Mr. E. Leader Williams, Jun., said the Author had so elaborately traced the details of the lift that little room for explanation was left. The river Weaver was a navigation of great importance, though little known out of the county of Cheshire, where, however, it was highly valued, because until lately it had produced a sum of between £15,000 and £20,000 per annum in reduction of the county rates. Up to the time of the construction of this lift it was, so to speak, merely a blind alley, leading from the Mersey at Weston Point up to the salt district of Northwich. The production of salt in that district was about 1,250,000 tons per annum, of which 1,000,000 tons were conveyed on the Weaver for shipment to Liverpool. When Engineer to the Weaver Trustees, he thought it was a pity that a navigation on which so much money had been spent—more money for its length, 21 miles, than on any other navigation in England—should depend solely on salt traffic, and the lift was designed with a view to join it with the canals at Anderton. The Trent and Mersey canal passed close to the river on the top of the cliff, and the question to be solved was, how best to construct the lift, as there was no room for an incline. There was nothing at all new in a canal lift. In the first volume of the Proceedings of the Institution there was a Paper descriptive of perpendicular lifts for passing boats on canals, as erected on the Great Western Canal,[1] but those only dealt with boats of 8 or 10 tons, while on the Weaver the craft were of 100 tons, and the height to be raised was 50 feet 4 inches. A strong lift was therefore required; but it appeared worth trying, and the Weaver Trustees placed the matter in his hands. He first designed a system of counterbalance weights with water, which undoubtedly was cumbersome. Fortunately at that time he was induced to visit the hydraulic lift graving dock at the Victoria Docks,[2] and on seeing the ease with which ships of 2,000 tons were there handled, he perceived that that was a proper mode in which to deal with the smaller craft on the Weaver, although the height was so great in the latter case. He put himself in communication with Mr. Edwin Clark, and with Mr. Duer's assistance the scheme was evolved. At first he was in favour of two presses, for it appeared to him that a long caisson or trough of 75 feet was rather too much to trust to one press; but on going into the question a difficulty arose about getting the two presses to work equally. That was a serious matter, because it was clear that if with a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), p. 26. Also, Transactions Inst. C.E., vol. ii., pp. 185–191 (with three plates).

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., pp. 292–309.

trough full of water one end was lifted faster than the other, more weight would be thrown on the other press. The proposal to have two presses was therefore given up, and one 3-feet ram was adopted. It had been a most successful work, and he had seen two boats taken up and two boats lowered in two and a half minutes. The work had been admirably carried out; it was perfectly water-tight and it did the contractors great credit. It was evident that if there had been any "scamping" such a work would have been a failure. He had expected to encounter some difficulty in the junction of the trough with the aqueduct, but by the adoption of the bevel form, and by the pressure against the rubber-joint, a water-tight joint was obtained, so that not a drop of water escaped. In that respect it had an advantage over the Monkland incline,[1] with a trough on wheels on which the load was supposed to float, but the boats were generally dry at the bottom of the tank when it got to the bottom of the incline. On the Weaver, however, the boat floated the whole of the time; and to his surprise the canal boatmen with their wives and donkeys took to it most comfortably, and although stairs had been provided, they were not used. Many eminent engineers, including Telford, Cubitt, and Sir John Hawkshaw, had been engaged in improving the river Weaver, and now 200-ton steamers worked from Winsford to Liverpool. Twenty years ago vessels of 100 tons only could be accommodated. What had been done was a good instance of how much could be accomplished by capital judiciously expended in assisting navigation. Great praise was due not only to Mr. Duer for the care which he had given to the details of the work, but also to Mr Sandeman, who had carried out the foundations in a most efficient manner.

