

Mr. J. D'A. SAMUDA explained, that in the mode of construction he proposed, the skin was attached to the vessel in the ordinary manner, the only difference being, that when completed it would form a flush side, instead of presenting the series of overlapping joints which was usual in vessels of the ordinary build. The armour plates would be so attached to the vessel, that all the armour fastenings would be independent of the skin, joints, and ordinary fastenings. Between the armour and the skin of the vessel he proposed to put a packing of canvas and india-rubber, from $\frac{1}{8}$ th of an inch, to $\frac{1}{4}$ th of an inch in thickness, similar to that used in screwing up the joints of ordinary steam-pipes. This packing was not to produce elasticity, as that would defeat the object intended; but, on the contrary, it was used to produce a solid joint, which could not be attained with the rough surfaces of the plates as ordinarily made.

Mr. J. DITCHEBURN observed, through the Secretary, that in all the experiments he had witnessed, with heavy shot on armour plates, the fastenings of the plates to the ships' sides had invariably proved defective. Scarfs, overlappings, tongueing and grooving, or rebating, uniformly assisted the shot to damage the armour plates. There could be no doubt as to the practicability of efficiently securing the plates to the sides, without recurring to those sources of weakness. As regarded the size of ships of war, and the model upon which they ought to be constructed, he considered, that, however great their tonnage, when fully equipped for sea service, their draught of water should not exceed 25 feet; that their top sides should be inclined inwards from the fire of the enemy; and that their mid-ship body, under the water-line, should be so formed as to attain the greatest speed, and to counteract rolling, without the addition of bilge pieces.

Mr. RICHARD ROBERTS considered that in the construction of iron vessels of war, the armour plating should extend over the whole length of a ship, and that it should have as smooth a surface as possible. The method of tongueing one plate into another was open to serious objections. If a shot struck the plating at a joint, one-half of the tongued plating would certainly be split. A vessel also would require to be nearly stripped before a damaged plate could be replaced. The packing proposed by the Author was too thin. Packing of 2 inches in thickness would have been preferable, so that the rivets might have been completely buried. The necessity for trimming off the rivet heads would then have been obviated, and the strength of the vessel would have been increased. Iron vessels would be much stronger if they were constructed with two keels, which might be considered in the light of a couple of girders, extending from end to end of the vessel. Strong gunwales might also be added to correspond with them, so that the entire structure

of the vessel would be similar to that of a beam. A vessel with two keels would have the further advantage, that if she grounded she would stand upright, and hence in time of action she would still be able to use her guns. A screw-propeller might be put at the end of each keel, but of a smaller size than that ordinarily used when a single propeller was employed. As the two screws would be more deeply immersed, the same, if not a greater, speed would be attained; and if constructed to act independently of each other, they would greatly facilitate the manœuvring of the vessel. They might also be so formed, that it would be impossible that they could be entangled by chains, or wreck. When steering the vessel by the screws, the steersman should be in the engine-room, and the orders should be conveyed to him in a similar manner to that adopted for conveying the orders to the engineer. Another improvement he would suggest, was, that the transverse beams of vessels should be made hollow. They could then be used for ventilating the ship, and in case of fire the steam could be turned into them, to aid in extinguishing it.

Mr. J. SCOTT RUSSELL remarked, that the Admiralty, prior to building the vessels referred to in the Paper, invited six of the principal iron ship-building firms, including the Author and himself, to assist them with suggestions and advice, as to the construction of iron ships of war; at the same time reserving to themselves the power of examining the propositions, and of adopting such portions as they thought desirable; the object being to use the talent of the six selected ship-building firms for the benefit of the public. In his opinion the Admiralty had acted to the best of their knowledge and ability. The Author had justly praised the 'Warrior' as a first performance; and it must, therefore, be admitted, that the Admiralty took advice, used it, and, considering all the circumstances of the case, had been so far successful. No doubt the structural combination of the iron in the 'Warrior,' and in her sister ships, was more complicated than was necessary; and if some of the more simple arrangements of the iron, with which ship-builders were well acquainted, had been adopted, the same strength would have been obtained, with a less weight of iron; and it must be remembered, that with less weight of material, less size and greater speed would have been obtained. There were two principal systems for the construction of iron vessels at present known. One, the ordinary construction of numerous and close frames—a legacy from wooden ship-building, undesirable to be so closely followed; and the other, which might be styled the longitudinal system, where most of the iron used in the structure of the vessel was placed lengthwise, the transverse strength being mainly dependent upon whole, or partial bulkheads. Mr. Scott Russell had adopted the latter system ever

since first he commenced ship-building. The Admiralty had adopted both these systems, in the vessels which they had constructed, and thereby the structural arrangement had become complicated, and too much material had been used.

In reference to the mode of construction put forward in the Paper, he had already expressed his opinion as regarded the desirability of dispensing with wood for backing; but at the same time he considered its continuance would be unavoidable, until the experimental trials at Shoeburyness had clearly demonstrated the superiority of iron. He agreed, as to the general principle, that the armour should enter into the construction of the ship, and be made use of to give strength to the whole fabric; but he did not think, that the system advanced in the Paper was that which was best calculated to attain those ends. The fastening proposed for the armour plating appeared to be its weak point; but as he had seen the most plausible theories dissipated by a single shot from a 100-pounder Armstrong gun, he only advanced that opinion for what it was worth. It was proposed, that the armour plating should be 5 inches in thickness; but he thought that a thickness of $4\frac{1}{2}$ inches would have been sufficient. That thickness appeared to be indicated by the experiments with the Armstrong 100-pounder gun. All practical men knew, that in each material there was a certain thickness which would crack, but which would not bend, under the impact of a given force, and that there was another thickness which, under the same circumstances, would bend, but would not crack. The experiments he alluded to had shown, that the latter result was attained with a thickness of 4 inches, or $4\frac{1}{2}$ inches, of good tough forged iron, but that a thickness of 5 inches, or 6 inches, of the same material, would crack before it would bend. If these views were correct, thinner plates might be used than those proposed by the Author, and the remaining material might be advantageously bestowed upon the actual structure of the vessel. Assuming that the wood backing could be dispensed with, which he hoped might be effected, he would prefer that the armour plates should be only 3 inches in thickness, and that the remaining 4 inches, or 5 inches of thickness, should enter into the solid structure of the vessel. Under present circumstances he, however, feared that such a disposition of the material could not be effected, but that a thickness of $4\frac{1}{2}$ inches would be required for the armour plating, which, with the same weight, would only leave a thickness of $3\frac{1}{2}$ inches of iron to put into the sides of the vessel. The problem therefore to be solved, was to build a vessel out of that amount of iron, in the strongest possible manner. As far as appeared at present, East India teak was believed to be the best material for backing. It was very desirable, that the armour plating should be made to

give additional strength to the mechanical structure of the vessel, but he feared, that the system of fastening proposed by the Author would not answer the end intended, and that under fire from the 100-pounder Armstrong gun, or any equally destructive ordnance, the fastenings would soon be torn away, and the inner structure of the ship be exposed. No doubt, it was a difficult task to so arrange the fastenings of a series of 5-inch plates as to bind all the plates together, and at the same time to obtain the benefit of their additional strength in the structure of the vessel; but, on the other hand, it must be remembered, that more strength could be attained, when the armour plating was fastened upon iron, than upon wood.

The Author appeared to consider that small vessels could be constructed with shot-proof armour from end to end; but Mr. Scott Russell doubted the practicability of carrying out that idea, if the speed, efficiency, and sea-going qualities of those vessels were to be preserved; or unless the height of their ports, above the water-level, was so much reduced, as to render them incapable of fighting in a sea-way. It had been unanimously decided by a committee, composed of naval officers—who, it must be remembered, were the persons who would have to carry those vessels into action—that a ship would be useless for fighting in a sea-way, unless her ports were 8 feet, or 9 feet, out of water. The model exhibited by the Author, in illustration of his proposition, was that of a class of vessel similar to the old floating batteries. All practical men must agree, that those vessels could not be taken as examples, when sea-going qualities were required. If it was true that the ports ought to be 18 feet apart, and 9 feet above the water-level, and that a vessel of war ought to be coated to a depth of 5 feet beneath the water-line, then the armour on the side of the vessel ought not to be less than 21 feet in depth from its top to its bottom. A small vessel, loaded with that amount of armour, would be so deficient in sea-going qualities, that however cheap she might be, it would be undesirable that the lives and honour of British seamen should be risked on board of her. He would go farther, and say, that one good ship costing half a million sterling, was cheaper than two bad ships, each costing a quarter of a million. Now, that was the point where he found fault with the Admiralty. Having built the 'Warrior,' they found she cost nearly half a million sterling; and then they built two ships, intending that the two should be built for the same sum that the 'Warrior' had cost. The consequence had been, that the nation possessed two slow and bad ships, and that those two cost more money together than the one good ship. No one could object to the great cost of a ship which should be faster, stronger, possess more armour coating, carry more guns, and in every way be a better sea-going ship than

her enemy. Such an investment of the public money would be a good one, and building a cheap ship could only prove a bad investment. The Author had assumed as an absolute necessity, that a vessel should be coated with armour through her entire length. No doubt it was desirable that, if possible, she should be so protected, but not if that protection deprived the vessel of her sea-going qualities. There were, however, circumstances in which small vessels were indispensable; and the practical solution of the problem was to give the greatest amount of protection to a small vessel, consistent with the preservation of her sea-going qualities. When Mr. Russell was consulted by the Admiralty, prior to the building of the 'Warrior,' he represented to the First Naval Lord, that the problem was a difficult one; the ship-building portion of it he would do his best to solve; but there remained what might be called the fighting portion, and upon that he asked, whether the Admiralty were prepared to sacrifice speed, and good sea-going qualities, to entire protection? or whether they would have a larger size of vessel, entirely protected, in which those points could at the same time be attained? or whether they would have a ship, with such an amount of protection as she could carry, consistently with the preservation of her sea-going qualities? The First Naval Lord, after carefully considering these questions with other naval officers, returned for an answer, that the vessel to be built must be of a certain size; that she must not have less than a certain speed; that the Admiralty would be content with a certain length of protection for her hull, engines, and a given quantity of her armament; but that they would not allow the vessel to be of the size, which Mr. Scott Russell had said would enable her to carry armour over her entire length, and would yet preserve her fighting and sea-going qualities. The plans were, therefore, sent in accordance with the stated limitations. The problem to be solved in the case of a small vessel was of a precisely similar character. Armour plating of 2 inches in thickness, although carried over her entire length, would be useless, as a shot would penetrate through it, and might strike her engines and boilers. If it was impracticable still to coat her from end to end with armour plates of $4\frac{1}{2}$ inches in thickness, her vital parts should be protected with serviceable armour. Partial protection, in small vessels, was therefore an inevitable condition; and although he agreed with the Author in the desirability of carrying armour plating throughout the entire length of a ship, he must maintain, that the sea-going and fighting qualities of a vessel should never be sacrificed.

Mr. JOHN GRANTHAM considered, that the mode in which iron vessels should be plated to defend them from projectiles was a question, which must necessarily rest with the Admiralty, as it was

only by direct experiment that the problem could be satisfactorily solved. It would, however, be well, where so large an expenditure was involved, that the Admiralty should carefully consider any representations which were made to them, by such scientific and practical men as had devoted their attention to the subject. It was the imperative duty of the Government to undertake the necessary experiments, for without those, no sure progress could be made. Why the experiments upon targets similar in construction to the sides of the 'Warrior' had not been made, until after that vessel had been built, was a question to which no satisfactory answer had hitherto been given. A series of experiments should have been made prior to her commencement. All properly qualified persons should have been allowed to be present at them, and all relevant suggestions should have been attended to. It was reasonable to suppose, that if that course had been pursued, the question, of the best mode of constructing armour-plated vessels of war, would long before the present time, have been satisfactorily solved. He believed, that the results of experiments, so carried out, would have clearly demonstrated, that iron was the best and, in fact, the sole material for the construction of vessels of war. It had already been proved to be the best for the construction of merchant vessels. Having given his close attention to the question of iron ship-building, for the last thirty-five years, he was not surprised at the opposition with which proposals for building vessels of war, entirely of iron, were met. There was the same hostility, when first iron merchant vessels were proposed. Experienced men said, an iron vessel was all very well in a river, or in a canal, but she would never do to go to sea, and that they might do very well when worked by steam-engines, but they would never do for sailing-ships. But let those who now thought in a similar manner, as regarded the construction of iron vessels of war, look at the great number of vessels which were actually afloat, and ask the leading shipowners of Liverpool and of the other principal ports of the kingdom their opinion of them. There were now scarcely any large vessels built for the Liverpool shipowners which were not built of iron; and even the decks of vessels were now being constructed of that material. The introduction of iron masts, yards, and rigging, and the substitution of chain for hemp cables had all been objected to in the same manner; but still the practical utility of iron had forced itself into notice. From his own experience, he was satisfied, that the time was not far distant, when there would not be another wooden vessel laid down to form part of the Navy.

Mr. SAMUDA explained, that since the Paper was written the question of adopting armour-plated vessels, entirely constructed of iron, had engaged the attention of the Admiralty. He was at

present constructing a large target for the purpose of experimenting on the subject, at Shoeburyness. At the time he wrote the Paper, there was such an apparent confidence in wood backing, that he was glad to have now the opportunity of stating, that an alteration had taken place on that point, in the views entertained by those in authority.

Mr. G. H. PHIPPS considered, that the third and fourth of the conditions which were laid down in the Paper as indispensable, were, to a great extent, antagonistic to each other. It was impossible, that the armour plates could at the same time contribute to the strength of the structure, and yet be capable of rapid replacement, or repair, any more than a portion of the upper, or lower web of a girder could be made easily removable. It was also doubtful, whether any additional strength would be obtained by attaching the armour plates on the system proposed by the Author. There were two modes in which the strain on the sides of a ship might be regarded. Looking at the transverse section of the vessel, the sides above the water-line and between the decks might be regarded as curved columns, having to bear the superincumbent weight of the decks, together with their loading. Now, in consequence of the points of application of the top load being upon the inner edge of the vessel's sides, the tendency would always be to curve them outwards, and thus to take the pressure off the armour plates, rather than to put more pressure upon them. As regarded the longitudinal strain, a vessel was sometimes borne up by the water in the middle of her length, and, at other times, at her ends, and hence had to fulfil the conditions which were required from a girder, where the strain on the top, or the bottom alternated from a state of compression to one of tension. On that account, the leading iron ship-builders placed a considerable amount of iron longitudinally in the decks, and the other upper portions of the vessel. This literally formed the upper web of a girder, corresponding and balancing with the keel, skin, and other lower portions of the vessel, which collectively formed the lower web. If this view were taken of the structural arrangement of a vessel, it would be obvious, that a very small amount of tensile strain could be transmitted through armour plating fastened to a vessel's side in the manner proposed by the Author, in consequence of the impossibility of obtaining an adequate connection between the butt-ends of such very thick plates, similar to that obtained in the covering plates of a girder. Should it be urged that the connection might be made more complete, by increasing the number of bolts, he would reply, that in proportion as that was done, the third indispensable condition laid down in the Paper, namely, that of facility of repair and removal, would be departed from. As regarded the Admiralty, he would remark, that when Engineers and

iron Ship-builders of undoubted experience and ability held opinions so opposed, as those which had been expressed, on the subject of the proper thickness for armour plates, it was unreasonable to require infallibility from a Board of non-professional men on that, or any other professional subject.

Mr. GEORGE TURNER advocated the employment of British oak, Malabar teak, and the best iron, as the proper materials for the construction of the hulls of vessels of war. Exterior armour plating was necessary to defend the hull from the fire of the enemy. In his position of master shipwright of Woolwich Dock-yard, he had naturally given much attention to the subject. His ideas as regarded the principles which should regulate the construction of vessels of war, would be best understood by an inspection of a model which he exhibited, and which he stated represented a frigate of the following dimensions, horse-power, and tonnage:—

Length, extreme	400 ft.	0 in.
" between perpendiculars	370 "	0 "
" of keel for tonnage	330 "	1 "
Breadth, extreme	64 "	6 "
" for tonnage	63 "	11 "
" moulded	62 "	7 "
Depth in hold	19 "	6 "
Draft forward	25 "	0 "
" aft	26 "	0 "
Height of midship port above load line	10 "	0 "
Engines of	1,000	H. P.
Weight of Hull	4,400	tons.
" Armour Plates	1,700	"
" Outfit	1,000	"
" Engines and Boilers	1,000	"
" Coal	1,200	"
" Reserve	263	"
Total displacement		<u>9,563</u> tons.
Burthen	7,170	"

The frame of the vessel was to be entirely solid, and of oak; the vertical joints were to be caulked inside and out; and the whole structure was to be bound together within the external planking by iron diagonal riders, so placed as to form squares with each other. In his opinion a vessel so formed of wood and iron would be much stronger than one constructed of wood alone. The case-mated midship portion was proposed to be covered with two thicknesses of iron plates, the inside plates to be 2 inches in thickness, and the outside $4\frac{1}{2}$ inches in thickness. The inside plates were to have a fastening which would be independent of the outside plates; but the fastening bolts of the outside plates were to pass through the inside plates and the sides of the ship. There would thus be a thickness of 2 feet 3 inches of wood, and a thickness of $6\frac{1}{2}$ inches

of iron, which would give a total thickness of 2 feet 9½ inches. The fore and aft portions were only to be covered with one layer of plate of 2 inches in thickness. The deck was also to be covered with a similar plating. Water-tight compartments were to be fitted inside the vessel. These were to be filled to just above the load-line with light tanks, the two lower tiers of which were to be filled with water, and the upper tiers were to be pressed full of cork chippings.

