Wm Fairbairn
Paper
'On Water Wheels
with Ventilated
Buckets'

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## No. 793.—"On Water-wheels with ventilated Buckets."—By William Fairbairn, M. Inst. C.E.*

SINCE the time of Smeaton's experiments in 1759, little, or no improvement has been made in the principle on which water-wheels have been constructed. The substitution, however, of iron for wood, as a material for their construction, has afforded opportunities for extensive changes in their forms, particularly in the shape and arrangement of the buckets, and has given, altogether, a more permanent and lighter character to the machine, than had previously been attained with other materials. A curvilinear form of bucket has been generally adopted, the sheet-iron of which it is composed affording facility for being moulded, or bent into the required shape.

From a work entitled "Méchaniques et Inventions approuvées par l'Académie Royale des Sciences," published at Paris in 1735, it appears, that previous to the commencement of the last century, neither the breast nor the overshot water-wheels were much in use, if at all known, and at what period, and by whom they were introduced, is probably equally uncertain. The overshot wheel was a great improvement, and its introduction was an important step in the perfecting of hydraulic machines; but the breast-wheel, as now generally made, is a still further improvement, and is probably better calculated for effective duty, under the circumstances of a variable supply of water, to which almost every description of

* The discussion on this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

water-wheel is subjected. It is not the object of the present paper to enter into the dates and nature of the improvements which have taken place during the last and the present centuries. Suffice it to observe, that the breast-wheel has taken precedence of the overshot-wheel, probably not so much from any advantage gained by an increase of power, on a given fall, as from the increased facilities which a wheel of this description, having a larger diameter than the height of the fall, affords for the reception of the water into the chamber of the bucket, and also for its final exit at the bottom.

Another advantage of the increased diameter is the comparative ease with which the wheel overcomes the obstruction of backwater. The breast-wheel is not only less injured from the effects of floods, but the retarding force is overcome with greater ease, and the wheel works for a longer time and to a much greater depth in backwater.

The late Dr. Robinson (*Professor of Natural Philosophy in the* University of Edinburgh), in treating of water-wheels, says, "There frequently occurs a difficulty in the making of bucket-wheels, when the half-taught millwright attempts to retain the water a long time in the buckets. The water gets into them with a difficulty which he cannot account for, and spills all about, even when the buckets are not moving away from the spout. This arises from the air, which must find its way out to admit the water, but is obstructed by the entering water, and occasions a great sputtering at the entry. This may be entirely prevented by making the spout considerably narrower than the wheel. This will leave room at the two ends of the buckets for the escape of the air. This obstruction is vastly greater than one would imagine; for the water drags along with it a great quantity of air, as is evident in the water-blast as described by many authors." *

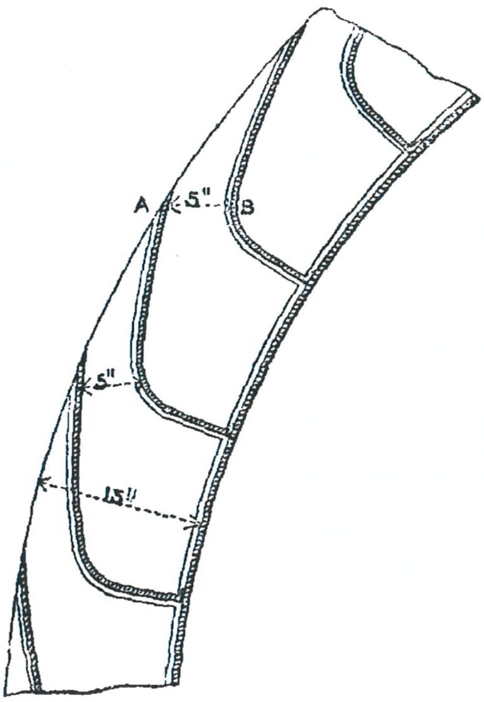
Such were the opinions of one of our first writers on Mechanical Philosophy; but the evil has been subsequently much increased by attempting to form a bucket which should carry the water down to the lowest point of the fall. In these attempts the opening became so contracted as to prevent the free admission of the water from the cistern into the buckets, and its free discharge at the bottom of the wheel.

In the construction of wheels for high falls, the best proportion of the opening of the bucket is found to be nearly as five to twenty-four; that is, the contents of the bucket being twenty-four cubic feet, the area of the opening, or entrance for the water would be five square

* *Vide* Robinson's Mechanical Philosophy, vol. ii. p. 598.

feet. In breast-wheels which receive the water at a height of 10° to 12° above the horizontal centre, the ratio should be nearly as eight to twenty-four, or as one to three, as shown in Plate II, Fig. 3. With these proportions, the depth of the shrouding is assumed to be about three times the width of the opening, or three times the distance from the lip to the back of the bucket, as from A to B, Fig. 1, the opening being five inches, and the depth of the shroud fifteen inches.

Fig. 1.




For lower falls, or in those wheels which receive the water below the horizontal centre, a larger opening becomes necessary for the reception of a large body of water, and its final discharge, as shown in Plate I, Fig. 3.

In the construction of water-wheels, it is requisite, in order to attain the maximum effect, to have the opening of the bucket sufficiently large to allow an easy entrance and an equally free escape for the water, as its retention in the bucket must evidently be injurious, when carried beyond the vertical centre.

Dr. Robinson further observes, "There is another and very serious obstruction to the motion of an overshot, or bucketed wheel. When it moves in backwater, it is not only resisted by the water when it moves more slowly than the wheel, which is very frequently the case, but it lifts a great deal in the rising buckets. In some particular states of backwater, the descending bucket fills itself completely with water, and in other cases it contains a very considerable quantity, and air of common density; while in some rarer cases, it contains less water, with air in a condensed state. In the first case, the rising bucket must come up filled with water, which it cannot drop till its mouth gets out of the water. In the second case, part of the water goes out before this; but the air rarifies, and therefore there is still some water dragged or lifted up by the wheel, by suction, as it is usually called. In the last case, there is no such back-load on the rising side of the wheel, but (which is as detrimental to its performance) the descending side is employed in condensing air; and although this air aids the ascent of the rising side, it does not aid it so much as it impedes the descending side, being (by the form of the bucket) nearer to the vertical line drawn through the axis.*

These were the difficulties under which the Millwrights of Dr. Robinson's time laboured; and the remedy which they applied (and which has since been more, or less continued) was to bore holes in what is technically called the "start" of the bucket. This was the only means adopted for removing the air from the buckets of overshot-wheels, in order to facilitate the admission and emission of the water. In lower falls, where wheels with open buckets were used, or straight float-boards radiating from the centre, large openings were made in the sole planking, exclusive of perforations in each bucket, in order to relieve them from the condensed air. The improved construction of the present time is widely different, the buckets being of such a shape as to admit the water, at the same time that the air is making its escape.

During the early part of 1825, and the two succeeding years, two iron water-wheels, each of one hundred and twenty H. P. were constructed in Manchester, for Messrs. James Finlay and Co., of the Catrine Works, under the auspices of the late Mr. Buchanan, and also for the same Company at Deanston, in Perthshire, of which firm Mr. James Smith (Deanston) was then the resident partner. Those wheels are still in operation, and taking them in the aggregate, they probably rank, even at the present day, as some of the most powerful and the most complete hydraulic machines in the kingdom. The construction of these wheels, and others for lower falls, first directed the Author's attention to the ingress and egress of the water, and led to the improvements which have since been introduced by him.

