SOME NOTES ON MONIER CONSTRUCTION,

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ABOUT twenty years ago, a novel system of construction was invented by one Jean Monier, and is now known by his name. The system, viz: a combination of cement mortar and iron, was perfected by two German engineers, Wayss and Koenen, and thoroughly tested by the "Austrian Society of Engineers' and Architects." These tests proved its great strength, durability and fire resisting properties.

Cement mortar and iron are in appearance very diverse materials, but they have some physical features in common, and when used conjointly, form a strong elastic and almost homogeneous mass, well adapted for works of construction.

Cement mortar is cheap, durable and readily moulded to any required shape; its compressive strength, however, is at least ten times as great as its tensile strength, and when subject to bending moments, it is impracticable to develop the full compressive strength, and at the same time provide the necessary area to resist the tensile stresses. In order therefore, to develope the full compressive strength of the mortar, it has been found necessary to augment its tensile strength, and thus decrease the total area of section, which would otherwise be required.

For cement mortar (3 of sand to 1 of cement) the average compressive strength is about two thousand pounds per square inch, and tensile strength, two hundred pounds, or a ratio of 10 to 1.

Experiments and experience have proved that wrought iron or steel bars are best adapted for this purpose, the ratio of the tensile strength of wrought iron and cement being about 250 to 1.

The chief features of this combination of cement and iron will now be briefly described :—

EXPANSION.

The expansion and contraction of cement mortar and iron are about identical. For a range of temperature of 100° C. or 180° F., the coefficient of expansion of cement mortar is from ·00137 to ·00148, whilst for iron it is from ·001235, to ·00145, so that the combination may be taken as expanding and contracting as one mass.

Elasticity.

From tests made in 1886, and later on in 1892, when a Monier arch, seventy-five feet six inch span, versine fifteen feet one inch, and six feet six and three-quarter inches wide, was tested to destruction by the "Austrian Society of Engineers and Architects" at Purkersdorf; it was shown that the stresses in Monier work distribute themselves over the materials in the direct ratio of their coefficients of elasticity.

The arch at Purkersdorf was designed to carry safely a one sided load of three hundred and six pounds per square foot; the first hair cracks appeared under a test load of 78·5 tons, and the arch failed with a load of 146·1 tons.

From the observed deflections of the arch under various loadings in the earlier stages of the test, the calculated coefficient of elasticity of the cement mortar was two million pounds, and taking the usual coefficient of elasticity for iron, or thirty million pounds, the ratio is 1 to 15. When the first hair cracks appeared, the mean value of the coefficient of elasticity of the mortar was four hundred and sixty-nine thousand pounds, and the ratio 1 to 65.

The average ratio from these tests is 1 to 40, which is the value generally assumed, at point of formation of first hair cracks, though further experiments to determine this ratio are desirable.

Adhesion.

Neat cement and cement mortar, when setting in air diminish, and in water increase their volume, but the mortar on account of the sand it contains, is subject to much less change in volume than the neat cement. This change in volume occurs chiefly during the first twenty-eight days, when the neat cement and cement mortar are most rapidly increasing in strength.

The change in volume when setting, causes the mortar to adhere to the iron, but the adhesion is also due to the chemical action of the cement on the iron, forming an insoluible double silicate of lime and iron, which binds the two materials together, excludes air and moisture from the iron, and acts as a preservative, preventing any deterioration of the iron. The adhesion is not destroyed by vibration or varying temperature, and is at least equal to the cohesive strength of the mortar.

For cement mortar (3 sand to 1 cement) three to six days old, the adhesion between mortar and iron is about three hundred and thirty-six pounds per square inch. Professor Bauschlinger gives the adhesion from five hundred and seventy to six hundred and seventy pounds per square inch of surface for mortar a few months old.

Adopting a mean value of four cwts. per square inch as the adhesive strength of cement to iron, and the ultimate tensile strength of iron as twenty tons per square inch, it will be seen that if twenty-five times the diameter of any rod is embedded in cement mortar, the adhesive strength of the mortar, is equal to the tensile strength of the rod.

