The Institution of Civil Engineers.

SELECTED ENGINEERING PAPERS.

BEING ORIGINAL COMMUNICATIONS ORDERED BY THE COUNCIL TO BE PUBLISHED WITHOUT DISCUSSION.

No. 27.

"VANCOUVER HARBOUR, B.C. (CANADA)."

BY

ANDREW DON SWAN, M. INST. C.E.

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LONDON:
Published by The Institution,
GREAT GEORGE STREET, WESTMINSTER, S.W.1.
1925.

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PRINTED IN GREAT BRITAIN BY
WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES

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"Vancouver Harbour, B.C. (Canada)."[1]

By Andrew Don Swan, M. Inst. C.E.

Although founded less than 40 years ago, Vancouver is the commercial metropolis of British Columbia, being the terminus of all the transcontinental railways and the Pacific steamship lines. It contains many fine buildings and beautiful homes, and has a population, including suburbs, of about 225,000.

Harbour.—The harbour, opening off the Strait of Georgia, includes English Bay and False Creek, Burrard Inlet with the North Arm and Port Moodie, and all other tidal waters lying east of a line drawn from Point Atkinson lighthouse southerly to the most western point of Point Grey. The total area of the harbour is 48·78 square miles; the section west of the First Narrows is 20·20 square miles; Burrard Inlet, 13·84 square miles; North Arm, 13·57 square miles; and False Creek, 1·17 square mile. The total shore line is 98 miles. The weather conditions are very favourable; the harbour is open to navigation all the year round, and the greater part is almost perfectly sheltered.

From its geographical position, the harbour is the Pacific terminus of the great Canadian transcontinental railway-systems, in addition to which there is a considerable business from the United States over the Great Western, Northern Pacific, and the Chicago, Milwaukee and St. Paul Railways, all of which have connections with the port. On account of its nearness to magnificent forests, fisheries, mines, and fruit-growing and wheat lands, the rapid growth of its manufactures and industries, and the fact that it formed the gateway to the East, the future trade of the port appears to be capable of rapid development if proper facilities and equipment for handling cargoes are provided at the earliest possible date.

Tides.—There is at Vancouver a considerable tidal range of

[1] Original Communication No. 4535.

rather remarkable and unusual character, and it was only after 7 years' continuous observations day and night under the supervision of Dr. W. Bell Dawson, M. Inst. C.E., Superintendent of the Tidal and Current Survey Department of the Naval Service of Canada, that the actual levels of the tides were determined. At Vancouver and Victoria, B.C., as well as throughout the Strait of Georgia generally, the tide is of such a type that the springs and neaps do not appear; and it is misleading to refer to them, as they are effaced by other features in the tide which are dominant in that locality. Therefore in dealing with tide-levels there, "average" levels and "extreme" levels are referred to, which are not in accord with the moon's phases, but with its declination. It is simply another type of tide, to which terms such as "springs" and "neaps," which apply in the North Atlantic, are not applicable. The charts of Vancouver harbour published by the Admiralty distinctly refer to high water spring and neap tides, but there is a note thereon as follows:—

"The diurnal inequality of the tides is great, causing apparently but one tide in the 24 hours on many days. The tide has the peculiarity of rising to nearly the same level at higher high water whether it be springs or neaps, whereas the level of low water varies in the usual manner. In summer the higher high water is at night and in winter during the day."

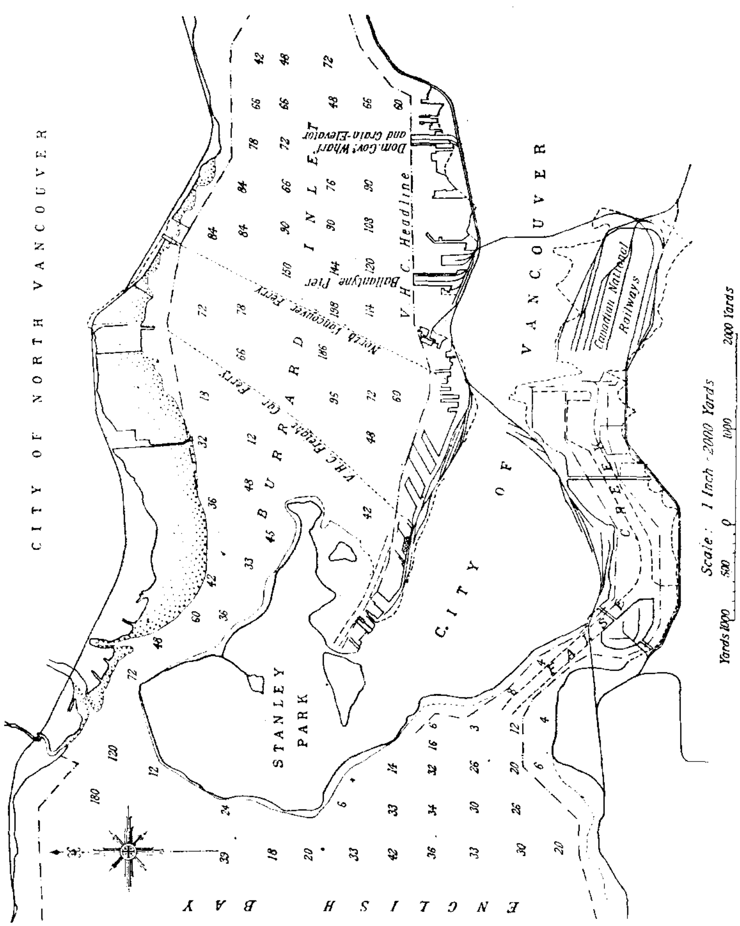
The tide-levels inside the First Narrows vary about 4 inches from those in English Bay.

Extreme low tides occur only twice per annum, in June and again in December or January. The actual levels adopted for all work in Burrard Inlet are as follows (above datum line adopted by Canadian Pacific Railway):

Extreme High Water	100·00
Higher High Water (taken to be equivalent to H.W.O.S.T. as referred to under the Dry Dock Act)	97·77
Average Ordinary High Water	96·25
Average Ordinary Low Water and Levels to which soundings are reduced	84·77
Extreme Low Water	83·45

Development.—In 1912 the Author was instructed by the Dominion Government to examine and report on the general conditions, and to make such recommendations for the future development of the Port of Vancouver as seemed to him most suitable to promote its growth and otherwise best serve the interests of the port and of the country. Although there were many most excellent sites for shipping facilities, Burrard Inlet (*Fig. 1*) seemed to be the natural deep-water harbour for ocean shipping. Accordingly the following recommendations were made:—That the work of widening the First Narrows, so as to give a width of 1,400 feet and a depth of 30 feet at low water, which involved about 2 million cubic yards of dredging, should be proceeded with; that additional wharfage should

Figs. 1.



be provided along the Vancouver City side of the Inlet; that False Creek, which extended almost into the centre of the city, should be dredged to a depth of about 20 feet at low water and used for coast-wise traffic, and that the upper end of False Creek, extending to about 300 acres, which was then dry at low water and covered with a few feet of water at high water, should be entirely filled with material dredged from False Creek and the land so reclaimed used as a great central railway terminal to which all the railways entering Vancouver should have access; that the North Arm of the Fraser river, extending from the city of New Westminster to the Gulf of Georgia, a distance of about 17 miles, and having a width of about 600 feet, should be dredged so as to give a minimum of 10 feet depth at low water; and that two training-walls should be constructed at the mouth of the Fraser river to prevent silting. The construction of a grain-elevator of suitable capacity was also recommended.