The object of these modifications may be generally stated to

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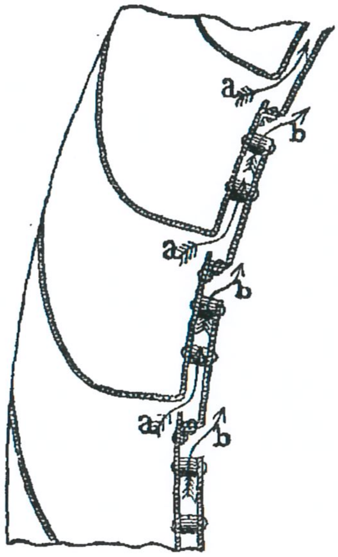
* *Vide* Robinson's Mechanical Philosophy, vol. ii. p. 599.

have been, for the purpose of preventing the condensation of the air, and for permitting its escape, during the filling of the bucket with water, as also its re-admission during the discharge of the water into the lower mill-race.

Shortly after the construction of the water-wheels for the Catrine and Deanston Works, a breast-wheel was made and erected, for Mr. Andrew Brown, of Linwood, near Paisley. In this it was observed, when the wheel was loaded, and in flood waters, that each of the buckets acted as a water-blast, and forced the water and spray, to a height of six, or eight feet above the orifice at which it entered. This was complained of as a great defect, and in order to remedy it, openings were cut in the sole-plates, and small interior buckets were attached to the inner sole, as shown at *b, b, b*, Fig. 2. The air in this case made its escape through the openings *a, a, a, a*, into the inner bucket, and passed upwards, as is shown by the arrows, through *b, b, b*, into the interior of the wheel. By these means it will be observed, that the buckets were effectually cleared of air, whilst they were filling, and that during the obstructions of back-water, the same facilities were afforded for its readmission, and the discharge of the water, contained in the rising buckets. The effect produced by this alteration, could scarcely be credited, as the wheel not only received, and parted with the water freely, but an increase of nearly one-fourth of the power was obtained, and the wheel, which still remains as then altered, continues, in all states of the river, to perform its duty satisfactorily.

Fig. 2.




The amount of power gained, and the beneficial effects produced upon Mr. Brown's wheel, induced a new and still greater improvement in the principle of construction; the first wheel erected on this, which has been called the "ventilated" principle, was one designed for Mr. Duckworth, at the Handforth Print Works, near Wilmslow, in Cheshire. This wheel was identically the same as that shown in Plate I, and was started in 1828. The improvement of the breast-wheel, with the close sole and ventilated buckets, as shown in Plate II, immediately followed.

Close bucketed wheels labour under great difficulties, when receiving the water through the same orifice at which the air escapes, and in some wheels, the forms and construction of the buckets are such, as almost entirely to prevent the entrance of the water, and to deprive the wheel of half its power. These defects may be easily accounted for, where the water is discharged upon the wheel in a larger section than the opening between the buckets, as under such circumstances, the air is suddenly condensed, and re-acting by its elastic force, throws back the water upon the orifice of the cistern, and thus allows the buckets to pass without their being more than half filled. Several methods have been adopted for relieving them of the air; the most common plan is, by cutting holes, as before mentioned, in the sole plates, close to the back of the buckets, or else making the openings between them much wider, in order to admit the water, and at the same time to allow the air to escape. All these remedies have been more or less effective; but they labour under the objections of a great waste of water and much inconvenience, by the water falling from the openings, down upon the lower part of the wheel, exclusive of the puffing and blowing when the bucket is filling.

Other remedies have been applied, such as circular tubes and boxes attached to the sole-plates, which extending upwards, furnish openings into the interior of the wheel for the air to escape; but these, like many other plans, have been, to a certain extent, unsuccessful, owing to the complexity of their structure, and the inadequate manner in which the objects contemplated were attained. In fact, in wheels of this description it has been found more satisfactory to submit to acknowledged defects, than to incur the trouble and inconvenience of partial and imperfect remedies.

In the improvements made by the Author, these objections are to a great extent removed, and a thorough system of ventilation has been effectually introduced. Before entering upon the description of this new principle of ventilation, it is necessary to remark, that in climates like Great Britain and Ireland, where the atmosphere is charged with moisture for six, or seven months in the year, it is no uncommon occurrence for the rivers to be considerably swollen, and the mills depending upon water, are either impeded, or entirely stopped by back-water; while at other times, a deficiency of rain reduces the water power below what is absolutely required to drive the machinery. On occasions of this kind, much loss and inconvenience is sustained, particularly in mills exclusively dependant upon water as a motive power, and where a number of workpeople are employed.

On the outskirts of the manufacturing districts, where the mills are more, or less dependant upon water, these inconveniences are severely felt; and in some situations these interruptions arise as frequently from an excess of water, as from a deficiency in the supply. To remedy these evils, reservoirs have been formed, and wheels have been constructed to work in floods; but, although much has been accomplished, for diminishing these injurious effects, and giving a more regular supply in dry seasons, yet the system is still imperfect, and much has yet to be done, before water can be considered equal, as a motive power, to the steam-engine, which is always available, where the necessary fuel is at hand. It is therefore obvious, that any improvement in the construction of water-wheels, whereby their forms and requirements may be better adapted to meet the exigencies of high and low waters, will contribute much to the efficiency and value of mills, situated upon rivers, and subjected to the changes before alluded to.

### *Ventilated Water-wheels as adapted to low Falls.*

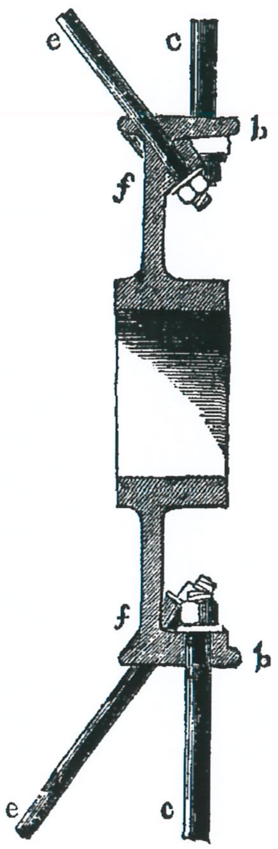
The first wheel constructed upon the ventilated principle was erected at Handforth in Cheshire, in the summer of 1828; it proved highly satisfactory to the proprietors, Messrs. Duckworth and Co., and gave such important results, as to induce its repetition, without variation, in cases where the fall did not exceed the semi-diameter of the wheel.

Plate I. represents a front and side view of a water-wheel, with ventilated buckets, adapted to falls of less than half the diameter of the wheel. Portions of the side shrouding and segments are removed, in order to show a section of the buckets, and the position in which they are placed to receive the water.

A, is the axle, or ribbed shaft, supporting the two centre discs C, C, from which the wheel is suspended; B, B, are projecting sockets, into which are inserted the malleable iron arms, *a*, *a*, and the diagonal stays or braces *b*, *b*, varying respectively from two inches to one and three-quarters inch in diameter. D, represents the buckets, with the shuttle, which regulates the supply of water, and which is made to slide downwards; F, the termination of the stone-breast, and E the tail-race, or point of discharge.

