

*(Paper No. 2881.)***"Cylindrical Bridge-Piers : New Zealand Midland Railway."**By HENRY WILLIAM YOUNG and WALTER CLEEVE EDWARDS,  
Assoc. MM. Inst. C.E.

MOST of the bridges in New Zealand cross streams which flow in channels of shingle or other alluvial drifts, subject to constant change from the processes of scour and deposit. Floods also occur, when a tiny stream becomes a wide foaming river bearing down large quantities of driftwood and uprooted forest trees. Under these conditions, the most suitable and usual forms for bridge-piers are those constructed either of driven piles, or of cast-iron cylinders sunk by pneumatic processes and filled with concrete. In timber-bearing streams, the bridge-piers must be capable of resisting the impact of heavy masses, and the piles must be driven well below the limits of possible scour. Driving has been successfully accomplished in most difficult cases by the use of round piles of Australian ironbark, varying from 12 inches to 16 inches or 18 inches in diameter, shod with cast-steel shoes of a hollow conical form weighing 100 lbs. each, and driven by rams weighing 35 cwt., falling through a height of between 6 feet and 10 feet. One such pile, after having been driven through 15 feet of tight gravel and boulders at the rate of forty-eight blows to a lineal foot, from a monkey weighing more than 35 cwt. falling 10 feet, was on withdrawal found to be quite uninjured. As a rule, the scour in shingle beds at bridge-piers does not exceed, and seldom reaches, a depth of 15 feet below the normal bed of the stream; but whenever it occurs about piled or cylindrical-piers, it is advisable to deposit in the cavity around them an apron of heavy angular stones or boulders to ensure immunity from further erosion. For first-class bridges, piers consisting of two cylindrical columns, ranging between  $4\frac{1}{2}$  feet and 8 feet in diameter, have been extensively adopted for upwards of twenty-five years.

The principal object of this Paper is to give some account of the methods, processes, and plant used in cylindrical bridge-piers built since 1887 on the New Zealand Midland Railway. The bridges

consist of series of 66-foot lattice- or plate-girders, supported on piers composed of two columns of cast-iron cylinders 4 feet 6 inches in internal diameter, sunk with the aid of pneumatic pressure and filled with concrete. The bases of some of these columns are enlarged by taper-pieces with 6-foot cutting-rings, Fig. 1, Plate 3, while others are 4 feet 6 inches in diameter throughout, excepting where the cutting-edge projects to 5 feet, Fig. 2. Six bridges of these types have been constructed, viz. :—

1. Arnold River bridge . . . .	six 66-foot lattice-girders.
2. Nelson Creek „ . . . .	five „ „ „
3. Ahaura River „ . . . .	ten „ „ „
4. Mawheranui River bridge . .	eleven 66-foot plate-girders.
5. Mawheraiti „ „ No. 1	ten „ „ „
6. „ „ „ No. 2	four „ „ „

The height of all the bridges has been determined by the highest known flood level, and is arranged to give a safe amount of clearance under the girders. The metal in all cylinders is  $1\frac{1}{8}$ -inch thick, the junction ends having feathered flanges with bolt-holes. The joining edges of the ends of the cylinders project slightly beyond their flanges, and are machined so that they fit neatly together and in accurate alignment. The flanges of joining rings do not meet, as the edge projections cause a space between them, which is securely packed so as to be air- and water-tight, the flanges being fastened together with 1-inch bolts. The highest cylinder ring, Figs. 3, which has no flange on its upper end, is of suitable length to complete the required height of column, and is finished with a capital which slips over and is bolted to it, a few inches of adjustment for height being possible. The capital is kept in position by distance-studs and bolts, and is thoroughly secured by the concrete filling. With cylinders of larger diameter, or where the weight of the pieces is limited by conditions of transport, the rings are cast in segments having vertical joints similar in construction to those between the rings. As the smaller cutting-rings, used where the nature of the foundations and the height of the piers permitted, were to some extent experimental, it may be interesting to compare their advantages with those of the larger rings. The former saved about £50 per pier in concrete and iron, exclusive of the saving due to the reduction of excavation by two-sevenths. The cutting-rings of an internal diameter of 6 feet allow two men to work on the bottom, while those of 4 feet 6 inches diameter give room for only one man. In certain strata it is expedient to have two men in the bottom while sinking a cylinder. In three bridges experience was distinctly in favour of the smaller rings, and proved

that they can be used with advantage under fairly favourable conditions.