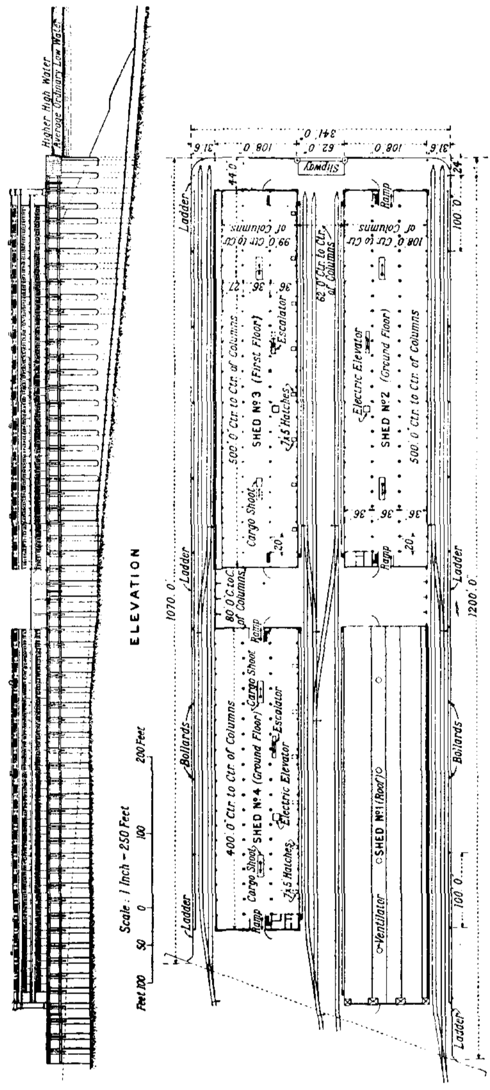
At the same time, owing to the greater part of the foreshore rights near the City of Vancouver having been acquired by the large railway-companies, it was strongly urged that the harbour of Vancouver should be controlled by one Board of Administration so as to permit of the systematic development of the port. Three alternative systems of port management were suggested: first, that the harbour should be considered as a national port and taken over by the Government, and a local Harbour Commission appointed, similar to that at the Port of Montreal; second, that the harbour should be acquired by the City of Vancouver and managed by a Committee of the City Council, as at Bristol, England; or third, that the harbour should be controlled by a Board of Representatives appointed by the various interests, such as the City of Vancouver, the railway-companies, the shipping companies, the Board of Trade, etc., as at London, Liverpool, Glasgow, etc. In accordance with the foregoing recommendation, the Government selected the first scheme, and by Act of Parliament, in May, 1913, the harbour was placed under the jurisdiction of a Board of three Harbour Commissioners, "with powers to regulate and control, by by-laws, navigation and all works and operations, and with other necessary powers for the proper development and administration of the Port, and to impose rates, fees, and dues for revenue purposes." Nearly all the other recommendations in the report for the development of the port were given effect to, but owing to the war progress was somewhat delayed.

At the beginning of 1919, however, the Author was again instructed by the Government to make recommendations for the further development of Vancouver harbour; and he found that, since his former report, the total import, export, and coast-wise traffic had increased in the year 1917 by 164 per cent. over the year 1913. It was, therefore, recommended that a comprehensive scheme for wharf-area, piers, railway-terminals, roads, sheds, warehouses, and freight-handling facilities in general should be designed on a broad basis and constructed by degrees as required, and that the following should be proceeded with at once :—A booming-ground for lumber in English Bay; a timber export-wharf; a harbour terminal railway; provision for six new deep-water berths or wharves; mechanical equipment; equipment for oil-storage; a fire tug; a railway and traffic bridge across the Second Narrows connecting the City of North Vancouver with Vancouver City; and a dry dock, to be constructed by the Government if not arranged for by private interests at an early date.

In connection with the question of recommending a site for further immediate construction of new berthage, it was found that the prices asked by private owners for foreshore frontage on the Vancouver City side were almost prohibitive: the Author, therefore, investigated the possibilities of considering some other site as an alternative, and selected Kitsilano on the south side of the mouth of False Creek (*Fig. 7*) as having many attractions. The land at Kitsilano was originally an Indian Reserve and was expropriated by the Harbour Commissioners in 1916. Its area was about 70·3 acres, and the price ultimately agreed upon was about $750,000, or $10,714 per acre. The completed scheme would have provided berthage-accommodation for twenty-one steamers. The railway-accommodation was good and in proportion to the berthage, and a large area of land was available on the reserve for warehouses and other industrial development. In order to protect this site, a sea-wall or break-water would have had to be constructed as part of the scheme, but the inner side of the sea-wall would have been available as a shipping-berth. The total cost of the complete development at Kitsilano, including land, dredging, embanking, quay-walls, sea-walls, lighthouse, two-storey reinforced-concrete sheds, railway-sidings, roads, lighting, equipment, and engineering, was estimated at $18,750,000. It was estimated that by the Kitsilano scheme similar wharfage could be provided for approximately $895 per foot of quay as compared with $1,353 at Burrard Inlet; and 100 per cent. more land would have been available at Kitsilano for industrial development.

The Harbour Commissioners who first held office rather favoured proceeding with the Kitsilano scheme, but before it was definitely decided, a change in Government, with a corresponding change in the personnel of the Commission, took place, with the result that the majority of the new Commission decided to proceed with the first large pier-development at Burrard Inlet; and the Author was instructed to recommend a suitable site on the main harbour-front. In this connection, one of the most important features for study was the provision of the necessary railway-connection so as to permit all the railways entering Vancouver to have access to the projected new works. The Canadian Pacific Railway runs practically parallel with the south side of Burrard Inlet, and consequently cuts off other railways from easy access thereto, in addition to which a very large portion of the main harbour-frontage nearest to the city, between the railway and the water, was owned outright by that railway-company. The Author concluded that a harbour terminal railway between the Canadian Pacific Railway and the water should, if possible, be constructed by the Harbour Commissioners and operated by them. At that time the Great Northern Railway had a single-track line about a mile long extending from what is now known as the Great Central Railway Terminal, built on land which previously had been a mosquito-infested swamp at the head of False Creek; and this branch railway crossed the main line of the Canadian Pacific Railway on the level near the Great Northern Railway pier (*Fig. 1*). All the inward and outward cargoes to be handled at this section of the waterfront from all the different railway-systems, both Canadian and American, entering Vancouver, with the exception of the Canadian Pacific, were handled over this crossing, and therefore it was desirable to construct the first pier as near to this crossing as reasonably could be done, so as to avoid having to purchase any more foreshore land than was absolutely necessary to begin with, since the land was valued at $1,000 to $1,200 per foot of frontage. The Author therefore recommended that a site immediately west of the Great Northern Railway Company's existing pier should be selected, and a vacant frontage of about 960 feet was purchased. It was proposed that the Harbour Commissioners should either purchase, or arrange running-rights for their terminal railway over, the Great Northern spur line before referred to, as the site selected offered the shortest railway connection with the central terminal, and was also in close proximity to the present commercial centre of the city. The substratum of the site was sandstone rock and offered a reasonably good foundation. The site selected also had the advantage that the adjoining site was offered at a reasonable price; and, although it was not purchased, it appeared that if it were ultimately acquired for future development the first pier would form one unit of a comprehensive consecutive scheme. The depth of water at a distance of about 1,500 feet from the shore was about 78 feet below low-water level. As the marine worm (*Teredo navalis*) is very active indeed in Vancouver Harbour, it was decided to use concrete in the construction of the new pier, although many of the other piers in the harbour are constructed of creosoted B.C. fir timber, which seems to stand the attack for at least 10 to 15 years. The water in Vancouver Harbour is less saline than in the Pacific Ocean, due to the fact that it is

