GRUSON'S
CHILLED CAST-IRON ARMOUR.

BY

JULIUS VON SCHÜTZ,

Engineer of Grusonwerk.

Translated into English

BY

COMMANDER H. H. GRENFELL, R N.

London:

PRINTED BY WHITEHEAD, MORRIS & LOWE,

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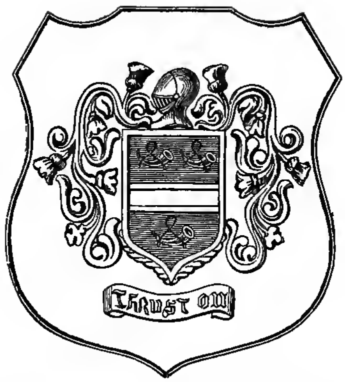
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PREFACE.

THE question of National Defence is occupying, at the present time, very great attention, not only in England and her Colonies, but also in America. An account of the experiments made with, and the development attained from, the only system of armour which has hitherto shown itself capable of resisting the attack of the heaviest modern guns, and of maintaining the protection given to the artillery and gunners placed behind it, must necessarily be of interest to all who are professionally engaged on this important subject.

Armour is acknowledged by all the leading authorities to be a necessity for the defence of positions of such importance, that the safety of the State would be compromised by their loss or destruction, and a perusal of the following pages will show that in presence of the tremendous attack capable of being delivered by the heavy guns now carried by ships of war, no other system of armour offers a security approaching to that given by the **Gruson Chilled Cast-Iron Armour.**

Its great merit is that it is capable of meeting fully any projected increase in the power of the attack, great as this may be, whereas with other systems of armour it is well known that the limit to their resisting powers is within sight, if it has not already been reached. It is for this reason that an endeavour is now being made in certain quarters to forego the use of armour altogether, inasmuch as penetrable armour is worse than none; but military engineers know that this is merely from an admission of the fact of the failure of these other systems of being able to compete with the guns, and that so long as weapons of the heaviest nature are carried afloat, similar guns must be employed for defence, and that in most cases to place these guns behind efficient armour is the only way in which their full and effective use can be ensured.

Based on principles which are technically sound, not only from a manufacturing, but also from a military point of view, the Gruson Armour is the only system which has been able to maintain its position *pari passu* with the increased development of artillery, and which offers in the future the same guarantee of effective protection which it has abundantly displayed in the past.

June, 1887.

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THE extraordinary activity which in the present day is displayed in improving and developing the materials of war, imposes on every writer who undertakes to describe its existing condition the necessity of frequently correcting and supplementing the information he furnishes, so great are the improvements and progress made in the course of each year.

Under the title of "The Gruson Chilled Iron Armour," we published in the year 1878 a short description of the Gruson Armoured Turrets and Batteries, and an account of the firing tests to which they had been submitted. We were able at that time to claim for the armour a notable superiority over the means of attack, a claim which was then fully admitted by most authorities on the subject. During the following years no further trials took place, as, notwithstanding the increasing powers of the attack, the data obtained remained an amply sufficient basis for determining the form and dimensions to be given to the armour.

In the meantime, however, great progress was made not only in the construction of guns and manufacture of powder, but also in that of projectiles. At the close of the last decade Gruson's chilled iron projectiles were still competing favourably with steel shot, as the problem of making these latter as hard as glass, and at the same time tough and tenacious, had not yet been solved. As far as we know, the credit of this improvement is due to the Krupp Works, whose armour-piercing shells are in the present day among the best made.

Although the size of guns and the weight of their charges were increased, so long as the material of which their projectiles were made remained the same, the proportionate increase of thickness necessary to be given to the armour could be calculated; but when a new material for projectiles was introduced whose effect on the armour was anticipated to be much greater, but could not be with accuracy determined beforehand, the resumption of firing trials became an unavoidable necessity.

This second series of trials began in the year 1882, and as they may be considered to have reached a conclusion in the experiments which took place at Spezia in April and June of 1886, the present time seems favorable for supplementing the earlier data and conclusions with the most recent results, and for establishing a comparison between them. We shall repeat the earlier results so that, following a brief account of the chilled armour and minimum-port carriages, a complete resumé will be presented of all the trials which have taken place.

CHAPTER I.

Description of the chief types of Chilled Cast-Iron Armour, and Minimum-Port Carriages.

BEFORE proceeding to a description of the above-mentioned types, a short notice of the material of Gruson's chilled iron and its mode of manufacture may be desirable.

All armour plating may be placed in two distinct categories :—

(*a.*) Those which by virtue of their hardness of surface deflect shot which strike them.

(*b.*) Those into which shot penetrate, but in which the effect is localized to the part struck.

The first comparatively hard armour was of steel, but the use of this was given up on account of the brittleness of the plates, which shivered into pieces under the blows of the shot.

For a number of years wrought-iron was the only material used for armour, until, in 1868, Gruson produced his chilled cast-iron armour, and by means of a series of trials established the correctness of his system.

The Gruson chilled iron is a mixture of different blends of pig-iron, cast in chill, to which it owes its hardness.

In accordance with the two chief qualities which he sought to obtain in his metal, Gruson chose two sorts of pig-iron for his principal materials, each of which possessed one of the desired qualities—a highly carbonised, steel-hard, white iron, and a soft grey iron.

Although it appeared impossible, by the mere mixture of the two materials, to combine hardness and toughness in the same stratum of iron, another way of solving the problem, to produce a hard surface on a soft elastic interior, seemed less difficult, if it were possible to combine the two different materials together with such a gradual change of their respective properties that no marked line of separation should occur; and this is the solution which Gruson, after years of effort, succeeded in reaching in such manner that even at the present day his chilled cast-iron possesses a superiority over that of other makers.

Gruson attained his object by a seemingly simple procedure. By the use of iron forms or moulds for casting, he prevented, by a rapid cooling of the surface, the always existing tendency in a fluid casting, for the carbon to separate off in scales of graphite.

It would be foreign to the scope of this compilation to specify the details of the manufacture of the chilled iron, and we will only describe the peculiar structure which characterizes the broken section of a piece of the Gruson chilled cast iron.

Fig. 1.

Section of a Chilled Cast Iron Bar.

It will be noticed in this figure, which shows the section of a chilled bar, that the exterior layer is of a fine fibrous character, which passes without visible lines of separation into the granular structure of the so-called mottled iron, which in turn gradually assumes the character and fine crystalline structure of the soft grey iron.

This is the great difference which distinguishes Gruson chilled iron from that of other manufacturers in whose iron the line of separation of the layers is always more or less distinctly marked, and the edge between the hard and soft metal visibly seen.

The Gruson chilled iron possessed consequently all the properties which are appropriate as a material for armour plates.

Hard armour was discredited because brittleness was thought to be a necessary accompaniment of hardness. Gruson's metal offers a hard surface on a tough interior, combining thus hardness with tenacity.

The attempt to distribute the effect of a shot over a large surface had to be given up on account of the difficulty of rolling such large plates as were required for this. Gruson's cast metal permits any required form and dimensions being given to the plates.

Finally, the curved exterior surface of armour was rejected on account of the impossibility of giving this form to wrought iron plates. With Gruson's metal any required external shape can be adopted.

Fully realising the advantages of his metal, Gruson completely abandoned the views which prevailed in England, and returned in every respect to the previous course of action. To his plates he gave a curved form, which in vertical section approached that of a quadrant of an ellipse. Such a surface, by its hardness, deflected the shot striking it, and besides it possessed this advantage, that, by reason of their arched form, the plates supported one another, and retained their position by their weight, without the necessity of securing them by bolts. Following this came the reduction of the port to a minimum, so as to prevent the entry of splinters of shell, and, as a consequence thereof, the old type of gun carriage had to be abandoned, and a new one devised in which the pivot round which the gun turned was placed in the port itself. The port became considerably reduced in size, and was almost completely closed by the chace of the gun, so that the port screens in use were no longer necessary, as there was but small chance of any splinters of projectiles entering by the small opening reserved between the sides of the port and the chace of the gun.

As the chilled iron can be made to take any desired form, it is applicable to every system of fortification, of which, however, the most usual forms are *protected fixed batteries* and *revolving turrets.*

I. Protected Batteries.

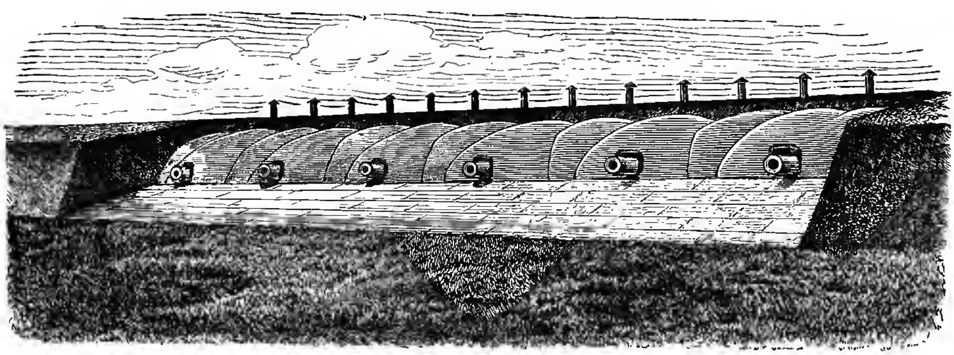
Fig. 2 gives an external view of a protected battery for six guns. The embrasure or port plates form the chief part of the armour, and stand on the so-called pivot plate, being supported on each side by a pillar plate (*see also* Fig. 3).

At each end the battery rests against masonry, which is protected by earth parapets against shot. In front of the battery is a concrete glacis, covered with substantial granite blocks.

Defence against curved fire is given by the roof plates which join in front to the port and pillar plates, and in rear rest on masonry pillars forming part of the casemates.

Fig 2.

View of a Chilled Iron Armour Battery.



The adjoining edges of the several plates are planed to a flat surface, and each edge is provided with a groove, into which zinc is cast when the battery is mounted, or iron keys inserted. Owing to the weight of the plates no further fitting is necessary.

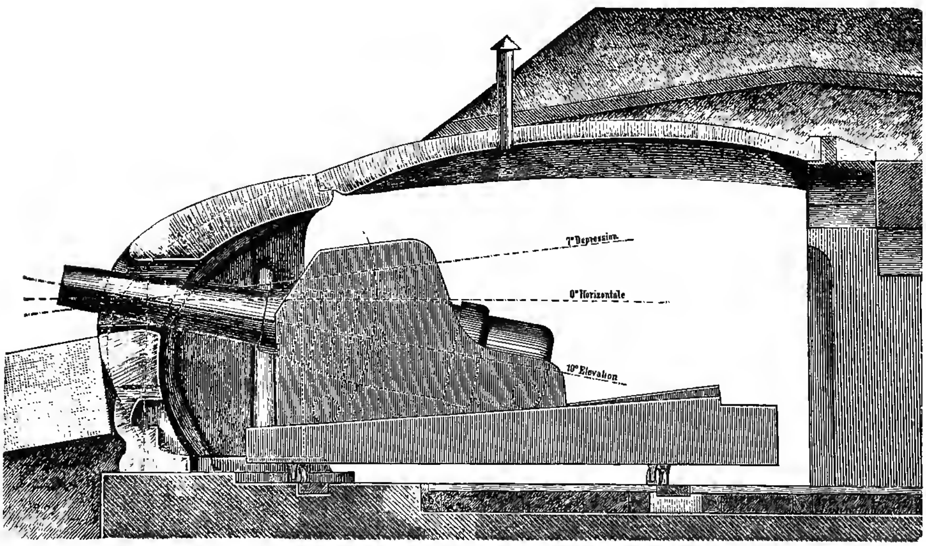
The whole structure lies on foundation plates, provided on their upper and lower surfaces with two ribs, of which the upper clasp the armour plates and render dislocation impossible, whilst the under ones are embedded in the masonry forming the foundation.

The form of the port, pillar, and roof plates is shown in Figs. 2 and 3, and it only remains to notice the pivot plates, which take their name from the pivot bars of the carriages which are connected to them. As already explained, the port pivotting or minimum-embrasure carriages are of special construction, the point round which the gun rotates being situated in the port itself.

As a large arc of horizontal training is required, the slide is furnished with four rollers travelling on two curved racers, and the pivot for the horizontal movement being placed vertically beneath the point in the port round which the gun works for elevation or depression, admits of any exact training, and this is effected by simple winch gearing.

Fig. 3.

Section of an Armoured Battery.



As will be seen from this, an armoured battery forms a spacious structure, which is connected in the rear to the casemates by means of wide passages.

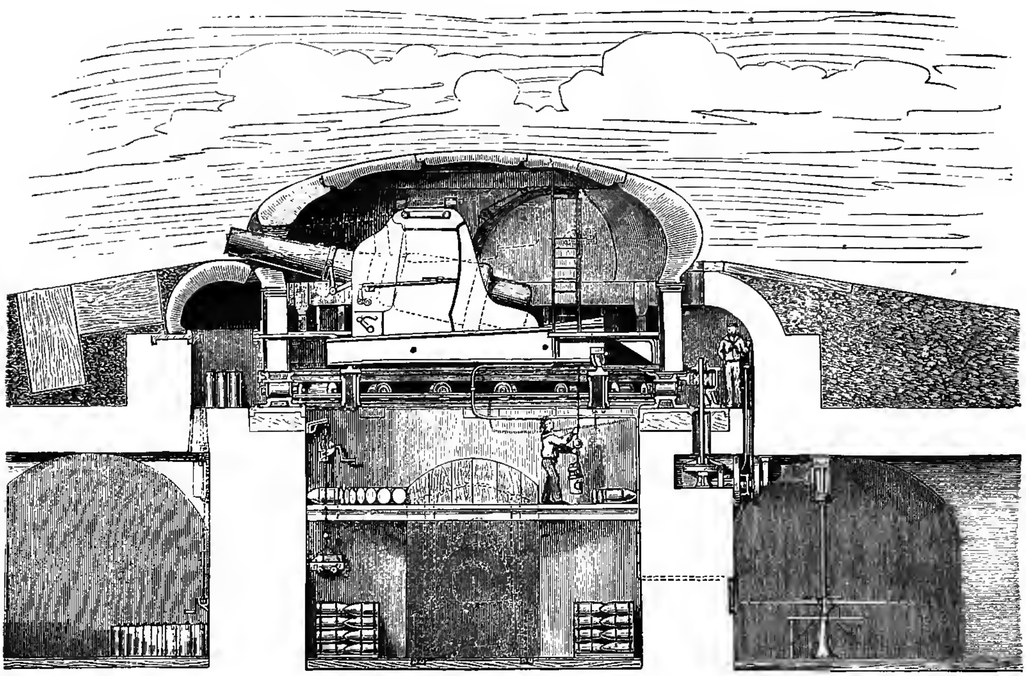
In the basement of the casemates the magazines are placed, communicating with the upper storey by means of lifts and staircases.

II. Armoured Turrets.

In cases where a greater arc of horizontal fire is necessary than can be easily obtained from a fixed battery, recourse is had to revolving turrets whose guns fire through the whole circle of 360°. Fig. 4 gives a section of such a turret, and clearly explains the mode of construction.

Fig. 4.

Section of a Chilled Iron Armour Turret.



The dome-shaped cupola rests on a wrought iron sub-structure, which rotates on a live roller ring running on a roller path fixed to the foundation, and is protected from shot by a glacis armour.

The lower roller path of the turret which is __┏━┓__ in section, is provided underneath with continuous ribs, which are embedded in the masonry of the foundation.

On this is the live roller ring, which, being without a central pivot, allows the whole interior space to be utilized, the gun being capable of being mounted in position through this central space from below.

On the rollers rests the upper roller path which carries the substructure of the turret, built up of iron plates and angles. The substructure carries on its upper surface the ring of cupola plates, whilst transverse girders fixed at its lower part support the gun carriage.

The cupola has the form of a dome, or flat arch, as already mentioned (accurately speaking, the shape is that given by the rotation of the quadrant of an ellipse), and consists of a number of separate plates, which, as their centre of gravity, in consequence of their construction and arrangement, passes through the middle point of the cupola, mutually balance, and, owing to their weight, do not require to be otherwise bound or tied together. The adjoining edges, moreover, are provided with grooves, as mentioned in the case of the battery, which grooves are filled with zinc or iron keys when the cupola is being set up.

The dome shape has the following advantages:—Attacking projectiles are deflected; the blow of impinging shot is distributed over the whole mass of the plate; space is economized; and lastly, there is no need for bolts or nuts to bind the plates together, and the construction of the roof is facilitated.

As in the battery, the roof plates lie in simple grooves, the joints being filled in on mounting the cupola.

The glacis armour, which protects the substructure, consists, as Fig. 4 shows, of a ring of curved plates, which either partly or completely encircle the cupola, as may be advisable. This is covered by a layer of concrete, with granite blocks. The cupola is rotated by vertical pinion gear, working in a circular rack fixed to the upper roller path.

The gear is arranged for working either by hand or power. The hand-gear consists of a capstan placed in the lower casemate, seen on the right in Fig. 4, and means are provided for giving either a quick or slow turning motion.

Heavier cupolas are fitted with both hand and power turning gear, each of which can be placed in and out of action as required.

If power is used, the engine is either connected directly to the turning gear, or this latter is actuated by means of a hydraulic motor and accumulator.

The necessary orders for the turning of the cupola are given through speaking tubes communicating from the look-out post of the officer in command, who, standing on a step, looks through a sighting hole made in the roof of the cupola, and directs the position of the gun.

The employment of the various chambers in the turret is seen in the Fig. 4.

The cartridges are passed from the magazine up through a tube to the middle platform. The shell magazine is in the central chamber below the cupola. A lift takes the projectiles on to the platform under the cupola, from where they are taken by a crane to the breech of the gun.

III. Gruson's Hydraulic Minimum-Port Carriage C/80.

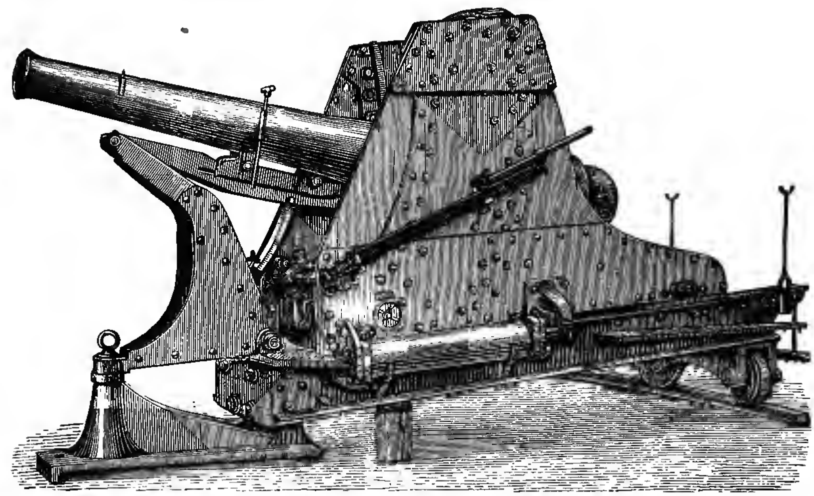
As already stated, the armoured batteries and cupolas are furnished with minimum-port carriages, the special feature of which is that the gun rotates both vertically and horizontally round a point which lies within the port.

The upper portion of the carriage, as Fig 5 shows, is formed of steel plates, and slides on recoil on the lower portion or slide, the recoil being controlled by two hydraulic buffers. The cylinders of these buffers are fixed to the slide, the rods of the pistons, which are pierced with holes, being attached to the upper portion of the carriage. When the carriage recoils, the piston rods are drawn out, and the passage of the fluid in the buffer through the holes in the piston checks the motion.

The gun is elevated or depressed by a hydraulic cylinder the ram of which, by means of a cross-piece, raises or lowers the two trunnion-bearings. These last slide up and down in circular grooves fixed to the brackets of the carriage, the centre of motion being the imaginary pivot in the port. The movement of the gun is controlled by a slide-bar, which, as the Fig. 4 shows, moves on a pivot placed in armoured structures vertically beneath the port. The gun is connected to this slide-bar by a clip-shaped guide-piece in such a manner that on recoil it slides on the bar but always preserves the axis of its bore parallel to the upper surface of the slide-bar. (The axis of the bore thus remains during the movement of the gun a tangent to an imaginary circle of which the centre is the pivot of the slide-bar.)

Fig. 5.

Gruson's Hydraulic Minimum-Port Carriage C/80.



In the smaller carriages the hydraulic ram which elevates the gun is worked by hand-pumps; with the larger ones accumulators are used.

These consist of long cylinders containing liquid, the pistons of which are weighted and operated upon either by hand or steam power. These cylinders communicate with the cylinder of the elevating press in the carriage. On opening a valve the fluid under pressure passes under the ram of the press and raises the gun. When the valve is closed the gun stops, when the escape valve is opened the fluid flows out of the press and the gun sinks.

The accumulators thus act as reservoirs and distributors of power. An important saving of power in the accumulator is effected by using Gruson's differential piston in the elevating cylinder of the carriage instead of the ordinary form of piston, but a description of this is unnecessary here.

The installation of the accumulators can be carried out in different ways.

In batteries with many guns several accumulators are combined, and all the guns are worked from one central reservoir of power.

In isolated turrets the accumulators are located in the basement, and can serve also as hydraulic cranes for changing the guns if necessary. Many carriages are fitted for working both by accumulator and by hand.

Fig. 5 shows a carriage for an armoured battery, which in that case runs on two racers by means of rollers. The pivot for this is seen in the figure. In revolving turrets no training movement is required to be given to the carriage, the latter being as a rule solidly fixed to the sub-structure, as before explained.

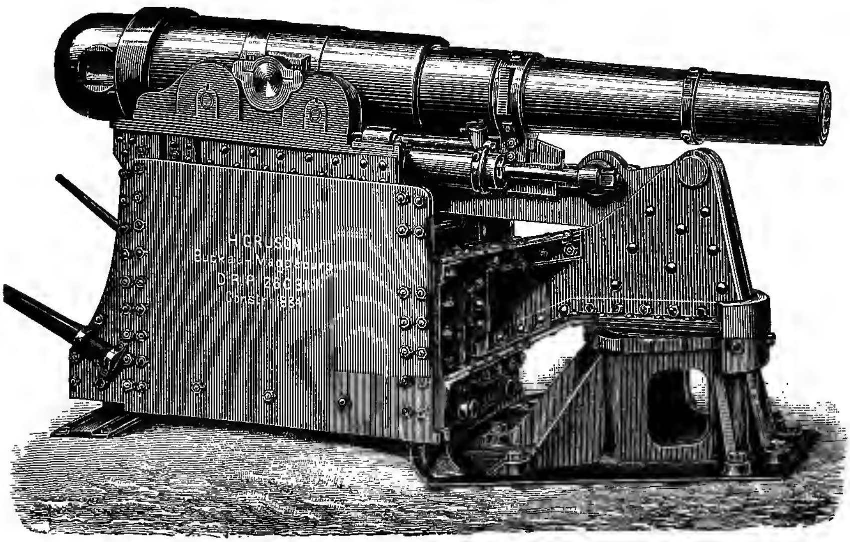
The leading particulars of a number of carriages type C/80, which have been completed, are given in the following table. For other carriages, compare table (page 17), the data there given are approximately correct for the type C/80.

Gun.				Carriage.			Number of Men required for			Time required for Raising the Gun to Extreme Depression and Lowering back to Extreme Elevation.		Shortest Interval between the Rounds.
Calibre.		Length in Calibres.	Weight.	Extreme Eleva-tion.	Extreme Depres-sion.	Weight.	Elevating. Hand Pump.	Elevating. Accumulator.	Training.	Hand Pump.	Accumu-lator.	
in.	cm.	No.	lbs. (about)	Deg.	Deg.	lbs.				Min.	Sec.	Min.
4·7	12	26.6	3,750	25	10	9,930	2	—	2	1	—	1
5·9	15	24	7,100	25	10	15,200	3	—	2	$1\frac{1}{6}$	—	$1—1\frac{1}{2}$
8·3	21	30	24,700	12	6	26,500	4	1	2	4	20—18	$2—2\frac{1}{2}$
9·4	24	30	41,900	12	6	44,100	5	1	2	7	22—20	$2—2\frac{1}{2}$
11	28	35	82,200	12	6	70,600	6	1	3	—	29—25	$2\frac{1}{2}—3$
12	30.5	25	84,900	12	6	70,600	6	1	3	—	34—30	$3—3\frac{1}{2}$

IV. Gruson's Hydraulic Minimum-Port Carriage C/84.

This carriage differs from the type C/80 chiefly in the altered arrangement for lifting the gun. In the latter the elevating press is attached to the carriage, and moves with it on recoil.

Fig. 6.
Gruson's Hydraulic Minimum-Port Carriage, C/84.



As seen in this figure, the carriage proper consists merely of bearings for the gun-trunnions. The slide proper on which the carriage moves in and out is surrounded by a frame of plates bolted together, fitted on the inside with guides for the upward and downward movement, which is given to both slide and carriage by a press placed beneath; the movement of the gun is regulated as in the carriage type C/80 by a slide bar, and the guide-piece is carried round the chace of the gun, as seen in the figure.

The slide-bar rotates round a pivot placed under the port, and the axis of the gun remains tangential to an imaginary circle, of which this pivot is the centre during its elevation or depression.

The recoil cylinders are in this type of carriage made fast to the guide-piece, their pistons being attached to the front part of the slide-bar. As the carriage runs on its slide by means of four rollers, but little of the force of the recoil is received on the slide.

The carriage shown in Fig. 6 is intended for an armoured battery, and runs on two curved racers by means of four rollers. The pivot for the horizontal training is seen in the figure.

Horizontal training being unnecessary in the case of a turret carriage, the frame is dispensed with, or rather is embodied in the substructure of the turret. These carriages can be adapted for either hand or power working. The type C/84 has several advantages over the earlier form. It is more compact, and also simpler, as the elevating cylinder does not take part in the movement of recoil, and moreover, the recoil cylinders and the slide being brought close up underneath the gun, the force of recoil acts at the end of a much shorter lever.

The principal dimensions, &c., of the carriages, type C/84, are given in the following table:—

Gun.				Carriage.				Number of Men required for.			Rate of motion of Gun when worked by Accumulator, Inches per second	Time for up and down movement of Gun, with Accumulator in seconds.	Shortest Interval between two Rounds in Minutes.
Calibre.		Length in Calibres.	Weight (about)	Extreme Elevation.	Extreme Depression.	Weight. Turret.	Weight. Battery. Without Pivot or Racers.	Elevating. By Hand Pump.	Elevating. Accumulator.	Training.			
in.	cm.	No.	lbs. (about)	Deg.	Deg.	lbs.	lbs.						
4·1	10.5	30	2,200	20	5	6,600	8,400	2	—	1	—	—	1
4·7	12	30	4,400	15	5	8,400	10,200	2	—	1	—	—	1
5·9	15	30	8,800	15	5	10,200	11,000	3	—	2	—	—	1—1½
6·7	17	30	15,000	14	5	11,500	13,260	3	—	2	—	—	1½—2
8·3	21	30	26,900	14	5	18,750	20,900	4	1	2	1·6–1·8	20—18	2—2½
9·4	24	30	41,900	13	4	26,500	29,800	4	1	2	1·6–1·8	22—20	2—2½
10·2	26	30	55,100	13	4	35,300	39,700	6	1	4	1·4–1·6	27—24	2½—3
11·	28	30	73,900	12	3	44,100	49,600	6	1	4	1·4–1·6	29—25	2½—3
12·	305.	30	97,000	12	3	50,700	57,300	7	1	4	1·2–1·4	34—30	3—3½
13·8	35	30	165,400	10	2	63,900	72,800	8	1	6	1·2–1·4	35—31	4—5
15·8	40	30	247,000	10	2	79,400	92,600	9	1	6	1·2–1·4	36—32	6—7

CHAPTER II.

Firing Trials of Gruson Chilled Iron Armour during the years 1869—1874.

As already stated, trials with the Gruson armour are divided into two distinct series, those between the years 1869 and 1874, and those between 1882-86. The subject of this chapter is the first series, which we have already described in a pamphlet, but here again summarise.

In doing so we take as our guide Major Küster's account in the "Mittheilungen des Königl. Preussischen Ingenieur-Comités," part 22. The quotations which we give from that account are reproduced word for word.

I.—Preliminary Trials of a Chilled-Iron Armour Emplacement for a 72-pounder (8.3 in.) Gun, at the Tegel range in the years 1869—1871.

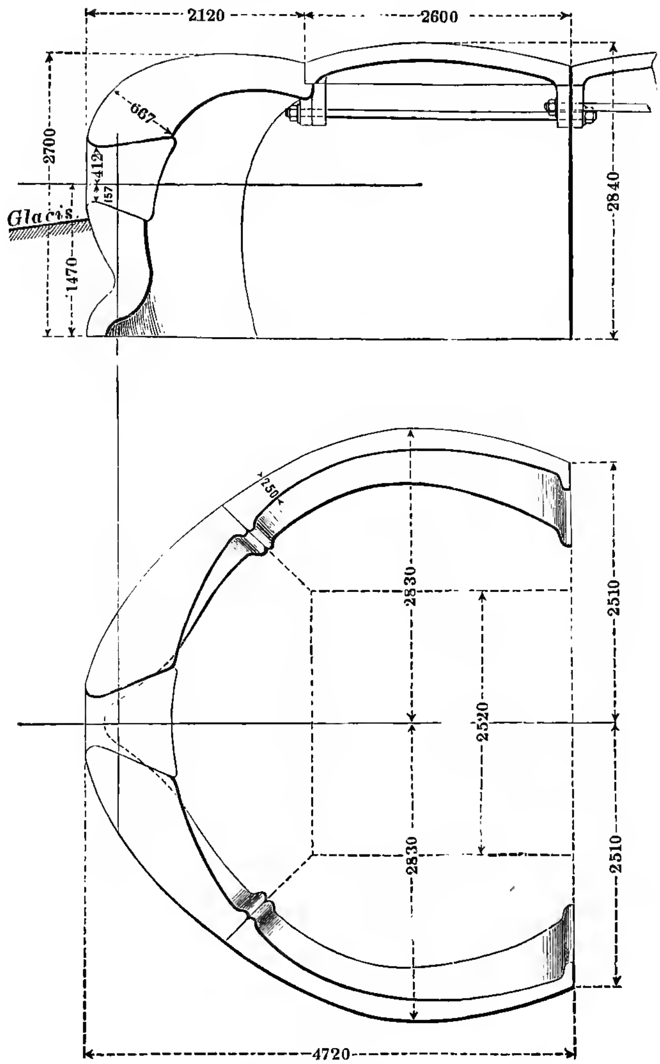
Object and Scope of the Trial.

The trial was intended to clearly demonstrate if Gruson's chilled-iron was suitable for armour, and the programme of the trial did not therefore proceed on the lines of representing, as in the later ones, the conditions of attack such as might occur in actual warfare.

The firing was chiefly carried out with 8.3 in. and 9.4 in. guns, which were principally used against coast batteries. On the other hand, the armour was struck far more frequently than is possible with fire from on board ship. We have for that reason styled this trial a preliminary one.

Fig. 7.

Chilled Iron Armour Emplacement for a 72-pounder 8.3in. Gun.



Vertical and Horizontal Section through the centre of the embrasure.

THE MEASUREMENTS IN ALL SKETCHES ARE MILLIMETRES.

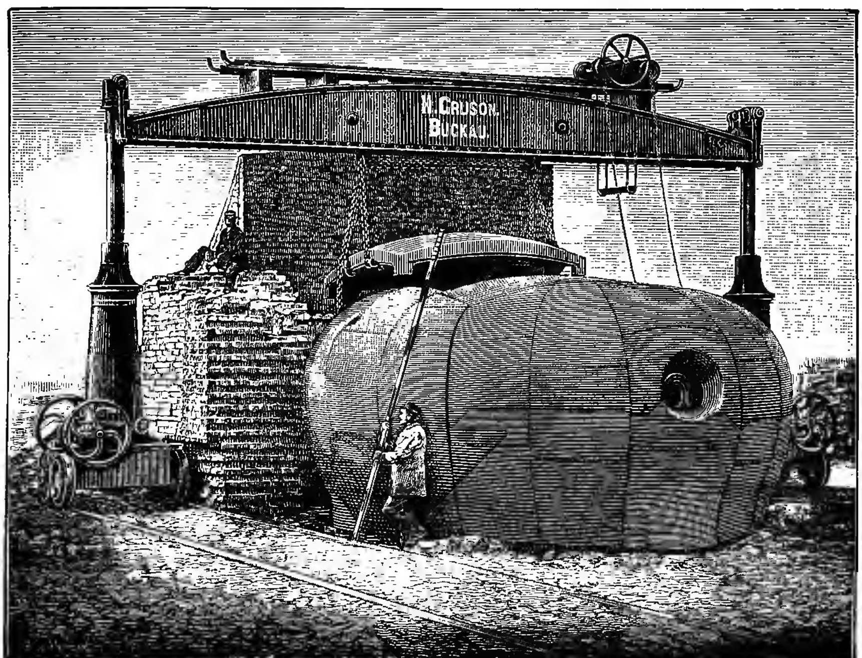
As the first trial of chilled iron armour, it possesses an especial interest; and as the design of the structure had been prepared without any data derived from earlier trials, and was indeed merely the result of an estimate of the power of the attack, it is desirable to give a somewhat ample description of the emplacement.

Fig. 7 shows a vertical and horizontal section through the centre of the embrasure.

The emplacement was composed of a curved embrasure plate, two side and two roof plates. The peculiar shape and principal dimensions are seen in the figure below.

Fig. 8.

Chilled Iron Armour Emplacement for a 72-pounder 8.3 *in. Gun in course of erection.*



From a Photograph.

The side plates and also the roof plates were tied together by wrought-iron connecting rods; the edges of the roof plate are shown in the horizontal section by dotted lines. The emplacement rested against masonry, of which the second plate shown in the figure formed the roof. The whole structure was covered with earth, as shown in Fig. 9, so that only the embrasure plate was exposed to the attacking fire.

The peculiar curve at the base of the embrasure plate, seen in Fig. 7, was formed to receive the pivot of the minimum embrasure carriage, which was fastened to a ground plate not shown in the figure. All the plates were cast in a foundry specially erected at Tegel for that purpose.

Fig. 8 shows the emplacement in course of construction.

On the surface of the plates, in Fig. 8, may be seen the square seams left in the casting, which was then made in several small chill-moulds placed together, and not in one large mould for each plate, as is now the case.

1.—Trial against the Embrasure Plate of a Chilled Iron Armour Emplacement for a 72-pounder (8.3 in.) Gun.