In answer to questions, Mr. Turner explained, that the communication between the compartments would not be entirely cut off. The model represented a vessel 5 feet 6 inches broader than the 'Warrior,' and 26 feet shorter. In fixing upon those dimensions he had in view the increased capacity required to enable the vessel to carry her armour plating. The casemated portion would form a battery of 250 feet in length, and the armament would consist of twelve 68-pounders and twelve of Sir W. Armstrong's 110-pounders.

Admiral Sir GEORGE SARTORIUS thought the Government had made a mistake, in not having given sufficient consideration to the fact, that the navies of the world were in a state of transition. The whole system of naval warfare had been changed by the experiments which had been made upon shot-proof batteries; and the number of vessels which had been sunk by steamers running into them, also proved, that a ship acting as a ram, could run down another ship, without being materially injured herself by the concussion. When the floating batteries were used in the Black Sea, two points were distinctly established: first, that wooden ships were useless when opposed to vessels which were comparatively invulnerable and incombustible; and, secondly, that if vessels were built of sufficient strength and speed to sink their opponents, they would be more formidable with their stems than with their guns. No ship could withstand their blow, nor could booms across a harbour resist their impact. He was at a loss to understand, why the English Government had built vessels of 6,000 tons to 7,000 tons burthen. In his younger days British seamen contrived to master their opponents, although the odds were two to one against them. He sincerely trusted that peace might long be preserved with France; but, as regarded naval matters, that country was the one which there was most reason to watch. Now, the war-vessels building in France were only of 3,000 tons, or 3,500 tons, burthen. Had British seamen degenerated that it had become necessary to reverse the proportions he had quoted? He firmly believed that they had not. The 'Warrior,' which had already been built, under the orders of the Admiralty, was deficient in some of the most material points that practical sailors of the present day considered essential for

a war-vessel. The points he alluded to were, power and strength to overcome the enemy, pivot-like dexterity and handiness in manœuvring, and considerable speed. There were some descriptions of vessels in which speed must be the first desideratum, such as those employed in the protection of the national commerce, the destruction of that of the enemy, chasing a privateer, or running with despatches. But speed was not required for fighting the great battles which decided the fate of a war, for acting on an enemy's coast, for covering the landing of armies, or for protecting harbours, or coasts. Strength and power to overcome the enemy were the qualities principally needed in vessels of war, but in combination with pivot-like handiness to use them effectively. It must also be remembered, that in any future war the enemy might not avoid fighting, but would probably seek it. The vessel which had been built of 6,000 tons burthen carried only 26 protected guns. That was a most insufficient proportion of artillery to the tonnage. A vessel of the dimensions of the 'Warrior' required much too large a space to turn in, and much too great a depth of water to float in, to get sufficiently near when attacking a battery. While, on the other hand, from the deficiency of her qualities as a sailing-vessel, if she were within range of a battery, and her screw were disabled, she would never be able to get away, or to escape shipwreck, if on a lee-shore in a gale. The 'Warrior' only carried five days' or six days' fuel, and, except in the finest weather, and under the most favourable circumstances, she could neither tack nor wear, and even then she required 19 minutes of time, and 2 miles, or $2\frac{1}{2}$ miles of space, to perform the latter manœuvre. Moreover, she steered badly, and when she took a sheer, no action of the helm could stop her. She was very leewardly, and rolled more than any ordinary line-of-battle ship. Although expressly built of sufficient strength to sink an opponent by concussion, a useless cut-water was added, which neutralized her power as a ram; and if she attempted to run down a vessel, her bowsprit and cut-water would be carried away, and probably her foremast would follow; so that, if she succeeded in sinking her enemy, she would, owing to the entanglement of the wreck of the two vessels, probably share the same fate herself; and, at the least, her screw would become fouled and useless. It had been asserted that, when an occasion arose, the carpenter's crew could soon knock away the cut-water, and render the vessel available as a ram. But let that alternative be fairly examined. It meant that ten men, or twelve men were to remove a mass of, at least, 20 tons weight, which was partly secured under water; and let it be remembered, that this operation would probably have to be performed when a ship was going into action, and possibly while she was under fire. In a dry dock it would take at least

a couple of days, even if as many men were employed as could muster round the work; and when effected, owing to the shape of the cut-water, it was very questionable if the bowsprit, and consequently the foremast, could be properly secured. Against batteries, even if under perfect command as regarded taking up, or leaving, her position, such a vessel would prove a failure. Of what use could twelve guns, or thirteen guns be, when opposed even to a moderately strong battery, which would be armed with, at least, twice that number of equally heavy guns? Then, again, as the least motion of a vessel deranged the aim of the gunners, and rendered her fire uncertain, it could only be effective, even in comparatively smooth water, at a distance of 300 yards, or 400 yards. Such being the facts of the case, how could a vessel drawing as much water as the 'Warrior' approach near enough to a battery, to act efficiently against it?

The 'Warrior' would also labour under a serious disadvantage, when in chase, owing to her having no protected bow-guns. If her opponent had, like the 'Gloire,' five, or six stern-guns, and it was desirable to reply to their fire, she must sheer round her broadside, thus giving her enemy time to escape; or else she must continue the chase at the risk of exposing her unprotected points to the strongest of those of the enemy. If caught in a gale on a lee-shore, the 'Warrior,' to make head against it, must keep up her steam as long as the gale lasted; so that, even supposing her whole stock of fuel was intact at the commencement of the gale, it might be exhausted before its completion; her sails would be of no use to her in working off a lee-shore; and as she could not stay, and as each time she succeeded in wearing, she would lose 2 miles, or $2\frac{1}{2}$ miles; there would be no resource but to allow the vessel to be wrecked. Surely every one of these defects, and many others which time would not permit him to notice, must have been known prior to the commencement of the vessel, to every practical seaman who had seen the drawings upon which she was proposed to be constructed. On the whole, he was of opinion that the plan of construction condemned in the Paper—namely, that on which the 'Defence' and the 'Resistance' had been built—was better than that which had been adopted for the 'Warrior.' Those vessels would be more effective, and would cost less money. The 'Defence,' were it not for her bowsprit, could sink the 'Warrior.' While the 'Warrior,' in consequence of the difficulty with which she manœuvred, could never run on board of the 'Defence' before the latter vessel had changed her position.

He considered that the only way by which the Government could arrive at a practical solution of the problem before the Institution, would be that of intrusting its examination to a committee composed of the principal wood and iron ship-builders, and of naval

and artillery officers. As regarded the relative advantages and disadvantages of iron and wood; an iron vessel was much more liable to shipwreck than the ordinary wooden sailing-vessel fitted with a screw. It had repeatedly happened, that the false keels of timber-built ships had saved those vessels from total wreck; for, on losing her false keel, a timber-built vessel might at once float off; where, in every similar instance, an iron vessel would have been lost, on account of her having no false keel. The great improvements which were being made in artillery, rendered a corresponding alteration in naval architecture imperative. He believed, that guns would eventually be built, capable of throwing projectiles of 500 lbs., or 600 lbs. weight, and there was no iron plate which would be able to resist them. As regarded the arming of vessels, he thought there would be no difficulty in constructing vessels to carry 500-pounder, or 1,000-pounder guns. There was no reason why vessels of 1,500 tons burthen could not be built which would carry two, or three of those guns, and the vessel herself might be used as a gun-carriage, if they were always fired in a line with the keel. The guns might be built in the wood, and the recoil partially broken by buffer springs, as well as by the action of the vessel herself; the means for elevating, or depressing the guns might easily be contrived, and the horizontal pointing could be effected by the rudder, or by screws.

The Admiralty instructions for building the iron-plated war vessels referred to, had expressly stated, that they were to be "made strong enough to sink by concussion, and at the same time to be provided against the effects of collision." It was well known, that a blow with the beak of a vessel was more effective against an enemy than prolonged firing, and that the qualities necessary to secure the power of sinking by concussion, need not be attained by taking away any other quality, but that, in addition to possessing the power of acting as a ram, the battery of the vessel might remain quite as formidable. From the drawings which had been made by Admiral Elliot, of the different vessels of war now building in France, it appeared that they were all built with a beak at the bow, similar to that advocated by himself, and which he recommended to the Admiralty some years ago. The French had not, however, adopted his entire plan, which was to make the bow and stern alike, and equally efficient for concussion. There were numerous occasions when a vessel fitted with beaks at the stem, and at the stern, might occasion great havoc amongst an enemy's fleet, as, for instance, supposing a fleet to be lying at anchor at Spithead, Cherbourg, or Plymouth Sound, one of those vessels might run in and sink such vessels as the 'Warrior' and 'Black Prince,' while they were at anchor, or getting under weigh. It had been

said that it was impossible for a vessel to give such blows without receiving injury; but Sir Edward Belcher had mentioned an instance of a vessel of 420 tons, which he commanded, running repeatedly against a mass of ice weighing about 59,000 tons. The vessel was successively run back, and then forward against the ice, at a velocity of 6 knots, or 7 knots, per hour, until it split and parted, but neither her masts, nor her engines suffered from the shocks. What, then, would be the effect of blows from a steam ram of 3,000 tons, or 4,000 tons burthen against a yielding object like a vessel afloat? The vessel assaulted would heel over, and her sides would be stove in, by a crushing, and not by a suddenly checked blow, so that those in the gunroom of the vessel which was acting a ram, would hardly be aware when a three-decker was sunk. He also believed that a vessel of 3,000 tons might be built as a steam ram, without any iron protection, for £150,000, and that such a vessel would be able to sink another, of the class of the 'Warrior,' if the attack was made at night, or when at anchor, or with her screw disabled. If shot of 500 lbs., or 600 lbs. weight were used, the armour plate would be of no avail, and what difference did it make whether the enemy's ships were destroyed by concussion, or by heavy shot? By either mode large unwieldy ships, like the 'Warrior,' could be destroyed by vessels of smaller size than themselves, while for general purposes smaller vessels would be far more useful. The tendency of the improvements which were being made in artillery, evidently pointed towards the necessity of having ships rather of moderate than of large tonnage.

Mr. SHEILDS said, it was an error to suppose, that there was any analogy between the vertical sides of an iron vessel and the horizontal flanges on the top, or bottom of a girder; but if the vertical sides of a ship, and the armour plates attached to them, were compared to the vertical web plates of a girder, the comparison would be correct. It did not appear to him, that the armour plates were in any way subject to tension, for even assuming the theory put forward in the Paper to be correct, namely, that they formed an integral part of the sides of the ship, the only good effect they could have would be to add stiffness to the construction. He, however, considered that, instead of adding to the strength, they tended to weaken the structure, by heavily loading it. Nevertheless, the plans by which the Author had provided for the disadvantages to which armour plates must in all cases subject a ship, were among the most efficient which had hitherto been proposed. The arrangement for attaching the heavy armour plates to a portion of the skin of the ship, specially made $2\frac{1}{2}$ inches in thickness, for the purpose of receiving them, was a decided improvement upon the ordinary method of attaching them to a thin

skin of only 1 inch in thickness, which was manifestly out of proportion to that of the plates, and comparatively insufficient for supporting them. It was obvious, that the plan proposed by the Author, allowed some degree of uniformity in relative size and strength between the skin plates, the armour plates, and the bolts, or fastenings which secured them to each other. It had been apprehended, that the heads of the bolts, by which the armour plates were fixed, would be knocked off by the blows of a shot coming against them. And in the elaborate experiments at Shoeburyness, the bolt-heads certainly did drop off in great numbers wherever the shot struck the plates; but as the Author proposed that bolts, or fastenings should be placed along all four sides of the plate, and as any three, or four of these bolts would be sufficient to hold the plate in its place, he believed the fastenings would be found to be practically sufficient. In fact, by the time that the fastenings along all four sides of the plate were knocked off, the plate itself would be demolished. It had been observed, that no matter how strong the armour plates might be made, the destructive power of the shot fired against them could be increased in greater ratio. The experiments at Shoeburyness had not, however, demonstrated that such was the case. Great improvements were being made in the manufacture of iron plates, and it was to be hoped that plates of 5 inches, and even of 6 inches, would hereafter be made with a much greater degree of inherent strength than at present. And as the strength of plates, which were otherwise uniform in structure, increased as the square of their thickness, it might be reasonably hoped, that the strength of the armour plates might be made to keep pace with any probable increase in the power of artillery. He approved of the system of vertical framing for ship-building, in preference to that of horizontal framing with bulk-heads, and recommended the adoption of a system of vertical frames, with inside horizontal frames attached to them at intervals of 6 feet, or 8 feet, over each other. By this arrangement there would be no necessity for bulk-heads, which had the effect of making a vessel rigid where the bulk-heads were placed, and weak in the intermediate portions. The system which he had recommended, on the contrary, tended to equalize the strength and rigidity of the vessel over the entire structure, and had the additional advantage of doing away with the division of a ship into compartments by bulk-heads; a clear space from end to end being a great desideratum in a merchant ship, for stowing cargo.

Mr. E. A. COWPER said, that in 1846 a number of experiments were made at Woolwich by order of the Government, on the effect of shot upon iron plates. A few of the plates experimented upon

were 1 inch and $1\frac{1}{2}$ inch in thickness, but the majority were only $\frac{1}{2}$ inch or $\frac{3}{8}$ inch in thickness. The ease with which the artillery of that period pierced through the plates, did much to retard the adoption of iron as a material for the construction of vessels of war, although the protection of vessels from shot by its means, had long been considered practicable by many eminent men. Some of the experiments were very remarkable, as showing that a much greater thickness of solid iron was required to resist the impact of shot. One of the shots passed through a coal-bunker made of plates of $\frac{5}{8}$ inch in thickness, and containing 4 feet in thickness of coal, but the only effect of the coal and the two iron plates was to reduce the velocity of the shot. Another experiment was made with sixteen boiler plates, each of $\frac{1}{2}$ an inch in thickness. These were riveted together, so as to give a total thickness of 8 inches. In that case, the shot also passed completely through, piercing one plate after another with little difficulty; and this simply because they did not form a mass of solid iron. The object to be attained was not that of lessening the momentum of a shot, as was attempted when protections of wood, coal, earthwork, &c., were used, but that of opposing a mass which, if it did not break up the shot, would at least resist it. A paving-stone, if thrown against a thin sheet of iron, such as was used to make a tea-tray, would probably destroy, or tear it, whilst the stone would remain comparatively uninjured. But if it were thrown down upon an anvil, it would most likely be broken to pieces. Precisely similar results ensued when a shot was fired against an armour plate. If the shot was not broken by the impact, it would go through the plate; but if the plate was heavy enough to present a resistance similar to that of an anvil, the projectile would be broken into pieces, and its fragments would be unable to penetrate the plate. It was obvious that the only portion of the plate which could be considered as an anvil, and against which the shot would be broken, would be that immediately around and at the point of impact. A plate would always have such an amount of elasticity, as to prevent its more distant parts from acting as an anvil, although, on the other hand, they acted as a tough support for holding the anvil in its place. In view of these principles, he could not agree in the mode of constructing armour plated vessels proposed by the Author. The division of the iron into several plates, and the fish plates behind the armour, were objectionable, and no advantage could be derived from packing of any kind; on the contrary, it would prevent the close contact of the inner and the outer iron plating. No one would think of making an anvil by riveting together a number of pieces.

As the edges of the armour plates were more liable to injury

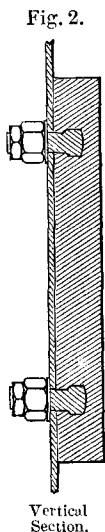
than any other part, it was desirable that the plates should be so connected together as to give additional strength to the vessel. To effect this, Mr. Cowper would propose that large square-headed screws, of about 6 inches in diameter, should be inserted in the joints of the plates, the thread being cut half into one plate and half into the other, so as to prevent any single plate being driven in; a contingency, which he maintained, could not possibly occur, unless the screws were cut in half, or the thread was completely stripped off. If the plates were made of sufficient length, and were so placed as to break joint with each other, the screw plugs which he recommended would have the further good effect of preventing the plates from sliding on each other lengthwise. The tension and compression could thus be continued throughout, and the plating on the side of the vessel, in its integrity, might then be considered as presenting similar conditions to the flat web of a girder, of the same depth as the armour plating. In addition to the strength which would be obtained by the adoption of the screw plugs, they would render the removal of a damaged plate a comparatively easy operation. To change a plate, it would only be necessary to take out the screw plugs, or if they were set fast, to drill them out, to fit the new plate in, and then to bore the holes, and to put new screw plugs in. A small portable engine, of about 3 H.P., might be used for boring the holes, and cutting the threads. The screw-bolts for fixing the plates to the ship could either be formed on the ends of the screw-plugs, or tapped into the plates, through about half of their thickness, from the inside, the heads being inside the skin of the vessel. The plan he proposed would render the joints nearly equal in strength to the centre portion of the plates. The system of grooving and tonguing was a source of much weakness, and rendered the plates liable to split at the joints, whenever a shot struck them near the edges. The bolts and screws, hitherto used in targets, had not been of sufficient size.

