IV. *On the strain to which Lock Gates are subjected.* By PETER W. BARLOW, *Civil Engineer.*

HAVING of late been engaged in estimating the dimensions of timber required for Lock Gates, I have been led to the consideration of the different strains to which they are liable, and the results of my investigations having, in some instances, been rather unexpected and interesting, I beg to lay them before the Institution of Civil Engineers, in the hope that they will prove of utility.

In England, of late years, lock gates of large dimensions have been constructed of an arched figure, with a view to increasing their strength; how far an advantage is gained by this construction, it is chiefly the object of the present paper to investigate. Previously, however, to entering into these enquiries, it will be necessary to explain the nature of the strains to which the common straight gate is exposed.

The best angle for the sally of lock gates made of straight timber is a subject which has already engaged the attention of some mathematical men, but I must observe, with respect to those investigations which I have had the means of examining, that they seem to be founded on data evidently incorrect. A common straight gate is exposed to two strains; one a transverse strain, produced by the weight of water at right angles to its surface, which is equal to half the weight applied in the middle; the other a strain in the direction of its length, produced by the pressure of the opposite gate upon its extremity. This latter strain, if the salient angle was of 45° , or the gates stood at right angles to each other, would of course amount to half the weight on the opposite gate, so that at this angle a lock gate has, in addition to the transverse strain, an equal strain in the direction of its length.

Before we can arrive at the angle at which, with given dimensions of timber, the greatest strength will be given to a pair of gates, it becomes necessary to know the amount of transverse strain produced by the end pressure of the other gate; or in a beam loaded in the middle, the additional transverse strain produced by a given degree of pressure applied at the ends. In order to ascertain this point precisely, it would be necessary to have a distinct set of experiments, which would not only be difficult to execute, but very uncertain

in their results ; and as precision in this point is not necessary to the present question, I think, by the examination of M. Girard's experiments, we may arrive at it sufficiently near for our purpose.

These experiments were made upon a large scale by order of the French government, and although there appears to be some irregularity in the results, I have no doubt they are as correct as the uncertain nature of such inquiries will permit.

The following is an abstract of his experiments on the strength of oak baulks loaded at the end, and with the weight the same timbers would bear loaded in the middle, calculated by the rules given in Barlow's work on timber ; by which a comparison can be made of the relative strength when subjected to a direct and transverse strain.

The timbers experimented upon by Girard were not in every case completely broken, but there is no doubt the weight they were subjected to was very little short of that which would have completed the fracture.

TABLE I.—ABSTRACT OF GIRARD'S EXPERIMENTS ON THE STRENGTH OF TIMBER LOADED ON THE END.

No. of experiments.	DIMENSIONS OF THE TIMBER.			Weight in pounds the beam bore applied to the extremity.	Weight in pounds the same beam would bear loaded transversely.	Ratio.	REMARKS.
	Length.	Breadth.	Thickness.				
	FEET.	INCHES.	INCHES.				
1	8	6.21	5.03	93616	8598	·092	Broken.
2	8	6.39	4.17	94018	6078	·064	
3	8	6.21	3.99	69165	5390	·078	
4	8	5.23	3.89	50526	4325	·085	
5	8.628	5.15	4.17	50608	4900	·097	
6	7.549	6.02	5.15	115359	9980	·087	
7	7.549	6.21	5.05	103799	9909	·095	
8	7.549	6.12	4.085	73095	6396	·087	Broken.
9	7.549	6.21	3.99	63177	6336	·100	Broken.
10	7.549	4.96	3.99	44857	4924	·109	Broken.
11	6.471	6.12	5.24	87494	12366	·141	
12	6.471	6.21	5.15	87481	12013	·136	
13	6.471	6.21	3.99	87079	7392	·085	
14	6.471	6.30	3.99	72823	7313	·100	
15	6.471	5.24	4.17	103622	6525	·063	
16	6.471	5.05	4.25	82261	6674	·081	
17	7.549	6.21	4.25	87443	7022	·080	Broken.
18	8.628	6.21	5.32	82332	9607	·116	
19	8.628	6.21	5.15	103863	8993	·087	
20	8.628	7.37	6.21	137966	15584	·113	
21	8.628	7.45	6.21	137866	15764	·114	
Mean . . .						·996	

It thus appears that the force required to break a timber in the direction of its length, is about ten times that which would break it if applied transversely at the middle; from which I infer that the strain in the direction of the gate produced by the pressure of the opposite one, is equal to an additional strain of one-tenth applied transversely.

A difference exists in the comparison made in the preceding Table and in the case of lock gates, which it is necessary to make some remarks upon;

viz., that a lock gate has a transverse pressure acting in addition to that produced by the other gate, so that the end pressure is exerted upon it after it is already deflected by a transverse strain, which is of course not the case in the comparison made in the Table. How far this may affect the question, or how much greater effect the compressive force may have in consequence of the beam being already deflected, it is very difficult to determine, but from an examination of the subject, I am induced to think that the deflection is so small as very slightly to increase the effect of the end pressure.