In February, March, and December, 1869.

The particulars of the attack, as well as the effect of the various rounds, are tabulated in the following table :—

The chief data given in the first edition are completed from the pamphlet, "Vergleichende Zusammenstellung der neuesten Schiessversuche gegen Panzer von Otto von Giese."

	No. of Round	Gun.	Shot.	Charge.	Distance. yards.	Velocity. yards.	Energy. foot-tons.	Point of Impact	Effect.
27/2/69	1	Rifled bronze 24pdr (5.9 in.) hooped Gun	Solid steel 80.5 lb. wt	6.6 lb.	328	269	365	*Left half of embrasure plate	White splash marks Shot broke up
	2	,,	,,	,,	,,	,,	,,	,,	,,
	3	,,	,,	,,	,,	,,	,,	,,	,,
	4	,,	Cast-iron shell 60.4 lb. filled	,,	,,	,,	,,	,,	Shell exploded covering the target with earth and brickwork
	5	,,	Shell 62.4 lb. filled	,,	,,	,,	,,	,,	
	6	Rifled 72 pounder (8.3 in.) Gun	Solid steel 230.4 lb.	26.5 lb. P. P.	1107	329	1,567	Right near the port	Slight indent
	7	,,	,,	,,	,,	,,	,,	Right low	Indent 0.3 in. deep
	8	,,	,,	,,	,,	,,	,,	Left edge of port	No results Inside, cramp broken
	9	,,	Solid chilled iron 221.6 lb.	,,	,,	336	1,560	Left side of plate	Slight indent
	10	Adapted 72 pounder (8.3 in.) hooped Gun	,,	33.1 lb. P. P.	,,	368	1,877	Lower edge of port	Dismounted the gun
11/3/69	11	,,	,,	,,	,,	,,	,,	Left, near the port	Indent 0.4 in. deep, 2 cracks about 9.8 in. long
	12	Rifled 96 pounder (9.4 in.) Gun	Solid steel 355.7 lb.	52.9 lb. P. P.	,,	369	3,049	Right, near the port, in line with the centre	Circular indent and crack to the port, a second up to the left
	13	,,	Chilled shell weighted 319.7 lb.	,,	,,	392	3,081	Right, and above the port	Indent 0.4 in. deep
	14	,,	Chilled shell weighted 338.5 lb.	,,	,,	380	3,081	79 in. to right, and in line with centre of port	Crack made by Rd 12 extended to 39 in. on inside
	15	,,	,,	,,	,,	,,	,,	47 in. to right and level with centre of port	Longish indent Crack lengthened to 59 in.

* Right and left is taken from the attacking gun.

	No. of Round	Gun.	Shot.	Charge.	Distance. yards.	Velocity. yards.	Energy. foot tons.	Point of Impact.	Effect.
16/12/69.	16	Long 72 pounder (21 cm) hooped Gun. The axis of the bore made an angle of 38° with the centre line of the armoured emplacement	Chilled shell weighted 217.2 lb.	37.5 lb. P. P.	166	448	2716.4	7 in. near the right edge of the port on No. 12	Outside and inside crack lengthened
	17	,,	,,	,,	,,	,,	,,	,,	Pieces scaled off. Cracks lengthened and widened
	18	,,	,,	,,	,,	,,	,,	,,	
	19	,,	,,	,,	,,	,,	,,	,,	Pieces scaled off to 6.3 in. deep. Inside crack widened New cracks
	20	,,	Solid chilled cast-iron shot 221.6 lb.	,,	,,	443	3706.7	,,	Part of the armour fell where cracks crossed. Pieces on inside also scaled off
	21	,,	,,	,,	,,	,,	,,	,,	Pieces of plate displaced. Connexion of plates much loosened
	22	,,	,,	,,	,,	,,	,,	,,	The upper portion of the port plate between the chief cracks fell down in front of the port

Summary: The port plate had, omitting the two filled common shells, received 20 shots with a total energy of 42,387.5 foot tons, and shown a power of resistance which, considering its small thickness, is surprising.

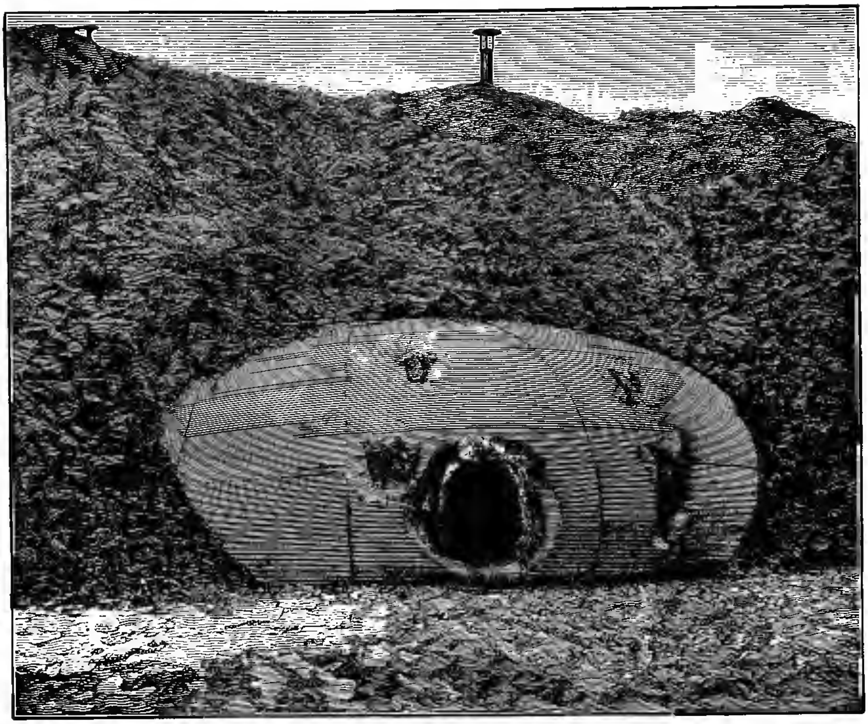
As the second column of the Table shows, the attack was gradually increased, and it was only by the continued firing from the 9.4 in. gun that the armour began to break up.

B2

Fig. 9.

The Port Plate of the Armoured Emplacement

for a 72 pounder (8.3 in.) gun after the 15th round, 11/3/69.



From a Photograph.

Fig. 9 shows the armour at the end of the firing with the 9.4 in. gun.

The cracks formed were so fine that they do not appear visible in the photograph.

To save ammunition, the firing was then continued with the long 8.3 in. hooped gun at a distance of 166 yards. It should be noted that 8 shots, rounds 12 and 16 to 22, struck on about the same place, close to the port. The experiment was intended merely as a test of the material, without the conditions of actual warfare, but was, nevertheless, a very severe trial on account of the small thickness of the plates.

The Experimental Committee considered the applicability of chilled cast-iron as a material for armour to be thoroughly demonstrated, even though doubts were expressed as to the size and weight of the plates necessary.

All the shot which struck broke up.

2. Trial against the Left Side-plate of a Chilled Iron Armour Emplacement for a 72-pounder (8.3in.) Gun.

14th and 21st April, 1870.

Gun: Rifled bronze 24 pounder 5.9 in. (15 cm) gun.
Distance: 166 yards (152 m.)
Shot: Solid chilled 76.5 lb. (34·7 kg.) weight.
Charge· 5.5 lb. (2·5 kg.) to 6.6 lb. (3 kg.) P. P.

The plate at the mean point of impact had a thickness of 7.1—10.2 in. Six rounds struck at angles between 80° and 90°.

The three first hits produced no result; the three last widened a casting seam, and formed several hair cracks in the plate.

The trial was resumed on the 21st April with the 5.9 in. hooped gun.

Gun: 24 pounder 5.9 in. (15 cm) hooped gun.
Distance: 166 yards (152 m.)
Shot: Chilled shell, weighted with sand to 78.3 lb. (35.5 kg.)
Charge: 11—13.2 lb. (5 to 6 kg.) P. P

The rounds were aimed at the left, and the least injured, portion of the plate. Mean angle of impact 70° to 75°. Thickness of plate 10.2—10.6 in.

The first six hits—Nos. 7 to 12—caused a number of cracks through the plate. Rounds 12 to 16 enlarged the cracks, and broke off flat pieces. No. 17 produced a hole of 11 in. diameter in the plate. No. 18 broke off several pieces of the plate.

3. Trial against the Right Side-plate of a Chilled Iron Armour Emplacement for a 72-pounder (8.3in.) Gun.

11th June, 1870.

Gun: 24-pounder 5.9 in. (15 cm) hooped gun.
Distance: 82 yards (75 m.)
Shot: Solid chilled 74.9 lb. (34 kg.) with blunt point.
Charge: 13.2 lb. (6 kg.) P.P.

Angle of impact about 72°.

The right plate was of harder character than the left one.

Mean thickness of plate 10.2 in. The first five rounds produced a number of through cracks.

After the sixth shot, a piece of the plate threatened to fall, but four additional shots on the same place failed to dislodge it.

The cracks showed that the seams formed in casting injured the strength of the plate.

4. Trial against the Dismounted Roof Plate of a Chilled Iron Armour Emplacement for a 72-pounder (8.3 in.) Gun.

7th October, 1871.

Gun: 8.3 in. (21 cm) Mortar.
Distance: 41 yards (37.5 m.)
Shot: Weighted Shell, 176.5 lb. (80 kg.) weight.
Charge: 4.4 lb. (2 kg.) with the first, 8.8 lb (4 kg.) with remaining rounds.
Velocity of impact: 229 yards (209 m.)
Energy: 581.5 foot tons (180 mt.)

The plate, of mean thickness of 7.1 in., was so placed against its supports as to be struck in the centre at an angle of 90°.

The four shots which struck produced no effect.

Summary of 2, 3, and 4: Considering the moderate thickness of these plates, the resistance of the left side plate must be considered excellent.

The trial of the right side plate demonstrated the disadvantage of making the moulds in pieces, the casting seams producing cracks.

That against the roof plate showed the effect of mortar fire against iron constructions to be very slight.

All the projectiles which struck broke up.

II. Firing Trials against Chilled Cast-Iron Armour for Inland Fortification in the Years 1873—74.

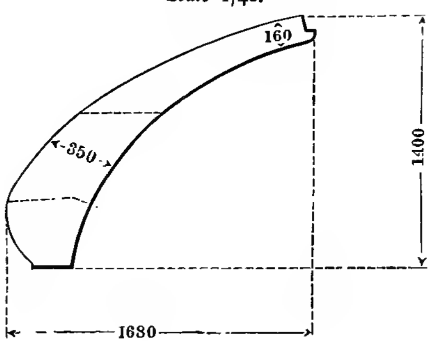
1. Firing Trial against the First Chilled Iron Armour Turret for two 5.9 in. (15 cm) Guns.

At the Tegel Range, March, 1873.

Scope and Programme of the Trial.

The trial was intended to form a comparison with the experiments in 1871—72 against a wrought-iron turret designed by Major Schumann, of the Royal Prussian Engineers. This turret had a cylindrical cupola, formed of several plates; the thickness of the port plate was 12.4 in. and the thickness of the plates decreased to 4.7 in. at the back of the cupola.

Fig. 10.
Profile of the Port Plate of the First Chilled Iron Armour Turret for two 5.9 *in. Guns. Scale* 1/40.



The trial of the Schumann turret had given comparatively favourable results, and as Gruson had offered to construct at less cost one of his turrets of equal resisting powers, it seemed desirable to adopt not only the same programme of trial, but also to follow the thickness given to the wrought-iron plates. In accordance with this, the port plate of the chilled iron turret was given a maximum radial thickness of 13.8 in. (see figure 10), which, both in the two side plates, the back plate, and the roof plate, decreased to 4.7 in. at the back. The maximum radial thickness of the glacis armour was 9.1 in. in front, the height and extension to the front being each 3.28 feet.

The weight of the port plate was 12.4 tons, of the side plate 10.1 tons, and the turret was mounted on the same sub-structure which had served for the Schumann turret.

Guns: Short 5.9 in. (15 cm.) naval hooped gun; 5.9 in. (15 cm.) bronze gun.

Distance: 412 yards (377m.)

Shot: 5.9 in. (15 cm) filled shell, 61 lb. (27·7 kg.) weight.

5.9 in. (15 cm) chilled shell, both filled and weighted 77.2 lb (35 kg.) weight.

5.9 in. (15 cm) solid chilled shot, about 79.4lb. (36 kg.) weight.

Charge: Varying from 3.1 lb. (1.4 kg) cannon powder to 13.2 lb. (6 kg.) prismatic.

Velocity and energy: On account of the variety in shot and charges—not separately recorded.

Major Küster, speaking of the results of this trial, says:—

"On the whole, the front plate received 55 hits, of which about 60 per cent. were chilled projectiles, the right* (left, looking from the gun) side plate 13 shots, of which 9 were chilled projectiles; the glacis plates 23 hits, 19 being chilled projectiles.

"Against the roof of the turret, 2 hits from the 11 in. rifled mortar, distant 1,585 yards, with 8.8 lb. charge and long shell weighted to 441 lb.

"The long or common shell which struck the solid armour produced no visible effect at the point of impact, on the other hand the chilled projectiles produced shallow indents and splintering, for the most part with concentric and also frequently radial hair cracks, which last, by the vibration of the next hits, were lengthened and deepened and eventually divided the plate into several parts. Sometimes also thin pieces of plate were knocked off the exterior of the armour, **but on no occasion was there any penetration into the latter.**"

Additional evidence was furnished of the unsuitability of using chilled iron in plates of small thickness when exposed to mortar fire, the roof plate of the cupola being fully breached by the second shot of the 11 in. mortar at a distance of 1,585 yards (charge 8.8 lb., shell 441 lb., elevation 30°).

By far the best resistance was shown by the glacis armour, which did not succumb to 23 chilled shots from the 5.9 in. hooped gun striking together on a small surface.

Summary: The general result of the trial is rightly considered by Major Küster as unfavourable. In determining the dimensions of the chilled iron, it had been forgotten that the radical difference between chilled iron and wrought iron forbade a similarity in this respect in the two systems, as was the case in this instance, and in consequence the advantageous properties of chilled iron for armour could not be shown.

Even if this trial clearly proved that when the thickness of

* Major Küster's "right left" means looking from the turret. As during the new trials, right and left is always taken to mean looking from the attacking guns, we shall adopt this latter course also.

plating is small, wrought iron is preferable to chilled cast iron, it did not the less give indications that in the case of greater thicknesses, cast-iron would have the preference.

It was noticed **that all the projectiles on striking broke up into countless fragments;** and, further, it was proved that the armour could only be destroyed by breaking it into pieces, which, however, the extreme hardness of the material and its extraordinary resistance to molecular displacement rendered a very difficult task, qualities which were greatly assisted by the double curved form, and likely to be still more strongly displayed with increased thicknesses of iron.

In accordance with these conclusions, the Committee already, at the termination of these first trials, recommended the use of chilled iron for glacis armour, giving, however, a provisional preference to the use of wrought iron for the turret itself.

It was considered desirable to undertake further trials, as the possibility seemed in no way excluded of obtaining a practically favourable result by giving an improved form and increased strength to the armour.

2. Firing Trial against the Second Chilled Iron Turret for two 5.9 in. (15 cm) Guns.

At the Tegel Range, May—July, 1874.

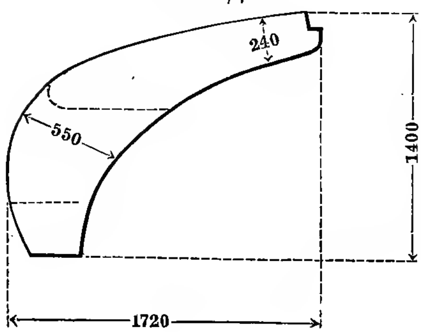
Scope and Programme of the Trial.

At the conclusion of the above described trial, Gruson had professed his readiness to supply, at his own cost, a new turret of increased dimensions, and more in accordance with the conditions shown to be essential.

At the suggestion of the Experimental Committee, the War Department undertook to supply the ammunition, but directed at the same time that the trial should proceed in accordance with a definite aspect of the subject obtained from a consideration of the numerous special necessities of the case brought to light by the preliminary trial, that the trial should approach in its conditions as near as possible actual reality, for the determination of which, use was to be made of the data furnished by siege operations.

It was assumed that the siege corps would be unprovided with the heaviest armour-piercing guns, and that the firing would commence with 5.9 in. long shell.

Fig. 11.
Profile of the Port Plate of the Second Chilled Iron Armour Turret for 2 5.9 in. Guns. Scale 1/40.



During a thirty days' siege it was calculated that the armour of the turret would be struck by from 1,000 to 1,500 shells, and it was considered entirely sufficient if a quadrant of the turret under trial withstood 200 long shells from the 5.9 in. hooped gun at a distance of 1,093 yards.

If this proved to be the case, then the armour was to be attacked by the 6.7 in. hooped gun, a condition accepted with confidence by Mr. Gruson.

With respect to a further trial being made with heavy siege-guns, fire would then only be opened on the turret, supposing circumstances allowed it, when the assailant had advanced as near as possible—say to 1,093 yards from the turret—so as to make the utmost use of chilled iron shell.

The first named series of rounds was therefore to be followed by a second, of 150—5.9 in. chilled shell, delivered on the second ring plate.

And, lastly, as it was within the bounds of possibility that a heavy coast battery gun of 4.9—5.9 tons in weight might be brought to a distance of 1,093 yards from the turret, a third plate was to be attacked with 20 chilled shells from the 6.7 in. hooped gun, and finally, the roof plate with five hits from the 11 in. mortar.

The Armour to be tried consisted of four newly made plates, viz.:— One port plate, two side, and one roof plate, which were placed on the original sub-structure, and supported in rear by an old port plate rejected at the first trial on account of faults in casting.

The profile of the port plate is shown in Fig. 11, which exhibits chiefly an increase in the radial thickness at the centre of the port from 13.8 in. to 21.7 in., and a corresponding thickness was given to both side plates 16.5 in.) The roof plate was also 16.5 in. thick. The glacis armour remained unaltered and was merely supplemented with an additional plate.

The change in profile between Figs. 10 and 11 of the external curve of the port plate is at once observable.

The first trial had brought to light the fact that shot striking the upper part of the curved surface at an acute angle did more damage than those which struck lower down at a greater angle. This curious result was explained by the fact that the ordinary cast-iron and chilled cast-iron shot in the first case broke up into large pieces, which made considerable indents into the surface of the armour, and in the latter case broke up into atoms, causing visibly less effect. In consequence of this the new plate was given a more rounded form, as seen in Fig. 11, so that projectiles should strike at a greater angle. The weights of the port, left side, and right side plates were respectively 19.7 tons, 16.4 tons, and 16.36 tons.

A. Trial against the Port Plate of the Second Chilled Iron Armour Turret for two 5.9 in. (15 cm) Guns.

(a) Attack of the Port Plate with 193 5.9 in. (15 cm) Long Shells.

Guns: Two 5.9 in. (15 cm) hooped guns C/72.
Distance: 165 yards (150 m.)
Shot: 5.9 in. (15 cm) long shell, filled, total weight about 61.1 lb. (27.7 kg.)
Charge: 9.1 lb. (4.14 kg) P. P., equivalent to 13.7 lb. (6.2 kg.) at 1,093 yards (1,000 m.)
Striking velocity: 400 yards (366 m.)
Energy: 612 foot tons (189,46 mt.)

The stipulated 193 hits were obtained in two days with 200 rounds, of which ⅓ struck the flatly curved part above the port, and ⅔ the part beneath it, but in general the effort was made to distribute the hits equally over the whole surface. Major Küster says on page 20 of his report on the trial:

> "The result of this first part of the trial was **completely satisfactory**, the turret at the end of the firing being practically uninjured.
>
> "At the 33rd shot a hit on the right edge of the right port (the left one looking from the gun) broke off a piece about 2 in. wide and deep, which injury, however, though the same spot was repeatedly struck, was only increased to a small extent, and that only superficially. The 70th round produced a fine superficial crack, starting from the injured place and running towards the inside of the port.
>
> "The effect of the individual rounds was only recognisable on the plate by oblique hits, causing indents about 0.08 in. deep, otherwise the hit was unrecognisable except by a discoloration of the part struck."

In view of this exceptionally favourable behaviour of the plate, it was decided, before proceeding with the programme, to attack it with 5.9 in.

chilled iron shell so as to establish a comparison between it and the slighter side plate which was to undergo the same ordeal with chilled shell, previous to inflicting more severe injuries with the 6.7 in. shell.

(b.) Attack of the Port Plate with ten 5.9in. (15 cm) Chilled Shells.

Gun : As before.

Distance : As before.

Shot : 5.9 in. (15 cm) chilled shell, weighted about 77.2 in. (35 kg) weight.

Charge : 10.6 in, (4.8 kg) P.P.

Striking velocity : 383.6 yards (350 m.)

Energy : 705.98 foot tons (218.57 mt.)

All 10 rounds struck between the 2 ports.

These hits produced, as Major Küster says, no visible effect.

It was therefore decided to proceed with the programme, and firing re-commenced with the 6.7 in. gun.

(c.) Attack of the Port Plate with twenty 6.7 in. (17 cm) Chilled Shells.

Gun : Short naval 6.7 in. (17 cm) hooped gun.

Distance : 165 yards (150 m.)

Shot : 6.7 in. (17 cm) chilled shell, weighted, about 121.5 lb. (54.9 kg) weight.

Charge : 20 lb. (9.10 kg) P.P., equivalent to 26.5 lb. (12 kg) at 1,093 yards (1,000 m.)

Striking velocity : 441.6 yards (404 m.)

Energy : 1,478.05 foot tons (457.6 mt.)

The first shot struck 7.9 in. above the glacis plate on the middle line, and produced no result.

Rounds 2 to 6 produced two short cracks running from the upper and lower edge of the right port.

Rounds 7 and 8 lengthened and deepened these cracks, passing right through the plate and separating the right corner, attributed by Major Küster to the defective condition of the upper girder of the sub-structure. Rounds 9 to 20 were fairly distributed over the plate, their effect consisted in a cracking off of the surface 10 in. long and wide and 0.4 in. deep. No additional cracks were made.

(d.) Attack of the Port Plate with sixty-five 5.9 in. (15 cm) Chilled Shells.* Details of Attack as under (b.)

The first eleven hits produced a through crack between the two ports,

* This part of the firing was only carried out at the conclusion of the whole trial in July, 1874.

which ran from the edge of the left port to the lower border of the plate. Rounds 12 to 47 increased the cracking and disintegration of the plate.

The 49th hit produced a vertical crack, running from the horizontal crack to the lower edge of the plate. Nos. 50 to 65 increased the damage. Portions of plate had been shaken loose on the inside, and had fallen down.

Summary: The plate had altogether received:

No. of hits.		Projectile.	Energy.	
193	5.9 in. (15 cm)	Long Shell	611.96 foot tons	(189,46 mt.)
20	6·7 ,, (17 ,,)	Chilled Shell	1478.05 ,,	(457·60 ,,)
75	5·9 ,, (15 ,,)	,, ,,	705·98 ,,	(218,57 ,,)
288 rounds with		... ...	200.615 foot tons	(62,110 mt.) energy.

Nevertheless, in the opinion of the Committee, the breaching of the plate was still far from being arrived at.

Major Küster sums up (page 24) that the plate **had displayed such a high degree of tenacity** that it would **doubtless have still resisted a far greater number of such blows.**

> "That, in addition, the plate had shown itself to a high degree capable of resisting 6.7 in. armour piercing shell; and, beyond that, a very considerable number of 5.9 in. chilled shell, so that the front plate seemed not only to have satisfied the programme, but was capable of **withstanding a far severer ordeal**, and with complete success could serve as a basis for future constructions of this category of armour-plating both as regards form and thickness."

All the shot which hit broke up.

B. Trial against the Left Side Plate of Second Chilled Iron Armour Turret for two 5.9 in. (15 cm) Guns.

Gun: Two 5.9 in. (15 cm) hooped guns C/72.
Distance: 165 yards (150 m.)
Shot: 5.9 in. (15 cm) chilled shell, weighted, about 77.2 lb. (35 kg weight.)
Charge: 10.6 lb. (4.8 kg) P. P.
Striking velocity: 383.6 yards (350 m.)
Energy: 705.98 foot tons (218,57 mt.)

The hits were proportionately distributed over the whole plate, and produced abrasions up to 0.3 in. in depth.

After the 12th shot, hair cracks connecting the points of impact were formed. The 39th hit made a vertical crack from the upper to the lower edge of the plate, separating the plate into two unequal parts. Hits 40 to 64 were placed on the larger portion and caused other two vertical and horizontal through cracks. Beyond the cracks no effect was visible on the inside.

The firing was continued against this plate until the conclusion of the experiment.

Hits 65 to 103 produced cracks and abrasions up to 3.9 in. in depth.

No. 104 hit dislodged small pieces of metal on the inside.

Nos. 105 to 133 produced a rapidly increasing disintegration of the fractured parts of the plate, and at the

134th round, a projecting portion of the armour was raised up, causing an opening through the plate.

C. Trial against the Right Side Plate of the Second Chilled Iron Armour Turret for two 5.9in. (15 cm) Guns.

Details of attack as under B.

The right plate was harder than the left, and the abrasions in consequence less.

The first through crack was produced by the 37th hit, and divided the plate from top to bottom. Hits 38—64 produced two other through cracks, vertical and horizontal, as well as a number of hair cracks.

The trial was discontinued after the 64th round, as this plate had behaved under the fire exactly as the left one.

Summary of B and C:

Although, in the case of the left side plate, the number of hits (150) assigned by the programme had not been reached, but only 134, the Committee considered the behaviour of this plate was favourable. They reported also that the requirement of 150 hits was enormously high, and that the plate had received the last 70 hits under peculiarly unfavourable conditions, as, the roof plate being injured, the proper supports were lacking. It is of interest to note that the Committee, as the result of their observations, recommended also for the side plates that the profile should be made to correspond with that of the port plate, that is, more perpendicular, or rounded at the bottom part and more sloped towards the upper portion, **because the formation of cracks, as a rule, began with oblique hits.**

No difference of behaviour between the softer left and harder right plate was established.

All the shot broke up on striking.

D. Trial against the Roof Plate of the Second Chilled Iron Armour Turret for two 5.9 in. (15 cm) Guns.

Gun: Rifled experimental 11 in. (28 cm) mortar.
Elevation: 30°.
Distance: 962 yards (880 m).
Shot: 11 in. (28 cm) long shell of 441 lb. (200 kg) weight, weighted.
Striking velocity: 107.8 yards (98.6 m).
Energy: 319.8 foot-tons (99 mt), equivalent to the energy of the 8.3 in. (21 cm) shell at 2,732.5 yards (2,500 m).

Five hits were obtained from 45 shots.

Nos. 1 and 2 struck the sighting hood and had no result.
No. 3 made two through radial cracks to the edges of the plate.
No. 4 as 1 and 2.
No. 5 made two new radial cracks to the edges of the plate, so that it was broken into 5 pieces.

Summary: In the opinion of the Committee, the roof plate had not satisfied the requirements, and they recommended for subsequent construction the use of wrought iron roof plates should be retained.

The general result of the trial as regards A to C is stated by Major Küster to be that not only had it been proved that chilled cast iron was applicable in the fullest manner as a material for armour for revolving turrets for land fortifications, but also that sufficient data had been obtained for determining all the more important details of construction.

III.— Trials against Chilled Iron Armour for Coast Defences in the Years 1873—4.

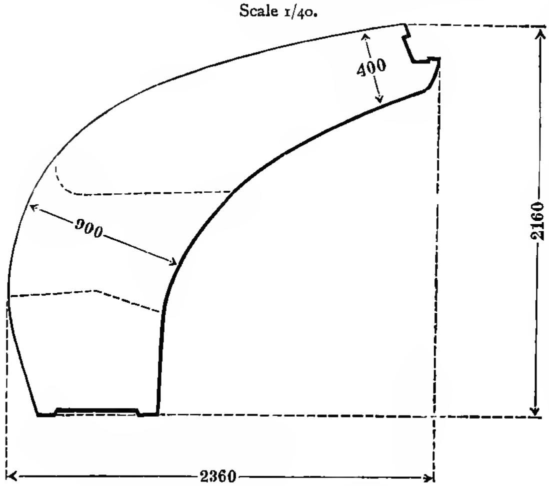
1.—Trial of the first Port Plate of a Chilled Iron Armour Battery for 8.3 in. (21 cm) Guns.

On Gruson's Firing Ground at Buckau,

5th December, 1873.

Scope and Programme of the Trial.

Fig. 12.
Profile of a Port Plate of the Chilled Iron Armour Battery for 8.3 *in. Guns.*
Scale 1/40.



Already, in accordance with the results of the preliminary trials in 1869, the Prussian Government had ordered from Mr. Gruson chilled armour for Langlütjensand. As some difference of opinion prevailed among engineers on the subject of these trials, a condition was attached to the order that certain portions of this battery were to be subjected to trial under conditions that they must satisfy certain tests.

These were that a port plate should be struck by 2 shots, one over the other, close to the edge of the port, from the 11 in. gun with a charge corresponding to that of 88. lb. (the service charge) at 820 yards, without becoming unserviceable thereby, or that cracks formed should involve the plate being unserviceable.

These trials had an entirely different aspect to the previous ones, inasmuch as there it was a question of land fortification, for which armour must be capable of withstanding a very great number of hits from medium guns, whereas coast fortifications are only liable to be attacked by a small number of shot, but these of the heaviest guns.

The subject of the trial consisted of an armoured battery like that previously described, and was composed of two port and three pillar plates, together with the pivot and cover-plates belonging thereto. The construction is shown in Figs. 13 and 16; Fig. 12 shows the profile of the port

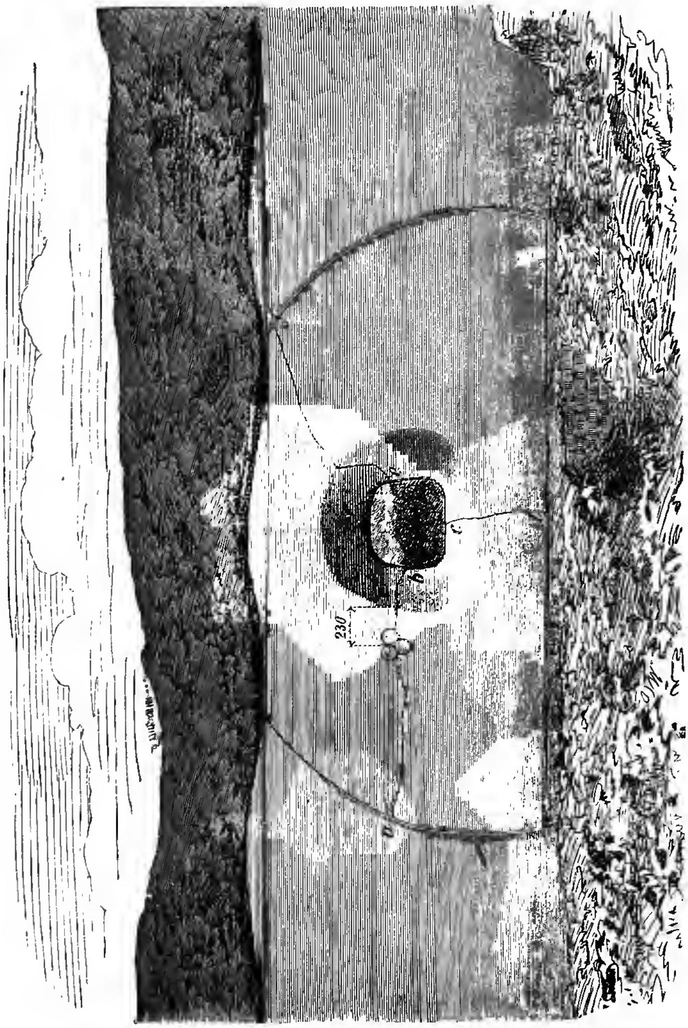


Fig 13.

The first Port Plate of the Chilled Iron Armour Battery for 8.3 in. (21 cm) guns, after the third shot, 5/12/73.

From a Photograph.

plate, the curve corresponding to that which had been shown to be the best during the first trials at Tegel. The target was provided with a strong wooden shield in front, which protected the attacking gun against broken pieces of shot flying off.

The breadth of the port plate was 14.4 ft. below, and 10.8 ft. at the top. The weight, 42 tons.

Gun : 11 in. (28 cm) gun.

Distance : 17.5 yards (16 m).

Shot : 11 in. (28 cm) chilled shell weighted, total weight, 512 lb. (232 kg).

Charge : 75 lb. (34 kg) P.P., equivalent to 88 lb. (40 kg) at 820 yards (750 m).

Velocity of impact : 420 yards (385 m).

Energy : 5,685 foot-tons (1,760 mt).

The effect of the first shot was a small and hardly perceptible indent and a short hair crack, and exhibited in a surprising manner the extraordinary reacting power of the material.

The effect of the second shot, which struck on exactly the same place, was cracks a, b, c, about 0.08 in. broad, of which, however, only *a* was visible at the back of the plate. Although the port plate had thus complied with the conditions of the contract, it was decided, on account of the interest attaching to the question, to place a third shot on the same spot, which formed, in addition to a fine crack at the point of impact, the crack e. f.

Summary : The plate had exceeded the conditions of the contract. As however, the result of the trial had thrown no direct light on the total resisting power of the material under prolonged attack, it was decided to have a further trial against the second port plate, and to represent the conditions of warfare by distributing the hits over the surface of the plate.

All shot broke to pieces on impact.

2.—Trial of the Second Port Plate for a Chilled Iron Armour Battery for 8.3 in. (21 cm) Guns, at Gruson's Firing Ground at Buckau.

27th July and 21st August, 1874.

Scope and Programme of the Trial.

The trial of the second port plate was, in the strict sense of the word, to be a test of the material, and the firing to be continued until the plate was breached, without consideration of the accepted conditions under which in war the attack of a coast battery would be made. It was, moreover, arranged to ascertain the result after the 10th hit, so as to enable a parallel to be formed with the earlier trials carried out in England.

The weight of the trial plate was 44 tons.

Gun: 11 in. (28 cm) gun.

Distance: 17.5 yards (16 m).

Shot: 11 in. (28 cm) chilled shell, weighted; total weight, 512 lb. (232 kg).