Mr. BRERETON, having had some experience in riveting together large masses of iron, in situations where the workmen could not get at the heads of the rivets to hammer them up, had, under those circumstances, adopted a plan which he thought might be rendered available for attaching the armour plates to the sides of vessels of war; and on the appointment of the Government Iron Armour-plate Committee, he had suggested, that some experiments should be made to ascertain to what size of bolt it could be made applicable. The plan in question consisted in forming a countersunk dovetail hole, as shown on Fig. 2 (page 210), reaching half way through the plates, for the reception of the attachment bolt, which, when heated, was hammered in, and completely filled up the holes. The Committee authorized experiments to be made

[1861-62. N.S.]

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with bolts of $1\frac{1}{2}$ inch diameter, and of 2 inches diameter, and he undertook a series of those experiments with different sizes and forms of countersunk holes. Doubts had been previously expressed, and it had been argued, that the attachment of the armour plates would be incomplete, owing to the imperfect filling-up of the countersunk holes, but the experiments showed, that in all cases, they were completely filled up. The Committee, however, notwithstanding the successful results of the experiments, had come to a conclusion unfavourable to the plan. It appeared, also, that they had been informed by some eminent ship-builders, that the system could not be used in some parts of a vessel. As it had been proved that the filling could be effectually accomplished, he considered that the only real test of the efficiency of his plan would have been, to have attached a plate to an iron target by the process he recommended, and by firing shot at it, to have ascertained whether that mode of fastening was stronger, or weaker than those which had been previously adopted, and which, it appeared, had been so generally condemned.



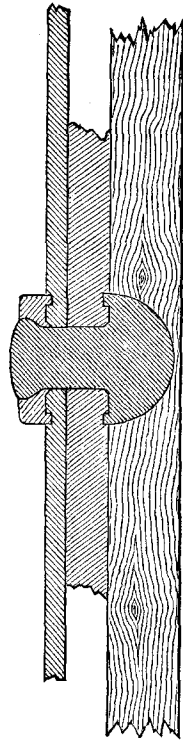
Mr. GIBBS considered, that the best mode of combining iron for the purpose of constructing a uniform defensive surface, would be that of crossing the iron plates at right angles to each other. If such a mode of construction was adopted, ribs, or stays would be unnecessary for sustaining the armour plating of a ship, or fort. The inner line of plates might be as thin as was considered desirable. The outer plates must of course be of the thickness required for defensive purposes. The method by which he would recommend that the iron should be put together so as to form the sides of a ship, or the face of a fort, was shown in Fig. 3 (page 211). The inner and outer line of plates should be fastened together by bolts and collars, which should be let into the front and back plates on the outside and inside respectively, so as to grasp the plates together. The shanks of the bolts were to be 6 inches in diameter. The combination he proposed would form a homogeneous mass of iron, which, without further bolting, or riveting, would be sufficient to resist the shock of a broadside, or the rolling motion of the sea. Although the heads of the bolts projected beyond the plates, it must be remembered that their size was proportionate to the size of the projectiles which would be likely to strike them. No doubt such projections would be a hindrance to a vessel's motion through the water, but the portion of the plating under the water-line might be covered with wood, as shown in the figure, recesses being left on the inside to receive the bolt-heads, while the outside of the

wooden covering would present a continuous surface. Great facilities of construction, and much additional strength, would be obtained by making the vessel with upright, or wall sides, as far as the defensive portion extended. Ships of that form were not much admired, but the upright side need only extend to a depth of 4 feet, or 5 feet, below the water-line, and beneath that level a more approved shape might be adopted.

In the present state of naval warfare, steam power for steering vessels was almost a necessary auxiliary. Under ordinary circumstances, the steering of a vessel was dependent upon the rate at which she was passing through the water, so that large and heavily-laden vessels were liable to be out-manceuvred by lighter and faster vessels.

During the Russian war, he suggested to the Admiralty a mode by which a ship could be formed, with a shield across her, for defensive purposes. A vessel so equipped, could present her front to an opponent, and fire from a few heavy guns through port-holes pierced in the shield. All the parts of the vessel in front of the shield, and the shot-proof bulk-head connected with it, would be liable to be injured by a shot from the enemy, but a water-tight deck, placed a little below the load line, and extending only along the fore part of the ship, would prevent the vessel from becoming disabled. A steering apparatus independent of the rudder would be indispensable, on account of the necessity of keeping the shield at right angles to the line of fire of the opponent. The shield would swing on a heavy shaft, so as to lie down in the line of the deck during ordinary times, and would be raised to its defensive position by an hydraulic arrangement, worked by the same steam-engine which would be used to steer the ship. A number of these vessels might be placed side by side and connected, so as to form a range of battery of any extent, but yet be capable of changing the line of front according to any new position taken up by an enemy. He believed, that such a combination would be most efficient in guarding roadsteads and the entrances of navigable rivers and harbours. With regard to the heavy cut-waters which were proposed to be placed upon vessels, he believed there was an example of a Prussian steam-ship at-

Fig. 3.



Vertical Section.

tempting to overtake a Danish sailing-brig and to run her down. Each vessel had peculiar advantages. The brig had a heavy battery, but no propelling power, while the steam-ship had the power of attaining great velocity. After a day's manœuvring, the steam-ship was not able to out-flank the brig so as to effect the purpose intended, because the brig always bore up, and presented her broadside just at the time the concussion was sought to be effected.

Sir JOHN DALRYMPLE HAY said, that he was glad to have an opportunity of defining the duties of the Iron Armour-plate Committee, of which he was chairman, as there seemed to be a general misapprehension on that subject. The Committee were only instructed to make investigations, as to the quality and description of iron which was best suited for defensive purposes, and incidentally, but not primarily, as to the modes of construction by which that iron might be made available, for the purposes of ship-building and fortification. The necessity for making the investigations with which the Committee was charged, had about a year previously become evident. The public was then called upon to spend large sums of money, for a new mode of protecting ships and fortifications with iron, and very little was known on the subject, even by the most experienced men. The results of the experiments in reference to the quality of iron had shown, that the softest description of iron—not the softer description of any other metal—was the best for defensive purposes. It was essential, that the iron should contain as small an amount of carbon as possible, that it should not partake, to any extent, of the character of steel, and that it should be extremely fibrous. It was at one time imagined, that the presence of phosphorus in iron was very deleterious, but from certain experiments, it was found that such was not the case; the fact being, that of all the chemical ingredients which were combined in iron, carbon was the most dangerous, when that metal was employed for defensive purposes. He would not now allude to the other chemical ingredients which it was desirable should be absent from iron, because the traces of them were very slight, and their effects were scarcely appreciable. The Committee had also ascertained, by experiments, the thickness and form of iron best calculated to resist the impact of a blow from a projectile. The results showed, that a thickness of 5 inches of iron gave the greatest protection in proportion to the weight employed. It had also been ascertained, with almost mathematical accuracy, that the resisting power of an iron plate increased approximately in the geometrical ratio of its thickness, or in other words, that sixteen plates of 1 inch in thickness united together mechanically by riveting, and not by welding, would only resist as much as one

plate of solid iron of 4 inches in thickness. If, therefore, a plate of 1 inch in thickness was taken as the unit, it might be said, that a solid plate of 4 inches in thickness possessed a power of resistance of 16, a plate of 5 inches in thickness a power of resistance of 25, and so on. With the present amount of knowledge on the subject, he thought that it was not desirable to attempt to use armour plates of a greater thickness than $5\frac{1}{2}$ inches. Beyond that thickness, the power of the machinery at present used in manufacturing the plates was insufficient, so that the iron was imperfectly united.

A variety of inventions of a very singular character had been brought before the Committee. Some persons, evidently considering that the protection of a ship from projectiles was a hydrostatic question, had proposed a thin iron casing, to be filled with water, and others had recommended a packing of hemp, and similar materials. The question of the best mode of fastening the armour plates was one of great importance. The Committee had ascertained, that if the plates were attached to the vessel's sides with bolts, a very good fastening was obtained. He did not say that it was the best, but he might safely state, that the public had not lost much money by that mode of fastening having been employed. Other means of fastening were occupying the attention of the Committee, and of the Admiralty, and he believed that a better system would ultimately be arrived at. Another point in which the public, having to make the outlay, was greatly interested, and which had received the studied attention of the Committee, was that of the necessity, or otherwise, for the wooden backing to the armour plates. There could be no doubt, but that the action and reaction of the iron and the wood, inducing oxidation in one and destroying the other, caused the structure of a vessel to deteriorate more rapidly than if the armour plates were directly secured to the iron skin of a ship. There were many reasons which rendered it extremely desirable that the ship should be constructed solely of iron; the experiments tending to make it probable, that the wooden element would be abandoned entirely. The experiments at Shoeburyness in November 1861, upon a target of the same section as the sides of the 'Warrior,' were of the most severe character. That target had a port, and was 20 feet long by 10 feet deep. It was fired at by the heaviest artillery of the old description, and at the greatest velocity, and also by the heaviest ordnance which Sir W. Armstrong had yet produced, and it stood the test remarkably well. At the same time, experiments were made upon four other descriptions of targets. One of these was composed of a plate $2\frac{1}{2}$ inches in thickness, backed by a solid block of cast iron. Another was backed by a block of granite. A third was backed by oak bolted together;

and a fourth by bitumen and cork, in order that the principle of deadening the concussion, or that of the buffer, might be tested. When these targets were fired at, it was found that the indentation made by the shot on the cast iron block was $\frac{6}{10}$ of an inch deep. Upon the granite block the indentation was slightly deeper, and the granite was also cracked and pulverized by the blow; whereas the cast iron, though split, was not displaced. In the case of the plate fastened upon oak timber, the shot penetrated the plate and destroyed it, making an aperture larger than the diameter of the shot, and penetrating 8 inches, or 10 inches into the oak. In the bitumen and cork a much larger hole was made. The experiments therefore proved, that the more rigid the plate, the greater was the power of its resistance to the projectile. When the bearing was rigid, the plate bent before it broke, but when it was not rigid, the plate was broken, or split, and was therefore destroyed. In the case of the 'Warrior' target, when oak was used for the backing, it was true that the plate was bent before it was penetrated; but, on the other hand, the oak backing proved so impervious, that the projectile never penetrated to the plate which represented the inner skin of the vessel. Since these experiments had been made, the Committee had caused another target, of the same size as the former, to be prepared, under the direction of Mr. Fairbairn, with a similar port, but without wood backing. The plates were a quarter of an inch thicker than those of the 'Warrior,' and rested upon a thicker skin, supported by iron ribs, but the total weight of the inner skin and ribs was less than in the 'Warrior' target. Experiments would shortly be made upon that target, to determine the extent to which the inner skin would be injured, by the shot impinging upon the outer armour of the structure. It was his impression that the inner rivets might be shaken out by the vibration; if such a result did take place, it would not prove that it was impossible to build a vessel entirely of iron, and would only go to show, that the system adopted, for putting armour plates upon wood, was not available for attaching them to the iron skin of a vessel. He hoped that the results of the intended experiments would be brought before the Institution, as well as the causes which had induced their success, or their failure.

Admiral Sir EDWARD BELCHER did not consider it necessary that a vessel should be armour-plated throughout her entire length. Such an amount of protection as would shelter the machinery from injury and render the vessel unsinkable would be sufficient. For the other parts, an adaptation of strong, yet moveable defences, to cover the guns and the men who worked them, similar in extent to that given to artillerymen in the field, was all that was essential. He did not concur in the opinion, that

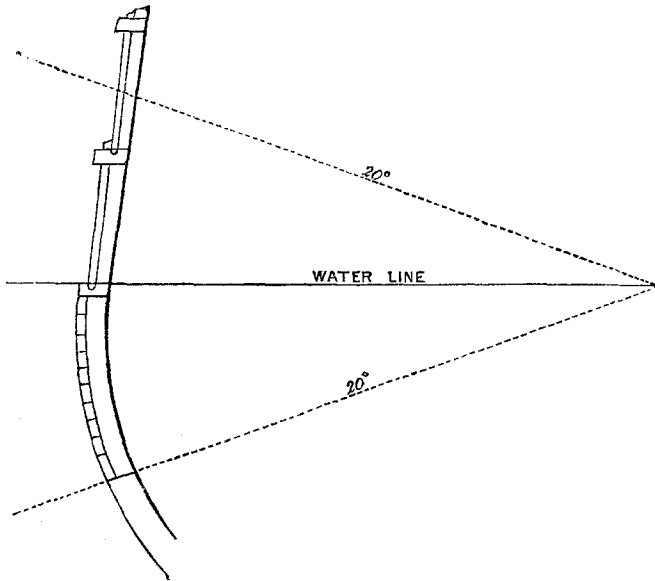
the armour should enter into the construction of the ship, but on the contrary, he considered that the structure of the ship should furnish aid to the armour. The wooden timbers formerly used, should be replaced by iron ribs of from 12 inches to 15 inches in depth, and of a wedge shape, 2 inches wide outside, to 1 inch wide inside, and so far asunder, as to act with the outer plates in preventing a shot from passing, or in other words, just the diameter of that shot which would perforate plates of $4\frac{1}{2}$ inches in thickness. It was possible, that an interval of 8 inches would answer the purpose, as it might be assumed, that no perforating bolt could pass entirely through the armour-plating, and it was certain that no shell could.

As regarded the question of speed, he could not agree with those who placed that quality last in order of importance. In his judgment speed in a vessel of war was preferable to armament. It was a matter of great moment that the armour-plating should be so fixed as to be capable of rapid removal. If one of the armour-plated vessels was found to be hampered at sea by her armour, or if she was aground, and required to be lightened, the armour plates, as at present fastened on, could not be hoisted in-board, or cast overboard. Although it was stated in the Paper, that the vessel might be relieved of her armour and used as a transport, he considered it impossible to meet the emergencies to which he had alluded, by the system of fastening proposed by the Author, or indeed, by any other which he had heard described, or of which he had seen plans, or models. The expensive modes of construction, the multiplicity of fastenings, the increased weight and labour required to extract the bolts, or screws, the necessity for the employment of skilled workmen, and that the vessel should be in smooth water, and in a state of repose, were all serious objections. The requirements of seamen were, a mode of disconnection at which they alone need be employed, and equal facility of replacement. The great size of the plates prevented them from being easily handled, and a further difficulty arose from their being applied longitudinally to the sides of the vessel. He, however, admitted that it would be difficult to apply them in any other manner without impairing the form and smoothness of the vessel, and thereby lessening her speed.

In the construction of vessels of war, Sir Edward Belcher would recommend, that an entirely new system should be adopted for fixing the armour plates. The longitudinal girder stringers, ordinarily used by ship-builders, should be placed at certain specified levels, one of which should be at the water-line, as shown in Fig. 4 (page 216), which represented a portion of the side of a frigate. Below the water-line the vessel should be plated in the usual manner with longitudinal plates, to such a depth as would

be exposed when she rolled about 20° . This in a frigate would be about 12 feet. The portions of the vessel's side above the

Fig. 4.



Vertical Section.

water level would thus be free from top hamper, and with the exception of the addition of the longitudinal girder stringers, she could then be completed, and tried as an unplated vessel. The next longitudinal girder stringer should be placed at 7 feet above the water-line girder, and if required, it might be ornamented. The upper girder should be placed at a similar distance above. All the longitudinal girders should be well secured to the main framework of the vessel, of which in effect they should constitute a part. The moveable armour plates, of which he had previously suggested the adoption, were to be made in short lengths not exceeding 12 inches in breadth. Their ends were to rest on the girders, and the upper shoulders were to be confined to the sides within the stringer bands, and when securely fitted, keyed, and caulked in, they would not only present the same opposition to shot, as the armour at present constructed, but the want of rigidity caused by the bolts would prove an advantage, as presenting an elasticity, not found in the solid bolted plates now in use. A vessel so fitted might also quit this country without her upper and second courses of plating, and in the event of war, might, under the directions of the Engineer and ship's artificers,

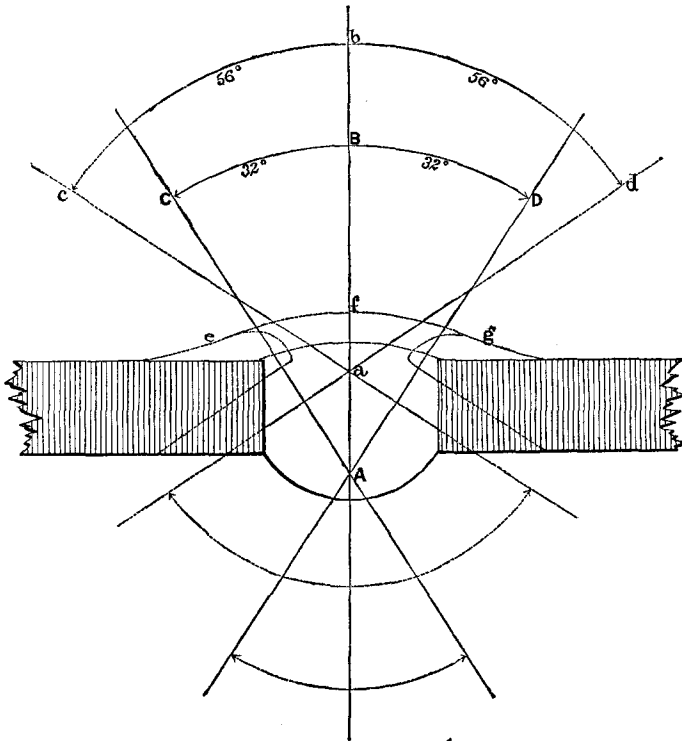
be completed for service by the crew alone. The 'Warrior,' owing to her draft of water, might be considered as a sea frigate, and not as a harbour battery, but the system of armour-plating which he had described would be available for harbour operations. In the still waters of India and China, batteries 'à-fleur-d'eau' might be rapidly constructed by removing the plates; and by using similar hanging plates at the water line, timber vessels of light draft of water, or even rafts, might speedily be converted into armour-plated floating batteries.