In Monier work it is usual to specify the rods to be free from oil, paint or varnish as they would prevent the mortar from adhering to the rod, and in making the joints in the rods, the overlaps should not be less than twenty-five diameters of the rod, so that the adhesion of the mortar to the rod will be at least equal to the ultimate tensile strength of the rod.

Non-conductivity.

Cement mortar and iron are very diverse in this respect, and it is due to the bad conduction of heat by the cement mortar, that the combination is a success and well adapted for fire-proof construction.

Experiments show that high temperatures have hardly any effect on the strength of cement mortars, they have been heated for several hours to a red heat with very slight decrease in tensile strength, and as mortar is a bad conductor of heat, the embedded iron has little tendency to expand.

Monier arches and plates were tested at Berlin in 1893, under conditions similar to what would happen in a large conflagration. They were subjected to a temperature of from 1800° to 2000° F. for one hour, and then suddenly cooled with water; the temperature was determined by the melting point of alloys. On examination, it was found that the heat was only felt for a short distance in the mortar, and the strength or stability of the work was not affected in any way; the arch was subjected to a load of five hundred and thirty-four pounds per square foot without causing any hair cracks, the rapid cooling, however, caused the mortar to peel off in several places.

Description.

The Monier system consists in embedding a rectangular grill or mesh of bars in cement mortar at the proper position to augment its tensile strength; the object of the grill is to take up and transmit the tensile stresses—primary and secondary—bind the mass together and give elasticity to the whole.

The rods forming the grill are wrought iron or steel round bars, consisting of longitudinal or carrying bars to augment the tensile strength of the mortar, and transverse or distributing bars, to hold the longitudinal bars together, and distribute the stresses over the whole grill. The bars are tied at each point of intersection with black iron wire about No. 22 gauge.

The spacing of the carrying bars depends on the amount of tension which they have to take up, but the distributing bars are usually spaced four inches centres, *i.e.* three bars to the foot.

The longitudinal or carrying bars vary from about one inch to three-eighths of an inch in diameter, whilst the distributing bars are three-eighths or a quarter of an inch diameter. These sizes are easily handled and form a flexible grill. Ordinary trade lengths of iron are used, breaking joint with some specified overlap, which for the carrying bars should not be less than twenty-five diameters, and the overlap is usually tied in three places with double wire. The rods and wire must be clean and free from paint, oil or varnish.

The mortar consists of three parts of clean, coarse, sharp sand and one part of Portland cement thoroughly mixed together and evenly moistened throughout with clean cold water, until the mortar has the appearance of moist earth, only sufficient water is used to moisten the materials, so that the mortar shows only a slight moisture on the surface when rammed in position. Mortar so mixed, forms better work than when a larger quantity of water is used. Sometimes fine gravel or screenings are added to cheapen the cost of the mortar, but this does not then of course adhere as strongly to the grill.

Round and oviform pipes and cylinders for bridges are manufactured on the Monier system, in various sizes from one foot six inches to six feet in diameter. Up to two feet six inches in diameter the pipes contain a single steel wire, which is sometimes wound eccentric ; above that diameter they contain two concentric steel wires. The method of construction of the pipes is as follows :—A collapsible steel drum, oiled to prevent the mortar from sticking, is covered with a thin layer of cement grout and mortar. A layer of stout black wire netting is then wound and the ends fastened off, and over the netting a spiral wire is wound and the whole covered with cement mortar; another spiral wire is wound, and the last coat of cement mortar put on. The pipes vary in thickness from one and one-eighth to two and three-eighths inches, and are light, strong and durable.

Various Monier pipes and cylinders, also the holes for the fish plates in the cylinders, are shown by the accompanying plate.

EXAMPLES.

Plates.

Monier plates are used in lieu of buckled plates on an overbridge at Lindfield, North Shore line. The plates, four feet square, six inches thick at crown, and three inches at sides, simply rest on the flanges of the supporting girders, and are covered with metal.

Sewerage and Drainage Pipes.