In the earlier construction of iron suspension wheels, by the late Mr. J. C. Hewes, the arms and braces were fixed to the centres, by screws and nuts upon their ends, as shown in Fig. 3. The arms *c, c,* passed through the rim *b, b,* and the braces *e, e,* which traverse the angle of the rim at *f, f,* are, as nearly as possible, in the position and form adopted by Mr. Hewes. This arrangement, although convenient for tightening up the arms and braces, was liable to many objections, arising from the nuts becoming loose, and the consequent difficulty of keeping the wheels true to the circle, and the arms and braces in an uniform state of tension; gibs and cotters were therefore substituted for the nuts and screws, and since their introduction into the large wheels of the Catrine Works, Ayrshire, the objections have been removed, and the arms and braces are now not only perfectly secure, but the periphery of the wheel is retained in its true and correct form. It will not, therefore, be necessary further to explain this part of the structure; as the plates are sufficiently explicit, to give a correct idea of all the parts.

Fig. 3.




Having noticed the obstructions offered to the entrance of the water, into buckets of the usual form, and the consequent loss, which ensues from its retention upon the wheel, after its powers of gravitation have ceased, it may be necessary to show the means whereby those defects were removed, and also to exhibit the relation existing between the breast and the undershot wheels. These terms have, however, become nearly obsolete, as every description of water-wheel, may now be properly called a breast-wheel, and in every fall, however low, it is generally found advantageous for the water to act by gravitation and not by impulse, as during the earlier periods of the industrial arts.

If the process of filling and emptying the buckets of the wheels shown in Plates I. and II., be traced respectively in each, it will be found, that in the event of a large body of water, being discharged into the buckets at D, Plate I, Fig. 1, it could not be filled, if the opening at *g* was closed, and the air was prevented from escaping in that direction. Under these circumstances the air would be compressed and pent up in the bucket, and the water be prevented from entering, or be blown out, as already described.

Now this is not the case, when they are properly ventilated, as a perfectly free passage is constantly open for the escape of the air, in the direction of *g*, and an equally free entrance is again afforded for the water at D.

This principle of construction is however more clearly shown upon a large scale, in Plate I. Fig. 3, the passage for the escape of the air being represented by the direction of the arrows through the openings *e*, *e*, and *e*, and also the connexion of the buckets with each other, by rivets and tubular blocks, as shown in the same plate. When a wheel of this description is heavily loaded, a small quantity of water will sometimes escape along with the air, above the lip of the outlets *g*, *g*, Fig. 1, into the interior of the wheel; but that is of little consequence, as it is again received into the buckets, as it falls upon the wheel, and even this defect may be removed, by carrying the edge of the plate higher upon the sole of the upper bucket. For low falls, the length of the tail side of the buckets, as given in Plates I. and II., will however be found in practice, quite sufficient, either as regards the economy, or the distribution of the water.

Having treated of the entrance of the water into the buckets, it is necessary to describe the facilities, afforded by this construction, for its discharge. A quick and easy outlet for the water, when no longer required upon the wheel, is as important as an expeditious inlet, and it is evident, that every drop of water, which is carried by the wheel beyond the vertical line of the centre, at E, Fig. 1, is so much useless absorption of its power; moreover, in the construction of the bucket, for the reception of the water, strict reference should also be had, to its free and uninterrupted discharge. Another main point of consideration is the distance to which the water is carried, by its momentum, or centrifugal action, when leaving the wheel, and it will be found advantageous to effect the discharge of the water, as soon as the bucket passes the lower edge of the stone breast at F. This discharge being seldom accomplished in time, in the old wheels, was a serious counterpoise to the power of the wheel, as the ascending buckets carried with them, portions of the water to a considerable height, on the opposite side of the vertical centre. In the improved construction, this defect is obviated; as the opening which allows the air to escape, during the filling of the bucket, re-admits it with the same facility during the discharge; there cannot, consequently, be any formation of a partial vacuum, and the wheel not only works easily, but to a much greater depth in the back-water. It has also been found necessary, in order to facilitate the escape of the water, to terminate the breast, at a distance of about ten inches from the vertical centre, and always to have a depth of from eighteen inches to two feet of water, under the bottom of the wheel.

These are considerations of some value, as the abrupt termination of the breast, at the point F, admits of a much quicker discharge of the water from the buckets, and the increased depth of the tail-race, gives room for its escape, after it has passed from the wheel. In fact, the benefits arising from this form of breast, and tail-race, are so great, that they should be strictly enforced, where it is desirable to have the full and effective use of the fall. In the erection of water-wheels, these principles should never be lost sight of, and instead of a shallow tail-race, with the water running from the wheel, at a rate of from six feet to eight feet per second, as is frequently the case with the old wheels, the current should be scarcely perceptible, and the water should flow steadily, and as smooth as in a deep canal.

It would, perhaps, be difficult to describe with accuracy, the properties and proportions of these improvements, without a long series of costly experiments, upon a large scale; and in order to make the comparison perfect, the new and old forms of water-wheels, should be placed in juxta-position, each having a proportionate load, and working as nearly as possible, under the same conditions, both as to the fall and the supply of water. Under these circumstances, the great difference, which exists between the one kind and the other, would become apparent, not only as respects superior economy, but also the perfect ease with which the ventilated wheel overcomes the resistance of the load, and the obstructions of backwater, to which wheels are subject, during floods.

On some future occasion an opportunity may present itself, for returning to this subject, when the superiority of water-wheels, with ventilated buckets, may be confirmed by more detailed experiments, and when the relative forms of wheels and buckets, may be respectively established. For the present, it will suffice to observe, that the wheel already described and exhibited in Plate I., will be found in practice, exceedingly effective, and probably the best adapted, with certain modifications, for falls not exceeding ten feet in height.

*Breast Wheels, with close Soles, and Ventilated Buckets.*

The preceding statements have been principally confined to the form of bucket, and description of water-wheel, adapted for low falls. It will now be necessary to describe the best form of breast wheels for high falls, or those best calculated for attaining a maximum effect, on falls varying from one-half to three-fourths of the diameter of the wheel. This is a description of water-wheel in common use, and is generally adopted for falls which do not exceed eighteen feet in height, and, in most cases, is preferable to the overshot wheel. It possesses many advantages over the undershot wheel, and its near approximation to the duty, or labouring force, of wheels of that description, renders it applicable, in many situations, especially where the fall does not exceed eighteen, or twenty feet, and where the wheel is exposed to the obstructions of backwater. In the latter case, wheels of larger diameter are best adapted, and provided sufficient capacity is left in the buckets, such wheels may be forced through the back-water, without diminution of speed. Every wheel of this kind should have capacity in the buckets, to receive a sufficient quantity of water, to force the wheel, at full speed, through a depth of five or six feet of back-water; and if these provisions are made, a steady uniform speed, under every circumstance of freshes and flood-waters, may be attained.