In the construction of the piers, the essentials may be classed under the heads of staging with hoisting-gear, pneumatic plant and appliances, placing and erecting, loading, sinking and filling with concrete. The staging, Figs. 4, usually consists of two combined structures, one comprising the erections required for guiding and controlling the cylinders, each formed of six driven piles with their caps and framing, and collectively called a "pig-sty"; the other consisting of piles, braces, caps and stringers between the "pig-sties" for the whole length of the bridge, employed to carry the travelling gantry which is used both for pier and girder construction. It was generally found sufficient to drive the piles of the temporary staging to a depth of 8 feet with a 1-ton monkey, from an outrigged staging pushed ahead of the fixed staging. As the staging was completed, iron rails were placed along the two outer stringer beams, and on these a movable gantry, carrying an overhead crab-winch, commanded the bridge works from end to end. In some cases, where the bridge crosses the bed of a river which is usually almost dry, the "pig-sties" only have been used; the conveyance and hoisting being performed from a temporary tramway laid on the bed of the river, or by overhead ropes and travellers worked from bank to bank.

The pneumatic plant includes a driving-engine, air-compressor, air-receiver, connecting-pipes and air-lock. In one very effective arrangement, the engine and compressor were combined in a direct-acting form, the steam-cylinder being 7 inches in diameter with a 16-inch stroke, and the air-cylinder 9 inches in diameter. The steam is supplied from a vertical boiler. The engine and boiler occupy one side of the engine-shed, the other containing the receiver. The air is cooled if necessary by wet sacks spread over the receiver and the air-lock. In another arrangement the power is taken by belt from a 10-HP. portable engine and applied to the driving-wheel of a 9-inch water-jacketed air-cylinder fixed on the top of the receiver. On the whole, the direct-acting engine and compressor with a separate receiver is to be preferred. It can be made as easily portable and for the same cost as the alternative design, and requires less attendance.

The air-lock, Figs. 5, forms the most important feature of the pneumatic plant. It is cylindrical in form, constructed of  $\frac{3}{4}$ -inch boiler-plate, stayed and strengthened, furnished with a door on the side, a manhole for access to the cylinders in the floor, two reversible shoots projecting outside from opposite sides of the chamber,

and the necessary air-piping, stop-cocks, pressure-gauge and dead lights. A length of rubber piping connects the iron air-pipe with the air-lock. The windlass is worked from the outside, being contained in an air-tight casing bolted on the top of the chamber, the axle passing through the casing in air-tight packing, Figs. 6. The two shoots, Figs. 7, are essential to rapid work. They are simply iron tubes, rectangular in section, with movable air-tight end glands, and are constructed so as to be reversible with either a downwards or an upwards slope from the air-lock. The glands and clamping-bolts have rubber packings, and are easily fixed or removed. Those for the air-lock openings run up and down in slides within the chamber, and are balanced by counterweights hung on light wire-ropes attached to the glands and passing over pulleys. The glands at the outer ends of the shoots are hinged so as to open clear, and are fastened when closed by a hinged clamping-bolt, Figs. 8. The manhole-door, Figs. 9, on the side of the air-lock is hung and closed in a similar manner to those of the shoots. The door between the air-lock and the cylinder, Fig. 10, is hinged to open downwards, and is closed and fastened from above by a clamp bar. All the air-pipe arrangements can be manipulated within the air-lock, and provide means for letting air in or out of the air-lock and cylinder respectively. A life-line secured and kept within the air-lock is provided in case of sudden flooding of the cylinder or of accident to the rope or winch. The bed-plate, which can be changed to suit the size of the cylinder, is a casting bolted to the flanged bottom of the air-lock and to the top flange of the cylinder.

