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THE MONIER SYSTEM AND ITS USES.

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In response to the invitation of the Council to supplement a paper on the Monier System, read by Mr. Cutler last year, the author from the many sources at his command, compiled a paper which he hopes will prove of interest, knowing that this system has been very prominently discussed during the last twelve months. To make the paper more interesting and easy to follow, the author has refrained from entering into any abstruse calculations or intricate theories, contenting himself with touching upon the general principles of the system, and bringing into notice the opinions and experience of none but leading engineers and scientists, together with the results of authenticated tests.

MONIER SYSTEM.

The component parts of constructions built on the Monier System referred to in this paper are:—

1. Round iron bars, and
2. Cement mixtures which are combined to form one mass.

The principle of this combination is to augment the tensile strength of the cement mixtures in those sectional areas, which are subject to tension by the judicious insertion of iron, in order to utilise to the fullest extent the great compressive strength of the former, and also to add elasticity to the construction.

It is well known that the tensile strength of cement mixtures is only from 1/10 to 1/20 of its compressive strength, consequently that part of the sectional area subject to tension must either be disproportionately larger than the part subject to compression, or if constructed of rectangular cross section, it must be designed entirely with regard to the tensile strength of the cement mixtures only, thus sacrificing a very large quantity of material in that area, which is subject to compression. To avoid this, the principle of the Monier System can be adopted, and thus the great compressive strength of the cement mixtures can be rationally utilised.

The principle of the Monier System, viz., the embedding of the iron bars in cement mixtures, is mainly dependent on three salient points:—

1. The adhesion of cement mortar to the Iron.
2. The action of the two materials under varying changes of temperature.
3. The impossibility of oxidation of iron embedded cement mixtures, and consequent non-destruction or loosening of the iron.

With regard to these points, no greater authority than the Late Professor Bauschinger, of the Technical High School, Munich, need be referred to, he being one of the leading authorities of the day on Building Materials, and recognised as such in the best English Engineering works on the subject.

In a report dated 20th December, 1887, he makes the following statements:—

1. "The adhesion of the two materials, cement and iron, is from 570 to 670lbs per square inch.

2. "Regarding the action of the two materials under varying changes of temperature, my tests to determine the co-efficient of expansion of cement mortar carried out in 1876, as well as those I carried out recently, showed that the co-efficient expansion of cement mortar cannot under all circumstances be accepted as equal to that of iron, but

it may be taken for granted, judging from the action of the tested Monier Objects, that no separation of the iron and cement Mortar, prejudicial to its strength, takes place, even under high and rapid changes of temperature, for the reason that the elasticity and great adhesion of the materials equalise any variations that may arise in the co-efficient of expansion and contraction between cement mortar and iron."

"Relative to the impossibility of oxidation of the iron in the cement, I may state that as the result of adhesion tests made with Monier objects three months old and exposed to all weathers, that the irons cut out of the cement mortar were perfectly clean and free from oxidation, whereas the exposed ends were very much rusted."

In his second report, dated 27th July, 1892, the Professor deals with the examination of fragments of Monier objects made in 1887, and states:—

"These objects had been exposed to all weathers for five years, some being nearly always covered with water (in a sewer inlet), frequently intermixed with urine. From the tests made I am satisfied that cement mortar in Monier objects adheres strongly to the iron insertions, and that the iron remains perfectly free from rust in spite of the influence of all weathers, and frequent changes of temperature."

These extracts from the reports of one of the most eminent scientists in the researches of building materials should be sufficient to set at rest all doubts concerning these three salient points of the principles of the Monier System. And taking these into consideration, it is evident that a combination of iron and cement mortar, as carried out in this principle, must form a homogeneous and elastic body, expanding and contracting conjointly—subject to the co-efficients of elasticity of materials—and not less durable than cement mortar itself under climatic changes.

The principal advantages of this system are:—

1. Strength, combined with elasticity.

2. Fire resistance.
3. Lightness in construction and saving in space.
4. Quickness and simplicity of erection.
5. Cheapness.

STRENGTH.

Regarding the Strength of the Monier Structures, the results of a few of the principal tests will be sufficient to allow a comparison to be made with structures of other materials.