A water-wheel, of this kind (Plate II.), of one hundred H.P., was constructed for T. Ainsworth, Esq., of Cleator, near Whitehaven, about four years back, for driving a flax-mill; it is twenty feet in diameter, twenty-two feet wide inside the bucket, and twenty-two inches deep on the shroud. It has a close riveted sole, composed of No. 10 wire gauge iron plate, and the buckets are ventilated from one to the other, as shown on the large scale at Fig. 3. The fall is seventeen feet, and the water is discharged upon the wheel, by the circular shuttle A, which is raised and lowered by a governor, as circumstances require. By this arrangement, the whole height of the fall is rendered available, and the water in dry seasons, may be drawn down from three to four feet, in order to afford time for the dam to fill, during the periods of rest, either during the night, or at meal-times.

In this wheel, the power is taken from each side, by two pinions working into the internal segments B, B, and these again give motion to shafts, and wheels at C, C, which communicate with the machinery of two different mills, at some distance from each other.

The position of the pinion, or the point where it "gears" into the segments, is of some importance in every water-wheel, but more particularly in those constructed on the suspension principle, which, upon inspection, will be found but indifferently prepared to resist a torsive strain, when the power is taken from the opposite side of the loaded arc of the wheel. Water-wheels of this construction, with malleable iron rods only two inches in diameter for their support, could not resist the strain; but would twist round upon the axle as a fixed centre of motion.

It therefore becomes necessary, on every occasion, to take the power from the loaded side of the wheel, and as near the circumference as possible, in order to throw the weight of the water upon the resistance of the pinion, and that such resistance, shall be at the point of the greatest velocity.

In the old water-wheels, where the power was generally taken from the axle, the whole of the force first passed through the arms to the axle, and afterwards by a pit-wheel, or some other multiplier of speed, to the machinery in the mill. Now, in the improved wheels, this is not the case, as the arms, braces, and axle, have only to sustain the weight of the wheel, and to keep it in shape, and by the power being taken from the circumference, considerable complexity of the transmission of the power, is avoided; a great saving is also effected, when the speed required is greater than that of the wheel.

It has already been shown, that this description of wheel has a close sole, and on reference to the figure, it will be found, that the tail-ends of the buckets *a*, *a*, *a*, Fig. 3, are turned up at a distance of two inches from the back of the sole plate, and running parallel with that part, terminate within about two inches from the bend of the upper bucket. The object of this construction is obvious, as the water in passing through the openings between the buckets, drives the air before it in the direction of the arrows at *a*, *a*, *a*, into the bucket above, and so on in succession, till each bucket is filled as it passes the aperture of the cistern, from which the water flows upon the wheel.

Irrespective of the advantages of clearing the buckets of air, additional benefit is obtained, by the facility with which the water is discharged, and the air again admitted, at the bottom of the fall, during the period of the emptying of the bucket into the tail-race.

This is strikingly illustrated where the wheels labour in back-water, as the ventilated buckets rise freely above the surface, and the communication being open from one to the other, the action is rendered perfectly free, at almost any depth to which the wheel may be immersed.

In breast-wheels constructed for falls of twenty-five feet, or upwards, the stone breast is not required, as the buckets are formed with narrow openings, and the lip being extended nearer to the back of the following bucket, the water is retained much longer upon the wheel. Under these circumstances a stone breast is of little, or no value, when attached to a wheel with close buckets, on a high fall.

The construction of the breast-wheels, as above described, is almost exactly similar to that for the lower falls; malleable iron arms and braces being common to both, as also the axle, shroud, and segments. These when duly proportioned and properly fitted to each other, form one of the strongest, and probably the most permanent structures that can be attained, in works of this description.

### *Common Breast-wheel (not ventilated), as constructed by Messrs Fairbairn and Lillie, between the years* 1825 *and* 1827.

These wheels were executed upon the plan of the overshot, or breast-wheel, taking the water at an elevation nearly equal to that of its height. Four wheels of this description were constructed for Messrs. James Finlay and Co., for a fall of thirty-two feet, at Deanston, in Perthshire, and two others, for the same firm, at the Catrine Works, in Ayrshire, on a fall of forty-eight feet. Taking into consideration the height of the fall, the Catrine water-wheels, both as regards their power and the solidity of their construction, are, even at the present day, probably among the best and most effective structures of their kind in existence. They have now been at work upwards of twenty years, during which time they have required no repairs, and they remain nearly as perfect as when they were erected.

It was originally intended to have erected four of these wheels at the Catrine Works, but only two have been constructed; preparations were, however, made for receiving two others, in the event of an enlargement of the reservoirs in the hilly districts, and more power being required for the mills. This extension has not as yet been wanted, as these two wheels are equal to two hundred and forty H. P., and are sufficiently powerful, except in very dry seasons, to turn the whole of the mills.

On referring to Plate 3, it will be observed, that in the original design the water-wheels were so placed and arranged, as to communicate their motion to a series of connecting cross shafts, and by means of large spur-wheels and pinions, to transmit the united power of the water-wheels through large horizontal shafts to a cottonmill at a considerable distance, and also by means of a pair of large bevil-wheels and shafts, to keep in motion another mill of equal magnitude in another direction.

These water-wheels are fifty feet in diameter, ten feet six inches wide inside the bucket, and fifteen inches deep on the shroud; the internal spur segments are forty-eight feet six inches diameter, three inches and a quarter pitch, and fifteen inches broad on the cog; the large spur-wheels are eighteen feet two inches and a-half in diameter, three inches and a quarter in the pitch, and sixteen inches wide on the cog; and the pinions are the same width, and pitch, but are five feet six inches in diameter; the large bevil wheels are seven feet in diameter, three inches and a half in the pitch, and eighteen inches broad on the cog, their proportions being calculated to convey the united power of all the four water-wheels, should the original design ever be completed.

The water for the supply of the wheels, is conveyed from the river Ayr, in a canal and tunnel, and from thence along the side of a rising bank, to the wheel-house. From this point it is conveyed to the water-wheels by a large sheet iron trough, supported on iron columns.

When viewed from the entrance, the two wheels already erected have a very imposing effect, each of them being elevated upon stone piers; and as the whole of the cisterns, sluices, winding apparatus, galleries, &c., are considerably elevated, they are conveniently approached in every part. Under the wheels, is a capacious tunnel, terminating at a considerable distance down the river.

The plates give the details of the pen-trough for conveying the supply of water to the wheels, and show the position of the pinions, which gear into each main driving-wheel near the point of gyration. The shuttle and the method of regulating the water to obtain uniform velocity are also given, but as these must vary with the locality in which the water-wheels are established, it is not necessary to enter minutely into a description of them.

Water-wheels, on a principle introduced by M. Poncelet, have attained some considerable reputation on the Continent, and as the author has constructed one of them for Mr. De Bergue, it is necessary to allude briefly to the peculiarities it possesses.

The buckets are of a curvilinear form, and are quite open at the back, without any sole plate; so that they are perfectly ventilated. The water impinges upon them at nearly the lowest point of the wheel, the shuttle being arranged to draw upwards, and as the water enters, it follows the inside cavity of the bucket, rises and falls over into the next in succession, and so on. By this system the force of the water is expended on the wheel itself, instead of losing much of its power in rushing along through the wheel-race, as generally occurs in even well made undershot wheels.