When working, the air-lock man remains inside, and the chamber is kept under pressure with the door open between it and the cylinders, except when men have to pass in or out at changes of shift or other times. The cylinders are, if possible, kept constantly under pressure. When excavated material is passed out, the air-lock man sends down the empty bucket, the windlass being worked by the men outside according to his signals; and on its return full he tips it into one of the shoots, which is then open at the chamber end and closed at the other. Whenever one shoot is full, the air-lock man closes and secures the gland at his end, and signals to the attendant outside, who opens the discharge end and empties the shoot, having previously prepared the other shoot for filling. The chamber man after filling and closing one shoot, opens and fills the other, and by this alternate use of the two shoots, the work is proceeded with continuously without alteration of the air-pressure. Under fairly favourable conditions,

the windlass is thus kept constantly going, and sinking proceeds as quickly as in an open shaft. Four men are required exclusive of sinkers, one being in the air-lock, two at the windlass, and one attending to the shoots and to the guidance of the cylinder.

The staging and plant being ready, a cylinder is placed and erected ready for sinking. If its position happens to be on the bank or dry bed of a river, an open excavation is first made slightly below the water-level. The cutting-ring is then brought forward by the gantry and is adjusted in position. Other rings with air-tight joints are then bolted on to it until a column is built passing up through the "pig-sty" framing and above the staging to the greatest convenient height. The column is then carefully plumbed and secured in a vertical position by the framing and wedges. The tubing and concrete kentledge subsequently described is inserted as the building proceeds, and is completed so far as is necessary; after which, if possible, it is left for a short time to give the concrete time to set. When the column is ready for use, the air-lock is placed on the top of it and bolted with an air-tight joint to the upper flange of the topmost cylindrical ring, when the air-connections are made and sinking under pressure can begin. If the cylinders have to be pitched in water, the cutting-ring and a convenient number of other rings are put together in the "pig-sty" above the water-level. The column thus constructed is carefully lowered and guided into its exact position, and completed as in the previous case, excepting that the tubing and loading are executed under pressure. When pitching a column in a strong current of water, it should be placed a few inches up-stream from its true position, and afterwards moved down by wedging. If placed out of position down stream its adjustment is difficult. To prevent the cylindrical column from being forced upwards by air-pressure, and to insure its descent as the sinking proceeds, it is loaded until it overcomes skin-friction and other resistance, whilst yet thoroughly under control so that it may be readily hung up when necessary. If the loading is insufficient, the column may be lifted with an increase of air-pressure or may fail to descend as the excavation below it is performed, in which event an inrush of drift may occur if the ground is loose. Under favourable conditions concrete loading is sufficient, but where more weight is necessary, rails or other available materials are placed on staging attached to the air-lock bed-plate.

In applying the concrete loading which forms part of the permanent filling, a feature called the "bell" is first formed. This is done by setting up an internal frame of "bell-irons," con-

sisting of 2-inch by  $\frac{3}{8}$ -inch rods bolted to the flange of the cutting-ring joint, sloping upwards at an angle of  $60^\circ$  towards and bolted to an angle-bar ring 2 inches by  $\frac{3}{8}$  inch and 18 inches in diameter, placed horizontally in the middle of the cylinder. Tapering lagging-boards 1 inch thick are then laid over the sloping iron frame which connects the flange of the cylinder with the ring, and upon the lagging concrete is laid. A length of tube, 18 inches in diameter, made of 3-inch by 1-inch timber staves, 6 feet long, bound with light hoop-iron, is then set up above the central ring, and is kept concentric with the cylinder. The annular space between the tube and the cylinder is filled with concrete, another similar length of tube and concrete work is constructed, and so on until the required height is reached. The bell-irons, lagging and tubing, which are easily removable, remain until the sinking is completed, when they are taken out. It is advisable to use more cement in making the loading than is required for ordinary concrete as time seldom admits of its setting, and sinking has often to proceed immediately after the concrete is placed. A safe height should always be left between the bottom of the cutting-ring and the bell, especially where sand or soft material may be met with; otherwise a sudden drop of the column would be dangerous to the men engaged below. The concrete loading is excavated with or without air-pressure as circumstances may require. Sheet-iron bells and tubes have been tried. They were easily set up, but were difficult to unfasten and detach from the concrete, and were abandoned in favour of the timber lagging.

