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INTERNATIONAL NAVIGATION
and its interests

IN

THE HARBOURS AND CANALS OF THE WORLD

AND

MEANS FOR THEIR IMPROVEMENT

BY

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INTRODUCTION.

This reunion in Paris of the votaries of the Science of Navigation comes at the auspicious time when from all the world have gathered representatives to consecrate and relegate to history a finished century. Now must the century be sifted and weighed; now must it proclaim what, out of its travail, its experience and its endeavour, it has evolved; and what, as supreme legacies, it transmits to its successor. Of its record there will be nothing which in importance, in national potency and in promise, shall precede its story of Navigation. Indeed, this pæan of the sea might not overboldly claim to be its central theme, to which all other phases of recital are but related, for there has been no science and no art, no industry and no invention, no dearth and no excess, no demand and no supply, to which Navigation has not brought tribute—from which she has not exacted tribute. Her white-winged ships—guardians, messengers, distributors, chalice-bearers, arbiters—they have coupled the strands, they have linked the continents, they have made mankind as one. To compass the rounded meaning of the main, we must have not alone the slow, steady chant of the workman, the triumphant refrain of designer and owner in our Oceanics and Deutschlands; not alone the splendid minors of our De Lesseps and our Eads, the scintillant flashes of our Edisons, the martial phrasing of monster battleships, but the full choral anthem for all, all—statesman, legislator, capitalist, engineer, producer and consumer, every vocation and every grade, sometime, somewhere, rises and falls on the surges of the sea, and must swell the chorus of its history.

WORLD ASPECT.

THE first fact that impresses one at this end of the century is, that throughout Europe and America there has come a fresh, mighty impulse of expansion. Colonization, largely latent in the earlier decades, has taken a new force. From South Africa to the Philippines all the waste places are being occupied, and all available territory is being struggled for and appropriated. The invention of modern machinery in the hands of steadily growing capital has increased in the West myriad-fold the capacities for production, and the latest great movement is the fruit of it—the effort to enlarge the market. The American continent has during the century opened to an enormously greater consumption of European products. The European continent has reciprocally expanded to America's exports. The growth goes on compounding. In addition both have now suddenly united in a resolute, impetuous movement upon the East—the sealed treasure-house which they have set themselves to industrially and commercially conquer. We stand in an epoch age. We are witnessing the beginning of a movement laden with an influence greater far than the Crusades, whose vastness outsweeps the reach of an Alexander or a Cæsar, whose dominion dwarfs the imperial vision of a Napoleon. The nations of the West, standing in the portal of the twentieth century, have entered on the battle of the Gods, and the stake is a peopled continent. What the struggle means, what Titan effort and competition will ensue, what the rewards will become—these are almost beyond the dream of the prophet. In one statement alone I would dimly foreshadow them. Of all the world countries, America to-day stands first in its internal commerce. But its internal growth is the tale of a few decades; it has scarcely begun its career. But already through the Sault Ste. Marie Canal, between Lakes Huron and Superior, there pass annually two-and-a-half times as many millions of tons as pass through the Suez Canal. The American freight is supplied by but a few million people seeking this one of many available routes. Now, to the East alone of the Suez passageway are eight hundred millions of people. What industries, what consumption, what exchange, what commerce, even in full recognition of the Orient's limited want, lie as potentialities in that statement—eight hundred millions of people! Our speech can find no words to at all convey it. There exist the vast Eastland populations; there lies that destiny highway, Suez; and here to the West, eager, adventurous, are the young Jason nations, sailing out on the golden quest. What is their equipment, what is their strength, who will reach the goal, who will possess the fleece ? The master who had trained him—the dying Centaur —alone could predict for each argonaut his destiny ; and so here, the master who trained—the dying Century—must tell with what equipment each later argonaut sets out for the guarded treasure. Let us hear by what principles they shall be measured.

The nation that would conquer a great future must anticipate the needs and demands of that future, and be ready for them. To be equal to immediate pressures alone is to be relatively retrograde; it is to gamble on seizing and securing fortune by sudden heroic measures of relief. The countries whose interior waterways, rail routes, terminals and harbours are not ready to accommodate increase, cannot draw increase, for here also must the law prevail—to him that hath shall be given. Expansion grows ; it gains volume and momentum ; it cannot be gathered back. This expansion is not alone internal in separated countries ; it is supremely international and intercontinental ; therefore it is supremely a movement over-sea, a movement of navigation.

In this navigation contest the one best equipped shall be he who can most nearly annihilate space and time. That the latest German ships for the China trade are over six hundred feet long, and that leviathans of even greater capacity are already laid down in the United States ; that multiplying fleets arise to fly the blazing sun flag of awakened Japan—in such things we see how well those people know that the race shall be to the swift and the strong. In the light of this law what can one say who learns that from Gibraltar to Australia there is not a single modern mechanical coal bunker ? Vessels must grow in speed, in size, in economy, per ton mile. When the limit is reached with available knowledge then must ingenuity summon other forces, and the new supplant the old. Already the invention of a Parsons hints a possible revolution in the internal mechanism of passenger ships ; and the development of the gas engine and the steam-sulphur dioxide gas motor both promise by their adaptation to nearly double the available equivalent of a pound of coal. In the tension of competition, ships must be ever perfecting. They must be more and more skilfully handled ; they must be massed in larger and larger numbers. Land transport and water transport must become more identical in interests ; must come into more identical hands, and those the hands of commanding capital. The day of the tramp is over. To-day the question is not of a ship, but of a fleet ; and in the economy of transportation the very first demand is that not a moment of unremunerative time shall count against them ; that facilities of ports, terminals, accommodations, shall be such that these flying shuttles shall never unprofitably pause.

It is surely fitting that all, whether in vocation high or humble, whether in capacity great or small, shall feel the privilege of being part of this world movement, and shall give of their highest for its supreme advance.

NATIONAL ASPECT.

In a general way, everything which involves the interests of large bodies of citizens is of national concern, but Navigation is a national matter in a much closer sense. Laws regulating its every function and phase are made by governments, and its international relations are regulated by conventions to which all countries must adhere. In studying national interest in Navigation, one is impressed with how little recognition has been made by many countries of their duty to shipping, and with how this industry neglected, transferred to other hands, has become an agent against the land that has transferred it. What has made England the power she has become? Chiefest, the world's carrying trade. When the items are summed up, of interest, dividends, insurance, premiums, banking and merchants' profits alone, it will be found that there becomes a surprising total of profit to be remitted abroad. It is every nation's duty first to reserve to its own citizens the monopoly of its interior and coast trade. It is its duty, second, to carry in its own ships, one-half of what it exports, and one-half of what it imports. It should be its aim, third, to secure its just proportion of the carrying trade of such nations as cannot or will not become maritime. A partial monopoly of navigation, with its engrossment of commerce, impels conditions of trade and of exchange favourable to the monopolist, but adverse to the recipient. The "open door" is unquestionably the best system for foreign shipping to demand of China, but for China itself a deeper wisdom would lie in emulating the navigation policy of Japan.

The upbuilding and equilibrium of states, commercial stability and naval peace, are all involved in these navigation principles. So thoroughly is now understood the meaning of the dominion of the sea, that all the progressive nations are in the throes of determined endeavour to wrest what they may of her dominance.

The effort to spread markets and upbuild commerce has led in its latest phase to the multiplication of treaties with "favored nation" clauses and special bounties instead of the old discriminating duty system.

The same result could be achieved, the writer believes, with the additional beneficence of building up a merchant marine, under another system, which can be here only outlined. Were each nation to undertake a free insurance of such ships engaged in the foreign trade as were built, owned and manned by her own citizens, together with their cargoes, such insurance would inevitably create preference of employment for the home bottoms, and its benefits would be felt not alone by the owners and operators, but by the producers. The insurance feature could be safeguarded by limitation to a specified amount, to vessels of a certain type, &c., and there must follow all the advantages which lie in a nation's doing its own full share of navigation work. In the United States there exists now governmental inspection of all vessels. The additional task of classification of ships and cargo for insurance purposes would not be serious.

The question of naval power is one too vast to be even touched upon. The future of the ironclad seems to the writer less predicable than that of the merchant ship. Its fate lies more in the hands of the inventor. A new gun, with a shell velocity of 4,000 to 5,000 feet per second, will relegate navies as now built to the cairn of the Vikings.

TECHNICAL ASPECT.

In the foregoing has been noted the world quality of the latest Navigation movement and the relation to it commercially of each Nation. This commercial relation rests back inevitably upon the technical. What the ship itself shall be—its strength, its speed, its serviceability—these lie fundamentally with the technician; even further, with the very specialised technician. But here, conversely, is the paradox true, that the man who is alone a specialized technician is perhaps the one least fitted for solving his own problems. It is the man large enough, universal enough, to be master of his subject, not solely in its narrow limit, but in its very broadest, in its every connection and relation, who is really fitted to know and to solve. The electrician who understands electricity alone is not an equipped and cannot make a large electrician. The engineer who is not able to devise the supply for a discovered need is a limited engineer. *Vice versâ*, the inventor who is not also engineer cannot satisfy all around the fateful demands of his calling. The marine architect finds his creation's path blocked by sands, clay or rock. He can fit his ship to earn its returns only within navigation limits. These he should be fitted to expand, if he is to be the best friend to his own ship.

Evolution in merchant and naval types has reached a status where each need, interior, coastwise or ocean-going, sets a line to its own form. Witness the oil barge system of the Volga, the ore carrying fleet of the American Lakes, the rubber gathering craft of the Congo, and the vessels which the toiling, half-human Chinese trackers drag up the rapids of the Yang-Tse gorges. The very fish are now gathered wholesale by huge steam trawler fleets, which within a decade have supplanted the old time craft. There are places unnumbered where water transport may be advanced when technical skill shall have specialized the thing rightly available for their conditions. In the other hand, in great industries, the tendency is pronouncedly towards standardization—not the standardization of a common type to carry wheat, oil and cattle alike, but of a prescribed type for a common trade. Nowhere is this tendency more marked than on the American Great Lakes.

When one realises that in the last century almost every notable stride has been the product of an invention, and that to-day in every department the captains of industry must be alert to seize or to guard against some supplanting process ; when into the calculation of every enterprise enters the factor of an individual—the inventor—an individual unknown, incalculable, liable at any moment to become the arbiter of that enterprise's future—I say, in view of what the inventor has become to modern civilization, it is incomprehensible that invention is not systematically promoted, instead of being left to its present isolated, desultory working. There are a thousand lines along which the world has grown old enough to advance with premeditation, not at haphazard.

In considering the ship, one must study the channel she is to traverse, and the harbours from which she goes and to which she comes as haven. In connection with watercourses and the desire to improve them, one is impressed with how inadequately sometimes local authorities study what they really possess to make the most of it. The beginning of improvement is to perfect to the uttermost what Nature has allowed. The right lighting, buoying and ranging of channels could certainly be secured, and an accurate and complete hydrography. The day of intuitive pilotage should be past, and those charged with lives and values should have the guidance of exact knowledge. One cannot overpraise the Russian governmental system for educating the pilots of the Volga, and for recording and publishing the daily variations of the river's barring sands. The navigators of the erratic Hoogli are similarly safeguarded. And here one would fain pay some tribute to the glorious, romantic, but mostly unknown and unrewarded record of the long line of mappers and observers of the earth's waterways. What many of these masters did with poor tools and ill-provisioned boats on unknown, dangerous and hostile coasts, in arctic cold and torrid heat, enhances our reverence for human courage and human thought. The lives of a La Perouse, a Cook, a Flinders, a Mercator and a Maury, reflect the same qualities that are immortalized in a Cabot, a Magellan and a Columbus. As a fruitage of the universe of precedent labours we latest workers have those marvellous Admiralty charts of the maritime nations sold for a veritable song.

In considering the improvement of waterways and the creation of perfect terminal facilities, there is a fertile question for a Congress like this, to determine how far governments should themselves execute and control public works, and how far they should instead foster their execution by private capital. In many of these older countries the sentiment is strong that the central authority must hold and itself undertake all national improvements. In America, heretofore, a mixed policy has seemed rather to prevail. In the last quarter of a century there the development of harbours and waterways has been enormous. The Government has been, naturally, the central agent. Since 1873 it has appropriated to this end over four hundred millions of dollars. It has now in contemplation an additional one hundred and fifty million for an Isthmian Canal. The expenditure of these four hundred million dollars has, during the interval, exerted a vast influence directly upon the industrial and commercial prosperity of the people. But indirectly it has drawn into co-operation private capital representing a much greater total than the government expenditure. Individual and corporate projects for dock, freight handling appliances for terminal facilities, for the extension of railways, for the location and development of townsites and back country, represent investments compounding enormously the original stimulus of the government initiative.

Another pregnant question would be how far it were the part of national wisdom and statesmanship to execute great projects, themselves not dividend-paying, yet vastly valuable to the prosperity of the people. Such works as the Assouan Dam, the Sault Ste. Marie and the Manchester canals, are instances in point. Such might (but might not) be the improvements through which Russia would enable the largest sea-going ships to go straight to all railway termini on the Black Sea, instead of trusting her national trade to small cargo units handicapped by lighterage to off-shore anchorages.

In all these departments, in every phase of human activity, the movement is inexorably forward and for its advance it depends quite as inexorably upon the advance of technical skill. That is chiefly why in these congresses, and supremely in this Congress of Navigation, we come together to consult. We would note wherein the valuable tried and proven old things, old forms and old methods, are still proving adequate to enlarged needs. We would also discern where they are failing and must be supplanted. In such cases we must take counsel together as to what are really the new conditions and the new demands; we must tell what each, in his own sphere, is doing in endeavour to meet those demands, and we must give the inspiration, advice, and encouragement which will elicit from each his highest. We revere the past, the immortal century, which Paris sets an exposition to crown. But the dead of the century have laid down their work, and to continue and increase it rests with us, the living. As we fall or as we rise, so must the new century fall or rise. Its destiny lies in us, the living, and its highest water mark shall be set in this generation by our achievements. That, therefore, we shall know each other's honest endeavour, that so far as in us lies we shall speed the promise to the fulfillment, seems the very worthiest mission of a Navigation Congress.