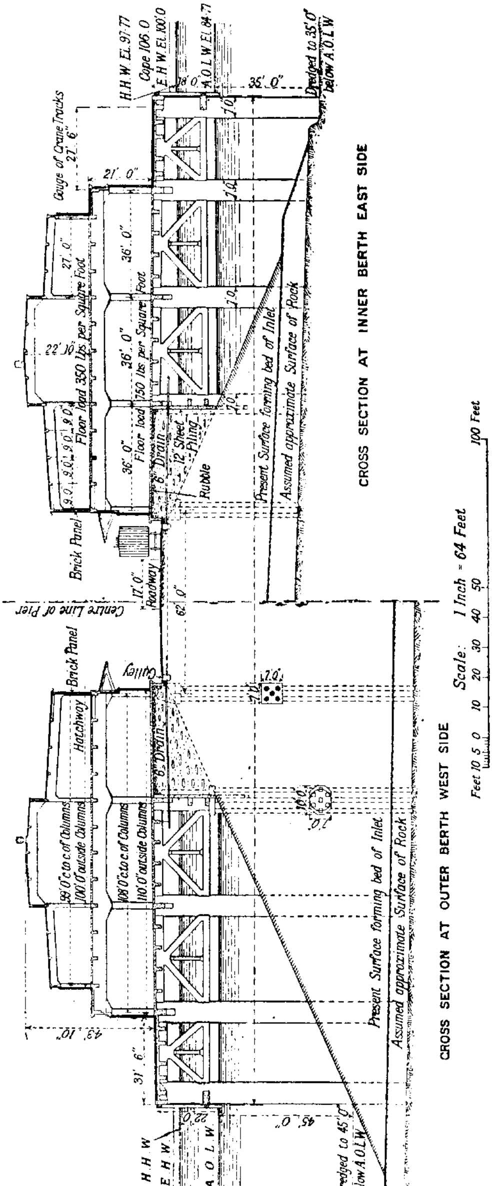
Figs. 2.



BALLANTYNE PIER.

diluted to a certain extent by fresh water from rivers running into the inlet, also by the fresh water from the Fraser river, which is carried back by the current into the harbour proper. Since the

Fig. 3.



BALLANTYNE PIER.

fresh water remains on the surface, owing to its lightness, this is of undoubted advantage in that it minimizes any chance of deterioration of the concrete between high and low water. In connection with the different types of construction there is also the difference in fire-insurance rates for general cargo passing over the wharf, which would have been \$1·75 to \$2·50 per cent. if the structure were of timber, as compared with about \$0·25 per cent. for a structure of concrete and reinforced concrete.

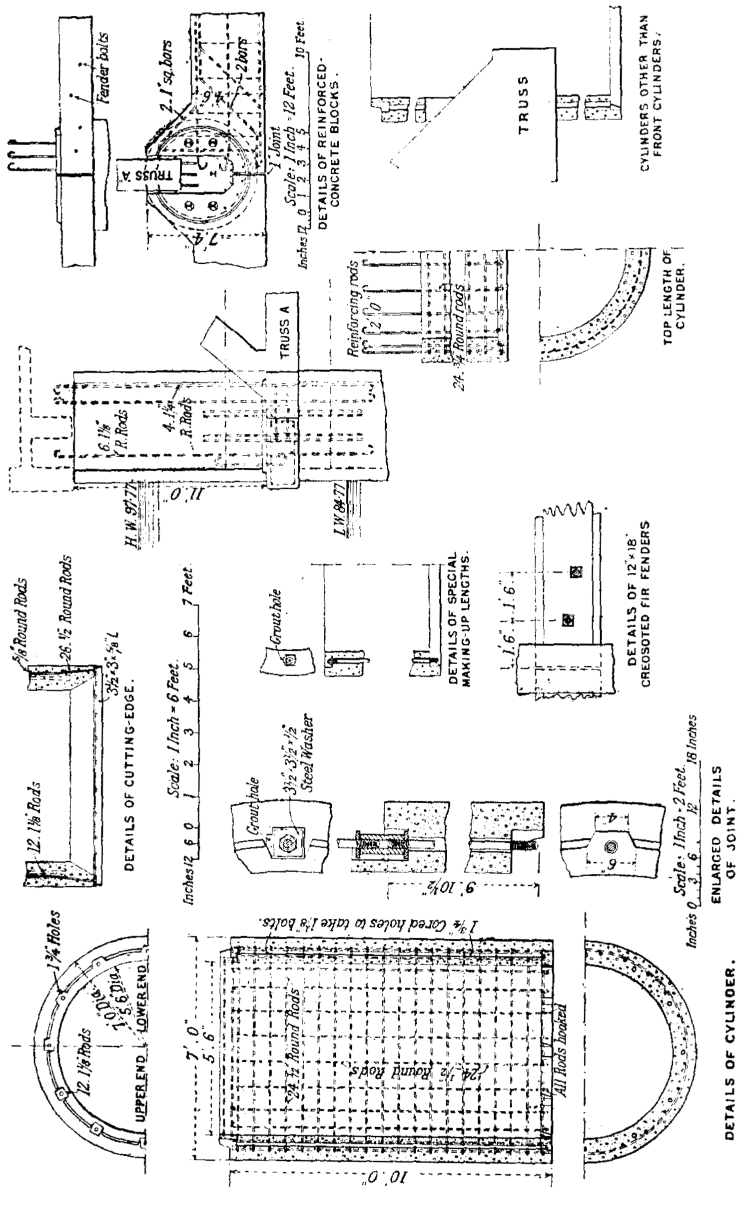
Nine alternative designs and methods of permanent construction of the pier, therefore, were prepared in detail, and complete estimates were made. It was found there was very little difference in cost between a concrete pile pier with solid filling and a concrete cylinder pier with solid filling; and the Author therefore decided to recommend concrete cylinders, since they would provide a more substantial structure than piles and would be less liable to damage and deterioration. As finally designed (*Figs. 2*), the pier was 1,200 feet long on one side, 1,075 feet on the other, and 341 feet wide, and there was in addition a shore quay of 350 feet in width.

Ballantyne Pier.—The heart of the pier (*Fig. 3*) was formed of sand and gravel filling, about 134 feet wide at the top with sides sloping at about 1 to 2·4. At the inner berths the basins were dredged to a depth of 35 feet, and at the outer berths there is a minimum depth of 45 feet below ordinary low-water level. The deck of the pier consists of reinforced concrete supported by precast reinforced-concrete trusses, which are carried on rows of reinforced-concrete cylinders resting on rock bottom. There are four rows of these cylinders at each side of the pier at the inner end and three rows at the outer.