The smooth straight sides, which had been adopted in constructing armour-plated vessels, had comparatively destroyed the facilities for the fore-and-aft training of the guns, to the acute angles which were afforded by the old curved forms of a vessel's side. When the 'Warrior' was launched, as it appeared that the angles to which her guns could be trained were limited to 32° forward and 32° aft, Sir Edward Belcher wrote to the Admiralty, suggesting certain alterations in the pivoting of the guns, and in the shape of the port-holes, which would have had the effect of increasing the angular range to 56° forward and 56° aft. His recommendations upon this point would be best understood by a reference to Fig. 5 (page 218.) When the vessel was originally fitted, the gun-carriages were pivoted, or centred upon the inner skin of the vessel at **A**, and the range was limited by the sides of the ports, as shown by the continuous black lines, to the arcs **CB**, and **BD**. Instead of that arrangement, he proposed, that the gun-carriages should be centred on the outer skin at *a*, and that the interior portion of the sides of the port should be cut away to the dotted lines on each side; by these means the gun would have ranged through the larger arcs *c b* and *b d*. To afford additional protection to the men working the guns, he proposed curved wrought-iron port frames of double thickness. The reply he received from the Admiralty was, "that the difficulty had in part been met by reducing the aperture," but he believed, that the main objection to the adoption of a plan which would have greatly increased the efficiency of the vessel was the real, or supposed unsightliness, of the series of car-buncular projections along the sides of the vessel, which it might have been thought would have spoiled the otherwise symmetrical appearance of the vessel. He had, however, seen such a plan successfully adopted in old ships of the line and frigates, fifty years ago.

As regarded the question of sinking the vessel of an enemy by concussion, Sir Edward Belcher had had some experience in charging floe ice. The shock received by a vessel running into the ice was such, that he was led to infer, that if a stubborn resisting body had been substituted, considerable damage would have been inflicted upon the vessel charging it. If a vessel re-

ceived a very severe shock in charging another, her machinery and standards would be so far injured, as to prevent her repeating

Fig. 5.



Horizontal Section of a Port-hole.

the blow, so that really such a mode of attack would be risking all on the chance of success. The inwardly-inclined, or 'tumble-in' cut-water and bow, which had been proposed for the steam rams, would be likely to force them underneath their opponents; whereas, the old overhanging shape of cut-water and bow gave a vessel a great advantage in charging another, as it would cause her whole weight to be forced on the top of her opponent to over-ride and submerge her.

The question of the amount of armour which a vessel could bear had frequently been discussed, and those acquainted with the subject were justly nervous, when it was proposed to increase the weight in a vessel by a few hundred tons. But while fixing upon the form for a vessel's bow and cut-water, it would be well to contemplate the imposition of the weight of the 'Warrior' upon

an overburthened iron-clad vessel. If that weight—9,000 tons—impelled at a velocity of 10 knots per hour, merely rested upon one of her extremities, where would her adversary be? Another reason why the high and commanding bow should be retained, was that it afforded a position from which the enemy's decks could be overlooked, and boarded, while that form of bow itself was adverse to any similar attempt which might be made by the enemy.

The question as to whether, or not, a vessel of war should be plated with armour throughout her entire length, was one upon which some hesitation was necessary. He considered that the waist of a vessel should be shot proof for a certain distance both above and below the water-line. By means of the system of armour plating which he had recommended, having completed a vessel without the upper courses of plating, he would allow necessity alone to be the guide, caring little for holes which did not touch a vital part, and which could be repaired at leisure.

As regarded the Admiralty, without proposing to appear as their champion, he would remark that they might possibly entertain the idea, that if they could build, they could also repair their vessels. The execution of the repairs was an important question, and one involving a large expenditure. Again, the Admiralty might imagine, that if they built the armour-plated vessels, they might possibly ascertain their actual cost, and hence save the commission on the expenditure. On all sides they were beset by complaints against the favourite of the iron-ship builders, the 'Warrior,' and as they had determined to try the experiment, although he did not contemplate they would obtain any great results, yet in the interest of the public he heartily wished them success.

Admiral FITZ-ROY considered, that to render conclusive the valuable investigations of the Iron Armour-plate Committee, experiments should have been made, to ascertain the effect which would result from projectiles fired at a series of successive plates, three, or more in number, say of 1 inch, $1\frac{1}{2}$ inch, or 2 inches in thickness, at varying distances and intervals apart. As far as he understood, in the experiments which had been made, a shot had been fired against several thicknesses of metal placed close together, they might possibly have been rolled together, but they did not form one solid homogeneous mass. Now he contended, that the conditions of a mass of iron 5 inches in thickness, formed into one truly homogeneous mass, under a Nasmyth's hammer, was different to that of an equal thickness of metal placed together, layer by layer, and merely rolled, or otherwise superficially united. To take an extreme case, the difference might be illustrated by comparing the one to so many sheets of paper, so

placed as to touch each other, but no one of which, although in close juxtaposition, was immediately connected with the others: and the other to a sheet of cardboard, or papier mâché, which was intimately and fibrously connected, as a solid substance, from one side to the other. The impact of a shot striking a solid mass of iron was felt quite through the mass and to the back of it. The shot could not penetrate the smallest fraction into that mass, nor could it cause any dent on the outside of the plate, without effecting a corresponding result on the back, or furthest side of that mass. Supposing that the iron possessed only a very small degree of elasticity, or yielding compressibility, if not pierced through, there might be an indentation to a certain distance, but the force of the impact would be felt entirely through the iron. If one hundred steel musket-balls were placed in a line close together, and confined, laterally, and the one at the end was touched, the same amount of impact would be given to the furthest ball in the line, or tube. Upon the same principle, the force exerted upon a solid mass was not to be measured, or estimated so satisfactorily by comparison of the effect of that force upon successive and contiguous layers, as by a variety of trials against equal, or other thicknesses of metal more, or less separated. If, when making the experiments, the plates of iron, instead of having been placed side to side, and united to one another, had been placed at certain distances, say, at 3 inches, 4 inches, 6 inches, 12 inches, or even more apart, the force would have been diminished in passing through the first plate, and it would not have acted upon the second plate with its primary momentum. Supposing that the shot had actually struck directly at right angles to the first plate, it was probable that it would be more, or less deflected before it reached the second, and the second and succeeding plates would deflect it still more. A shot striking a series of plates, so placed at intervals apart, would not only be deflected, but in many cases it would be broken. The thickness of the sides of the 'Warrior' being about 3 feet, a succession of such 'shot plates,' might be placed within that distance, and the projectiles which passed through the outer plates would probably be deflected, so that they would merely fall between the spaces without penetrating the inner plating, or skin of the ship. It appeared that some experiments were about to be made at Portsmouth, with the object of ascertaining the extent to which a shot passing through a comparatively small thickness of iron, say of $1\frac{1}{2}$ inch, would be checked and deflected. The result of those experiments would, no doubt, to some extent, show the correctness, or otherwise, of his views.

In a letter which he had written on this subject in April 1861, and which had been published in the 'Shipping and Mercantile Gazette,' he had expressed the opinion that any degree of tenacity,

ductibility, or toughness, could be procured by working good iron properly; and if successive plates, one within, or behind another, either contiguous, or separated by moderate spaces, with abundance of angle iron, or ribs in every direction, were substituted for clumsy, unmanageable, and very unreliable thick plates, any degree of strength, any amount of gradual resistance, equivalent to that of wood, and any check to the inward flight of splinters, might be obtained. He had also recommended that the tubular, or cellular principle—that of bridges, built beams, or girders—should be adopted extensively, the number of plates being increased, at various distances, so as to ensure strength, good work, and good iron. By the tubular, or cellular principle, he, of course, implied that structure which the late Mr. Robert Stephenson adopted in the Britannia Bridge, and which, to a great extent, the late Mr. Brunel had employed in constructing the 'Great Eastern' steam ship. An outer covering, or skin, separated from, but connected with, an inner coat, or lining, was, in fact, an inner case. The separate, continuous, and water-tight platings might be a few inches, or a few feet apart, according to the vessel's size. In a large ship-of-war they might be about 3 feet apart, and have an intermediate similar case, of tough plate iron. Between these skins any number of plates could be introduced, a few feet in length, about 1 foot wide, and perhaps of iron $\frac{1}{2}$ inch in thickness. These would slide into, be suspended edgewise by, and be keyed to the ribs of angle iron, or their substitutes, namely, transverse plates of iron bolted to both the inner and the outer cases. All these plates might be similar; every hole, tenon, and key, every bolt and rivet alike, in sets, or sizes, for each class of ships. When not preparing for defence, a ship so fitted might displace her shot plates (which would be only from about the water-line to the upper bulwark) and stow them below. The lower part of such a ship, from about 2 feet below the water line, need not have any such plates, but a third skin, and additional diagonal angle irons as sleepers, trusses, or ribs. Strength should be obtained by placing plates of iron edgewise, multiplying, combining, and connecting, while separating them; not by unwieldy masses of uncertain nature within, which would not expand, or contract equally with thinner and less inflexible metal.

If a shot struck a solid mass, every atom in its line of force was impinged upon almost equally; but the impact on a plate within, or behind, not a part of the mass first struck, was much less, and proportionally for any number. The iron ships that had been broken through by shot, or by rocks, except the 'Great Eastern,' had no such second, much less third, or fourth skin. Combinations of wood and iron were well known to be objectionable, theoretically and practically.

In war, vessels constructed of wood alone, were mere fuel for modern incendiarism. Iron ships required to be coated with a preparation, which would preserve the metal and poison marine parasites. If such a coating was applied once a year, it was sufficient. Internally, vessels required abundant ventilation, on account of moisture being deposited when sudden and considerable changes of temperature occurred. They also required pannel linings for cabins and other wooden coverings, all light and moveable. Iron masts and yards had already been made tubular, and sufficiently jointed. Iron rigging had long been in use.

An important point to be kept in view on board long iron ships, was the expansion and contraction of the iron, as it affected the fixings of the engines, which were comparatively permanent; but that point only required to be mentioned, as the remedy was well known to Engineers. Much remained to be done by using iron that did not corrode, by the application of a thin sheathing of galvanised iron, as copper was used on wood, or by aluminium, or by electro-plating the pieces used in water. But on the whole, iron ship-building could no longer be considered experimental, and he felt convinced that there was nothing attainable in a wooden ship that might not be better effected by the use of iron, or some other metal. The practice of fixing extra armour plates to the sides of an iron vessel was grounded upon an erroneous idea. When Engineers and Ship-builders were called upon some years ago to protect the sides of wooden ships with iron, it was indispensable to devise the best means of uniting such plates to their sides. Further experience had, however, shown that it was a mistake to put iron plates upon wooden ships, and that the two substances were so much at variance, as never to work together properly on the side of a vessel. When it became necessary to build iron ships of war which would be shot-proof, the whole question should have been reconsidered, instead of following the old beaten track, which was pursued by those who were only accustomed to put armour plates on wood. At present large masses of iron were proposed to be bolted to the iron ships of war. Surely that iron being of a certain weight and strength, should, while affording protection against shot, be so disposed as to add strength to the whole frame of the vessel. No doubt, if the Admiralty, or any public body having the power of the purse, was to say to Engineers and Ship-builders, "We want the best ship you can give us. She must possess certain qualities, build her according to your own views," a ship of iron would be constructed, with no iron wasted, no weight thrown away, or injuriously applied, and no part stronger than the weakest part. It was a well-known principle, that however much one part of a ship might be strengthened, it would not add strength elsewhere, and that the strength of any structure was

measured by the strength of its weakest part. At present the iron war vessels were strong in some parts, while weak in others. Such a mode of construction should not have been authorized, and ought not to be continued.

The 'Warrior' had peculiar defects, and it was desirable that they should be pointed out, before another vessel of that class was constructed. Her ports were so narrow, that if, in an emergency it were necessary to cast her guns overboard, that operation could only be performed with extreme difficulty. Protection for the crew who fought the guns was not so indispensably required, as on that account to exclude other, and possibly more important requirements. Proper provision should be made for ventilation, for the easy working of the guns, and for the guns being cast overboard, or hoisted in-board through the ports. There were occasions, when it might be indispensable that the guns should be got on board through the ports, instead of by the hatchways. The method by which the armour plates of the 'Warrior' were united to the fabric of the vessel, which rendered it impossible to remove a plate needing repair, without taking a large part of the vessel's side to pieces, was one which required revision in other ships.

Sir JOHN HAY explained, that in the experiments about to be made at Portsmouth, it was proposed to place two iron plates of $\frac{5}{8}$ ths of an inch in thickness at a distance of 15 inches apart. These plates were to be attached to the side of the 'Java.' They were then to be fired at, to ascertain whether the momentum of the shot would be lessened in passing through the outer plate, and if so, whether it would retain sufficient force to break the inner plate. He would not detain the Meeting by entering into the scientific reasons, which induced other members of the Iron Armour-plate Committee, as well as himself, to entertain the opinion, that the fracture of the outer plate would not absorb the momentum of the shot, or prevent its conveying the force, derived from the explosion of the powder, to the second plate. The shot must be viewed as a connecting link, between the original explosive force of the powder, and the remaining momentum arriving at another object, which object must absorb that momentum, or must suffer. Unless the second plate was of sufficient thickness to absorb the momentum, it would certainly be injured; and such he believed would be the practical solution of the question which would result from the experiments.

Mr. FAIRBAIRN said, that the investigations he had made on this subject, had convinced him, that the principles of constructing iron ships, heretofore adopted, were radically imperfect. If an iron vessel was treated as a tubular girder, by resting her weight on her bow and her stern, and leaving the intermediate portion unsupported, it would be found that there was not a sufficient amount of material in the upper deck to resist compression and to support

the vessel in that position. The law of the balance of the two forces of compression and tension appeared to have been generally neglected, and with the exception of the 'Great Eastern,' almost every vessel was deficient in that respect. All vessels, and particularly vessels of war, which had such heavy armaments to carry, ought to have the areas of the bottom, and of the upper decks, so equalised, that in whatever position the vessel might be placed, she would have the maximum power of resistance. He concurred in the principle that the armour plates should form part of the construction of the ship. Additional strength might, by that means, be obtained in the line of the upper deck. It had been correctly remarked, that the 'Great Eastern' was one of the most powerfully-resisting ships that ever floated. Her power of resistance was entirely owing to her cellular construction. There was a probability that, in future, the length of vessels would be increased, and their depth be diminished. If such an alteration in their proportions took place, it would be imperative to adhere to the known laws of construction in order to attain the maximum power of resistance. As a member of the Iron Armour-plate Committee, he concurred in the opinion of his colleagues, that nothing but a perfectly homogeneous plate could successfully resist the impact of shot. Armour plating, similar to that which had been used for the 'Warrior,' and which was about to be applied to the vessels of war in course of construction, might be considered to be the best, according to the present state of knowledge. With respect to the system which had been suggested, of placing several plates at some distance asunder, he had very little doubt that the experiments would prove its inutility. There could be no doubt that, taking a theoretical view of the case, a portion of the momentum of the shot would be absorbed in the ratio of the resistance presented by each successive plate, and that its velocity would be gradually diminished, as it successively passed through the whole of the plates, or until it was brought to a state of rest at some intermediate point by their resistance. But he believed, that in practice the resistance of the plates would produce no appreciable result.

Much depended upon the quality of the iron which was used for armour plates. It was essential that those plates should be of the most perfect quality that could be obtained, that they should have a great deal of fibre and very little crystallisation, that they should be ductile, and combine tenacity with softness. If plates of that character and of adequate thickness were attached to the sides of a vessel, he believed that they would be impenetrable by any ordnance which had yet been constructed.

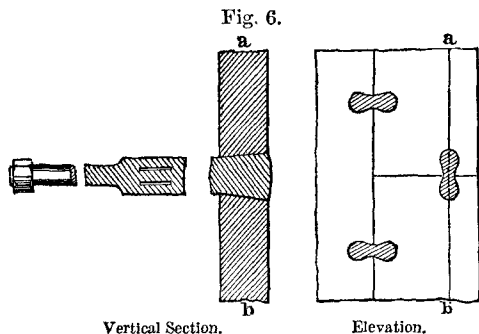
As regarded the question of the mode in which the plates were to be fastened to the sides, he would remark that if a great number

of bolts were used, they would have a tendency to weaken the plates. What was wanted to prevent deflection was a very strong framing behind, for the support of the armour plates. In the experiments which had been referred to, when the plates were supported by a backing of cast iron, the impression of the shot, or rather the injury done to the plates, was very trifling, compared with the indentations which were made in those which were supported by stone, or wood. In the case of the plates, which were backed with alternating layers of fir, india rubber, and cork, the shot went through those substances without the slightest opposition. The great desideratum was a perfectly rigid frame and skin upon which to bolt the armour plates. If that could be attained, he had every hope that the armour plating would resist the Armstrong, or any other projectile at present in use. It was proposed to construct a target of similar dimensions to that known as the 'Warrior' target, but with very strong ribs, and with a skin of 1 inch in thickness, firmly riveted to them. The internal structure would therefore be about three times as strong as that of the 'Warrior.' The experiments would then show, whether the resisting power of that target would be inferior, or superior to the wooden and iron sides of that ship. Although of the same dimensions, the target would be of rather less weight than the 'Warrior' target. It was possible that the jar and vibration of the shot might knock off some of the heads of the rivets. If that should prove to be the case, he thought that a thin layer of pasteboard dipped in tar, and inserted between the armour plates, would soften the blow and destroy the vibration. The results of these and other experiments, he had every reason to believe, would enable the Iron Armour-plate Committee to establish a system of sound principles for the construction of armour-plated vessels of war.