It is in view of this end that the writer turns now from the general survey of what has appeared to him the newer conditions and the newer needs to tell what in his small way he has individually striven to do towards meeting those conditions and needs.

HYDRAULIC DREDGES.

At the last Navigation Congress, held in Brussels, the writer's paper dwelt upon the history and evolution of High-Powered Hydraulic Dredges and their application to public works. The principles of their mechanism were explained and illustrated. It was demonstrated by actual work records that along this highway lay great possibilities of power and an economy far exceeding that in any other way attainable. That their work is not confined to sands and similar materials, but that they cope admirably with clays has been proved in many places on the Pacific, Atlantic, Lake and Gulf Ports in the United States, and has been indisputably proven in the tests at St. Petersburg. These high powered dredges have shown themselves a mighty and a broadly applicable tool, and that there is a need which they are adapted to fill will be conceded, since in the improvement of the world's waterways and harbours, in the reclamation of tide and overflowed lands, and for fillings on the water frontage of cities, probably 80 per cent. of material can be handled hydraulically. Rock, indurated clay, hardpan, and such refractory substances alone are beyond economic handling by properly designed hydraulic dredges.

Since the last report on this subject, a powerful example of the writer's type of machine—then being built for the Russian Government—has been finished, tested and delivered. It is a pleasure to be able to state that the plant fully realised the designer's expectation in capacity. The Government, having generously stimulated design by the offer of a premium for capacity in excess of guarantees at the rate of two hundred roubles per cubic meter, paid all the prize allotted, one hundred and thirty-two thousand five hundred roubles (132,500 roubles.)

A summary of tests is given later in the paper.

A clay test was made in the mouth of the Little Neva at St. Petersburg. Over two thirds of the material excavated and discharged was plastic blue clay. When the Imperial Minister (present), His Excellency Prince Hilkoff, requested a sample of the material it was obtained under the writer's direction, by first stopping the main pump at the conclusion of the test recorded, and then giving the cutters several turns. When raised to the surface they brought up tons of clay so tenacious that it took hours to dig it out with picks and bars. This test demonstrated also that if the pump and cutter mechanisms are handled properly by the operator the cutters and pipes will not choke in actual dredging.

Since the "Volskaia" was designed, in response to other demands, the author has engaged to deliver dredging plants where the local conditions were so different as to require some interesting features in new design—notably in machines for India, Australia, Tasmania and China. Some of these types are illustrated herein.

With the introduction of high-powered dredges nearly every engineering project took on a new aspect, or was capable of a different treatment, and the writer has been compelled to formulate projects of improvements in the light of the powerful tool now given for their execution. He cites some of these engineering projects as characteristic and as illustrative of certain principles of improvement which he believes to be true. The treatment in each case has necessarily been governed by local conditions in the determination of directive, protective or regulative works.

Still another pregnant question might be interposed here on the relative values of regulation works and dredging. The writer follows neither school to an extreme position. It is fundamentally the duty of the engineer to accomplish for navigation the greatest good at the least cost. Sometimes the result can be obtained best by dredging alone, as at the entrance to New York Harbour. Usually it is wisest, for permanency, to combine both methods of improvement.

VOLGA MOUTH.

Epitomized from a Report made to the Russian Government.

THROUGH an intricate Delta, meeting the tideless waters of the greatest inland sea, is the magnificent distributing artery of the Volga and its many tributaries, water and rail. It may be said to serve the whole Empire of Russia. During the year last past, there laboured through the sand-barred passes of the Delta a recorded commerce of 500,000,000 pouds of oil alone, besides the tonnage of other products and merchandise. This commercial movement is not one still to be created; it is there, actively increasing, but fettered. If it be the generous, as it is unquestionably the wise policy to unbar this waterway, a great impetus will be given, not alone to the trade of Astrakan, however entitled that may be to consideration, but to that of all Russia.

It is an enunciated principle in the economics of commerce, that the speedier and easier the products of any section pass along the trade routes, the greater will be the return for the labour of the producer, and the further will go the purchase money of the consumer. It should be made possible for vessels to enter to Astrakan drawing first ten, twelve or fourteen, afterwards sixteen, eighteen and twenty feet of water. In some future time, also, at some point in the Delta, the Railway System of Russia should come into direct contact with the sea ship of deepest draught.

The twenty-foot contour line approaches within twenty-three miles of the mouth of the Kamysiak Branch of the Volga, which recent surveys have shown to be the most promising for improvement. In considering any improvement here, one must reckon with first, what one may call the normal state of things—a smooth sea and a peaceful river flowing through its many winding passes. In addition, he must calculate also the effects of:—

1. Annual floods.
2. The breaking up of the winter ice.
3. The littoral currents.
4. Wave motion.
5. The advance and recession of vast volumes of water at the northern end of the Caspian Sea, as the result of the action of the southerly and northerly winds.

When the silt-bearing waters of the river reach the sea, they drop their load, and each one of the river passes is engaged in a work of perpetual bar-building across its path. We have here no such situation as at the mouth of the Mississippi or the Sulina Pass of the Danube, where short jetties terminate at the ends of relatively steep coutours, but a long, gentle slope. Were jetties constructed to reach the twenty-foot contour, they would be twenty-three sea miles long. Even if jetties of such length could meet the situation, without dredging, which is exceedingly problematical, their cost as usually constructed is prohibitive.

What is wanted is a project which will best serve the growing demands of Navigation—a deep water entrance into the river, together with a future railway terminal, and a site on which the population (10,000 to 15,000) now engaged in transportation pursuits in a veritable floating city forty miles at sea, may live in greater comfort and security.

The river must also be prevented, so far as possible, from directly resilting the channel. There must be a dredging plant able to cope with the shore currents and with the effects of winds and waves. A sketch of the writer's project is shown on the accompanying Plate I. It consists essentially of the following elements:—

1. Curved jetties, carrying the Kamysiak Branch to the westward.
2. Townsite on the outer Island to the eastward of the outer jetty.
3. A harbour basin with slips and other navigation conveniences of proper size.
4. A dredged channel of adopted width and depth, which may be extended to the twenty-foot contour line, protected, if necessary, by suitably designed works.
5. A lock between the harbour basin and the deep water of the concave made by the outer jetty.
6. A powerful dredging fleet in constant commission, this fleet designed to work effectively in both smooth and rough water.

The Kamysiak Branch will then maintain along the concave jetty a deep channel. It will build itself a new bar several versts to the westward of the established channel line, and it may be left to do so.

The writer is aware that the curved jetty system, which is here proposed, has not been directly used elsewhere. The nearest parallel to it is furnished at St. Petersburg. The main channel to St. Petersburg traverses the Gulf of Finland and enters the Neva River at a deep water point, far within its outer bar. While the Neva is not a silt bearing river to the same extent as the Volga, yet there is a persistent bar at its mouth, which the St. Petersburg Canal practically avoids by its course. This Canal does not need a lock between it and the Neva, because the Neva is (as is said) not a great silt bearing stream. If it were, the parallel would be sufficiently complete.

Soil excavated from the harbour basin and the river is designed to be utilised to raise the land of the outer island so as to form the townsite of Kamysiak. The grade of the island should be established above the high water of the river and sea. On it should be laid off streets, locks and lots which would be utilised by the population, now domiciled upon the open sea in the outer roads. There also can be located a future railway terminus. The lock constitutes a device for getting, without obstructing commerce, from the deep water of the harbour basin to the deep water on the concave of the river, while preventing the waters of the river from silting up directly the harbour basin and the channel. Outgoing ice will also be carried far to the westward of the channel, by a prolongation of the curved jetty.

The dredging fleet may be used in the river above the townsite to dam the lateral outlets and to improve several bars and bends between Kamysiak and Astrakan. It may also be employed as occasion requires to raise the banks on either side, in order to concentrate the waters of the Kamysiak. In the construction of the main channel, material may be deposited on either or both sides of the cutting in parallel bands, or behind suitable bulkheads.

THE HOOGLI RIVER.

PROPOSED DEEP-WATER APPROACH TO CALCUTTA.

Epitomized from the Report made to the Calcutta Port Commissioners, India, 1899.

FROM the days of the earliest British settlement on the Hoogli its navigation has been both difficult and perilous. In view of its greater and greater importance to the growing Indian Empire, and of the many perplexed problems which its *régime* presents, the River has been studied by Engineers the world over, and several within the last half century have reported projects for its betterment.

Physical Characteristics.

Physically the Hoogli is one of the Delta mouths of the Ganges. It is a tidal estuary, subject to variable fresh water discharges from the Ganges, and from the watershed of its three principal tributaries—the Damudar, Rupnarain and Haldia. The discharges from the Ganges at its annual flood are sometimes enormous, and always silt-laden. All the tributaries are subject to tidal influence. The Damudar and Haldia are normal tidal rivers. The Rupnarain presents the phenomenon of a very large bottle-shaped basin just above its mouth. This river, with its peculiar basin, the Damudar River, and the double Fulta Point concave, are together responsible for the chief phenomena of the currents and bars in the Hoogli from Fisherman's Reach to Hoogli Point. Plate II.

Between Fisherman's Reach and Hoogli Point is the river's difficult navigation and its main problem. Elsewhere, except at the Moyapur and Royapur crossings above, a deep channel swings from concave to concave in admirable fashion.

The Rupnarain basin acts upon the incoming flood tide like a huge suction pump, and draws its axis irresistibly towards the Mornington bank opposite Hoogli Point. It has secured here the only deep flood-tide channel (between the Muckraputty and Mornington Sands) to be found along the whole course of the river. From this, the western gut, the flood trends towards the Ninan concave, and with the help of the Damudar suction crosses again towards the west bank, making a variable and small channel among the Fulta Sands. After the expansion at the mouth of the Damudar, the flood rearranges itself in the straight Fisherman's Reach, and proceeds up the river without further travail.

Scouring Action of the Tides.

It has been contended that the flood tide is the main scouring producing tide, but this statement is at variance with every modern authority. The ebb-tide channel is the world over almost invariably in tidal rivers, the navigated channels, because it is deeper, and the Hoogli is no exception. In it the eastern gut, an ebb-tide channel, is the navigated course. The ebb does the most effective scouring work because it has a place to take the alluviul to—the sea—while the flood tide, Sisyphus-doomed, has no final place at which to free itself of its load, but must deliver its burden to some shoal, or to the no less industrious but more successful ebb. The ebb is the effective "worker" when it has the chance.

Tidal and Freshet Channels.

Navigation is beyond question best served when flood and ebb traverse a common channel. When from natural causes their axis is not the same, and it is impossible from physical or financial considerations to compel them to the ideal *régime*, if one must be favoured it is best to give the working chance to the ebb. Little commercial reliance is anywhere placed in flood-tide channels. Further, the freshet channel is necessarily coincident with the ebb channel, so that the vast preponderance of effective silt-moving effort is along the ebb tide axis. The flood tide has, with all its opportunities, scoured no *deep* navigable crossing from the western gut to the Ninan Reach (only three or four feet), while a variable part of the ebb, tormented by the combined action of the upper Fulta concave, and the variable tidal and fresh water discharge of the Damudar (at the Ninan Bar), has yet partially reasserted itself, and succeeded in securing a deep pool from Ninan to Hoogli Point, and the several tracks navigated across the James-and-Mary Bar.

Obstacles to Navigation.

The obstacles to navigation in the Upper Hoogli are:—

1. The James-and-Mary Bar.
2. The Ninan Bar.
3. The doubling of Fulta Point.
4. The Royapur Bar.
5. The Moyapur Bar.

No plan of improvement has been adopted, and naturally, therefore, none has been executed to improve the conditions at any of these places, except the Leonard attempt at Moyapur.

There has been evolved, however, a most perfect Intelligence Department, giving daily, and often hourly information, and this in turn sustains a highly developed Pilot Service. These measures secure the best results possible under the present infinitely variable conditions of tracks and bars. But there are inevitable delays in going up and down, and very present dangers, which, even in favourable times, keep pilot, captain, crew, and passengers alert, nerved, and prepared for an emergency, since to sheer, to touch, may be fatal. It is not alone the James-and-Mary, Ninan and Moyapur bars, but the doubling of Fulta Point also which now need bettering in the interests of safe navigation. In the reports of previous engineers, there is no serious recognition of the ruling parts which the Rupnarain basin (just inside the heads) and Fulta Point, with its double concave, play in the river's derangement. A double concave is always a bad thing, and sure to give trouble. When it is further complicated by the eccentricities of such a stream as the Damudar, the case is worse. No survey of the Rupnarain basin is available, but it contains many square miles.

Remedial Projects.

(*A*) Those which would utilize the Hoogli from the sea to Calcutta for the navigable approach, and which seek to increase and render stable its ruling depths.

(*B*) Those which would utilize the river in part, and which propose canals for the rest.

(*C*) Those which abandon the Hoogli and contemplate the use of another Ganges mouth and canal.

Under *A* are grouped the formulated projects of various engineers, the suggested diversion of the Damudar into the Rupnarain, or of both into the Haldia, and the Hoogli point cut-off scheme.

Under *B* are placed the Diamond Harbour and Calcutta Canal and the Canal from Diamond Harbour near Hospital Point to Fisherman's Reach above Fulta Point.

Under *C* is placed the Mutla Canal proposition.

The various projects enumerated under the last two groups have been eliminated from probable realization. Technical and public discussion, self evident difficulties, and a cost manifestly in great excess of a sum obtainable and warranted, have placed them beyond the pale of serious entertainment.

It should, however, be remarked that the canal from Diamond Harbour to the Kiddepore Docks has not been examined lately with reference to the economies of modern excavating tools. These could now assure a wider and deeper canal for an expenditure materially lower than the estimates of ten or twelve years ago.

But as the river is itself, so to speak, a canal already built and needing only regulation in a few places to become in commercial efficiency superior to any other possible canal, the writer confines his attention to the *Hoogli* and its tributaries, and this analysis concerns in consequence group *A* alone.