Mr. Edwin Clark remarked that in this case the novelty consisted in lifting a piece of the canal itself, and not simply a vessel on a pontoon. Practically, the canal was continued over the river until it became vertical above the spot to which the barge was lowered, and a piece of the canal descended with the barge in it; similarly that same piece rose again. One of the difficulties experienced in docks was, that the vessels were said to be strained and damaged in many ways, but that had been got over in the present case by lifting and lowering a piece of the canal itself, so that it was impossible for the barge owners, however rotten the barges might be, to say that they had been damaged. The lifting of so large a pontoon with a single press was a problem which had involved a good deal of thought. It was a large press, with

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., pp. 205–209.

a long stroke, and it was a question how far, with so heavy an overhanging weight, reliance could with safety be placed on a bracket of that kind. But inasmuch as the load was immovable, the water being quiescent, it appeared to be a case in which there was no danger in putting on the top of the single press a weight which, with any varying load, would have involved danger. He was convinced, from the experience on the Weaver, that the limit to which a single press might be applied had not been attained. He did not think there would be any difficulty in raising ships of 700 or 800 tons, and in fact a question of that kind was being considered in respect to the navigation of the Volga, where vessels of large dimensions had to be raised in the canals. The hydraulic lift was capable of application in a way which, perhaps, at first sight might not be imagined. Many rivers, like the Volga, were subject to great rises and falls, and in such cases considerable difficulty was incurred by the engineer when he wished to communicate between the river and the canals. The Volga was sometimes, for instance, 1 mile wide, and at other times 3 miles wide, overflowing muddy banks on each side, and it was no uncommon thing for its level to vary 30, 40, or 50 feet in three months. Under such circumstances it became a difficult problem how canals should be connected with such a river. Now, the system followed on the Weaver was peculiarly applicable to such a case; for it was only required to run the canals over to the river itself, to be independent of the level of the river, whether it rose 10, or 30, or 50 feet. All that was necessary was that a maximum lift should be provided to meet the greatest difference between the level of the water in the river and in the canals. He thought the principle was capable of great extension and application. The rising and flowing of tides in harbours had been a difficulty for engineers to contend with, but in the plan described in the Paper they were totally independent of the level to which the river might rise or fall, having always the same facility for lowering or raising any load. In that respect he thought the system would hereafter be found of considerable utility.

Mr. J. W. SANDEMAN observed, through the Secretary, that from an intimate acquaintance with the construction and working of this ingenious canal lift, he was pleased to be able to confirm what the Author had stated as to its complete practical success. Although the number of barges at present transferred by its means was comparatively small, yet it was increasing, and there was reason to look forward to its more extended use, when sufficient time had elapsed to enable a traffic more commensurate with its capabilities to be developed. In 1872, when he succeeded Mr. E. Leader Williams, Jun., as Engineer to the Weaver Navigation Trustees, he found the contract for the ironwork and machinery of this canal lift had been let. During the progress of the work, in discussing the details with Mr. Duer, he was much impressed with the readiness and confidence with which expedients were devised for overcoming the difficulties that necessarily presented themselves in such a novel work. He could not speak too highly of the ease with which the lift was worked, and of the forethought displayed to provide against all contingencies. He should also make mention of the watertightness of the various joints, with which there had not been the slightest trouble. The saving of time and of water effected by this lift had been referred to, as compared with a chain of locks. The saving in time would, in many situations, be an object of great importance, particularly upon a navigation where many locks existed in close proximity; also in cases where the advantages of more rapid transit, by steam towing, must be to a certain extent neutralised by the slow process of locking. The mode of towing barges in trains could also be readily provided for in a lift, by an extension of the lifting troughs or caissons, and by increasing the number of rams. The saving in water was also an important feature, as, assuming the up and down traffic to be equal in tonnage, the loss of water would only be a depth of 6 inches, as compared with the depth of the deepest lock in any series of locks; because, in comparing the lift with a chain of locks, it must be assumed that, by means of intermediate basins in the latter, barges could be passed up or down continuously.