Captain BEDFORD PIM, R.N., said, that the present mode of fastening armour plates might be greatly improved. The methods of bolting, and tonguing and grooving, sensibly weakened plates, and rendered them less able to withstand the impact of shot. If an armour-plated ship, as at present constructed, encountered heavy weather and rolled continuously for some length of time, the plates would probably be loosened to a very injurious extent. He concurred in the correctness of the principle of making the armour plating enter into the structure of the vessel. An iron ship should be as nearly as possible one continuous plate. He had bestowed considerable attention upon the subject of the best mode of fastening on armour plates, but without any satisfactory result, until Mr. George Fawcus, of North Shields, suggested to him, that the principle of dovetailing might be adopted for that purpose. In conjunction with that gentleman he had tried a series

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of experiments, which had enabled him to produce the specimen of iron plating, joined by double dovetailed rivets and bolts, submitted to the Meeting. Figure 6 showed the details of the system.



It was originally intended that the bolts by which the armour plates were to be connected, should have been of an angular shape, but upon subsequent consideration, a rounded form was adopted. The holes in the plate could thus be drilled, by which means a saving of time and expense was effected, and a better form was given to the bolt. A hole, or holes were slotted, or drilled through it, to admit a key, which was inserted close up against the backing. The end of the bolt was rounded off, and a thread cut for the reception of a nut, which being screwed up against the ribs of the vessel, brought all parts into close contact. He would draw attention to the fact that the edges of the plates were not proposed to be tongued and grooved, and by a process of thickening, which he intended to have tested, he hoped to make these portions of the plate the strongest instead of the weakest. The degree of closeness of the joint, which had already been attained, would be seen by the specimen before the Meeting. At present he could not say that it was water-tight; but he believed it could eventually be made so. The iron plates should be placed diagonally on the vessel's side instead of horizontally as at present, and be supported at each joint by a diagonal bracing, which should be rather stronger than the intermediate ones. Curved, or arched tubular beams, of great strength, should be used to support the upper deck, instead of the present weak form of structure, and tubular diagonal bracing might be used with advantage. If, added to these a vessel had a tubular stern-keel and stern-post, the chief requisites of naval architecture would be complied with, and by the adoption of the system of fastening he had recommended, each plate would be properly secured to its neighbour, as there would be no horizontal edges to

open with the rolling of the ship. All working would thus be prevented, and the armour plating would form one continuous sheeting from stem to stern.

Mr. PHILIP THORNTON having, in his position of Assistant Master Shipwright, of Woolwich Dockyard, been engaged during the last seventeen years, in superintending the construction of iron ships, for war purposes, and having also been recently employed in the construction of ships of the same class as the 'Warrior,' would offer a few remarks upon the subject. The Author had admitted, that the three large ships now building for the Admiralty, possessed the two first of the conditions which were laid down in the Paper as indispensable, but asserted that they were deficient as regarded the two last. Now Mr. Thornton contended, that the vessels in question, in addition to possessing speed, and being protected by armour plating throughout their entire length, would also possess the advantage of a rapid and easy mode of replacing and repairing the armour plates. The system of tongueing and grooving had been abandoned, and another method was substituted, which would give quite as much facility for removing and replacing the armour plates, as that proposed by the Author. He disputed the accuracy of the principle of its being desirable that the armour plates should be made to enter into the construction of the vessel.

In discussing the effects of projectiles upon armour plates, too much attention had been given to the indentations on the outer sides of the plates, whilst very little attention had been paid to the appearances of the fractures on their inner sides. This had possibly arisen from the want of an opportunity of examining them. Fig. 7 showed the front, the back, and the section of an armour plate which had been fired at by the heaviest ordnance in use.

Fig. 7.

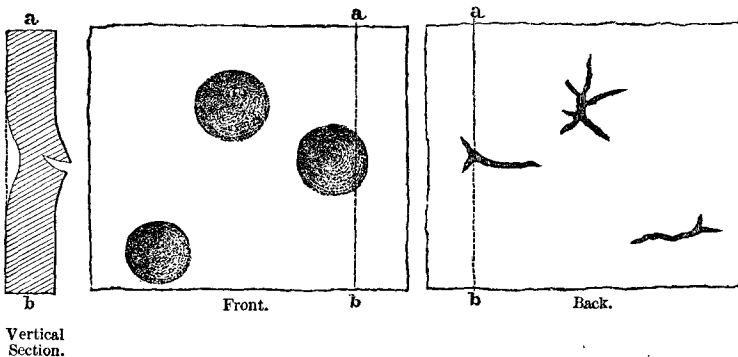
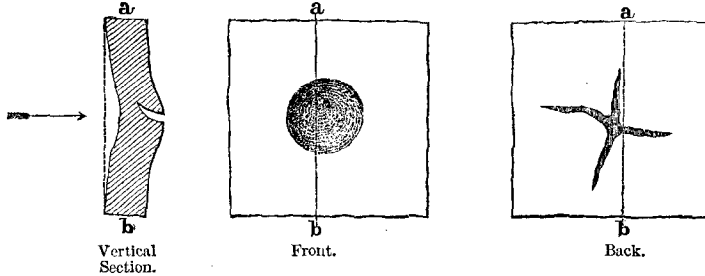


Fig. 8, in like manner, represented a plate of 4 inches in thickness, which had been fired at by an Armstrong 100-pounder gun, the plate being secured at an angle of 30° .

Fig. 8.



It would be observed, that the effects of the shot were similar in both cases, the plates being merely indented on the outer sides, while they were much fractured on the inner sides. Both plates had a backing of oak 10 inches in thickness. Looking at these results, he must consider, that as the vessel proposed by the Author would only have plates of 1 inch in thickness in the rear of the armour, without any intermediate wood backing, the inner skin, or side of the vessel itself, would be shattered if struck by a shot; and if that occurred below the water-line, the vessel would immediately commence leaking. As regarded the fastenings of the armour plates, he had observed, that in all cases in which the plates had been split, the fracture commenced at the bolt-holes and extended to the edges. If therefore a shot struck a plate fastened in the manner proposed by the Author, it would certainly fracture it. In the 'Warrior' the fastenings of the armour plates were placed 2 inches, or 3 inches farther from the edges of the plates, and he thought that plan was much more efficient.

Speed was considered to be primarily essential for iron-cased vessels; how long could that speed be preserved as compared with vessels constructed of timber? Until some provision was made for preventing the rapid fouling of the bottoms of iron vessels, timber ships must necessarily have the advantage. Mr. Thornton exhibited a cluster of barnacles 5 inches in length, as a small sample of a large collection which had covered the bottom of an iron vessel, in a period of between two and three years, and which had reduced the speed 30 per cent. It might be urged, that the vessel ought to have been placed in a dock before that period had expired; but it must be remembered that a ship of war was expected to remain on a foreign station from four years to five years. It was argued that the Admiralty ships of 6,700 tons were too large, and it was proposed to build a ship of 5,600 tons, which

would carry the same armament, and possess greater speed. Mr. Thornton regretted that the data upon which this calculation was based had not been furnished, as he believed that further examination would prove it to be erroneous. It had also been urged that the 'Warrior' did not carry sufficient coal; but the vessel proposed by the Author would carry still less. It was said that the 'Warrior' rolled too much; but it appeared to him, that the vessel proposed by the Author would roll still more. Another reason urged in favour of a smaller ship was, that she would be lighter, if constructed according to Lloyd's rules for an ordinary first-class steamer; but all past calculations had clearly proved, that vessels of the size and mode of construction of the 'Warrior,' had the advantage of combining a maximum amount of strength with a minimum weight of hull. The Author had complained, that the Admiralty had the monopoly of the construction of vessels of war; that statement had already, to a certain extent, been disproved. It was shown that the leading iron-ship building firms had been called upon to design vessels for the Admiralty. That practice had indeed been followed as far back as seventeen years ago; but he could not say much as to the advantages derived from it, inasmuch as the only two ships which were really efficient, had been constructed by an Admiralty official. The question might be asked, why was the Admiralty in a better position than any private firm to construct vessels of war, whether of iron, or of wood? The answer was a very simple one. The Admiralty had been iron ship-builders for the last twenty years. They had now a fleet of forty vessels of iron, irrespective of those which were being coated with armour. They also possessed records and data of every large iron vessel which had been built. Most of the finest iron steam ships were the property of one, or other of the different Post-office mail companies, and before any ship was allowed to carry a mail, it was carefully surveyed by Admiralty officers, and every particular, as to her construction and scantlings, was noted and recorded. The Admiralty therefore possessed a greater amount of information on the subject of iron ships, than could possibly be found in any other establishment in the world.

Mr. R. TAYLORSON concurred in the advantage of increasing the strength of the internal structure of armour-clad vessels, and of appropriating to that purpose, a portion of the iron which was now exclusively employed as armour plating. But in his judgment, the most important point to be decided, as regarded the internal structure of a vessel, was the question, whether the greatest amount of strength could not be obtained, by a diagonal rather than by a longitudinal system of construction. In illustration of his views, he would briefly refer to some of the notices which, from time to time had appeared in the public journals, of the different melan-

choly accidents to iron vessels. In narrating the loss of the iron ship 'Eva,' the 'Times' stated, "that she was struck by a heavy sea, whereby all on board were alarmed by a loud report, which, on investigation, was found to have been caused by the breaking of the keel right in the centre, the vessel having broken her back." And again, as regarded the 'Birkenhead': "She went on shore, and broke in two halves—400 of the passengers perished." The 'Liverpool Albion,' speaking of the then new screw ship 'Yorkshireman,' said, "She went on shore and broke in two." The 'Shipping Gazette,' in speaking of the loss of the 'Duchess of Sutherland,' said, "that in entering the Port of Aberdeen she broke in two halves." The 'Tayleur' shared the same fate, when 450 persons perished in the wreck. And in the memorable instance of the 'Prince,' at Balaklava, the 'Times' stated, "that she struck on a sunken rock, filled with water, drifted, grounded, and in less than twenty minutes she broke in two parts, and all on board were immersed in the deep." The loss of the 'Transit,' in the Southern Ocean, occurred in a similar manner, her plating having split, and 600 tons of water having been pumped out of her within twenty-four hours. Many similar cases might be adduced, such as the 'Nemesis,' the 'Ida,' the 'Loire,' the 'Pacific,' the 'City of Glasgow,' the 'Ada,' and the 'Brigand, &c.' Unhappily, such disasters abounded in the public records, and in the 'Times' of the day on which he was speaking, the loss was recorded of a fine new iron ship, the 'New York.' All these vessels, to use the uniform language of these painful narrations, had "broken their backs," or, in other words, been broken into two parts, from the gunwale to the keel.

At present, iron ships were built upon a solid rectangular bar of iron. Now the keel, mechanically speaking, should answer the double purpose of a base on which to rest the frames, and from which to spring the outside plates, and also to act as a foundation of strength to the whole structure. The question naturally arose, was this solid rectangular bar the best and the strongest form to meet these requirements? It appeared to him that it was not, and that a hollow girder keel and keelson combined, would give an increase, in point of stability, of about 40 per cent. It was well known that the solid rectangular bar of iron had very little power of bearing a load, or of resisting a transverse strain, and that if it was placed on its edge, on props at the extreme ends, it could hardly sustain its own weight; but that laid flat, and kept in place by side attachments, as a hollow girder keel, its strength would be augmented, owing to its increased area, to resist transverse strain, to an extent of not less than from 30 per cent. to 40 per cent. That principle was exemplified in the tubular bridge which spanned the Menai Straits.

The reason of the inherent weakness of iron vessels, as at present constructed, was obvious. On looking at an iron ship of the ordinary construction whilst standing in frame, it would be seen, that the frames, without the plates, offered no resistance to any force tending to tear the ship asunder, in the direction of its vertical plane. The frames were placed vertically, and parallel to each other; and, instead of giving strength to the structure, they absolutely required the outside plates to keep them in their places. These frames were secured to the outside skin by rivets, in a direct vertical line from the gunwale to the keel, on each side of the ship, thus presenting a series of lines of weakness, owing to the displacement of the iron to make the rivet holes necessary for attaching the outside plates, just as was familiarly illustrated in the perforations in a sheet of postage-stamps. The frames also being in a vertical direction, and parallel to each other, could not offer sufficient resistance to any force, or strain having a tendency to tear the ship asunder transversely; while the frames being secured, as stated, to the outside shell, by rivets running in a direct vertical line from the gunwale to the keel, entailed one continuous line of weakness in that direction. In the case of the vertical principle, the line of resistance to any force, acting in the direction of the vertical plane of the ship, would be in a line with the shortest circumferential line of the body of the ship, thereby opposing the least amount of resistance to fracture coming in the direction of those planes; whereas, in the case of a ship built in accordance with the principle of fixing the frame diagonally, the line of resistance to forces acting in the direction of those vertical planes, would be diagonal to the circumferential line of the body of the ship, thereby opposing the greatest amount of resistance that could be given, at an angle equivalent to the inclination of the frames. The same reasoning would apply to the perforations in the plates, or outside skin, which, running in the same vertical line with the frames, also produced a series of lines of inherent weakness in the structure of the ship. This defect might be remedied in a similar manner, by making the line of junction of the butts of the plates diagonal, instead of vertical. Had the ill-fated ships, to which he had referred, been built on the diagonal principle, in all probability, the melancholy loss of life and property which had been recapitulated would never have occurred.

It might, perhaps, be urged, that in building a vessel on the diagonal principle, a greater amount of iron would be required for the framework, than if she were constructed on the vertical system. That might be the case, if it was necessary that the frames should be placed at the same distance as that adopted in iron ship-building on the vertical plan; but owing to the greater structural

strength attained by the diagonal system, the frames of the diagonally-built vessel might be placed at a greater distance apart, and yet be able to sustain her armour plates, from stem to stern, without fear of strain, or injury. The greater buoyancy which would thus be obtained, would be a great desideratum for a vessel of war, and the additional strength for offensive and defensive purposes would be a valuable acquisition whenever it was attempted to decide an action by sinking by concussion.

Mr. W. A. BROOKS said, that the late Lieut. Robert Wall, R.N., about thirty years ago, planned a system of ship-building in which the frames, or ribs of the vessel were to be placed diagonally. In the year 1836, a drawing in illustration of that system was published in the 'Appendix to the Report of the Select Committee of the House of Commons on Shipwrecks.' It showed diagonal ribs, or timbers crossing, and let into each other for a quarter of their thickness. In the system proposed by Mr. Taylerson, the diagonal frames, or ribs ran in one direction on the starboard side of the vessel, and then passed under the vessel and up the port side at an opposite direction, or inclination. Mr. Brooks considered the system adopted by Lieut. Wall was preferable, and submitted to the meeting a drawing, showing an adaptation of that plan, which he considered would enable the armour plating to enter entirely into the structure of a vessel of war. He proposed that the plates should cross each other diagonally, so as to form two thicknesses of plates riveted and bolted together. From the great strides which were being made in the construction of artillery, it was probable, that armour plating of 5 inches in thickness, would before long, be insufficient to resist the projectiles which might probably be launched against it. It would therefore, in his opinion, be better to construct the sides of ships of war strong enough to resist shells, and to let the solid shots, or bolts pass through.