The cylinders (*Figs. 4*) are 7 feet in external diameter, with a thickness of 9 inches, and there are altogether about 30,000 linear feet, or $5\frac{3}{4}$ miles, in the piers, containing about 25,000 cubic yards of concrete. They were cast in lengths ranging from 4 to $17\frac{1}{2}$ feet. In addition to the circular reinforcement, longitudinal rods were provided, which projected at each end of the cylinder and were screwed so that various sections of the cylinder could be bolted together with nuts and clips, thus furnishing continuous steel reinforcement from top to bottom of any desired length. The forms used for the cylinders were of steel. The concrete of the cylinders is in the proportion of $1 : 1\frac{1}{2} : 3$ throughout, and particular attention was paid to the grading of the aggregate.

The four transit-sheds are built in two lines, each line of two sheds being about 30 feet back from the coping-line of the pier so as to provide space to accommodate two railway-tracks along the front of the sheds. A single rail is laid at coping-level to support the

Figs. 4.



DETAILS OF CYLINDERS.

vertical leg of the semi-portal cranes which span the tracks, the other crane-support being carried on a platform at the level of the second storey. The transit-sheds, three of which are 500 feet long and one 400 feet, are all of reinforced concrete, two storeys in height by 110 feet in width. Between the sheds along the middle of the pier there is accommodation for three railway-tracks and a roadway for vehicular traffic, giving access to the loading-platforms. The ground floor of the sheds at the front is at the same level as the coping of the pier and is constructed on an easy gradient from the front to the back so as to obtain the requisite height to permit of direct loading from the platform into railway-cars. The level of the tracks and roadways between the sheds is practically the same as that of the coping.

Mechanical equipment for handling cargoes is provided: it consists of a number of semi-portal electric cranes spanning the two railway-tracks in front of the sheds and capable of handling cargo either to or from either floor of the sheds and the hold of the largest steamer afloat; whilst inside the sheds, motor-trucks, electric conveyors, and elevators are provided for the rapid handling of cargo.

Construction.—The first contract let was for dredging the basins on both sides of the pier, and for filling the shore quay and forming the hearting of the pier. Tenders were invited, and that of the lowest tenderer, Messrs. Grant & MacDonald, Ltd., Vancouver, amounting to $513,121, was accepted, three other tenders being received, ranging from $795,000 to $969,000. This contract was commenced in September, 1920, and completed in November, 1921; but work had progressed sufficiently to permit of the second contract being commenced in March, 1921.

The quantities of material comprised in the dredging and filling contract were approximately 81,000 cubic yards of soft dredging, consisting of mud, silt, and sand (of which quantity about 12,000 cubic yards was used as filling), 86,000 cubic yards of rock varying from a very soft sandstone to a very hard concrete-like conglomerate, and 615,000 cubic yards of filling, of which about 80,000 cubic yards was in the shore quay and the remainder in the pier hearting. The rates for these items were $0·32 for the soft dredging, whether used as filling or not, $2·98 for the rock, and $0·36½ for the filling.

The plant used by the contractors consisted of: a 3½-cubic-yard dipper dredge; a 2½-cubic-yard dipper dredge with a very long dipper-stick, which enabled it to operate at 45 feet below low water; two clam-shell dredges; two single-unit drills; two tug-boats; and five dump scows. In addition a suction dredge was rented for a time.

The rock dredging was carried out by two drills and the two dipper dredges, the smaller one being principally engaged on the deeper outer portion of the work. The softer part of the rock was drilled with a special arrangement called a "bull drill." This was mounted on a pile-driver and consisted of a timber casing which travelled in guides in the leader of the pile-driver and which was lowered down until it rested on the bottom. Inside this casing was a long steel drill about 3 inches in diameter, the lower end being of drill steel welded on to the shaft. The upper end of the drill was enlarged, and below the enlargement was a loose collar which was attached by means of two short chains to the ordinary pile-driver hammer above it, in such a manner that there was about 3 feet between the hammer and the top of the drill when the chains were tight. In operation the hammer was lifted, taking with it the drill at the full extent of the chains. The whole arrangement was lifted clear of the bottom and then dropped; when the drill struck bottom the hammer followed, striking a blow on the drill as in driving a pile. The drill and hammer were then lifted again and the process was repeated. The effect was that the drill was driven in the same way as a pile, except that between every blow it was lifted in the hole, and thus jamming was prevented. The arrangement was very cheap to operate and in practice could rapidly penetrate 8 to 10 feet in the soft rock. The holes were loaded and fired in the usual manner. These drills were not capable of dealing with the harder portions of the rock; for this work two single-unit steam drills were used, which also were operated from the pile-drivers. The spacing of the holes ranged from about 7 feet to 3 feet between centres, according to the nature of the rock, and generally the work was carried out in three lifts.

The filling was dredged from the neighbourhood of the Second Narrows by the larger dipper dredge, fitted with a 6-cubic-yard bucket for the purpose, and transported to the pier, a distance of about 2½ miles, in dump scows. The material was a coarse clean gravel ranging in size from sand to small boulders about ½ cubic foot in volume. This material stands permanently at a slope of about 1 to 2·4 under water.

The elevation of the top of the pier-hearting is 4 feet above high water. The bulk of the material for this hearting was deposited directly in place by the scows which, making use of the tides, brought it to about 3 feet above low water. Above this level the bank was built up by two clam-shell dredges, working one on either side of the bank and lifting material from the toe of the filling at the outer end and depositing it on the bank behind. The shore quay filling, carried to a height of 7 feet above high water, was in too shallow water to permit of any of it being deposited direct, and consequently a bank was thrown up at the seaward face of the filling by the clam-shell dredges, and the area behind was filled in by a suction dredge which took material from the pier hearting before the latter had reached low water-level, this material being replaced by the dump scows.

The entire contract was completed, and all claims were settled, for about $1,000 less than the original tender.

Tenders were invited for the second contract, which included the whole of the concrete work of Ballantyne pier and a short piece of the shore quay-wall, and the construction of the two-storey reinforced-concrete sheds, with paved roadways, railways, and tracks. The lowest tender, as submitted by the Northern Construction Company, Ltd., & J. W. Stewart of Vancouver, was accepted at a figure of $4,403,324, four other tenders being submitted, ranging from $4,596,804 to $7,335,922. Both British and Canadian firms tendered.

Moulding-Yard.—The first work undertaken was the pre-casting of the concrete cylinders, and for this purpose the contractors leased about 30 acres of level filled land at North Vancouver, about 2½ miles across Burrard Inlet from the site of the works. The sand, gravel, and cement were delivered by water, this material being handled from the scows by means of a travelling timber gantry crane operating a 1-cubic-yard clam-shell bucket, which delivered either direct to bins over the mixer or to storage on either side.

Mixing-Plant.—The mixing-plant consisted of overhead bins which discharged into measuring-boxes and thence into the hopper of a 1-cubic-yard Smith mixer, which discharged into buckets on cars. A 20-ton stiff-leg (Scotch) derrick crane was used for the cylinder fabrication, the cylinders being arranged around it in the form of a circle. The concrete for the trusses, piles, beams, etc., was distributed in conical buckets, the trains carrying the latter running on standard-gauge tracks, and being hauled by a gas locomotive. The concrete was delivered direct from the mixer to the cylinder forms by the derrick, which was also used to set up and take down steel forms, reinforcement, and steaming tarpaulins, as well as to handle the concrete cylinders and load them on cars for removal to the skidways.