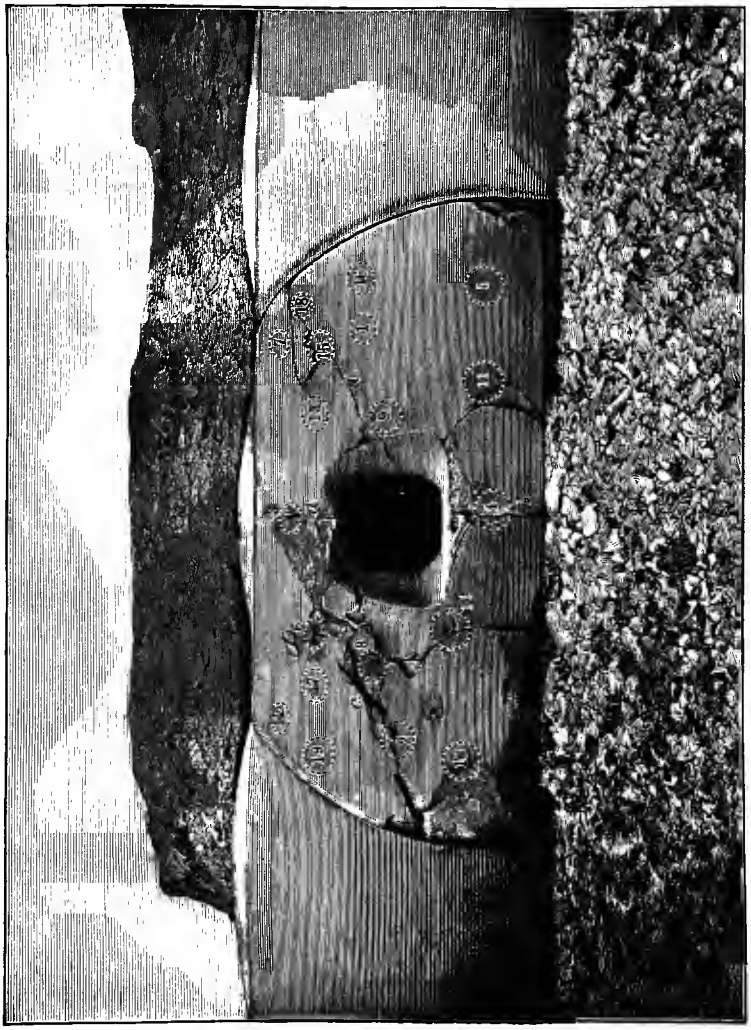


Fig. 14.

The Second Port Plate of the Chilled Iron Armour Battery for 8.3 in. (21 cm) Guns, after the 19th Shot. 21/8. 74.

From a Photograph.

Charge: 75 lb. (34 kg) P.P., equivalent to 88 lb. (40 kg) at 820 yards (750 m).

Velocity on impact: 420 yards (385 m).

Energy: 5,690 foot-tons (1760 mt).

The sequence, as well as the points of striking of the various hits, are shown in fig. 14. The two first shots, which struck the plate at angles of 79° and 52°, had no effect whatever; the third (at an angle of 36°) caused crack *a*, visible at the back of the plate.

The fourth hit produced crack *b*, under *a*, splitting the plate into two halves, also crack *c*.

Rounds 5 to 10 made an external crack *d*, and an abrasion about 3 in. deep near the left upper edge of the port.

The condition of the plate after the 10th round was observed. At the back of the plate cracks *a*, *b* and *c* were visible.

The trial was considered (Küster, page 47) to be more severe than that made with a wrought iron plate in England in 1871, which was judged to have shown a more than needful resistance when it withstood nine rounds from a 12 inch gun, with a total energy of 43,000 foot tons. In that trial the two external layers of the English armour were perforated by all the shot, and the third injured, whilst the chilled armour had received no material injury on the inside, and had in no way lost its interconnexion.

> "We," says Major Küster in conclusion, "may state, without hesitation, that a port plate of the construction and dimensions as in the experimental plate, would fulfil all probable requirements of actual warfare as regards its power of resistance. This favourable judgment," he adds, page 48, "was further confirmed, and that to a degree beyond all expectation, by the subsequent trial of the 21st August, 1874."

The conditions of attack were the same as in the first part of the firing. Round 11 (continued from the first part) cracked the plate through from the point of striking to the under edge of the plate. No. 12 increased this crack. No. 13 dislodged a small piece on the left upper quarter of the plate. Nos. 14 and 15 produced cracks on the inside of the plate, mostly at the lip of the port. No. 16 broke off a narrow strip from the adjoining pillar plate. 17 to 19 remained without visible effect.

After the 19th round the firing was suspended at the request of the Committee, on account of the demolition of the protecting shields, the plate having withstood nearly double the number of hits which probability assigned as likely to strike it.

Following this the **middle pillar plate** was tested, one shot being fired at it without effect, excepting a slight indent. This pillar plate was subsequently used in the construction of the battery at Langlütjensand, as the effect of the hit was so slight that the point where it struck was with difficulty discoverable.

Summary: The plate had withstood nineteen 11 in. chilled shells with a total energy of 108,010 foot-tons, without suffering any material alteration of form. It is true that the second series of rounds had dislodged certain portions which had been loosened by cracks. Nevertheless, the armour must, in its subsequent condition, be considered to have without question retained its protecting power, which the Experimental Committee admitted.

The trial was, as already stated, a crucial test of the material and not a trial under conditions of warfare, and the result may be summarized that the 8.3 in. battery had shown a considerable surplus of resisting power against the attacking guns of that date.

3. Trial of a Roof-plate for a Chilled Iron Armour Battery for 8.3 in. (21 cm) Guns.

21st August, 1874.

Scope and Programme of the Trial.

Firing against the roof plate was not carried out, as in the Tegel trial, with a 11 in. mortar, but with a 11 in. gun, the attack being arranged to correspond with the probabilities of hitting armour in coast defences.

2,190 yards was chosen as the attacking distance, and the corresponding charge and angle of impact determined.

At that distance the angle of descent of the 11 in. shell is 5°, and the trial plate was inclined to that extent to the front, the angle of impact on the curve surface being about 20°.

The trial plate was 10.8 ft. wide by 16.4 ft. long. The greatest thickness, which was in front, was 1.08 ft., and from the centre to the back the thickness was uniformly 0.7 ft.

Weight of plate 28.4 tons.
Gun: 11 in. (28 cm) gun.
Distance: 17.5 yards (16 m).

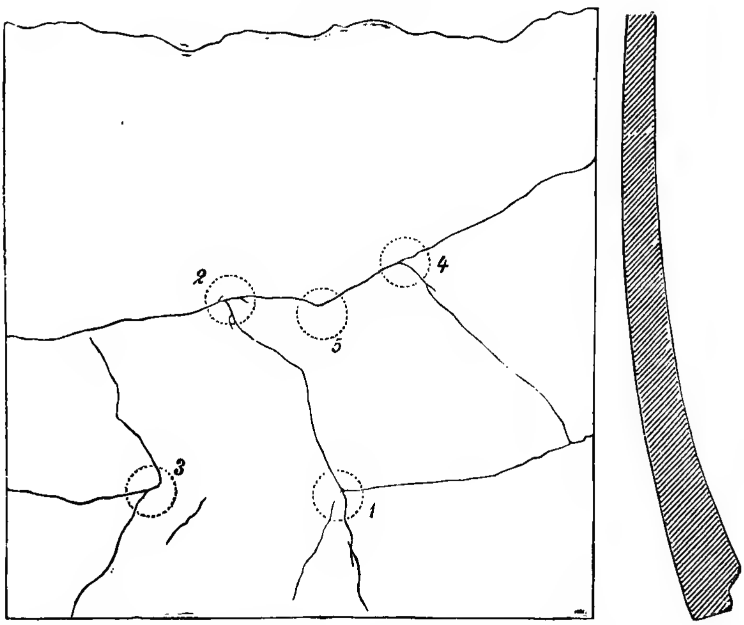
Shot: 11 in. (28 cm) chilled shell, weighted; total weight, 511.6 lb. (232 kg).
Charge: 57.3 lb. (26 kg) P P., equivalent to 88 lb. (40 kg) at 2,186 yards (2,000 m).
Velocity of impact: 366.5 yards (335 m).
Energy: 4,306 foot-tons (1,333 mt).

The target made is shown by Fig. 15.

Fig. 15.

Profile and Position of Hits of the Trial Roof Plate of the Chilled Iron Armour Battery for 8.3 in. *(21 cm) Guns.* 21/8/74.

Scale: 1.40.



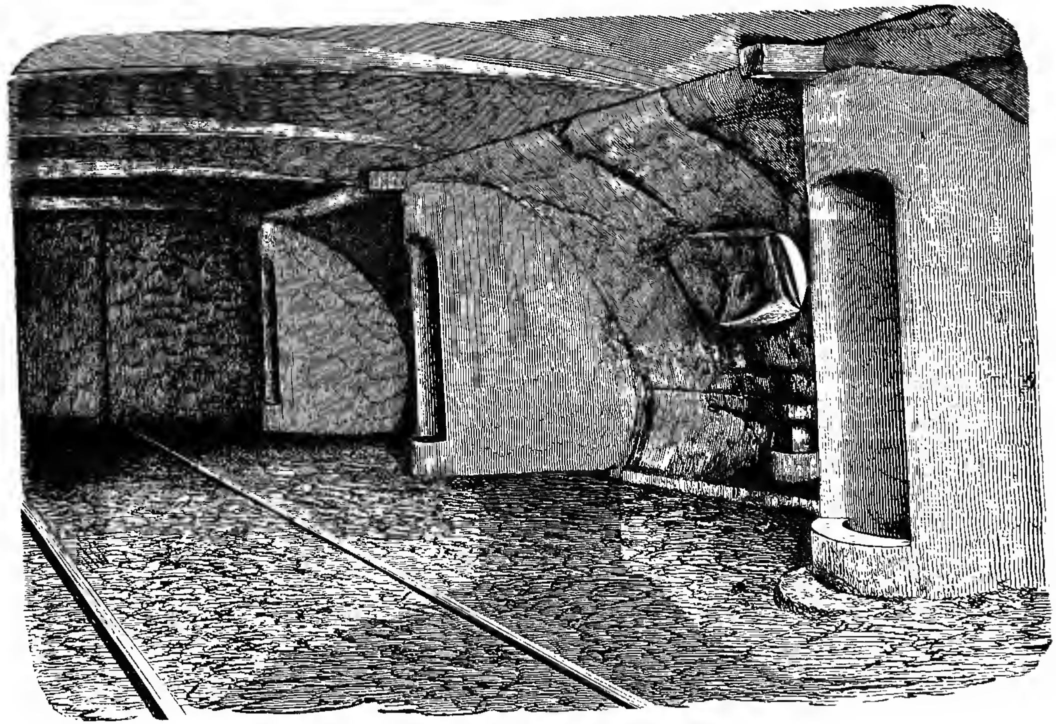
Five hits in all were made; of these the two first only starred the surface, the third cracked the plate as shown, the fourth cracked the plate into two parts, the fifth made no new crack but extended the previous ones to the under surface, and from crack 4 broke off a piece weighing about 2.2 lb. which fell through.

Summary: The Committee declared the plate to have displayed **most satisfactory powers of resistance**, and moreover, considering the small target exhibited by the roof-plate ($\frac{1}{6}$ of the port plate), it was improbable that a ship would be able to place so many hits upon it.

All the shot broke up on striking.

Fig. 16.

Interior of a Chilled Iron Armour Battery for 8.3 in. *(21 cm) Guns, at the conclusion of the firing.* 21/8/74.



From a Photograph.

IV. Conclusions.

The Gruson armour had in the above described trials exhibited so striking a superiority to the guns of that date that important orders for turrets and batteries were received from the Prussian Government.

Not only were all those valuable properties attributed by Gruson to his material shown by the trial to be present, but others were brought to light which, with respect to the applicability of the metal for armour, were of not less value. The trial had clearly demonstrated the extreme hardness of the metal, on which all the impinging shot glanced and broke up, being thrown off at large or nearly right angles.

From this followed the great advantage that the greater part of the energy of impact was not given off on the plate, but was expended in breaking the shot into fragments.

The hoped for effect of the soft layer under the hard surface was also clearly demonstrated by the fact that only continued firing produced cracks in the armour. In the same way, the absence of effect of such powerful blows can only be explained by an unusual elasticity of the armour material, and, in fact, experiments have shown that the chilled iron does possess this to a high degree.

Whilst, on the one hand, this elasticity distributes the blow from the point of impact over the whole mass, so it also absorbs in part the energy of the projectile, whose effect is in consequence considerably reduced.

The curved form of the plates was shown to be highly advantageous, for not only did it tend to effect the glancing of the shot, but also in furtherance of the tendency of the metal only to crack radially, assists in preventing loosened portions of the plate from being forced through to the interior; in fact, it was observed that pieces already loosened were, by subsequent hits, firmly wedged again into place.

And, finally, the weight and thickness of the plates, which at first were thought to be defects, were shown to be advantages, as completely separated pieces of the armour plates, after continued firing, were not displaced from their positions, and the gunners within the battery remained in complete security.

As already stated, the trial of the first Tegel turret had disclosed the remarkable fact that chilled shells striking normally were shivered into atoms without causing injury of importance; but if the shells struck at an acute angle they broke up into a few large pieces, which produced surface abrasions to a greater or less extent. In consequence, the flat profile curve of the first Tegel turret was abandoned in the second, and as the also here shown analogous appearance disclosed, the rounded curved profile was adopted seen in fig. 17 p. 48.

CHAPTER III.

Firing Trials of Gruson Chilled Cast Iron Armour during the years 1882-1886.

BETWEEN 1874 and 1882 no firing trials were made against Gruson armour, as the results obtained had furnished sufficient data by which to determine the necessary dimensions to resist the increasing gun charges.

These were approximately determined by means of an empirical formula, derived from the results of previous trials. In the formula $d = 0.294 \sqrt[4]{\text{foot-tons}}$, d is thickness of armour in ft. and foot-tons the energy of the shot in foot-tons. The above formula applies to coast fortifications. In the case of interior fortifications the resulting dimensions for the various calibres required to be increased 10 %.

Very soon, however, in presence of the entirely altered conditions due to changes in the velocity and quality of material of the projectiles, it became a question whether the formula would still be of value. In 1874, for instance, the heaviest projectile with which coast armour was subject to attack was the 11 in. shell with an energy of 5,685 foot-tons; now we had to deal with the 12 in. with 16,150 foot-tons energy, entirely excluding greater calibres, the employment of which will, probably, always be limited.

At that time, also, chilled shells were used, as their effect was greater than that of the soft steel shell; now, hardened steel shells were employed, with which chilled shells were no longer able to compete.

As at the close of the last decade, important orders were received from Austria, Italy, and Holland for armour at the Gruson Factory, renewed trials of the metal were projected. These trials appeared to be desirable from another point of view, as after the manufacture of these heavy armour plates had commenced, it appeared impossible to avoid the formation of shallow fissures on the hard surface during the operation of casting.

Although it could be anticipated that these cracks, on account of their slight depth, would have no prejudicial effect on the plate, it seemed not the less desirable to determine this point by firing trials.

These trials fell into two series: (*a*) siege guns against inland fortifications, and (*b*) heavy naval guns against coast defences.

I.—Firing Trials against Chilled Cast Iron Armour for Inland Fortifications, in the years 1882-1885.

The 5.9 in. hooped gun was used for these trials, being considered, as in the case of the Tegel experiments, the largest calibre applicable for siege purposes.

The trials formed a complete series in themselves, and showed how the chilled armour, by improving the profile given to it, was able to recover the superiority against shot, endangered by the improvement in steel shell, without increase of size.

1.—Trial of Side-Plate for a Chilled Turret for two 4.7 in. (12cm) Guns 26,7 calibres long, at Gruson's Firing Ground at Buckau.

23rd December, 1882, 10th January, and 27th April, 1883.

Scope and Programme of the Trial.

The object of these trials was to ascertain whether the so-called chill cracks occasionally to be found in chilled armour had any influence on its endurance. The firing should therefore be continued until light be thrown on this point through the formation of fresh cracks.

Target: A side plate of a turret for two 4.7 in. guns, containing chill cracks of the nature mentioned, and being rejected by one of the foreign officers inspecting the construction, was selected for trial.

The construction of the turret in question corresponded nearly to that shown in Fig. 4. The cupola had an outside diameter of 17 ft., and consisted of a port-plate, four side plates, and a roof-plate in two halves. These both together were 10.5 ft. in diameter, and at the joining edge had a sighting embrasure for use with a manhole in the roof. The height inside of the turret from the upper edge of the plates to the roller path was 11.8 ft. Below the roller ring the space was closed by a masonry arch, differing from the arrangement shown in Fig. 4. The glacis armour was formed of six plates of chilled iron. Both guns were placed in minimum port-carriages C/80 (Fig. 5), the axis of the bores being 4.4 ft. apart, 25° elevation, 10° depression, and 3° lateral training could be given to the guns.

Turret and carriages were worked by hand gear, a complete revolution of the turret being made by four men in one minute.

The trial plate was placed between two strong iron blocks of nearly similar weight, supported by masonry and concrete, on the same level as the gun.

A wooden screen with a small aperture for the passage of the shot was placed in front as a protection against shot splinters (compare Fig. 29). In the plate was a chill crack *a* about 18 in. long by 0.08 in. wide (*see* Fig. 17), and this crack was filled in with thin strips of sheet iron, so as to be able to notice any widening which might be brought about by the firing.

The plate also contained an irregular chill seam b which arose from a crack in the mould; it was 0.06 in. deep and 0.08 in. broad.

Lastly, beneath b was a deeper crack b^1 about 0.47-0.51 in. deep and 0.08 in. wide. Before commencing the firing the extremities of the cracks were marked.

Expanded, the surface of the plate measured 10.5 ft. horizontally and 6.8 ft. vertical. Its actual perpendicular height was 4.8 ft. maximum thickness 1.5 ft., 13.8 tons weight.

Gun: Short 5.9 in. (15 cm) hooped gun 23 calibres long, mounted in Prussian half-slide carriage.

Distance: 24 yards (22 m).

Shot: Gruson and Ternitz solid shot and steel shell 2,5 to 2,7 calibres long, empty.

Charge: 17.1 lb. (775 kg) seven channelled P. P.

Velocity of Impact: 488 yards (446 m), with shot weighing 76 lb. (34,5 kg).

Energy: 1,129.5 foot-tons.

Round No. 1:

Shot: Gruson's 5.9 in. hardened steel shell 78.3 lb., empty.

Point struck: Centre line of plate, 28 in. above lower edge.

Angle of impact: 81°. (By angle of impact is meant the smallest angle between the shot's trajectory and the tangent to the curve of the surface of the plate at the point struck.)

Effect: An indent, 0.1 in. of maximum depth, formed within a bright round mark of about 6 in. diameter, in which some nearly concentric circular rings of compression were seen.

The plate was entirely uninjured, the cracks *a* and *b*ˡ being neither lengthened nor widened.

The shot broke up in numerous large pieces.

Round No. 2:

Shot: As in round No. 1.

Point struck: 6.3 in. left from the centre line.

30 in. over the lower plate edge.

Angle of impact: 79° 10′.

Effect: Exactly the same as No. 1, an indent being formed of maximum depth of 0.08 in. Crack *b*ˡ showed no change, and the plate itself was in all respects intact.

The shot broke up into numerous pieces.

Round No. 3:

Shot: Gruson's 5.9 in. hardened steel shell, 78.3 lb., empty.

Point struck: The centre line.

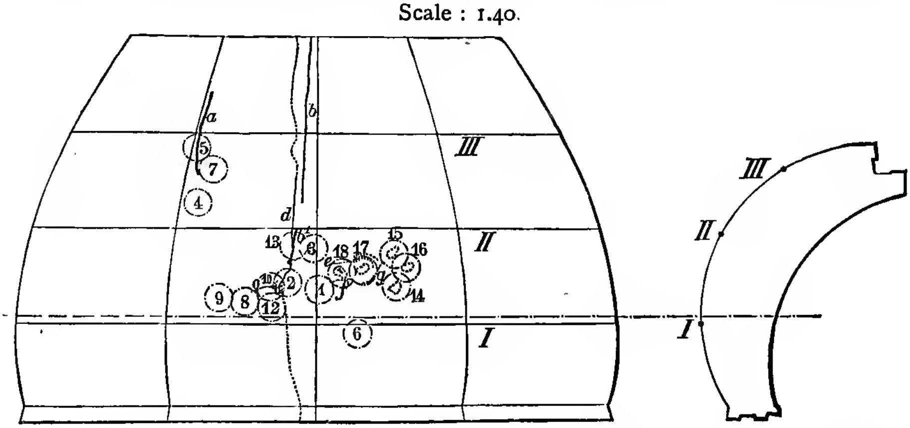
37 in. above the lower edge.

Angle of impact: 68° 40′.

Fig. 17. *

Profile and Position of hits of the Trial Side-Plate of the Chilled Iron Armour Turret for two 4.7 in. (12 cm) Guns. 23/12/82, 10/1 *and* 27/4/83.

Scale: 1.40.



Effect: The same as in rounds 1 and 2, an indent 00.8 in. deep, marked

* NOTE.—The trial-plate, like all others used later on, was divided into squares by vertical and horizontal lines. These lines are shown in the sketches as they make our explanations more easily understood.

The surface of the Plate is shown as if it was perfectly flat.

by a bright spot 6 in. in diameter. The compression rings were again noticeable.

The old cracks were unchanged, and the plate intact.

The shot broke up.

As the crack b^1 had been shown to be absolutely without prejudicial effect on the plate, crack *a* was subjected to a similar, and even more severe trial.

Round No. 4.

Shot: As before.

Point struck: 26 in. to left of centre line.
46 in. above lower plate edge.
5 in. under crack *a*.

Angle of impact, 50° 5′.

Effect: The sole result was an indent 0.06 in. deep and about 3 in. in diameter, marked by an oval bright spot which, however, had no rings of compression, as before noticed. Crack *a* was unchanged, the sheet-iron filling-pieces entirely closing the crack as before the hit.

Shot broke up.

Round No. 5:

Shot: as before.

Point struck: 26 in. left of the centre line.
58 in. above lower plate edge.
6 in. above lower end of crack *a*.

Angle of impact: 34° 20′.

The centre of the part struck was marked by a scratch on the iron filling-wedge and edge of the crack about 0.08 in. deep and 0.04 in. long. In addition, a bright spot about 4 in. broad, going upwards on the plate with an indent about 0.01 in. deep. Crack *a* entirely unaltered, and still fully closed by the iron wedge.

Round No. 6: 10th January, 1883.

Shot: Gruson's soft forged 5.9 in. solid steel shot, 80 lb. in weight.

Point struck: 9 in. right of centre line.
20 in. above lower plate edge.

Angle of impact: 82°.

Effect: A bright splash 8 in. in diameter; no indent and no marks of compression.

Shot broke up.

Round No. 7:

Shot: Gruson's forged and hardened 5.9 in. solid steel shot, weight 80 lb.

Point struck: 24 in. left of centre line.
55 in. above lower plate edge.
3 in. right of crack *a*.

Angle of impact: 41° 20′.

Effect: A bright splash; no visible indent; crack *a* unaltered.

As it did not seem that crack *a* would be changed by further firing, the remaining rounds were placed on the middle line of the plate.

Round No. 8:

Shot: Gruson's 5.9 in. hardened solid steel shot, weight 86.7 lb.

Point struck: 15 in. left of the centre line.
26 in. above lower plate edge.

Angle of impact: 78° 20′.

Effect: An indent 6 in. in diameter, and 0.08 in. deep, a few compression rings visible, also a fine hair crack *c* 6 in. long, beginning close above the point of impact, and running to that of round No. 2, (*see* dotted line in Fig. 17).

Shot broke up.

Round No. 9:

Shot: As in round 8.

Point struck: 20 in. left of centre line.
27 in. above lower plate edge.

Angle of impact: 77° 30′.

Effect: A bright splash, extending to mark 8. No indent or compression marks. Hair crack *c* unaltered.

Shot broke up.

Round No. 10:

Shot: Gruson's hardened steel shell, weight 81.6 lb., empty.

Point struck: 9 in. left of centre line.
27.6 in. above lower plate edge.

Angle of impact: 79° 10′.

Effect: Crack *c* closed up. Impact mark 0.2 in. deep, and a fine hair crack running into b^1 4 in. long, but not apparently connecting with *c*.

Shot broke up.

Round No. 11:

Shot: Gruson's 5.9 in. hardened steel shot, weight 81.2 lb.

Point struck: 9 in. left of centre line.
28 in. above lower plate edge on No. 10.

Angle of impact: 79° 10′.

Effect: Crack *c* unaltered and closed up. Impact mark deepened to 0.3 in.

Shot broke up.

Round No. 12:

Shot: Gruson's 5.9 in. hardened steel shot, weight 81 lb.

Point struck: 8 in. left of centre line.
24 in. above lower plate edge.

Angle of impact: 84° 30′.

Effect: A bright splash; crack *c* unchanged.

A new fine hair crack *d* 12 in. long, beginning 5 in. left of the middle line, and in the centre of chill crack b^1.

Shot broke up.

Round No. 13:

Shot: Gruson's 5.9 in. hardened steel shot, 81.2 lb.

Point struck: 5 in. left of centre line.
40 in. above lower plate edge.

Angle of impact: 68° 15′.

Effect: A bright splash; crack *d* lengthened about 28 in.

Shot broke up.

Round No. 14:

Shot: Ternitz 5.9 in. steel shell,* empty, weight 82 lb.

Point struck: 18 in. right of the centre line.
30 in. above lower plate edge.

Angle of impact: 78°.

Effect: Indent 2.3 in. long, 1 in. wide, and 0.2 in. deep. No compression markings were visible.

The shot broke up.

Round No. 15:

Shot: Ternitz 5.9 in. steel shell, empty, weight 81.8 lb.

Point struck: 16 in. right of centre line.
36 in. above lower plate edge.

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* The steel shell of the Ternitz works is the armour-piercing shell adopted in Austria, and displays superior hardness

Untempered steel shell was not used subsequent to this, so that by the term "steel shell" **tempered** shell is to be understood.

Angle of impact: 65°.

Effect: A round mark 1 in. in diameter and 0.09 in. deep. No concentric lines.

Shot broke up.

Round No. 16:

Shot: Ternitz 5.9 in. steel sheel, empty, weight 82.7 lb.

Point struck: 19 in. right of centre line.
33 in. above lower plate edge.

Angle of impact: 70°.

Effect: Indent 1.8 in. in diameter, and 0.2 in. deep. No concentric lines.

Shot broke up.

Round No. 17:

Shot: Ternitz 5.9 in. steel shell, empty, weight 83.1 lb.

Point struck: 10 in. right of centre line.
33 in. above lower edge.

Angle of impact: 72°.

Effect: Impact mark 2 in. in diameter, and 0.2 in. deep, 2 parallel hair cracks *e* and *f* 4 in. long towards mark 2, and one *g* 3.5 to 4 in. long, towards mark 15.

Shot broke up.

Round No. 18:

Shot: Ternitz 5.9 in. steel shell, empty, weight 83.1 lb.

Point struck: 5 in. right of centre line.
31 in. above lower edge.
between hits 1, 3, and 17.

Angle of impact: 73°.

Effect: A mark 2 in. in diameter and 0.3 in. deep.

The crack made by round 10 was extended to the lower edge of the plate, and that caused by round 13 extended to the upper plate edge, thus forming a vertical crack which passed right through the plate and divided it into two halves. The lengthening of the crack caused by round 18 is shown in Fig. 17 by dotted lines.

The shot broke up.

Summary: With formation of crack *d* breaking the plate into two halves, the object of the trial was reached, for as this crack took its departure from the middle of the chill crack *b*1 (which was 0.5 in. deep) it may with certainty be considered that the chill crack was entirely without influence in determining the formation of *d*.

It is further noticeable that 3 hits fell in close proximity to the chill crack *a* without either lengthening or widening it. This want of influence on the part of the chill cracks—which, considering their very small depth in proportion to the thickness of the plate, was reasonably to be expected—was confirmed by all subsequent experiments.

As regards the behaviour of the plate the following is to be noted:

By examination of the target it was found that the plate, through failure of the front supporting struts, had moved about 0.2 in. towards the front and, in consequence, had lost contact with the lateral supports.

This, probably, had had a very great influence in diminishing the resisting powers of the plate during the later rounds, a conjecture which had all the more weight, inasmuch as the upper edge of the plate was not supported from the first, and, consequently, finally was quite free to move.

However, notwithstanding this unfavourable condition, the plate had withstood 18 hits, with an energy of 20,329.6 foot tons, of which 14, with a total energy of 15,810.9 foot tons, had struck within a small pentagonal space 2.5 square feet in size, before a through crack was formed.

The 18th round produced the first through crack, but the plate was in other respects so completely intact that, judging by the results of the Tegel trial, it would still take a long time to breach it.

All the shot broke up on impact, but the Ternitz shot showed considerable superiority to the Gruson shot, as they effected actual, though small, indents into the plate, which had not been previously observed either with Gruson steel or chilled shell.

2. Trial of a Port-Plate of a Chilled Iron Armour Battery for eight 5.9 in. (15 cm) Guns, 23 calibres in length.

On Gruson's Firing Ground at Buckau,

16th July, 1883.

Object and Programme of the Trial.

Test of the armour-metal by means of five hits concentrated on a small space on the plate from the 5.9 in. hooped gun, in accordance with the terms of the government contract.

Target.—The armour battery for which the trial-plate was intended differed chiefly from the construction shown in Figs. 2 and 3, in that the port plate was divided into two halves (*see* Fig. 18).

The battery was composed of 16 half port plates, 9 pillar, and the necessary foundation, pivot, and roof plates.

The breadth of the port half plates at the level of the centre of the port was 5.6 ft., that of the pillar plates 2 ft., and of the roof plate 4.6 ft. The latter had a length of 14.1 ft., and rested in rear on so-called support plates, borne on one side by iron columns and on the other by masonry pillars. The space between led to the casemates. The roof plates were protected by masonry and earth, and the height of the battery from base to upper edge of the front was 9.2 ft. The guns were mounted in minimum port-carriages C/80. The distance between port and port was 13.1 ft., angle of elevation 25°, depression 10°, and training 50°.

The target was constructed as if part of the battery, and consisted of two half port plates, a pivot block, two pillar, and three roof plates, all reposing on both sides against masonry. In front there was a concrete glacis up to the port, and a stout wooden screen in front was placed to catch splinters of shot (*see* Fig. 29).

The half port plate subjected to attack had on the curve a dimension of 5.9 ft. horizontally and 8.9 ft. vertically; the perpendicular height was 6.2 ft., maximum thickness 1.9 ft., and weight 10.3 tons.

Gun: Italian 5.9 in., 23 calibre gun, G.C.R. (ret.) in Gruson's minimum port carriage C/80.

Distance: 42.6 yards (39 m), the gun being directly opposite the centre of the port.

Charge: 16.3 lbs., Fossano progressive powder, 0.8—1 in.

Shot: Krupp steel 2.8 calibre shell, weight 85.3 lb. (38.7 kg) filled.
Velocity of impact: about 454.7 yards per second.
Energy of impact: 1114.4 foot-tons.

Ronnd No. 1:

Shot: As above, weighted with sand.
Point struck: 19 in. from the line OA.
3.5 in. above the line OB.
Angle of impact: 63°.
Effect: Indent 2 in. in diameter, and 0.4 in. deep.
Shot broke up into numerous pieces.

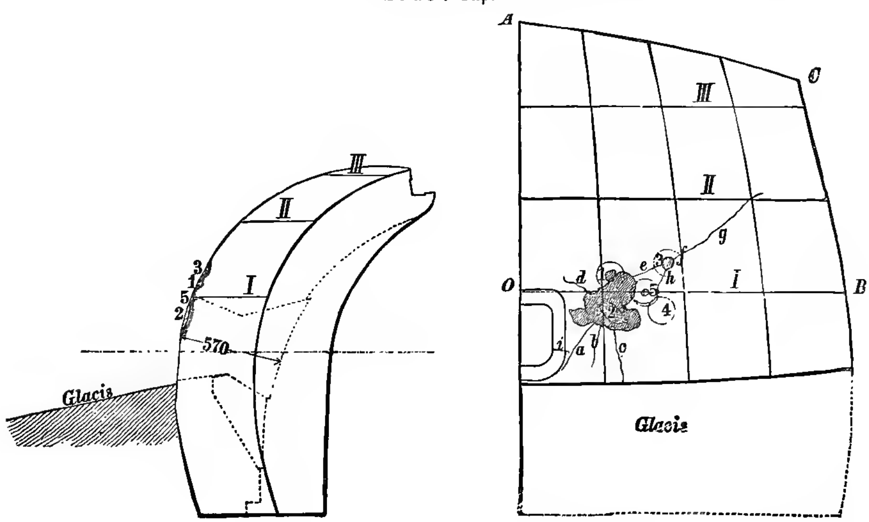
Round No. 2:

Shot: As before:
Point struck: 19.7 in. from the line OA.
4. in. under the line OB.
Angle of impact: 74°.
Effect: An oval indent, 7.4 in. long, about 2 in. broad and 1.2 to 1.4 in. deep, round which was a flat surface abrasion about 0.2 in. deep, 5 fine cracks, *a* down to left (2 in. deep); *b*, 3.5 in. long, 1.2 in. deep; *c*, hair crack 11 in. long; *d*, hair crack 6 in. long, and in the lip of the port a short hair crack *i*.
Shot broke up.

Fig. 18.

Profile and Diagram of hits of the Trial Port Plate of the Chilled Iron Armour Battery for Eight 5.9 *in.* (15 *cm*) *Guns.* 16/7/83.

Scale: 1.40



Round No. 3:

Shot: Krupp steel 5.9 in. shell, filled, weight 85.3 lbs.

Point of impact: 31.5 in. from line OA
6.8 in. above line OB

Angle of impact: 61° 30′.

Effect: A round indent 2.4 in. in diameter, and 0.6 in. deep. A fine crack 7.4 in. long and 0.6 in., reaching to hit No. 2. Hair crack *f*, 5 in. long.

Shell exploded.

Round No. 4:

Shot: As before.

Point struck: 30.4 in. from line OA.
4. in. under line OB.

Angle of impact: 73°.

Effect: Indent 0.1 in. maximum depth. No cracks.

Shell exploded.

Round No. 5:

Shot: Krupp steel shell filled with sand, weight 85.3 lb.

Point struck: 26.8 in. from line O A,
on the line O B,
and nearly in the centre of the four previous hits.

Angle of impact: 69°.

Effect: Indent 0.2 in. deep. Hair crack *h* 4 in. long. Crack *f* lengthened about 21.7 in. (*g*), also *a* somewhat widened. At back of plate a crack in the direction *a*—*g*, which, however, seemed not to connect on the outside with either *a* nor *i*.

Shot broke up.