The various projects advanced under group *A* may be arranged in five classes:—

1st. Those which propose raking or scraping or mechanical agitation, with the expectation that the tide will carry the material away.

2nd. Those which propose dredging alone through the River Bars from Saugor Island to Moyapur.

3rd. Those proposing diversions of the tributaries or of the Hoogli.

4th. Those advocating the construction of submerged dykes, jetties, or training walls, and reliance on natural scour after such regulation to erode deeper channels.

5th. That recommending—a system of training banks or walls and the removal of Fulta Point, in order to bring the river to normal width and to an alignment adopted in consonance with calculations based on modern hydraulic principles for river regulation; in order, also, to regulate the propagation of the tides and fresh water discharge.

CLASS 1.

Mechanical Agitation.

In the first class interesting and yet unsuccessful attempts have been made. All these measures fail for the simple reason that bars exist between two eroding "fields" (to use an electrical simile) and the current is rarely able to carry material stirred up into the next "field," but merely drops its unwilling load close to the mechanical device. Mechanical agitation will succeed only when a device is perfected which acts effectively and covers the distance between the selected contours at the same time. Agitation must be so extensive as to give material no chance to precipitate, until carried past the bar.

CLASS 2.

Dredging in Hoogli Estuary.

It has been suggested by several, and the writer affirms it as certain, that for securing and maintaining better depths from Diamond Harbour to the sea, dredging must be and can be confidently relied upon, providing a proper plant is employed. This should excavate along an axis, selected after due surveys, and modified as changes occasioned by floods and deposits may make such desirable.

Dredging at Moyapur and Royapur.

The possibility of conducting successful dredging operations at the Moyapur and Royapur is conceded and assured. Dredged cuts here will have some value, and a measure of permanence, but their duration in times of ordinary tidal fluctuation can be determined only by trial. The freshets will change the ordinary tidal *régime*, and, carrying anew vast quantities of silt, will surely restore the bars, in whole or part. By dredging each recurring season after the annual flood the amelioration may be made valuable, but it will be perfected only when the river bed is brought to its true width and alignment.

A trial can be made at the Moyapur by the small dredge just built on the writer's system for the Kiddepore Docks. It may be employed at any time (except at the period of high water, when the depth is excessive) in any of the following ways:

(*a*) It may work radially, taking each cut to a width as great as 200 feet, along or across the axis of the bar, throwing the spoil to one side, or

(*b*) Using a bow and stern and side lines, it may take numerous straightaway cuts five feet wide, the cutter size, throwing the material 400 feet away.

(*c*) It may discharge wing and wing, *i.e.*, to either side, and allow the current to carry the sand into the adjacent pools.

In these operations from 300 to 1,000 cubic yards per hour can be excavated during periods of low tide.

But to make the dredging relatively permanent, it is indispensable that the river should be brought to a proper width and alignment by training walls, as later stated.

Dredging on Ninan and James-and-Mary Bars.

On the Ninan and James-and-Mary bars in the navigable tracks dredging is a very much more difficult proposition. Only two or three hours a day could or would be allowed by the authorities. During these times operations will be hazardous, and what can be done must be subject to daily or even hourly variation. This Kiddepore dredge, however, will be too small to warrant that a proper judgment could be formulated before trial or even after assiduous effort.

The reason of this is that the causes of trouble would not be modified by her procedure. These causes are adequate to undo the work of dredging as fast as it is done along the navigated line. Therefore, the opinion is here recorded that little or no good could be accomplished by such employment of this small machine, or other mechanical devices, directly on the Ninan or James-and-Mary bars. For improving the doubling of Fulta Point by its removal, machines of twenty times the power would be desirable.

It is the writer's conclusion that reliance upon dredging along the navigated tracks on the James-and-Mary and Ninan bars is inadvisable, but might fortuitously do good temporarily, and enough to warrant occasional employment; that at the Royapur very little, if any, dredging will be necessary, when the river is brought to proper width and curvature above and below; that at the Moyapur (since the training banks must go in gradually) a certain amount of direct dredging through the bar will possibly have measurably satisfactory results, and will diminish in quantity when and as the width and alignment are corrected.

On the other hand, dredges may be easily employed to assist in making training banks, anywhere on the convex side of the river, without the least interference with commerce.

CLASS 3.

Diversion of Tributaries.

The suggested diversion of the Damudar into the Rupnarain is a very natural one, but several established facts militate against its advisability. Fulta Point is historically reported to have existed before the Damudar broke through its banks and made its present mouth. What the Hoogli *régime* was before this event occurred does not appear. The Damudar has now a tidal fluctuation and a fresh water discharge of variable volume. To a positive but variable extent it draws the flood tide to the west, already deflected in that direction by the lower Fulta concave. Its ebb forces the Hoogli ebb to the east bank, instead of allowing it to cross to the west from the lower end of the upper Fulta concave, as it would otherwise for the most part naturally do. The River Damudar, moreover, is commercially used and of importance to trade.

It could be diverted into the Rupnarain, and remain usable. But its tidal prism would be lost to the Hoogli above the Point, and the abstraction of so large a tidal volume is contrary to the accepted tenets of river hydraulics. Its tidal fluctuation and fresh water discharge would be added to that passing between the Rupnarain Heads, and would inevitably augment the evils due to that river, without commensurate increase of the good accomplished by the Rupnarain tidal prism in helping to scour navigable ways through the bars of the estuary. The results of such diversion would form an interesting problem, the exact solution of which the river itself (or an exact model) alone could work out. But in general the double Fulta concave would still exist and would exercise a still more confusing effect than now. The ebb then, as well as the flood, would cross to the west bank, but too high up to help the tracks into the western gut. The present navigable tracks over the Ninan and James-and-Mary bars, by the eastern route, would deteriorate in depth and there would be no surety that new ones, carrying even similar depths, would open into the waters of the western gut, much less could there be assured better conditions of navigation.

The whole trough of the river—from the lower end of Fisherman's Reach to Diamond Harbour—is full of irregularities, which mark the struggles of the waters and the sands. These irregularities the mere diversion of the Damudar would not change, hence numerous collateral works would be required for regularisation. On account of the inherent impossibilities of abolishing the eastern gut, these must remain inevitably of a problematic or academic character.

Nothing is to be gained by diverting the tributaries, except in a project to open to navigation the western, and close the eastern gut.

A Damudar diversion canal and dam, and the collateral works in the Hoogli, would be very expensive, and the latter would be during execution an insufferable obstruction to navigation.

These measures become much more prohibitive when we come to consider the diversion of the Rupnarain and Damudar into the Haldia. Questions, obviously very serious, arise, relating to the cost and location of diversion canals, tidal propagation, effects on present channels and navigation, acquirement of lands, the results to local drainage, irrigation, cultivation and trade, the character and position of the necessary dams and regularisation works; and to the time, methods, and expense of execution. The preliminary examination discloses a probable cost in great excess of the sums available and compels the elimination from serious consideration of these suggested diversions of the tributaries, or any radical interference with them.

Diversion of Hoogli.

The Brooks Project (which is illustrated on the comparative Chart) may be classed as a diversion of the Hoogli. Its factors are a cut-off canal of small dimensions back of Hoogli Point, and a jetty out from the west bank, whose purpose would be to deflect the down current into this cut-off canal, and thus cause an enlargement to the dimensions of a new river bed. By reason of its easier bend, this, it is claimed, would effect the needed improvement.

It assumes that the river would take the cut-off course and enlarge the cutting. But there can be no certainty of this, without the entire closing of both the western and eastern guts—an enterprise impracticable, from executive, commercial and financial considerations.

Its line of thought, therefore, needs no detailed discussion; besides which, the project does not deal at all with the conditions around Fultá Point and the mouth of the Damudar and Rupnarain, and the Ninan Bar.

CLASS 4.

Those advocating the construction of submerged dykes, jetties, or training walls, and reliance on natural scour after such regulation to erode deeper channels.

The subject has now brought itself to the serious reports and projects (some of which occupied attention three decades ago), and to the consideration of other means, to render the western a deep, safe, navigable route.

The improvement of the Moyapur, Ninan, and James-and-Mary Bars is recognised as a necessity in all the projects.

The betterment of the Royapur may become soon desirable, as vessels of deeper draught will seek Calcutta, when the other bars are ameliorated.

The writer's projects in addition comprise in the estuary the ultimate use of a powerful dredging plant constructed for employment above Hoogli Point, the normalising of the expansions and contractions of the bed of the Hoogli, the abolition of the difficulties at Fulta Point, and the consideration of measures to minimize the irregularities of tidal propagation.

I.

Projects to make the western gut the navigable channel.

Under I. again are several sub-heads :—

(*a*) Directive and concentrative work in mid-river on the Muckraputty Sands to improve the Ninan and James-and-Mary Bar depths.

(*b*) Directive works :—Long or short spurs or walls to low or half-tide, connected to the shore on one or both sides of the river at Moyapur, Royapur and Fulta Point, and having a current directive position.

(*c*) Changing mouth of Damudar so as to allow an ebb cross-over at Fulta Point.

A.

Mid-River Works.

The plan of the isolated construction in mid-river on the Muckraputty Sands, has not been available for inspection, and local traditions do not enable one to know whether it was designed to be transverse or longtudinal. This uncertainty, and the fact that the proposer did not have the opportunity to inspect the situation nor to give it intimate study, compels one to pass with regret his unusual and interesting suggestions of thirty-five years ago. If such a work were transverse, it could aim manifestly at the James-and-Mary Bar only, and could have no effect upon the Ninan Bar and Fulta Point concaves. If it were found to be longitudinal, and to extend from the Ninan to the lower end of the Muckraputty Sands, its alignment could theoretically be such that the work would, by its concentrative and directive action, cause the partial eroding of the Ninan Bar or the western gut tracks. It certainly does not essay to block the eastern and navigable channels as do those in class B following.

But the possibility of beneficial effect at the lower end of this isolated work is not so clear. A simple longitudinal work hardly affords scope for a safe concentration across the James-and-Mary Bar. An artificial island or loop, wide at its lower end, might conceivably in theory unite the functions of a transverse and longitudinal work and produce a measure of beneficial effect at both ends. It would thus occupy the site of the Muckraputty quicksands, of unfathomed depth, in the centre of the whirling waters of Hoogli Point. In such form it might increase the velocity of the ascending and descending tides, already sufficiently violent.

To the wreck of the "City of Canterbury" has been credited a better bar than existed before this memorable disaster. The wreck, though all but engulfed in these treacherous sands, is in its position analogous to a transverse work.

The design, the location, the proper material and plan, and method of construction, the cost, the effects and efficacy of the works that lie within the realm of this suggestion (which has a special value from the distinguished successes of its author) are worthy of attentive study by whatever commission shall some day be charged with an exhaustive and authoritative review of all alternatives offered for the Hoogli's improvement.

B.

Submerged Training Works.

The more one has to do with water, the more he respects it; the closer one lives to its moods and methods, the more insistently he will avoid crossing them, and, if set the task of mastery, guide always, but rarely and cautiously try to compel, even in a small river. But the several projectors under this division (illustrated on the comparative chart annexed) all appear to conceive the realisation of academical ideals by measures of drastic compulsion in opposition to currents of tremendous power. The Leonard measures were comparatively moderate, though on such parts as found practical expression the river has long ago visited the chastisement of obliteration.

His were:—

1st. Directive works consisting of spurs, or projecting training walls on both sides of the river at the Moyapur and Royapur, as indicated on the comparative plan.

2nd. The reduction of the expansion at the mouth of the Damudar in the manner shown on the plate (disclosing on the part of Leonard an apprehension of the situation here, which is not reflected in the analogous project).

3rd. A training wall from Fulta Point down stream—half way to Hoogli Point—with a view to diverting the ebb into the western gut.

4th. The contraction of the mouth of the Rupnarain—a measure absent also from the kindred project under this heading, and aimed at improving the propagation of the tides referred to under Class C.

The spurs run out from the banks at the Moyapur crossing were tried and found wanting. They failed to accomplish the result sought—the erosion of the bar—and have vanished.

They were an impressive and sufficient lesson to the guardians of this waterway, of the truth of the principle, that in this river, out from its concave banks—projecting beyond the low tide line into the fields of live and powerful erosive currents, which have secured its concave troughs—no works should be placed.

This is not to say that the banks shall not be protected from erosion by rip-rapping or rectified by longitudinal training walls, near or above the average low tide line. Such precautions are feasible and desirable, and in common use elsewhere. It is one thing (and ordinarily a safe and wise thing) to have erosion-preventing works along a natural concave bank. But it is wholly another matter to put a concave training wall, of whatever construction, into and across the concave trough of a river, subject to twenty-one foot tides, bores and freshets—having a demonstrated ability to scour to a depth of 75 to 100 feet, and having currents with a recorded velocity of six, seven, and even eight knots per hour. Yet this is just what was first proposed in 1864, and revived in the project of December, 1896. It constitutes a necessary feature of these western gut projects.

Primary Tests.

Engineering remedies must not violate the fundamental, the elementary principle of the art of improving commercial waterways, *i.e.*, they must first of all, be possible—possible technically, executively, and financially.

But these measures (Plate II.) attempt deflections and ulterior contractions without reference to freshet and tidal *régime*, and inevitable effects. Tried by practical principles, the position of the recommended works is obviously without reference to the possibilities of execution and maintenance. At the Moyapur, the latter one essays to invade a concave eroded trough for over a mile. Below Fulta Point they would both cross and close the Ninan concave and the navigated tracks, and the latter one traverses for four miles the Muckraputty whirlpool sands. Such a work to be finished must be begun—begun at the ends, middle, or bottom. If it is begun at Fulta Point or at Hoogli Point, the navigated course is first to be rendered hazardous by plant, craft, and false work, and then to be blocked. If the middle section along the Muckraputty sands is first put in, the procedure merely postpones the projected closing of the navigated route to a period when the difficulties of so doing will be enhanced by the rush of water through the gap. The tides unaided are not to be relied on to erode the millions of cubic yards necessary to open up a deep channel from Fulta Point into the western gut simultaneously with the closing of the eastern pass to shipping. Such wholesale work must be put upon the freshet, and a freshet time would hardly be a gap closing season. During the period of attempted construction, no idea even of an alternative route is presented, for the vast and already enough hampered commerce of Bengal. It is not shown, nor can it be, how traffic can negotiate the eastern channels, barred by mattresses, piles and brickwork, blocks and barges. The mattress or wall placing methods employed at the mouths of the Columbia, Mississippi, and Danube, at Tampico, Galveston, or anywhere else, afford no clue for a demonstration on the Hoogli that two bodies can occupy the same space at the same time. The western approach is to navigation a blind, sand-barred passage, and in the best view would remain so for several years. A construction blockade of unknowable duration could not but occur. An indefinite, but long cessation of Calcutta commerce would ensue. Attacked by deep scouring currents, founded upon an unstable bed, of concave alignment, and in a position which provokes erosion, the narrow wall, as planned, could not stand to be built, much less afterwards endure topping by tides, bores, and freshets, and the pressure and destructive action of attacking velocities.