M. Poncelet has treated this subject at such length in his able work on water-wheels, that it is not necessary here to enter into further details; but it may be observed, that a practical improvement might be effected, by terminating the lower stone platform of the race somewhat short of the vertical line of the centre of the wheel, as the escape of the water would be facilitated, and the ascending buckets would be more easily relieved of their contents; this is a point of such importance for all wheels, that it must equally apply to this form.

In this Paper, the turbine, with the improvements recently introduced in it by Fourneyron, Zuppinger, Whitelaw, and others, has been entirely omitted. There are many published statements relative to these improvements, but its limited employment in this country, up to the present time, scarcely renders it necessary to refer to it. It is however asserted that as much as ninety to ninety-two per cent., have been obtained from M. Fourneyron's turbine, but that gentleman, in a recent visit to this country, kindly furnished the Author with data taken from several of his machines, which reduce the duty to a mean of seventy-two per cent. M. Zuppinger and Mr. Whitelaw, do not claim a higher duty in their machines, the average being from seventy to seventy-four per cent. upon the theoretical value of the fall.

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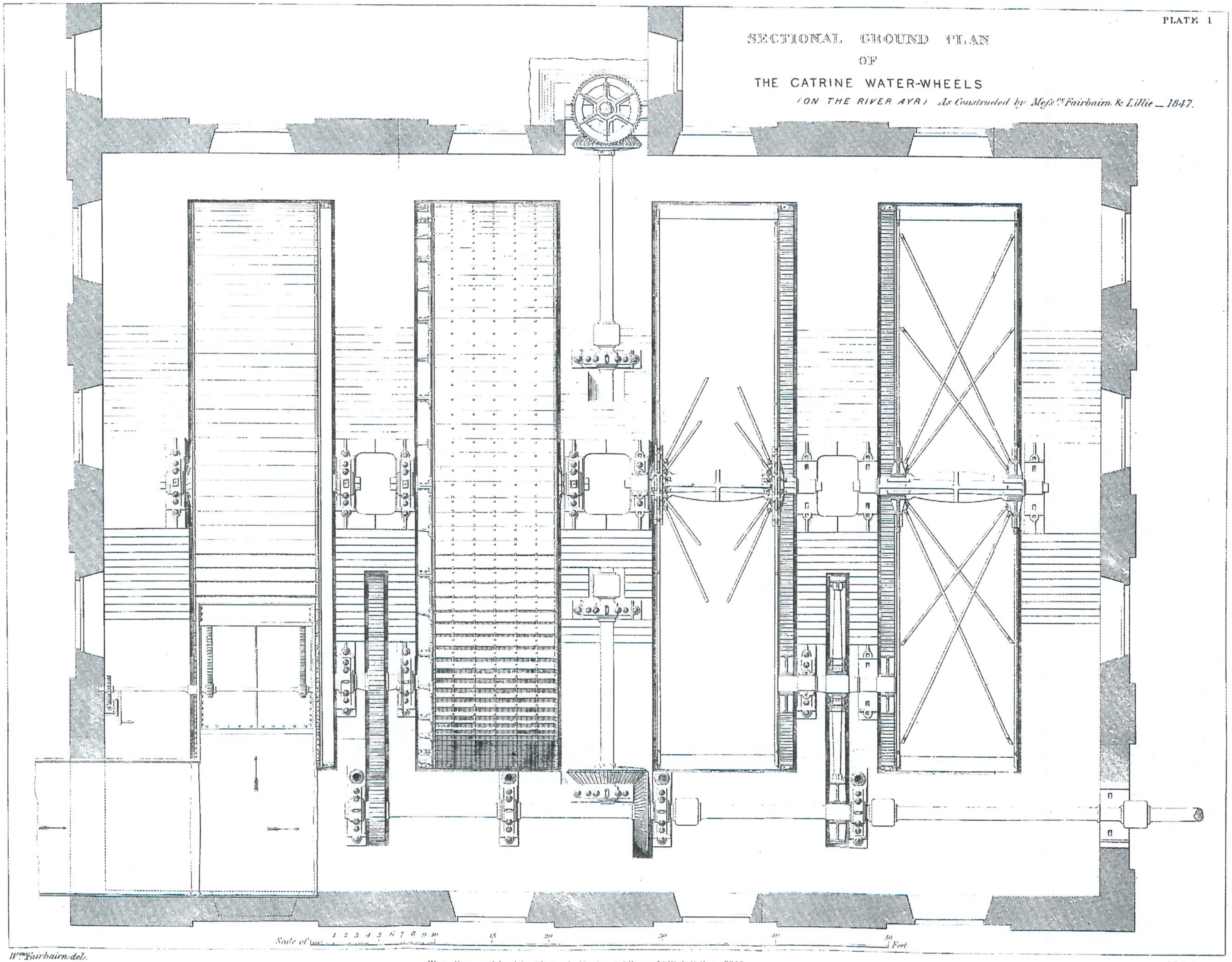
Mr. Rennie said, Mr. Fairbairn's experience in the construction of water-wheels, was so great, and the general remarks of the Paper were so accurate, that little could be added, and he was grieved to disagree with any point in it; but he could not accord with the statement of few improvements having been introduced since the time of Smeaton. Mr. Rennie must claim some merit for his late Father, who had carefully studied both the theory and practice of water-wheels, and he would not permit Mr. Fairbairn to detract from his own merit, as he was universally acknowledged to be at least one of the most successful constructors of these machines.

The late Mr. Rennie introduced the system of laying the water on to the wheel in a thin stream, not exceeding ten inches in depth. In addition to this, and for the purpose of taking the utmost advan-