In commencing the construction of the cylinders, tamping of the concrete in the usual manner by hand was adopted, but this was soon altered to tamping by means of two small air hammers which vibrated the outer steel shell of the form while the concrete was being poured. This was found to produce a denser mass with a better skin than that obtained by hand tamping. Steam curing was resorted to, so as to enable the forms to be removed and sections to be handled as soon as possible after the concrete was poured. Steam jets, one on the inside and one on the outside of

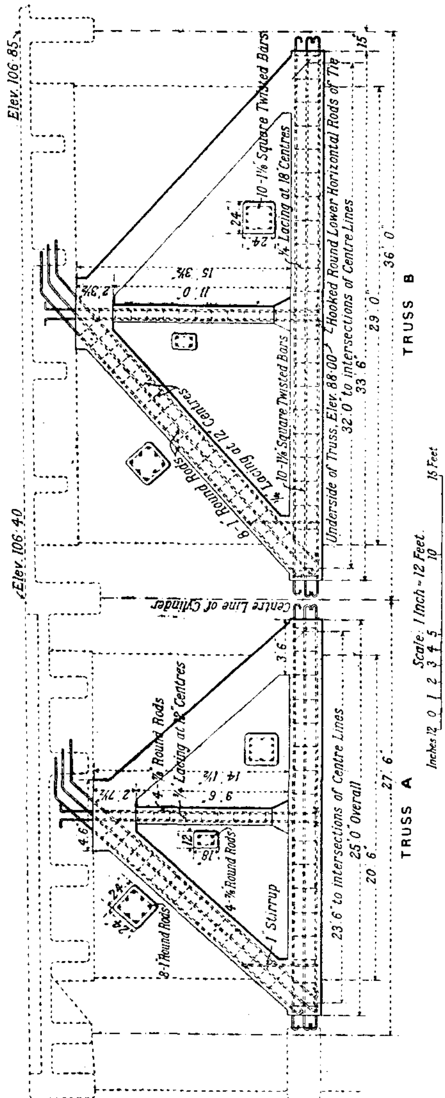


Fig. 5.

Typical Precast Trusses.

each cylinder, were turned on after the forms had been filled and covered with a canvas tarpaulin like a tent. The cylinders were steamed for 4 hours, after which the covers were removed and the forms stiffened. In cold weather the steaming-covers were replaced, and an additional 4 hours' steaming was given. Four days after pouring, the cylinder sections were placed on a car running on a depressed track so that the floor of the car was level with the skidway, and the sections were rolled off on to the skidways, where they lay during the curing or setting process for 2 to 3 months before being used in the pier. The trusses, fender-blocks, struts, sheet piles and walings, etc., were cast, on platforms surfaced with sheet iron, inside sectional wood forms lined with steel, and the steel reinforcing-rods were left projecting beyond the concrete in the units so as to tie them properly together and form a bond in the completed structure. The trusses (*Fig. 5*) were cast four high, one on top of another, so as to save space, a wooden form covered with sheet steel being placed between each truss. All the steel for the reinforcing steel cages and other parts was bent by a large motor-driven bender.

Tests.—All cement for works had to comply with the specifications of the Canadian Engineering Standards Association, and was tested at the cement-works before being shipped, the bins being sealed by inspectors after acceptance. All sand was tested for organic impurities and grading: it was of good quality, and in almost every case gave higher results, in comparative tests of 1 : 3 briquettes, than did standard sand. The gravel was tested for grading. Compression tests for the concrete were made at regular intervals, to check the quality of the work. The usual times of test were at ages of 7 and 28 days. One set of cubes was made for tests over longer periods, and this may be taken as typical of the 1 : 1½ : 3 concrete. Six-inch cubes were cured in air along with the cylinders for 28 days. One set was then broken, and the remainder were placed in the sea. The results were :—

Age 28 days	Average	3,858	lbs. per sq. in.
,, 2 months	,,	4,110	,, ,,
,, 4 ,,	,,	4,410	,, ,,
,, 7 ,,	,,	4,682	,, ,,
,, 13 ,,	,,	5,192	,, ,,

The usual average at 7 days was 2,000 lbs. per square inch.

In addition to the above, a number of blocks 3 feet by 6 inches by 6 inches have been made, with a 1-inch steel bar in the centre. These have been placed between high and low water to determine the effect of sea-water on the various mixtures used. They are still less than 3 years old, and there is nothing to report.

Sinking Cylinder Piers.—The cylinder piers, of which there were

413 in the pier proper and 57 additional in the shore quay, consisting of pre-cast sections bolted together, were placed in position and eventually sunk by the use of specially-constructed cylinder-drivers carried on timber staging. The sections of the cylinders were towed across the inlet on scows, lifted therefrom by a floating derrick, and built up in the leader of the driver as the cylinder was forced down through the material to bed rock or to suitable foundation. The drivers were capable of handling sections of cylinder bolted together weighing 85 tons.

In many instances, as the cylinder-drivers were the only machines available to set the cylinders, a driver was moved to another cylinder as soon as it had sunk one a considerable distance, and sinking operations were completed by what is known as a skid derrick. This plan permitted of more rapid and expeditious work of the drivers, of which there were five. As the cylinder sank, the material was excavated from the inside with orange-peel buckets in the usual way, and 6- and 12-ton special cast-iron rings were used as kentledge when necessary to overcome friction. In some cases 240 tons additional weight was put on the cylinder, indicating skin-friction of about 375 lbs. per square foot. High-pressure water-jets were used where the material encountered by the cutting edge could not be excavated by the orange-peel buckets. Water for the jets was supplied by two Worthington turbine pumps driven by a 650-HP. motor placed between them. These were capable of maintaining a constant pressure of 200 lbs. per square inch. An Allen three-stage pump driven by a 440-HP. motor was used as a standby. Boulders were lifted out with a hoist after being drilled by a diver for the insertion of pins and shackles. The cutting edges of the cylinders were of two types, depending on the loading and on the nature of the foundation to which the cylinders were to be sunk. One type of shoe was 17 feet 6 inches long, and the other was 9 feet in diameter and only 5 feet in length. The maximum applied load on any cylinder was 500 tons: the unit pressure allowed on the hard conglomerate was about 14 tons per square foot, and on the softer conglomerate and sandstone about 8 tons per square foot. The cylinders were built up in the leader of the driver by the floating derrick placing a length of cylinder on the top of the cutting-edge section so that the joint could be rendered waterproof and the two sections bolted tightly together; and this operation was repeated with each section as the sinking process continued, until the top of the cylinder was at about high-water level. When the necessary lengths were all in place and connected, an additional 15-foot length was added temporarily to give increased weight and also to permit of the material from the orange-peel bucket being discharged free from the actual completed cylinder; this top length was afterwards unbolted and used in a similar manner on subsequent piers. When the cylinder was finally sunk to a suitable foundation and approved by the Resident Engineer, who had to make all examinations inside these cylinders in a diving-dress, the loose material inside the cylinder was cleaned out by a diver, and a seal of rich concrete was made, generally deposited by means of under-water concrete buckets. When the seal had set sufficiently, the top weight section of cylinder was unbolted, and a wooden coffer-dam was placed on top of the cylinder so as to bring the aperture well above high-water mark; the cylinder was then pumped dry, cleaned, inspected, and finally filled with mass concrete in proportion of either 1 : 3 : 6 or 1 : 4 : 8 up to a level of a little above low-water mark.

The next stage of the work was the setting of the reinforced-concrete trusses (*Fig. 5*) on the top of the filled cylinders, and, in the case of the front row, the fender beams. The trusses were lifted and put into position by the skid derricks, and where the ends of the trusses rested on the cylinders, that part of each cylinder was carefully filled and rammed with mass concrete in the proportion of 1 : $1\frac{1}{2}$: 3.