Finally, financially it could not be, as planned in December, 1896, built and made to stay, for the original estimate or even for several times that amount.

This remedy is, therefore, impossible from all the standpoints, technical, executive, commercial and financial, as well as from that of durability.

C.

Possibility of utilising Western Gut by changing Mouth of the Damudar.

The above alternative is one considered by the writer when first examining and analysing the subject. The elements of a project under this head would be:—

1st. Removal of the Damudar outlet to head of western gut by means of training walls.

2nd. Excavation of the west bank of the Hoogli to form a new west bank for the Damudar below its present mouth.

3rd. Rounding off of Fulta Point.

Under such a scheme, the last two items are essentially feasible. But the first, the training wall, forming the east bank of the Damudar, and the west side of the Hoogli, would present concave flanks to the ebb of both streams. For if the Damudar mouth is moved, the ebb tide axis will cross to the west side, just below Fulta Point, cross on the west bank, and re-cross to the east side, spilling partly into the western gut. On the contrary, if we follow the flood, its axis will cross from the head of the western gut at the new outlet of the Damudar to the Ninan concave, thence from Fulta Point to the west bank, and then up Fisherman's Reach.

Because of the peculiar topography, the ebb and flood would have no common channel from Hoogli Point to the Reach any more than now. The *régime* would not be bettered, the eastern gut tracks across the Ninan and James-and-Mary would deteriorate, and the tracks of the western route would not improve enough to be as deep as those on the other side. In the assumption that the walls could be built, and stay, harm and not good to navigable depths would probably result, even if a considerable amount of the ebb spilled into the western gut. Hence this alternative is too problematic to be reçommended.

There are no other saving means to get the ebb, or any larger part of it, to cross to the west side. The idea of obtaining a common main ebb and flood channel through the western gut must, however reluctantly, be decisively abandoned.

IMPROVEMENT OF TIDAL PROPAGATION.

Is it feasible so to regulate the tidal regime of the Damudar and Rupnarain, that the action of the Hoogli will be sufficiently bettered?

The less the volume of tidal fluctuation of these rivers, the more unhampered will the tide propagate in the Hoogli.

Either might be temporarily throttled—the Damudar even closed; but the tidal rise is so great that an increased difference in levels would cause such velocities at the Rupnarain gorge, that the waters would restore the section in a short time by scouring vertically. This, in turn, would destroy inevitably the contraction works.

Leonard sought some promise in this direction, and shows spurs at the outlet of the Rupnarain. But no one since has had the temerity to advocate such a struggle with this stream. Successful contraction works are hardly possible in so short a throat.

There are no surveys to disclose the areas and depths of the Rupnarain basin. But it is shallow—only a few feet deep at low tide.

If through the lake a new bank were built with piles, fascines, and dredgings, so as to establish a normal tidal river width, two alternative methods would become possible of governing the indraft and discharge of the Rupnarain.

1st. The abnormal tidal volume required to fill and empty the basin might be eliminated by a continuous septum. But this would radically diminish the volume available for scour in the estuary.

2nd. The opening into the new basin—lying, say, south of the new bank—could be made at the upper end some miles from the mouth, and a different tidal *régime* might be thus set up in the Rupnarain, and also for the Hoogli.

The technical and financial possibilities that lie within the province of this idea could only be fully developed after a careful survey, with tidal observations and computations supplemented perhaps by an accurate working model.

The writer believes it would be concluded that the abstraction of a large part of the tidal prism, would entail collateral work of unknown expense and extent below Diamond Harbour, even if the Rupnarain were normalised. But possibly either palliative is one that might aid the regularisation of the Upper Hoogli. They offer ways for bettering the tidal propagation of the Hoogli, and for adding, perhaps, to the depth over the James-and-Mary bar, and rendering most stable that anticipated by the main project advanced and supported by the writer. Either treatment would modify the action of the tides, the first much more than the second. The power of the flood to advance the Hoogli back sands would diminish, and the velocities up the western gut also. There are no other than these two ways to put a safe and durable brake upon the tidal velocities. The data, however, do not exist upon which to base a final judgment as to the amount of good which would ultimately result in either case, nor what would be the cost of the improvement.

The dredges employed to remove Fulta Point could readily construct a tide regulating bank through the Rupnarain Basin, if the physical conditions should be found as favourable as it seems natural to expect.

It is not believed that the diminution of the flood velocity into the Rupnarain will sufficiently improve the James-and-Mary bar. It will rather permit the abnormal depth of the western gut to silt up, and render the James-and-Mary track more stable, though still inadequate.

The remedy does not touch the Ninan bar, or the conditions at Fulta Point. Hence, it is but a supplement to the regulation of the widths and alignment of the Hoogli.

Four opinions may be entertained, after due consideration of the data collected. One, that such regularization should precede the Hoogli project; the second, that it should follow it; the third, that it should be done simultaneously; and the fourth, that it should be executed only after the main regulation is accomplished, and it is found necessary to provide for ships of still deeper draft than the largest now passing the Suez Canal. To the last the writer inclines, reserving, however, a conclusive opinion until after a survey of the Rupnarain Basin has been concluded and model experiments have been effected.

CLASS 5

EASTERN ROUTE.

Evolution of the Author's Project.

The foregoing eliminations have brought the matter to the consideration of the only remaining alternative—the Eastern Route.

Fundamental River Bed Factors.

The bed of a river is defined chiefly by six factors, and is the resultant of all the forces acting through it. It has:

1st. Length.
2nd. Breadth.—The low water, high water, and average.
3rd. Depth.—The least, extreme, and average.
4th. Alignment.—Consisting normally of a succession of curves, the concaves first on one side, then on the other, with occasional straight reaches between.
5th. Grade.
6th. Tributary Beds,—and their like factors.

The principal object sought by the Hoogli Improvement is increase of the least depths to a navigable standard. The change of any one of the other factors of the bed will modify depth.

The length of the river from Calcutta to the sea does not admit of material increase or decrease, consequently the depth, slope, and velocity cannot be favourably altered through this factor.

It has been seen that the navigable depth cannot be permanently altered by mechanical means alone, or safely increased by the spurs or training walls so far considered.

The grade, or general level of the district, cannot be altered.

The tributaries may not be diverted, nor their tidal or fresh water volumes affected without involving great direct expense, and indirect consequences of a serious nature to the estuary channels, and other interests.

There remains then, two factors capable of modification—width and alignment. Hope lies no other way. It is clear that if these factors of an alluvial bed are modified, the depth will be affected. If they are abnormal, the depths will be irregular.

Through these factors the cross sectional areas can be most naturally, cheaply and permanently normalized.

Normal Alignment and Widths.

A simple inspection of the accompanying maps will at once disclose the abnormalities of alignment. The principal ones are:—

1st. The double concave at Fulta Point.

2nd. The sharp bend at Hoogli Point.

The first can be reduced by the excision of Fulta Point. The second cannot be done away with, though safe measures are feasible to give better direction to the ebb and flood, and to so serve an important and useful purpose. There are minor irregularities at different stages, often occasioning effects disproportioned to their apparent size. These are easily remedied. The range of tide and freshet is so great that a correct high as well as low water alignment is desirable.

The abnormalities of the Hoogli bed are readily disclosed graphically. Curves derived from such a presentation are shown on Plan No. III. accompanying. The low and high tide widths are platted. From a selection of normal widths the natural apparent lines of gradual expansion are deduced and drawn from Buj-Buj to the Damudar, and thence to Diamond Harbour, with allowance for the tributaries.

The high and low tide sectional curves show the Hoogli to be a succession of contractions and expansions.

The diagram automatically diagnoses the trouble at the Moyapur and Royapur Crossings. It discloses that the low tide widths are here excessive, and points the remedy. It reveals the contraction at Fulta Point. It lays bare the expansions at the Buj-Buj, Achipur, Hiragunj and Brul Sands, Damudar mouth, and at and below Hoogli Point. Where the river has a normal width it presents the best condition for safe navigation.

Results of Abnormal Conditions.

It is unquestionably wisest to have a generally uniform velocity of flow in a river. This is the condition of the least bar-forming disposition. An expansion causes a bar to form, because the velocity is reduced, and a portion of the water-borne silt is deposited. A marked contraction or deflection causes the erosion of undue depths. An undue low-tide width at crossings results in bars.

Ratios of Expansion.

Given a uniform velocity and a stable depth, in a straight reach of a tidal river the width must gradually expand by a ratio per unit of length. At a given station a certain width passes the tidal volumes of the river above, and at a station below the width must be proportioned to pass the first volume; plus that of the tidal prism between the stations. Again, according to the ratios of expansion employed, one can vary the depth, or the velocity. When a tributary comes in, its tidal volumes must be cared for in the regulated bed. The factors of the tributary beds are vital to considerations of tidal propagation.

From a small scale survey of the river one can graphically approximate the natural ratio, by selecting a number of normal sections, and striking average lines on either side. Close computations and observations are necessary to establish the best ratio, with reference to curvature and the depth sought, and to make a final location of the lines of rectification. Consequently it is prudent to make the reservations the writer made in putting out the preliminary project. But it is assuredly true that no material departure in principle from the lines shown is practicable on the Hoogli.

The alignment of the projects recommended is simply translated from the diagram to the actual river, having regard for its present curvature and an abiding respect for its erosive fields.

Guiding Factors.

The writer's conceptions of the subject have led him to a preference for a treatment which makes no possible struggle with these mighty waters and engulfing sands, which enlists the co-operation of the currents, and which, from beginning to end of the work, does not employ a craft of any kind in the navigated tracks to interfere with shipping.

Nothing should go into the deep water of this river on its concave side. Erosion of concave banks should be prevented or arrested, and the proper width should be secured at expansions by training banks placed where natural forces work for maintenance and not destruction. This is on the convex side. The excision of Fulta Point reduces two concaves to one and also abolishes a constriction. The long single concave will also inevitably carry both the ebb and freshet volumes past Hoogli Point and across the James-and-Mary Bar, after abolishing the difficult navigation at Fulta Point and the Ninan Bar.

To perfect the river bed at the Moyapur and Royapur Crossings, it is necessary to bring the high water width to at least the present low tide width. This is a measure which must be led up to gradually. The treatment must begin by normalizing the expansions at Achipur, Hiragunj and Brul Sands, not necessarily by reclamations, as has erroneously been surmised was the purpose, but by new banks or walls.

Difference between Reclamation, Training Banks and Training Walls.

A distinction has here to be drawn between reclamations, new banks, and training walls.

Reclamations at the great expansions of the Hoogli involve vast quantities, would inadvisedly reduce the tidal prism, and are unnecessarily expensive measures. Training walls to low or half tide, swept over by freshets and tides, to be stable must employ great quantities of piles, fascines, rock or burnt brick. Rock is scarce and expensive. Low, quarter, or half tide walls are usually dictated by motives of economy. They are admissible in rivers whose currents are moderate, and whose tidal fluctuations are not excessive and whose freshets are of but short duration. The Hoogli is not such a paragon. It is not a Weser or a Scheldt.

It is not possible to concur in the idea that a low training wall is everywhere better than a high training bank for the regularization of a river, when by skill under local conditions one is able to construct the latter for the same or less expense per lineal foot, and without diminution of the tidal prism, and besides normalize the cross-sections, by well directed dredging.

One is not able to subscribe unreservedly to the advocacy of low training walls, where suitable material does not exist to insure stability, where tidal currents are notoriously violent, and where for months a high water freshet *régime* dominates the situation. Silt-laden freshets might use low training walls on the Hoogli to make such a series of new bars immediately below, that a year's work of the usual tidal currents would not suffice to erode them before another silt-laden freshet came.

In the Hoogli, with nearly the same water-level on either side, a training bank on the convex side (rapidly, easily and cheaply constructed by an hydraulic dredge) with a wide base in combination with a structure of piles and fascines, and carried to a safe height above high water, affords the ideal local measure for regulating the width and alignment. A suitably placed opening will admit and discharge the tide if wished. It is to be stated, however, that an increase of the tidal volume will be provocative of increased velocities, while any radical diminution of the tidal prism is to be deprecated. The Fulta Point excision would add, if the enclosed areas on the convex side are tidal, nearly 600,000,000 cubic feet to the Hoogli's tidal volume. These areas may be made to act as reservoirs to scour the Eastern Channel, if deemed desirable, by the adoption of low training walls, if after practical trial such a structure will be found appropriate for Hoogli conditions. By use of hydraulic dredges, moreover, low walls may be converted into high training banks, if it is demonstrated that low ones are unsuitable technically, or comparatively too expensive to build and maintain. In view of the Fulta Point tidal volume created, the writer regards the silting up of the areas behind the training walls or banks as not vital to the navigable depths sought. If, with the excision of Fulta Point (and the regulation of the Rupnarain, which surveys and model experiments may demonstrate to be desirable), it be found that low walls or shorter walls are cheaper and will serve all the needs of navigation, they should be adopted in the interests of economy.

Rectification.

From Calcutta to the Damudar no tributaries enter. The ratio of width expansion of the rectified banks will be affected chiefly by centrifugal force, which varies with the radii of the curves. If for preliminary purposes, this varying force is omitted from the calculation, the ratio would be practically unchanged from, say Buj-Buj Sands (top of map) to the mouth of the Damudar.