The most important tests of arches were those carried out at Matzleindorf, in 1889 and 1890, and at Purkersdorf in 1892.

The Matzleindorf test was instituted by the Imperial South Railway Company in order to satisfy the demands of the Goverment regarding the suitability, or otherwise, of the Monier system for overhead bridges.

The Railway Company was obliged, through the alteration of its rolling stock, to increase the height of its existing overhead bridges on the Liesing to Felixdorf line and after careful consideration and tests, they decided that the Monier System was the most suitable to allow of this being accomplished without raising the existing road levels, and at the same time the cheapest, as iron structures involved a very large expenditure.

An arch 32ft. 8in. span, 13 feet wide, 6 inch thick at the crown, and 8 inches at the abutment was erected, and tested exhaustively, first with rolling stock, and then with a one sided load of iron rails, with most satisfactory results, the arch finally collapsing with 17cwt. 3qrs. per square foot owing to the abutments spreading.

The most exhaustive and scientific tests of arches on record is the one made at Purkersdorf, in 1892. It was carried out by the Austrian Engineers' and Architects' Association to obtain the fullest information in order to prove and perfect the theory of the arch construction.

Four test arches were built:—Rubble, Brick, Concrete, and Monier. Each arch had a span of 75 feet 5 inches, versed sine of 15 feet 1 inch and a width of 6 feet 6¾ inches.

These arches were calculated to carry with safety an equally distributed one sided load of 306lbs. per square foot horizontal surface. The tests were made with a one-sided load extending to the crown, the load being placed on an iron staging which transmitted the pressure by means of six supports on to level and equally spaced footings built on the Arch.

The first hair cracks occurred in the Rubble under a load of 56.5 tons, in the brick arch under 42.2 tons, in the concrete arch under 63.3 tons, and in the Monier arch under 78.5 tons.

The Rubble arch collapsed under 74 tons.
The Brick arch collapsed under 67.5 tons.
The Concrete arch collapsed under 83.3 tons.
And the Monier arch collapsed under 146.1 tons.

Making a comparison of these figures it will be seen that the breaking load of these arches compared with the Monier Arch (the latter taken as 100) is:—

For Rubble	51
For brick	46
For Concrete	57
And for Monier	100

And comparing the tensile strengths of the materials used it is found that the tensile strains which caused the first hair-cracks in the different sectional areas varied:—

In the Rubble arch from 95 to 133lbs. per sq. in.
In the Brick arch from 58 to 109lbs. per sq. in.
In the Concrete arch from 205 to 369lbs. per sq. in.
In the Monier arch from 522 to 712lbs. per sq. in.

thus demonstrating the great tensile strength and homogenity of the Monier material.

A test of two arches was made at Forest Lodge on the 14th November, 1895, in the presence of Mr. C. W. Darley, Engineer-in-Chief for Public Works. The arches were built on the 18th September, 1895, and were, therefore, only two months old when tested.

The span of the arches was 20 feet 6 inches; width 4 feet; versed sine 1 foot 10 inches; thickness at crown, 3 inches; and at abutment, 5 inches.

Gauges were fixed on to the faces of the arches, and constructed to register both vertical and horizontal deflections.

The loading consisted of Pig-iron, bags of cement, and sand carefully weighed and distributed over the arches, amounting to 34.5 tons on the one, and 35 tons on the other, or 910lbs. and 922lbs. respectively per square foot.

This test was deemed ample and satisfactory for strength. As no cracks had occurred, and further loading would probably have endangered the men's lives, on account of the height of the load. Further tests were then made for electricity, which is referred to later on.

Numerous other tests were made by Professor Bauschinger in 1887, some of which are detailed as follows:—

(1) A plate 1½ inch thick, 3.28 feet wide was fixed at ends supported on piers 3.28 feet apart, and tested with 282lbs per square foot equally distributed, when fine hair cracks appeared on top of the plates near the supports. With 538lbs per square foot equally distributed, two fine hair cracks appeared in the centre on the lower side of the plate, and it was then loaded with 649lbs per square foot without further damage.

It was then unloaded, and a concentrated load of 366lbs was applied at the centre, crushing the plate, which, however, did not collapse as it supported the load for several days.

