself to that manifestation of it which preserves the gun from longitudinal fracture. But a gun may be fractured transversely, or diagonally, as well as longitudinally, although I have heretofore fully proved, that, if made of a material which has an equal strength in each direction, the gun, or any hollow cylinder, has a vastly greater power of resisting cross, than longitudinal fracture. This is likewise applicable to any diagonal fracture. But as these guns owe their superiority in a great degree to their being formed, in part at least, of fibrous wrought-iron, the direction of the fibres being in the circumference of the gun, and moreover not perfectly integrated with the cast-iron as making one piece with it, it becomes necessary to consider the resistance to cross-fracture.

By a recurrence to the former Memoir, it will be seen that the cast-iron body alone, if possessed of a tensile strength of 30,000 pounds per inch, may be relied upon for preserving the gun from cross-fracture. But I cannot say that I have always been without some shade of doubt, whether the cast-iron, when exposed to the crushing force between the fired powder and the hoops, would exhibit the same resistance to cross-fracture that it would when free from this condition. It was in some degree to guard against any defect that might possibly arise from this source, that I proposed that the hoops be made in two layers, and be fitted to the body and to each other, by a screw-thread. In this case the screw was not to exercise its usual function of a mechanical power; but to serve, by the interlocking of the threads upon the body with those of the hoops, to so cramp the two together, that the body could not be fractured crosswise without either stripping the thread through a space equal to at least half the length of the hoop, or fracturing the hoop crosswise before or at the instant when the body gave way. Now, to strip the thread of a screw through half the length of the hoop would require a force sufficient to make a shear cut, through a section of metal equal to at least one-third the internal surface of the hoop. The inner surface of the inner hoop, being $28 \times 3.14 = 88$ inches in circumference and 15 inches long, gives a surface of 1,320 inches, one-third of which is 440 inches. To strip or cut through a screw-thread forming a section of this magnitude, taking each inch to require but even 30,000 pounds, demands a force of 13,200,000 pounds, while, as is shown in the former Memoir, the whole force of the charge tending to produce cross-fracture is but 4,896,000 pounds, being the pressure of 32,000 pounds per square inch upon 153 inches,— the area of the caliber. The other alternative, that of fracturing one of the hoops at its weakest point, that is, where it breaks joint with two of the hoops of the other layer, and where, of course, one thickness alone gives its support against cross-fracture, furnishes the following computation: The area of the cross-section of the inner and smaller hoop, contains 346 square inches, which, giving the iron, in this its weakest direction, a tensile strength of 40,000 pounds per inch, shows that a force of 13,840,000 pounds will be required to tear the hoop asunder.

The preceding computations, therefore, place it beyond doubt, that, even allowing that the lateral pressure of the fired powder upon the cast-iron body of the gun may impair the tensile strength of the body in resisting cross-fracture, yet, under this condition, and thus admitting as a truth that of which we have no evidence, we see that we may rely with perfect confidence upon the strength of the hoops alone, when secured to the gun by the screw-thread, as described in the former Memoir, to preserve the gun from cross-fracture.

In the Specification and Memoir before mentioned, I propose to form the screw "of about eight threads, each thread taking about one-eighth of an inch space, so that one turn advances each thread one inch," and "to make the threads of the female screws sensibly finer than those of the male, to draw by the shrink, the inner rings together endwise." The advantage of this form of construction will appear in this: that by the rapid advance of the hoop to its place, the shrinkage from cooling during its passage over the body will be avoided; while the dividing of the inch space of the spiral into several parts, enables us to give a great bearing surface to very shallow threads.

I give, in *Figure* 5, a drawing of the threads as I would form them for a six-threaded screw. They

Fig. 5.

have an .18 inch pitch, and a depth of .04 in., being 11 in. thick at the root or bottom, and .07 in. breadth upon the face. Threads of this shape may be more easily and exactly made than any other, as a large part of the surfaces left by the boring and turning tools requires no change from the screw-tool, but remains and forms the flat faces of both the male and female screws. By this means the gauged sizes and requisite diameters of both the body and the hoops are more easily ascertained and preserved, when the screw-threads are formed.

The depth of the threads given in this figure must be ample; for, as the threads, when once interlocked and in place, are kept in contact by the shrinkage of the hoops and the distension of the gunpowder, the idea of the outer threads slipping and riding over the inner ones, like a loose nut upon a screw bolt, is simply preposterous.