It will be seen from *Fig. 3* that, owing to the great depth of the filling, the fourth and fifth rows were carried on piles; and the original design allowed for these to be either of concrete or timber, as might be subsequently decided. A number of concrete piles 16 inches square and 35 to 60 feet long were prepared, and an attempt was made to drive these piles through the gravel filling; this, however, was found to be almost impossible. The hammer used for driving the piles was a No. 2 Warrington steam hammer, in which the steam lifts the moving part and then leaves it to fall by its own weight, the moving part weighing 3,000 lbs. The hammer has a 36-inch stroke and delivers 60 to 80 blows per minute. A wooden block with a cushion of rope or of sawdust and shavings was used between the block and the pile. The piles would only set about 1 inch to 20 or 30 blows, and there was considerable rebound in the driving. The water-jet was used, but without success, as the jet seemed to wash out the sand from the gravel, leaving a bed of stones. In handling, the 45-foot piles were slung from four points so as to avoid any undue tension. Very soon after driving commenced, minute hair cracks were discovered in the piles. It was thought at first that these cracks were due to strains in preliminary handling, but microscopic inspection failed to reveal any indication of cracks in the piles previous to driving. Another probability was that there was too much concrete cover

over the steel for the size of the pile, the main steel being only $9\frac{3}{4}$ inches from centre to centre. Under slight bending or contraction strains, the concrete at the outer fibres may not have been sufficiently supported by the reinforcing steel, and if so this was probably the cause of the minute surface cracks. The trouble with the concrete piles was not that they could not be driven, but that they could not be driven without cracking them. When sufficient cushion was used to save the piles, they would not drive. A second attempt was made to drive them with an Arnott hammer weighing 25,000 lbs. The moving part weighed about 2,800 lbs., and the steam delivered a blow also, making the effective blow 7,500 lbs. The stroke was 22 inches, and the machine delivered 100 to 120 blows per minute. It was found that timber piles 55 or 60 feet long could be driven quite successfully, consequently they were used, and in the fourth row, at about the level of low water, the timber piling was surrounded by pre-cast concrete sheet piling so as to permit of the mass concrete being carried well below low water and at the same time to prevent any possibility of the tops of the timber piles being exposed and rotting at about that level. This was found to be quite satisfactory. The timber piling was driven and capped so as to keep pace with the sinking of the cylinders, and the concrete cap was carried up, working between tides. After the trusses, fender-blocks, and top cylinder-lengths were grouted into their proper position and the walings for the sheet piles placed in their slots, forms were fastened around the cylinders at the points where the units entered, and the steel reinforcement was thoroughly cleaned. Many of these units weighed as much as 25 tons. Before filling the outside row of cylinders with concrete to the level of the deck-girder slots, reinforcement of old rails was added, so as to increase the bond.

In order to retain the solid filling supporting the floor of the third bay of the shed between the fourth and fifth columns, reinforced-concrete tongued-and-grooved sheet piling was driven, a single-acting No. 2 Warrington steam hammer, working in conjunction with a water-jet, being used.

Main Deck.—The main deck of the pier was usually poured in lengths of 40 feet, construction-points being formed at the middle of the bays. The minimum covering of concrete over the steel was $2\frac{1}{2}$ inches, and the work was carefully supervised to make sure that the steel reinforcement was not disturbed during concreting operations, which were carried on simultaneously from a floating plant with a shoot and a land mixer working in conjunction with side-tipping cars hauled over a narrow-gauge track by petrol locomotives. The mixture used throughout the main deck section was 1 : 1½ : 3 concrete. The sand and gravel were all fresh-water washed, and the gravel was screened and graded, the largest size of gravel passing through a 1¼-inch ring. Compression tests were made on all pours of the deck, the average compressive strengths being 1,880 to 2,330 lbs. per square inch at 7 days, and 3,020 to 4,835 lbs. per square inch at 28 days.

Sheds.—The transit-sheds were of reinforced concrete, with certain brick panelling. The principal forms were of steel, so as to provide for speedy erection and stripping, and the forms for the main girders of the first floor were carried on steel trusses. Owing to the fact that the prices of steel and labour were high, however, whereas lumber was cheap, it seems to the Author questionable whether it would not have been better to adopt timber forms throughout. The main columns were constructed of 1 : 1½ : 3 concrete, whilst a 1 : 2 : 4 mixture was used for the remainder of the sheds. Here also compressive tests were made of all pours. Tests of the 1 : 1½ : 3 columns gave much the same results as already stated for the deck, while average values for the 1 : 2 : 4 concrete were 1,500 lbs. per square inch at 7 days, and 2,500 lbs. per square inch at 28 days.

Tests.—Various tests were made from time to time to determine whether the calculated loading was justifiable.

A timber pile with a designed load of 30 tons was loaded with 54 tons. The settlement after application of the load was 0·5 inch, which was all regained within 48 hours after the removal of the load.

A reinforced-concrete pile, which could not be driven beyond 18 feet penetration, was loaded with 72 tons, and settled 0·05 inch. The designed load in this case was 50 tons.

Several cylinders were subjected to test loads. The cylinders selected for tests were some in which it had been found difficult to obtain as satisfactory a foundation as was usual. A typical example is one which was loaded with 342 tons for 24 hours without settlement. The shoe was 7 feet in diameter, and the penetration in the gravel filling was 31 feet. This gives a pressure of 8·9 tons per square foot due to superimposed load alone. It is probable that skin-friction supported the weight of the cylinder itself, which was 230 tons.

A bay of the deck was loaded with gravel to 750 lbs. per square foot without any sign of deflection.

The lower crane-beam was subjected to a test load of 27 tons, placed to correspond to the position of the crane-carriage imposing maximum bending-moment, and no sign of deflection was observed.

Flooring.—The ground floor of the transit-sheds is covered with a bituminuous mixture called "Asbestophalt," which consists of 14 per cent. of bitumen, 8 per cent. of carded asbestos, and 78 per cent. of sand carefully graded between a No. 8 mesh and a No. 200 mesh screen. The whole was mixed mechanically at a temperature of 300° F., and conveyed in motor-lorries to the work from a central mixing-plant in the city. It was spread so as to give a thickness of 1 inch when thoroughly rolled, and was capable of carrying traffic as soon as it had cooled. So far as the Author is aware, this material had not been used to any extent before in Canada. Before deciding to use it in the sheds, a small area was laid in one of the busiest streets in Vancouver, and observations extending over several months showed that it gave very satisfactory results. The quay-space in front of the sheds between the rails was covered with bitulithic paving. On completion the interior of the sheds was finished with two coats of cold-water paint consisting of 7 per cent. of glue, 10 per cent. of china clay, and 83 per cent. of best air-floated English whiting, put on by sprays.

Electrical Equipment.—The whole of the cranes, transporters, elevators, and other cargo-handling appliances are electrically driven. The current is supplied from outside the property by the B. C. Electric Company, the current being 2,300 volts, three-phase, for transmission, transformed to 115–250 volts, single phase, for lighting, and 550 volts, three-phase, for power. The transformer-room and switchboard-room are in shed No. 4. The C. H. E. Williams Company, Ltd., were the electrical contractors. Approximately 20 miles of conduit was constucted, and 90 miles of insulated wire and 1¼ mile of trolly wire were installed. The offices in the various sheds are electrically heated. The total contract amount for the complete electrical installation, plus engineering and inspection charges, is $158,287.