(2) A plate 2½ inch thick on supports 6 feet 6 inch apart, broke under a load of 501lbs per square foot, but did not collapse, the load being still supported.

(3) Another plate 4 inches thick on supports 9 feet 8 inches apart was loaded with 823lbs. per sq. ft., the plate broke, but did not collapse, the load being still supported.

In February, 1886, the Police Authorities at Berlin tested a pipe similar to the pipe exhibited by Carter, Gummow & Co., at the recent Engineering and Electrical Exhibition, Sydney. The pipe 3 feet 3 inch diameter, 1½ inch thick was loaded with 5.1 tons which caused the pipe to crack at the outside surface of the horizontal diameter, but the cracks did not extend through the thickness of the pipe, so that it would still remain watertight.

An oval pipe 3 feet 2 inches by 2 feet 4 inches resting on supports 3 feet 8 inches apart was tested, and subject to two concentrated loads 3 inches apart equally spaced between supports. With a total load of 3.2 tons, a crack extending along the enti e length appeared near the bottom, on the outside only.

A pipe 6 feet 6 inches diameter and 4 inches thick with a load of 23.5 cwt per square foot, showed hair cracks on the inside of the pipe at crown and invert, the load was increased to 38.7cwt per square foot without seriously damaging the pipe, as the cracks did not extend through its entire thickness, but reached only to the middle from either side.

A Monier Wall, self supporting, 13.12 feet, between supports 8 feet 2½ inches high, 2½ inches thick was tested by Professor Bauschinger in 1887, and with 7 tons showed no signs of buckling.

A Monier Wall 11 feet 6 inches high, and 1¼ inches thick, on supports 6 inches apart, was tested in February 1886, by the Berlin Police authorities, a load of 10 tons did not cause a vertical deflection or buckling, although holes had been cut in to test its stability.

ELASTICITY.

From tests made in 1886-7 it was definitely agreed that the theory of elasticity was applicable to Monier constructions, the correctness of which was later on proved by tests made at Purkersdorf in 1892.

The scientific observations made at these later tests comprised:—

(1) The vertical and horizontal deflection of points on the centre line of the arch and the abutments in relation to fixed points outside.

(2) The measurements of the alteration of the angle of cross section of the arch.

(3) The recording of cracks or any other developments.

The object of these tests was not only to find the most exact calculations for the statical stresses, but also to discover from the test data, the manner in which the inner stresses distribute themselves over the Concrete and iron insertions respectively, and to what extent the latter assist.

The examination was based on the method of Castigliano's "Theory of Elastic Systems," which is independent of every approximate assumptions of form and cross-section, in order to attain the most exact result.

The recorded deformations and cracks were in perfect accord with the calculations, and it must be specially noted that the appearance of the cracks taking place near the unloaded abutment, next at the so-called dangerous points, and then lastly near the loaded abutment, was in accord for the calculations for the theory of elastic arches, and proved the homogenity of the material and the fact that this theory can be correctly applied to arches without abutment joints on the Monier system.

The tensile strain at the different cross-sections of the arch when the first hair-cracks appeared were from 522 to 712 lbs per square inch, and as the tensile strength of the concrete alone was only 284lbs., it is clear that the iron insertions embedded and forming with the concrete a homogeneous mass increased the strength of the body to double that of the concrete thus showing what an important factor the iron insertions play in the Arch.

The co-efficient of elasticity of the body, as derived from the deflections noted, showed a gradual decrease under the increased loading, but it was found that this decrease was of no consequence, as the arch still acted as an elastic body on account of the iron insertions being still perfectly elastic.

The ratio of the distribution of the stresses through the Concrete and iron, under an assumption of a constant co-efficient of elasticity for the iron insertions, varied from 1 to 15 to 1 to 70, as the load was increased to 78.5 tons at which stage hair cracks appeared, showing that the elastic limit of the homogeneous material had been exceeded.

The tensile strain on the iron at that stage varied from 8.2, 5.1, and 5.3 tons, showing that the iron was still perfectly elastic, though the elastic limit of the arch had been overcome, thus showing that a very marked increase in the safety of such an arch, is obtainable, by the insertion of iron rods when compared with an arch of concrete alone, so that greater stresses can be allowed on the sectional area of a Monier construction than would be admissable in stone, brick, or concrete.