Captain HALSTED, R.N., believed, that no service gun had yet been produced, which was capable of doing any serious harm, to either men, or material within the sides of a vessel constructed like those of the 'Trusty,' namely, with a thickness of 25 inches of oak timber, covered outside by iron plates of 4 inches in thickness. The 'Trusty' was the only vessel built for the purpose of resisting shot, which to any extent had been submitted to experimental firing. Having witnessed and carefully recorded the experiments upon that vessel in 1859, he would mention a few of the more important results. Several shots were fired at her port side, from an 80-pounder, the first heavy gun constructed by Sir William Armstrong;—the vessel being placed at the respective distances of 200 yards, and 400 yards from the gun. The shots fired were of various materials, from hardened steel to ordinary cast iron; but after two days' firing only one shot entered

the vessel. Two shots had struck almost identically on the same spot, only clearing each other by about $1\frac{1}{2}$ inch. The first of these two shots struck the joint of the plate, and opened it to the extent of $\frac{3}{4}$ of an inch. The next shot struck this opening in its centre. The shot being 6 inches in diameter, $4\frac{1}{2}$ inches of its area met with no resistance from the armour plates. The timber backing had already been shattered by the first shot, and the way being thus cleared, the second shot entered the ship, but it was quite spent, and did not reach a distance of more than 10 feet from the side; it, however, threw a splinter before it, a fragment from one of the plates, and that fragment crossed the deck and entered about 4 inches into the timber of the ship on the opposite side. That was the only instance, in which serious harm would have been done to any person at the main-deck guns of the ship. Another shot, of hardened steel, weighing 100 lbs., struck the vessel about a foot above the main deck platform. On looking for the effect of that shot on the inside of the ship, the place where it struck could not be detected, until some one noticed by chance, that the pieces of dried whitewash which had fallen from the side had formed a sort of conical figure upon the deck, and by the line of the apex of that cone, the place where the shot had struck the outside of the vessel was determined. That shot was fired at 200 yards. Since those experiments, Sir William Armstrong had produced his 100-pounder gun, but it was doubted, whether the 110 lb. service shot of that gun would be more destructive in its effect, than the 80-pounder gun had been when using the steel shot weighing 100 lbs. It was true that the diameter of the shot had been increased from 6 inches to 7 inches, but the amount of the charge had only been increased from 12 lbs. to 14 lbs. The gun was in other respects the same; and although the shot was somewhat heavier, yet the force of that shot was distributed over an area of 21.991 square inches, instead of, as formerly, over an area of 18.849 square inches. A 32-pounder Armstrong gun was also brought as close as possible to the vessel, and every effort was made to pass a shot through her, but, with the exception of two shots, which struck exactly upon joints, there was not one that would even lodge. The plates were damaged, no doubt, but only as the old armour in the Tower had been battered by the blows from swords and spears. The men who were inside that armour had, doubtless, escaped unhurt, and that was all the amount of protection which, in both cases, was required. He asked the Committee conducting the experiments to fire some shells against the vessel, but as the firing with the steel shot had produced no effect, they considered it unnecessary. The other, or starboard side of the 'Trusty,' was fired at from a Whitworth 80-pounder. The Whitworth gun proved

to be superior to the Armstrong gun, inasmuch as the shot fired from it lodged in the side, but only one shot passed completely through, into the inside of the vessel. The plate struck was, however, defective. The shot cut a piece out of it, which was carried into the ship; but neither the piece of plate, nor the shot went more than half way across the deck. The timber behind the plate was also rotten. The inner planking, of 7 inches in thickness, could be compressed with the hand; and amongst the timbers of 10 inches in thickness there was extensive dry rot going on. This experiment did not, therefore, fairly represent the resistance of a sound ship of the same scantling as the 'Trusty.' Several of the armour plates were also bent, or 'buckled,' by the shot, but that was to be accounted for in a similar manner. The vessel had been built in a great hurry, of green timber, which had shrunk so much that in many places the wood backing was as much as $1\frac{1}{2}$ inch distant from the plates, and when struck, they were driven against it.

As regarded the use of bolts for fastening the armour plates to the vessels' sides, Captain Halsted did not consider, that the bolt-holes weakened the armour plates to the extent which had been generally supposed. In the experiments which he had witnessed, where there was a solid backing in contact with the plates, there was no evidence of the commencement of cracks at the bolt-holes. In one case, a bolt had been struck by one of the shots. In the part which fitted into the plate, it remained of its original dimensions, but where it was imbedded in the timber, immediately behind the plate, it had been swollen, or 'set up' by the blow, the effect of the shot having been that of tightening the hold of the bolt on the wood. At one time it was urged as a strong objection against the use of bolts, that if one was struck, it would be liable to fly out, and act as a shot. No such instance had come under his observation, nor had he heard that such a result had ever occurred. As regarded the question of tonguing and grooving the plates, he would notice, that wherever a shot had struck within 6 inches of the edge of a plate, the whole force of the impact had expended itself in the direction of that edge, as presenting a line of least resistance; and while the remaining portion of the plate was comparatively free from injury, the edge was in most cases so completely smashed, as to render it evident, that the tonguing and grooving would not only afford no support to the plate struck, but would cause the damage from the shot to spread to the neighbouring plates.

Some doubts had been expressed as to the advantage derived from timber backing. One of the experiments, intended to be made upon the 'Trusty,' was that of firing a shot through one of the portholes, so as to strike the thickness of 25 inches of oak

backing on its reverse side, but owing to the motion of the gun-boat from which the shots were fired, the first shot—a 100-lb. shot of hardened steel—instead of entering the port as intended, struck the plates at its side, which it injured, but the shot did not lodge, being knocked to pieces by the resistance of the plate. The next shot—an 80-pounder of cast iron—passed through the port as proposed, and struck the timber on the opposite side, behind the corresponding plate to that which had been struck by its predecessor. This shot drove one-third of the plate about 50 feet into the air. The effect of these two shots showed the result produced upon two perfectly similar plates, the one having 25 inches thickness of timber behind it, and the other 25 inches thickness of timber before it, and thus afforded conclusive evidence as to the value of the wood backing.

It was much to be regretted, that the results of the experiments upon the 'Trusty' had not been more carefully considered, by those intrusted with the designing and building of the armour-plated vessels of war which had since been constructed; as taken in connection with the results of similar experiments, upon the 'Meteor' and 'Erebus,' two other armour-plated vessels which had also been fired at: they afforded more trustworthy data than any which had since obtained. The 'Erebus' was an iron ship having only $5\frac{1}{2}$ inches of thickness of teak backing between the skin of iron and the armour plate, and it was found that even a 32-pounder shot had a considerable effect upon her side. The first 68-pounder shot which struck her, although it broke to pieces, passed through the side, into the ship, in destructive fragments. It struck the corner of a plate and forced it inwards. The plate did not break up, but the corner was bent into the ship, piercing through the backing, and the iron skin; the side of the ship, for a space of 12 feet, or 15 feet in length, being bulged in, to the extent of $1\frac{1}{2}$ inch. An experiment had been made at Shoeburyness, upon a target of similar construction to the sides of the 'Erebus,' but the armour plate being fastened by screws, after receiving the first five shots, tumbled down from the side it was intended to protect. There could be no question as to the inefficiency of screw fastenings. In the experiments at Portsmouth upon angulated plates, arranged on the system proposed by Mr. Jones, at an obliquity of 50° , the screws, used to fasten the plates to the target, were larger than those used in the experiments previously noticed, being $1\frac{7}{8}$ inch in diameter; but every one of them broke, with the exception of those which were struck directly on the head, in which case, the momentum of the impact seemed to be sustained by the screw, in its longitudinal axis. The broken screws were found to have given way at the first part of the thread. Similar results ensued during the experimental firing at the Cupola

shield of Captain Coles. Wherever screws were used, they all broke at about the first thread. Mr. Jones had expended £7,000 in order to exhibit publicly the value of the principle of deflecting shot; and while the naval administration of every other maritime nation entertained it, the English Admiralty had rejected it, and certain experiments made by the Iron Armour-plate Committee had been quoted in Parliament to prove that it was of no value. A second series of experiments had further demonstrated the advantage which would be derived from the adoption of the principle, in the construction of armour-plated vessels.

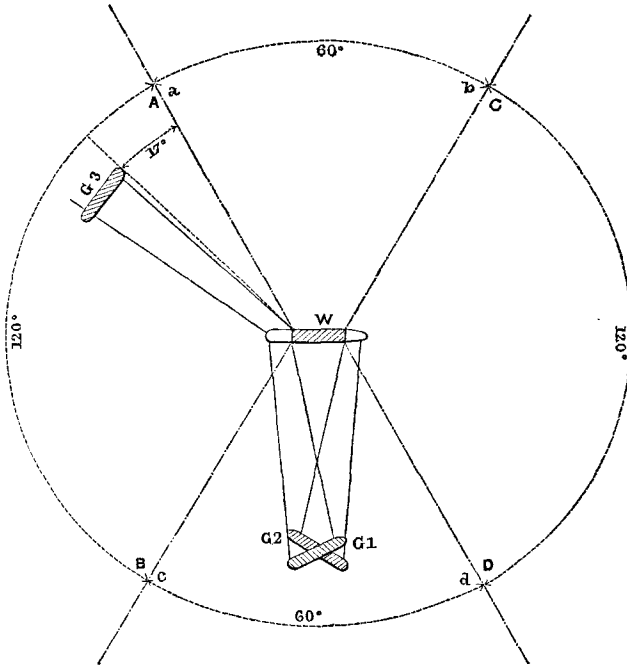
There seemed to be much uncertainty as to the precise thickness of plate, which would suffice to prevent the explosion of a conical shell. It was well known, that a spherical shell was rendered inexplusive, if it was fired against a plate $\frac{5}{8}$ ths of an inch in thickness. The experiments at Shoeburyness, with the Armstrong 80-pounder or 110-pounder gun, had also shown that a $1\frac{1}{2}$ -inch plate would render inexplusive, a conical shell when fired from those guns. The precise point between those two limits had not yet been ascertained. When the spherical shell was fired against a plate of $\frac{5}{8}$ ths of an inch in thickness, the shell was instantaneously broken up, and the powder of the charge not having time to ignite, became but a cloud of black dust, so that in effect, a spherical shell fired against a plate of iron of $\frac{5}{8}$ ths of an inch in thickness, might as well be loaded with sawdust as with powder. As regarded the thickness of iron plates which would afford sufficient resistance to break a shot, he would notice that in the experiments made on board the 'Excellent,' between 1849 and 1851, every description of shot and shell then in use, from 68 lb. solid shot to 32 lb. grape-shot, was fired against a target built on the model of the side of the 'Simoom,' having iron plates of only $\frac{5}{8}$ ths of an inch in thickness. In the Report of those experiments, it was stated, that every shot and shell was "shivered into innumerable pieces, passing on as a cloud of langrage with great velocity;" and the Reporter added, "This would be most destructive, and I firmly believe men could not stand behind it."

The present system of proving the quality of the armour plates to be used in war vessels was extremely imperfect. He was not aware that any of the experiments had been carried out under conditions analogous to those to which the plates would be subjected in actual service. The plates were tried on different kinds of backing, so that no real test could be afforded of their comparative quality; and their absolute efficiency for resisting shot could never be determined, when small targets were used to represent large masses, as, for instance, in the case of the 'Warrior' target of 30 tons weight, which was used as a substitute for a vessel of 9,000 tons burthen. There ought to have been a proper

proof ship, and the established results of all such experiments should have been made public, so that the Government as well as the manufacturers, might have been acquainted with the exact merits, or deficiencies of the plates supplied.

As regarded the relative advantages and disadvantages of partial and complete protection, he would draw attention to Fig. 9, in which the larger vessel in the centre, marked **W**, represented the 'Warrior,' and the smaller vessel marked **G 1**, **G 2**, and **G 3**, represented the 'Gloire' in different angles of position. The arcs *a b*, *c d*, showed the portions of the circumference on each side covered by the protected guns of the 'Warrior,' at the limited angle of training which they possessed, namely, 30° forward and 30° aft. The other two arcs, **AB** and **CD**, of 120° each, represented the spaces within which, the protected guns could

Fig. 9.



not be directed, and within which, her destruction could be more easily effected. Any antagonist, with complete protection, would naturally take up her position within either of the spaces **AB** and **CD**, as she could then only be opposed by the batteries in the weak ends of the partially-protected vessel.

The extreme ends of the 'Warrior' being only covered with

plates of $\frac{5}{8}$ ths of an inch in thickness, every effect of firing from 10-inch shot to grape, &c., as shown in the Report on the 'Simoom' experiments, must equally take place in action on the $\frac{5}{8}$ ths inch plate of the 'Warrior,' or any other vessel of similar construction. Moreover, as far as the shot would range, they would be effective against those ends. The foremast, at the one end, and the mizenmast at the other, would furnish two lines of direction for aim, however distant the combatants might be. So vulnerable were vessels of the 'Warrior' class in their unprotected portions, that her sister vessel the 'Defence' was sent into harbour, to repair a dangerous hole in the $\frac{5}{8}$ ths inch plates in her bows, which had been made by a blow from her own anchor. One of the arguments in favour of partial protection, was based on the supposition, that an antagonist would be obliged to take up a raking position before she could destroy the unprotected portions at the bow and the stern, and that the effect of such a position could be nullified, by the resistance of the shot-proof bulkheads, which were placed across at the ends of the protected portion of the vessel. Such an assumption was, however, erroneous, as her destruction would be much more easily effected by a full-armoured vessel in one of the oblique positions, G 1, or G 2, when, if the broadside of her opponent was concentrated upon her bow, or her stern, every shot must pass through, and destroy both sides at once.

On the whole, he considered, that ships built on the principle of partial protection could never successfully contend against ships of equal force, built on the principle of complete protection. The following Table would, however, further illustrate and confirm his views on this subject:—

COMPARISON of the ENGLISH and the FRENCH ARMOUR PLATED Fleets, in respect to the principles of partial Protection, or complete Protection.

Points of Comparison.	English.	French.
Armour ships now afloat	4	6
Number of protected guns	80	252
Ditto on broadsides	40	132
Additional ships to be completed in 1862	7	10
Number of their protected guns	222	360
Ditto on broadsides	112	190
Relative force at end of 1862 (ships)	11	16
Number of their protected guns	302	612
Ditto on broadsides	152	322
Additional ships to be completed after 1862	4	Not known.
Number of protected guns	149	..
Ditto on broadsides	76	..
Total force afloat and building in ships	15	16
Number of protected guns	451	612
Ditto on broadsides	228	322
The protected guns in the broadsides of these several ships of the two Fleets will vary in number {	from 7 to 21	19 27

The protected guns of the French ships were all 50-pounders, rifled to throw shot of about 90 lbs. weight. The British protected guns would, with trifling exceptions, be the smooth-bore 68-pounder. Each French ship like the 'Gloire' had two protected guns on the upper deck, capable of being fought on either broadside. That would be the case with only two of the British ships expected to be finished this year, and with only three more of those to be finished later. But beside the 451 protected guns of the British ships, they would have, as at present intended, 28 unprotected guns on their main decks, and 151 on their upper decks, making in all, 179 unprotected guns. The British aggregate would thus exceed the French by 18 guns. Hence arose the question—Was this great addition of unprotected guns, a source of strength, or of weakness? The 28 main-deck guns and their crews would be defended by iron plates only $\frac{5}{8}$ ths of an inch in thickness, which the Parliamentary Reports had proved were penetrable by every missile down to the 32-pounder grape-shot; and no experiment had been made as to whether they were proof, or not, against the conical and the incendiary shell. The 151 upper-deck guns and their crews would be defended by timber only, which would vary in thickness from 14 inches to 17 inches, but was not solid like the 18-inch teak backing of the 'Warrior.' That wooden defence was not penetrable by the same grape-shot as the $\frac{5}{8}$ ths inch iron plate; but, besides being liable to splinter, it was penetrable by every larger shot, spherical, or rifled, hot, or cold, and was likewise destructible by every shell, explosive, or incendiary. Taking the crews of the vessels, at a rough estimate, to be 20 men per broadside gun, the number thus exposed at the unprotected guns of the British ships would amount to 1,800; while the French guns, though less in total number by 18, were all protected, and could be fought without any exposure on the part of the crews except at the port-holes. Thus the two great principles of complete protection in the French fleet, and partial protection in the British fleet, were assuming proportions far more important than in the two first specimens respectively of the 'Warrior' and the 'Gloire.'

Should the British Admiralty persist in the principle they had adopted, the great national hazard of doing so, would be demonstrated by the issue of a war; on the other hand, should that Board give the subject a reconsideration, and determine to afford the guns and crews, the same protection throughout the entire length of the vessels, as that afforded by the French ships, it would be evident, that the ships now built, must be so entirely altered, as to the weight and disposition of their armour, that the experience they could furnish, in their present state, would be of little practical value. But assuming the existence of a doubt, as to the course now being pursued, an open experiment by all modern

missiles, on the $\frac{5}{8}$ ths inch iron plates and the 14 inch wooden sides, which would defend the 179 guns, with their 1,800 men, would, no doubt, furnish results either to confirm the principle of partial protection, or else to elicit an expression of public opinion, which would be sufficient to justify the adoption of the principle of complete protection.

Mr. G. W. HEMANS considered that, hitherto, in the structure of vessels the importance of strengthening the deck had not been sufficiently regarded. The extremely long vessels which were at present built—from 400 feet to 500 feet in length—must occasionally be in a position, where their weight would rest on a wave at each end, or, if they grounded, they might be supported by the middle, on a rock, or shoal. In either of those cases, the strains, to which the structure of those vessels were submitted, would be similar to those sustained by a hollow girder. But in the ordinary mode of building iron vessels, there was no provision for resisting the longitudinal strains, either of extension, or of compression, which would occur in the top of a vessel, looking at it as a girder; and, although thus unsupported, the ribs were placed at right angles, without any diagonal ties to resist the strains. It was admitted, that the armour plating, in many cases, weakened instead of strengthening, the vessels which carried it; and it must therefore be obvious, that additional strength would be required, in the structure of the hulls of such vessels. He might mention, that two of the steam-ships built for the Galway and American trade had to be withdrawn, on account of the weakness of their structure; and he thought the subject of making the decks more compact, by strong longitudinal girders on the cellular system, or on some other method, which would impart a corresponding strength to that which was given to the keel, would be deserving of the careful consideration of iron ship-builders.

