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“Pier-Foundations of the Wanganui Bridge, New Zealand.”

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THE main road from Wellington, the capital of the Dominion, at the southern extremity of the North Island, along the west coast to Taranaki, passes through the town of Wanganui, situated near the sea, on the river of the same name.

Early in the settlement of the Dominion it was found necessary to bridge the river, which for a considerable distance inland is wide and deep and quite unfordable. The Provincial Government of Wellington in existence at that time accordingly entered into a contract with Messrs. Kennard, of London, for the manufacture, and with Mr. H. McNeill, of New Zealand, for the erection, of a bridge consisting of wrought-iron lattice-girders, carried on cast-iron cylinder piers, to plans prepared by the late Mr. Robert Stephenson, Past-President. The erection of the bridge was completed during 1871, and it was opened for traffic on the 29th November by the Governor, Sir George Bowen, the date being about 30 years after the first settlers arrived in the district.

Nearly the whole of the basin of the Wanganui River is hilly to mountainous and covered with dense forest, with the undergrowth of shrubs, ferns and mosses characteristic of the New Zealand indigenous forest. This dense forest has the effect of materially reducing the discharge of the rainfall, and also the rate of discharge, thus extending it over periods much longer than the duration of the rainfall. The forest thus acts as a reservoir, and this effect is so marked that in many places small creeks and river-beds suffice to carry the discharge. The destruction of the forest to obtain timber for industrial purposes and to clear the land to allow of settlement by farmers has naturally curtailed the forest reservoir, so that the rain discharge is not extended for so long a period as formerly, heavier floods of shorter duration occurring.

Immediately below the bridge, on the right bank, is situated the railway station and the shipping wharf or quay. As the town had

been surveyed and land alienated without making suitable provision for the railway station, it became necessary to encroach upon the river-channel to the extent of reclaiming sufficient land for the purpose, thus reducing the width of the waterway at the bridge by 205 feet, or 27 per cent.

The bed of the river at the bridge consists of alluvial matter, containing sand, mud, a little gravel, and timber from trees washed down from the forests above. The increasing intensity of the floods, coupled with the narrowed waterway, increased the velocity of the current to such an extent that serious erosion of the left bank occurred, also deepening of the river, the alluvium offering little resistance to scour.

At the time of the erection of the bridge the depth of water at high tide at Pier No. 5 was 27 feet, and at Pier No. 6, 14 feet. During a very heavy flood, some time before it was decided to strengthen these piers, erosion occurred which lowered the bed of the river to within about 5 feet of the bottoms of the cylinders, giving a depth of about 42 feet at high tide. A succession of minor floods caused silting, until the depth was about 32 feet at each pier when the cylinders were lowered. High floods rise about 7 feet, or within 4 feet of the under side of the girders, when the depth of water will be about 49 feet after the scouring of the recent silting has taken place.

It seems remarkable that no settlement of the cylinders occurred, considering the soft nature of the river-bed and the short length of support remaining. At the time of the heavy flood the water was about 47 feet deep at the two piers and running with a velocity of at least 10 miles per hour, carrying large quantities of heavy drift timber, including whole trees, with roots and branches, from 40 to 70 feet in length over all, and up to 4 feet in diameter of bole. The bridge is situated immediately below a sharp bend in the river and where the channel is narrowest, so that it has to bear the brunt of the current at maximum velocity.

It soon became apparent that the foundations of the piers were being seriously weakened, so preventive steps were taken by depositing some heavy rock around them. This acted well for some time, but as the floods continued to increase, and the scour to undermine the rock, it became apparent that further measures must be taken to prevent destruction of the bridge. As several floods had risen higher than formerly, causing inundation of the lower parts of the town along the right bank, anything which tended to reduce the water area had to be avoided.

The Borough Council of Wanganui, in whom the bridge is vested, obtained the opinions of several engineers, who submitted reports on alternative schemes for protecting the foundations, but as the reports lacked definiteness, the Council, as laymen, demurred at accepting the responsibility of deciding which scheme to adopt: accordingly, the Author, who had in the meantime been appointed Engineer-in-Chief of the Dominion, was asked to report, with a definite recommendation.