PLATE 1

# SECTIONAL GROUND PLAN OF THE CATRINE WATER-WHEELS

(ON THE RIVER AYR) *As Constructed by Mess.rs Fairbairn & Lillie _ 1847.*




*Wm. Fairbairn del.*

*Plate Presented by John Weale, Architectural Library, 59, High Holborn, 1849.*

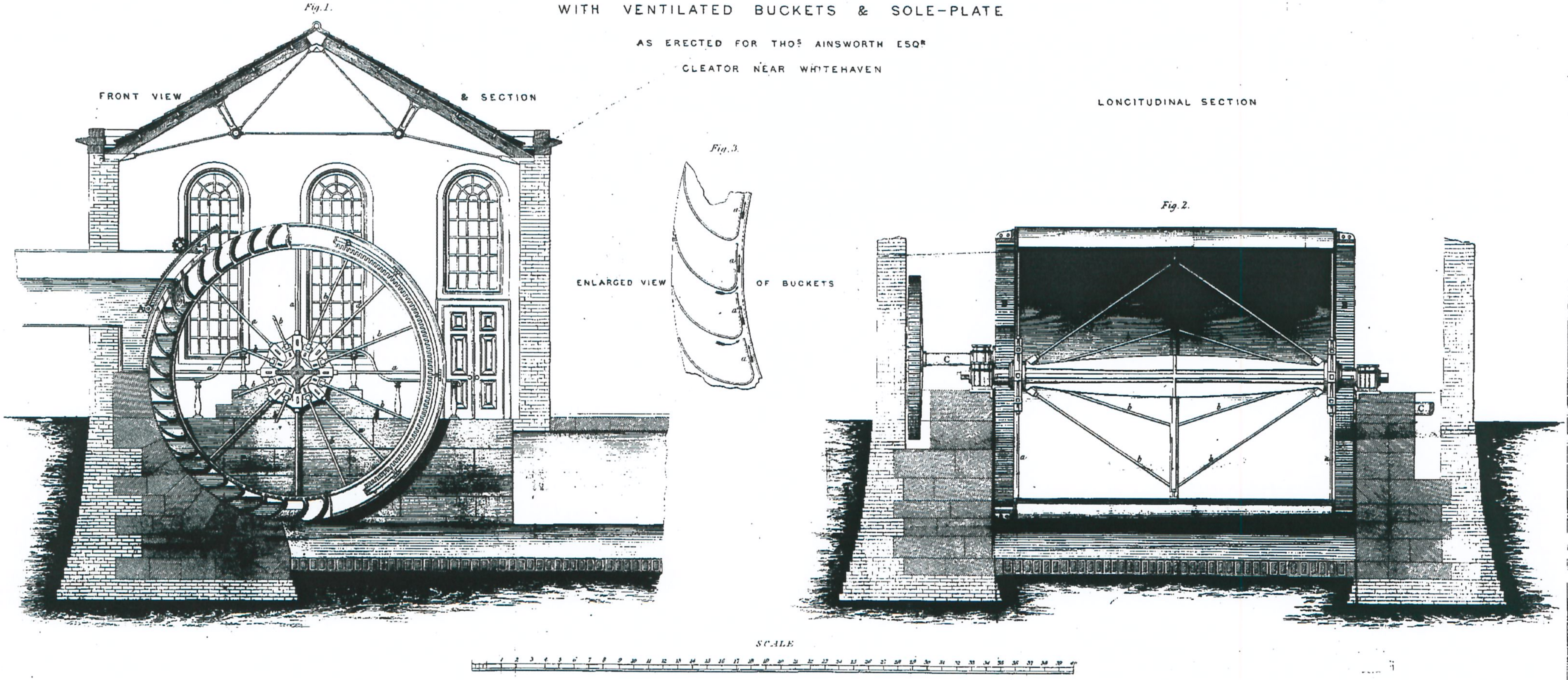
*W. A. Beever sc.*

# SECTIONAL VIEWS OF MR FAIRBAIRN'S IMPROVED WATER-WHEEL.

## WITH VENTILATED BUCKETS & SOLE-PLATE

AS ERECTED FOR THOS AINSWORTH ESQR

CLEATOR NEAR WHITEHAVEN




Wm Fairbairn del.

Plate Presented by John Weale, Architectural Library, 59 High Holborn, 1849.

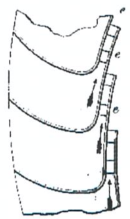
W. A. Beever sc.