In carrying out the foundations of the canal lift, and the masonry of the basins and approaches, the design and execution of which devolved upon him, the following features might be interesting. The foundations for the press cylinders, which contained the lifting rams, were provided by sinking cast-iron cylinders of 5 feet 6 inches in diameter to a depth of about 70 feet. The ground in the interior was excavated by hand, and the water excluded by compressed air, which at one time reached 26 lbs. per square inch above atmospheric pressure. The pneumatic process had to be resorted to, in consequence of the great infiltration of water from the river, through the strata of sand and gravel, which extended to a depth of upwards of 50 feet; but below this, the hard stratified marl, which overlaid all the rock salt in this district, was reached, and this formed an excellent foundation for the press cylinders. The piling for the support of the retaining wall for the upper basin had to be of a substantial character, in consequence of a portion of the superstructure having to be built upon the face of a bank composed of sand and clay. The bottom of the upper basin was puddled clay, about 1 yard in thickness, and below the level of this clay apertures were left through the masonry of the retaining walls, so as to prevent any accumulation of water behind by infiltration from above; and although slight leakages showed themselves at first, through these apertures, they soon ceased, and therefore proved that there was no further risk of water permeating through the clay bottom of the basin.

Sir WILLIAM ARMSTRONG said it generally happened that the best Papers were the least productive of argument, for the simple reason that nothing in them was capable of being disputed, and the present Paper was a case in point. It was a good feature in the scheme that the vessels were maintained in a state of flotation during the operations. By that means unequal strains were avoided, which would necessarily be involved in lifting the vessels by direct attachments. Another good feature was that chains were entirely dispensed with, the lift being performed by the direct action of the press. He quite agreed that, by an extension of the same system, weights might be lifted far exceeding any that had hitherto been contemplated. So impressed had his firm been at Elswick with the desirability of using direct lift with presses, where the weights to be lifted were very great, that the system had been applied to shears and cranes, and a crane was being constructed to lift 160 tons by a press suspended at the end of the jib. A ram was not used, as in the present case, but the alternative of a piston. The press was suspended on gimbals at the end of a long jib; and although the lift was 50 feet, no difficulty was anticipated in raising the load directly, and at the same time in giving to this mode of suspension all the flexibility of chains. The same arrangement was also being applied to shears for lifting 120 or 130 tons. Both those machines were rendered necessary by the enormous weight that guns had now reached. Guns were attaining such a weight that they could hardly be moved about at all, and chains were so treacherous, and involved so many probabilities of accident, that his firm had been obliged to dismiss the idea of using them.

Mr. A. GILES said some years ago he designed and erected a pair of shears for the purpose of lifting 100 tons. He proved them up to that weight, and they had been since constantly used, but he quite indorsed what Sir William Armstrong had said about the risk of trusting to chains. There had never been an accident with the shears, but he could quite see the force of the remarks about the advisability of using appliances like those which, under the practical management and design of Mr. Edwin Clark, had proved so successful. But the expense of putting up a pair of shears even to lift 100 tons was limited compared with the cost of the apparatus described in the Paper; and although he fully admitted the admirable way in which the matter had been brought forward, neither the cost of the work, nor the cost per ton of raising or lowering, nor the amount of work that could be done in a day, had been given. If the Author would supply these details he thought the members would be much benefited.

Mr. E. Leader Williams, Jun., said, unfortunately the work had been let when the price of iron was at a maximum, and considering the large proportion of iron employed, that fact made a difference of almost one-third in the cost. His original estimate was something like £16,000, but he was bound to say the cost of the lift had been a great deal more than that. He did not remain there long enough to be able to give an opinion as to the exact working; but, from his knowledge of the place, he considered the scheme was much cheaper than working a chain of locks. In the latter case there must have been five or six locks. Brindley, with great skill, put his chain of locks at Runcorn, and from there he ran up the Trent and Mersey to Middlewich, and also up the Bridgewater Canal to Manchester and the North at one dead level. Now any work proposing to take water from these canals to a river which had already more water than was wanted at once raised a storm of opposition. The Bridgewater Trustees of course thought this to be a serious matter. They had a right to think so, because the lift was to take the traffic of the Trent and Mersey and the Bridgewater Canal, and allow it to go down the Weaver and join the Mersey at another point. He felt the difficulty of devising some method by which water might not be wasted, and the scheme was carried in Parliament notwithstanding opposition. He was in a peculiar position with regard to the matter, because he was now Engineer to the Bridgewater Navigation Company, and he was bound to say it was not his original plan to use 6 inches of water each time, but to pump it back again to the canal. As it happened, however, the descending weight of goods was so much greater than the ascending weight that there was no practical loss of water. The cost of working was moderate. There was one man at the engine house and one man up in the office above actuating the working valves. If there had been a chain of locks the cost of working and of maintenance would have been greater. He quite felt, however, that the cost of the work should have been stated in the Paper, though it had been so large for the reason which he had mentioned, namely, that iron was at the time excessively dear. He thought if the work had to be done again the cost might be much reduced. Although one of the lifts acted as an accumulator to the other, yet it was not always possible to secure that a barge should be going in at one end at the precise moment that another was going in at the other, and he thought there was not that practical advantage in having two rams and two lifts that he had previously anticipated. If the work had to be done again, he thought one-third of the cost could be saved by only using one ram, and by putting the pressure on to a large accumulator, and he believed that, in actual practice, as much work might be done in the day. Certainly one ram and one lift would suffice for the work that was likely to be required on the Weaver for the next thirty years.