After examining the bridge, the original plans, flood-records, and recent surveys of the river-bed, it appeared that the only way to minimize flooding of the town and to avoid abnormal increase in the velocity of the river-current was to allow the channel to deepen, as it could not be widened. The plan of depositing rock around the piers could not therefore be entertained. To provide for the deepening of the river it became necessary to sink the cylinders of two piers deeper, which was accordingly recommended and adopted by the Council, the Author being entrusted with the carrying out of the work.

The piers each consist of two cylinders of cast-iron plates, connected together above high-water mark by open bracing of angle-bars. The cast-iron cylinders, 7 feet in external diameter, were originally sunk by dredging inside. Owing to the soft nature of the bed of the river, it was not possible to remove the soft material down to the bottom of the cylinders, and the lower part of each cylinder was filled with mud for from 5 to 8 feet, upon which the concrete filling rested. This, however, had not apparently affected the stability of the piers, as no movement or settlement could be detected, in spite of the rough treatment to which they had been subjected. The cylinders were found to be in an excellent state of preservation, so little corrosion having occurred that there was no hesitation in sinking them lower instead of replacing them by new cylinders.

Several schemes were considered for obtaining a deeper foundation, the first being to pull the existing cylinders over so as to lie parallel to the stream and sink new cylinders, thus avoiding interference with the scouring of the bottom necessary to obtain increased waterway. Another scheme was to surround the existing cylinders with others slightly larger, so that the existing cylinders might be recovered for use elsewhere. The scheme adopted was found on carefully preparing estimates to entail the least expense.

Staging.—The first work undertaken was the erection of suitable staging. The design required much consideration, owing to the depth of water, soft river-bed, heavy floods, driftwood, and load to

be supported. The load consisted of the bridge girders with traffic, also the derrick used to lift the air-lock and plates into position. In addition, the staging was required to act as a guide to the

Figs. 1.

STAGING.

cylinders when sinking and to support them. It was finally decided to drive piles as shown in *Figs. 1*, suitably connecting them with diagonal braces and horizontal walings and caps.

The erection of the staging was attended with some difficulty, through the great length of pile necessary to reach a depth which would be clear of risk of disturbance during the progress of the sinking. Owing to its enormous strength and toughness, ironbark (*Eucalyptus paniculata*, *siderophloia* or *crebra*) was used for the main piles of the staging, the secondary piles being of white pine, an indigenous pine timber of harder and closer texture than the European pines. The ironbark piles, in 50-foot lengths, were driven as far as possible by means of a dolly. They were then lengthened by joining on extension pieces in the manner indicated in *Figs. 2*. Several forms of joint for lengthening the piles were tried, but that shown was the only one which would stand the driving. The dowel is to prevent any tendency to lateral movement during driving. It was found to be absolutely necessary.

The size of the bolts holding the iron scarfing cylinder to the pile was determined by trial—at first $\frac{7}{8}$ inch in diameter, and finally $1\frac{1}{2}$ inch in diameter, the smaller bolts being sheared off by the iron plate, the friction against the pile being insufficient to overcome the inertia of the plate when the pile received a blow from the pile-driving ram.

The piles had to be driven deeply, so as not to be disturbed during the cylinder-sinking, which would have probably caused damage to the spans which were resting on the staging. For the braces, etc.,

Figs. 2.

below water green timber was used, so as to avoid inconvenience by floating when being fixed in position. On several occasions during the progress of the work floods brought down considerable quantities of driftwood, which collected against the staging, causing some anxiety as regards its stability; but constant vigilance enabled it to be removed before the accumulation became dangerous. The drift often consisted of trees up to 40 feet in length and 3 feet in diameter.

The girders having to be supported between two panel-points, a temporary solid web-plate was riveted to the chords and stiffened. To continue the sinking it was decided to sink a shaft 3 feet in diameter down the full depth of the cylinder, namely, 53 feet (the depth of the cylinders was 56 feet, but 3 feet were removed from the top as hereinafter mentioned).