These pipes, circular or oviform, are made in lengths of three feet seven inches, they are jointed by simply butting the pipes, and covering the joint with wire netting and a layer of cement mortar. They are strong to resist both inward and outward pressure, and are used for the same purposes as glazed earthenware pipes (sewerage drainage, stormwater, etc.,) but they are not so liable to crack, and when cracked do not fall to pieces. Some twelve thousand lineal feet of Monier pipes of various sizes and shapes, have, up to February, 1901, been used in the construction of sewerage works in New South Wales, while about ten thousand lineal feet have been used to carry off stormwater.

Pile Protection.

Pipes eighteen inches internal diameter for hewn piles, and twenty-one inch diameter for round piles, are used for protecting piles in tidal waters from the ravages of the teredo, the protection extends from one foot above High Water Mark to six or eight feet below bed of river. The pipes are not cut by the drifting sand, or acted on by the sea water, and form a strong durable and efficient protection. The pipes are threaded around the piles, jointed up in one length, and then sunk to the requisite depth by the water jet, assisted in some cases with jacks. The joints are made with wire netting and cement mortar (2 of sand to 1 of cement), and the space between pile and pipe filled in with sand, except the top nine inches, which is filled in with fine concrete, and finished off with a concrete cap.

Some seventeen hundred lineal feet of twenty-one inch diameter pipes, and one hundred and thirty lineal feet of eighteen inch diameter pipes have been used up till February, 1901, in protecting the piles of bridges built in tidal waters.

Cylinders.

Monier cylinders are made from three feet six inches to six feet in diameter, about three feet seven inches long, and have proved to be an efficient substitute for cast iron at about one half the cost.

They are used for foundations of moderate depth, and may be sunk by open excavation, or under air pressure, the connections between the cylinders have been designed to withstand a head of water of forty feet. Each cylinder has several pairs of connecting strips built in, the number of which depend on the diameter of the cylinder; between these connecting strips in two adjacent cylinders a fish plate fits, and is secured to the connecting strips by steel wedges.

Red lead, bitumen and cork, and similar preparations are placed between the cylinders before jointing, to keep them watertight; pilot wedges are driven through the connecting strips to press the cylinders together, the permanent wedges are then put in, replacing the pilot wedges, and the holes around heads of wedges filled in with neat cement. Each bottom length of cylinder has a cast iron cutting edge bolted to it, and the cylinders in each pier are braced together with wrought iron bracing.

Monier cylinder piers have been sunk at Cockle Creek to thirty-six feet below water, and at the Wilson River, at Telegraph Point, to a similar depth; contracts have also been let for three other bridges in which they will shortly be used—Mulwarrie Ponds at Goulburn, Wyong Creek at Wyong, and MacIntyre River at Inverell—and so far, four hundred and seventy-seven lineal feet of three feet six inches diameter cylinders, one hundred and twenty lineal feet of four feet six inches in diameter, and seventy-two lineal feet of six feet diameter, have been constructed, or are in course of construction in New South Wales.

Aqueducts.

The first Monier structures erected in New South Wales were the Monier aqueducts across Johnstone and White Creeks at Annandale. They were erected in 1897 by Messrs. Carter, Gummow & Co., for the Sewerage Branch of the Public Works Department, under the direction of Mr. J. Davis, Engineer-in-Chief for Sewerage Construction.

The aqueducts carry the main northern sewer for Annandale and Leichhardt, they are similar in design and connect with sewer tunnels at each end. There are seventeen arches in all, seventy-five feet clear span, and eighty-two feet ten inches from centre to centre of piers. The arches are twelve inches thick at crown, and fourteen inches thick at springing, with a grill of iron bars near the intrados, three inches square mesh, carrying bars three-eighths of an inch in diameter, and distributing bars one-quarter inch diameter, a short length of grill extending twelve feet from each pier, is also placed at the extrados of the arch.

The Monier arches are built of cement mortar 3 to 1, but the small jack arches and aqueduct are built of bluestone concrete. The Monier arches were built from pier to pier each in one day, and bases left on the extrados to form footings for the concrete piers carrying the jack arches. The acqueduct was then built on these jack arches, and expansion joints left over each main pier.

As these works were of a novel character, and the first of their kind in Australia, the Contractors were required to maintain them for three months, after erection, and further to guarantee to remove and replace them by suitable structures, if any defects were found within a period of three years. This period has now expired, and the structures have proved satisfactory.