Summary: The plate had withstood five hits concentrated on the small space of 0.86 square ft.; and consequently had fulfilled the conditions of the contract. All the shot broke up, the base and cylindrical part in many pieces, the head and point were shivered in shapeless atoms, coloured blue by the heat.

No superiority in effect of the filled over the weighted shell could be observed.

3.—Trial of a Port Plate of a Chilled Iron Armour Battery for six 5.9 in. (15 cm) Guns, 23 calibres long.

On Gruson's Firing Ground at Buckau,

18th August, 1884.

Object and Programme of the Trial.

Proof of the armour metal by five rounds from the 5.9 in. hooped gun corresponding to the terms of the contract with the government.

Contrary to No. 2 trial, the hits to be distributed over a larger part of the plate's surface, so as to note the difference of result.

Target: The armour battery for which the trial-plate was intended was of exactly similar construction to that described under No. 2, only differing in the number of guns, and was composed of twelve half port-plates, seven pillar, and the corresponding foundation pivot and roof-plates. In other respects the description previously given applies also to this battery.

The target, to be attacked as in actual warfare, was composed of two half port-plates, one pivot-block, two pillar, and three roof-plates. It was supported as in No. 2, and protected by a similar front screen against splinters. The right half port-plate was attacked. Its dimensions were the same as under No. 2. Weight 10.3 tons.

The same gun, charge, and distance were employed.

Round No. 1:

Shot: Krupp steel 5.9 in. (15 cm) shell weighted with sand to 85.3 lb.

Point struck: 21.7 in. from line OA.
8.3 in. under line OB.

Angle of impact: 77°.

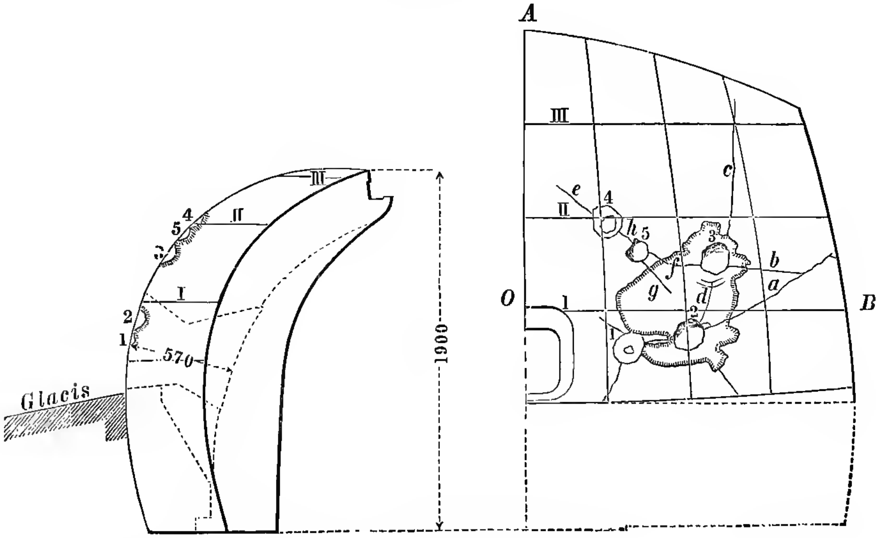
Effect: A bright splash, 5.5 in. in diameter and 0.4 in. maximum depth; a piece of the steel point was found in the metal near the centre of the splash; other small portions of the shot were similarly found near the point of impact.

The shot broke up into numerous minute pieces.

Fig. 19.

Profile and Diagram of hits of the Plate under trial for the Chilled Iron Armour Battery for six 5.9 in. (15 cm) Guns. 18/8/84.

Scale : 1.40



Round No. 2:

Shot: As before.

Point struck: 35.5 in. from line OA.
4.7 in. under line OB.

Angle of impact: 74° 30′.

Effect: Indent 5.9 in. diameter and 2.8 in. deep. Round the same a surface abrasion about 26.4 in. diameter, and maximum depth 0.8 in. A fine crack *a* from the point struck to 4 in. from the right edge.

The back of the plate was intact.

Shot broke up; the pieces of shell showed very great hardness, exceeding that of the first round.

Round No 3:

Shot: As before.

Point struck: 60 in. from the line OA.
10 in. above the line OB.

Within the abrasion caused by Round II.

Angle of impact: 54° 40′.

Effect: Indent of 6 in. diameter and 2 in. depth; round the same an abrasion of 0.8 in. maximum depth, joining that formed by Round 2. A crack *b* from impact point to crack *a*; a vertical crack *c*, stretching to 8 in. from upper edge; a crack *d* in the direction of hit II.

In addition, two radial hair cracks at hit 1, and one at the lower edge of the abrasion formed by Round III.

Back of plate: Crack *a* was visible, running to 7.4 in. from the right edge; under this a fine horizontal crack 14.8 in. long, about the level of Shot II., but not visible in front (*see* Fig. 20).

Shot broke up. Hardness about the same as Round I.

Round No. 4:

Shot: As before, but filled.

Point struck: 18 in. from the line OA.

18·5 in. above the line OB.

Angle of impact: 42° 38′

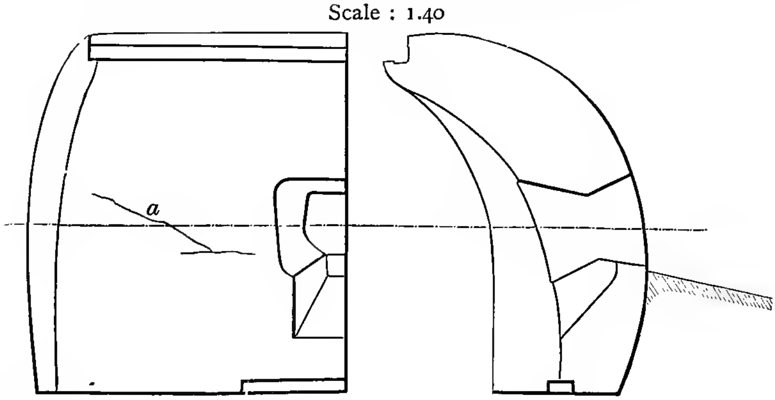
Effect: Mark blackened by powder, 7·9 in. in diameter, at lower right part of which a flat indent of 3·1 in. diameter and 0·4 in. depth; no abrasion. Two radial hair cracks, *e* and *f*, 8·7 in. and 5·5 in. long. Back of plate unchanged.

Shell exploded.

Fig. 20.

Back of the Trial Plate of the Chilled Iron Armour Battery for six 5.9 *in.* (15 *cm*) *guns, after the fifth shot,* 18/8/84.

Scale : 1.40



Round No. 5:

Krupp's 5.9 in. (15 cm) steel shell, weight 84.1 lb., burster 1.3 lb.

Point of impact: 24 in. from the line O A.

13.4 in. above the line O B.

Angle of impact: 50°.

Effect: Flat indent 4 in. in diameter, and 0.5 in. deep.

Hair crack *f*, lengthened to hit III.

A fine crack *g*, 9.2 in.
Back of plate unaltered.
Shell exploded.

Summary: The plate had complied with the conditions, but no parallel could be drawn with trial No. 2, although the conditions of attack were apparently the same. The indents, and also the effects of the individual hits—as for instance, rounds 2 and 3—were unexpectedly great, so that the suspicion was entertained that the armour plate was softer than that tested on the 16/7/83. This, however, was refuted by the test pieces taken on casting the plate, and also round No. 1, notwithstanding its greater angle of impact, gave such a less effect that undoubtedly there were differences in the quality of the shot.

The superior effect of rounds 2 and 3, in comparison with the trial of the previous year, pointed to a better quality of projectile. All the projectiles broke up on striking, the filled shell having less effect than those not charged.

4.—Trial of a Glacis Plate of a Chilled Iron Armour Turret for two 23½ calibre 4.7 in. Guns.

On Gruson's Firing Ground at Buckau,

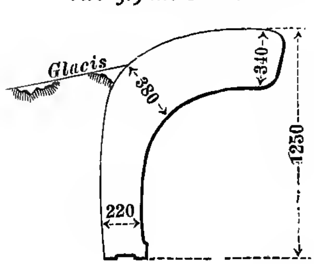
12th February, 1884.

Object and Programme of Trial.

Test of the plate by five shots from the 5.9 in. hooped gun, as also of the dimensions prescribed for the armour.

Target: The turret for which the plate under trial was destined corresponded in dimensions and construction to the turret previously described for two 4.7 in. guns, 26.7 calibres long.

Fig. 21.
Profile of the Glacis-Plate for the Chilled Armour Turret for two 5.9 *in. Guns.*



The glacis armour was composed of seven plates.

The maximum diameter of the glacis armour was 23.9 ft. Each plate had an extreme breadth of 10.2 ft., measured on the chord.

The other dimensions are given in the Fig. 21.

The trial plate was fixed between two cast-iron supporting-plates resting against masonry, the lower part being protected by granite blocks, and security against shot splinters was given by the usual wooden screen in front.

The weight of the trial plate was 10.5 tons.

Gun : Italian 5.9 in. (15 cm) hooped gun, 23 calibres long G. C. R. (ret) in a Gruson minimum-port carriage, C/80.

Distance : 49.2 yards.

Shot : Krupp steel sheel, 2.8 calibres, weight about 85.3 lb.

Charge : 16.3 lb. progressive Fossano powder 0.8 in.

Striking velocity : 454.7 yards per second.

Striking energy : 1114.4 foot-tons.

Fig. 22.

The Glacis Plate for an Armour Turret for two 4.7 *in.* (12 *cm*) *Guns after the* 6*th round.* 12/2/84.

From a Photograph.

Round No. 1:

Shot : Krupp steel shell, 2.8 calibres, weight about 85.3 lb , weighted with sand.

Point struck : The shot struck 17.7 in. in front of the armour on the glacis, glanced, and then grazed the plate 6.3 in. above the upper edge of the glacis.

Effect : A long splash.
Shot broke up.

Round No. 2:

Shot : As before.

Point struck . 2.4 in. left, near the centre line.
2.4 in. above the glacis edge.

Angle of impact: 41° 25′

Effect: The only result was a bright splash of 0·2 in. maximum depth. No hair cracks found.
Shot broke up.

Round No. 3:

Shot: As before.

Point struck: 11 in. right, near centre line.
3.2 in. above edge of glacis.

Angle of impact: 38° 40′

Effect: A bright splash of 0.4 in. maximum depth; four star-shaped hair cracks of 6 in., greatest length round point struck; also, after Round No. 3, two hair cracks, 4 in. long, showed at Hit 2.
Shot broke up.

Round No. 4:

Shot: As before.

Point struck: 12.6 in. left from the centre line.
1.6 in. above edge of glacis.

Angle of impact: 40°.

Effect: The shot struck the upper edge of the covering glacis, making a cavity there 2.8 in. deep, also an indent 0.4 in. deep on the plate; four short hair cracks, of which one connected with hits IV. and II.
Shot broke up.

Round No. 5:

Shot: As above.

Point struck: 27 in. right of centre line.
0.8 in. above glacis edge.

Angle of impact: 46° 20′.

Effect: A cavity 3·1 in. deep in the upper edge of the covering glacis. Indent on plate about 0·4 in. greatest depth.
Hair crack formed by hit 3 lengthened, joining hits III. and V.
This was the only crack whose depth could be probed.
Its greatest depth was 1.8 in.
Also two short hair cracks.
Shot broke up.

Round No. 6:

Shot: As before, charged.

Point struck : 3.5 in. right of the centre line.
5.5 in. above glacis edge.
(between hits II. and III.).

Angle of impact : 41° 30′.

Effect : Indent, in which was a sharp chisel mark 0.3 in. in greatest depth; below to the right a slight abrasion 0.2 in. deep. Two fine hair cracks.

The effect of this hit was evidently somewhat greater than the previous ones.

Shell burst.

Summary : The resistance of the plate had proved amply sufficient.

Of the fine hair cracks formed, only one could be measured with a fine probe. Its mean depth was 1.2 in., maximum 1.8 in.

The smaller effect of the shot on the armour compared with the previous trials showed without question that the effect varies in inverse ratio with the size of the angle of impact.

Trials made at the same time against coast armour confirmed this, and in consequence the profile shown in Fig. 25 was adopted, which, departing from the previous experience, approaches that used in the first plates tried at Tegel.

The shot broke up as in the earlier trials into small pieces, showing an uncommonly hard material, which could not be touched with a file.

5.—Trial of a Port Plate of a Chilled Iron Armour Turret for two 4.7 in. (12 cm) Guns, 23.5 Calibres long.

On Gruson's Firing Ground at Buckau,

28th August, 1884.

Object and Programme of the Trial.

Test of the material by five shots from the 5.9 in. (15 cm) hooped gun.

The plate belonged to the cupola of the same turret, of which a glacis plate was tried in the last experiment. It was fixed with two side and a roof-plate, so that the whole target formed nearly a half turret. At the back the target was supported by masonry pillars, tied to the plates by three cast-iron struts.

A wooden screen with earth was provided in front to catch shot splinters.

At the level of the port the plate had a radial thickness of 1.7 ft. Its greatest expanded width was 10.6 ft.; height, 6.9 ft.; perpendicular height, 4.9 ft.; weight 14.6 tons.

Gun: Italian, 23 calibre, 5.9 in. (15 cm), hooped gun, on Gruson minimum port-carriage, C/80.

Distance: 49.2 yards, the gun being normally opposite the centre of the plate.

Shot: Krupp 2.8 calibre steel shell, weight about 85.3 lbs.; also Gruson steel shell, and solid steel shot.

Charge: 16.3 lb. progressive powder, Fossano, 0.8—1 in.

Striking velocity: About 454.7 yards per second.

Striking energy: About 1114.4 foot tons.

Round No. 1:

Shot: Krupp steel shell, weighted to 85.3 lb.

Point struck: 11.8 in. left of the centre line.
20.5 in. above lower edge of the plate.

Angle of impact: 81° 20′

Effect: An indent about 8 in. in diameter and 3.5 in. deep. From this to the port a splintering of the surface 4.3 in. in greatest depth. No crack visible on the exterior of the plate.

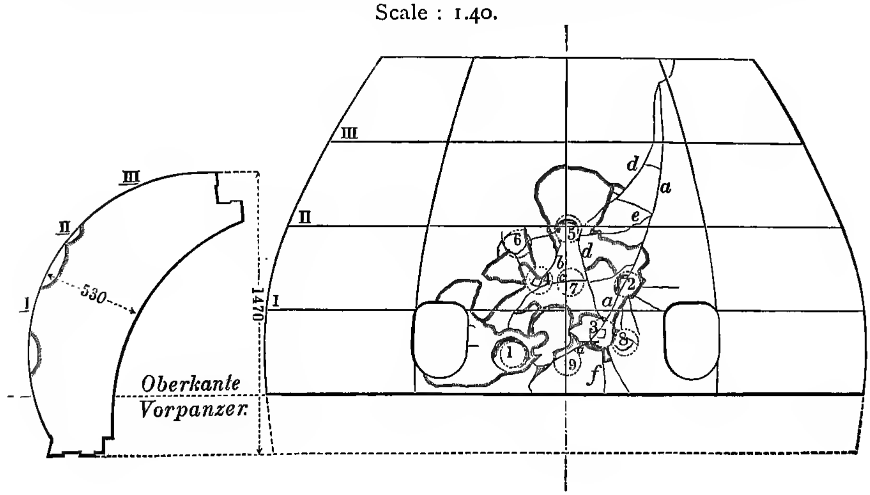
The back of the plate showed a fine horizontal crack 15.7 in. long, beginning at the level of the part struck at the port and running to the right (*see* Fig. 24).

Shot broke up, exhibiting extreme hardness of material.

Fig. 23.

Profile and Diagram of hits of the trial Port Plate of the Chilled Armour Turret for two 4.7 in. (12 cm) Guns. 28/8/84.

Scale: 1.40.



Round No. 2:

Shot: As before.

Point struck: 12.6 in. right of centre line.
34.7 in. over lower plate edge.

Angle of impact: 70° 35′.

Effect: Indent 8 in. in diameter and 1.2 in. deep; from above down to this an unimportant abrasion, 3 radial hair cracks, of which one, *a*, stretched 7.1 in. down to the left.

Back of the plate: the horizontal crack was lengthened about 2 in. in the direction of the lower edge.

Shot broke up.

Round No. 3:

Shot: Krupp shell, as before, filled.

Point struck: 7.1 in. right of centre line.
25.2 in. above lower plate edge.

Angle of impact: 84°, 45′.

Effect: Indent and slight abrasion of 7.1 in. diameter. Point of shell (1.2 in. diameter) fixed in plate. Radial crack down to right. Crack *a* into hit 1 and running over hit 2 to 7.1 in. from the upper edge of plate.

Back of plate: crack *a* showing as a hair crack.

Shell burst.

Round No. 4:

Shot: As in last round.

Point struck: 6 in. left of centre line.
35.8 in. over lower plate edge.

Angle of impact: 68° 40′.

Effect: Indent and slight abrasion; point of shell fixed in plate; cracks *b* and *c*; crack *a* lengthened to upper edge of the plate.

Back of plate unaltered.

Shell burst.

Round No. 5:

Shot: Krupp flat-headed steel shell 5.9 in., weighted with sand to 85.3 lb. (flat of head 3 in. diameter).

Point struck: On centre line, 46 in. above lower plate edge.

Angle of impact: 52°.

Effect: Indent 8 in. diameter and 2.4 in. deep, slight abrasion from above downwards to hit.

Crack *d* from point struck down to hit 3, and upwards towards and joining crack *a*; a radial crack *e* to *a*.

Back of plate unchanged.

Shot broke up.

The programme was now completed, but as the plate had suffered but little, it was decided to continue the firing with four shots in hand.

Round No. 6:

Krupp 5.9 in. steel shell, weighted to 85.3 lb.

Point struck: 9 in. left of centre line.
43.7 in. above lower plate edge.

Angle of impact: 57°.

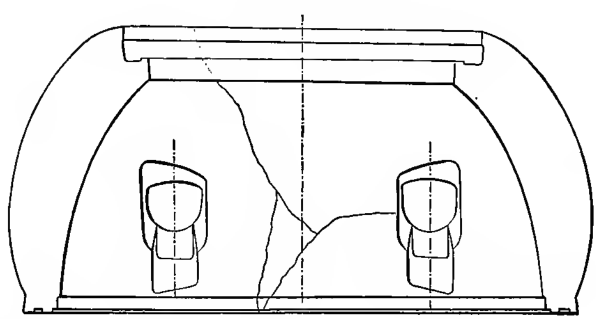
Effect: Indent 4.7 in. in diameter and 0.8 in. deep; beneath, a slight abrasion, and a radial crack in direction of hit 5.

Shot broke up.

Fig. 24.

Back of Trial Plate of Chilled Armour Turret for two 4.7 *in.* (12 *cm*) *Guns after ninth hit,* 28/8/84.

Scale: 1.40



Round No. 7:

Shot: As in last round

Point struck: 0.8 in. right of centre line.
35.4 in. above lower plate edge.

Angle of impact: 69° 50′.

Effect: A wedge shaped piece, bounded by cracks, *b*, *c* and *d* knocked out, maximum thickness 4.7 in.

Also a chiselling of surface, 4 in. deep, at point of junction of cracks *a* and *b*.

Back of plate unchanged.

Shot broke up.

Round No. 8:

Shot: Gruson's 5.9 in. steel shell, 79.8 lb., weighted with sand.

Point hit: 13 in. right of centre line.

23 in. above lower plate edge.

Angle of impact: 82° 50′

Effect: Oval indent about 2.8 in. in diameter and 0.4 in. deep. Slight abrasion around hit; two radial hair cracks. 6 in. long, downwards, and one towards Shot 2. A fine crack, *f*, from Hit 3 to under edge of the plate.

Back of plate: The two cracks lengthened to edges of the plate; crack *f* visible in rear.

Shot broke up.

Round No. 9:

Shot: Gruson's solid steel shot, 80 lb.

Point struck: On centre line.

19 in. above lower plate edge.

Angle of impact: 82° 30′

Effect: Indent 5.9 in. in diameter and 0.8 in. deep.

Back of plate: the piece of plate bounded by cracks *a* and *f* forced back about 0.04 in.

The cylindrical part of the shot was found close to the plate.

Summary: The plate had shown a satisfactory resistance in every respect.

All the cracks, as far as could be determined, ran across nearly radially to the rear, and in consequence even the broken and loosened parts of plate showed a more than sufficient resistance to the blows of the shot. This was especially seen by shot 9, which separated a piece of plate without being able to drive it to the rear.

As seen by the sketch of the back of the plate after the 9th round, the protection was still complete, although these 9 rounds had been concentrated between the ports on a space 6.9 square ft. in superficies.

Of the Krupp shell, the first showed extreme hardness, and a superiority of effect over the others, which however, was favoured by the nearness of the port.

6.—Trial of a Side Plate for a Chilled Iron Armour Turret for two 4.7 in. (12 cm) Guns, 26.7 calibres long.

On Gruson's Firing Ground at Buckau,

19th and 20th January, 1885.

Object and Programme of the Trial.

Test of a side plate for the above-mentioned turret by 15 rounds (eventually increased to 20) of hardened steel shell from the Prussian short 5.9 in. hooped gun.

The programme ran as follows :—

The firing took place with hardened Ternitz steel shell, with a charge of 15.2 lb., P. P. C/68, the equivalent gun charge for a distance of 1,039 yards, and was directed, to save ammunition only, on the left half of the plate.

And the endeavour was to be made by grouping the rounds 1 to 5, as shown by hits 1, 3 and 5, to make a vertical crack dividing the plate into nearly two equal parts, so that the following firing should give a result quite free from objection.

The gun was placed for the first six rounds, as well as for No. 20, normally opposite the centre of the plate, and for the remainder it was moved 24° to the left.

And of the intended 20 hits 5 to be with flat-pointed steel shot.

If the plate was not breached after the 15th round (that was about 10 shots per square yard of the vertical projection of the target), and showed no loosening of parts at the back injurious to the stability of the turret, the resistance to be considered sufficient.

Five additional steel shells were then to be fired, and the trial concluded.

Target: The turret for which the trial plate was intended corresponded in the main with Fig. 4, but differed in the profile of the cupola. The turret cupola had a maximum diameter of 19.7 ft., and consisted of a port plate, 4 side plates, and a wrought-iron roof plate of 11.2 ft. diameter and 4 in. thick.

The two sights were placed on the roof and were used through a manhole. The height inside the turret from the upper edge of the cupola plates to the edge of the roller ring was 11.2 ft. The arrangement of the lower spaces corresponded to that shown in Fig. 4. The ring of glacis armour consisted of ten chilled iron plates. The two guns were mounted in minimum-port carriages C/80, their axes being 4.4 ft. apart, and admitted of 25° elevation, 10° depression, and 3° side training. Turret and carriage were worked by hand, the former being worked from an adjoining casemate by a capstan, by means of which four men turned the turret through 360° in one minute.

The trial plate differed considerably in form from those previously tried, being constructed in accordance with the *data* established by these previous experiments.

The profile was considerably flattened, so that on level ground angles of impact superior to 46½° were impossible.

The trial plate was supported between two side and a roof plate, forming thus together nearly half a cupola. In rear it rested on masonry pillars supported by cast-iron struts. The glacis armour was protected as before with concrete blocks to the level of its upper edge, and a screen was provided in front to catch splinters of shot.

The thickness and dimensions of the trial plate are shown in Fig. 25. The greatest width expanded was, at the level of the glacis 12.5 ft., and at the upper plate edge 7 ft.

The weight was 19.6 tons.

Gun : Prussian short 5.9 in. (15 cm) hooped gun, 23 calibres long.

Distance : 39.4 yards.

For the first seven rounds the gun was placed normally opposite the centre of the plate; for the other rounds it was inclined at an angle to the left of 24°.

Shot: Ternitz, 5.9 in. steel shell 2.5 calibres long, weighted with sand to 76 lbs.

Charge: 15.2 lb. P. P. c/68—equivalent to service charge at 1,093 yards.

Velocity: About 431.7 yards.

Energy of impact: About 687 foot tons.

Round No. 1.

Ternitz steel shell, as above.

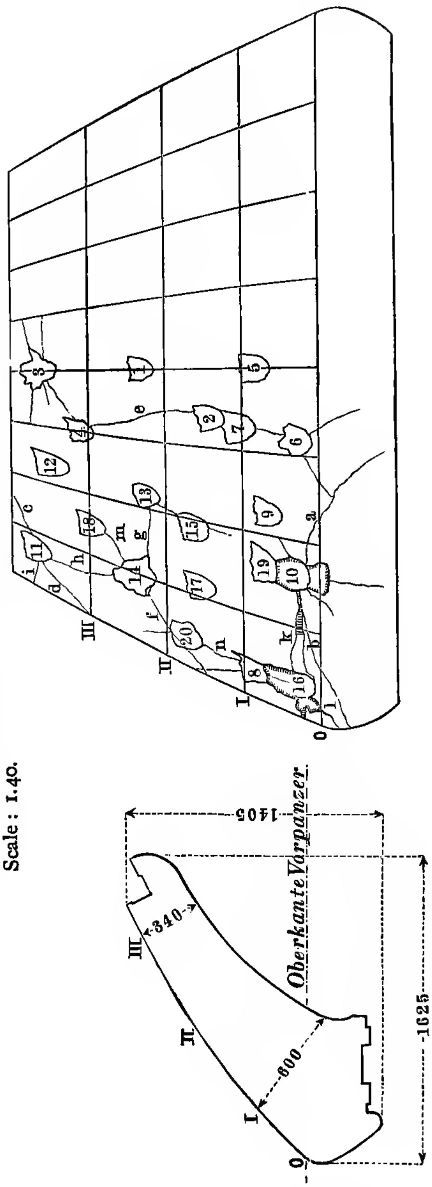
Point struck: 55 in. left of centre line, 37.4 in. above glacis plate edge.

Angle of impact: 34° 15′
Effect: Indent 4 in. broad, and 0.3 in. deep.
No cracks.

Fig. 25.

Profile and Diagram of Hits of the Trial Side Plate of a Chilled Armour Turret for two 4.7 in. (12 *cm*) *Guns* 19 *and* 20/1/85.

Scale: 1.40.



Shot glanced upwards and split into many small pieces, which showed, as did also the subsequent rounds, a great degree of hardness.

Round No. 2:

Shot: Ternitz steel shell, 76 lb. weight.

Point struck: 54.3 in. from left edge of plate.
22.5 in. above edge of glacis.

Angle of impact: 40° 10′.

Effect: Indent 4.3 in. broad and 0.4 in. deep.
No cracks, shot glanced upwards and broke up.

Round No. 3:

Shot: Ternitz steel shell, flat headed, 73 lb in weight. Diameter of flat 5 in. The flat part was sunk in centre about 0.4 in. deep, so that it had a sharp cutting edge. The shell was weighted with lead and sand to 76 lb.

Point struck: 46 in. from left edge of plate.
58.2 in. above edge of glacis.

Angle of impact: 25° 56′.

Effect: Indent, 3 in. broad and 1.3 in. deep. Upwards and on the side downwards to point hit surface chiselled to slight depth. 5 short radial hair cracks.
On the back of the plate no crack visible.
Shot glanced upwards and broke up.

Round No. 4:

Shot: Ternitz steel shell, 76 lb., without sand filling.

Point struck: 37.5 in. from left edge of plate.
50·4 in. above edge of glacis.

Angle of impact: 29° 27′.

Effect: Indent 3.5 in. broad and 0.2 in. deep.
No cracks.

Shot glanced and broke up as before.

Round No. 5:

Shot: As in last round.

Point struck: 68.4 in. from left plate edge.
13.8 in. above glacis plate edge.

Angle of impact: 43° 22′ 30″.

Effect: Indent 4.7 in. broad and 0.3 in. deep.
No cracks.
Shot glanced and broke up.

Round No. 6.

Shot: Ternitz Steel Shell, 77.3lb. in weight, without sand filling.

Point struck: 55 in. from left plate edge.
4.7 in. above glacis plate edge.

Angle of impact: 46° 15′.

Effect: Indent 5 in. broad and 0.5 in. deep.
Two short hair cracks downwards to right and left.
Shot deflected upwards and broke up.

Round No. 7:

Shot: As in round No. 4.

In order to avoid bringing the gun back to the initial position later on, this round was directed on the spot originally intended by the programme for the 20th round.

Point struck: 55 in. from the left plate edge.
16.5 in. above edge of glacis.

Angle of impact: 42° 19′

Effect: Indent 5 in. broad and 0.2 in. deep.
A radial hair crack to Hit No. 6.
No crack visible at back of plate.
Shot glanced and broke up.

The trial was suspended after Round 7, and continued on the 20th January; the gun, in the meantime, being moved 24° to the left, in accordance with the programme. Distance 39.5 yards.

Round No. 8:

Shot: As before.

Point struck: 6 in. from the left edge of plate.
13.8 in. above the edge of the glacis.
(Hit No. 7 of the programme.)

Angle of impact: 43° 11′.

Effect: Indent 5 in. broad and 0.2 in. deep.
A hair crack upwards to left, another downwards.
At back of plate no cracks visible.
Shot deflected upwards and broke up.

Round No. 9:

Shot: As before, weighted to 76 lb.

Point struck: 39.4 in. from left edge of plate.
11 in. above edge of glacis.

Angle of impact: 43°, 44′.

Effect: Indent 4.3 in. broad and 0.4 in. deep.
No cracks.
Shot deflected upwards and broke up.

Round No. 10:

Shot: Flat-headed Ternitz steel shell 73.4 lb., weighted with sand and lead to 76 lb.

Point struck: 29.2 in. from left edge of plate.
4.7 in. above the edge of glacis.

Angle of impact: 46° 28′.

Effect: Indent 5 in. broad and 1.5 in. deep; abrasions upwards and downwards.

Two cracks, *a* and *b*, about 4 in. deep.

The cracks, to all appearance, did not penetrate the interior of the plate, but were confined to the surface; two vertical hair cracks of small length.

At back of the plate no crack visible.

Shot deflected up and broke up.

Round No. 11:

Shot: Flat-headed Ternitz steel shell, 72.8 lb., weighted with sand and lead to 76 lb.

Point struck: 7.4 in. from the left plate edge.
59.8 in. above edge of glacis.

Angle of Impact: 25° 57′.

Effect: Indent 5.5 in. broad and 0.4 in. deep.

2 hair cracks, *c* and *d*.

No crack visible at back of plate.

Shot deflected and broke up.

Round No. 12:

Shot: As in last round.

Point struck: 26 in. from left edge of plate.
56.5 in. above edge of glacis.

Angle of impact: 26° 22′ 30″.

Effect: An indent 3.5 in. broad and 0.4 in. deep.

A crack *e* between hits 2 and 4.

No visible crack at back.

Shot deflected and broke up.

Round No. 13:

Shot: Ternitz steel shell, 76 lb., without sand filling.

Point struck: 30. 8in. from left edge of plate.
36.2 in. above edge of glacis.

Angle of impact: 34° 45′.

Effect : Indent, 4 in. broad and 0.1 in. deep.
No cracks.
Shot deflected and broke up.

Round No. 14:

Shot : Flat-headed Ternitz steel shell, 72.1 lb., weighted with sand and lead to 76 lb.

Point struck : 13.8 in. above left edge of plate.
34.6 in. above edge of glacis.

Angle of impact : 35° 30′.

Effect : Indent, 7.1 in. broad and 1 in. deep.
Irregular chisellings of small depth upwards and to the side.
3 hair cracks *f*, *g*, and *h* ; a hair crack, *i*, from hit, No. 11 to the left edge.
No visible crack at back.
Shot deflected and broke up.

Round No. 15:

Shot : Ternitz steel shell 76 lb., without sand filling.

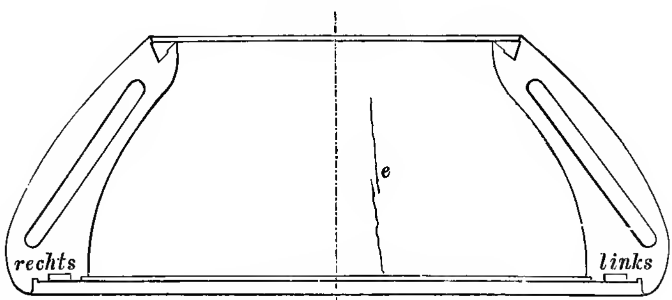
Point struck : 29.6 in. from left edge of plate, 26.7 in. above upper edge of glacis.

Angle of impact : 38° 40′.

Fig. 26.

Back of Trial Side Plate of a Chilled Armour Turret for two 4.7 *in.* (*12 cm*) *Guns, after the twentieth round,* 20/1/85.

Scale : 1.40.



Effect : Indent 4.7 in. broad, and 0.2 in. deep
Two radial hair cracks.

At the back of the plate, crack *e* as a hair crack visible for 28 in., beginning about 21.3 in. from the upper edge, and running vertically downwards about 8.7 in. from the centre line.

Shot deflected and broke up.

Fig. 27.

Side Plate of Chilled Iron Armour Turret for two 4.7 in. (12 cm) guns after Round 20. 20/1/85.

From a Photograph.

Round No. 16:

Shot: Flat-headed Ternitz steel shell weighted with sand and lead to 76 lbs.

Point struck: 7.4 in. from left plate edge.
4.7 in. above upper glacis edge.

Angle of impact: 46°, 6′.

Effect: An indent with surface abrasions.

Shot's head fixed in indent, whose depth could not therefore be measured.

A crack *k* to hit 10 with abrasions.

A crack *l* down to left. Hair crack *a* widened.

Back of plate unchanged.

Shot broke up.

Round No. 17:

Shot: As round 15.

Point struck: 17.7 in. from left plate edge.
25.2 in. above edge of glacis

Angle of impact: 39°.

Effect: Indent 5 in. broad and 0.1 in. deep.

No cracks.

Back of plate unchanged.

Shot deflected and broke up.

Round No. 18:

Shot: As last round.

Point struck: 19 in. from left plate edge.
50.4 in. above edge of glacis.

Angle of impact: 30° 30′.

Effect: Indent, 4.7 in. broad and 0.3 in. deep.

A hair crack *m* to hit 14.

Back of plate unchanged.

Shot deflected and broke up.

Round No. 19:

Shot: As last round.

Point struck: 28 in. from left edge.
11.8 in. above edge of glacis.

Angle of impact: 43° 35′

Effect: Indent 6.7 in. broad, 0.6 in. deep; no new cracks; crack *a* widened 0.4 in.

Back of plate unchanged.

Shot deflected and broke up.

Round No. 20:

Shot: Ternitz steel shell, 75.96 lb., weighted with sand to 76 lb.

Point struck: 5.5 in. from left edge.
28.4 in. above glacis.