Cylinder-Sinking.—As the bridge could not be closed to traffic, and as there was not sufficient room between the under-side of the bridge and high-water mark to admit an air-lock and allow sufficient margin for sinking, several schemes were worked out, but all were abandoned in favour of removing a short length of cylinder at the upper end of each and using a dome top, to which the air-lock was attached (*Figs. 3*). The top consisted of a hemispherical dome, with a trunk on one side to support the air-lock and form a passage-way between cylinder and air-lock. On the opposite side of the dome two cantilever girders were fixed, and connected with the trunk, to carry counter-weights. On the lower side of the trunk the shoot usually attached to the air-lock was fixed where shown, and through this the excavated materials were ejected. This was, however, not much used, as the men preferred to pass both the outgoing and incoming materials through the shoot when attached to the air-lock in the usual position.

To facilitate the sinking of the shafts, a small hammer-drilling machine, worked by compressed air, was used with good effect, small holes being drilled and small charges of explosive used to avoid damaging the surrounding concrete and the cast-iron cylinder. The rate of progress exceeded expectations. On reaching the bottom it was found that the last 6 feet had not been filled with concrete, as it had apparently been found impossible to remove the mud and fine silt right to the bottom. Experience gained in the further sinking showed that this is what had happened. The concrete above water-level proved to be hard and of good quality, but below water-level it was inferior and softer, showing that whatever system had been adopted for placing the concrete in position under water had not been perfect. As the cylinders were not sunk by the pneumatic process, no visible attempt had been made to render

them water- or air-tight. This caused great loss of air, so that in several places a diver had to caulk the leaks outside.

Directly each cylinder had been got into working order for

Figs. 3.

sinking, the silt in the lower length of cylinder below the concrete was removed. The air-pressure being then released, the cylinder sank without difficulty, the concrete remaining therein proving of

sufficient weight. This procedure was repeated until the additional depth of 30 feet had been reached.

At the bottom of each cylinder 2 cubic yards of rough broken stone were first placed, then a layer of canvas, then about 6 feet in height of concrete, under air-pressure, which was maintained until the concrete had set sufficiently to resist influx of water (about

Figs. 4.

24 hours). The air-lock was then removed and the shaft filled to the top at atmospheric pressure.

The two cylinders in each pier were connected above low-water mark by a substantial diaphragm, which was connected diametrically through each cylinder with the opposite side, so as to avoid all risk of rupturing the cylinder should the diaphragm exert excessive tension from any cause, as usually diaphragms or connecting braces are only attached to the adjacent faces of the cylinders. The diaphragm (*Figs. 4*) consisted of $\frac{1}{2}$ -inch mild-steel plates, stiffened

with angles, and riveted to a $\frac{1}{2}$ -inch gusset extending to inside the cylinder, through the joint of the cast-iron cylinder-plates. This diaphragm served the double purpose of bracing the cylinders together and preventing driftwood during floods from catching between the cylinders. Heavy trees, when drifting in a position normal to the current, are apt to swing round on striking the upstream cylinder, so that the end passes between the cylinders, in the absence of a diaphragm, when they are liable to catch. Directly one log catches it forms the nucleus of a jam which frequently causes the destruction of a bridge.

When the shaft in the third cylinder was being sunk, a patch of concrete was met with which had very little cement in it. On removing this inferior part it was found that one of the cast-iron plates was cracked, and this, by allowing influx and efflux of tidal water, accounted for the poor concrete. The damaged plate was situated about 30 feet below water-level. After the concrete had been removed a careful examination was made of the plate, but before anything further could be done a large piece of it was blown out by the air-pressure. The piece was recovered by a diver from the river-bed, and replaced in position after several studs had been screwed into it, which on being built into the concrete filling of the cylinder would retain it in position. It was then decided to construct a short length of reinforced-concrete cylinder inside the iron cylinder, covering the damaged plate, and overlapping the sound plates above and below by a few inches, to obtain an air-tight connection. The concrete cylinder was made 12 inches thick and reinforced with $\frac{1}{2}$ -inch bars circumferentially, sufficient to withstand the air-pressure, a few vertical bars being introduced to secure the horizontal bars in position. After the bars were placed in position, a short length of inside profiling of timber was fixed, and concrete placed in position by the "tremie" system. A galvanized sheet-iron tube about 6 inches in diameter, with hopper at upper end, and a short length of canvas tube at the lower end, was used. The tube was first filled with gravel, the canvas tube being closed by tying; the gravel was then allowed to run out, the hopper at the same time being kept filled with 1 : 2 : 4 cement concrete. As soon as the concrete appeared, the canvas tube was directed so as to place the concrete in position. The whole of this work was carried out by a diver in a remarkably short time. After being allowed to set for 3 weeks, air-pressure was applied up to the maximum necessary to complete sinking, when the concrete cylinder was found to be perfectly satisfactory and quite air-tight. The length of the concrete cylinder was 15 feet. To prevent water flowing