Captain GALTON said, there were several large canals in the centre of England where water was much required, and he wished to ask if the system described was applicable to those canals which already possessed locks. The Author had said that if a boat descended a series of locks 50 feet it would require a depth of water of 50 feet to take that boat down, but in reality in descending the locks the boat would only require about 8 feet 6 inches for each lock. On the canal with which he was particularly acquainted, the Birmingham Canal, which had probably the largest traffic in England, it was arranged that a boat should always go up at the same time that a boat came down. By these means it was generally contrived, where water was scarce, that no more than one lockful of water should be lost each way. If a comparison had to be made between the system described and a chain of locks, that point should be taken into consideration in the question of cost. Of course last year there was an abundance of water, but sometimes water was so excessively scarce, that it was necessary to have it pumped back, and he wished to know what was the cost of the present scheme as compared with the cost of pumping back the water.

Sir JOHN HAWKSHAW, Past-President, thought this lift was a proper application of the system in this particular case. If the Author was able to state the cost, that should be compared with the cost of a series of locks to get up the same height. If there were 10-feet locks, five would be required on the Weaver, and he was afraid that the cost of these could not be given; and the same observation would apply to that which Captain Galton seemed desirous of ascertaining, namely, whether a system of this sort would be universally applicable to canals. He thought it would not. There might be cases, where there was abundance of water, where it would be better to go on according to the old method of making locks, but there were other cases where it might be desirable to apply the particular mode of lifting a boat from one level to another described in the Paper. When the matter was under consideration, there were only two points which had presented any difficulty. One was the mode of making a joint; whether it should be according to the plan which had been adopted by making the faces bevelled, or by putting a small press at the other end, so as to press the trough against the face. The other question was that of poising the somewhat long trough upon one single press.

Mr. BRAMWELL observed that the works on the Weaver had been compared to the incline on the Monkland Canal.[1] Two or three years ago he had occasion to look into the working of that incline. There were certain points of similarity, and also of difference, in the two cases, which perhaps it would be as well for him to allude to. The incline on the Monkland Canal was worked by means of a travelling caisson upon wheels, and that caisson certainly was quite competent to keep the barge which it brought up afloat the whole time, if it were so desired; but the reason given for not allowing the barge to float was, that an oscillation was set up, and then the barge was liable to beat against the doors of the caisson and do harm. As much water, therefore, was deliberately let out as it was thought necessary, to allow the barge to settle upon the bottom of the pontoon, while leaving water enough to support the barge, and thus to prevent its being strained by the cargo. The caisson was wound up by a chain, and there were ratchets alongside, and palls, which would go into gear at any time in the event of the chains breaking. The joint at the top was made with indiarubber, and there was an hydraulic press to give the final push to the caisson to close this joint water-tight. The pontoon having come up with as much water in it as would just fail to float the barge, there was a difference of level between the water in the caisson and that in the canal, and thus it happened that when (on the indiarubber joint being closed) the doors at the end of the canal and at front of the caisson were opened, the water coming out of the canal into the caisson had sufficient velocity to drive the barge outward by the mere regurgitation of the current. Alongside the Monkland incline there was a staircase of locks, which presented, by their cost, complexity, and obstructiveness, a strong contrast to the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., pp. 205–209.