A mechanical equivalent for the screw-threads may be found in small circular prominences formed upon one surface, to fit into corresponding grooves upon the opposite surface. The principal objection to this mode of cramping or interlocking the surfaces will be found in the necessity of heating the hoop to a much higher temperature than is required with the screw-thread, in order to expand it so that it may pass to its place upon the gun. These prominences and grooves, doubtless, might serve a better purpose than the mere roughness left by the turning tools, as now often used. I am confident, however, that no device can be made, superior to the screw-threads, and nothing better than this is needed.

The benefit, moreover, to be derived from making "the threads of the female screws sensibly finer than those of the male," must, I think, be evident after a little examination. By making this difference the $\frac{1}{1000}$th part, or perhaps a little more (that is, by making 1000 turns of the spiral of the female to occupy a shorter space upon the hoop by a $\frac{1}{1000}$th part than the same number of turns do upon the body), they will be more nearly equal when the hoop is expanded by heat, than if they had been formed of equal fineness or pitch. The hoop will, therefore, go more readily to its place when expanded, from bearing this finer thread. When the first layer is shrunk in its place, each hoop will be under a lengthwise strain; and, again, when the second layer is shrunk upon the first, the first layer, and, under it, the body of the gun, will be drawn together lengthwise, and thus the body will be guarded from cross-fracture, as it is guarded from longitudinal fracture by the circumferential strain of the same hoops.

Having thus exhibited the principles which should direct us in the construction of hooped cannon, and the experiments by which these principles are come at, I now proceed to describe the method of forging the hoops, and of giving to them that combination of hardness, elasticity, and tenacity, which has been shown to be so important to the strength of the cannon.

To construct one of the hoops for a cannon of the size before mentioned, that is, of 14-inch caliber, the hoop having, when finished, 27.972 inches' internal diameter, and being 3½ inches thick, and 15 inches long (or broad), I take a flat bar, say 14 inches wide, from half an inch to an inch thick, and of such length that, when wound into a coil, it shall form the thickness required for the hoop, after allowing for the waste in welding, forging, and finishing. After its ends have been scarfed to a long wedge form, it is to be heated to a low red heat, and then wound upon a cylinder of say 25 or 26 inches diameter, as a ribbon is wound upon a block. Next, it is to be heated in a proper furnace to a good welding heat, and then, being placed upon an arbor, or mandrel, of about 25 or 26 inches' diameter, and between proper dies, setts, or swages, it is to be completely welded, or the several layers or coils are to be made to form one piece. This may be done by compressing it with the swages, by a hydrostatic press, or by a steam hammer. After it is properly welded and condensed in this way, and has cooled as low as 600°, it is to be placed upon a cold arbor, or mandrel (shown, in section, at *A*, *A*, *Figures* 6 and 7), which is supported at both its ends by the upright studs of the heavy iron frame *B*, *B*. It is then to be hammered by the steam hammer *C*, until its internal diameter is enlarged to about 27 inches.

Fig. 6.

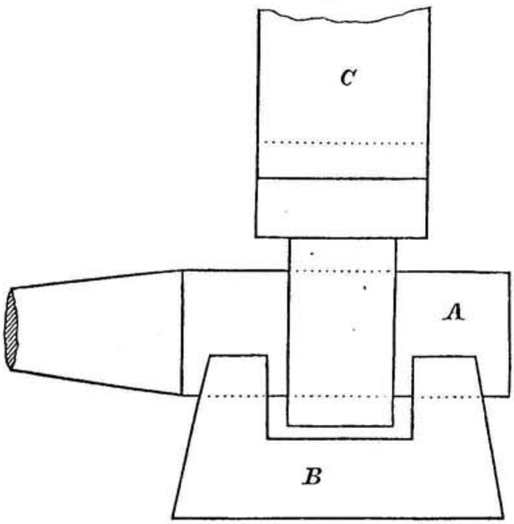
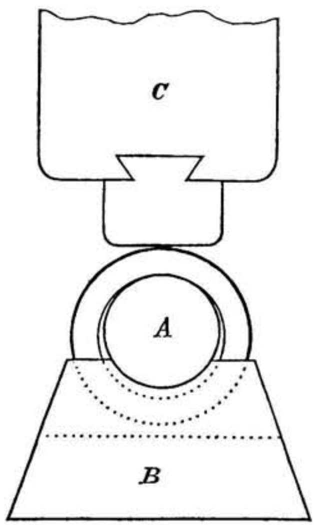


Fig. 7.



The last part of the hammering is to be performed after the hoop has become cold. Instead of operating in this way with the steam hammer, we may produce the same effect upon the hoop by a rolling-mill, in which the operating part of the rollers is made to project beyond the housings, or frame.