Bridges.

A road bridge on the Monier principle has just been completed over Read's Gully, Main Northern Road, by the Bridges Branch of the Public Works Department, at a cost of £480.

The arch is about thirty feet span, six inches thick at crown at ten inches at abutments. The carrying bars are three-eighths of an inch diameter, spaced three inches centres, and distributing bars a quarter of an inch diameter, spaced four inch centres, and the grill is tied at each point of intersection with No. 22 B.W.G. black wire, the overlap of the bars is twelve inches, tied in three places with double wire. The bridge is shown by the accompanying Plate.

The scaffolding consisted of gauged timber, planed on one side with sufficient space between the planks to allow them to swell freely when wetted, templates cut to the exact thickness of the arch were then nailed on either side of the scaffolding.

The grill was supported on small pats of cement mortar placed irregularly on the surface of the scaffolding to keep the grill in its proper position. The cement mortar (3 to 1) was spread in two layers, the lower one about one and a quarter inches thick, was rammed between and completely covered the grill, the upper layer was of the requisite thickness to bring the mortar to the top of the templates. It is essential to keep the lower layer about one foot in advance of the upper one, so that the unfinished ends form steps for jointing, and the work must be finished between the supports without any intermission.

The arch was tested with a one sided load of eighty-seven pounds per square foot, consisting of wet sand, and did not give the slightest deflection.

An overheard bridge consisting of three forty-two feet spans, eight inches thick at crown, has been erected by the Railway Commissioners at Strathfield station, partly to carry the road traffic, and partly to support the new station buildings.

Several bridges have been erected on the Monier principle in Victoria.

The bridge across the Yarra (see Plate), consists of three spans each ninety-five feet in the clear, carrying a roadway eighteen feet wide, and two footways each six feet wide. The rise of each arch is twelve feet seven and-a-half inches; thickness at crown, sixteen inches; at abutments, twenty inches. The arches are built of 3 to 1 Portland cement mortar, and contain two lattices, one at the intrados, and one at the extrados consisting of three-eighths inch carrying bars, and quarter inch distributing bars. The total width of the bridge is thirty-two feet over all, and was built in three sections, each outer one eleven feet wide, and the centre section ten feet wide. Centering twelve feet wide was erected the full length of the bridge, and one of the outer sections built across the three spans in three consecutive days, the strip for each arch being built in one day. It was allowed to set for twenty-eight days, and the scaffolding removed and erected for the other outer section, which was built and allowed to set as before; and whilst each outer section was setting, its parapet and spandril wall was built. The outer sections were built with sloping inner edges to wedge in the centre section, the rods of the outer sections also projected. When the second section had set, the scaffolding was removed and erected for the centre portion. The lower grill was then put in place, and connected to the projecting rods of lower grills in the sections already built. The sloping faces of the finished portions were picked over and well rubbed with neat cement grout, and the mortar for the centre portion put in, up to the level of the upper grill, in two layers; the upper grill was then fastened to the projecting ends of the rods, and the remainder of the mortar rammed in place. Each arch took three days to build, or nine days for the whole superstructure. The bridge was tested with a sixteen ton steam roller, and the temporary deflection in no case exceeded one-sixteenth of an inch. The bridge was also tested with a uniform load of one hundred pounds per square foot of roadway and footway, with about the same deflection.

Wheeler's Creek Bridge, near Creswick, Victoria, consists of two seventy-five feet spans, rise sixteen feet six inches; thickness at crown, twelve inches; at abutments, fourteen inches. The arches are built of cement mortar (3 to 1), and contain an upper and lower grill of three-eighths inch, and quarter inch bars.

Moorabool Creek Bridge, Geelong, consists of three spans, two of sixty feet, and centre span of one hundred feet, with versines of nine feet four inches and fourteen feet respectively. The sixty feet spans are eleven inches and fourteen inches thick at crown and springing, whilst the one hundred feet span is fourteen inches and twenty inches. Each arch contains two grills consisting of three-eighths inch and a quarter inch bars.