On account of the great elasticity of this material, the many and considerable impacts caused by rolling loads on bridges, are taken up and distributed throughout the construction, instead of being heaped up at the point of impact as is the case in less elastic bodies; so that the live force of the impact exhausts itself without any injurious effect.

The great number of bridges in use substantiate this, as well as the fact that Monier arches tested as coverings for bomb proof chambers have given such excellent results that it is extensively used for that purpose in the new fortifications of Germany. A bridge at Ingolstadt, erected 1891, is a striking example of the suitability of the system to Bridge Construction. The roadway lies direct on the Monier plates, which are only 2¾ inches thick, and the traffic is a very heavy one, the bridge being frequently crossed by marching regiments and heavy artillery.

The system has also been applied to Railway Bridges, Railway Culverts, etc., with the greatest success. Among these may be mentioned the railway bridge, Jever to Carolinensiel. 13 feet span; bridge to Neustadt, Western Prussia, 42 feet span; four bridges at Hamburg, 42.6ft. span, besides a great number of culverts in Europe and South America.

One of the tests of the arches erected at Forest Lodge had for its object the elasticity of the same. Earth was placed on to each arch and levelled to 1 foot above the extrados of the crown. Then fifty able-bodied men stood on top, and observations were taken of the gauges whilst the man kept time jumping together, and it was found that 1/20th inch was the greatest deflection at the centre.

As already mentioned under the heading of strength, one of these arches was loaded with 35 tons. The gauges fixed at the crown of the arch showed a deflection of 13/20 inch, which disappeared gradually whilst unloading, and when the load was altogether removed the arch had returned almost to its normal condition without leaving an appreciable permanent set or cracks in any part.

FIRE RESISTANCE.

The question of fire resistance is one of the most vital points which determine the value of a material to be used in building constrictions, and in dealing with this subject special stress must be laid on the fact that no building material can be said to be absolutely fireproof; but only fire resisting, such resistance being of incalculable benefit in checking the spread of a conflagration until preventive means arrive.

The opinion of the authorities, in whose hands rest the supervision and responsibility of the erection of buildings, the experience gained from large fires, and the result of extensive tests, should convince the most sceptical of the great fire resisting qualities of the "Monier" material.

In 1886, the Police Authorities of Berlin, after a most exhaustive test with this material, issued a proclamation that the Monier system could be used for the ceilings and walls in the erection of perfectly fireproof constructions and that no objection would be taken to its applications for the mantlings of iron columns without an isolating layer of air.

A great fire which occurred in 1889 at the Spirit Factory of Heinrich Helbing, at Wansbeck, near Hamburg, fully justified the issue of the proclamation.

The floors and ceilings of this factory were built of Monier plates resting upon iron Girders, throughout every story; the plates having a thickness of 1¾ inches to 2¾ inches according to the load they had to sustain. The Girders were not protected in any way, the floors simply resting upon the upper flanges.

The outbreak of the fire occurred in the roof, which quickly burnt down to the garret floor. This floor effectually checked the progress of the fire, preventing it from reaching the lower floors, in which were stored tanks of spirits, leaving sufficient time for the removal of the spirits to another building.

The City Architect in his report upon this fire, stated that the Monier floors successfully resisted the heat, remaining intact and prevented not only the flames from spreading, but also the water which poured into the building, from flooding the lower stories.

In 1889, the Association of the Private Insurance Companies of Germany placed at the disposal of the Committee of the Exhibition for the prevention of accidents in Berlin, the sum of £500 to be expended in prizes for improvements against risk of fires; and tests were accordingly instituted in order to discover the best system of building construction to withstand conflagrations.

In order to assist in this matter, the City of Berlin presented to the Committee a condemned building in which to conduct their experiments.

The interior of the building was demolished, and the various competing systems were erected therein in accordance with the usual design of every-day buildings.

The Monier structures consisted of an arched floor 13ft. span and $3\frac{1}{8}$ inch thickness, and plates, resting in some instances on the upper flanges and in other cases on the lower flanges of iron girders; and a staircase constructed with Monier side walls in the shape of rising arches supporting a plate 3ft. wide and 2 inches thick on which the steps were concreted.