Mr. JAMES BRUNLEES said, that about two years ago, he had occasion to make some experiments upon puddled steel plates; and using a blunt instrument of 3 inches diameter, hemispherical at the end, upon a plate $\frac{1}{8}$ th of an inch in thickness, he found that the resistance presented by it was equal to 24,640 lbs.; and with a plate of the same metal $\frac{1}{4}$ of an inch thick, he found the resistance to be equal to 52,080 lbs. Taking the mean of two experiments made by Mr. Fairbairn, with the same description of instrument, upon the best Staffordshire iron plates $\frac{1}{4}$ of an inch thick, the resistance was found to be only 16,792 lbs. Hence it appeared, that the puddled steel plates were three times stronger than the best Staffordshire iron plates. He did not mean to say that similar results would ensue when the plates were fired at by shot and projectiles, but he thought, that there was enough in these results to justify further experiments being made. With reference

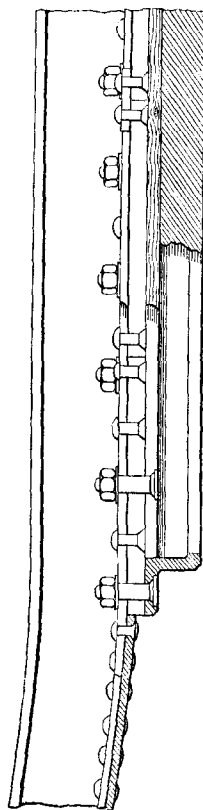
to the fixing of the plates on the sides of iron vessels, built in the ordinary manner, for commercial, or transport purposes, he suggested that at certain intervals bolts should be introduced, fastened with nuts inside instead of rivets (Fig. 10). A vessel so fitted, might be plated with armour, in the following manner. The bolts along the ribs could be withdrawn, and in the line of each rib a rolled beam of the form shown, or any other that might be preferred, could be bolted on to the skin. The armour plates might be inserted between these outer ribs, and allowed to slide down into their respective places. If the armour-plating was fitted on this plan, in the event of any plate being injured, there would be little difficulty in drawing it up, and replacing it by a new one. All the joints, of either form of plate, were also protected from the effects of shot, and the bolts being inside, were all covered by the armour plates. By the general adoption of vessels constructed on this system, the country might obtain the advantage, previously suggested, of possessing fleets of ships, equally well adapted with those now in use for all purposes of commerce and transport, but which, provided the necessary beams and plates were kept in store, could be armour-plated and turned into ships of war, at a few days' notice.

Mr. POLE stated, that armour plates of steel, as well as of combinations of steel and iron, had been tried by the Iron Armour-plate Committee, of which he was a member; but it had been satisfactorily shown, that no kind of steel, or steely iron, possessed good resisting qualities, when made in large sizes. It was true, that thin plates of that material had afforded great comparative resisting power; but these qualities did not seem to be attainable, by any means yet in operation in larger masses. When thick plates were tried, they invariably and signally failed.

The extraordinary toughness and strength exhibited by the steely materials, when made in small pieces, appeared to be due to the great quantity of work employed in their manufacture. The effect of work in strengthening iron and steel was hardly yet sufficiently appreciated among Engineers, and he would mention some remarkable illustrations of it which had lately come to his knowledge. Iron wire,

[1861-62. N.S.]

Fig. 10.



Vertical Section.

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for example, was very much stronger than bar iron;—the wire, made in Manchester for the Niagara Bridge, withstood a tension of 45 tons per square inch, which was probably about double that of the iron bar from which it was made. The wire of the Fribourg Bridge, in Switzerland, bore about 50 tons per square inch. But he had lately obtained results, still more extraordinary, from some trials he had made of the strength of steel pianoforte wire, specimens of which he had found to bear the enormous tension of from 110 tons to 120 tons per square inch. This was the strongest material known; and probably hitherto, the very existence of such a strength could hardly have been suspected. The strength was probably due to the amount of manipulation of the wire in the process of drawing; and therefore, he conceived it afforded a useful hint to Engineers and to iron manufacturers, which might, perhaps, be hereafter advantageously applied. The Committee were of opinion, according to their present experience, that simple wrought iron was the material best adapted for defensive purposes, and that the qualities most desirable in this material were the utmost possible softness, combined with toughness and soundness of texture. If a plate was hard, it was always to a certain extent brittle, and this led to the cracking of the plate under blows—the special result which it was most desirable to avoid. The most perfect defensive plate was that which would resist the greatest amount of battering and knocking about without cracking; and that result was only to be anticipated in a soft material. The Committee were not inclined to recommend the use of very high-priced irons for armour plates, as the required qualities could be sufficiently well obtained in those of moderate cost.

The question whether rolled, or hammered plates were best, had also engaged their attention, but it was found, that each sort possessed both advantages and disadvantages, and improvement was still required in both processes, particularly for very thick plates. Hitherto the result of experience did not appear to warrant much confidence being placed in plates, either rolled, or hammered, above 5 inches in thickness.

The Committee was composed of six members, three representing the arms of the service most interested in the question, namely, the Navy, the Royal Engineers, and the Royal Artillery, to whom were added one eminent metallurgist, and two Civil Engineers, chosen for their experience in regard to iron. Their first active measure, after collecting the records of what had been previously done, was to take the evidence of the most eminent men in the manufacture and use of iron, in artillery, iron ship-building, and other branches of the subject: the call had been liberally responded to, and a valuable mass of evidence was thus collected, which would be published. The Committee had further invited Engineers, and

others interested in the subject, to forward any plans, or suggestions which might occur to them as likely to be useful; and he had himself been commissioned to make a special communication of this nature to the Council of this Institution. The experiments of the Committee, though not exactly public, had been open to the inspection of all parties, who could show a reasonable claim to be present, and they had often been largely attended. The manufacturers of plates, for example, were always specially desired to be present, in order that their attention might be directed to the effects of the firing upon the material; it was pointed out to them, that improvement was desired, and might be reasonably expected in the quality of the plates, and that by personally examining the effect of shot upon them, they would be able best to form an opinion as to how improvements might most successfully be introduced. The Committee had found this system to work remarkably well. Their labours would probably be prolonged for some time, as many plans had yet to be tried. He hoped, on some future occasion, to be able to lay before the Institution, a fuller account of their proceedings.

Mr. GEORGE CLARKE considered, that if the quantity of iron proposed to be used in the construction of a vessel was distributed over the whole surface, in the form of a double skin, a greater degree of strength would be imparted to the structure than by the arrangement proposed by the Author. From the results of experiments which he had witnessed upon trial targets, he believed, that projectiles from the 100-pounder Armstrong, or from the 68-pounder smooth-bore gun, at a high velocity, would penetrate into, or break through, a plate of iron 6 inches in thickness. The armour plating proposed by the Author might be considered as a series of panels of that thickness, the armour plate being 5 inches in thickness, and the skin 1 inch in thickness. Moreover they were fixed, exactly in the position in which a plate of iron would be placed, for the purpose of punching a hole through it, a hollow space being left under the portion where the force was to be applied, by which means it would be more easily penetrated. The same causes would also render the plate more liable to curl up at the edge, or as it was ordinarily termed, to buckle. In nearly all the cases in which the effect of buckling from the impact of shot was most apparent, the backing had been of wood, which not offering sufficient resistance, had been driven in, and the buckling had taken place. It was worthy of observation, that in all the experiments which had been made, the principal damage had been caused by the backing being of wood, and its yielding to the effect of the blow. In the experiments upon the 'Warrior' target, that effect was most distinctly shown. When the last shots were fired at it, the wood was driven in, and the iron was crushed into the

wood, whilst the ends of the plates were torn away from the backing, so that the bolts at the extremity were drawn out $1\frac{1}{2}$ inch, or 2 inches from their bearings, whereas when there was a hard backing of iron, as in the case of Mr. Fairbairn's target, whenever the projectiles struck over the angle iron ribs, representing the timbers of the ship, the iron did not yield, and there was a very slight impression, or indentation made upon the plate itself. One of the small targets, constructed of plates $2\frac{1}{2}$ inches in thickness, backed by cast iron, was fired at with a 40-pounder shot, without producing any impression on the plate, except an indentation of 3 inches in diameter and $\frac{1}{2}$ inch in depth. A 100-pounder, or 120-pounder shot, was afterwards fired with a full charge. This struck the plate towards the edge, and slightly grazed the head of one of the bolts. Where the plate was struck outside the bolt, no impression was made, except an indentation $\frac{3}{4}$ of an inch in depth, and 6 inches, or 7 inches in diameter, and no other damage was done to the plate. The inadequacy of the bolt as a fastening was however clearly shown. On being struck, it acted as a wedge, burst part of the plate away, and broke into fragments a portion of the cast-iron backing. Under any circumstances, the bolt was a defective fastening, being exposed to the impact of projectiles, it became if struck a source of damage to the plate, which moreover was weakened by the bolt-holes. The system of fastening proposed by the Author aggravated these objections. The bolts being placed in lines along the edges of the plates, left only an inch of iron between the bolt and the outside of the plate; and if a bolt-head in this position was struck by a shot, it would fracture the plate and separate it from its fastening.

The results of the different experiments had clearly shown, that the most essential question, as regarded the armour plating, was the character of the substance upon which it was fixed. If that backing was of sufficient hardness, rigidity, and strength of structure, to resist the crushing effects of projectiles, their penetrating power would be reduced to a very small amount; and much thinner plates, than those now adopted, would answer the purpose of resisting the effect of projectiles. The question of the backing of the armour plates was intimately connected with that of the mode of fastening them. If fastenings were inefficient, the armour plate could not resist the effect of projectiles. It was true that a backing of solid iron of sufficient thickness could not be adopted, on account of its great weight; but he believed that a backing might be composed of a series of cells, which by presenting their ends, instead of their sides, to the armour plating, would effectually support it. In constructing such a cellular backing, the diameter of the projectiles, which would probably be used against the vessel, should be taken into consideration, and the cells should be made

of such a size as would ensure, that at every blow at least two cells would be covered by the diameter of the projectile. With such a cellular arrangement for the backing, he had no doubt that projectiles, at the highest velocity, might be successfully resisted. From models and drawings which he had prepared, he found there would be an advantage in distributing the greater portion of the material used in armour-plating a vessel, in strengthening the backing. The weight of the iron and the wood together in the 'Warrior' was equal to a plate $6\frac{1}{2}$ inches in thickness. By properly distributing the amount of iron to which such a thickness of plating was equivalent, armour plates of $2\frac{1}{2}$ inches, or 3 inches in thickness would be sufficient; and the remaining portion of the iron, being put in a cellular form, some inside and some outside the skin of the vessel, a backing and plate would be obtained, which together would have a thickness of from 20 inches to 24 inches, and by some such combination, the problem of rendering vessels invulnerable to shot would no doubt be solved.

Mr. G. P. BIDDER (Past-President) said, in the course of the discussion it had been inferred, that because there was a department of the Government specially charged with the investigation of the subject of the construction of armour-plated vessels of war, little good would be obtained by its being again brought before the Institution. He however held a contrary opinion, and he considered, that great public benefit would be derived, from a fair and open expression of opinion, on the several topics which had been introduced by the Paper and the discussions. Questions of a similar character had been repeatedly brought before the Institution; and he had no hesitation in saying, that both the science and the art of iron ship-building had thereby been benefited. The observations which he had made with regard to the capabilities of the 'Great Eastern' to resist the impact of waves, had been fully sustained by her performances. Whatever mischances might have befallen her, none of them were due to her size, or to the method of her construction. When the question of the National Defences was before the Institution, he had pointed out why three-deckers should no longer be used to form the line of battle;¹ and since then, even the three-decked vessels on the stocks had been cut down to one deck, and the old three-decked ship of war had become obsolete. He had also pointed out, the expediency of making great alterations in the rigging, and at the present time the Government officials were trying, whether the rigging of vessels of war could be so reduced, as to enable them to send down their yards in time of action. Many other changes had been first mooted at previous meetings, and therefore it could not be cor-

¹ *Vide* Minutes of Proceedings, Inst. C.E., vol. xx., p. 518.

rectly stated, that the discussion of these subjects by the Institution was unattended with public benefit. It had been said that the Admiralty possessed a larger stock of knowledge, as regarded iron vessels, than Civil Engineers. He was not, however, prepared to admit that such was the case; but if that Board had a maximum amount of knowledge and experience, he could only say that it had produced a minimum result. Eventually compelled to admit, that iron must enter largely, if not solely, into the construction of the Navy, they had resisted that change to the last, and had used ships for the purpose of experiments, apparently with the sole view of retarding its introduction. Up to the present time, the proper class of vessels to be built, had not been determined upon. Vessels of all kinds were being built, some fast, some slow, some weak, and some strong. Although it could not be correctly stated, that England had not a fleet, capable of meeting that of any other nation, yet the vessels were neither so numerous, nor of that capacity, or efficiency as the nation had a right to expect, in exchange for the very large amount which had been expended. That inadequate result was mainly due, to the reluctance of the Admiralty to introduce the improvements which modern science had, for so many years, been pointing out. Socially and politically, it was of the utmost importance, that the speed and capacity of vessels should be increased. It was easy to account for the slow advance in these points of the English mercantile marine, as, owing to the laws for determining the tonnage of vessels, ship-owners had been reduced to the necessity of carrying 1,600 tons of cargo, under 600 tons of registration. But the same argument would not apply in the case of the Navy. In his opinion, the Admiralty had failed, because of the exclusive system which they had pursued, and their strict adherence to routine. He would cite as an instance, that up to the present time, whatever the build, or the form of the ship, there was but one common regulation as regarded the size and disposition of the spars. In the clipper-built vessels of the Navy, the masts were placed exactly as they were in the old form of ships. The position of the foremast in the 'Warrior,' might be taken as an illustration of the extent to which their science in naval construction had advanced. He had therefore no hesitation in saying, that the public investigation of these subjects had an undoubted tendency to let in the light of true science, by dispelling the clouds which hung over the official mind.

The Author had put before the Institution, a practical method of using the defensive armour, supposed to be necessary for ships of war, in such a manner as to add to the strength of those vessels, but the extent to which the armour, when fixed, might be capable of resisting the impact of modern projectiles, was a question which experiment alone could decide. The other matters alluded to in

the Paper were, however, of more importance, as the primary question to be solved, was that of the form and capacity which were necessary for vessels of war. It would be well to review the different duties they would be required to perform. Vessels of war were needed, first, for the attack of forts; secondly, to form a powerful line of battle; and thirdly, to protect commerce, by acting as convoys to merchant ships, and also by chasing, capturing, and destroying the cruisers and privateers of the enemy. As regarded the first point, the result of the last war with Russia had clearly proved, that the former class of men-of-war was incompetent to cope with land batteries. They failed signally at Sebastopol, and were only saved from destruction by being hidden in their own smoke. Looking to the fact, that it was now proposed to protect forts with iron plates 10 inches in thickness, and where they could use the heaviest modern artillery, it would be equally impossible, that such a vessel as the 'Warrior' could successfully contend against such forts, as would probably now be built. If it was proposed to attack forts, in which modern improvements had been adopted, it would be necessary to provide a special class of vessels for that service. Whether it was possible to do so, he would not then discuss. The second point to which he had referred, was the difficult problem of forming a line-of-battle with modern artillery. He thought there must be some misapprehension as to the details of the experiments upon the 'Trusty.' It was true that when the firing with the Whitworth 70-pounder guns took place, some of the shots did not go through the $4\frac{1}{2}$ -inch plates. Yet it was obvious that, with the Whitworth gun, a bolt could have been fired through that thickness of iron. The rear of the bolt might also have been constructed as a shell, so that when the iron was perforated, the timber would have been blown to atoms, and thus have created great destruction between decks.

The 'Warrior' was a complete failure, except in one respect,—that she was a fast vessel. It was admitted that she did not steer, but that defect might be remedied. The principal defect was, however, that notwithstanding her great length—400 feet—she had only about twenty-four protected guns, while a length of 100 feet at each end was left unprotected; an enemy in close action would undoubtedly assail those weak points. Her spar-deck was also entirely unprotected. It was impossible to combine in one vessel all the qualities essential for general service, unless she was built of such a size as would render her practically useless, except on some occasion which she might never be called upon to fulfil. Speed could not be combined with the necessary stowage for her crew and for coal. The appointment of the Iron Armour-plate Committee had undoubtedly given a great stimulus to the

manufacture of iron plates of a superior quality. As regarded the deduction which had been drawn from their experiments, he admitted that the explosive power of the powder, regulated the mechanical effect of the shot, and that the mechanical effect itself could be measured by the indentation, or fracture of the plate, but it was an error to say, that the power of breaking a plate was determined under all circumstances by the force of the powder. Let it be assumed, that a shot of 100 lbs. weight, with a given velocity, broke a plate of a certain thickness, and then let the same weight of metal be distributed into a hundred shots weighing 1 lb. each. If those shots were fired in succession against a similar plate, it would be probable they would never break, or even indent it. As far as he understood the deductions which had been drawn from the experiments, the relative resistance of a plate was assumed to be as the square of its thickness, while the relative effect of a shot was assumed to be, as the square of its velocity, multiplied by its weight. Now, it was quite true, that great effect was produced upon the sides of the 'Trusty,' by firing at her with a Whitworth gun at 200 yards' distance, and that great damage was done to the plates whenever the shot hit them at right angles. But how were similar conditions to be unfailingly secured in action? An enemy would not regulate his motions to suit the convenience of his opponent; the exact distance also, could not be determined, and the firing must be subject to all the uncertainties arising from the motion of vessels at sea. A fight might be continued for an entire day, without a single shot being fired under circumstances similar to those of the experiments. It appeared to him, that the choice must be made, between having an invulnerable ship, and therefore restricted in speed and capacity, and a ship which might be rendered comparatively invulnerable, but which would possess the element of speed, in a high degree. Taking the latter view of the case as the correct one, a ship might be constructed, with the whole of her sides covered with plates $2\frac{1}{2}$ inches in thickness. With that thickness of metal, there might be great latitude as to armament, space, and capacity, while the degree of strength would be much greater than that required for any of the ordinary circumstances of sea risk. The plates of the 'Great Britain' were not more than $\frac{3}{4}$ inch in thickness, yet that ship, after being for a whole winter on shore in Dundrum Bay, was got off, and although built twenty years ago, was still a fine sea-going ship. A vessel, with plates of $2\frac{1}{2}$ inches in thickness, might not resist a heavy projectile, fired from a short distance, but the probability was, that she would be missed by ninety-nine out of one hundred shots.