Below this place the ratio must reflect the accession of the contributory waters of the Damudar and Rupnarain. The approximate natural average lines of expansion laid down on the diagram showing the shape of the normal river bed reveal the abnormal departures.

The amount of the abnormal departure which can be tolerated varies with the navigable depth sought. The greater the depth desired, the less abnormal the width or sectional areas can be permitted to remain. The measures of correction to secure 16 feet of water are not the same, but less than those which would be required for 20 feet. This is particularly true at the Moyapur and Royapur, where the diagram discloses that there are large expansions above and below and that the low tide widths at the crossings are too great. The low tide lines opposite these bars should be the high tide line. Were this so, the 18 feet contours of the concave troughs would merge, and the bars disappear, so far as navigation to that depth is concerned, providing that the expansion either side were reduced to normal widths.

The Feasible Solution.

As it has been demonstrated that the Western route is practically impossible it is necessary to examine the eastern or present channel, and apply to it the same searching tests of possibilities. Having ascertained the normal river widths, they are transferred to the actual river. The alignment should respectfully abstain from any serious invasion of the erosive fields of the concaves, and throw the regulation for the reduction of expansions on to the convex side, where such works will stand, if not topped by freshets and tide.

The left bank line is projected to cut away Fulta Point, reducing its double concave to one. It is carried thence around Hoogli Point, having regard to the guiding principle of normalizing the width so far as possible, without invading the erosive field. Such a course is tranquilizing, not combative. When this line is carried around Hoogli Point, it does not contract the mouth of the Hoogli, but merely reduces the abnormal expansion below. It also fortuitously carries the ebb tide point of spill far enough to move the James-and-Mary Bar into the powerful erosive field of the main river. It also directs the flood upon the same duty, with no needed change of the angle at which the Hoogli waters join those of the Rupnarain. Pilots and ships would not here modify their present procedure, going up or down.

When an expansion is normalized by a training bank on the convex side, the ebb and freshet do not impinge with undue power on the concave bank. The radii of the curves are unchanged. A greater volume passing over the normalized bed will erode a bottom stratum, whose end area, with that of the section dredged to make the bank, will compensate for the end area of the excluded section. The flood tide will necessarily cease tending to make channels back of the sands at Fulta, Brul, Harigunj and Achipur and will follow the axis of the ebb; nor is it to be feared that it will attack concave banks which have resisted the combined attacks of the fresh water discharge and the ebb, and of annual freshets.

When the expansions either side are normalized, flood, ebb and freshet currents must approach crossings such as the Moyapur and Royapur along nearly common tracks, and therefore the least depths at the crossings will be increased, because all currents act in harmony and the water is not permitted to dissipate its scouring power.

When the Fulta Point contraction is remedied (a single concave being substituted for the present double one), when the expansions opposite on either side of the mouth of the Damudar are normalized, a condition will be created which must produce far-reaching effects.

1st. It is perfectly clear to the navigator that when the Point no longer exists the present hazards of doubling it going up or down must vanish.

2nd It is conceded by even the most adverse criticism that the Ninan Bar will inevitably be abolished. It cannot be otherwise because within the long single concave the undiverted ebb and freshet currents of the Hoogli and the Damudar will have been brought to compass its obliteration at the same moment that the causes of its formation have been forever swept away.

3rd. The volume of this bar removing flow is composed of the following elements:—

- (*a*) The tidal prism of the Hoogli above the normal section A-B (see chart and cross section plan).
- (*b*) The tidal prism of the Hoogli between A-B and the Ninan Bar section E-F.
- (*c*) The tidal prism of the Damudar river.
- (*d*) The tidal prism of the convex basins which may be utilized to increase, if desired, the present tidal volume by 600,000,000 cubic feet, or to the extent of 1,000,000 cubic feet per minute, equal to a stream 520 feet wide 18 feet deep and flowing two miles per hour each flood and ebb. These basins will very gradually silt up.

(*e*) The fresh water discharge of the Hoogli river.
(*f*) The fresh water discharge of the Damudar river.

To show graphically the effect which will be produced upon the Ninan Bar, the normal section A-B, which contains only the elements "a" and "f" of the foregoing analysis, may be superimposed on the Ninan section E-F (Plate IV.). This discloses that, without counting the other elements "b," "c," "d," "e," the width of the new channel under the single concave must be not less than 1550' between the 18 foot contours, 1080' between the 20 foot curves, and 800' at the 30 foot plane, and the greatest depth cannot be less than 37 feet.

Obviously the volumes of the elements "b," "c," "d," "e," which are very large, come also within the laws of hydraulics and the dominion of the single concave. Therefore the channel can be really made much wider and deeper than the normal one at A-B.

The volume of the normal section A-B plus all the other elements, following the continuous concave, must vanquish and pass the site of the Ninan Bar.

Erosive Effects below the Ninan Bar.

To obtain a graphic expression of what the volume of the normal section A-B alone must do further down stream, its waters being still within the control of the single concave and undivertable, this section may be imposed on a section G-H taken when the ebb tide now begins to spill around Hoogli Point.

Such a diagram shows the erosive ability of the volumes "a," and "f." The real effect of all the elements must be more. Comparing the normal section A-B with that of the present eastern gut, it is noted that the end area below the eighteen foot plane in the first is nearly three times greater than in the second. A contention, therefore, that the eastern gut now carries all the ebb is manifestly without basis.

Below the Ninan the ebb to maintain a bettered channel has work to do. The flood tide continuing to cross from the western gut to the concave opposite Shipgang Point, which is unchanged by the project will pour sand into the flank then as now. But as the ebb now carries off this same daily contribution, when reinforced it will certainly not fail to do so.

The Muckraputty Sands split the river, and the widening and deepening of the eastern gut necessitates the erosion of the eastern side of this deposit, and the removal longitudinally of the eroded sand. This action will be best secured when the annual freshet dominates the tides. Then, when the Fulta cut is opened, the concave being unyielding, the river's erosive power and sand carrying capacity greatest, the freshet will perform the work of erosion desired so thoroughly that from Fisherman's Reach to

Hoogli Point the recurring tides will find a self-maintainable, broad and unvexed channel, the making of which has not interfered for a moment with navigation. It is beyond question that the freshet will carry a wider and a deeper channel than that of the section A-B, to the present point of spill G-H, and that the tides undiverted by Fulta Point will occupy and defend its enlarged, dredge and freshet-made channel.

The James-and-Mary Bar.

The crest line of this famous bar may be likened to a butcher's hook. The Muckraputty Sands form the shank. The left hook bars the ebb and the eastern gut, the right hook bars the flood tide and the western gut and approach. The tracks across the eastern hook are the navigated paths. It is very rarely that a deep track opens up through the western crest.

It is easier to make a good thing better than to make a bad thing good. Previous projects have all essayed to make the bad route best by blocking straightway the only usable course, without a line of care for the travail of the shipping of Calcutta.

Is it not a more reasonable procedure to better what is, when such can be done without interference with that sensitive organism —commerce ?

By the removal of the Fulta Point and the advancing of the Damudar Bank, there will have been brought past Ninan to the point of spill around Hoogli Point, the volumes of the elements heretofore referred to by the letters "a," "b," "c," "d," "e," together with "g," the latter being the tidal volume between the Ninan and Hoogli Point, less those portions of each which flow over the Muckraputty Sands and through the western gut into the main river. The action and behaviour of the water along the navigated tracks at and below the Point may be determined with certainty by graphic analysis and confirmed by a working model.

It is to be noted first that just below the point the Hoogli has an under width. To remedy this the long single concave is merged into a tangent which curves to the left in 6 feet of water south of the point and joins the left bank. The angle at which the Hoogli and Rupnarain waters join is not to be changed by this tangent.

The effect of this tangent prolongation is to carry the point of spill south of the present one. Consequently the deep contours of the ebb channel can not begin to run out until the new turning point is reached and passed.

The end area of the present ebb spill conserved is shown by the triangle on section I-J-K (Plate III.) measuring 12,180 square feet at high tide. It constitutes obviously a valuable factor. Manifestly also the bank J-S would lead the flood tide to move its pool A further out.

In analysing the behaviour of the down stream currents one may allow that only the volume of the normal section is to be brought to the new point of spill where the 18', 24', and 30' contours are respectively 1,550, 1,030, and 800 feet apart and 37 feet maximum depth. Cross section I-J-K is taken through the new Hoogli Point.

The normal section is carried full to this place 1,950 feet beyond the previous point of spill. When imposed on section I-J-K it shows the erosion which must transpire on the east side of the Muckraputty Sands, also the enhanced volume, depth and width of the scouring tide. Below the 18 foot plane the present end area is but 1,950 square feet, while the new channel will measure at least 18,250 square feet.

Run-Out of Contours below Point of Spill.

An inspection shows that when depths begin to run out they do so at the rate of about 1 to 100 in the eastern gut. At this section, I-J-K, of the present channel both the 24' and 30' contours have run out, and the area below 18' has run down to 1,950 square feet, which disappears 300 feet further out. If a similar rate of run-out is allowed for the new contours (a very conservative allowance when the greater volumes are considered) then 18,250 feet will run down to 13,800' in 1,950 feet, and 13,800 feet will run down to 11,850' in 800 feet more. Thus there must be 11,850 square feet of end-area 2,750 feet beyond the new point which is below the 18 feet plane.

But no such distance is needed to obliterate the James-and-Mary bar so far as navigation is concerned.

Sketch No. 1 shows the new contours, and No. 2 shows those of the chart inspected.

On sketch No. 2 is noted the axis of the bar and the line of growth of the flood-borne sand of the back of Hoogli from B toward B'.

On sketch No. 1 this axis instead of running along the bar crest is shown to meet an 18 foot channel 2,500 feet wide and a 24 foot channel 900 feet wide and 30 feet deep in the centre.

Hence when the growing spit B (as a result of flood tide action in the low water season) seeks to encroach on the navigable channel it must meet the ebb of the dimensions quoted.

In order to illustrate this a section is shown along the crest line D-B' using for soundings the published depths of January 30th, 1899, in the various tracks. On this section the contours of sketch No. 1 are platted, also, a line showing an extra bad bar condition (7 to 8 feet).

This section is along the line of growth of the split B when pushed forward by the flood and discloses the difficulty it must experience to advance under the new conditions.

The Hoogli ebb sweeping past the new point will curve down stream further out than it now does, and the part which now spills into pool A will then impinge directly on spit B. As a result of the deposit of sand below the new points and the position of the wall J-S, pool A both in so far as it is made by flood and ebb, must move out to some position A′. Whatever distance south it moves it will by the same amount reduce spit B, and will obliterate it altogether when it moves 500 feet, which it should certainly do. Such results by the expected movement of pool A are not vital but deserving of consideration, as showing how the new conditions all work to defend the new fairway against such attacks as now raise the crest of the eastern hook of the James-and-Mary bar during the low water season.

The navigable fairway thus created may be from 1,500 to 2,000 feet wide and in the deepest part should be 23 to 24 feet deep at low tide.

In another view, the present tracks into the eastern gut are exposed on the flank from P to P′, a distance of 4,450 feet to the deposits of the flood. The exposed flank of the new fairway is but 2,500 feet long and the new channel has much more self-protecting power owing to its greater width, depth and volume.

The crest of what is left of the James-and-Mary bar must then be 600 to 700 feet further out than now. This is demonstrated by the longitudinal profile which shows how, beginning at the present commencement point of spill, the contours of the present gut run out, also the long exposed flank over which the flood may carry sand to be picked up by the ebb in part and dropped on the spit and bar. It indicates the erosion due to the new channel whose contours can not begin to run out until the new point is passed. What sand the flood tide spills over the shortened flank would be then promptly carried within the powerful field of the main channel currents and hurried away. The new crest will doubtless fluctuate, but its limits will be from -18 to -30 instead of from -7 to -18 and the fairway will be wide. The margin for navigation is so large that the new point may be considerably rounded. The propagation of the tide around the corner will then be easier.

While the major portion of the flood tide due to its direction, momentum, and the indraft of the Rupnarain Basin will take the western gut, it is certain that a larger amount than now will go up the eastern gut, and this too will be beneficial. It is fortunate that the Rupnarain comes in just at the place it does to prevent any undue impinging on the south bank at Gowanhalli.

The conclusion of this synopsis of a graphic analysis is that as a result of all the forces and the new conditions the James-and-Mary Bar, as a menace to an 18 foot channel will cease to exist at the entrance to the Eastern Channel, though the "James-and-Mary" at the upper end of the sands will bar probably more effectually than now the western gut.

Execution.

The execution of the works concerned in this project has only become possible economically by the development by the writer of the powerful hydraulic suction and distance-discharging dredges now available. By this system the maximum effective horse-power can be concentrated upon a given work at the minimum outlay of time and labour. The large dredge plant recently designed and built by the writer for the Russian Government has a recorded capacity of from 4,000 cubic yards per hour when handling blue clay at St. Petersburg, to 9,000 cubic yards per hour of light sand near Antwerp.

The cutting away of Fulta Point involves the removal of a triangular piece of country, measuring about three miles on the base and three-fourths of a mile deep at the point. This can be best done by dredges, which would be specially designed for the purpose.

Procedure at Fulta and Hoogli Points.

The method of procedure would be to acquire the land shown on the chart, together with a rectangle of the same length and width as the triangle to be cut away, and, consequently of double the area. The total amount of land required would be about 2,000 acres.

An embankment being first thrown up by native labour around the whole area, which is generally below high water of spring tides, water would be admitted from the river and also pumped on it by the dredges, which would then, working inside, excavate the triangular portion, depositing the material dredged on the rectangle prepared for the purpose.

A shell would be left until the last, which would be removed at a favourable opportunity in the freshet season after Hoogli Point had been extended southward. A channel at least six or seven hundred feet wide would at once be opened under the new concave banks similar in section to the normal one A-B in Fisherman's Reach. The rest of the wall of earth defining the old Fulta Point would be subsequently removed as by the advance of the training walls on the opposite bank the normal width of the river was effected.