# SECTIONAL VIEWS OF Mr FAIRBAIRN'S IMPROVED WATER-WHEEL.

## WITH VENTILATED BUCKETS, WITHOUT SOLE-PLATE

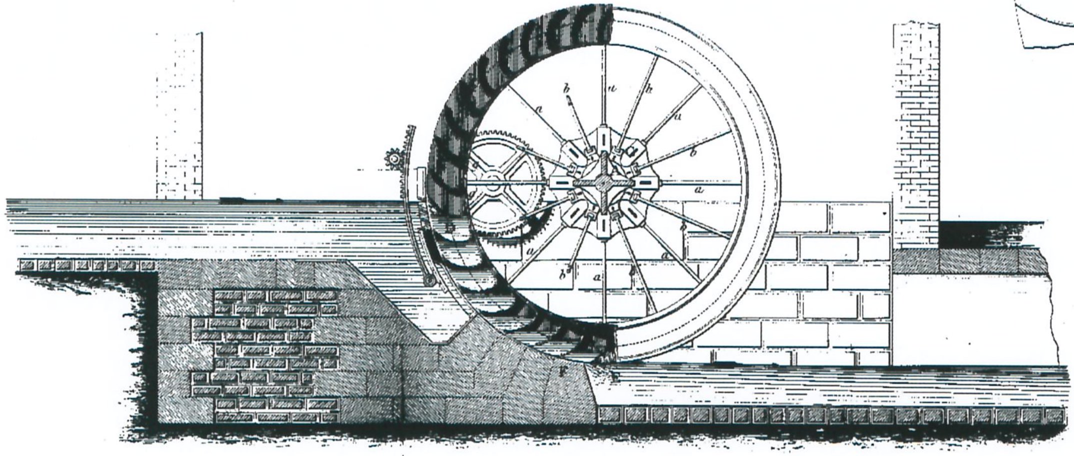
*Fig. 3.*

ENLARGED VIEW OF BUCKETS



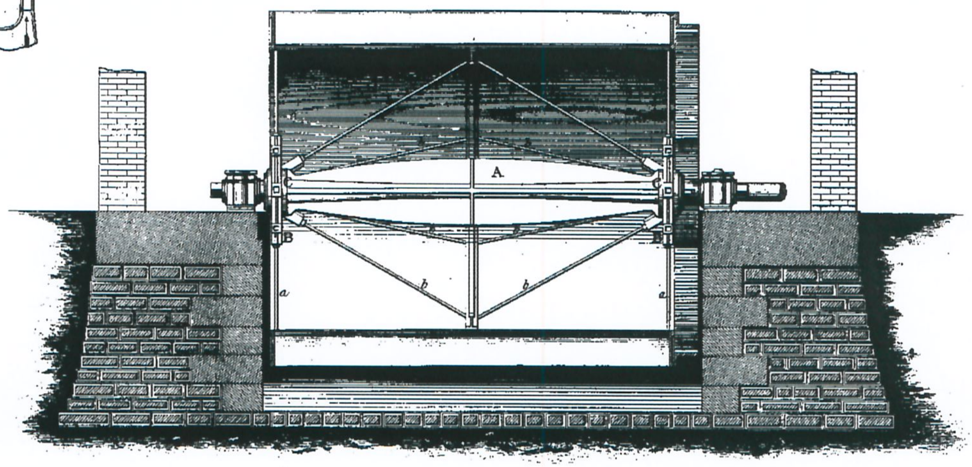
SIDE VIEW & CROSS-SECTION

*Fig. 1.*

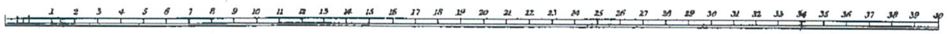



LONGITUDINAL SECTION

*Fig. 2.*




*SCALE*




*Wm Fairbairn. del*

*Plate Presented by John Weale: Architectural Library, 59, High Holborn 1849*

*W. J. B. sc.*

PLATE 1

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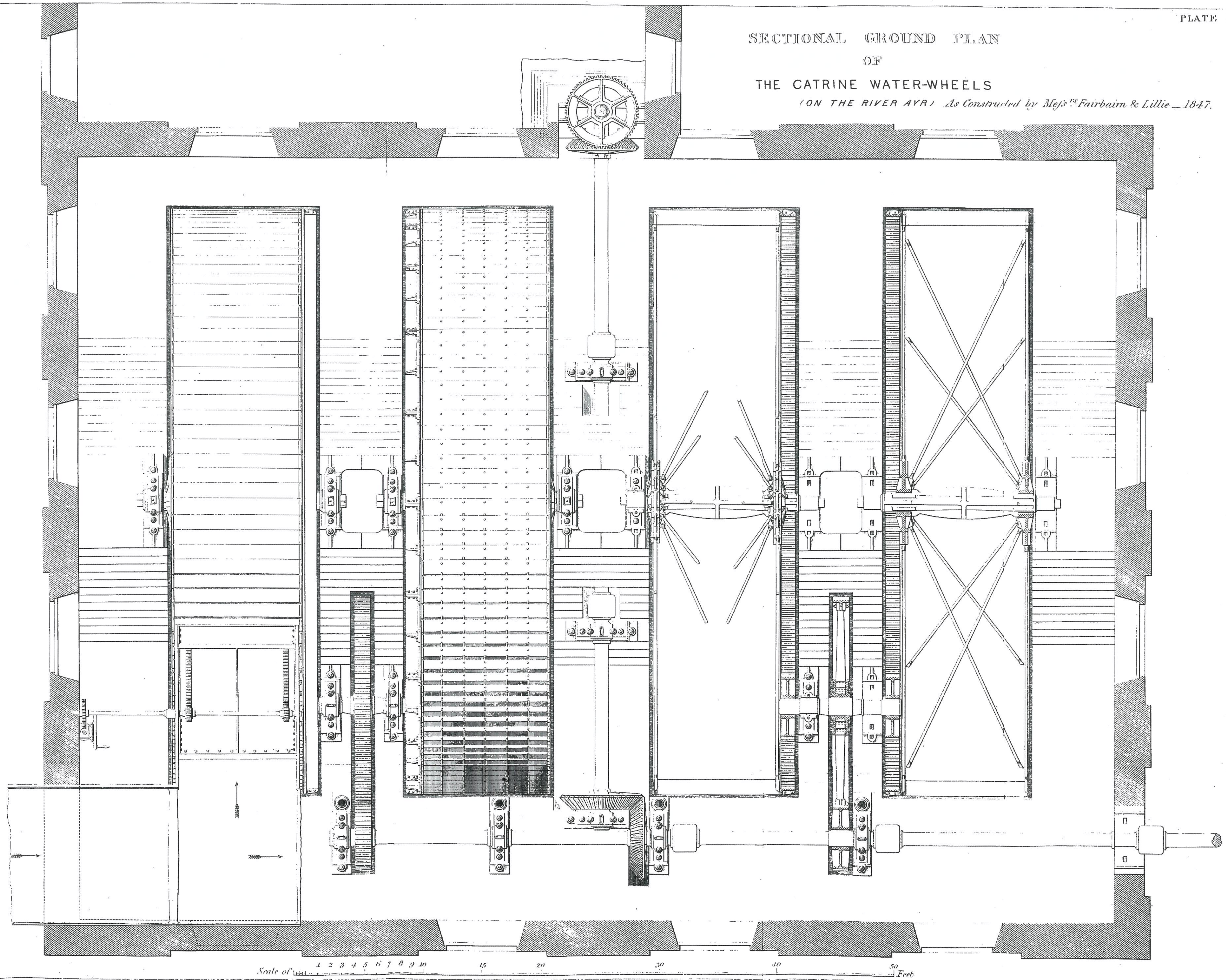



Wm. Fairbairn del.

Plate Presented by John Weale, Architectural Library, 59, High Holborn, 1849.

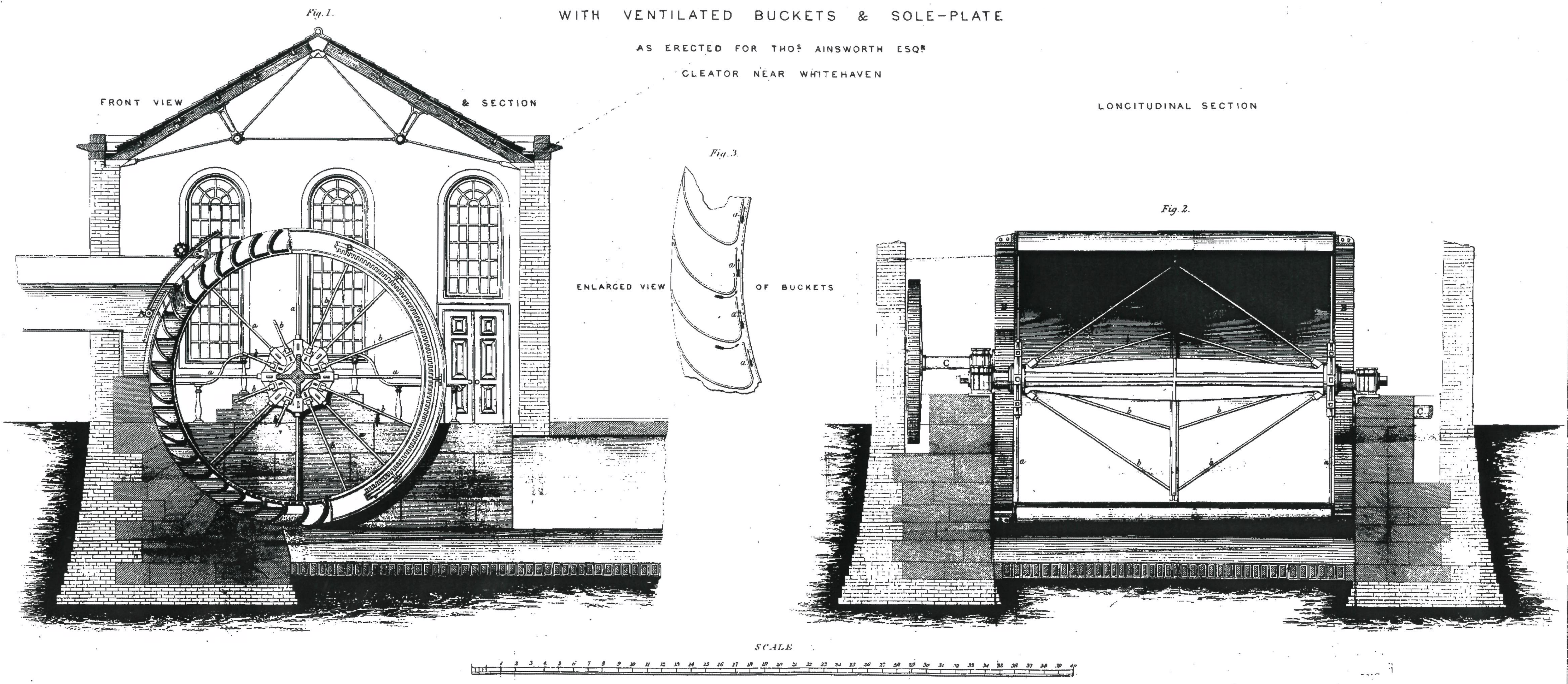
W. A. Beever. sc.

# SECTIONAL VIEWS OF M^R FAIRBAIRN'S IMPROVED WATER-WHEEL.

## WITH VENTILATED BUCKETS & SOLE-PLATE

AS ERECTED FOR THO^S AINSWORTH ESQ^R

CLEATOR NEAR WHITEHAVEN




W^m Fairbairn. del.