Reservoirs.

One of the first applications of the Monier system of construction in Europe, was the building of circular tanks and reservoirs up to sixty feet diameter. The first example in New South Wales of this class of construction is the service reservoir at Kiama, designed by Mr. C. W. Darley, Engineer-in-chief for Public works, the Monier portion of which was completed at a cost of £750 (see Plate).

The reservoir is thirty-two feet diameter, sixteen feet high, and when filled within nine inches of the top, has a capacity of one hundred and ninty-two thousand gallons.

The vertical or distributing rods, spaced four inches apart centres, are a quarter of an inch diameter, every fifth rod is, however, three-eighths inch in diameter, the overlap of the rods is seven inches, tied in three places with wire.

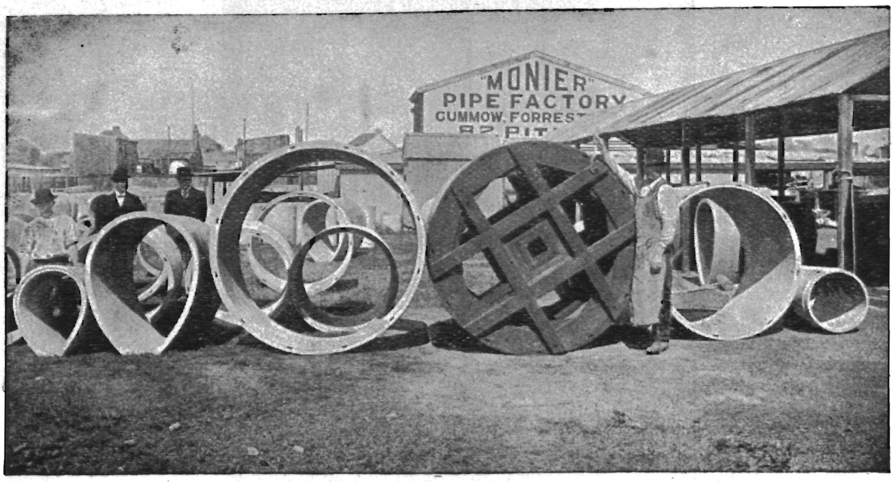
The horizontal or carring bars vary in diameter and spacing, but the overlap of all the rods is one foot six inches, and is tied in three places with wire, the horizontal rods are spaced as follows :—

From	top to 2 ft.	level,	rods are	$\frac{3}{8}$ in.	diameter,	4	per foot.
,,	2 ft. to 4 ft.	,,	,, ,,	$\frac{3}{8}$ in.	,,	5	,, ,,
,,	4 ft. to 6 ft.	,,	,, ,,	$\frac{1}{2}$ in.	,,	5	,, ,,
,,	6 ft. to 8 ft.	,,	,, ,,	$\frac{5}{8}$ in.	,,	4	,, ,,
,,	8 ft. to 10 ft.	,,	,, ,,	$\frac{5}{8}$ in.	,,	5	,, ,,
,,	10 ft. to 12 ft.	,,	,, ,,	$\frac{5}{8}$ in.	,,	6	,, ,,
,,	12 ft. to 14 ft.	,,	,, ,,	$\frac{3}{4}$ in.	,,	5	,, ,,
,,	14 ft. to 16 ft.	,, (bott'm)	,, ,,	$\frac{3}{4}$ in.	,,	6	,, ,,