Sprinkler System.—The sheds are equipped with fire-extinguishing apparatus of the Grinnell type, which consists of a dry-pipe system of 4,370 Grinnell automatic sprinkler-heads. The total cost of the sprinkler installation was $75,761. As the buildings are almost entirely of reinforced concrete, the reason for installing the sprinkler system was to obtain reduced insurance-rates, particularly on the cargo. If this sprinkler protection had not been installed, the rate on the buildings would have been $0·25 per $100 and on the contents $0·85 per $100, whereas with automatic sprinkler equipment installed the insurance on the buildings was reduced to $0·10 per $100 and on the contents to $0·30 per $100. It was estimated that the net annual saving on insurance by installing the sprinkler system was about $10,000.

Equipment.—Semi-portal electric cranes were provided along the fronts of the sheds spanning the two railway-tracks. The leading dimensions of the cranes are:

Capacity	6,000 lbs. (3 Canadian tons)
Test load	7,000 lbs.
Minimum outreach from face of quay	20 feet
Maximum ,, ,, ,,	45 ,,
Height of rise above quay-level, revolving type	60 ,,
Height of rise above quay-level, straight-line type	45 ,,
Depth below quay-level	60 ,,
Distance between centres of tracks	27 feet 6 inches
Hoisting speed, with 6,000 lbs.	175 feet per minute
,, ,, ,, 3,000 ,,	300 ,, ,,
Sluing speed	$1\frac{1}{2}$ revolution per minute
Travelling speed	100 feet per minute.

Wheel loads in the worst condition of loading in the case of the front pier rail do not exceed 60,000 lbs. for a single wheel, and 36,000 lbs. if two wheels are used 5 feet apart. For the rail on the upper storey of the sheds, the loads must not exceed 32,000 lbs. and 20,000 lbs., respectively.

Fenders are fixed to the cranes so as to prevent any two cranes from being placed too close together.

Four cranes were of the Stothert & Pitt type, two by Babcock & Wilcox, and the original intention was to supply two only of a comparatively new type of crane known as the "Modern Method" straight-line type, manufactured by the Colby Steel & Engineering Company, Vancouver. It was decided later, however, to increase the number of the straight-line type to seven, as it was found feasible to add a supplementary grain-conveying gallery to the boom of the crane, so that the straight-line cranes, when not in use for handling general cargo, could be used for grain-loading, or vice versa. These are of steel construction throughout. The straight-line cranes have an ultimate capacity of 10,000 lbs., an average working capacity of 6,000 lbs., and a high-speed gear device for handling 3,000 lbs. The hoisting-speed on the 6,000 lb. load is 175 feet per minute, while on the 3,000-lb. load it is 300 feet per minute. The cranes are moved along the face of the dock to any desired point, under their own power, controlled by the operator in the cab through the combined hoist and power unit. On these cranes only one motor is used. The straight-line or trolly movement of the load hook along the boom in connection with the hoisting motion constitutes the main movement in the process of transferring cargo. The crane travels along the pier to gain a favourable position relative to the ship's hatches. A combination of the travel and swinging motions may be employed when necessary for moving heavy loads direct between ship's hold and railway-wagon or motor-lorry.

Electric Freight-Elevators.—Each of the sheds is equipped with one electric freight-elevator. The purpose of these elevators is to transfer electric or other types of small trucks from the one floor to the other; they are not intended for teams or heavy carriages, as the upper floor of the sheds is only designed to carry 350 lbs. per square foot. The freight-elevators handle a maximum load of 18,000 lbs., the cars, 18 feet by 12 feet, being large enough to permit electric or petrol lorries and trailers to be run on and off. The cars have gates at each end, so that the trucks may run right through, and fireproof doors and standard safety appliances are provided.

In order to avoid the use of a penthouse projecting above the ordinary level of the shed-roofs, the cables are anchored to "dead-men" on the upper floor and pass on sheaves underneath the car to the elevator machine, also on the upper floor, but on the opposite side to the anchorages, so that the car practically rests in the slack of the main cables between the anchorages and the machine. The counterweights travel inside the shaft, and their cables pass over sheaves which are located just beneath the shed-roof. These elevators are driven by 35-B.HP. squirrel-cage induction motors.

Escalators.—One escalator is provided in each shed for transferring general freight from the pier deck floor to the upper floor. These escalators are capable of handling packages about 5 feet in width and up to 1,000 lbs. in weight at 60 feet per minute. Each is operated by a 1·5-HP. Lancashire motor placed on the first floor of the sheds.

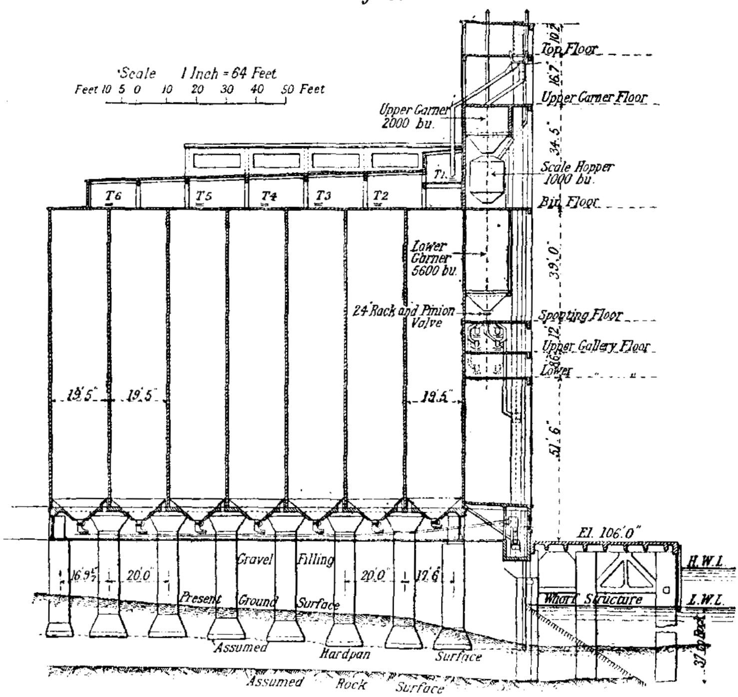
Capstans.—A number of electric capstans of the usual type have been provided in different places for hauling railway-cars when necessary.

Grain-Elevators.—New reinforced-concrete grain-elevators, having a total storage-capacity of $1\frac{1}{2}$ million bushels, have been completed, and other grain-elevators for private owners are in course of construction. The principal business of the grain-elevator plant (*Fig. 6*) installed on Shore Quay is to receive grain from the car-unloading shed, to clean and store it, and to ship it to ocean boats via shipping-galleries on Ballantyne pier and at the jetty gallery to the east of the elevator plant.

Grain is received in the car-unloading shed, which contains twelve pits, each capable of receiving 1 car per half-hour. It is carried on three belt conveyors through tunnels to the receiving-house, where it is elevated, weighed, and discharged to conveyors running over the storage-bins. If it is desired to clean the grain, it is discharged directly from the scales to garners over the cleaning-machines, the cleaned grain being spouted to re-elevating legs, weighed, and discharged to conveyors running over the storage-bins.

The cleaning-equipment consists of sixteen No. 12 separators, which clean the grain, if desired, as fast as it is received. The screenings from all the separators are collected by screw conveyors and elevated by a small leg (in the centre of the receiving-house) to bins.

Fig. 6.



GRAIN-ELEVATOR.