As regarded speed, there could be no doubt, but that it was a primary element in naval warfare. It enabled a naval officer to close with his enemy and to board if required. A slow ship could

not board a fast one, while at the same time, it would be impossible that the slow ship could get away from her fleetier antagonist. Whether the tactics of sinking by collision were adopted, or not, a vessel ought to be able to take her option of either fighting at a distance, or of closing with her enemy, but neither of these objects could be accomplished without speed, and therefore speed was a qualification, which as a primary element, should be attained at any cost.

Mr. SAMUDA, in reply, said, that his object in writing the Paper had been to reduce under as few heads as possible, the characteristic points, to which he thought attention should be turned, in the construction of a vessel, protected with armour plates, and suitable to cope with the existing description of artillery. Of the four points which he had laid down as indispensable, he considered speed the most important; and with scarcely one exception, the necessity for its existence had been recognized in the course of the discussion. As regarded the question of entire protection, the whole progress of opinion and events seemed to show its necessity, but the problem, of uniting it with the other indispensable conditions, had greatly increased in difficulty. Those countries which, like England, were about to go to the expense of large armour-plated vessels of war, had considered perfect protection to be indispensable, and had entirely dismissed the erroneous plan of only protecting the middle portion of the vessel. It was scarcely to be believed, that a nation, who like the English, had been the first to build ships with iron frames and iron casings, should resort to such an expedient. It was to be hoped, that the examples of partial protection would be confined to the vessels already afloat. The third condition, that of the armour plating being capable of easy replacement and repair, would alone develop its full importance in actual service, but it was a matter strictly within the province of the members of the Institution, and of those following mechanical pursuits, to discuss in all its bearings. It was impossible to make ships absolutely invulnerable, inasmuch as the improvements in artillery would always overtake the improvements in defence. A vessel which could not replace, or repair the injured portion of her armour plating, would have her efficiency greatly lessened, and would be placed at a serious disadvantage, when opposed to vessels, the armour plates of which could be easily repaired, or exchanged for new ones. A very little experience had proved, that the edges of the armour became curled up under the impact of shot and projectiles; but when that was discovered, one error was employed to remedy the defects which had proceeded from another, and the tongue and groove fastening was introduced. As that system of fastening was now about to be abandoned, he had proposed the system of fastening, the details of

which he had laid before the Institution. He did not say, that the method was the only one by which the existing want might be supplied, but he would strongly urge the general proposition, that a system of fastening which would admit of the plates being easily repaired, or replaced, was an indispensable condition in the equipment of modern vessels of war.

The fourth proposition—that the armour-plating should enter into the composition of, and add strength to, the structure of the vessel, had not been doubted, or denied, although the special means by which he proposed to accomplish that result had been considered, by some persons, to be insufficient. If a vessel was to be taxed by putting a large amount of iron upon her top-sides, it was imperative, that that material should enter into the structure of the ship, instead of straining her, by its weight. He believed the plan which he had proposed would effect that desirable object, and he would add a few words in further explanation. A vessel without armour, and with sides merely completed like any ordinary iron vessel, might be considered as a girder, the top of which was represented by the sides of the ship. When stranded, or lying upon a rock, before she could break up, the sides of the girder, including the skin of the ship, must first be torn in two from the top. Experience had, however, repeatedly proved, that plates of $\frac{5}{8}$ of an inch, or $\frac{3}{4}$ of an inch in thickness were sufficient to withstand the ordinary resistance brought on the sides by the sea. It therefore followed, that if on the top edge of the girder, an additional longitudinal rib was placed of 12 inches in depth and $2\frac{1}{2}$ inches in width, it would, in effect, be an additional girder over the whole length of the ship; and when the armour-plates were fastened to it by the bolts, so that every plate would butt against the neighbouring plate, it followed that before those plates could separate from one another, the bolts from end to end of the vessel must be broken, or else the plates must tear away the $2\frac{1}{2}$ inch web from the top of the ship. Hence, if the power to break the bolts was greater than that necessary to tear the $2\frac{1}{2}$ inch rib asunder, the strength of the top rib would be increased to the extent of $2\frac{1}{2}$ inches sectional area, and thus an additional skin was given to the outside, the minimum strength of which was represented by $2\frac{1}{2}$ inches of thickness; and the strength of that $2\frac{1}{2}$ inches would be conveyed to a plate of greater thickness, throughout the entire exterior of the armour skin of the vessel.

It was now more than two years, since he had first laid his proposals on these points, before those whose consideration and adoption of them might have produced an earlier result, in the direction which he hoped the building of armour-plated vessels would eventually follow.

As regarded the wood backing, it was obvious, that the elas-

ticity of wood was much greater than that of iron; or, in other words, the particles of wood were much more distant than those of iron, so that when it was attempted to support the iron against the impact of a shot, by means of wood backing, the iron was broken, before the wood was sufficiently compressed to yield the required support. It might, therefore, be said, that practically the wood backing offered no support to the armour plating, except in the case where the momentum of the projectile would have been insufficient to break the plate if it stood alone; when it would serve to distribute the strain, more uniformly over the back of the plate. But there was another serious objection to wood backing. If the armour plate was fastened to iron, and the contact was made complete by only a small interposed packing, then it would be held fast without movement; but it was not so when the armour plating was fastened upon wood, owing to the different conditions of the two materials. With the working of the ship, the holes in the wood became larger, whilst the bolts became smaller; and thus, after a certain time, the fastening of the armour plates became more and more loose, until, ultimately, the whole process of fixing the armour on to the wood backing would have to be repeated.

It was generally admitted, that the resistance of a plate to the crushing force of a projectile was in the ratio of the square of its thickness. But it had been urged, that an additional advantage was derived from the great thickness of the wood backing. As regarded that theory, he would point out, that there could be no additional resistance, without a corresponding weight of material. It should be remembered that the thickness of armour plating in a ship was limited to the weight she could bear, and that, in consequence, any improvement should rather have the effect of taking away from, than adding to, the weight which the ship had to carry. For armour plates of $4\frac{1}{2}$ inches in thickness, according to the received formula, the relative resistance would be equal to $4.5^2 = 20.25$. In the 'Warrior' the backing consisted of 18 inches in thickness of teak, which, for the same surface, was of equal weight to an iron plate of $1\frac{1}{2}$ inch in thickness. Supposing that $1\frac{1}{2}$ inch was added to the armour plating, so that its total thickness was 6 inches, by the same formula the relative resistance would be increased to 36, instead of 20.25. Would any one say, that the iron plate and wood backing combined would present that amount of resistance to the impact of shot?

As regarded the mode of fixing the armour plating, which he proposed, every fastening of the armour plates was distinct and separate from the fastenings in the skin, and therefore the plates might be removed, and exchanged, even under fire, with no greater risk than had been run by thousands of sailors when plugging shot holes in timber ships of war.

In reference to the 'Warrior,' Mr. Samuda wished it to be distinctly understood, that on many points he considered she was a very fine vessel. He had heard on good authority, that no communication had been made, as to her alleged excessive rolling, by the officers in charge of her, and therefore he was inclined to disbelieve that such was the fact. It had been argued, that, inasmuch as the designers of the 'Warrior' had not succeeded in giving her a displacement sufficient to enable her to carry her armour plating to her extremities, it was quite impossible that a vessel of smaller size could do so. Under these circumstances, and to controvert that opinion, it would be well, that he should give the following general outline of the character, dimensions, and displacement of the model, which he had submitted for the inspection of the meeting:—

Length	382 feet
Beam	55 "
Depth from main deck	31½ "
When drawing 25 feet of water:—	
The displacement would be	8,505 tons
The midship section	1,145 square feet
The midship port cill above water	9 feet
The particulars of the displacement were—	
Iron work in hull	3,300 tons
Armour-plates (5 inches in thickness in midships, and reduced at the ends to 3½ inches), and also longitudinal ribs	1,600 "
Wood work	930 "
Outfit, and specified Admiralty weights, stores, &c.	1,000 "
Engines of the same horse-power as the 'Warrior'	875 "
Coal	800 "
Total displacement	<u>8,505 tons</u>

The lines, upon which the proposed vessel was to be built, were somewhat finer than those of the 'Warrior,' and the body of the vessel was to be fuller. If the same mechanical power was applied to her, as to the 'Warrior,' she ought to have a speed of 14½ knots per hour at her deepest draught, and a speed of 15 knots per hour with one-half the stated supply of coal.

The idea that the momentum of a projectile would be destroyed, or to a great extent neutralized, by a series of plates placed at a given distance, although it was completely fallacious, was by no means novel. Some time back, in consequence of a proposition

laid before him by an officer of artillery, Mr. Samuda made some experiments to set the question at rest, and he found, that whether the plates were placed at intervals apart, or close together, no appreciable difference was found in the result. The depth and extent, and the shape of the penetration of the shot, were the same under both conditions. He also made a further experiment, of the effect of the shot on an united mass of iron, of the aggregate thickness of the several plates, and in that case, the resistance was much greater, and in conformity with the law which had been previously enunciated.

Although he had expressed the opinion, that iron vessels of war would eventually supersede those built of iron and wood combined, he still thought, that the Government was pursuing a right course in utilising the present wooden ships by plating them; and he believed that the transition, from wood to iron, would not be the less effectual for being gradual. Those ships would be effective and valuable ships for a time; and, looking to the necessity which existed for obtaining a mail-clad navy, within the shortest possible period, and to the length of time, which iron structures necessarily occupied in building, he had no doubt, that the Government was exercising a wise discretion in fortifying the wooden vessels, with iron armour plates, to the extent to which they were capable of carrying them. At the same time, this expedient should only be considered as a provisional measure. In armour-plating wooden vessels, iron longitudinal ribs should be let into the wood back, to support the edges of the plates, upon a similar system to that which he had proposed for iron vessels. The plates should be bolted to the timber sides, and the longitudinal ribs, while they prevented the edges of the plates from curling up, would add strength to the sides of the vessels.

Mr. HAWKSHAW,—President,—said, that the importance of the subject which the Author had so ably brought before the Institution could hardly be overrated. The question of the best form and mode of construction of iron-plated vessels of war, probably involved a larger expenditure of money, than any other which could be submitted for consideration. The present progress in the science and art of attack and defence, would, no doubt, lead to the modification of the navies of all maritime nations. The pecuniary question alone, might form some excuse, for the length and proportions which the discussion had taken, and the mechanical portion of the subject also presented great difficulties. Steam-ships of war, even before the new system of warfare was propounded, were already very complicated machines. There was the question of steam power, and of sailing power, and of the relative value and proportions of each; and to a country like Great Britain, having to defend its dependencies even at the Antipodes, as well as

the narrow seas at home, it was evident, that when the problem to be determined, was the proportions that those two powers should bear to each other, in an ever-varying sea service, the question was not of easy solution. When the subject of steam power was dealt with, the capacity for carrying, and the possibility of obtaining supplies of coals, must necessarily be studied. The difficulties connected with a regular supply of coal, forbade the abandonment of sailing qualities; but when, in addition, it was proposed to render steam-ships of war invulnerable, it was evident that the difficulties which previously surrounded the subject were greatly augmented. It seemed to be expected, that the Admiralty, or some other department connected with the Government, should solve these very complicated questions by inspiration, and grievous complaints of the tardy proceedings had been made. But it should be remembered, that there was a general proneness to find fault, and that under any circumstances, it was much easier to complain of others, than to solve the existing difficulties. Now he was not at all certain, that the propositions, which had been laid before the Institution by the Author, could ever be fully accomplished. He hardly at present believed in the possibility of rendering ships of war quite invulnerable, and at the same time making them swift, lively, easy to manœuvre, and also of effecting such a disposition of the iron plates, as would admit of their being put on and taken off at pleasure. In making these remarks he did not wish to discourage investigation on the subject; for although he considered it a matter of doubt, whether all these qualities could be combined in one vessel, yet the Author was quite right in putting them forward as desiderata. There was one point connected with the use of iron which might, however, greatly modify any opinion as to the propriety of its universal adoption in naval construction. He alluded to the fouling of the bottoms of iron ships. It was generally admitted that ships of war must possess great speed, and therefore, great mechanical power and capacity for coal; but what would this avail, if the bottom of the vessel accumulated such a mass of organic matter, as would neutralize her speed and render her a slow, instead of a fast vessel? It was to be hoped that modern science might aid in remedying that drawback. If no other expedient presented itself, it might be worthy of consideration, whether the bottom of an iron vessel could not be covered with timber planking, so that copper-sheathing could be placed outside of it in the usual manner. There might be some difficulty in attaining proper fastenings, but it did not seem to him to be insuperable.

The suggestions which had been put forward by the Author were valuable, and many of the other proposals were very ingenious. It seemed possible, that iron vessels of war could be so con-

structed, as to be proof against shells and a considerable amount of firing with ordinary shot. He must, however, confess that his own preconceived notions had been greatly modified by the experiments which he had witnessed at Shoeburyness. He had there seen the effects of the new artillery, and he believed, it would be well for all who thought they could make a perfect and invulnerable vessel of war, to refrain from expressing strong opinions until they had seen the effects which had been produced upon the targets. The fact was, that not only was the experimental plate generally knocked to pieces, but also the framework beyond it. The effect of the firing upon these targets had convinced him, that after heavy firing the attachment of new armour to the skin, would not be so easy an operation as it was thought to be, by those who seemed to assume that the skin would remain perfect.

The primary object of the investigations of the Iron Armour-plate Committee was to ascertain the best kind of iron for resisting shot and projectiles, and in consequence, they did not devote much attention to questions of construction. The trials appeared to have proved, that iron of the toughest, but not of the hardest quality, was the best for the purpose of resistance. It might have been readily surmised, that thick plates were stronger than thin ones, but the proper thickness still required investigation. Even admitting, that the strength of armour plates, other things being the same, varied as the square of their thickness, and that plates of 5 inches, or 6 inches in thickness were the best for resisting shot, the question arose, How was a ship to be built with plates of that thickness? The practical solution of that question had occupied the attention of the Institution, and undoubtedly it presented the principal difficulty. Admitting all the premises as regarded the proper thicknesses of the armour plates, it was still necessary to put together large masses of iron, so as to make a vessel, say, of 350 feet in length; and the structure so put together would, under certain circumstances, be required to fulfil the conditions of a beam, and under others, those of a bridge. It would also be liable to cross strains in every direction, and should be so constructed, that every particle of material should in some way, or another, add to the strength of the structure. He certainly had seen no plan which would answer all those conditions, and indeed he had not seen any in which the 5-inch plates would be of the slightest benefit in resisting the strains upon the internal structure, or hull of the vessel. He had designed two targets for the Iron-plate Committee, and in doing so, he had merely considered the best mode of structural arrangement. They were made of plates of such a size and thickness, as to prevent the joints from coming in the same line with each other, and to secure as nearly as possible, a perfect bond and a uniform strength throughout. The iron in

the targets was also disposed in such a manner, that each plate should bear a strain, as nearly as might be, in all directions. He considered, that such a mode of construction would be that which would be most available for fixing armour plates to a vessel's side. But he was quite aware, and he had stated before the targets were made, that plates so laminated, would not be so successful in resisting shot, as if they were welded into one solid mass. On the other hand, such an arrangement of the plates afforded great facility of construction. By its means the thickness of the plating could be increased, or diminished as required, and the iron could be wrought into any form which might be thought desirable. A ship, or a fort, could thus be made more structurally perfect, than by any other system with which he was acquainted; and at present, he was not aware of any other plan so good for securing a homogeneous structure.

The Institution and the public were much indebted to the Author. The Paper had elicited a great number of opinions and facts, and had led to careful consideration of the subject of the construction of vessels of war, which would produce benefit. It would be well, however, to bear in mind, that all the experiments at Shoeburyness, had been made with what, in the lapse of time, might probably prove to be small artillery, namely, 68-pounder and 100-pounder guns. It was possible, that before long, guns might be constructed capable of throwing projectiles of 300 lbs. weight. It would, therefore, be a difficult task to make the invulnerability of vessels keep pace with the improvements in modern artillery; and even if such a result could be attained, it could only be done by making a vessel as heavy and unmanageable, and as unfit for warlike purposes as the men-at-arms of the middle ages, who were frequently smothered in their own armour. The problem, which some supposed the Admiralty ought to have already solved, might not be settled for some years. It was, further, possible that mistakes of greater, or less magnitude would be made, before a satisfactory result could be attained. To make a ship swift, lively, manageable, perfectly invulnerable, and yet easy to repair, required no ordinary amount of research, ability, and actual trial; but, looking at the present position of the question, he thought that the point to be aimed at in naval construction, was to secure a swift ship, which would be perfectly manageable, and easily handled; and, having done that, to make her as invulnerable as possible; but, above all, to be careful not to sacrifice speed, for the sake of securing any other quality.