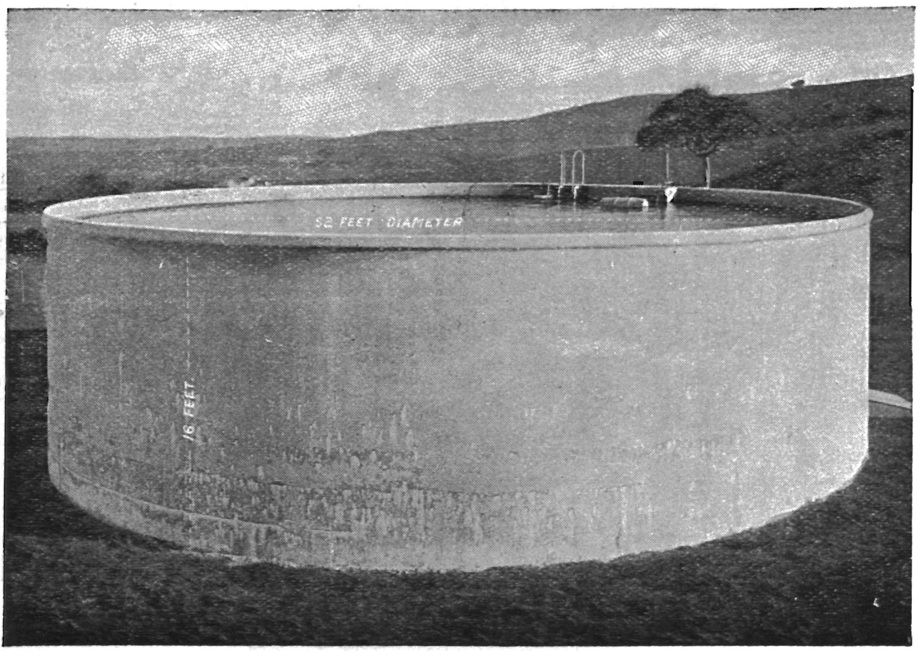
The mortar consists of three parts sand to one part cement, the Monier work is three and one-quarter inches thick at top and nine inches thick at bottom, including inside and outside floating.

The wall is taken down into the rock, and the surface of the rock forming the bottom of the tank, is covered with a layer of concrete.

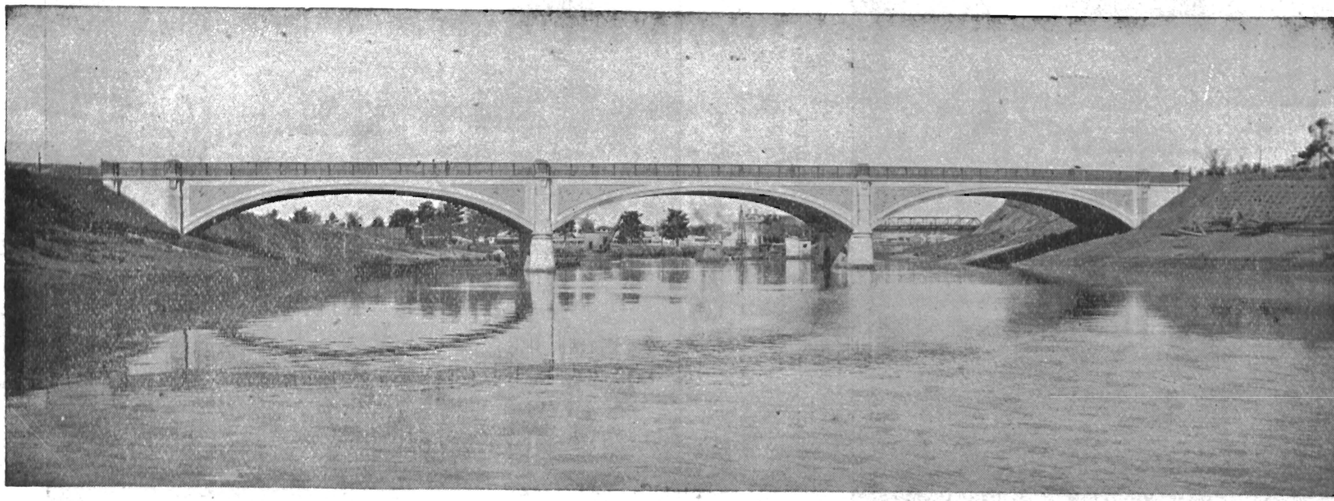
In conclusion the author wishes to thank Mr. Hickson, Under Secretary for Public Works and Commissioner for Roads, for permission to use the Plans of the Department, also Mr. Baltzer for his kindness in supplying much of the information contained in the paper.



Monier Pipes and Cylinders.



Monier Storage Reservoir, Kiama.



Monier Bridge over Yarra River, Melbourne.

Read's Gully, Main Northern Road.