The dredge plant could always work inside the Fulta shell and the various training banks, consequently their operations would not interfere with navgiation nor be impeded by the currents of the stream, however strong they might be.

Construction of Training Banks.

The approximate alignment is shown by a continuous line on either side of the river. Only such parts of this alignment need be the site of training banks as it is decided are requisite to obtain the benefits sought for navigation.

The Hoogli Point extension would advisedly be a reclamation.

The works either side the mouth of the Damudar would terminate at Dhaja and Shipgang Points, a length measuring with those defining the outlet of the Damudar, 36,600 feet

The section north of the Damudar mouth should be built before that on the south.

Moyapur Bar.

Referring to Plate III., the new banks at the Achipur and Hirangunj Sands should be divided into sections and constructed in the following order:—

Hirangunj Training Bank.

1st. The central section defined by a full line.

2nd. The section between No. 3 crossing marks and the upper end of the central section, would be best put in a third of the distance at a time, commencing at the lower end.

3rd. The lower section between Katakkali Hirapur Khal and Dukinpara Khal should be built in connection with a future Royapur bar improvement after the Brul sandbank had been completed.

Achipur Training Bank.

Subsequent to the execution of sections No. 1 and No. 2 of the Hirangunj bank, the Achipur should be constructed in two successive sections. If the upper section is made first it will render easier the putting in of the lower one.

Brul Training Bank.

The Royapur crossing will be benefited by the Hirangunj bank, because a larger volume of both flood and ebb and freshet will thereby be caused to flow through the tracks of the present crossing. The incident erosion will probably be sufficient for the needs of navigation. But the normalizing of the great expansion at the Brul Sands will be of sufficient benefit to justify the construction of the Brul Bank from the Royapur tide gauge site to Chungra Khal after the obstructions at Fulta, Ninan and Hoogli Point and the Moyapur have been removed.

Though the works required for the improvements of the Moyapur and Royapur crossings are of less magnitude than those prescribed for the removal of the Ninan and James-and-Mary bars, those near the Moyapur especially can hardly at once be made so complete in their effects. An inspection of the chart shows that the deep channels under the concave backs overlap each other, and the diagram shows that the low tide width is so great that it leaves room for the mid-river bar to form. The aim must be by the progressive construction of the sections of the Hirangunj and Achipur banks to bring the 18 feet contours closer and closer so that they may be made ultimately to coincide.

If before the proper low tide width is realized they do not make the deep channels quite join, they will yet reduce the dividing shoal to such a narrow width that a Fulta Point dredger can work on it along and not athwart the axis. In a single tide such plant as would be available could completely remove the dividing shoal, leaving a channel probably a thousand feet in width which would require for maintenance very little annual dredging.

The writer's proposals for the improvement of the approach to Calcutta may, therefore, finally be summarized as follows:—

1st. That a proper bank alignment and ratios of expansion be calculated and finally located and adopted in accordance with the principles enunciated and with the preliminary location sketched on the plans for,—

- (*a*) The Hoogli River from Calcutta to the Rupnarain River.
- (*b*) The Damudar River at its lower end.
- (*c*) The Rupnarain River from the mouth to the upper end of the basin (after survey and due consideration of data obtained).

2nd That Fulta Point be removed so that the resultant bank shall form a continuous concave from the vicinity of Fisherman's Point anchorage to Hoogli Point.
This excision shall include rectification of the banks near the focus leading mark of the James-and-Mary bank tracks. Excavated material is to be distributed on a tract adjacent to the point and indicated on Plate II.

3rd. That Hoogli Point be filled out to lines to be definitely established but substantially those indicated on plan.

4th That combined pile, fascine and earth embankments or walls of suitable design be constructed opposite Fulta Point, defining the outlet of the Damudar river and a new right bank to the Hoogli river adjacent thereto as indicated in the foregoing text.

5th That similar new works be constructed at the Achipur and Hirangunj Sands to be ultimately carried to a tapering connection with the concaves on either side of the Moyapur crossing as set forth.

6th. That a similar construction be made at the Brul Sands wherever it becomes desirable to improve the Royapur crossing and to normalize the Brul expansion.

7th. That all of the excavation, filling and embanking, except certain preparatory work performed by native labour, shall be done by a specially designed hydraulic dredging plant, the dredgers to be adapted also to work in the lower river below Diamond Harbour.

In sequence to the writer's visit, and report, the Calcutta Port Commissioners sent a delegation to Antwerp to witness the trials of the Russian Government machines ; a dredge ordered by them, and constructed by Sir Wm. G. Armstromg, Whitworth and Co., is *en route* to India, and a survey of the Rupnarain and model experiments are in progress.

MACQUARIE HARBOUR, TASMANIA, & PORT ARTHUR,

MANCHURIA.

Macquarie Harbour, Tasmania and Port Arthur, Manchuria, are respective types of commercial and naval harbours whose *régime* is practically undisturbed by river discharge.

At Macquarie, the area of the harbour is so great, the tidal prism so large, and though the tidal range is small, the tributary streams are masked. Port Arthur has but little water coming into it, but the basin has gradually silted from the detritus of the denuded hills. Both are entered by narrow channels. At Port Arthur there are no outer or inner crescent bars as at Macquarie. In the first instance, to perfect the harbour it is merely a question of removing up to 36,000,000 cubic meters of favourable alluvium. It has been the habit of engineers, viewing such propositions from the standpoint of the multiple-bucket dredge and barge system, or the self-contained hopper type of suction machine, to specify that all material excavated should be carried to sea, while it is certainly true that in dozens of ports and approaches, if the material had been used to reclaim low lands adjacent to towns, the value of the reclamations would have long ago written off the entire capital cost.

At Port Arthur, allowing ten per cent. of the average fill proposed for the compression of tidal flats (which will accord with the experience of the writer), the adjacent area will hold 24,000,000 cubic meters, when filled to an average grade of 21·5 feet above datum.

The dredging and depositing of this quantity to the grade mentioned is well within the economical powers of hydraulic dredging. There remains some 12,000,000 cubic meters which must be loaded into hoppers and dumped at sea. Instead of depositing 6,000,000 cubic meters on the flats and taking 30,000,000 to sea, it is (given a high-powered, special plant) quicker, cheaper, and more profitable to utilize the flats to their full capacity and take the minimum quantity on the long haul. The work of depositing on shore requires less plant and is a continuous operation. Such filled land can be readily drained and used. At certain times sea dumpage will have to be suspended, but work inside can continue night and day, at all seasons and in all weathers.

MACQUARIE HARBOUR.

Epitomized from Report to Tasmanian Government.

At Macquarie we have a condition which confronts the hampered commerce of a great mining district, whose magnificent deposits of shipping, as well as low grade ore, are diminished in available value because shipments must be sent out over an 8-foot bar to Melbourne and there transferred into deep-sea craft. If these ocean vessels could enter and depart from Macquarie Harbour, a freight saving would be effected justifying many times the outlay.

There has been under consideration a project which is shown upon the accompanying Plate VI. In analysing it one notes that for the amelioration of the outer bar it was proposed to build two converging breakwaters on the east and west sides of the entrance and to construct a supplemental training wall under the east head.

The Eastern breakwater was to overlap the Western. The conditions resulting from overlapping breakwaters are particularly noticeable at the approach to the similar harbour at Durban. Here the shorter has had to be extended out equal with the longer breakwater.

For the construction of the Eastern breakwater it was proposed to put in a temporary bridge and pile approach, across the navigable channel near Wellington Head. In the best view of the matter, this bridge must constitute a serious impediment to free intercourse for some years. Between the abutments the currents will run from two-and-a-half to five knots per hour, and a drawbridge with but 70 feet openings cannot fail under such conditions to be a menace to safe navigation.

For the deepening of the inner bar it was proposed to construct a training wall from Wellington Head easterly.

The scour was relied upon entirely for the removal of the outer bar. While it was intimated that dredging might be used on the inner bar, no allowance was made for it, thus placing all remedial reliance upon the scouring action of the currents, redirected by the inner wall. This is a doubtful reliance, not justified by numerous parallel cases.

It is a governing principle that it is best across the inner bar to make the ebb and flood currents move through a common channel. To obtain a channel 300 feet wide and 27 feet deep, the removal of 2,430,000 cubic yards is requisite; for one 20 feet deep, 1,080,000 cubic yards. If this labour be imposed upon the currents, these vast quantities must be carried in a longitudinal direction, if carried at all. The results of such a movement are hardly to be foreseen. That it will involve elements of risk is unquestionable. The truest safety lies in removing this material by methods which can direct its deposit and which may not constitute it an added hazard rather than a relief to navigation.

It is, however, easily possible, simultaneously with the construction of the inner training wall, to excavate the new channel by dredging, and deposit the material where it can by no possibility do harm.

No definite width and depth for the channel across the inner bar was put forward in the Report, recommending regulative works alone. It was to be left to some indefinite time for a channel to be scoured and the inner harbour and the outer ocean establish an equilibrium. What width and depth would thus be obtained was not stated. The great copper deposits of the Lyell district now require not a 20ft. waterway for the economical marketing of their product, but a channel whose depth admits ships passing the Suez Canal.

Convinced that dredging is indispensable for opening an adequate channel through the inner bar, the writer holds the opinion that the construction of this training wall and dredging should go hand in hand, in a plan which shall economise rock and time. Great as is the desirability of dredging this channel from the standpoint of a 20ft. channel proposed, it becomes vastly more so when the depths are contemplated which would best serve the interests of the port and mines.

Referring to the adoption of the jetty principle for the improvement of the outer bar, the writer's belief is that it is hardly quite safe to generalise that jetties are suitable to every port, and to this one in particular. At many of the places cited—notably at the Sulina mouth of the Danube, at the mouth of the Mississippi, at Galveston (Texas), and at other places—dredging has had to supplement the jetties in order to attain and maintain the depth required by modern ships. Galveston (Texas) offers something of a parallel to Macquarie Harbour, because of a similar tidal variation and area of inner basin. The harbour of Liverpool has been made accessible without breakwaters by dredging through the sandy estuary of the Mersey. Twenty years ago it was believed that New York could be made accessible to deep-draft ships by means only of a jetty system costing a million pounds or more, but after practical experiments in hydraulic dredging this expenditure was found entirely unnecessary; and at the last session of the United States Congress an appropriation was made and a contract has already been let to deepen Sandy Hook channels to 40ft. depth by dredging alone.

At Durban, South Africa, we have a notable illustration of the effect of jetties or piers under conditions not dissimilar to those of Macquarie. A steady seaward advance of the contours was observed as the pier heads advanced. A point has finally been reached at which reliance is placed almost entirely upon dredging. Sir Charles Hartley and Sir John Wolfe-Barry, after a profound investigation, decided that the principal hope of relief was to be expected from dredging, and the Natal Government has provided itself with a very powerful fleet, which has demonstrated satisfactorily its ability to cope with a situation, without which a vastly different complexion might have been given to recent affairs in South Africa.

It is to be noted at Macquarie that there is an outlying shoal in a line with the proposed approach. If, as is altogether likely (and as took place at Durban), a new bar were to form in front of the new entrance, it would be aggravated by this shoal, and the evil would accrue beyond the protection afforded by Point Sorrell. Relief by dredging or by a future extension of the breakwaters would, in view of the heavy seas in these Roaring Forties become very problematical. It is now an established principle of the hydraulics of such bars that a deep-water channel placed in such direction that the flood and ebb currents act in harmony, if the depth be made sufficient, it will be nearly permanent and will maintain its width and depth until there is a departure from the ordinary *régime*, which would be due in this case to very prolonged and violent gales from the exposed quadrant.

Another cause of shoaling in such a channel is littoral drift, due to winds and tides. This is not wholly preventable, but it is observed that such drift will not extend far below water lines, and that the sand-moving energy of littoral currents will be smaller the greater the depth of the channel made, while the large tidal volume oscillating in and out of such a harbour will be sufficient for removing the material which shall enter through the agency of waves or tides, with the assistance of moderate dredging annually.

Analyzing the Macquarie project as a dredging proposition, it becomes evident that a dredge plant must be designed and proportioned to:

1st. Maintain and improve present navigation facilities.
2nd. Excavate within the adopted lines of ultimate alignment, systematically enlarging the waterway across the outer and inner bars.
3rd. Remove deposits so rapidly as to securely safeguard the possession of an open port.
4th. Work simultaneously or in proper sequence at both bars and thus progressively realize the deep-water channel.

Work at the inner bar requires a plant able to put the material over the bank or distribute it on the shallows at a sufficient distance from the channel and in such manner as to prevent its return.

Work on the outer bar requires that the plant be designed to load its own hoppers and proceed to deposit at sea; or to make such smooth water belt distribution through pipe pontoons, or rough water distribution in belts without pontoons.

The work of removing gale deposits requires that the plant shall be able to discharge wing and wing—that is, to either side—reopening the navigable way along the range lines, under conditions that secure the maximum output and sufficient side distribution. Such a combined design is shown upon Plate VII. In order that there may be the greatest insurance against accidents or breakdown of plant, two dredges of this type are contemplated. It is understood, of course, that spoil temporarily thrown into side deposit belts will later be rehandled, should this prove necessary.

Material excavated from the outer bar may be disposed of when the dredging is in progress in one of three different ways, according to ruling circumstances:

1st. It may be loaded into self-contained hoppers and carried out to sea.

2nd. It may be distributed by a pipe line on either side of the cutting, or into deep water either side of the bar.

3rd. It may be discharged directly from the dredge at water level to each side, when a strong ebb is running, so as to be carried out to sea.

The first is the normal way of working. The second is one which can be employed only when the sea is smooth. The third is one which may be used in case of emergency, in order to undo as quickly as possible the bad effects of prolonged heavy weather.

Material excavated from the inner bar should be deposited upon the Flats with simple supplementary safeguards for preventing the return of spoil into the channel or its circulation in and out through the entrance.

RIVERS AND HARBOURS OF QUEENSLAND.

Epitomised from Report made to the Queensland Government, 1898.