For separating wheat from oats, a double Carter-disk machine is provided: it is fed from a garner that can be supplied with grain from receiving-leg No. 1 or from the transfer belt which is fed from the shipping-legs, and thus can be reached from any part of the storage-house.

Grain in storage is drawn for cleaning from a storage-bin, conveyed to the shipping-leg, elevated to the top floor of the shipping-house, spouted to transfer belt T1, from which it may be spouted to the oat garner, one of the separator garners, or to transfer belt T7 in the receiving-house, and distributed to any of the other garners. After grain is run from the upper garner through the separators, it is spouted into the boot of a cleaner leg, elevated above the scales, weighed, and spouted to the bin-floor belt, either direct or by means of transfer belt T7, and returned to the storage-bins.

For shipping from storage-bins through the scales to the shipping-galleries the grain is drawn from a storage-bin, conveyed to a shipping-leg, elevated above the scales, weighed, and spouted through the lower garner to shipping-conveyors leading to shipping-galleries.

After the grain is stopped, any that remains in the garners or scales may be spouted from the lower garner to the shipping-leg, elevated to the top floor of the shipping-house, and spouted to transfer belt T1 in storage, and from there it may be spouted to storage belt T2 or to transfer belt T7 in the receiving-house, from which it may be discharged to any one of the storage belts T3, T4, T5, or T6 and be returned to the bin whence it came.

Grain to be turned over in storage is drawn from a storage-bin, conveyed to the shipping-leg, elevated to the top floor of the shipping-house, spouted to transfer belt T1, and thence spouted to bin-floor belt T2 or to transfer belt T7 of the receiving-house, from which it may be spouted to bin-floor belts T3, T4, T5, or T6 and returned to the bin whence it came.

Grain may be loaded to railway-wagons by means of a spout receiving grain from the end of the transfer belt in the shipping-house.

Structures and Equipment.—The foundation consists of concrete cylinders bearing on hardpan. The cylinders are in general 7 feet in diameter, enlarged at the bottoms to give bases 13 feet in diameter. The bearing-pressure on the hardpan is approximately 10 tons per square foot. The outer row of columns of the shipping-house rests on the inner row of the cylinders which form the foundation of the concrete wharf.

The receiving-house is of reinforced concrete and is supported partly on the storage-bin walls and partly on independent columns. The principal equipment consists of three receiving-legs, four 2,500-bushel scales, each with one 1,500-bushel garner above and four 1,000-bushel garners below, sixteen Monitor No. 12 Style B receiving-separators, one No. 2523-A double Carter-disk oat-separator, two cleaning-legs, one screenings-leg, one oat-leg, and four screw conveyors. Provision is made for the future installation of screenings-separators. There is also one passenger elevator.

The storage-house consists of fifty-six circular bins, 20 feet in diameter by 100 feet high, each of 23,500 bushels capacity; forty-two interspace bins each of 5,000 bushels capacity; and fifteen interspace bins each of 2,500 bushels capacity; making a total capacity of 1,560,000 bushels. The storage-house is entirely of reinforced concrete, except for the beams supporting the bin floor, which consists of a $2\frac{1}{2}$-inch concrete slab, resting on, but not anchored to, steel beams. Each bin has individual ventilation to the outside air. There are two monitors over the storage roof. In the basement are eight 36-inch belt conveyors with a spout and leader from each bin. In the storey over the bins are five 36-inch belt conveyors, each with a two-pulley tripper feeding the bins, and there is also one 36-inch belt conveyor receiving grain from the shipping-legs and delivering to the north end of the receiving-house.

The shipping-house is of reinforced concrete and is supported partly on the storage-bin walls and partly on independent columns. The principal equipment consists of six shipping-legs and six 1,200-bushel hopper scales with 2,000-bushel garners above and 5,600-bushel garners below.

A dust-collecting system has been installed for conveying dust from cleaning machines, floor-sweeps, all belt-conveyor head spouts, and all elevator boots to dust-collectors located outside the buildings. The dust from the collectors is to be spouted to housed-in receptacles, from which it will be carried away. The dust-collecting system extends throughout the receiving-, storage-, and shipping-houses.

A compressed-air system has also been installed for blowing dust out of motors and assisting in general cleaning in inaccessible places. This system extends throughout the receiving-, storage-, and shipping-houses.

All power is electric. The current for motors is 550 volts, 60 cycles, three-phase. Current for lighting is 110 volts, 60 cycles, single-phase. A complete electric lighting system is installed through the elevator-plant, and the heating of weighmen's offices is by electric heaters.

Drives to the receiving-, cleaner-, and shipping-elevator legs are double-reduction double-helical gears. Drives to the screenings and oat legs are double-reduction silent chain and roller chain drives without friction clutches. Drives to screw conveyors and Carter-disk separators are light double leather belts with friction clutches for the conveyors only. Drives to screw conveyor counter-shafts are $\frac{7}{8}$-inch manila transmission ropes. Drives from counter-shafts to warehouse separators are double leather belts with friction clutches. Drives to fans and air compressor are Whittle belts. The Engineers for the grain-elevators are the John S. Metcalfe Company, Limited.

Conclusion.—The very rapid increase of business of the port is shown by the fact that the number of ocean-going vessels entered inwards from foreign ports in 1923 was 68 per cent. more than in

1921. For the same period the net registered tonnage increased 51 per cent., whilst the cargo shipped to foreign ports increased 193 per cent., and there is an even greater corresponding increase for the first quarter of 1924 over 1923. In regard to shipments of lumber, there has been a 550-per-cent. increase in cargo shipments in the past 5 years, the quantity rising to 521 million feet.

In the Author's report to the Government on this harbour in 1912, he stated that in his opinion the grain-crop from the Province of Alberta and at least part of Saskatchewan could and should be shipped more profitably from Vancouver than from the Eastern ports, which involved a long railway journey. It is only recently, however, that effect has been actually given to this view, and apparently the grain-acreage likely to ship from Vancouver has very materially increased, as in 5-year periods the average acreage under wheat in the three Western Provinces was :

	1911 to 1915.	1916 to 1920.
Manitoba . . .	2,830,000 acres.	2,748,000 acres.
Saskatchewan . .	6,617,000 ,,	9,748,000 ,,
Alberta . . .	1,650,000 ,,	3,550,000 ,,

It will be seen that the Alberta acreage has increased about 120 per cent., and for 1923 the Alberta acreage increased a further 62 per cent. to 5,628,000 acres.

In addition to the foregoing works, several grain-loading jetties for large vessels are being constructed, mostly of reinforced-concrete cylinders similar to the type used in the Ballantyne pier, and, in certain places, of timber cribwork sheathed on the outside with reinforced concrete so as to protect the timber from attack by marine worms. A new dry dock, pier, and large ship-repairing yard are under construction for the Burrard Dry Dock Company. A new railway and vehicular bridge across the harbour is now being constructed, which will give good railway connection to the whole of the North Shore and North Vancouver. The Author is Engineer of these works.

The Resident Engineer in charge of the whole of the works since their commencement has been Mr. E. H. James, Assoc. M. Inst. C.E., assisted by Mr. T. W. W. Parker, Assoc. M. Inst. C.E., Mr. R. M. Wynne-Edwards, and Mr. A. L. Harvey. The Author desires to record his indebtedness to these gentlemen.

The Paper is accompanied by ten tracings, two blue prints, and two drawings, from some of which the Figures in the text have been prepared.

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