Angle of impact, 38° 23′.

Effect: Indent 4 in. broad, and 0.6 in. deep.

A hair crack *n* to hit 8, a short hair crack upwards.

Back of plate: Hair crack *e* lengthened to lower plate edge (see fig. 26), no other crack visible at back.

The joint of left support opened about 0.08 in.

Summary: The plate had resisted 20 steel shells, each with 887 foot tons energy; that is 891.5 foot tons per ton weight of plate, or, reckoning only the half plate attacked, 1,783 foot tons per ton, without losing any considerable part of the protection offered. The only effect worthy of note was the crack *e* at the back, which, however, did not extend to the upper edge, and had no influence on the resistance of the plate.

Crack *a*, after removal of the glacis, was seen to run below the upper surface, but it did not reach the edge, so that the piece affected was in firm connexion with the plate.

The effect of the new flattened curve of surface had shown itself to be extremely favourable, all the shot glancing.

The flat-headed shell had more effect than the pointed ones, still they did not produce serious injury.

The plate had exceeded the demand made upon it, which was that it should resist fifteen rounds. Nevertheless, no approximation could be made as to what further amount of firing would break it up.

The Ternitz shell exhibited throughout an extremely hard material, the broken pieces, as with Krupp shell, scratching glass. No great difference could be noted between the qualities of the two kinds of projectiles.

Conclusions.

There is but little to add to the several summaries of the trials, which are very explicit.

All the plates had satisfied the demands made upon them, but as the latter vary greatly, a few remarks are necessary.

The object of the first firing trial was to determine if chill cracks were injurious or not, the position of which led to a concentration of the shot. This trial, as well as the following ones, clearly proved **that these chill cracks are without any influence on the power of endurance of the plate.**

In trials 2—5 a concentration of rounds, fired with full charge, took place on a small surface of the plate, but the number of hits was proportionately small, as the only object intended was to note the behaviour of the plate under this concentrated fire.

Trials 1—5 must therefore be considered under the aspect of a test of the material, but at the same time the results led to an important alteration in the construction of the armour, namely a flattening of the profile.

An armour plate, improved in correspondence therewith, formed the subject of Trial No. 6, which thus may be considered in distinction from the previous trials **as a test of the design of construction.**

The conditions of this trial were in all respects those of actual warfare.

The number of hits which the plate had to stand was considerably greater—20 on the half plate, equal to 40 for the whole plate—but they were distributed over the surface, and the attacking gun did not fire a full charge, but only one corresponding to a distance of 1,093 yards.

The result of this trial showed most distinctly that the conclusions on which the construction of this plate had been based were correct; the profile had proved itself to be advantageous, and the dimensions selected appropriate.

We will revert to this subject after describing the trials against coast defence armour.

II.—Firing Trials against Chilled Armour for Coast Fortifications in the years 1883—1886.

For the purposes of the firing trials against coast armour, a number of plates for two different chilled armour turrets were employed, namely:— Three side plates for a turret ordered by the Dutch Government for two 12in. (30.5 cm) 35 calibre guns, and a side plate for a turret ordered by the Italian Government for two 35 calibre 15.7 in. (40 cm) guns. The construction of this last followed the experience gained with the trial which preceded it, and this whole series of trials thus stands complete by itself.

Like those previously described, these trials were originally called for by the existence of a number of chill cracks in the different plates, of which it was necessary to demonstrate the absence of injurious influence. This demonstration could be considered as established by the first trial, and the subsequent ones treated as tests of material and design. Corresponding to the selection of armour for coast defence, the attack was made with the 12 in. (30.5 cm) and 17 in. (43 cm) naval guns. The number of hits, however, exceeded those which, in all probability, coast armour would be called upon to withstand in practice, and attention must be paid to this in forming an opinion on the results, if the trials are to be considered from the point of view of actual warfare,

1.—Trial against a Glacis Plate of a Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns, 35 calibres long.

On Gruson's Firing Ground at Buckau.

13th August, 1883.

Object and Programme of the Trial.

Apart from a general test of the design and dimensions of the plate, by concentrating several rounds from the 25 calibre 12 in. (30.5 cm) gun close to certain chill cracks existing in the plate, to determine whether these latter influenced its resisting powers.

Target.—The turret to which the trial plate belonged corresponded in the main to the type shown in Fig. 4.

The cupola was formed of 11 chilled plates, and had a diameter of 33.5 ft. The height from the edge of the roller ring to the upper edge of the ring of cupola plates was 15.7 ft., and that from the roller ring to the base of the lower storey 19 ft.

The glacis armour was also in 11 pieces, of which 5 plates placed in front had a height of 5.7 ft., the others 4.1 ft. The roof of the cupola, 21 ft. diameter, was in two parts, with the sights placed in the joining grooves, and used from a covered man-hole.

The horizontal training of the turret was carried out either by hand or steam power, as convenient, a whole turn being made by steam in 4 minutes 20 seconds, and $\frac{1}{4}$-turn by hand in 4 minutes. The engine was of 26 I.H.P. Ten men worked the hand gear.

The guns were mounted in Gruson's minimum-port carriage C/80, worked by two accumulators. These were placed in the lower storey of the turret, and served also as hydraulic cranes for changing the guns. The carriage gave 12° elevation and 6° depression. No provision was made for lateral movement.

In the trial glacis plate there was a chill crack stretching almost without break from the upper to the lower edge in the centre line. The plate was built up with four others so as to form almost half a ring of plates, the ends being supported by masonry pillars. Before the lower part of the plate (see fig. 28) a protecting layer of granite was placed; the other plates were similarly covered with concrete which terminated at the masonry pillars.

The chill crack was throughout about 0.4 in. wide and 2.8 in deep, and is shown in fig. 28 by a dotted line.

The usual wood and earth screen was placed in front to guard against splinters of shot.

The thickness of the trial plate is given in Fig. 28. Its greatest expanded breadth was 13.8 ft., height 8.9 ft., and weight 36.9 tons.

Gun: Krupp's 25 calibre, 12 in. (30.5 cm) gun in Gruson minimum-port carriage C/80. Gun fired with 6° depression.

Distance: 29.5 yards.

Shot: Krupp steel shell, empty, 12 in. (30.5 cm), 3.5 calibres long, weight about 981.3 lb.

Charge: 264.6 lb. P.P. C/80.

Striking velocity: About 486.4 yards per sec.

" energy: " 14,519 foot tons.

Round No. 1:

Shot: Krupp's shell, as above, weighted with sand and lead to 981.3 lb.

Point struck: 8.7 in. right of centre line.
2.8 in. above glacis edge.

Angle of impact: 48°.

Effect: Chisel cutting 2.4 in. deep, maximum (greatest depth, at left near hit on chill crack, 1.7 in.)

Surface abrasion in maximum 19.2 in. broad and 20 in. high.

Three short hair cracks *a*, *b* and *c*.

Chill crack unaltered.

Glacis torn up, 6 in. deep at point struck.

Back of plate intact.

General state of target: upper edge of trial plate had dropped about 0.4 in., due to movement of masonry pillar. Shot broke up.

Round No. 2:

Shot: As in 1.

Point struck: 8 in. left of centre line on upper glacis edge.

Angle of impact: 53°.

Effect: Indent and chiselling of point struck 2.4 in. deep. Abrasions round both hits 20 in. greatest breadth and 22.8 in. high. Horizontal crack *d* through centres of both hits, crossing the chill crack at right angles. Chill crack unchanged.

Back of plate: Crack *d* visible throughout its whole length, dividing the plate into two parts.

General state of target: The plate was pushed back 1.4 in. on the left and 1.2 in. on the right, and had dropped about 0.4 in.

The glacis was so torn away by hit 2 that the plate was laid bare over a breadth of 22.8 in. and 7 in. in depth.

Shot broke up.

Round No. 3:

Shot: As before.

Point struck: On centre line (chill crack) 2.4 in. above original edge of glacis.

The chilled surface was entirely removed at the point struck.

Angle of impact: 52°

Effect: Indent 5.3 in. deep. Abrasion of surface increased to 30.7 in. broad and 18.5 in. high.

A vertical through crack *e*, stretching to the upper edge from a point 8 in. right of centre line ran along 8 in. from a portion of the chill crack; leaving this, struck into the chill crack 6.7 in. below, leaving it again about 10 in. lower down, and finished downwards to the left. The upper end of the chill crack was lengthened about 8 in. by a hair crack, but was otherwise unaltered.

Back of plate: Crack *e* visible throughout its length, dividing the plate into four parts.

General state of the Target: On removal of the glacis, crack *e* was seen to cross the chill crack and its branches, reaching the lower plate edge 13.8 in. right from the same. The crack at lower part of the plate was 1.4 in. wide. The two upper parts of the plate had dropped about 4 in., and its upper edge pushed back about 5.5 in. more.

The shot broke up.

Round No. 4:

Shot: As before.

Point struck: About 27.6 in. left of centre line.
8 in. above glacis edge.

Angle of impact: About 40°.

Effect: The two upper parts of the plate were thrown inwards and a number of pieces knocked off the piece struck.

The plate was thus breached. A new crack *f*. Chill crack unchanged.

Back of the plate: The back of the portion still standing was no longer visible, being covered by broken parts fallen down. Later it was seen that the crack *e* was widened at the lower part.

General state of the target: The whole target had apparently been moved considerably, as the joints between the trial and adjacent plates had been opened from 0.4 in to 1.2 in.

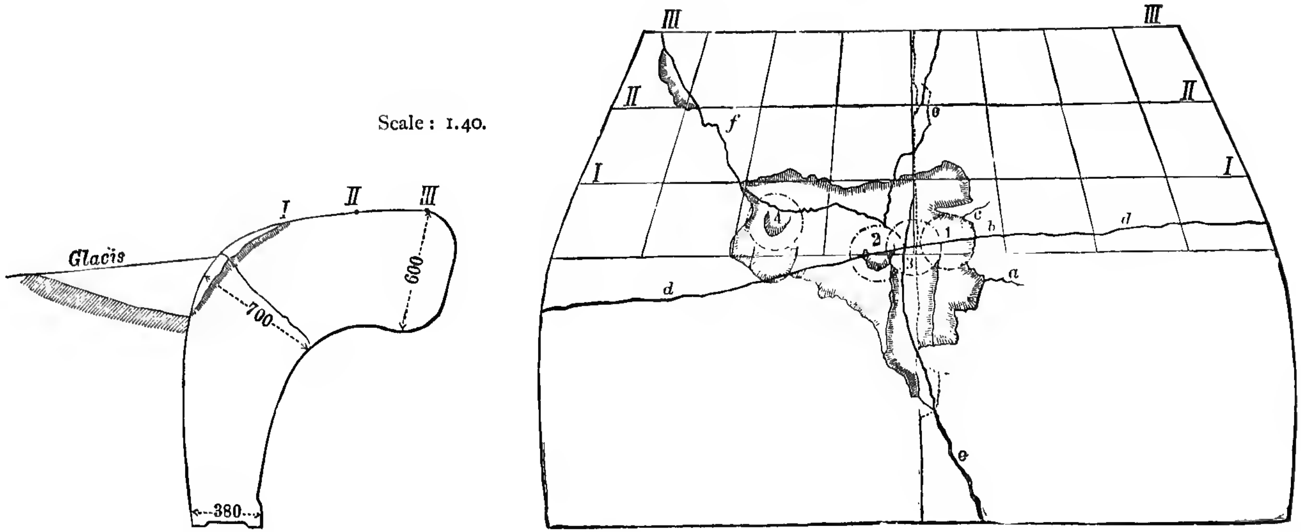
The shot broke up.

Summary: (*a.*) Behaviour of the chill crack. As already noted, the chief object of the trial was to ascertain the influence of the chill crack, and for this purpose three rounds were concentrated on a straight line 15.7 in. long, with a total energy of 43,605 foot tons. To form a test of the *design* of the plate, the hits should have been distributed, in accordance with the conditions of actual warfare, over the surface, as it is not reasonable to make a plate stronger, and so dearer, than actual practice requires.

Fig. 28.

Profile and Diagram of hits of the trial glacis Plate of the Chilled Iron Armour Turret for two 12 *in.* (30.5 *cm*) *guns.* 13/8/83.

Scale: 1.40.



On inspection of the glacis, it was seen that crack *e*, instead of following, as was supposed, the chill crack, crossed and formed a branch towards the bottom edge of the plate (*see* Fig. 28).

In the upper part of the armour plate the crack *e* followed twice for a short distance the chill crack; but it is to be noted that the plane of fracture was a constant curve, and only joined superficially the irregular zigzag of the chill crack From this it was clear that the crack *e* was in the interior of the plate entirely independent of the chill crack, as might be expected from the small depth of the chill crack (2.8 in.) in proportion to the thickness of the plate (27.6 in.)

Further evidence that the chill crack had no injurious effect lay in the fact that crack *e* diagonally crossed, at the under part of the plate, the four-sided piece, bounded by the chill cracks, without following either side or running into the lower chill crack.

That chill cracks do no harm seemed by this sufficiently proved, and the real object of the trial was in consequence fulfilled.

(*b*.) Behaviour of the armour plate and of the structure. A close examination of the target showed that the foundation under the trial plate had sunk about 0.8 in., so that the nearest part of the plates adjoining did not rest upon the foundation.

The inner projection of the bed-plate at the left joining edge was broken away, and both joints between the four plates not fired at had opened about 0.2 in. Lastly an opening between the concrete covering and the masonry pillar showed that the latter had been pushed back, the right one about 0.4 in., and the left one 0.3 in., which was accounted for by the fact that the masonry had not sufficiently set, the mortar being for the most part still wet.

The state of the target showed that the four unattacked plates had moved round on the bed-plate in a nearly circular direction, and had pushed the masonry pillars back. This backward yielding, together with the sinking of the foundation, made it possible that the crack *e* below had opened 1.4 in. without bringing the lateral joining edges of the plate into contact with those of the adjacent ones, the point of bed-plate breaking as a result of this separation, as it had alone to resist the tremendous blows given.

From the sinking of the plate observed after the first round, it is evident that the movement of the target had already taken place at this round, and consequently the plate was standing loose at the next round.

These circumstances explain the falling out of pieces loosened by cracks, which never would occur with a properly built up glacis armour.

That the upper half of the plate which before the third shot was only loosely resting on the lower half, and had sunk about 1.6 in., hanging between the adjoining plates, was not crumbled up by the 3rd shot into numerous pieces, points to an excellent quality of material.

The following result was observed as worthy of notice:—

If a shot struck on a part from which the layer of white iron had been already removed, it did not cause any very much greater injury than shots striking on an uninjured part, as the hardness of surface seemed to extend much deeper than the white layer. The cutting away of the surface only showed an increased toughness of material.

Although the stout resistance offered by the plate to concentrated fire, even after the foundation had failed, led to the apparently valid conclusion that, in actual practice, it would be found amply strong enough when made use of in the construction of the turret, the Dutch Committee for the Trial decided to make an alteration in the construction of the front glacis plates, which chiefly consisted in the provision of pillars on both sides of the plate, which made it impossible for upper pieces, which might be broken loose, to fall down.

All the shot broke into pieces, showing an unusually hard and excellent material.

2.—Trial against a Side Plate for a Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns, 35 calibres long.

On Gruson's Firing Ground at Buckau.

22nd October, 1883.

Object and Programme of the Trial.

Test of the armour by 4 shots from the Krupp 12 in. (30.5 cm) gun, and also to determine by the trial whether

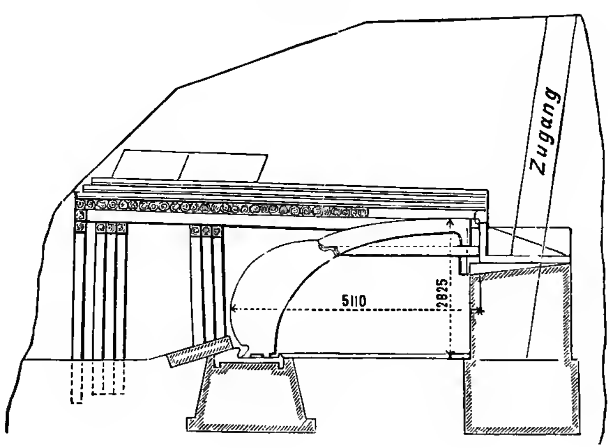
(*a*) The dimensions selected for the armour of this turret were appropriate.

(*b*) The behaviour of chill cracks existing in the plate would confirm the results of the trial of 13th August, 1883, as regards their lack of influence on the endurance of the plate.

Fig. 29.

Structure for the Side Plate of the Chilled Iron Armour Turret for two 12 *in.* (30.5 *cm*) *Guns.*

Scale : 1.40.



Target: The trial plate formed part of the cupola of the turret previously described as ordered by the Dutch Government. It was placed between four other side-plates and a roof-plate, so as to form half a turret, which rested at the rear against three strong pillars of masonry, connected with the armour by three stout specially cast struts.

The structure is shown in Fig. 29.

Above the roof-plates was a layer of timber baulks as a screen against splinters of shot. As seen in the figure, the baulks did not lie on the roof-plate. They were weighted with three layers of iron rails, and the whole covered with earth some yards high.

In the inside of the turret, to which a staging led, were plummets and gauges for measuring any change in the position of the roof-and ring-plates, an exactly adjusted pendulum hung on either side of the central masonry pillar from the roof, whilst the distance of the bottom surface of the trial plate from the centre pillar was ascertained by three gauges.

In the trial plate were ten chill cracks made in the casting, of greatest depth 0.6 in., which in the figure are marked in dotted lines with small numerals 1 to 10.

The dimensions of the plate are shown by Fig. 30. Its greatest breadth expanded was 9.5 ft., height 11.5 ft.

Weight 46.7 tons.

Gun : Krupp's 12 in. (30.5 cm) gun, 25 calibres, on Gruson minimum-port carriage C/80. The gun fired with a depression of 2° 12′—4° 30′.

Distance : 29.5 yards.

Shot : Krupp's 12 in. (30.5 cm) steel shell, 3.5 calibres, empty, about 981.3 lb. weight.

Charge : 264.6 lb. P.P. C/80.

Velocity of impact : About 486.4 yards.

Energy of impact : About 14,519 foot tons.

Round No. 1 :

Shot : Krupp's 12 in. steel shell, empty, about 982.6 lb. weight.

Point of impact : 1.6 in. right of the centre line of plate, 35.4 in. above the lower edge.

Angle of impact : 90°.

Effect : An abrasion round the hit 1.4 in. in greatest depth, 19 in. broad, and 20.5 in. high.

On the point struck, the tip of the shot, which was forced flat, was welded on to the plate, and showed as a flat disc about 6 in. in diameter, with a slight rise in the centre, but no indent was apparently formed on the plate, only a flat depression, but the steel held so firmly to the armour that when cut out it brought away on its point a piece of the chilled metal.

F2

Five short radial hair cracks were formed from the point struck.

A horizontal crack *a* reached both edges of the plate, on

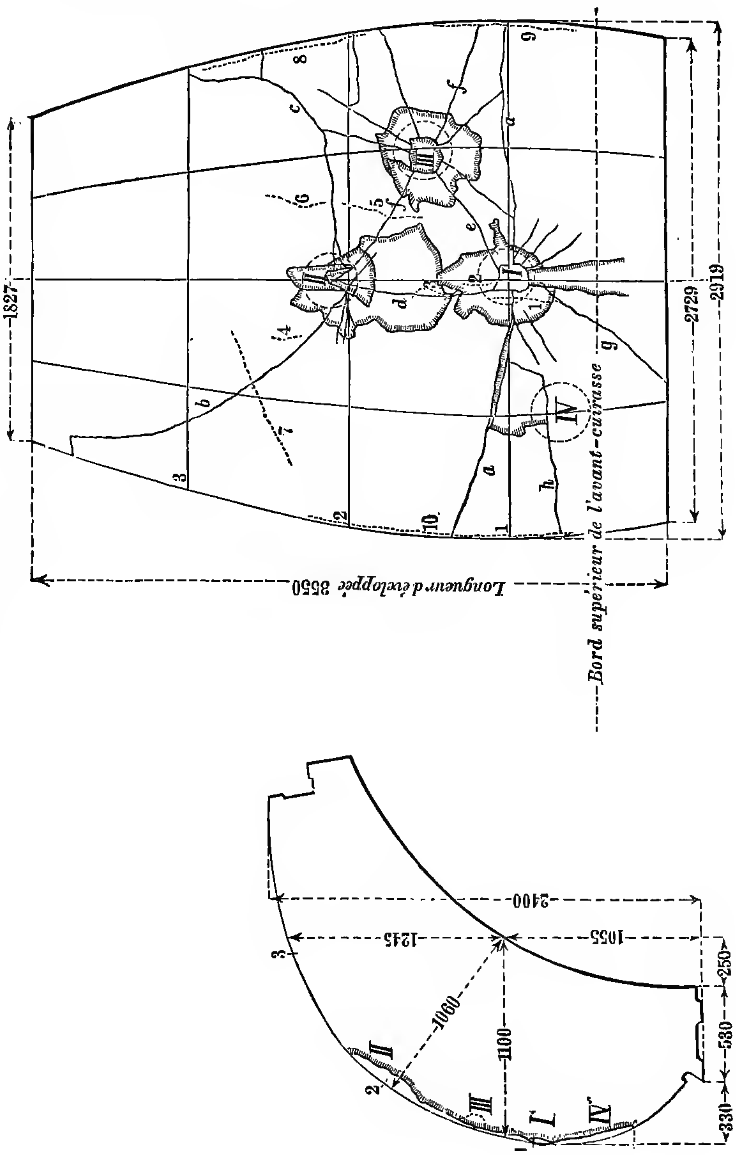


Fig. 30.

Profile and Diagram of hits of the Trial Side Plate of the Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns. 22/10/83.

Scale: 1.40.

the left 49.2 in., on the right 35.8 in. Above the lower edge of the plate, along the crack, to the left of point struck, an abrasion 1.2 in. broad, and 11.8 in. by 15.7 in. long.

Back of plate: On inspection of the interior the crack *a* was seen to have gone right through and showed as a fine hair crack, beginning 17.7 in. from left edge of the plate and running to 8.7 in. from the right edge. A crack *g* branched off in the middle about 17.3 in. long towards the lower edge with a slight bend to the left, and finishing 6.7 in. above the edge.

General state of the target: By means of the plummet it was found that the roof-plate had receded about 0.04 in. on the right and 0.1 in. on the left hand. Also at the base the plate fired at had been pushed nearer to the pillar, as was shown by the fact that the wooden gauges placed between the pillar and the plate were in part broken.

The joint between the trial-and roof-plate was closed up, and those between the trial-plate and its plates at the side opened, on the inner edge of the joint, an average of 0.1 in. An opening had been made between the masonry pillars and the struts attached to them 0.04 in. broad on the right and 0.1 in. on the left.

This condition of the interior showed that the masonry pillars had not been able to prevent a movement outwards of the whole structure; but this was so slight that it did not furnish a reason for discontinuing the trial.

Shot broke up.

Round No. 2:

Shot: Krupp's 12 in. (30.5 cm) steel shell, empty weight, 984 lb.

Point struck: On the centre line:

74.8 in above the lower plate edge.

39.4 in. above Round 1.

Angle of impact: 51°.

Effect: A long chiselling at the point struck 27.6 in. greatest depth, 19 in. long, and 4.7 in. broad, abrasion around about 21.7 in. greatest width, as shown in the sketch.

Four hair cracks about 8 in. long.

A crack *b*, bending upwards to the left from the point struck, and finishing 19.7 in. from upper plate edge, and 6.7 in. from the left edge.

A crack *c* from the hit, curving to the right, and finishing after a sharp bend at the plate edge.

A vertical crack, *d*, joining Hits 1 and 2; no prolongation of this crack below crack *a* was observable, but the same probably existed, as a crack in this direction was already formed by the first round at the back of the plate.

Back of the plate: Horizontal crack *a* seen to stretch to both plate edges and opened about 0.04 in. The other cracks, *b*, *c*, *d*, were not visible there.

General condition of the target: by the plummet the roof-plate had further receded on both sides about 0.1 in., whilst the distance of the pillar from the foot of the plate had not altered. The roof-plate had also pushed back slightly its supporting plates.

The joints between the trial and the roof-plates had, in consequence, apparently, of the yielding of the support plates of the latter, gone back to their original dimensions; those between the trial plate and its side plates had closed up about 0.2 in.

This closing of the lateral joints seemed to point to a closing together and consolidation of the dome or arch of the target under external blows. As the joints between the masonry pillars and the supporting struts showed no material widening, the yielding of the roof plate 0.1 in. did not seem important.

The shot broke up.

Round No. 3:

Shot: As before, weighted with sand and lead to 978.6 lb.

Point struck: 26.8 in. right from the centre line.
53 in. above the lower edge.
33.6 in. from shot 1, 35.4 in. from shot 2.

Angle of impact: 72°.

Effect: at the point struck a chiselling out 2 in. deep, with abrasions around, as in Fig. 33.

Eight radial cracks from the hit, *e* joining hits 1 and 3, *f* joining 2 and 3, and running upwards to the right edge of the plate; *f* did not run into *b*, but ran parallel to it for a short distance.

c was lengthened upwards, *b* widened to about 0.3 in.

Back of the plate: Two additional cracks showed after round 3, starting from a point on the left edge, one with a nest of small branches ending in crack *a*. the second finishing 8 in. above this. It seemed possible that the larger of these two cracks connected with crack *b* on the inside, although on the outside *b* reached nearly to the upper edge.

The state of the back of the plate after the 3rd round is seen in Fig. 32. The few through cracks seemed for so heavy a plate as not of serious moment.

General state of the target: The gauges showed that the roof

Fig. 31.
Side Plate of the Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns after the third round. 22/10/83.

From a Photograph.

had been pushed back a further 0.08 in., and also that the whole right edge of the plate had moved inwards some millimetres. On the left the roof and edge of the plate had apparently not moved.

The joints between the roof- and trial-plates were opened to a further considerable extent as also the joints of the trial and right plate at the side, which showed an opening, on top 0.2 in., below 0.4 in.; that with the left plate was 0.2 in. on top and 0.2 in. below.

The left pillar showed an important change, the joint between it and the strut having opened 0.2 in. No change was visible on the right.

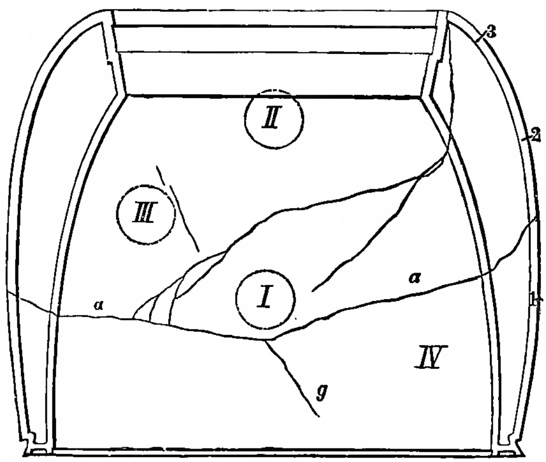
It was unmistakeable, that on the left, owing to the yielding of the plates, the strength of the dome was considerably reduced, but it seemed nevertheless capable of withstanding a fourth hit.

The shot broke up.

Fig. 32.

Back of the Trial Side Plate of the Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns after the third round, 22/10/83.

Scale: 1.40.



Round No. 4:

Shot: Krupp's 12 in. steel shell, 980.3 lb., weighted with sand and lead to 981.3 lb.

Point struck: 29.6 in. from the left plate edge.
25.6 in. above the lower plate edge.
33.1 in. from hit No. 1.

Angle of impact: About 75°.

Effect: The fourth round breached the plate and forced a piece of plate bounded by cracks *a, g* and *h,* inside the turret against the centre pillar, which caused other pieces of plate on the left to fall down, so as to partly close the breach again, the separated pieces of armour remaining therein.

The plate was broken into 6 pieces by cracks *a, b, c, d, f, g.*

Back of the plate: The cracks at back were much widened by the falling of the parts of the plates in front; but no new cracks were observed, as the effect of the round had been concentrated on the

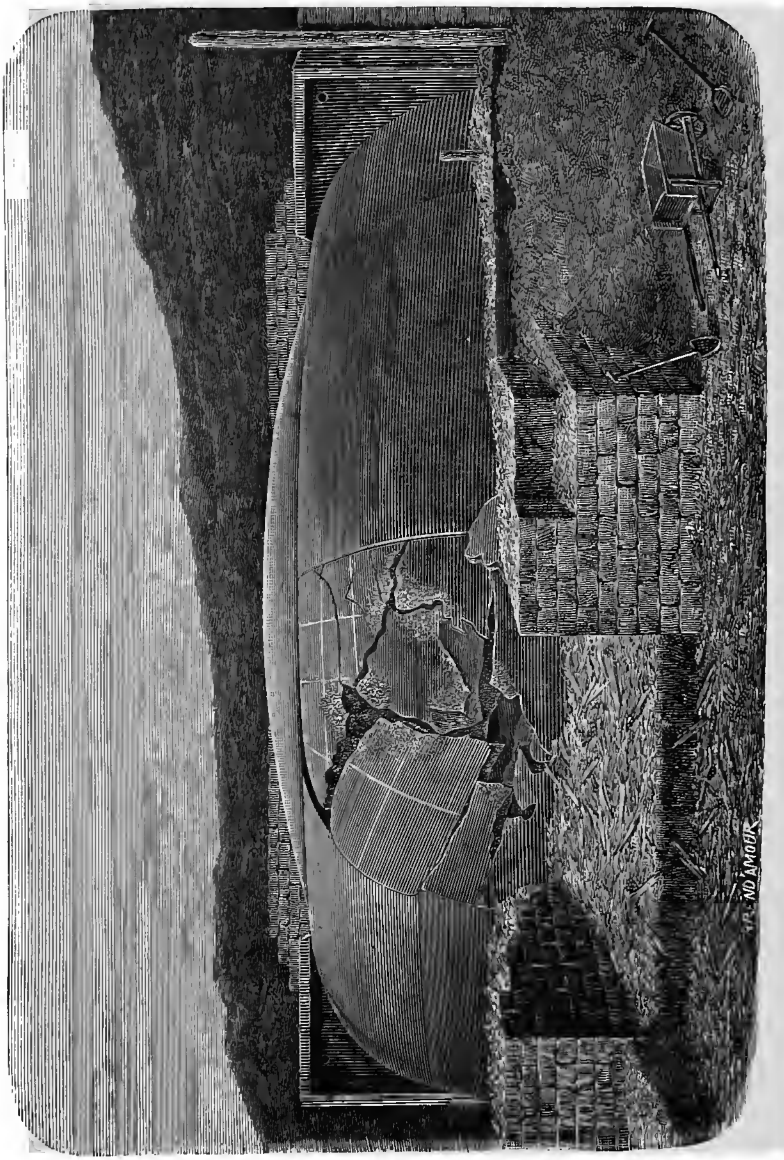


Fig. 33.
Side Plate of the Chilled Iron Armour Turret for two 12 *in.* (30.5 *cm*) *Guns after the fourth round*, 22/10/83.

From a Photograph.

piece bounded by cracks *a* and *g*. Several pieces of plating and of the shot lay on the inside.

General state of the target: The roof plate had not receded further by Round 4, but the opening of the joints between the pillars and struts had increased to 0.6 in., so that a sideways yielding of the whole structure was shown to have occurred.

This was confirmed when the earth was removed from the target. Between the roof and side plates on the left, which before the firing were placed close together, an opening 1.2in. wide had been formed, and showed that both the left side plates, with their bed plates, had been pushed outwards.

The shot broke up.

Summary: The plate resisted three rounds, with a total energy of 43,508 foot tons, or 914 foot-tons per ton of armour, without decrease in the protection afforded to the interior of the turret. After these rounds the plate was separated into several large pieces by numerous cracks passing partly from side to side, and through the thickness of the plate, but no displacement of parts had occurred.

The surface showed injuries round the points hit, which had a certain extension, but only a few inches of depth.

No penetration of the shot, or of their points into the plate, had taken place.

Several obvious circumstances brought about the breaching of the plate by the fourth round.

Crack *g* was formed already, before the round, and visible at the back of the plate. Crack *a* went right through the plate, so that the upper small part on the left was already loosened. Had the other plates and the pillars not moved, the piece would in all probability have withstood another round, but as it was, the whole effect of the shot could be expended in dislodging the piece of plate, which, as a natural consequence, was driven inwards to the interior of the turret.

The chill cracks in none of the four rounds had shown to have any injurious influence on the plate.

As seen in the drawings, the cracks set up by the shot took their course quite independent of the chill cracks, and in no case was even a lengthening of the latter produced by the blow of a shot.

The steel shells behaved in this trial as in all previous ones, viz.: they broke up into numerous pieces of the size of a fist to that of a pea.

3.—Trial against a Half-roof Plate for a Chilled Iron Armour Turret for two 12in. (30.5 cm) Guns, 35 calibres long.

On Gruson's Firing Ground at Buckau.

26th and 28th May, 1884.

Object and Programme of the Trial.

Proof of the roof for a turret by 4 shots from the Krupp 12 in. (30.5 cm) gun.

The test in this case had less reference to chill cracks, as the previous trials had sufficiently shown their want of injurious effect, but was rather directed to discover if the dimensions of the plate were sufficient to withstand the attack of the Krupp 12 in. gun.

Target: The trial plate formed one half of the roof of the turret described under trial No. 1. The shape is seen in Figures 34 and 35, as also the rib on its straight edge, which rested on a corresponding rib in the other plate when placed on the turret. The manhole in the centre, as well as the sighting holes, are mentioned in the previous description.

The trial plate was, corresponding to its position in the turret, supported by three cast-iron plates of 39.1 tons weight placed in a half ring and keyed together. The other "half plate" was replaced by three similar cast-iron plates resting against three masonry pillars. The cast-iron ring plates were fixed by means of ribs to a base plate, and also the centre ring plates were bolted together with two bolts.

In order to obtain increased angles of impact the trial plate was not placed horizontally, but at an angle of 5°, that is, the imaginary plane of its location made an angle of 5° with the horizon.

A number of small chill cracks existed in the trial plate, which were closed with steel wedges, and there were further in the plate three holes 4.7 in. in diameter for use in placing the plate in position on the turret.

The usual wood and earth screen against shot splinters was provided.

The chief dimensions of the trial plate are given in Fig. 34.

Its weight was 46.7 tons.

Gun: Krupp's 25 calibre 12in. (30.5 cm) gun in Gruson's minimum-port carriage C/80.

The gun was fired with a depression of from 3° 44′ to 5° 6′.