When constructing and sinking a pier, the two columns forming it are under execution at the same time, the air-lock being moved from the one to the other as the operations require. When work under pressure is proceeding, all joints in the apparatus should be frequently examined, and leakage should be carefully guarded against. The compressor should be kept in good order and under careful management, as fitful and unsteady pressure is exceedingly trying to men working under it, and allows the water-level to fluctuate in the cylinder. Success in sinking depends greatly on the intelligence of the engine-driver, who, instead of remaining in the engine-room and working only by the signals, should watch the work carefully and notice the bubbles of air that ascend outside the cylinder. These tell to an experienced eye in what degree the signals for more or less air are to be acted on—the object being to maintain exact equilibrium between the air-pressure within the cylinder and the water-pressure at the bottom of it. Special care must be taken to prevent breakage in the pipe and connections,

and thoroughly to secure the air-lock doors when under pressure. If possible, a column, when once started, should be kept moving until it reaches bottom, as in some ground it is liable to silt up and become plugged if sinking be stopped. Such plugging is often difficult to break through by any air-pressure that can be brought to bear upon it. It is then necessary to probe the bottom round the cutting-ring with bars, and when the level of the water in the cylinders is reduced below that of the river, the bottom crust or plug is further destroyed by stopping the engine and suddenly relieving the air from the cylinder, when the inrush of water from the outside scours up the deposit. During the process of sinking, the column may take a list to one side, or may move bodily out of its proper position from unequal settlement or from the force of the current. By careful manipulation of the wedges which bind and guide the column within the "pig-sty" frames, accurate results can generally be obtained. If, during sinking in loose ground, the position of the bottom of the cylinder is correct, but is not plumb, it can be brought vertical by wedging and careful excavation. If the column is out of position at the bottom, the top is first brought over in a direction opposite to its true position, so that the downward inclination is towards it. It is then sunk for a short distance and wedged plumb, and the process is repeated if necessary until it is accurately in position and vertical. In the bridges referred to, the eye can detect no irregularity in the range of the completed piers. When men are not at work in the cylinders, all manhole-doors should be left open, so as to prevent the accumulation of foul gas. On more than one work in the colony serious accidents have happened from explosions caused by inflammable gas met with during sinking.

The concrete for filling the cylinders is mixed on the air-lock staging, and consists of Portland cement and river gravel. When filling cylinders, the air-lock shoots are reversed so as to incline upwards, and the concrete is passed in by operations similar to those used in passing out the spoil. After the "bell" and tube have been removed, the bottom is lined with tarred canvas; the cylinder-men ascend into the air-lock, the concrete is dropped from the shoots into the cylinders, and after a sufficient quantity has been deposited, the men descend to trim and ram it, the process being repeated until the filling is above water-level, when the air-lock is removed and the concrete is finished to the top. When depositing concrete, the air-pressure should be kept steady and as low as possible, gradually decreasing so as not to blow through the bottom and disturb the cement. The column is completed by

adjusting, bolting, and fitting on the cap-ring. The corbels are bedded on the concrete filling of the cap-ring and are secured by holding-down bolts built in, Figs. 11.

Where the columns are high and are not rigidly connected by cross girders, it is advisable to couple them so as to strengthen the piers against lateral impact or pressure of drift timber. Horizontal stays with cross bracing, unless well above flood-level, are liable to catch and retain drift wood. To obviate this, horizontal cast-iron tubular stays are used, the ends resting in cast-iron sockets bolted to the cylinders. These tubes are made about 6 inches shorter than the distance between the bearings, and the spaces thus left are filled in with cement so as to make a sound joint without the necessity for machining the ironwork to an exact fit. 2-inch iron bolts, with nuts at each end, pass through the pairs of cylinders diametrically and also through the bosses and tubes. The bosses have movable covers to admit the tube-ends and cement, and resemble turned base mouldings. The cylinders sunk passed through gravel with occasional layers of boulders, silt, or other alluvial deposit. The bottom was of soft sandstone locally known as "sand reef," formed of deep-sea sludge. In some cases the cylinders were sunk for a few feet into this "sand reef," which can be excavated with picks and gads.

The work described was executed for the New Zealand Midland Railway Company, the engineer-in-chief being Mr. Robert Wilson, M. Inst. C.E.; Mr. C. N. Bell, M. Inst. C.E., being the resident engineer, until his retirement at the end of 1891. The Authors were respectively Chief Assistant Engineer and Engineer Resident on the Construction.

The Paper is accompanied by five photographs and by four sheets of tracings, which have been used in the preparation of Plate 3.