travelling caisson system. He could state, from being in possession of the whole of the particulars, that the saving in point of time, as compared with the locks, was undoubtedly considerable, as was also the saving in first cost. It appeared to him that for a great height of lift the ordinary locks—a necessity when mechanical science was not far advanced—should never now be resorted to; if such a proposition as that were agreed to, the question was reduced to one between an incline and such a lift as had been described. He thought the incline had one advantage—that if anything gave way, the ratchets and palls provided a check; while if anything gave way in this lift, the whole affair would come down with a hideous crash. He could not help thinking that the press cylinders should have been of wrought iron. It was true the pressure per square inch was not great; but after all, cast iron was a treacherous material, and he should have liked to see the external cylinders made of wrought iron; or if cast iron were retained, it should be hooped. As a measure of precaution it might be well to have two other rams, one at each end, not to aid in raising the load, but simply to draw water into their cylinders as they rose, which water would on their descent flow out through small apertures, sufficiently large to admit of the free exit of the water when the load descended at a proper pace, but so small as to check the outflow demanded by a too rapid descent, and in this way serious accident might be prevented.

Mr. JOHN CORRY observed that there were some points of detail in which he thought improvement could be effected. He considered that the making of the joint by the bevelled facing was defective in principle, inasmuch as the pressure of the water in the aqueduct tended to separate the tank. By a simple method of interlocking one vessel coming up behind the other, the pressure could have been directed so as to make the joint more perfect, and in a large work he thought some such arrangement would be absolutely requisite. It would also prevent the necessity for any of the external support at the end, because the pressure would be thrown on the aqueduct.

Mr. J. W. SANDEMAN furnished, through the Secretary, a statement showing that the prime cost of the ironwork and machinery, including the royalty, of the hydraulic canal lift at Anderton was £29,463, while that of the foundations of the lift, masonry of basins, approaches, &c., was £18,965, making a total of £48,428. About September 1872, when the contract for the ironwork, &c., was let, the price of iron had reached the highest point ever known in this country. In this particular lift the aqueduct, which contained the greatest portion of the wrought iron comprised in the work, was longer than would be necessary under ordinary circumstances, in consequence of its having to span a branch of the river before reaching the site for the lifting troughs or caissons.

With the lift in full operation the working expenses per week amounted to about £15, to which should be added £93, or 10 per cent. on the prime cost, being 5 per cent. for interest and 5 per cent. for depreciation, making a total of £108 per week.

In estimating the full capabilities of the lift for traffic, it had been calculated that an equal number of laden barges and of light barges would be transferred continuously. Taking all the circumstances into consideration, it would not be justifiable to assume that a greater traffic would be conducted by its means, for, although in many instances the same barges which might pass through it in one direction laden would also return laden, yet it would not be possible to maintain a continuous succession of barges passing through the lift. The lift was capable of transferring sixteen barges per hour, eight up and eight down, and, proceeding upon the basis assumed, this would give four hundred and eighty light and four hundred and eighty laden barges transferred per week; the laden barges at present averaged about 25 tons burden each, or 12,000 tons of goods transferred per week, which, divided into the average working cost per week, gave 2·16*d.* per ton. The parliamentary tolls were:—

	s.	*d.*
Per ton for all goods	0	1
For each laden barge	1	0
For each light barge	2	6

Tolls for one week's traffic would therefore be:—

	£.
12,000 tons at 1*d.*	50
480 laden barges at 1*s.*	24
480 light barges at 2*s.* 6*d.*	60
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If, therefore, the lift were in full operation, the tolls would more than cover the working expenses, interest on first cost, and charge for renewal. The lift was likely to prove much more remunerative by attracting trade to the navigation which it did not possess before; it had already done so to some extent, and this trade paid toll for the navigation independently of the tolls charged for the use of the lift.