Distance: 31.7 yards.
Shot: Krupp's 12 in. 3.5 calibre steel shell empty, weight about 981.3 lb.
Charge: 176.4 lb. P.P. C/80.
Velocity of impact: 392 yards per sec.*
Energy of impact: About 9,503 foot-tons.

Round No. 1:

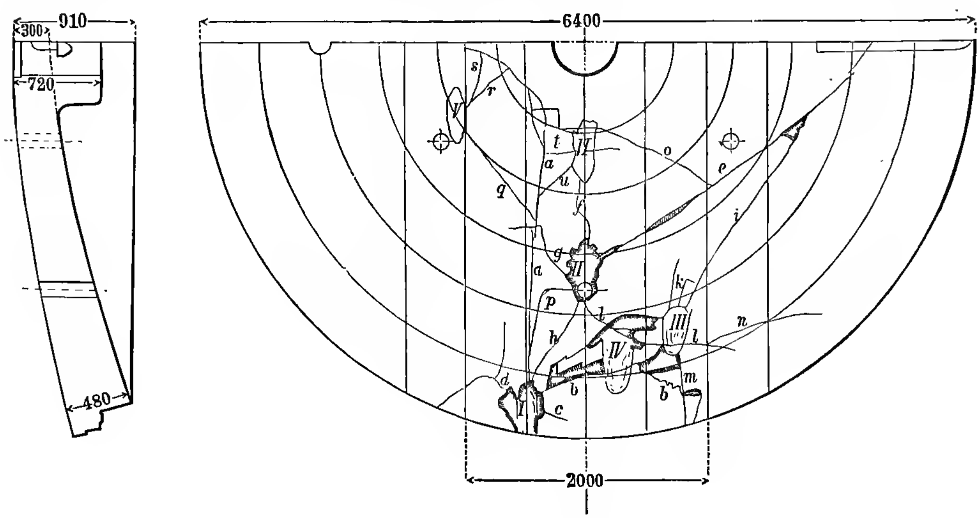
Shot: Krupp's 12 in. steel shell, 978.6 lb. weighted with sand and lead to 981.3 lb.

Point struck: 19.7 in. left of the centre line.
13.4 in. from the round edge of the plate.

Fig 34.

Profile and Diagram of Hits of the Trial Roof-plate of a Chilled Iron Armour Turret for two 12 *in.* (30.5 *cm*) *Guns.* 26 *and* 28/5/84.

Scale: 1.60.



Angle of impact: 24° 14′.

Effect: Chiselling out of surface 0.9 in. deep, with abrasions of 23 by 11.4 in. greatest extension.

A radial crack *a* from the point struck, and finishing 24.4 in. from the straight edge of the plate.

3 hair cracks *b, c, d.*

Back of plate: crack *a* was visible throughout its entire length.

* NOTE.—This figure is taken from the Official Reports of the Dutch Commission, and is probably more correct than the figure 377 yards previously given.

General state of the target: The position of the plate in the structure of the target was apparently unaltered, the joints between the ring plates showing no change.

The shot broke up.

Round No. 2:

Shot: Krupp's 12 in. steel shell; weight 984.5 lb., empty.

Point struck: On centre line, 49.6 in. from the round edge.

Angle of impact: 19° 35′.

Effect: The shot struck the central hole for lifting the plate and made a chisel mark on the upper half 4 in. deep with abrasions of 11.8 in. by 19.7 in. greatest extension and small depth. Crack *b* was lengthened to the round edge of the plate. A new crack *e* from the point struck ran upwards to the right, finishing 25.2 in. under the straight edge. Hair crack *f* 15.7 in. long, *g* crossing crack *a* at a sharp angle, *h* 12.6 in. long.

Back of plate: Crack *a* extended from edge to edge, *e* began at the back 25.2 in. below the straight edge, passed through the centre mounting hole and stretched in zig zag to the round edge. Crack *f* ran nearly radially from the centre mounting hole to the straight plate edge 38.2 in. in length, the direction differing considerably to that on the front of the plate. Crack *g* was visible at back as far as crack *a* (see fig. 35).

General state of the target: The radial crack in the central plate of the base ring had widened, and the plate sunk about 0.06 in., but the joints of the ring plates were unaltered.

The shot broke up.

Round No. 3:

Shot: Krupp's 12 in. steel shell, 980.3 lb., weighted with sand and lead to 981.3 lb.

Point struck: 28.3 in. right of centre line.
27.6 in. from the round edge.

Angle of impact: 22° 52′.

Effect: A long indent without abrasions. A crack *i* from the point struck running to crack *e*, three short cracks, *k*, *l*, *m*, the last reaching the round edge. Crack *a* extended upwards to the left, ending 4 in. from the straight edge.

Back of plate: Crack *i* visible throughout its length, *l* connecting with *d*, separating, as seen in the figure, a piece of the plate. Crack *m* visible, apparently connecting with *k*.

General state of the target: The crack in the centre supporting plate was somewhat widened and the right half of the plate sunk 0.08 in. to 0.1 in.

The shot broke up.

Round No. 4:

Shot: Krupp's steel sheel 981.5 lb. in weight, empty.

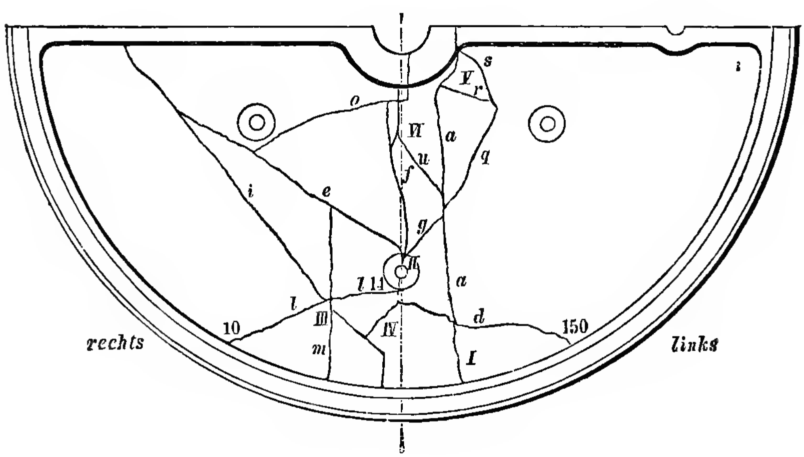
Point struck: 11 in. right of centre line, 17.8 in. from the round edge between hits 1 and 3.

Angle of impact: 23° 25'.

Effect: The shot hit the piece of plate loosened by cracks *b*, *h* and *l*, and, in addition to an indent, caused abrasions upwards like rounds 1 and 3, as shown in Fig. 34.

Fig. 35.

Back of the Trial Roof Plate of the Chilled Iron Armour Turret for two 12 in. (30.5 *cm*) *Guns after the sixth round*, 28/5/84.



New cracks *n*, *o*, *p*, *d* to the edge of the plate, *h* lengthened to hit 1. The piece of plate bounded by crack *b* was thrust up about 1.4 in.

An examination of crack *b* showed that it ran in the metal close to the round edge of the plate, but was not visible at the back of the plate.

Back of plate: the 4th round had not produced any new crack, but had caused the sinking of the piece bounded by cracks *l* and *d*. This was 6 in. on the left, 0.6 in. in the centre, and 0.4 in. on the right. The separated part remained fixed in the cracks.

The general condition of the target was apparently unaltered.

Shot broke up.

The plate had thus fulfilled the terms of the contract, but as it seemed yet completely able to afford protection, the trial was continued on the 28th May.

Round No. 5:

Shot: Krupp's flat-headed 12 in. steel shell, empty, weight 981.3 lb. Diameter of flat part, 5.4 in.

Point struck: 41.7 in. left of centre line, 23.6 in. above the straight edge.

Angle of impact: 12° 18′.

Effect: A long indent 0.4 in. deep without abrasions.

3 cracks, *q*, *r*, *s*, which were all visible at the back of the plate.

General state of the target: The piece separated by cracks *l* and *d* had further sunk about 1 in., but still remained fast in the plate. The crack in the central supporting plate was widened to 0.4 in.

Shot broke up.

Round No. 6:

Shot: As in round 5.

Point struck: On centre line of plate 33 in. under the straight edge.

Angle of impact: 13° 14′.

Effect: A long indent without surface abrasions. Two fine cracks *t* and *u*. Crack *f* lengthened.

Back of plate: *f* lengthened to the edges of the plate, *o* and *u* visible. No further drop in part broken loose.

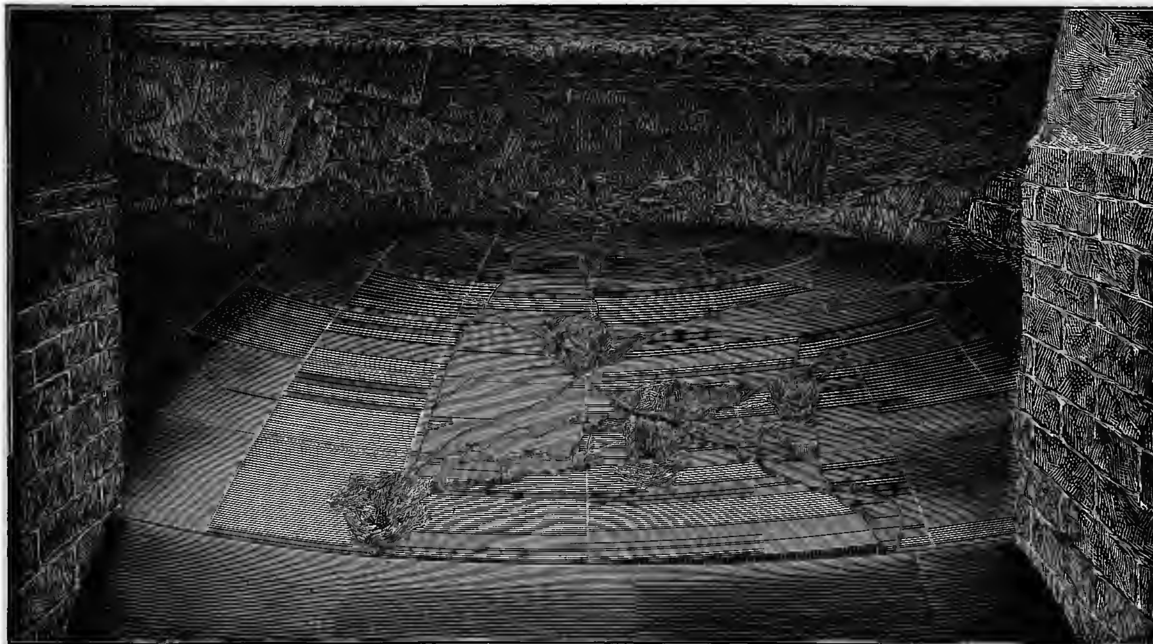
General state of the target: The trial had to be stopped after the sixth round, as the butt for stopping the shot was so much injured as to offer no further guarantee for arresting subsequent rounds.

Moreover, as the official report of the Trial Committee stated, it was not to be expected that a few more hits on the plate would effect any great change in its condition.

The shot broke up.

Fig. 36.

The Roof Plate of the Chilled Iron Armour Turret for two 12 in. (30.5 cm) Guns, after the sixth round. 28/5/84.



From a Photograph.

Summary: The plate had withstood six rounds with a total energy of 57,016 foot tons, that is, 1198.3 foot tons per ton of material of the armour, and thus displayed an endurance beyond the necessities of actual service, as in this case the shot could never strike at so great an angle. The dimensions selected had proved appropriate, and the advantage of the arched form had been clearly demonstrated, as, for instance, round 4 struck a piece of plate completely loosened, but was unable to drive this piece into the interior of the turret, although the resistance of the arch, owing to the cracking of the bed plate, had been considerably reduced. The 6th round, also, struck an already loosened piece without being able to dislodge it towards the interior.

The chill cracks proved, as before, to have no effect on the endurance of the plate, as the cracks produced by the hits commenced and ran quite independent of the former.

The great effect of the angle of impact on the injuries resulting from the hits was of interest. The effect of the rounds directed against the lower part of the plate was disproportionately greater than that of rounds 5 and 6, although these, when they struck the plate, found it already weakened. To all appearance, after the ogival head of the shot had hit the plate, a second blow was struck by the base of the shot, and this blow, to which it seemed that most of the shot's effect was due, was heavier in proportion as the angle of impact increased. The greater angle of impact obtained by depressing the gun and inclining the plate may be considered, in view of actual service, to have more than balanced the higher powder charge. Moreover, this heavy blow of the base of the shell may explain why they all broke to pieces on impact, which, considering the quality of Krupp's steel, would have been a matter of surprise on the assumption of a mere twisting of the ogival part.

4.—Conclusions of the Dutch Commission respecting Trials 1 to 3.

As already mentioned at the beginning of the chapter, the Trials 1 to 3 were undertaken at the instance of the Dutch Government, who appointed a Commission to carry them out, consisting of Lieut.-Colonel Voorduin, of the Engineers, Captain Scherer, of the Artillery, and Captain Snyders, of the Engineers.

The report of this commission was subsequently published by the Dutch Ministry of War, entitled "Verslagen omtrent schietproeven tegen pantseringen, 1884."

The report contains, in pages 149—157, the conclusions on the results obtained, which we now reproduce verbatim.

Conclusions and Decisions arising therefrom.

As regards the *first trial*, the glacis armour plate exhibited a tendency to crack through under the blows of the hits, *independent of the chill cracks existing in the upper surface of the plate, or of their direction,* but exactly in the direction of a plane in respect to which the moment of the part of the plate which hung over, and was separated by fracture, must be nearly a maximum. If it followed from this circumstance that the section of the plate at the point attacked was too small to offer an adequate resistance to fracture, on the other hand, it was clearly shown that, in consequence of its unfavourable profile, the plate, in whose section a considerable arching existed, was thereby in a measure already prepared for fracture.

Moreover, this first trial clearly showed that the side connection between the plates placed together in the glacis was too slight to prevent the pushing away of separated portions, so that if in the actual structure these defects cannot be avoided, the free movement of the cupola placed inside of the ring of glacis armour can very soon be compromised.

In opposition to these serious defects, the glacis armour showed the following good properties during the trial :—

(*a*.) An appropriate degree of hardness on the surface, which apparently renders penetration by the shot impossible.

(*b*.) Great resistance against such penetration also in the so-called transition layer, and, within certain limits also, in the interior of soft metal.

(*c.*) Complete homogeneity of the so-called "Gruson metal" in the different layers, with great fineness of crystals and entire absence of internal casting faults.

(*d.*) Non-injuriousness, within certain limits, of faults in the chill casting, as cracks or projections on the upper surface, which sometimes arise in the manufacture.

On the ground of these considerations, the manufacturer was informed at the close of the trial that, subject to the approval of the War Minister, the glacis armour, on account of its slight dimensions and the inappropriate proportions of its sections, was not satisfactory, and that a request would be made to replace it by other of improved construction, and that also measures should be taken to increase the connection, both of the plates forming the ring, as well as of parts of the same loosened by blows.

The second trial against a cupola plate made it appear likely that, under the influence of such hard shot as those used in this trial, the armour in question would break up into large pieces sooner than any part of the plate would be penetrated or loosened.

These plates certainly soon showed through cracks, which, as in the glacis armour, all ran in the plane of the least section, but with the great difference, that so long as the parts of the plate were not so cracked as to lose all connection between themselves, no displacement worthy of note took place, and not once the slightest dislodgement of these parts occurred.

As good properties of the Gruson armour system, the following were disclosed by the trial :—

(*a.*) The degree of hardness of the surface was sufficient to prevent penetration into the plate, even of normally striking shot, and the system offers consequently complete resistance to perforation, or anything like it.

(*b.*) The so-called chill cracks or similar defects on the hard part of the plate, which were the cause of the trial, occasioned no special disadvantage.

(*c.*) Lastly, it appeared that after three rounds with such great energy, and so large angles of impact, as in this case, not even the smallest piece of plate was dislodged from the inside of the armour or thrown inwards, so that this armour offers a protection—apart from the advantages of the simple construction and advantageous external form peculiar to this system—superior to that of any other system in existence or in construction.

The forcing through of a comparatively loosened piece of the plate by the fourth round, which was necessarily followed by the pushing to the rear of the upper part of the plate, was nowise, as in the case of the glacis armour, a necessary result of the form, but must chiefly, if not exclusively, be explained by the failure of lateral connection between the armour plates, principally at the lower edge, as also by the fact that one shot struck a very small piece of the plate already entirely separated by cracks. This pointed to the necessity of providing against this defective condition as far as possible in the actual structure of a turret.

Further, the effect of the different hits showed—greatly against the original view of the manufacturer, who, however, later on, entirely agreed with this opinion—that it was desirable so to construct the external curve of the armour (as far as this could be done), that normal hits should be almost impossible.

With regard to the decisions arising from these considerations, it may be remarked :—

1. The trial was made under the very severe conditions of the contract, which had been accepted by the manufacturer on the ground of the experience gained in former trials, conditions which on our part were maintained, although used in a manner unfavourable to the plates. For instance, the first shot was aimed at such a point that the part of the plate, below an imaginary horizontal line through the point of impact, had a relatively small mass, by which, perhaps, the cracking of the plate by the first hit can be completely accounted for.
2. The two following shots were placed close to the first hit, but, notwithstanding these three rounds which were close together, and struck almost normally, not the slightest change of form was produced on the inner side of the cupola, nor had a single piece been loosened either from the plate struck or those adjoining, so that in reality the working of the guns could have been carried on within the cupola without any interruption, a result which must truly be termed astonishing. The expectations which, at the conclusion of the trial against the glacis armour were somewhat diminished, were by this result after the 3rd shot considerably surpassed.
3. The 4th shot was directed against a portion of the armour, which was not only completely separated from the plate by cracks, but also was of very small dimensions. Moreover, through the yielding

of the incompletely fixed plates, it had acquired a certain amount of play, and became in consequence the piece of the plate most incapable of withstanding a blow. Without doubt it is to the mass and the immovable locking together of parts to which this nature of armour owes in particular its powers of resistance.

4. Had not, following what is stated under 3, a part of the separated piece hit by round 4 been completely forced out of the armour, there would naturally have been no consequent falling down of the parts lying above it; so that the plate, after the 4th round, although injured and cracked, might have been expected to remain nearly, if not entirely, in its original state.

5. The mode of determining the resisting power of the plates previously employed, by adding the total energies developed by the different rounds, without taking into consideration the angle at which the shot struck, is of but little value.

   The energy of the individual rounds, the quality of the shot used, and above all, the part of the energy thrown on the plate, due to the greater or less approach to striking normally, compose the proper measure for determining the above-named resisting power.

   In this respect the demand made on the plate was considerably greater in the trial than is actually to be feared in war time.

   In the usually very short duration of an action between ships and coast batteries, in which the former are limited in their supply of ammunition, both as regards number and kind, it is hardly to be expected that four of the same kind should hit close together on one plate at nearly 90° with such an energy as occurred in this trial.

6. The circumstance that in this trial really less favourable factors had play, forbade coming to the unreserved conclusion that all the other cupola plates as well would be reduced by four shots to the same condition as the trial plate, so that a condemnation of all the other plates on the ground of the result obtained did not appear justifiable.

To reach entire security in this respect, further trials against several plates would have been necessary.

As, however, the trial had shown already that apparent defects in the plate could not rightly be treated as such, although the value of the plate as armour had been called in question thereby, the contract afforded no ground for demanding a trial of the other plates, entirely or partly, at the cost of the maker.

To reject lightly at our own cost what was ready for use and paid for for the most part, and then replace it by similar material without security of having for the probably trebled expenditure an armour offering a proportionate increase of resistance, would have been a useless waste of money.

This was all the more so because if the armour did not satisfy all the extremely stringent terms of the contract, which the manufacturer had bound himself to accomplish, still the armour in question did constitute the really best possible material for coast defences available at the time.

Moreover, it appeared very probable that the resisting power of the armour already delivered could be considerably increased by very simple means.

On all these grounds the manufacturer was informed, the day after the trial, that, subject to approval of the War Minister, and irrespective of all considerations as to the issue of this test, as well as of the consequent estimate of the value of the cupola plates now made as armour, these would provisionally be accepted according to the terms of the contract. The condition was added that, as far as possible, without sacrificing work already completed, use was to be made of the experience gained in the trial to improve the said armour in respect to fixing it on the wrought-iron substructure, and also as touching the danger of the forcing through of pieces broken loose.

For the armour of the forts at Ymuiden, the improvements in the whole arrangement and in the erection of the armour must apply.

It was shown also in the three firing trials against the cupola roof plate even more clearly, that a probably general feature of the chilled iron plates was that they soon cracked through and separated into numerous pieces of different sizes and weights by the impact of hardened forged steel shell —such as those delivered by Krupp. **At the same time it was irrefutably shown that even in this case no failure of protection ensued, so long as a displacement and corresponding yielding of the different parts into which the plate is divided, does not occur.**

The claim of the manufacturer that his system of armour owes the greater part, if not the whole, of its value to the dome or arched form, which only can be used in this manner, received a striking confirmation in this trial. The trial gave, therefore, no reason for demanding any change in the roof plates already cast or those to be made, but warranted, on the contrary, the very valuable assurance that a means of protection had been found in the plates which offers a sufficient cover for the safety of the interior of the cupola against direct and other fire, as well as the greatest security to the turret motor and mechanism for laying the guns."

In conclusion, the report of the Trial Committee mentions the changes recommended in the glacis and cupola armour plates.

These were, for the glacis plates, an increase in weight and thickness, decreasing and supporting the overhanging part by means of brackets, and improving the connection between the plates by means of wrought iron keys.

For future cupola plates, a flattening of the profile curve, increase of weight, and adoption of wrought-iron connecting keys.

To briefly sum up what has been said: The glacis plate had not satisfied the requirements, the cupola plate had done so, but for future construction changes were desirable, whilst the roof plate had surpassed the tests arranged and had shown a considerable excess of strength.

5.—Trial against a Side Plate of a Chilled Iron Armour Turret for two 15.7 in. (40 cm) Guns 35 calibres long.

On the Firing Ground at Seno della Castagna, near Spezia.

20th, 24th, and 29th April, 1886.

Object and Programme of the Trial.

Test of a cupola plate of a coast turret for two 35 calibre long 15.7 in. guns, ordered by the Italian Government, by 3 shots from the 100 ton Armstrong 16.9in. gun (Type Lepanto).

The points of impact to be separated at least 1 metre, or 39 inches.

Target: The turret to which the trial plate belonged corresponded in its chief points to the type Fig. 4. The armoured cupola consists of 15 plates in a ring, and has an extreme diameter outside of 46.6 ft.

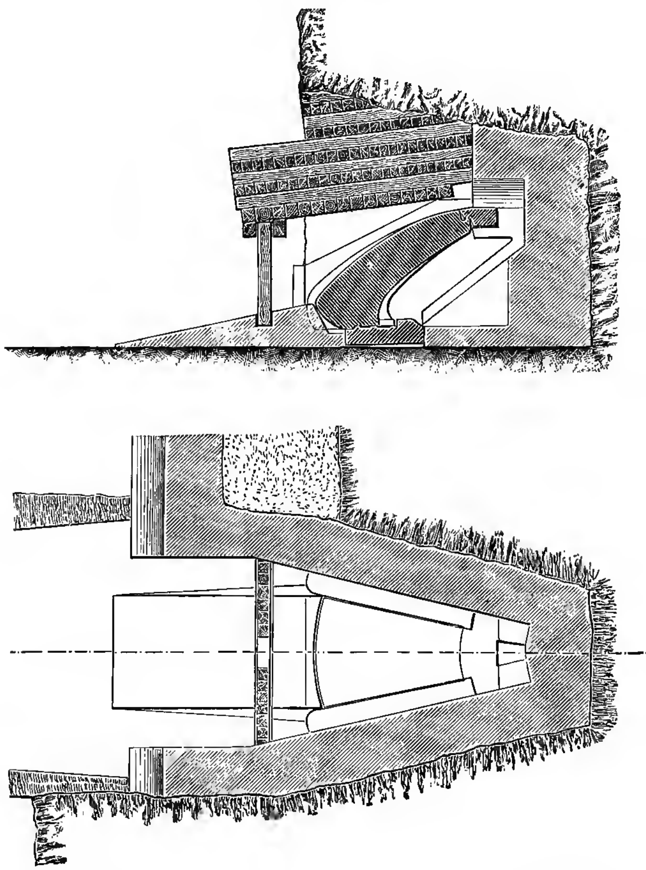
The roof, which is provided with a manhole and sighting opening, is put together in two parts, like the Dutch turret, and has a diameter of 21.7 ft. The ring of glacis armour has 15 plates, which have on the side of the turret exposed to attack a height of 6.6 ft.; on the others 4.3 ft. The extreme diameter of the glacis armour ring is 64.6 ft. The guns lie in Armstrong hydraulic minimum-port carriages.

The trial plate was made in accordance with the experience gained in the previous trials, and, in correspondence therewith, had so flat a profile, that angles of impact of shot of more than 50° seemed excluded.

The plate was built into the limestone rock on the shore of the Seno della Castagna, near Spezia (See Fig. 37), and rested on a bed plate let into the rock, weighing 40.8 tons.

Fig. 37.
Structure for the Side Plate of the Chilled Iron Armour Turret for two 15.7 (40 *cm*) *Guns.*

Scale : 1.200.



The side connection to the rock was obtained by means of two specially cast plates, each 44.1 tons in weight, with masonry work. The trial plate was connected to its two side-supporting plates, as in the construction of the turret, by means of tongues and grooves. On the left side a tongue was cast on to the plate, which entered a groove formed in the side plate, whilst on the right the tongue was in the side plate and the groove in the trial plate. In the groove on the upper edge of the trial plate, and in the corresponding recesses in the supporting plates was placed a traverse, representing the roof plate of the turret, 5.2 tons in weight, which rested sideways, like a wedge, against the masonry. This left a free opening, by which access could be had to the inside of the armour.

The rock above the target was removed to a height of about 10 feet. This space before each round was filled with wood to diminish the injury to the overhanging rock and to partially protect the target.

The gun was protected against splinters of shot by a strong wooden screen in front.

The upper part of glacis armour in front of the trial-plate was represented by a glacis of concrete.

In the trial plate there were a number of cracks formed in casting in chill, shown by dotted lines in the figures, which also give the dimensions of the plate.

The breadth at the level of the upper edge of the glacis was 9.8 ft., at that of the armour plate 6.2 ft., and its weight 86.5 tons.

Gun: Armstrong, 16.9 in. (43 cm), 100 ton gun, 27 calibres long (Type Lepanto), in Armstrong hydraulic minimum port carriage.*

In order to increase the angle of impact, the base of the plate was inclined 1° 29′ to the front, and the axis of the gun was at such a level as to point, with 1° depression, at the base of the plate at a spot 8 in. above the upper edge of the glacis.

Distance: 146.5 yards.

Shot: Krupp 2.8 calibre 16.9 in. (43 cm) steel shell, empty, about 2,205 lbs. in weight.

Charge: 827.5 lb. brown P. P (one hole) from the Rhenish-Westphalian Powder Factory.

Striking velocity (mean): 587 yards per second.

,, energy (,,): 47,481 foot tons.

Round No. 1: 20th April, 1886.

Shot: Krupp shell as above, weighted with sand and lead to 2,205 lb.

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* The gun was placed in a pontoon anchored to the shore. A good description of the carriage is found in the Mittheilungen über Gegenstände des Artillerie und Genie Wesens 1883, page 34. A further description is given in the "Italia Militare" and Engineer 1883, page 73.

Velocity : At the muzzle, 591.5 yards.*

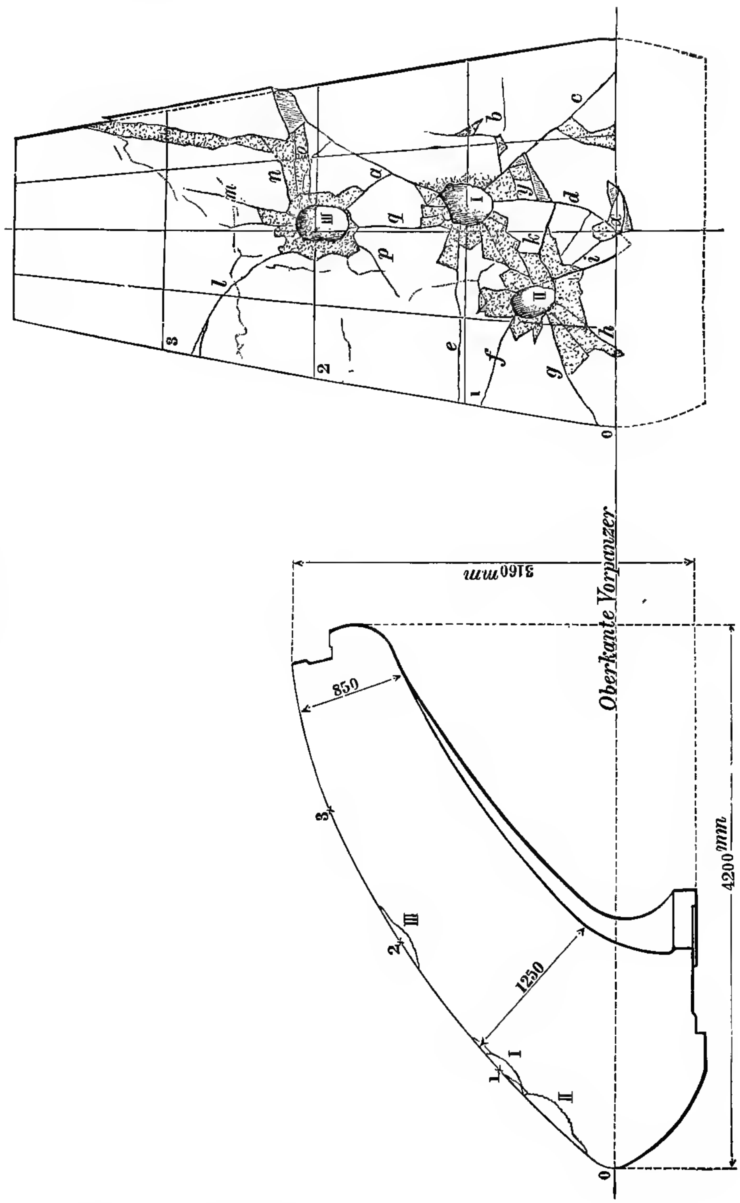
„ 93 yards from the muzzle : 588.7 yards.

„ At the target: 587.1 yards.

Fig. 38.

Profile and Diagram of hits of the Trial Side Plate of the Chilled Iron Armour Turret for two 15.7 in. (40 cm) Guns. 20, 24 29/4/86.

Scale : 1.60.



Energy on impact : 47,510 foot tons.

* The Velocities were measured with the Le Boulanger chronograph.

Point struck: 8 in. right of centre line. (*See* Fig. 38.)
46.4 in. above upper glacis edge.

Angle of impact: 44° 30′

Effect: A chiselling of the surface 18 in. long, 13.4 in. broad, and 2 in. deep.

Also the following:—

A crack *a* 0.2 in. wide from the points of impact to the right edge of the plate. A hair crack *b* to the right plate edge. A crack *c* 0.3 in. wide running downwards to the right. A crack *d* and one horizontally *e*, and finally some short hair cracks.

At the point struck there were some insignificant abrasions of the surface. A scaling off of the surface at the lower part of crack *c*, which ran close below the upper layer of the surface, and separated a piece therefrom of 4 in. greatest thickness was more important.

Back of the plate: At the back of the plate (*see* Fig. 42) only one crack was found proceeding from the right edge of the plate, and ending about 11.8 in. above the lower plate edge. From the position of the crack, it was assumed that it connected with the crack in front marked *a*.

General condition of the target. An examination of the target showed that it had moved slightly, as openings about 0.04 in. wide had been formed between the armour plate and its two side supporting plates which, however, could in no way prevent the continuation of the trial. This, however, had to be suspended owing to the destruction by the blast from the gun of the wooden stage to which the pontoon was moored.

The shot broke up.

Round No. 2: 24th April, 1886.

Shot: As in Round I.

Velocity at the muzzle: 592.3 yards per second.

„ at 93 yards from the muzzle: 589.4 yards.

„ at the target: 588 yards.

Energy of impact: 47.632.8 foot tons.

Point struck: 19.7 in. left of centre line.
27.6 in. above edge of glacis.
31.5 in. from hit No. I.

Angle of impact: 48°

Fig. 39.

The Side Plate of the Chilled Iron Armour Turret for two 15·7 *in.* (40 *cm*) *Guns after the first round.* 20/4/86.

From a Photograph.

Effect: Surface excision 15.8 in. long, 13.8 in. broad, and 4 in. maximum depth, surrounded by irregular abrasions of the upper layer, also running radially from the point struck to the edge.

Crack *f* 0.3 in. mean width, *g* 0.6 in., *h* 0.2 to 0.6 in., *i* 0.4 in., and *k* 1 in. width, as also several short hair cracks.

The cracks *a* and *c* were widened on an average to 0.4 in., and the former extended to hit 2. Deserving of mention was an abrasion between hits 1 and 2, which, running obliquely on both sides to crack *a*, had a depth of 1.2 in. to 1.6 in.

At the upper edge of the glacis a small three-cornered piece, 0.8 to 1.2 in. large, was knocked out (marked *x* in Fig. 38), as also a four-sided piece *y* under hit 1.

The greatest number of cracks ran with the strong projecting lower part of the plate, but, on account of the glacis covering, it could not be seen whether they reached the lower edge of the plate or not. Cracks *h* and *i* apparently ran under the upper layer and joined in the interior with *d*, as the piece of plate bounded by these and crack *k* was pushed out about 0.8 in., and *k* had a width of 1 in. or a depth of 1.6 in. This supposition was confirmed by the fact that cracks *h* and *i* notwithstanding a width of 0.4 in. to 0.6 in. were not visible at the back of the plate.

Back of the plate (Fig. 42): crack *a* formed by the first round was extended to the lower edge of the plate, breaking off a small three-cornered piece 8 in. high, 2.4 in. wide at bottom, and 1 in. thick.