"ADVANCE AUSTRALIA" is the appropriate motto of the Island Continent. Prosperity is now so nearly universal that in the remotest countries the improvement of navigation is the active order of the day. At Fremantle, Port Adelaide, Melbourne and Sydney, the enterprising citizens of the new Commonwealth have met the needs of navigation with intelligent zeal. The ports of New South Wales, Victoria, and South and West Australia have their physical difficulties, but these are much slighter than those connected with the unique subtropical conditions in Queensland. The latter—almost if not quite the best Colony of Britain—is one of the most attractive lands upon the Earth.

It has been the privilege of the writer to examine, for the Government, personally and in detail, eight of its harbours and rivers, and to formulate projects for their improvement. He was further charged with providing the tools necessary for carrying out the comprehensive schemes recommended to the Government, and its subsidiary Harbour Boards.

The commercial centres of population in Queensland lie at the head of practicable navigation on its numerous rivers. These rise in a coast range and empty into an island-studded sea behind the Great Barrier Reef, which defends North-eastern Australia from the long surges of the Pacific.

Normally these rivers carry but little fresh water, and the approaches to the cities, are practically tidal inlets with a calm *régime*. But occasionally in the rainy season cyclonic storm clouds from the great ocean precipitate themselves upon coast and range so suddenly as to make records of rainfall as high as 34 inches in twenty-four hours. The rivers become torrents with an enormous discharge completely masking the tides.

Small channels laboriously made by low-powered dredges in years of work, may be obliterated in a single day,—a condition more disastrous as an embargo on navigation than could be brought to those far-off shores by any naval war.

To minimize the menace of such commercial catastrophes, the writer is now finishing at the works of Sir William Armstrong, Whitworth & Co., at Newcastle-on-Tyne, the most powerful wardens which ever stood guard over the navigating fortunes of a people (Plates VIII. and IX.)

They are three in number, aggregating about 10,000 I.H.P. and designed to put forth enormous capacity in emergency. Should such a flood as that of 1893 recur in the Brisbane river before the completion of its regulative works, the deposit of those commerce-ruining hours could be removed in eleven days instead of in the nearly three years, which, in spite of the arduous efforts of a whole fleet of small dredges, elapsed hitherto before the channels could be restored.

The rivers will be also regulated, with training walls located in accordance with the latest proved principles of river improvement—principles so illustriously applied by our Nestor of Navigation Engineers, Herr Franzius, at Bremen.

The dredges will distribute the excavated material behind these growing walls, until ultimately flood and ship can come and go, unvexing and unvexed.

TREATMENT OF CROSS-OVER BARS IN RIVERS.

THE bars of a river may be classified according to their causes, as (1) Obstruction bars, due to sunken craft, snags or to natural occurrences of rock, shingle or not easily erodable material; and (2) Expansion bars, due to abnormal increases of the cross-section or the spreading out of the erosive current of a concave.

The navigation obstructing bars of rivers are usually of the cross-over type. Sometimes they are simple, and at others complicated by islands and divided channels.

A simple cross-over bar is a submerged sand dam, in longitudinal section, showing a long slope from the lower end of the upper concave to a crest forming the edge of the opposite deep concave pool. Where a bar is complicated by side channels it is desirable to stop the undue diversion of the water. In such work a proper dredge can be most usefully employed. In dredge attack upon the main bar, the operations may be conducted (1) up-stream only (2) down-stream, or (3) in either direction alternately.

Up-stream movements are advisedly made in right lines; down-stream a dredge may work straightway or radially. If a bar is to be essayed with a radial dredge it is best to begin several hundred feet above the crest and operate so as to take as large a bite as practicable in a short time out of the crest. The river will best perform its erosive work rushing through such a gap, but the dredge must be powerful enough to carry a fairly increased depth with its advance. If the section it removes is at once restored by the moving river bottom, one may be sure the craft is underpowered for the undertaking. The value of this method of attack has not yet had the full demonstration its promise merits, but has been successfully employed by the writer in minor operations. Either a multi-bucket or suction dredge could be employed, but these should be of high power, cutting a swath 150 to 200 feet wide, and should possess a distributing pipe pontoon system leading down stream, otherwise the pipe line is difficult to handle in a current.

The multi-bucket dredge is usually so small and its work necessarily so ineffective that it takes it a very long time to remove a bar, and its method of piecemeal intermittent attack too often does not call to its aid the full erosive powers of the current.

The relative capacity of hydraulic dredges and their relative cost per unit of work as against the bucket type have been a subject of much misapprehension. The work of bucket dredges is naturally estimated by bucket count or barge measurement. In the case of hydraulic dredges, the rate, except in still water, is very difficult of exact determination. It includes an element whose neglect by some supposedly conversant with river hydraulics is a continuous surprise. To measure the output of an hydraulic dredge, when at work on cross-over bars, by the advance per foot or by the prism apparently removed, is quite fallacious. The volume actually handled by the machine is made up of two factors :

1. A volume measurable by the breast taken and the advance per minute.
2. The volume brought to the suction by the current.

This amount can be somewhat appreciated when it is stated that in the case of each of the Dredges "Volskaia" a stream 6 feet per second 31 feet wide and 5 feet or more deep is continuously passing the suction field, carrying a varying percentage of sand. This sand, part rolled along the bottom, part in suspension, may be from one to five per cent. Now three per cent. would be equal to one cubic yard per second, and much additional goes by on either side. To advance the dredge, the dredge must handle much that comes into its suction field, consequently the advance is slower than in still water.

The foregoing will explain the fact that while hydraulic dredges, as tested on the Scheldt or Mississippi, ran a high rate of advance per minute, when they come to attack a cross-over bar, though they could not have changed their capacity, yet they show a rate of progress much less. The advance is pronouncedly connected with the amount brought to the suction by the river.

The following summary, compiled from a United States Government Report of a season's work upon bars of the Mississippi River shows the relation between the Apparent Output and the Rated Capacity of the four dredges then employed. While the width of the suction field of each dredge differed, the cuttings made are equivalent to the following:

Total length....................	155,000 feet.
Average width..................	31 feet.
Average depth taken	3·5 feet.
Quantity apparently handled $\frac{155{,}000 \times 3{\cdot}5 \times 31}{27}$	622,870 cubic yards.

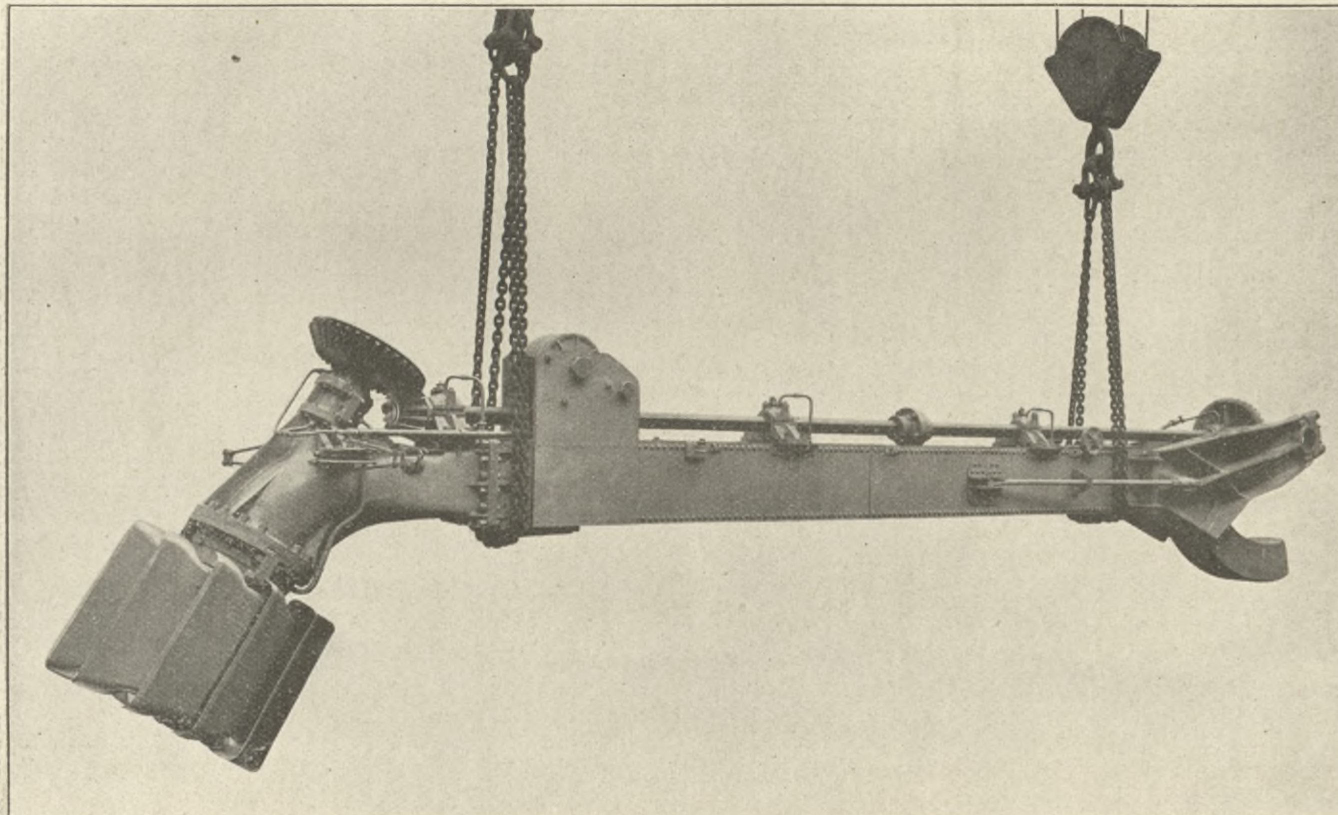
The officially rated capacity of the pumps of the four dredges was 6,000 cubic yards per working hour ; this total is about one-half the average of the official tests of the machine. The total number of actual dredging hours was 3,115. The quantity handled at rated capacity was 18,690,000 cubic yards. The average ratio between the apparent output and the rated capacity here appears to be 1 to 30.

The writer has no reason to question the ratings, because if dredges are expertly officered and manned, there is no reason why they should not approximate the official testing averages, which are double the above ratings. It is visibly impossible to institute a comparison of cost or capacity per cubic unit between bucket and hydraulic types and omit the great quantity actually handled, which lies between the apparent output of the latter as computed from the cuttings made and the rated or tested capacities.

CONSOLIDATED TABLE OF DREDGE TESTS, SHOWING RESULTS AND DETAILS OF OPERATIONS.

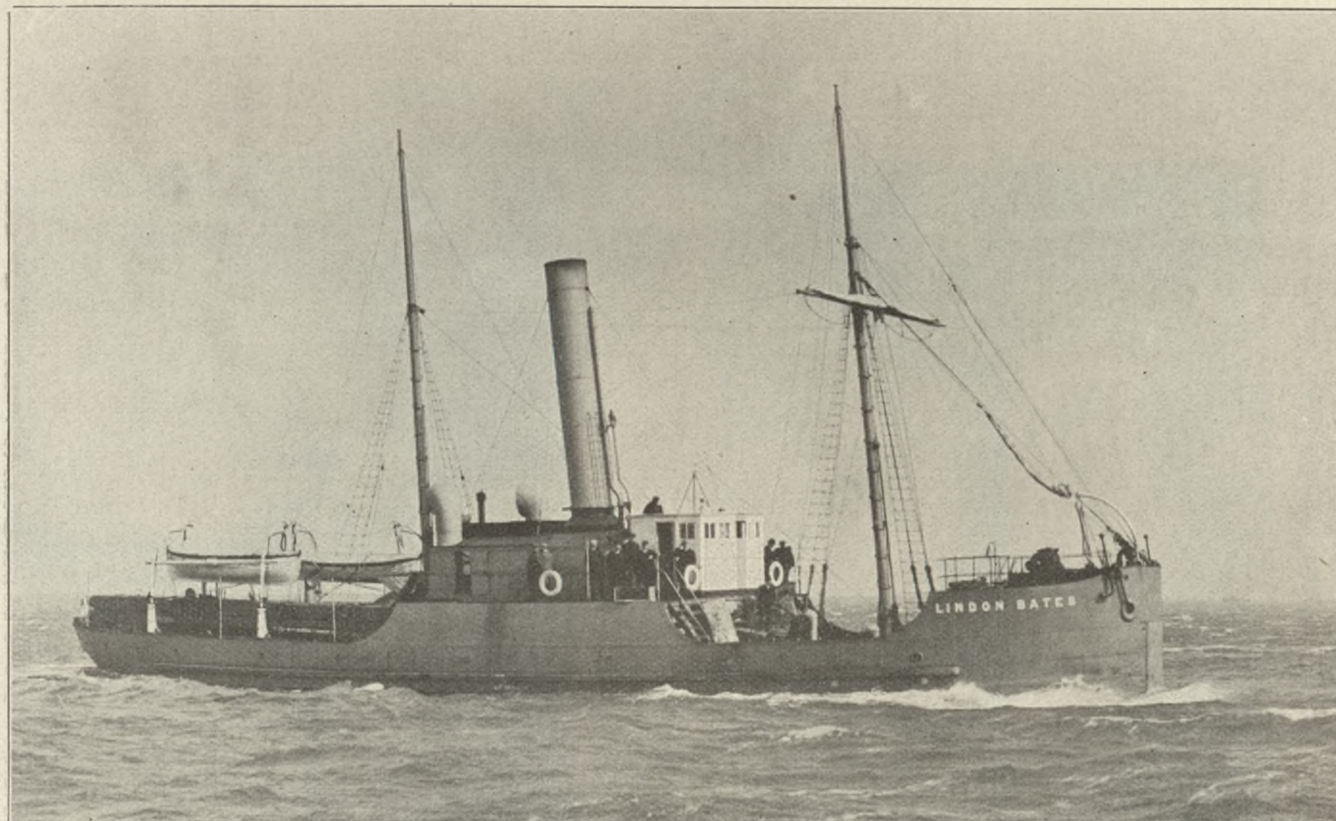
Compiled from Annual Report of U. S. Secretary of War, 1899, and the Tests of the Volga Dredges of the Bates' System by the Russian and Belgian Governments, 1899.