Plate Presented by John Weale, Architectural Library, 59, High Holborn, 1849.

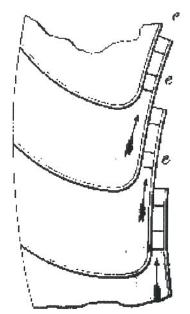
W. A. Beever, sc.

# SECTIONAL VIEWS OF Mr FAIRBAIRN'S IMPROVED WATER-WHEEL.

## WITH VENTILATED BUCKETS, WITHOUT SOLE-PLATE

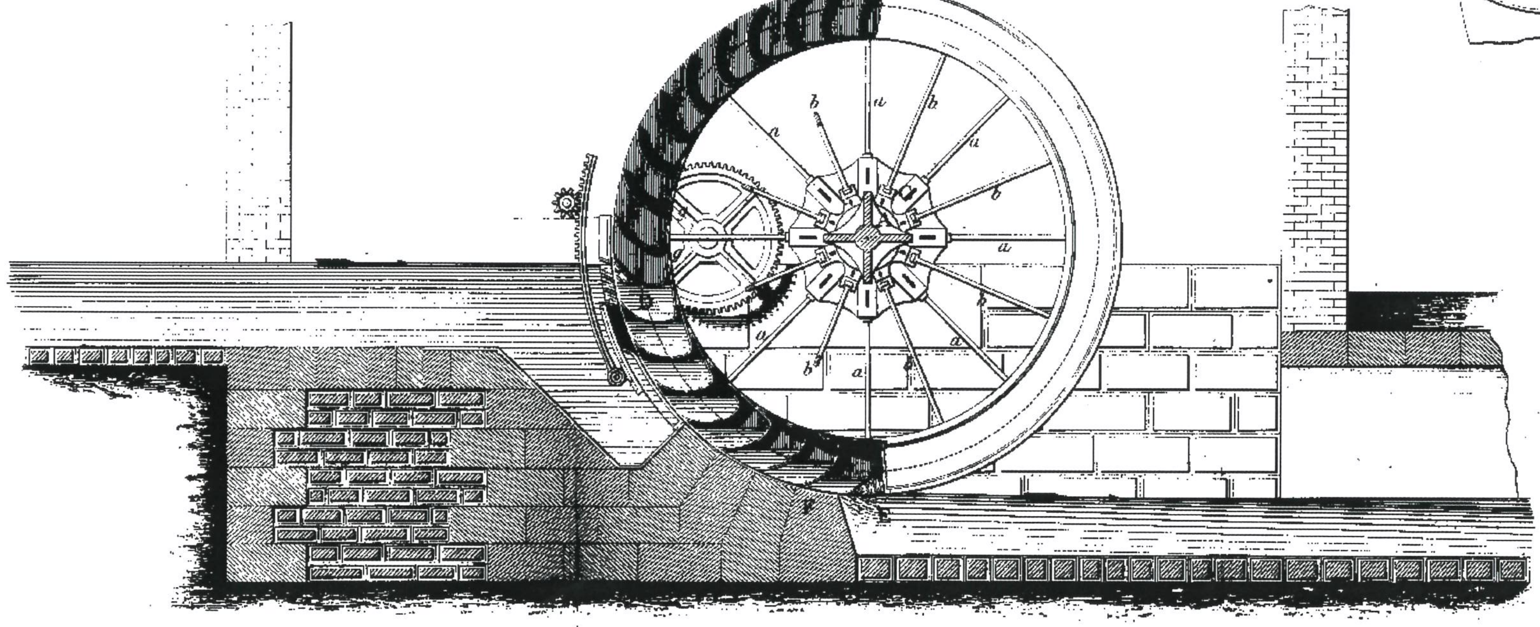
*Fig. 3.*

ENLARGED VIEW OF BUCKETS



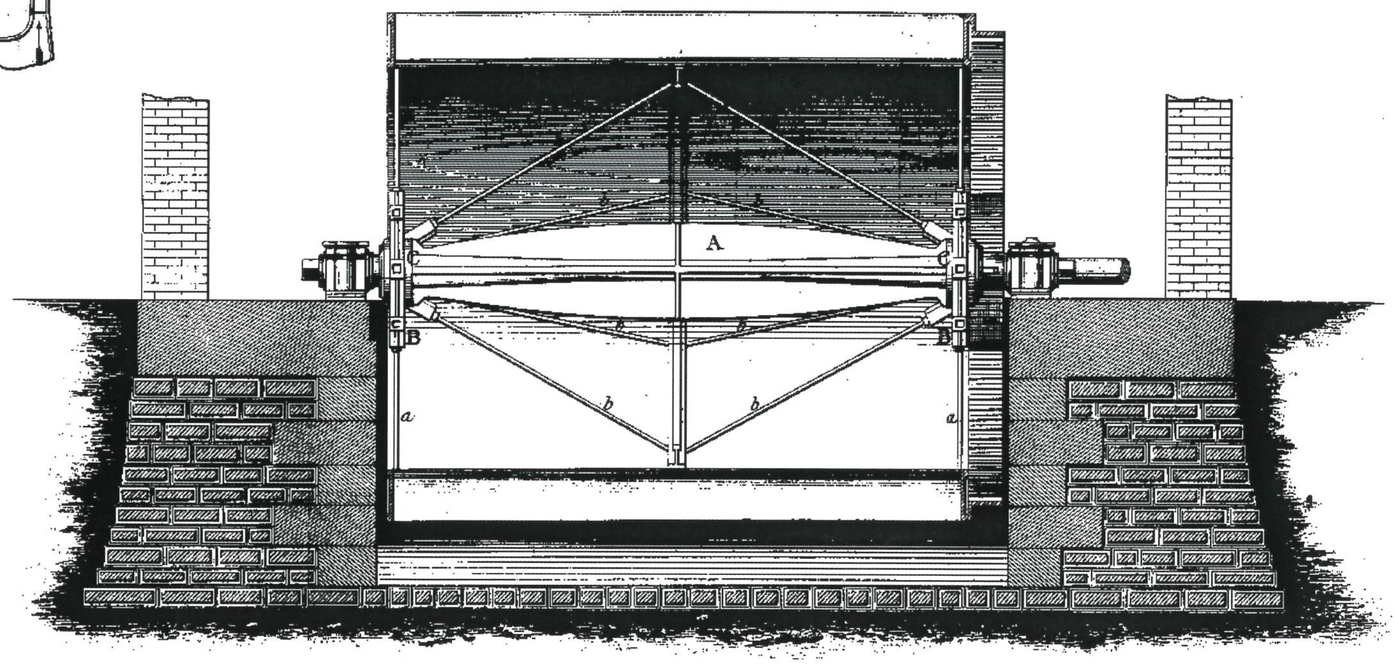
SIDE VIEW & CROSS-SECTION

*Fig. 1.*

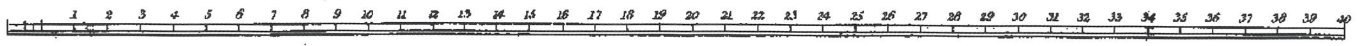


LONGITUDINAL SECTION

*Fig. 2.*



*SCALE*




Wm Fairbairn. del.

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