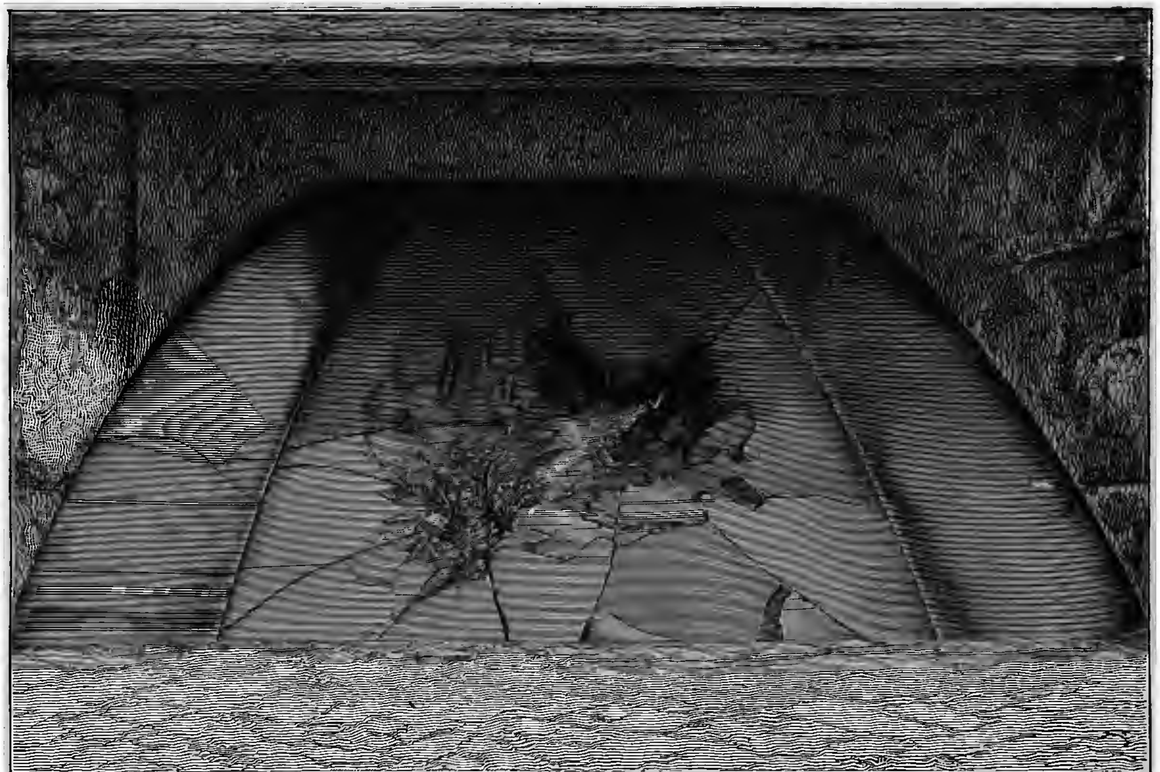
Also about 19.7 in. above the lower edge appeared a nearly horizontal zigzag crack, 0.06 in. to 0.1 in. wide, with a branch to the left and another to the right, running into crack *a*, connecting apparently with exterior cracks, *f*, *g* and *k*, and consequently marked with these letters in Fig. 42.

In other respects, the back of the plate was quite intact.

General state of the target: On examination, the joint between the armour plate and its right supporting plate was found widened 0.1 in., whilst the left joint remained 0.4 in. wide, also the left supporting plate was cracked at a level of 27.6 in. above the glacis edge which crack however was not discoverable inside the target.

Fig. 40.

The Side Plate of the Chilled Iron Armour Turret for two 15.7 in. (40 cm) Guns after the second round. 24/4/86.



From a Photograph.

In presence of this general loosening of the structure of the target, the manufacturer had the right, by the terms of the contract, to postpone the third round until the structure was again consolidated. As this would have occupied a long time, and the plate by its excess of resisting power seemed able to bear the 3rd round without additional support, the manufacturer waived his right, and the 3rd shot was delivered without repairing the structure further than to replace the wooden pier broken previously.

The shot broke up.

Round No. 3: 29 April, 1886.

Shot: As in Rounds I and II.

Velocity at the muzzle: 590.3 yards.

" at 93 yards from the muzzle: 587.5 yards.

" at the target: 586 yards.

Energy at impact: 47,322.7 foot tons.

Point struck: 4 in. right of centre line.
90.5 in. above glacis edge.
44 in. from Round No. I.

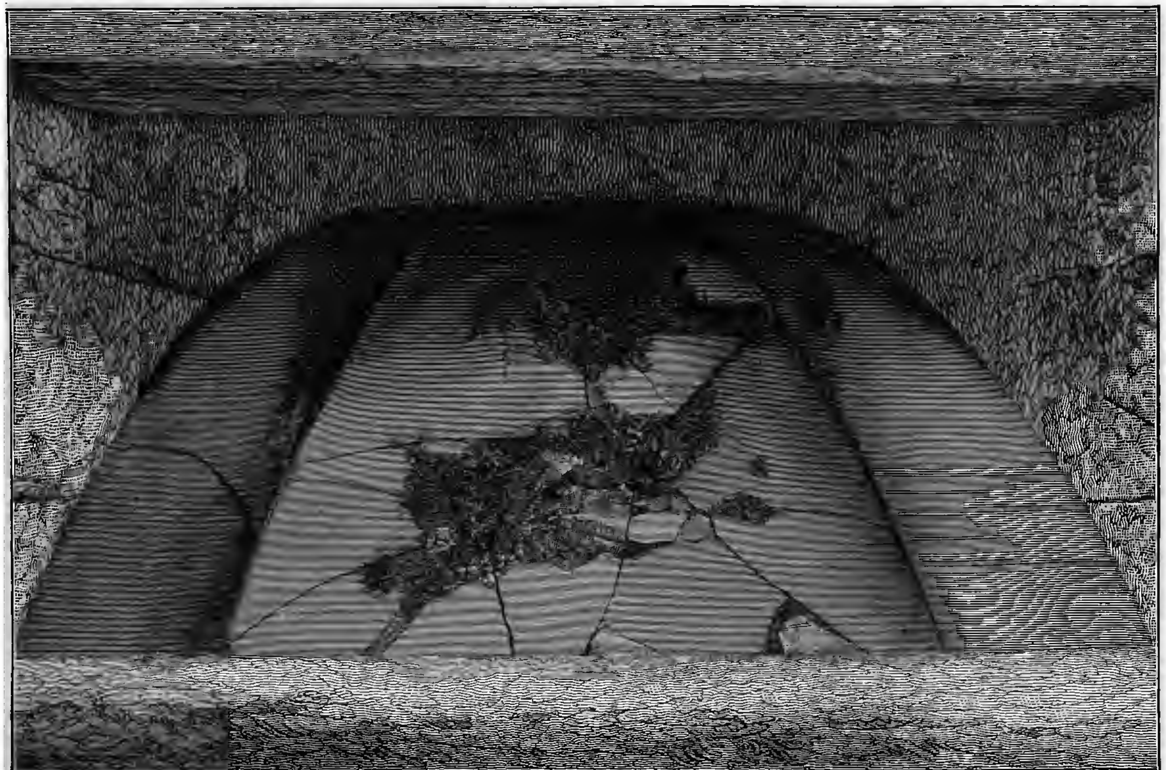
Angle of impact: 35° 30′.

Effect: Excision 15.7 in. long, 11.8 in. broad, and 1.6 in. deep, with surrounding abrasions also running radially from the point struck to the edges hair-cracks *l*, *m*, *n*, *o*, *p*, and a vertical crack *q* 0.2 in. wide. In consequence of the want of lateral support the upper part of the plate was forced downwards a little, so that the under parts stood out along crack *a* about 0.4 in. and along crack *e* about 0.2 in., and, in consequence, at the right edge a large piece of plate, seen in Fig. 38, had broken away and was pushed out. The greatest thickness of this fracture was 10 in., the other dimensions are seen in the Fig.

No widening of cracks formed by the previous rounds had occurred.

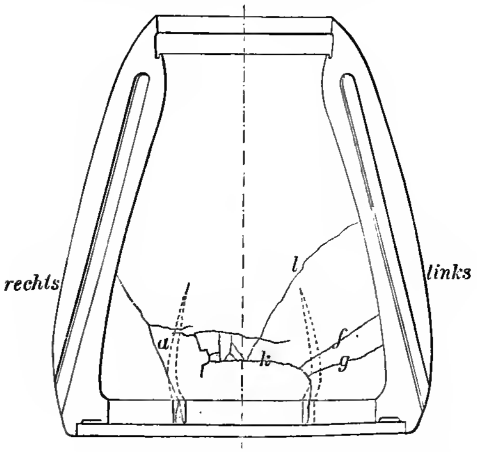
Fig. 41.

Side-Plate of the Chilled Iron Armour Turret for two 15.7 *in.* (40 *cm*) *Guns after the third round.* 29/4/86.



From a Photograph.

Fig. 42.
Back of the Trial Side Plate after the third round.
29/4/86. Scale: 1.60.



Back of the plate: A new crack running upwards and to the left from the centre line was seen apparently in connection with the hair crack *l* on the front surface; *k* was lengthened to the lower edge of the plate, and between *k* and *b* a nest of several small cracks had appeared owing to which a small wedge-shaped piece weighing about 4.4 lb., shown in dotted lines, had fallen from the inner surface. It measured 3.5 by 4.3 by 3.2 in.

Close to this there was a small surface abrasion about 0.4 in. deep.

The sinking of the upper part of the plate was also obseıvable on the interior of the plate, the upper part of which stood outwards along cracks *a*, *k* and *l*, about 0.6 in. to 0.9 in., 0.8 in., and 0.2 in. respectively.

General condition of the target: The openings in the joints between the armour plate and its side supports formed by the two first rounds had, by the sinking of the former, closed up again, on the left completely, on the right to 0.4 in. wide.

As the 3rd round completed the stipulations of the contract, the trial was stopped, although the plate doubtless would have withstood further shot.

The shot broke up.

Summary: The plate under trial had in every respect complied with the conditions of the programme. These maybe considered extremely severe, as the energy which the gun used in the trial displays under normal conditions, at the same distance, is only 44,251 foot-tons (charge 772 lbs. Italian powder; shot, weight 1,841.2 lbs.), but in this case was increased by using a heavier charge. Further, the small distance between gun and target, which alone rendered possible the development of so high an energy, must be considered; and lastly, the number of rounds must be looked upon as very large, in respect of the fact that the gun is one of the most powerful in existence, and that the cupola, of which the trial plate was a section, consists of 15 similar plates; and, moreover, it may be added that the points of impact were proportionately very near each other.

The three rounds which struck the armour represented an energy of 142,465.6 foot tons, or 1,618.2 foot tons per ton weight of plate. The plate, however, did not suffer to such an extent as to appear incapable of withstanding further shot of the same calibre, and it has to be added that the third round was received under very unfavourable conditions, as the lateral support had failed. Nevertheless, the cracks caused after the third round were of very small dimensions, and only in the slightest degree visible at the back of the plate.

The chill cracks previously existing in the plate proved themselves to be, as in all previous trials, absolutely without effect on the endurance of the plate. The cracks formed in the firing crossed the former in all directions without once following their course.

The profile of the plate as selected was proved to be correct. The penetration of the shot was proportionately very slight, and the cracks formed were neither so numerous or so serious as might have been expected from the severity of the attack.

Krupp's steel shell showed the same excellence of material as is usual with the smaller shells of this firm. Naturally, they broke in pieces on striking; no shot having ever yet remained whole after striking chilled armour obliquely.

6.—Second Trial against the Side Plate tested in April, 1886, for a Chilled Iron Armour Turret for two 15.7 in. (40 cm) Guns, 35 calibres long.

On the Firing Ground at Seno della Castagna, near Spezia.

22nd June, 1886.

Object and Programme of the Trial.

To supplement the results obtained in April, 1886, by testing the behaviour of shot of different calibres and manufacture on striking the chilled armour already tried.

The new firing trial was occasioned by the circumstance that the three 16.9 in. steel shells had broken up on striking the chilled armour into small pieces, whereas in earlier trials Krupp's 5.9 in. shell had perforated wrought iron plates without showing the least deformation.

Doubts had in consequence arisen whether Krupp's 16.9 in. shells were of the same good quality as the shells of smaller calibre, and, at the suggestion of the Trial Commission, the Italian War Minister decided to continue the trials with several Krupp 5.9 in. shells. First, a 16.9 in. steel shot of St. Chamond make (France) was to be fired at the upper and still intact part of the plate, so as to compare its effect with those of the Krupp shell.

The trial was, therefore, chiefly as a test of projectiles, for which the Gruson chilled plate, already definitively accepted by the Italian War Minister, served as a target.

Target: The structure shown in Fig. 42, and previously described, had seriously suffered by the preceding trial, so that between the armour plate and its lateral supports, as well as between the latter and the masonry, openings had been formed at the joints. In order to restore as far as possible, the lateral support, these openings were now filled with steel wedges, and zinc was also poured in.

Weight of the trial plate: 86.5 tons, kg.

Gun: 1. Armstrong's 5.9 in. (15 cm) gun, 28 calibres long, in Albini carriage.

2. Armstrong's 16.9 in. (43 cm) 100 ton gun, as in last trial.

Both guns in the pontoon moored to the shore.

Distance: 146.5 yards (134 metres).

Shot: Krupp 5.9 in. steel shell, 2.5 calibres, weight 79.4 lbs. (36 kg.), and a St. Chamond 16.9 in. steel shot 2.5 calibres long, weight 2,205 lbs. (1,000 kg.)

To facilitate reference in the following account, the numbering of the shots and the lettering of the cracks follow those of the last trial. (*See* Fig. 38).

Round No. 4:

Shot: Krupp's steel 5.9 in. shell, empty, 2.5 calibres, weight 79.4 lbs.

Charge: 32.2 lbs. progressive Fossano powder (0.8 to 0.9 in)

Velocity at impact: 546.5 yards per sec.

Energy „ „ 1482.6 foot tons.

Point struck: 34 in. right of the centre line, 52 in. above the glacis edge.

Angle of impact: 44°

Effect: Unimportant abrasion of the surface at the point struck.

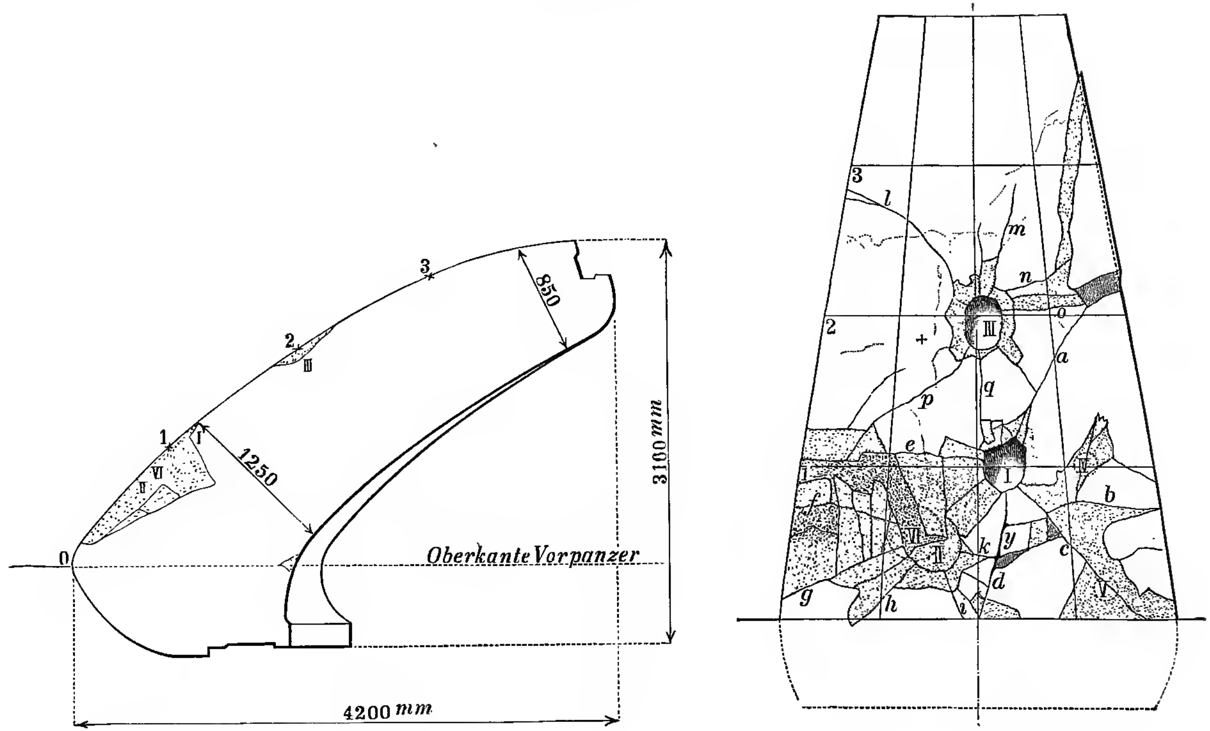
Back of plate unaltered.

Shot broke up.

Fig. 43.

Profile and Diagram of Hits of the Trial Side Plate of the Chilled Iron Armour Turret for two 15.7 in. (40 cm) Guns fired at on the 20th, 24th, and 29th April, and 22nd June, 1886.

Scale: 1.60.



Round No. 5:

Shot: As before.

Charge: 39.7 lbs. progressive Fossano powder (0.8 to 0.9 in.)

Striking velocity: 616.4 yards per sec.

,, energy: 1886.3 foot-tons.

Point struck: 40 in. right of the centre line, 9 in. above the glacis edge.

Angle of impact: 50° $30'$.

Effect: Abrasion of surface 2 to 4 in. deep between cracks *b* and *c*. It appeared that cracks *b* and *c* ran superficially under the upper layer of the armour, as the plane of fracture of the abrasion was covered with a layer of rust.

Back of plate unchanged.

Shot broke up.

As both the 5.9 in. shells had broken up on striking the armour, the Committee considered the first part of the programme was satisfied, and proceeded with the firing of the Armstrong 100 ton gun.

Round No. 6:

Shot: St. Chamond 16.9 in. steel shot, 2.5 calibres long; weight 2,205 lbs.

Charge: 827 lbs., one-hole brown P. P. (Rhenish-Westphalian Powder Factory).

Velocity at the muzzle: 589 yards.

,, at the target: 584.7 yards.

Energy of the shot on impact: 47,167.7 foot tons.

Point struck: Aim was taken on the upper and still intact part of the plate.

20 in. left of the middle line.

89 in. above the glacis edge.

(See the cross in the diagram of hits). In consequence of the movement of the pontoon by the waves, the shot struck too low, exactly on hit No. 2 of April 24.

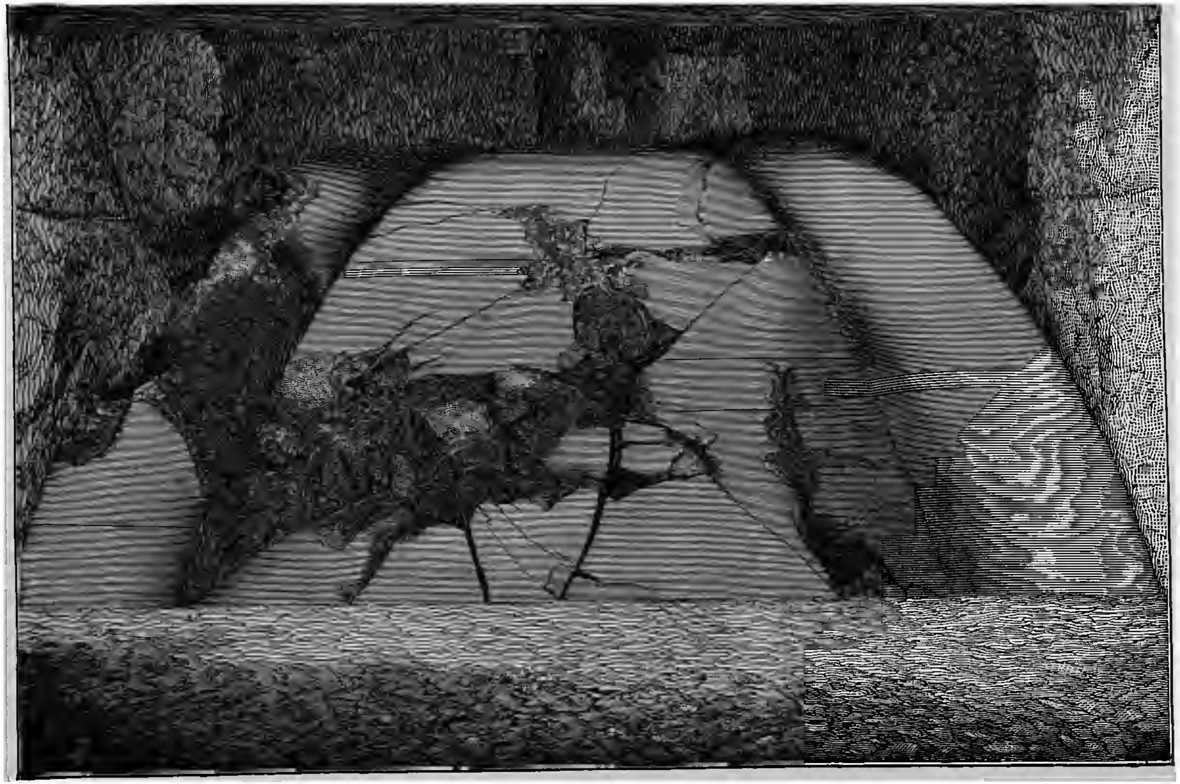
20 in. left of the centre line, and

27.6 in. above the upper glacis edge.

Angle of impact: The shot struck a much injured point, where the surface presented a nearly vertical plane.

Fig. 44.

Side Plate of the Chilled Iron Armour Turret for two 15·7 *in.* (40 *cm*) *Guns after the sixth round.* 22/6/86.



From a Photograph.

The angle of impact was therefore apparently between 80° and 90°.

Effect: The shot struck out of the plate between cracks *e* and *g* already existing, a number of pieces of different thickness (in maximum 20 in.)

Crack *p* was lengthened to *e*, which pushed the piece *y*, thrust outwards by the previous shooting, to the right.

Back of the plate: Two fresh cracks, probably connecting with cracks *m* and *n*, visible on the front of the plate, and are, therefore, marked with the same letters. Also a short crack *r* in the left pillar.

Between cracks *k* and *b* appeared a wedge-shaped splitting out of the surface 27.6 in. broad, 8 in. high, and 6.3 in. deep. The loosened pieces had fallen perpendicularly and so were not dislodged. Between crack *a* and the right edge of the plate a small three-cornered piece, 8 in. long in the side, was pushed out about 2.4 in.

The lower part of the plate was forced inwards by the shot
along crack *b* about 1.4 in.
" " *f* " 2.4 "
" " *r* " 1.6 " beyond the upper part.

The displacement of the left pillar took place along the previous crack *k*, whose under part appeared to connect with cracks *i* or *h* visible on the front surface, but the displacement was not observable on the front.

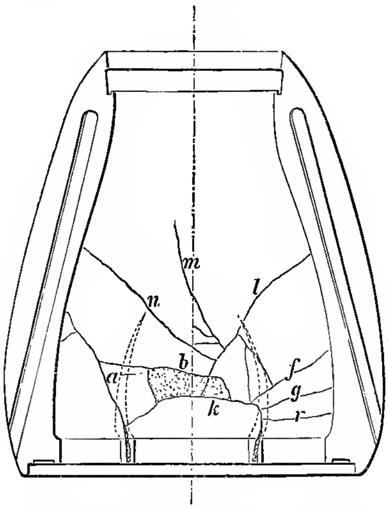
General condition of the target: The left supporting plate, whose front surface had suffered considerably from glancing pieces of broken shot, showed a through crack opening 0.4 in. to 0.8 in., as also the upper traverse which took the place of a roof-plate of a turret.

The upper part of the plate was, notwithstanding, in close contact with the supporting plates, and still possessed adequate power of resisting other shot from the same gun, but the trial had to be discontinued as no further 16.9 in. shot were at hand.

It is to be noted that the heated pieces of the shot at the last round set fire to the timber baulks of the screen in front, which was speedily consumed.

The shot broke up.

Fig. 45.
Back of the Trial Side Plate of the Chilled Iron Armour Turret for two 15.7 in. (40 cm) guns after the sixth round.
22/6/86. Scale: 1.60.



Summary: The first part of the trial had showed once more that steel shot of small calibre break up on striking an oblique surface of armour, in the same way as the 16.9 in. shell fired in April.

The second part of the programme produced no tangible result, as the St. Chamond shot struck the cracks on the most injured part of the plate and a comparison of its effect with that of the Krupp shell was in consequence excluded.

This shot was, nevertheless, of great interest, showing how little the time of breaching a plate can be judged by cracks already formed. The shot, whose point of striking was marked by a circular and on the right and below, sharply edged erosion of the surface, hit a part of the plate already much injured by round 2, and its angle of impact must have been between 80° and 90°, which was proved by the fact that the broken pieces of the shot were not deflected upward on the curve of the plate, but were thrown directly at right angles to the left, where they injured the projecting part of the side supporting plate. Notwithstanding this, the armour withstood also this round, or an attack in total of 192,970 foot tons, that is, 2,196.5 foot tons per ton of plate. The dislocation of the left pillar, visible at the back of the plate, must, in consideration of the weakened support of the same by the earlier rounds, be reckoned as inconsiderable.

Without doubt the whole upper part of the armour would have been equal to further shots from the same gun, and it may be consequently affirmed that the trial plate possessed a resisting capacity considerably in excess of what was necessary against the attack of even the 100-ton gun.

Any difference between the material of the Krupp and St. Chamond steel shell could not be determined on account of the facts previously stated.

CHAPTER IV.

Comparative Analysis of the results obtained, and Conclusions.

THE result of the series of trials is best shown by the profile and dimensions of the armour which were finally designed in consequence thereof.

The firing trials against armour for inland fortifications, and those against coast defence armour, described on pages 45 and 76, afford this information. From the former arose the armour profile, shown in Fig. 25, and from the latter the profile of the plate tried at Spezia, given in Fig. 38. Both profiles proved at the trials to be correct, and both agree in regard to the external curve.

Comparing the last—neglecting the dimensions for the moment—with the profile of the first Tegel turret (Fig. 10), we find that, as already mentioned, the later trials brought them back to a profile similar to that which Gruson, by the results of the preliminary experiments, had chosen for the first Tegel turret.

We have before stated the reasons which seemed to necessitate a change in this profile, and shall later on have occasion to give them more in detail.

To form an opinion of the results of the trials it is indispensable to compare them together, and we have consequently drawn up the Table of data of the trials to be found at the end.

The Table contains, in the columns 3 to 9, the guns and charges used in the attack at the different trials, the figures being extracted directly from the reports of the trials.

The columns 10 to 21 contain the chief dimensions and weights of the plates tried, either taken from the drawings or calculated from them, and for the most part left out in the official reports, as each figure is only of value when it can be compared with the corresponding figures of other material tried.

It may be asked if beyond the thickness and the profile of a plate there are other proportions requiring consideration.

In the literature of chilled cast-iron armour these are not given, and even the empirical formula for finding the thickness of chilled armour follows by analogy the formula for determining wrought-iron armour, and neglects the other dimensions. If we reflect that the destruction of chilled armour takes place not by perforation, but only by breaking up, then all the dimensions seem more or less to be of value, as it must without doubt be easier within certain limits to break up a small plate by cracks into numerous pieces than a large plate of the same thickness.

We say within certain limits, for a limit doubtless exists, and indeed has been always felt and respected by the Constructor. We should promise too much if we presumed, from the 18 firing trials, to exactly define the most favourable dimensions to give to an armour plate, but it nevertheless seems well worth while, in so entirely empirical a subject, to closely examine the results of the trials, so as to obtain a clear view, if possible, of what these dimensions should be.

We now proceed to an examination of the Table, and remark, in passing, that the figures given for the first Tegel turrets are merely to complete the Table, and are not made use of, as a rule, in our comparative analysis.

1. The Proportions between the Greatest and Least Thickness of the Armour.

In columns 10 and 11 of the Table we have placed together the greatest and least thicknesses of the plates of armour tried. A comparison with the profiles shows that the greatest thickness is throughout found at the level of the centre of the port, and the least at the upper edge. The few variations are given in the Table.

Column 12 contains the proportion of the smallest to the greatest radial thickness, a proportion which has the greatest influence on the endurance of the plate.

In the Tegel turrets for land fortification, these figures vary between 1 : 2.3 and 1 : 2.5, and in the later plates, for the same class of fortification, between 1 : 1.3 and 1 : 1.7

In the earlier plates, coast batteries, the proportion was 1 : 2.6 (excluding the roof plates); in the later plates between 1 : 1.4 and 1 : 1.7 (excepting the glacis armour plates).

The decrease in the thickness of the upper part of the plates in the recent types is so small that the respective figures point the way to a comparison between the behaviour of older and newer armour plates.

As already stated in the commencement of this chapter, the later trials led to the same profile as that chosen for the first Tegel turret. This early profile had been given up because chilled iron shell used against the upper oblique portion of the plates had a greater effect than those hitting the lower and more perpendicular part.

This fact was made apparent at the trial of both the first and second Tegel turrets, and is confirmed in the "Proceedings of the Engineer Committee," so that there can be no doubt about it.

A second question is, whether the explanation commonly given, and adopted by ourselves, of the circumstance that chilled iron projectiles shiver into atoms on striking normally, but break up into large pieces when striking obliquely, which pieces injure the upper part of the plate, is correct. In presence of the figures of column 12, we incline rather to the opinion that the earlier plates were too weak in their upper portions, and that the greater effect of the oblique hits was entirely due to this fact, and not to the material of the projectiles used.

Major Küster remarks, on page 28 of the Proceedings, that the Experimental Committee recommended that the thickness of the plate, from the roof downwards, should decrease less rapidly. They proposed at the same time to give, by means of a sharper curve, a more perpendicular profile to the lower part and a more oblique one to the upper, and stated that the cracks had, generally, originated with glancing shot. The demand for a more perpendicular lower section apparently rested on the assumption that normal hits had less effect than glancing ones, and this demand was perhaps the cause of the frequently given explanation of the varying behaviour of the projectiles.

The figures of column 12 seem to us to show that this explanation is not correct, inasmuch as no solid reasoning can be adduced why a shot hitting normally should have less effect than a glancing hit. Also, the explanation that the larger pieces of chilled projectiles did more harm to the upper part of the armour than the smaller pieces did to the lower seems to us incorrect, as the earlier reports of trials expressly state that the cracks began with the glancing hits, but the cracking of the plate must be independent of the greater or less injury to the surface, and be chiefly proportional to the strength of the blow in relation to the thickness of the armour.

We, therefore, are of opinion that the profile of the first Tegel Turret was discarded in consequence of erroneous assumptions, that the success of the second Tegel turret was not due to its steeper profile, but was, in spite of it, due to the dissimilar greater thickness of the plates; and lastly, that the cracking noted in the upper part of the second Tegel turret was due to the still too rapid decrease in thickness of this part.

2.—The Proportion of the Expanded Length of the Unprotected Part of the Profile Curve to the Greatest Expanded Breadth of the Armour Plates.

Before mentioning this proportion, given in column 13 of the Table, a word may be said as to the reason for calculating this ratio. It is understood at once that a narrow plate will not resist shot so well as a broad plate of the same profile, and for this reason it would seem desirable to establish a proportion between the total length and the breadth. This, however, was found to be impossible, as the profile curve at the base of the plate makes a sharp bend, and if the whole curve from top to bottom were taken into consideration it would lead, owing to the different character of the profiles, to a false estimate; but on the upper part of the plates the curve throughout is fairly regular, and can be well made use of in obtaining a ratio with the breadth.

In column 13 the ratio of length to breadth in the Tegel turrets is given as 1 : 2; in the later armour for coast batteries, VI. to XI., this becomes (excepting the glacis armour) 1 : 1.8 to 1 : 2.3, and only the two half-port plates of the batteries show a ratio of 1 : 0.9. In the last, too, the length was greater than the breadth, which is still more apparent when the part of the plate's profile covered by the glacis armour is reckoned.

This ratio, which differs from the others, had its own special reason. In the battery plates the port occupies a large proportion of the external surface, and in consequence, in the relatively slight parts above and below the port, the metal is left by the casting in a state of tension, which facilitates the early formation of cracks. For example, in the trials of the 8.3 in. battery in 1873—74, cracks of this nature were formed, and for this reason it appeared preferable to divide the plates down the centre, and to obtain the accurate connection of them by keys placed therein, submitting in this alteration to the undoubtedly unfavourable loss of weight and mass.

We find greater differences in the coast armour (XII. to XVIII.) than in that for inland forts.

For instance, comparing the roof plates (XIV., XVII.) and the glacis plates (XV.), we find in the older battery plates a ratio of length to breadth of 1 : 1.4, and in the later turret plates it is from 1 : 0.9 to 1 : 0.6.

These varying figures have also their special reason. The form as well as the weight of the heavy armour plates is governed by the conditions of transport. The form by the size of the railway truck and the weight by the carrying capacity of the bridges and other railway structures. All Gruson armour plates are transported on special wagons, that for the Spezia plate having 12 axles, and as the length of the plate profile cannot be diminished, the breadth must be kept down. In coast battery armour this is not of great importance, as they are called upon to withstand only a relatively small number of shot. The fact is characteristic that in the Dutch as well as the Spezia plate only horizontal or oblique cracks were formed and not vertical ones, as observed in the higher plates, which is natural, as the vertical section is very large in proportion to the horizontal section.

3.—The Proportion of the Vertical Section to the Front Superficies of the Armour Plate.

The ratio of the vertical section to the expanded front superficies of the plate is given in columns 14 to 19 in two forms. Columns 14 to 16 give the amount and ratio of the total superficies and total vertical section, whilst columns 17 to 19 exhibit only the ratio of the part of the surface exposed to shot to the corresponding vertical section. The cause of this two-fold ratio is again the fact that only the part of the profile exposed to shot possesses a uniform curve, the rest making a sharp bend under the glacis armour, but the figures in columns 16 and 19 show so little difference that we may confine our analysis of them to those in column 16.

In the second Tegel turret we find the ratio to be 1 : 11 and 1 : 12.2, which falls in the newer turrets for inland fortification (excepting the glacis armour) to 1 : 7.6 to 1 : 6.8, and in battery plates to 1 : 3.8.

The reasons for dividing the battery plates have already been explained, and we leave it to be gathered from them whether the plane of section, preserving nearly the normal weight, might not have been increased.

As regards the newer turret plates (VI., X. and XI.), the proportions, notwithstanding the decrease of superficies in relation to the Tegel plates, was, without doubt, more correct, as horizontal cracks, in particular, were not formed in them.

That, with the same vertical section, a broader and heavier plate possesses a greater proportion of resisting power than a narrower and lighter plate is, we think, a certainty, if a state of tension is avoided in casting the former. It would, however, be of great interest to establish by trial what is the best ratio of the vertical section to the superficies for a given constant weight. Such trials, however, would be very costly, as they would only give reliable results if conducted on a large scale. In consequence, it is fortunate that such trials, though interesting, are not absolutely necessary, as the proportions of the plates tried (VI., X., and XI.) proved generally favourable. In particular, the last named plate of new profile displayed such resisting power, that practically it is really not in question whether the same endurance would have been reached had a small reduction in weight been made.