	Water-jet Dredges, Mississippi River.			Horizontal Cutter Dredge "Delta," Mississippi River.	BATES' SYSTEM Vertical Cutters Volga Dredge.	
	Sand. Gamma, Epsilon.		Sand & Clay Zeta.	Sand.	Sand.	Sand and Clay.
Average width of suction, ft.	19	20·3	20·3	33·6	32	32
Number of cuts made..	8	4	6	4	7	1
Length of cuts (in feet)....	4,566	2,015	1,785	2,711	5,482	1,008
Time actually dredging (hours)	45·50	24·83	62·92	27·38	6·89	1·2
Average advance per hour (feet)	100·3	81	28·4	99	795	840
Average depth of cut in feet..	7·16	9·6	20·6	6·55	2·38 to 5·66	2·68
Average speed main pump, revolutions per minute....,	150	178	179	140·9	150	155
Total cubic yards moved....	46,856	32,407	40,991	34,462	21,169	3,057
Average number of cubic yards per hour............. ...	1,008	1,306	652	1,259	3,072	2,550
Average discharge, length in feet	750	1,000	250-600	1,000	700	700
Diameter of discharge, inches	33	33	33	34	33	33
Equivalent hourly advance 32′ by 3′...	283·5	367·3	183·4	354·1	863·7	717·2



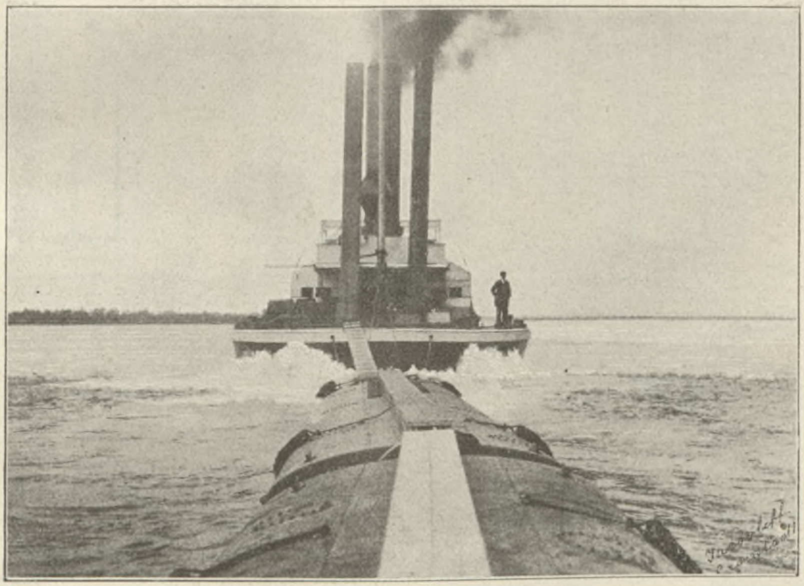
SUCTION PIPE AND CUTTER,—BATES' SYSTEM.

TUYAU DE SUCCION ET TREPAN,—SYSTÈME BATES.

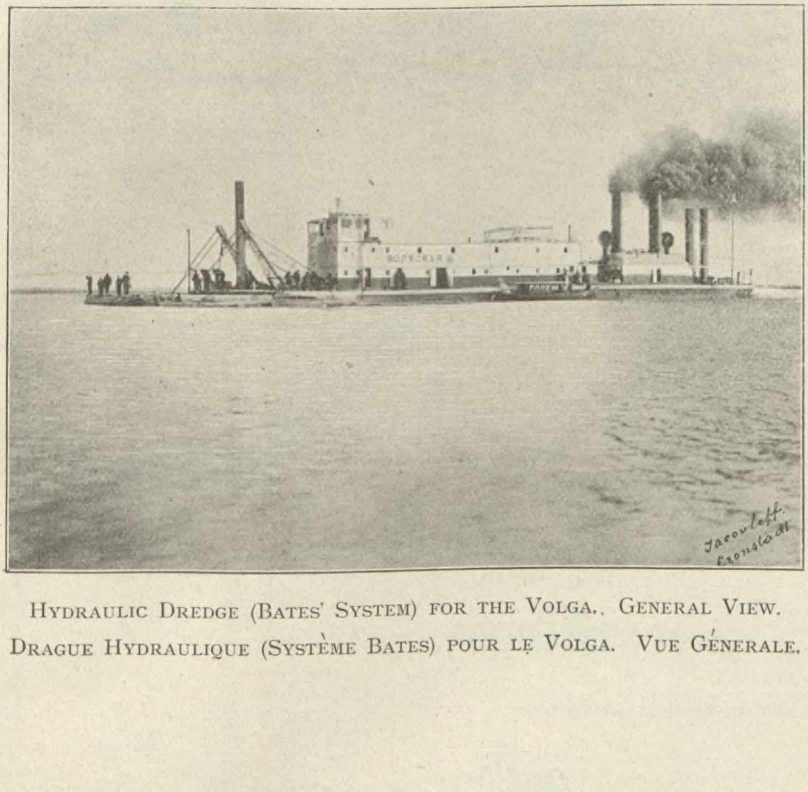


SUCTION DREDGE FOR HUGLI RIVER,—BATES' SYSTEM.

DRAGUE À SUCCION DU HUGLI,—SYSTÈME BATES.



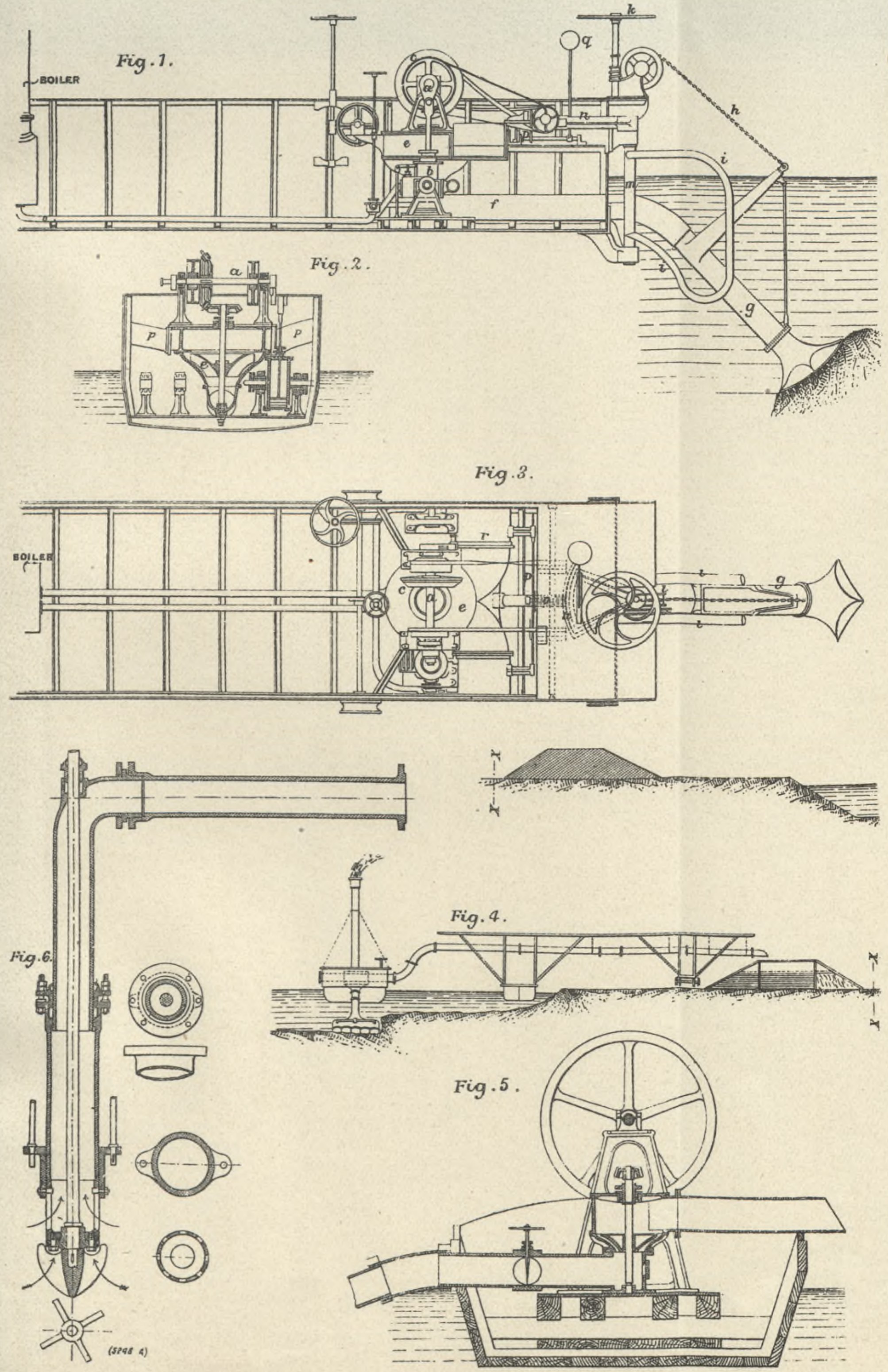
Hydraulic Dredge (Bates' System) for the Volga, with Pontoons.
Drague Hydraulique (Système Bates) pour le Volga, avec Pontons.



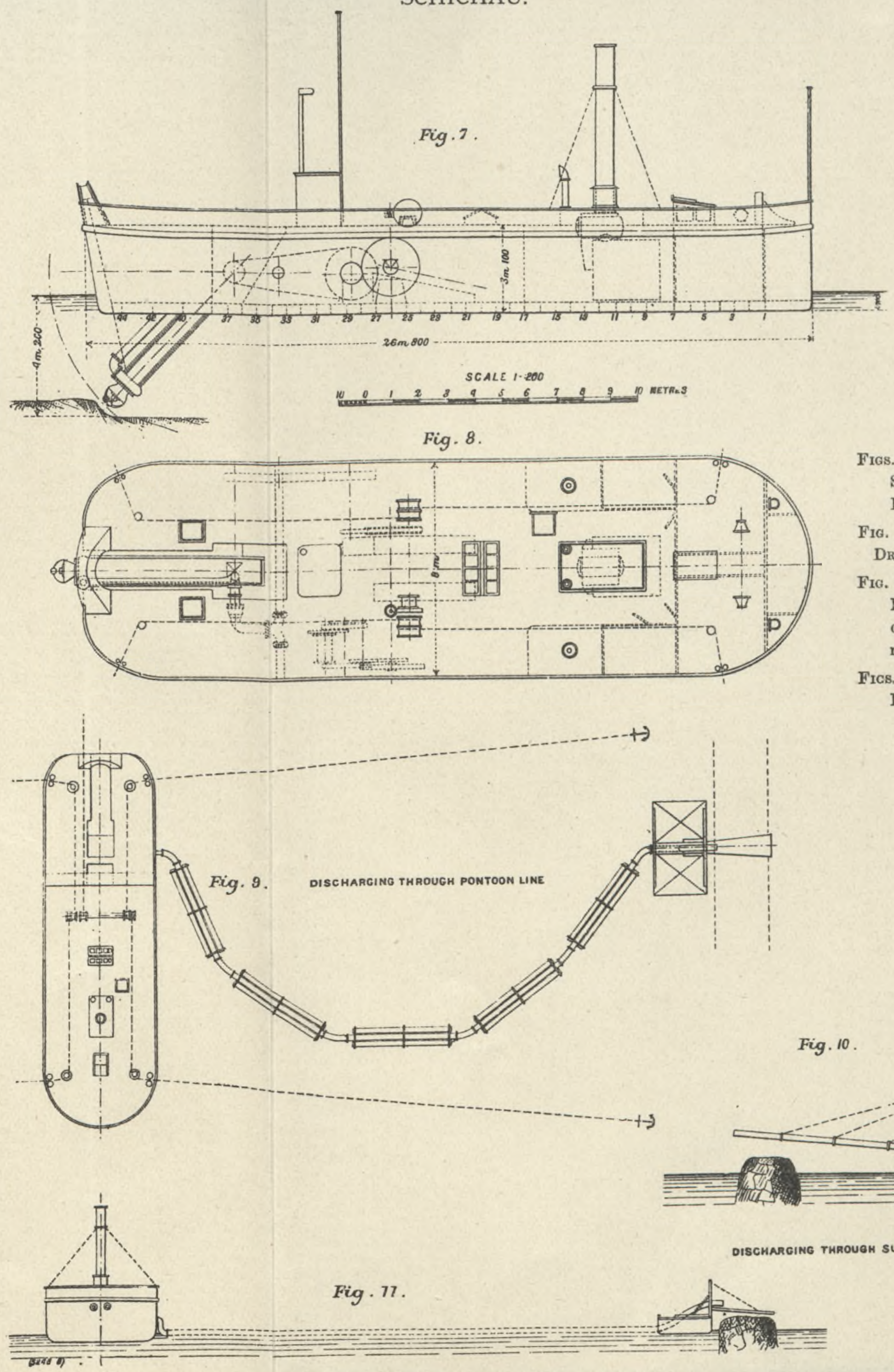
Hydraulic Dredge (Bates' System) for the Volga. General View.
Drague Hydraulique (Système Bates) pour le Volga. Vue Génerale.

TYPES OF PIONEER SUCTION DREDGES, GERMANY.
PREMIERS DRAGAGES A SUCCION, ALLEMAGNE.

1856-8.
HOFFMAN—SCHWARTZ KOPFF.



1878.
SCHICHAU.



Figs. 1 to 4. Schwartzkopff, 1856 (from Schwartzkopff's specification, A.D. 1856, February 9, No. 350).

Fig. 5. Detail of a Centrifugal Dredging Pump of the same date.

Fig. 6. Detail of Cutter and Suction Pipe of a Schwartzkopff Dredge, constructed in 1858 (the first type of rotary cutter).

Figs. 6 to 10. Schichau, 1878. Suction Dredge for Elbing Harbour Works.