Mr. Duer, in reply, said he had not given any details as to the outlay upon the work because he thought they would be misleading; and though Mr. Sandeman had answered the questions as to first cost and cost of lifting per ton, he did not think it was fair to the system to take those figures as guides in estimating the expense of such a lift. The subsidiary works connected with the lift at Anderton were of an extensive character, and part of them were not properly chargeable to the lift. The contract for the ironwork, which formed so large an item, was let when the price of such work was higher than it had ever been. The foundations were much more substantial than would generally be considered necessary. The neighbourhood of Northwich being liable to serious subsidences, as the brine was pumped from beneath the surface of the ground, it was essential to provide, as far as possible, against any contingency of that kind occurring with the lift. He thought also that less extensive basins and approaches might have sufficed, and that the banks of the lower basin might have been merely sloped and pitched. Further, if the peculiarities of the site had not rendered an aqueduct indispensable, then the expense would have been greatly decreased. Taking all these facts into consideration, he did not hesitate to say, that such a lift, with the subsidiary works, could generally be constructed for about one-half the outlay at Anderton, and consequently that the cost of lifting per ton might be less than $1\frac{1}{2}d.$, instead of $2 \cdot 16d.$, as calculated by Mr. Sandeman.

It was originally proposed to have four presses, one at each corner; but with four presses it would have been difficult to keep the trough horizontal, in case a leakage occurred in one of them, and the weight being only 240 tons, he thought that was not too much for one press 3 feet in diameter. If it was necessary to construct a large lift on this principle for vessels of 1,000 tons, or upwards, a few presses could be grouped together at or near to the centre, and if all were connected they would practically form one press, without any of the dangers that might accrue if they were separated. With regard to the quantity of water that was taken by boats passing up and down through a chain of locks, if two boats with equal displacement, traversing a system of inland navigation, had to pass each other at a chain of locks having a total fall of say 50 feet, they could not do so without taking a column of water from the upper level, whose base was equal to the area of one lock and whose height was 50 feet. The lift would in such a case take a column of water having the same base, but only 6 inches high; or, in other words, it would only take 1 per cent. of the water used by the locks. A chain of locks could, however, be worked so as to use less water than this, by making the boats wait until several were ready to follow each other in the same direction. Suppose, for instance, that six boats were ready to ascend a chain of six locks with a total rise of 50 feet, and that all the locks were empty. This was a fair assumption, for if the locks were full the preceding boat must also have ascended, and would be one of the series under consideration. The first of the six boats would then take five lockfuls of water from the upper level, and the other five would each take one lockful; or the six boats would require ten lockfuls to enable them to ascend. Now suppose six boats had to descend: of course, finding the locks full, the first would take six lockfuls from the upper level, and the other five would each take one lockful, or eleven lockfuls would be required for the six boats to descend. In other words, for six boats to ascend, and for six afterwards to descend, twenty-one lockfuls would be required, or $\frac{21 \text{ locks} \times 50 \text{ feet}}{6} = 175$ feet. To do the same work the lift would require 6 inches × 6, or 3 feet, that was 1·7 per cent. of the water necessary for the locks, and it would obviate all loss of time from boats having to wait for each other. Mr. Bramwell had, he thought, overstated the possible danger from anything occurring to the presses. The troughs always travelled up and down very fast, and though there might be an important leak in a press, or one of the joints might give way, the trough would only come down a little faster than usual, but he did not think that the consequences would be serious. He could not imagine that a press would burst suddenly; and as the press was in the centre, the trough would always come down horizontally and fall into the water, making, no doubt, a splash, but most probably doing no other mischief. This danger was, however, provided for by having strong presses, and also by having a ready means of testing the apparatus periodically, by loading the troughs with an extra quantity of water when at the bottom of the lift. The danger to life could never be so great as that constantly incurred in hotel lifts. Referring to Captain Galton's remark, as to the extent of the adaptability of lifts to canals instead of locks, no doubt for small differences of level locks were cheaper. If, however, the canal systems of England had to be rearranged, these lifts would play an important part, as they were pre-eminently useful for saving water; and even where water was abundant, the lift still saved a great deal of time. If the lift were made single with a large accumulator, the cost would probably be less than for a double lift, and it might be adopted with advantage where great traffic was not expected.