We consider the ratio of 1 : 7.4 between the vertical section and the superficies to be correct, as it seems to offer a guarantee against the production of a state of tension in the casting.

In the earlier coast armour the ratio was 1 : 6.9; with the two new turret plates in question it was 1 : 1.3 and 1 : 2.2. As already stated, the form of these plates was governed by the necessities of transport, and as the Spezia plate showed a considerable excess of resisting power, it becomes a matter of little moment whether, with the same vertical section, the resisting power would have increased to a certain extent with the breadth or not.

4.—The Proportion of the Energy of the Attack to the Weight of the Armour Plates.

As already mentioned, we consider the weight of a plate to be the most important factor in its resisting power, which makes it desirable to establish a ratio between this weight and the energy of the attack expressed in foot-tons. We obtain thereby a sort of measure of the amount of the unit of attack in relation to the size of the plate, and though this measure may not be of great accuracy, the figures are of interest as completing the data relating to the trials made.

Had the various plates been fired at until they were breached, it would have been best to establish a proportion between the total energy exerted by the whole number of hits and the weight of the plates. This breaching was only effected in particular cases, so that it only remains to proceed on the assumption that armour of the same character —that is, for inland or coast defences—is intended to withstand approximately the same number of hits. (This assumption is only conditionally correct, as the number of rounds to which a turret may be expected to be exposed must vary with its position. Among the turret plates tried, however, no such great differences arose as to need special consideration in this respect). Our ratio only gives a measure of the attack which a plate had to *expect*, whilst the manner in which it withstood it can only be ascertained from a comparison of the firing results.

We now pass to a consideration of columns 20 and 21 of the Table, in which are given the weights of the plates with reference to the energy per ton of plate.

For the port plate of the second Tegel turret this ratio cannot be simply expressed, as a change was made from the 5.9 in. to the 6.7 in. gun, and ordinary cast-iron as well as chilled iron shells were used. For the side plates of the same turret we have the figures 43 and 43.2 foot-tons per ton of plate, which in the later trials (VI. to X.) become 76.3, 81.9 and 108.2 foot-tons, falling again in trial XI. to 35 foot-tons.

It appears from this that the work thrown on the metal of the plates in the trials VI. to X. of the Table, was extremely high in comparison with that of the Tegel trials, even excluding the difference in the quality of the shot.

The ratio between the weight of the plate and the attack is for the first time restored in trial XI., the favourable issue of which was due not only to the good profile adopted, but also to the greater weight of the plate. The total performance of the plate in comparison with the two Tegel side plates is therefore of interest.

In the latter the first through crack from edge to edge of the plate was produced by rounds 37 to 39. The new plate (XI.) received 20 hits on its half section from steel shell, equal to 40 shots distributed on the whole plate. No crack through from edge to edge was formed, and although the formation of such a crack may not be considered as an unconditional measure of the resistance of the plate, we think we may state that the total endurance of the later plate in respect to that of the older one, showed **that its construction and material had more than exceeded the superiority of the steel shell over the chilled iron projectiles used in the respective trials.**

It is evident that the ratio of the attack, in the case of the heavy armour for coast defences, to the unit of weight can be carried much higher, as these plates are only liable to be struck by a few projectiles.

With the older sort of coast defence plates, the attack, as seen in our Table, increases from 128.9 to 135.4, and 151.6 foot-tons. These figures, however, are small to those of the later trials, XV. to XVIII., which vary between 205.6 and 548.9 foot-tons per ton of plate.

If our ratio is accurate, which may be called in question, then the attack of 548.9 foot tons per ton of plate, as was the case in the Spezia armour, is enormous. Several points, however, have to be considered in this respect before attaching value to our ratio.

Speaking exactly, it cannot be said that, in the trial of inclined armour, a plate has withstood so many foot-tons of energy, but only that a vertical plate in the place of the one fired at would have resisted such a number of foot-tons. This advantage applies to all chilled armour, according to their curve of profile, in greater or less degree, and can, consequently, be neglected in comparing different forms of this nature of armour.

On the other hand there is a factor which cannot be neglected: every projectile shivers to pieces on striking chilled cast iron armour, and, consequently, cannot deliver a greater blow thereon than that which is necessary to break up the projectile into the pieces into which it separates. The difference in the effect of two shots of the same size and quality which strike an inclined plate, as well as the different energies due to different charges of powder, would, consequently, be proportionately small, supposing each shot broke up in the same way into small pieces; but it is a matter of no doubt that with shot fired with increased energies, the breaking up or similar deformation is more complete, and the blow delivered on the plate is also greater, but this last in no way increases directly with the energy of impact, but after passing a certain limit increases more slowly the higher the energy may be.

An increase in the power of the attack consequently seems to follow an increase in the energy of impact only in a secondary degree; a larger calibre and a better quality of shot—that is toughness and hardness—being the principal influencing factors in augmenting the power of the attack.

If we examine the Spezia trials from this point of view we understand why the Gruson factory confidently exposed the plate to the enormous attack of 548.9 foot-tons per ton of plate, as, in reality, only that part of the blow would be borne by the plate which was necessary to break up the shot. How great that part was could neither be assumed nor calculated, but in no case could it be equal to the total energy.

A third factor to be mentioned in this connection, to which lately considerable importance seems to be attached, as regards the effect of the attack, is the form of the shot.

In technical papers it is frequently stated that cylindrical armour cannot be considered as absolutely inferior to inclined armour, seeing the latter can probably be overcome with flat-headed projectiles.

We have carefully examined the trials with this kind of shot, and do not deny that flat-headed shot have a greater effect on inclined armour than pointed ones, and we admit at the same time that by placing a point of soft metal on a flat-headed shot, accuracy of flight can be obtained without interfering with its efficacy on striking, but we cannot hold the superiority of the flat-headed projectiles to be so great as to make us believe that this superiority is sufficient to call for a change of any importance in the present relationship between gun and armour. Even flat-headed shot are always broken up on striking chilled armour, and consequently only give out on the plate that portion of their energy which corresponds to their power of resisting fracture. This portion will probably be greater than in the case of pointed projectiles, as the flat-headed shot bite better into the surface of the plate, but the increased effect will probably be shown in greater injury to the surface of the armour and not have great influence in forming cracks, which mainly arise from the weight of the blow inflicted.

Certainly, the effective component of the total energy, as regards inclined armour, must only remain a fraction of that energy, and the relation between flat-headed shot and inclined armour will consequently never equal that of pointed projectiles against vertical armour. A certain excess of resisting power being always provided for in the construction of the chilled armour, as was shown to be the case in the various firing trials, we do not think that the employment of flat headed shot would render any increase in the weight and thickness of the armour necessary, even if no technical difficulty stood in the way.

Reverting now to the main point of our argument, it appears that, as that portion of the energy delivered on the plate by the projectile can neither be estimated nor calculated, so the relation between the energy and the weight of plate can be used as an approximate measure only in the case of trials where shot of the same quality and calibre are used.

This condition is not fulfilled when comparing the earlier and later trials, as the chilled iron projectiles used in the former were far inferior to the steel shell employed in the latter, and the demand on the metal's endurance was all the greater in the later trials, as, corresponding to the dissimilarity of the projectiles, the amount of the energy delivered by the chilled shot on the plate was much less than that exerted by the steel projectiles.

Naturally the Gruson Factory thoroughly noted this relation in the construction of the later type of armour, but they could with confidence submit to the increased severity of the tests in presence of the great improvements effected in these later types of plates. As we have seen, the Factory went so far as to make but little provision by an increase in the size of the plates against the nature of the attacking projectiles, and even considerably reduced them in proportion to the attack.

5. Empirical Formula for Designing Chilled Armour.

We have made frequent reference, in the previous sections, to the relation of the dimensions and weight of the chilled armour, both in connection with the question of resisting power, as also as completing our review of the results of the trials.

It is obvious that a formula for calculating the design of armour plates in harmony with this relation will, in proportion to its accuracy, be of much utility.

Should a plate, for instance, for some reason have to be made narrow, it would appear desirable to cast it thicker in order to reach the same weight than, in other circumstances, would be convenient, but the sole existing formula proposed by the Gruson Factory only takes notice of the maximum thickness of the plates. The difficulty consists in bringing into the formula a number of different factors, without an exact knowledge of the particular influence of each; and, on the other hand, as we shall see, a formula based on correct data would give results incapable of being used in practice.

The Gruson formula, as we say, only refers to the maximum thickness, and leaves it to the constructor to estimate the other dimensions according to his judgment.

The formula gives the maximum thickness of the armour in proportion to the fourth root of the number of foot-tons of the energy of the attacking shot, and applies, in the first instance, to coast defence armour.

For such armour this formula is :—

1. For port plates . . . . $d = 0.29 \sqrt[4]{\text{foot-tons}}$.
2. For side plates . . . . $d = 0.27 \sqrt[4]{\text{foot-tons}}$.
3. For glacis plates with earth in front . $d = 0.22 \sqrt[4]{\text{foot-tons}}$.
4. For glacis plates with granite in front $d = 0.2 \sqrt[4]{\text{foot-tons}}$.

These dimensions are increased ten per cent. in the case of armour for inland fortifications, the formula becoming :—

1. For port plates . . . . $d = 0.32 \sqrt[4]{\text{foot-tons}}$.
2. For side plates . . . . $d = 0.29 \sqrt[4]{\text{foot-tons}}$.
3. For glacis plates with earth in front . $d = 0.24 \sqrt[4]{\text{foot-tons}}$.
4. For glacis plates with granite in front $d = 0.22 \sqrt[4]{\text{foot-tons}}$.

Before discussing these formulæ it will be of interest to compare the actual maximum thickness of all the plates with the thickness given by the formula. The following Table gives this, the reference number being the same as in the Table at the end.

	Armour for Inland Fortifications.									Armour for Coast Defences.						
	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII
Actual Maximum Thickness in.	21.7	mean 18	18	18	22.5	22.5	15	21	23.6	35.4	35.4	13	27.6	41.7	19	49.5
Calculated Maximum Thickness in.	19.9 * 23.9	18.3	18.3	20.6	22.4	22.4	14.9	22.4	19.5	30.6	30.6	—	25.8	35.4	—	47.5
Difference in.	mean —0.2	—0.3	—0.3	—2.6	+0.1	+0.1	+0.1	—1.4	+4.1	+4.8	+4.8	—	+1.8	+6.3	—	+1.8

* The figure 19.9 in. refers to the 5.9 in. gun, 23.9 in. to the 6.7 in. shells.

It will be seen that the difference between the actual and calculated armour thicknesses in trials III. to XI. is very slight. Trial VI. shows a difference of 2.9 in. in favour of the calculated thickness, and trial XI. 4.1 in. in favour of the thickness actually given.

In the coast defence armour the differences are greater. In the two earlier battery plates XIII. and XIV. the actual thickness is 4.8 in. in excess of calculation; in the turret plate XVI., 6.3 in., whilst in the Spezia plate, XVIII., the figures are approximately the same.

On the whole we may say that the actual and calculated thicknesses agree fairly well, and though not in entire accordance throughout, the dimensions given to the later plates approximately agree with calculation.

The formula was originally based on the results obtained with chilled iron projectiles, and armour plates of nearly vertical profile in the lower portion (Fig. 30). The chilled shots were superseded by steel projectiles, which latter proved that the dimensions calculated for plates of the above profile were proportionately too weak, but as this profile was abandoned for a more sloping one, the formula again regained its correctness, so that the Spezia plate could be calculated by it, the formula obtained with chilled projectiles serving thus for steel shell as well.

The Gruson formulæ, since their first publication in the year 1882, have been repeatedly discussed by the technical press. The most comprehensive examination of them is found in the recent essay of Engineer Josef Schwartz of the Imperial Austrian Marine Artillery, entitled "Ueber die Panzerwirkung der Geschosse. Pola, 1886."

Mr. Schwartz, on page 54 of his pamphlet, gives a graphic illustration of 14 armour thicknesses obtained by the formula varying from 0 to 41.990 foot tons, the foot tons being shown as abscisse and the calculated thicknesses as ordinates in his diagram. He remarks (page 53):—

"The curve itself follows a somewhat curious course, increasing at first very quickly, but soon an increase of 3,230 foot tons energy requires only a very slight addition of thickness in the armour." "Suppose, for instance," he adds, "that an 11 in. steel shell, with 12,920 foot tons energy is an exact match for a chilled plate of 37.6 in maximum thickness, it is impossible to understand why a 12 in. steel shell with 19,380 foot tons energy should not be more than a match for a plate 41.5 in. in greatest thickness;" and he concludes later that the number of normal hits (angle of impact 90°) will be always very small* in proportion to the total and

* Mr. Schwartz proceeds on the assumption that the armour is always hit at an angle of 90°, which, however, as Column 9 of our Table shows, is not the case, even with armour of the old profile.

equally small number of hits, from which it may be assumed that the formula gives good results up to 19.380 foot-tons of energy.

Mr. Schwartz's deductions seem at first sight convincing in all respects, but we rely, notwithstanding, on the subsequent Spezia trial, which gave proof that the formula, when a correct profile is adopted for the plates, gives accurate results, even for the highest energies (47,481 foot-tons).

To explain this apparent contradiction we must refer again to the conclusions of the last section, where we saw that only that portion of the shot's energy took effect on the plate which was requisite to break the shot to pieces. Consequently, the greater the energy of the shot becomes, the farther does its effective energy differ from its nominal energy, and the increase of 6,460 foot-tons, referred to by Mr. Schwartz, has in consequence probably hardly any noticeable effect on the armour.

The nature of the curve, calculated from the formula, which at first increases quickly and then more slowly, seems to us to show that this formula though somewhat arbitrarily constructed from among the numerous relations between the dimensions of the plates, does for the present correspond very well to the actual conditions, and that no reason has been shown on the ground of those relations to construct a new formula, but that on the contrary the simplest and most correct plan is for the constructor of the armour to continue as before to calculate its maximum thickness, and to determine all the other dimensions in accordance with his experience and the results obtained from the trials made with the plates.

Should the breadth of the plate, then, for other reasons, be decreased to an unusual extent, it becomes necessary to restore, as far as possible, the normal weight by increasing the thickness.

6.—Conclusions.

It was natural that the enquiries which we undertook in the previous sections should be based throughout on a comparison of the earlier and later plates tried, and their results, as after the earlier series of trials the superiority of the armour over the gun was generally admitted.

In the interval, between the series, the attack had made very great progress, and it was necessary to determine whether the armour had similarly advanced or had been left behind. It was shown by the trials that the form of the older type of plates was not the most favourable, even for the shot of those days, the thickness having been too much reduced at the upper edge of the plate.

It was shown also that the ratio of the superficies to the vertical section was correct both in the old and new plates, and in the latter always remained within admissible limits.

In comparing the weights of the armour with the energy of the shot, we arrived at a very important difference. The ratio in the case of the earlier armour was so much more favourable to the plate than in the more recent trials, that the endurance shown by the latter to the improved shot and heavier charges could only be explained by an important improvement in the armour.

In the concluding trial against armour for inland fortifications, it was shown that armour of improved profile, in which the proportion of weight to the power of the attack was nearly restored to that which was established in the case of the Tegel plates, gave entirely analogous if not still better results as regards resistance than the Tegel plates, so that the armour had entirely kept pace with the notable progress in artillery.

The trial at Spezia against a plate of recent and improved profile gave the same indication as regards coast defence armour, so that we may affirm, without exaggeration, that the superiority of the armour to the attack shown in the earlier trials has been maintained, practically without change, to the present day; and this is proved to be the case both by the results of the trials—that is by the behaviour of the new plates under fire—as well as by the fact that the thickness of these recent plates corresponds almost exactly to that given by the formula which was obtained from the results of the earlier trials.

Of all the recent trials those carried at Spezia in April and June naturally have a claim to chief attention.

For a long time previous to the trial it had been much discussed in professional circles whether an armour plate could withstand three rounds from the 100-ton gun with an energy of 47.481 foot-tons, the opinion being generally against such a possibility. In consequence of which it was natural that numerous representatives of foreign governments availed themselves of the permission granted by the Italian War Office to attend the trials.

As a matter of fact, it was not the private interests of the Gruson Factory which were at stake in this trial, but in great measure the whole future of armour. Had the plate failed, it is more than probable that armour for coast defence would have been given up, to which the opinion of many was already tending, and the proof of the disproportionate severity of the test of the plate, which we still maintain to have been demonstrated, would hardly have received its due attention in presence of such a result, and have averted this conclusion.

A correct estimate of the severity of the test applied to the Spezia plate is only obtained by a review of the earlier trials made with guns of the heaviest calibre against compound and steel plates.

In the year 1876 trials were made at Spezia with the Armstrong 16.9 in. muzzle-loading gun against wrought-iron plates manufactured by Brown, Cammell, and Marrel, and a forged steel plate by Schneider.

All the plates had a thickness of 21.7 in. Gregorini chilled cast-iron shells were used, weighing 2,002 lbs., maximum charge 341.8 lb., giving a velocity of 492.7 yards, and an energy of 30,058.4 foot-tons. The targets were in all cases perforated by the shot. In trials which took place in December of the same year the charge was increased to 396.9 lbs. of Fossano powder, but without marked increase in the velocity.

Heavier charges were employed in the trials made at Spezia in 1882 with the Armstrong 17.7 in. muzzle-loader. The plates tried were two compound plates by Cammell and Brown, and a steel plate by Schneider. All three plates had a thickness of 10.8 ft., a height of 8.5 ft., and a breadth of 1.6 ft. (For further details see "Mittheilungen über Gegenstände des Artillerie und Geniewesens," 1883, p. 241).

The compound plates had a facing of steel about 6 in. thick; the Schneider plate was of forged steel. All three plates were fixed to a wood backing 47.2 in. thick.

The following Table gives the chief data of the trials :—

Experiments against Armour-Plates with the Armstrong 17.7 in. M. L. Gun in the year 1882.

No. of Round.	Target.	Gun.	Distance. yards.	Projectile.	Charge. lb.	Velocity of Impact. yards.	Energy. foot-tons.	Penetration. ins.
1.	Cammell Plate.	Armstrong 17.7 in. M. L. Gun in hydraulic carriage on a pontoon.	101.5	Gregorini Chilled Cast Iron Shell. 2002 lb.	328.6 lb. Fossano Powder	405	20646.2	7
2.	Schneider	,, ,,	,,	,,	328.6	410.5	21092	8.3
3.	Brown	,, ,,	,,	,,	328.6	407.2	20756	3
4.	Schneider	,, ,,	,,	,,	478.5	514.8	33185	9.3
5.	Brown	,, ,,	,,	,,	478.5	520.5	33921.5	8
6.	Cammell	,, ,,	,,	,,	478.5	521.4	34034.5	8
7.	Schneider	,, ,,	,,	Terrenoire Steel Shot 2,078.2 lb.	478.5	512.5	34125	12.6
8.	Schneider	,, ,,	,,	Gregorini Steel Shot 2,124.5 lb.	478.5	504.4	33808.4	11.8

Cracks were, as a matter of course, formed in all three plates by the firing which ultimately brought about their complete destruction. According to the opinion of the Committee superintending the trial, rounds 4 to 8 were capable of passing clean through wrought-iron plates of 23.6 to 24 in. thick. The Committee also decided in favour of the two compound plates.

We find a still further increase of charge in the trial made with the 100-ton Armstrong B.L. gun at Spezia in the year 1884. (*See* "Mittheilungen über Gegenstände des Artillerie und Genie Wesens," 1885, page 52.)

The plates under trial were :—

1. Cammell compound plate, 10 ft. broad, 8.2 feet high, and 19 in. thick.
2. Brown compound plate, 10 ft. broad, 8.2 feet high, and 19.1 in. thick.
3. Schneider steel plate 10 ft. broad, 8.2 ft. high, and 18.8 in. thick.

All three plates were secured to a wooden backing 20.5 in. thick, with an iron plate 0.8 in. thick in rear.

The following Table gives the principal data :—

Experiments against Armour Plates with the 16.9 in. Armstrong B. L. Gun, in the year 1884.

Target.	Dis-tance. yards.	Gun.	Shot.	Charge.	Velocity of Impact. yards.	Energy. foot-tons.	Effect.
Cammell Plate	108.3	Armstrong 16.9 in. B. L.	Krupp's Steel Shell 1,841 lb.	771.8 lb. Fossano Powder.	623	44664.4	Plate and backing per forated with a surplus of energy, hole in plate 27.6 in. in diameter. Plate broken into 6 parts.
Brown Plate.	,,	,,	,,	,,	619.7	44196	Plate and backing per-forated with a surplus of energy, hole 25.5 in. in diameter. Plate broken into 8 parts.
Schneider Plate	,,	,,	,,	,,	619.7	44196	Plate and backing per-forated with a surplus of energy, hole 20 in. in diameter. Plate broken into 3 parts.

According to the Krupp formula, each of the rounds could have gone clean through a wrought-iron plate 28.8 in. thick.

After the above rounds, the largest piece of each plate was fired at by one round from the 10 in. gun. The Schneider plate proved superior.

We find in the trials at Spezia a continual increase of charge, viz. :— 341.8 lbs., 397 lbs., 478.5 lbs., 771.8 lbs. of Fossano powder, which reached a maximum in the case of the trial of the Gruson plate, in which case the exceptional charge of 827 lbs. Brown P. P. was employed with the above gun.

If we consider that an energy of 47,481 foot-tons is sufficient to drive a 16.9 in. shot, when striking normally, right through a wrought-iron armour plate 32 in. thick, leaving a surplus of unexpended energy, it will be appreciated how severe was the test applied to the Gruson plate, and how little, in general, was the anticipation of its successfully with-standing it.

Nevertheless, the plate supported most successfully the attack of the

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three rounds, and also withstood—apart from the two 5.9 in. shells—a fourth hit from the 100-ton gun, striking on the most unfavourable and most injured spot at an angle of 80° to 90°, the lateral support being at the time entirely insufficient.

A glance at Fig 45 shows that the plate, even after this round, would have given every security to the gun detachment behind it, and the large and almost uninjured part of the upper half of the plate proved that it was still capable of withstanding further rounds from the same gun.

The more unfavourable the anticipations were before the trial as to the endurance of the plate, they only gave additional point to the result as it turned out, and the technical journals did not fail to recognise, as far as we have seen them, the striking and exceptional issue of the trial.

Our own opinion that the terms of the trial were beyond those to which coast defence armour can ever be called upon to resist, did not affect this favourable issue.

We do not mean to affirm that artillery may already have reached the limit of its development, although it is certain the velocity of the 16.9 in. shot used at Spezia was only reached by means of an exceptionally heavy charge; we prefer to point more to the short range of 148.5 yards, at which the firing was conducted.

Assuming that in the future guns are employed which are able to develop the energy of the Spezia trial from a fighting range, we ask: How many rounds could such a ship's gun place on a single one of the 15 cupola plates? Any one who had noted how great was the difficulty of laying the gun from the pontoon, when the motion was very slight, comes necessarily to the conclusion that it would be an entire impossibility to systematically place three rounds on one and the same plate from a heavy gun on board ship—an opinion repeatedly expressed by naval officers at Spezia.

Even supposing that still more powerful guns are in future mounted on board ships, how many of such guns will a fleet possess?

We consider the object of coast defence armour to be to defend the guns and gunners against hostile shell fire, and to withstand being breached by casual single hits. This object would, however, be fulfilled by a much slighter armour, and we therefore do not think that the dimensions of the plate tried at Spezia will constitute a measure for all the subsequent armour to be constructed, which opinion does not, however, detract from the high value of the issue of the Spezia trial.

The small penetration of the shot into the chilled armour (in maximum 4 in. on the parts not already injured) shows how small a portion of their total energy was delivered on the plate. The deeper the penetration, the greater is the blow on the plate, and in the diminishing of the effective blow, we see the special advantage of the system of chilled iron armour over armour of wrought iron.

Quite apart from cylindrical wrought-iron armour, inclined armour of the same nature invariably suffers much injury in partial penetration from the fire of heavy guns, and the blows of the striking shot are so heavy that we seriously doubt whether the ports of a turret carrying such armour which effect or give scope for the revolving movement, could be made strong enough to withstand them.

The case is more favourable as regards steel and compound armour; still we do not believe that in the present condition of manufacture these last can have given to them the same hardness as chilled iron armour without at least its having serious influence on their tenacity.

Moreover, with armour of this class the smaller amount of weight, which contributes so much to compensate the blows received, always acts unfavourably in the presence of the heavy projectiles used in the attack. It indeed may be possible to make wrought-iron or steel plates of equal weight to that of the Spezia plates, but for practical purposes such a proceeding would involve too great an expenditure. We are consequently of opinion that the chilled iron armour is in the present day in a more favourable position as regards the guns for the attack than the other systems of armour, in which as yet, so far as we know, no attempt has been made to construct turrets and batteries to protect 15.7 in. guns.

Although accustomed to radical changes and improvements in technical matters, we do not think that this superiority of chilled iron armour will be disturbed in the near future, as it is based upon two qualities which distinguish this system from all others, namely, its hardness and weight.

Whether those who, like ourselves, hold the above opinion as to the object of coast-defence armour are right or not, or whether the future will bring about a great increase in the precision of the fire from ships' guns, which formed the basis of the programme of the firing trials at

Spezia, can with as little certainty be decided as the question whether in the future the power of the attacking guns will receive a great increase, but we believe we may assume with confidence that, even in the latter case, no important increase will be necessary in the dimensions of the armour plate tried at Spezia, inasmuch as the whole energy of a shot never takes effect on the armour. Should we, however, be also mistaken in this respect, the superiority of the chilled cast-iron armour in relation to the weapons of attack could hardly be affected, as no technical difficulty, as we have shown above, exists to increasing the strength of the chilled iron plates.

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e Firing Trials against Gruson Chilled Cast Iron Armour.

11.	12.	13.	14.	15.	16.	17	18	19	20	21
Smallest radial thickness of the Plate, in inches.	Ratio of the smallest to the greatest thickness of the Plate.	Ratio of the expanded length of the unprotected part of the profile curve to the greatest expanded breadth.	Area of the front surface, in square feet.	Area of the Vertical Section of the Plate, in square feet.	Ratio of the Vertical Section to the front surface of the Plate.	Area of the portion of the front surface of the Plate exposed to shot, in square feet.	Area of the Vertical Section corresponding to the exposed part of the front surface of the Plate, in square feet.	Ratio to the exposed part of the front surface of its Vertical Section.	Weight of the Armour Plate in tons.	Energy per ton weight of Plate, in foot tons.
5.51	1 : 2.5	1 : 2	92.54	6.03	1 : 15.3	74.24	4.95	1 . 15	12.3	—
4.73	1 : 2.3 to 1 1	1 : 2	92.54	4.3 to 6.03	1 : 17.9 (mean)	74.24	3.55 to 4.95	1 : 17.7 (mean)	10.1	—
9.45	1 . 2.3	1 : 1.9	103.3	9.36	1 : 11	88.88	8.39	1 : 10.6	19.6	for the 6.7 in. shot 75.4
9.45 to 4.51	1 : 2.3 to 1 2.5	1 : 2	92.54	6.03 to 9.36	1 : 12.2 (mean)	78.12	5.06 to 8.39	1 : 11.7 (mean)	16.4	43
9.45 to 4.51	1 : 2.3 to 1 . 2.5	1 : 2	92.54	6.03 to 9.36	1 : 12 2 (mean)	78.12	5.06 to 8.39	1 : 11.7 (mean)	16.36	43.2
3.39 Upper edge 0.23 Lower edge	1 : 1.3 1 · 1.7	1 : 1.8	56.49	7.42	1 : 7.6	47.88	6.24	1 : 7.6	13.78	81.9
13.39	1 . 1.6	1 : 0.9	45.19	11.84	1 : 3.8	33.89	8.93	1 : 3.8	10.3	105.9
13.39	1 1.6	1 : 0.9	45.19	11.84	1 : 3.8	33.89	8.93	1 : 3.8	10.3	108.2
3.39 Upper edge 8.66 Lower edge	1 1.1 1 : 1.7	1 : 3.4	55.2	5.49	1 : 1	25.39	2.8	1 : 9.1	10.5	106.1
13.39	1 . 1.5	1 : 1.8	56.49	8.29	1 : 6.8	47.88	6.99	1 : 6.8	14.6	76.3
13.39	1 : 1.7	1 : 2.3	68.33	9.25	1 : 7.4	56.49	7.21	1 : 7.8	19.6	35
13.58	1 : 2.6	1 ; 1.4	148.49	21.52	1 : 6.9	128.69	18.29	1 : 7	42	135.4
13.58	1 : 2.6	1 : 1.4	148.49	21.52	1 : 6.9	128.69	18.29	1 : 7	44.1	128.9
7.87	1 : 1.6	1 : 1.6	177.54	10.76	1 : 16.5	177.54	10.76	1 : 16.5	28.4	151.6
3.62 Upper edge 4.96 Lower edge	1 : 1.1 1 : 1.8	1 : 3.5	90.38	14.42	1 : 6.2	50.36	7.10	1 : 7.1	36.9	393.4
24.41	1 : 1.7	1 : 0.9	91.46	27.33	1 : 3.3	83.93	2.47	1 : 3.3	46.7	310.5
11.81	1 : 1.6	1 : 2	87.16	12.8	1 : 6.8	87.16	12.89	1 : 6.8	46.7	205.6
33.47	1 : 1.4	1 : 0.6	132.56	60.36	1 : 2.2	108.39	50.36	1 : 2.1	86.5	548.9

Table showing the Principal Data of all the Firing Trials agains

1. Reference Number.	2. Nature of Plate and Date of Trial.	3. Calibre of Gun, in inches, L=Length of Gun in calibres.	4. Projectile.	5. Weight of Projectile in lbs.	6. Weight of Powder-charge in lbs. P. P.	7. Velocity, in yards.	8. Energy of Impact, in foot-tons.	9. Angle of Impact.	10. Greatest radial thickness of the Plate, in inches.	11. Smallest radial thickness of the Plate, in inches.	12. Ratio of the smallest to the greatest thickness of the Plate.	Ratio of t[he] length unprotecte[d] profile c[u] greatest bre[adth]
A. Armour for Inland Fortification.												
I.	Port-plate of 1st Tegel Turret for 5.9 in. (15 cm) guns. 1873.	5.9	Long Shell. Chilled Shell.	61 77.2	3.1—13.2	—	—	—	13.77	5.51	1 : 2.5	1
II.	Side-plate for ditto. 1873.	5.9	Long Shell. Chilled Shell.	61 77.2	3.1—13.2	—	—	—	11.02—4.73	4.73	1 : 2.3 to 1 : 1	1 :
III.	Port-plate for 2nd Tegel Turret for 5.9 in. (15 cm) guns. 1874.	5.9 6.7	5.9 in. Long Shell. 5.9 in. Chilled Shell. 6.7 in. „ „	61 77.2 121	9.1 10.6 20	335 382.6 441.6	611.96 705.98 1478.05	—	21.65	9.45	1 . 2.3	1 :
IV.	Left Side-plate for ditto. 1874.	5.9	Chilled Shell.	77.2	10.6	382.6	705.98	—	21.65 to 13.77	9.45 to 4.51	1 : 2.3 to 1 : 2.5	1 :
V.	Right Side-plate for ditto. 1874.	5.9	Chilled Shell.	77.2	10.6	382.6	705.98	—	21.65 to 13.77	9.45 to 4.51	1 : 2.3 to 1 : 2.5	1 :
VI.	Side-plate of a Turret for 4.7 in. (12 cm) guns 27/4/83.	5.9 L 23	Gruson Steel Shot. Ternitz Steel Shell.	78.3—86.7 81.8—83.4	17	488	1129.54	65—81°	17.72	13.39 Upper edge 10.23 Lower edge	1 . 1.3 1 . 1.7	1 :
VII.	Port-plate of a Battery for 5.9 in. (15 cm) guns. 16/7 83.	5.9 L 23	Krupp Steel Shell.	85.3	16.3 Prog. Powder.	457	1114.4	61—74°	22.45	13.39	1 1.6	1 :
VIII.	Ditto, ditto. 18/8/84.	5.9 L 23	Krupp Steel Shell.	85.3	„	457	1114.4	42—77°	22.45	13.39	1 1.6	1 :
IX.	Glacis-plate for a 4.7 in. (12 cm) Turret. 12/2/84.	5.9 L 23	Krupp Steel Shell.	85.3	„	457	1114.4	38—46°	14.95	13.39 Upper edge 8.66 Lower edge	1 1.1 1 : 1.7	1 :
X.	Port-plate of ditto. 28/8/84.	5.9 L 23	Krupp Steel Shell.	85.3	„	457	1114.4	52—84°	20.87	13.39	1 : 1.5	1 :
XI.	Side-plate of ditto. 20/1/85.	5.9 L 23	Ternitz Steel Shell.	76	15.2 P. P.	431.7	686.95	25—46°	23.62	13.39	1 1.7	1 :
B. Armour for Coast Defence.												
XII.	1st Port-plate of a Battery for 8.3 in. (21 cm) guns. 5/12/73.	11	Chilled Shell	513.8	75	420.8	5685	80°	35.43	13.58	1 2.6	1 ;
XIII.	2nd ditto ditto. 27/7 and 21/8/74.	11	Chilled Shell.	513.8	75	420.8	5685	20—90°	35.43	13.58	1 : 2.6	1 :
XIV.	Roof-plate of a Battery for 8.3 in (21 cm) guns. 21/8/74.	11	Chilled Shell.	513.8	57.3	365	4305.6	about 20°	12.98	7.87	1 : 1.6	1 :
XV.	Glacis-plate of a Turret for 12 in. (30.5 cm) guns. 13/8/83.	12 L 25	Krupp Steel Shell.	981.3	264.6	486.5	14519	40—53°	27.56	23.62 Upper edge 14.96 Lower edge	1 : 1.1 1 : 1.8	1 :
XVI.	Side-plate for ditto. 22/10/83.	12 L 25	Krupp Steel Shell.	981.3	264.6	486.5	14519	51—90°	41.73	24.41	1 : 1.7	1 .
XVII.	Roof-plate for ditto. 28/5/84.	12 L 25	Krupp Steel Shell.	981.3	176.5	392	9503	12—24°	18.9	11.81	1 : 1.6	1
XVIII.	Side-plate of a Turret for 15.7 in. (40 cm) guns. April & June, 1886.	16.9 L 27	Krupp Steel Shell. St. Chamond Steel Shot.	2205	827 Brown P. P.	586.9	47481	35—90°	49.21	33.47	1 . 1.4	1