After the hoop has been condensed and enlarged in this way, it is next to be placed upon an annular anvil, *D*, *D* (*Figures* 8 and 9), and the segmental swages or blocks, *E*, *E*, are to be adjusted within it. These segments form a cylinder upon their outer surface, but inside they form a hollow cone. A solid conical plug, *F*, is fitted to be driven into this hollow cone within the swages. With this arrangement, the whole being under the drop or steam hammer *G*, the plug is driven by repeated blows into the hollow cone, by which operation the hoop is stretched sufficiently to destroy all conflicting strains or tensions that might have been produced in it by the hammering. The strain is thus reduced to a circumferential direction, and the hoop put as near as possible into the condition of the hard wire (as shown in *Figure* 2), after it had been subjected to the first series of strains (as shown in *Figure* 1).

The hoop may be stretched by this last operation the $\frac{1}{100}$th part of its diameter, and, if it is made of very soft and tough iron and has not been hammered very hard, much more than this quantity. The extent, however, to which this hammering and cold stretching may be carried, must depend upon the quality of the iron and the heating and working to which it has

Fig. 8.

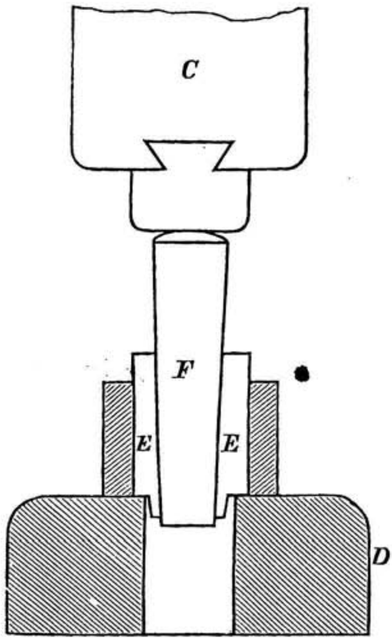
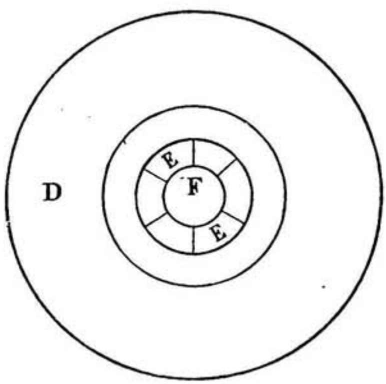


Fig. 9.



been previously subjected. It will be well, when the stretching is commenced, to have the hoop warmed up to 200° or 300°.

After the hoop has been prepared in this way by cold hammering and stretching, it is to be bored and turned; and, whether it is to be fixed to the gun by a screw-thread, or by any equivalent, it is to be carefully and equably heated to such a temperature (but never up to an annealing heat), as shall expand it sufficiently, and, in this state, is to be placed upon the gun.

In all the preceding computations of the force which the cannon is required to resist (both in this paper and in that to which this is intended as a sequel), I have considered the powder, when fired, as acting by a pressure generated with inconceivable rapidity, and with an intensity sufficient to produce the required velocity in the missile; — this velocity being produced by the pressure alone. I am fully aware, however, that the force thus produced, almost instantaneously, from a single point within the gun, does, and must, throw a shock upon, and a vibration through, the whole mass, the destructive effect of which must be provided against in addition to that of the mere pressure of the fired powder, if that pressure be supposed to act as the pressure acts in the hydrostatic press, for example, where it is raised and communicated slowly and gently to its object, thus producing its motion without violence or shock. Although we are without the knowledge requisite to subject to a rigorous computation the destructive effect of this shock and vibration from the discharge, yet it is necessary that a sufficient strength should be provided in the gun to resist it. Nor are we without the light of experience to direct us to this end; for, although it has not yet been determined, by direct experiment, what strength is required in a gun of say 14-inch caliber, in addition to that thrown upon it by the pressure of the charge, in order to withstand the sudden shock and vibration before mentioned, yet we have direct experiments which have determined this element in guns of smaller caliber. Thus the cast-iron 32-pounder, $6\frac{1}{4}$ inch caliber, if made of good iron, and in the usual proportions, that is, with walls of one caliber in thickness, has been proved, by the experience of ages, to be quite reliable for long-continued use with service charges.