All the exposed iron parts of the ceiling construction, the sides, upper and flanges of girders were protected by Monier mantles.

The Constructions were tested on the 11th February, 1893, by being exposed to a great heat for one hour, the temperature for the ceilings reached 1800 degrees Fahr., and for the Staircase 2000 degrees Fahr. Water was then freely poured into the building until the flames were extinguished, and an examination of the various structures made.

The Monier ceilings were found to be practically uninjured excepting that the rendering had peeled off in some places, but their stability had not been affected in the slightest degree as a load of 534 lbs per sq. ft. which was then placed upon them did not cause any deflection or cracks.

The edges of the large arch openings in the side walls of the Monier Staircase showed the iron netting partly exposed in several places, caused by the peeling off of the cement covering.

This was probably due to the rapid cooling of the material owing to the action of the water with which the building had been deluged.

The staircase otherwise remained intact. On being loaded up to 470 lbs per sq. ft. it showed no signs of injury.

After exhaustively examining the various systems tested, the Committee decided that the Monier system was perfectly fire-resisting, and it was accordingly awarded First Prize.

LIGHTNESS AND SAVING IN SPACE.

The lightness of the Monier Constructions, and consequent saving in space compared with other structures can plainly be seen by reference to photos exhibited or to the illustration which appeared in this Journal on the 24th July last.

The new Catholic Church at Munich has a ceiling of Semi-circular design consisting of a Monier arch 52 feet 2 inches span, and 2½ inches thickness.

The casing round the High pressure Reservoir at Emerich, built in 1888, has walls of only 1½ inches thickness.

The walls, roof, reservoir, and chimney of the Municipal Baths at Munich are constructed on the Monier System.

The Cupola over the Mausoleum of the Emperor Frederick at Potsdam, consists of an outer and inner mantle each of only 3⅜ inches thickness.

The Reservoir at Drossen represents a type generally used at small stations on the Continent. The Reservoir is 3¼ inches thick, and the encasing 2 inches.

The Reservoir tower at the Municipal Gasworks, Charlottenburg, is constructed with Monier Floors, roof and reservoirs. The reservoirs up to 23 feet diameter have walls of only 2½ inches thickness.

Types of floors consisting both of plates and arches, as well as staircases are also exhibited. It is hardly necessary troubling you with the thickness of these as they depend upon the loads they have to carry.

This system has been a great boon in overcoming the difficulties experienced in the construction, and re-construction of overhead bridges, namely to get the necessary Head room without lowering the Railway line or raising the road level.

Finally, it is very evident from the number of works shown that a considerable saving in space through the lightness of the structures can be achieved.

QUICKNESS OF ERECTION.

Quickness of erection of a structure is often an essential factor in the building, or re-construction or means of communication, especially in cities.

At the Aqueducts erected for the Government Sewerage Department at Forest Lodge, N.S.W., an arch of 75 feet span and a length of carrier of 82 feet 10 inches were respectively built in one day.

A Bridge erected in Austria last year of 131 feet span, 14 feet 11 inches versed sine, 1 foot 2¼ inches thickness at crown, and 1 foot 7½ inches near abutments, was finished in 15 hours, 180 cubic yards of Monier Mortar being placed in position in that time.

The overhead bridge erected on the deviation of the Southern Railway, between Hilltop and Colo Vale, by the Railway Commissioners was completed in 4½ hours, the bridge being 40 feet span, 23 feet wide, 8 inches thick at crown, and 1 foot at abutments.

During the erection of the shipping stores at Trieste, 600 sq. yds. of flooring, consisting of Monier Arches, filling in of haunches, and cement rendering were finished daily, the contract comprising a total area of 312,000 sq. yards, or nearly 65 acres.

COST.

With regard to the question of cost, there are so many varying conditions and circumstances to be considered, that it is scarcely advisable to enter into this matter further than to say that where iron, concrete and brick structures are necessary, this system will be found in the majority of cases to be much cheaper.

In conclusion, the Author drew attention to the report of Mr. C. W. Darley, Engineer-in-Chief for Public Works, and Mr. J. Davis, Engineer for Sewerage, attesting the undoubted success of Monier Constructions built at Forest Lodge, N.S.W. in connection with the Sydney Sewerage.

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