through the concrete during fluctuations of tide, the outside of the cylinder was covered with a layer of canvas by a diver, the canvas being held in position by a few iron bands with bolt joints. A hole was bored through a sound part of the old concrete and the cylinder to allow the tide free ingress and egress, to prevent, as far as possible, any difference of level inside and out and consequent pressure on the green concrete. The timber profiling inside was lined with canvas to prevent wash by currents made by the diver when moving about.

The river-bed proved to be very unsatisfactory as a foundation. As sinking proceeded, layers of tenacious mud, with alternate thin layers of fine gravel, were passed through, but on reaching a depth of 74 feet below high-water mark a fairly firm sandy stratum was reached, which was judged sufficiently satisfactory. Up to the present no signs of settlement have occurred. The appearance of caisson sickness among the men engaged in the cylinders induced the suspension of sinking perhaps a little sooner than extreme prudence would have justified.

A very effective jointing material for the cylinder-plates consisted of two parts of lead wire of about No. 12 gauge. Hemp, with red- and white-lead, was, however, principally used. The interior of the air-lock and cylinder was illuminated by electric light produced by a small direct-current dynamo driven by a $3\frac{3}{4}$ -HP. Gardner kerosene engine. An Ingersoll-Rand air-compressor was used, Type XI, 7 inches by 9 inches, two cylinders, vertical, driven by a portable steam-engine. A maximum pressure of 30 lbs. per square inch proved sufficient, being as much as the cylinders were deemed capable of standing with a fair margin for safety.

The sinking of the second cylinder in each pier caused a slight disturbance of the first, which, however, proved no detriment. When the cylinders were completed, the trusses were lowered on to them and allowed to remain for some time in order to ascertain whether any subsidence occurred. One cylinder only showed any signs of sinking, and then only for $\frac{3}{8}$ inch. When it became reasonably certain that no settlement need be feared, the diaphragm between each pair of cylinders was fixed in position. The bridge was carrying considerable fast and heavy traffic, including traction engines and herds of great cattle, during the testing period, which produced severe vibration.

The various strata forming the river-bed caused the sinking to be very erratic. Sometimes the cylinder would only descend a few inches when the pressure was relieved. Generally the movement reached a few feet; but on one occasion one of the cylinders

dropped 11 feet, being then arrested by the air-lock fouling the staging.

Difficulties of an unforeseen nature were continually encountered, which, but for the indomitable energy, resource and perseverance of the officer in charge (Mr. S. H. Agar), would have necessitated radical and expensive alterations in the plans. Once a workman sank in the mud at the bottom of the cylinder so as to require the rigging of a tackle to extricate him, but fortunately no personal injury was suffered.

The depths of the cylinders were originally 56 feet below bed-plates of girders. The final depths are :—

Pier No. 5 . .	85 feet 2 inches upstream, and 79 feet downstream.
Pier No. 6 . .	86 feet 7 inches „ 84 feet 1 inch downstream.

Pier No. 6 is situated on the concave side of the river, where the maximum current and scour occurs, Pier No. 5 being in a less exposed place. The lesser depth of one cylinder in Pier No. 5 was caused through disturbance of the deeper one in sinking the former, it not being considered advisable to incur further risk and remedial expense.

The work occupied about 8 months, being commenced during May, 1909, and completed during December, 1909. The estimated cost of the work was £6,000. It actually cost £5,249. The cost was very much increased through having to keep the bridge open for traffic the whole time, the purchase of special plant, and the broken cylinder-plates.

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The Paper is accompanied by three tracings, from which the Figures in the text have been prepared.