Now, it was shown, in my former Memoir, that a maximum pressure, from the fired powder, of 920 atmospheres, will give a velocity of 1,600 feet a second to a 32-pound shot; and, further, that, computing the strength of the gun from the tenacity of the iron, taken at 30,000 pounds per inch, it is capable of resisting a force of 1,333 atmospheres; or, the strength of the gun is to the maximum pressure of the powder as 144 : 100. Hence, we have an excess of 44 per cent., which has proved sufficient to sustain all the extra violence from the shock and vibration occasioned by the suddenness of the discharge, from the heat, and from all other adventitious causes. It is furthermore shown, in the same Memoir, that a spherical shot of 14 inches' diameter will receive a velocity of 1,600 feet a second, if fired from a cannon, the bore of which is 112 inches long from the seat of the ball to the muzzle, under a maximum pressure of 2,133 atmospheres. But we have seen, that a 14-inch gun, constructed with hoops as herein described, will sustain a pressure of more than double that required to throw the ball with 1,600 feet initial velocity. There can be no doubt, then, that, as 44 per cent. above the necessary powder pressure has, through long experience, proved sufficient, in the 32-pounder, to provide for the contingent strains from shock and vibration, 100 per cent. must be more than sufficient to provide against the same contingencies in the 14-inch gun; and, indeed, that 14 inches does not approach the size to which guns may be safely trusted, if constructed upon the principles, and in the manner, herein laid down.

Although it is hardly to be expected that the preceding method of cold working will impart to the hoops, if made of common iron, the elasticity and tenacity possessed by the wire used in the experiments herein related, yet, by the use of iron of superior quality, I think that that standard may be reached. But, should it be found, in the end, that 10 per cent. must be deducted from the tenacity of the wire, in computing that of the hoops, we shall still find the gun constructed in this way, for all that I can see to the contrary, *more than twice as strong as any hooped gun ever yet constructed, of the same materials, weight, and dimensions*; and, by the use of iron of a somewhat steely character, or of some of the *low* steels, the standard of the strength of the wire may be much surpassed.

I cannot conclude this paper without observing, that, although in the Memoir formerly published no particular method of hardening the hoops was pointed out, and thus the process of cold hammering and stretching was omitted, still it was always my intention, whenever I should undertake the manufacture of hooped cannon, to prepare the hoops by some process of condensing and hammer hardening. So fully was I impressed, from my experience in the working of iron, with the importance of thus preparing the hoops, that, in 1862, when I had made an arrangement, with the Massachusetts Committee on the Defence of the Ports and Harbors of the State, for the manufacture of two hundred large cánnon (an arrangement which was entirely approved by the Executive government of the State, and which failed to be consummated only by the rejection of the appropriation bill, in the Senate, by a majority of one), I visited several of the large machine-shops in the vicinity to find where I could best procure the construction of the steam hammer and tools for performing the operation herein described. My ideas (which were not then very definite) of the importance of subjecting the hoops, to be used upon cannon, to this condensing and hardening process, have been fully confirmed and defined by the experiments herein detailed; and the conclusions that I have drawn from these experiments will, I think, be assented to by any practical engineer who may take the pains to examine them. Indeed, it seems to me remarkable, that, with all the attention that has been given to the subject of hooped cannon in Europe, as well as in this country, for several years past, the cause of the great defect, which it has been one object of this paper to point out and remedy, does not seem to have been discussed nor seen, although the defect itself has been made known by the bursting of such guns in so many instances as to have shaken, if it has not destroyed, the confidence of artillerists in them, when used with heavy charges. To avoid this defect, resort has been had to the use of *low* cast-steel, under the name of homogeneous iron; or to an adoption of the manufacture with wrought-iron, after the method invented and practised by me more than twenty years ago, and which I afterwards improved into the simpler and cheaper form so fully described in these Memoirs.

I may also observe, with regard to the theory of the strength of hollow cylinders, when exposed to a bursting force, that many changes to the original formulas of Mr. Barlow have been proposed as expressing more exactly the physical conditions of these cylinders. These changes, however ingenious or learned, are of very trifling practical importance in the manufacture of cannon. The omission of Mr. Barlow to consider the pressure, as acting as a crushing force upon the internal portion of the cylinder, and thus as aiding, to some unascertained extent, its action as a distending force, in rupturing the walls of the cylinder, was, I believe, first made known by me in my former Memoir. So, also, no writer or engineer has yet, so far as I know, perceived or shown, that the theory of the strength of hollow cylinders, as now generally adopted, is wholly inapplicable to cylinders or hoops made of malleable materials, such as wrought-iron or bronze; for the reason, that the inner portion of such a cylinder will, as shown by my experiments herein detailed, be permanently elongated or stretched circumferentially, without being ruptured or weakened until after the outside has given way; a fact entirely at variance with the foundation of the theory. For, the assumption, on which the whole theory rests, requires that the fracture shall first take place upon the inside of the cylinder; an assumption that can only be true in fact, when the cylinder is formed of a material which is unmalleable, that is, incapable of being elongated or stretched to any considerable extent beyond the limits of its elasticity.