The amount of the effect will of course depend upon the degree of deflection the beam has sustained from the transverse pressure, and if it amounted to a quantity exceeding one-twentieth of the length, (which would make the lever by which the end pressure acted exceed one-tenth of that by which the transverse strain acted,) a greater effect than one-tenth would be produced; but as the ordinary load which timber is expected to sustain, does not produce at the utmost a deflection exceeding one-hundredth part of the length, I cannot conceive the transverse strain above named materially to alter the comparison, and I have accordingly, in the following investigation, assumed one-tenth as the amount of additional strain produced by the end pressure of the opposite gate.

It now becomes necessary to get an expression for the amount of the strains above mentioned at any angle of salience, which is arrived at in the following manner:—

Let AB, AC, represent the two gates, meeting at the point A; draw the line AD from the point A perpendicular to BC, and let BD, which represents half the breadth of the lock, = l , also

let the pressure of water upon the length l of the gate be indicated by w and the angle $ABD = \phi$.

Then the length of the AB and any angle ϕ will be expressed by $l \sec \phi$ and the pressure upon it by $w \sec \phi$

The transverse strain produced by this pressure on the centre of the beam at the same angle, will be $\frac{1}{2}w \sec \phi$

It now remains to find the amount of compression in the direction of the gate, produced by the opposite gate.

Let AF represent the force or tendency of the gate AC to turn upon the point C , which is of course equal to half the weight upon the gate AC ,

$$\text{or} = \frac{1}{2}w \sec \phi$$

The force may be resolved into AG , FG , the one GF is supported by an equal and opposite force in the gate AB , and the other will represent the force in the direction of the gate, the expression for which may be found as follows;

$$\text{as } \sin \angle AGF : AF :: \sin \angle AFG : AG$$

$$\text{or } \sin \phi : \frac{1}{2}w \sec \phi :: \cos \phi : \frac{1}{2}w \sec \phi \frac{\cos \phi}{\sin \phi} = \frac{1}{2} \text{cosec } \phi$$

The whole amount of transverse strain at any angle ϕ will therefore be represented by the expression,

$$\frac{1}{2}w \sec \phi + \frac{1}{20}w \text{ cosec } \phi$$

from which we may readily obtain the angle at which the strain is a minimum as follows;—

$$\sec \phi + \frac{1}{10} \text{ cosec } \phi = \min$$

$$\text{or } \tan \phi \sec \phi d\phi - \frac{1}{10} \cot \phi \text{ cosec } \phi d\phi = 0$$

$$\text{whence } \tan^2 \phi = \frac{1}{10} \cot \phi$$

$$\text{and } \tan^3 \phi = \frac{1}{10}$$

$$\tan \phi = \sqrt[3]{\frac{1}{10}} = \frac{1}{10} \sqrt[3]{100} = .4641 = \tan \angle 24^\circ 54'$$

The salient angle of a pair of oak gates, when the strain is a minimum, is therefore $24^\circ 54'$.

In the question of the best angle for lock-gates, it becomes necessary to consider that the length of the gate also varies as the secant of the angle ϕ . The angle $24^\circ 54'$ is therefore not that at which, with a given section of timber, the greatest strength will be obtained; for although the strain is the least at this angle, yet the gates, by their greater length, are less able to resist it than at some

intermediate angle, when the strain is slightly increased. The expression now becomes

$$\sec^2\phi + \frac{1}{10} \sec\phi \operatorname{cosec}\phi = \min$$

$$2 \sec^2\phi \tan\phi d\phi + \frac{1}{10} (\tan\phi \sec\phi \operatorname{cosec}\phi - \cot\phi \operatorname{cosec}\phi \sec\phi) = 0$$

$$2 \sec\phi \tan\phi + \frac{1}{10} \tan\phi \operatorname{cosec}\phi = \frac{1}{10} \cot\phi \operatorname{cosec}\phi$$

$$2 \sec\phi \tan^2\phi + \frac{1}{10} \tan^2\phi \operatorname{cosec}\phi = \frac{1}{10} \operatorname{cosec}\phi$$

from which the cubic equation,

$$\tan^3\phi + \frac{1}{20} \tan^2\phi = \frac{1}{20}.$$

This, being reduced, makes the $\tan. = .25701$, or the angle $19^\circ 25'$, at which a pair of lock-gates should be situated, so as to have the greatest strength with a given section of timber.

Having obtained, in a manner I hope satisfactory, the angle of greatest strength for gates of straight timber, I conclude this part of my paper with a Table of the necessary dimensions of oak timber for lock-gates, varying from 6 to 20 feet in length, and from 8 to 20 feet in depth, which I believe are the limits of the dimensions of gates of this construction.

The first column in each division of the Table gives the amount of transverse strain produced by the pressure of water upon three feet depth of surface, at an angle of $19^\circ 25'$; and the second column the dimensions of square oak timber necessary to bear three times that strain.

TABLE II.

Length of Gate.	6 FEET DEEP.		8 FEET DEEP.		10 FEET DEEP.		12 FEET DEEP.		14 FEET DEEP.		16 FEET DEEP.		18 FEET DEEP.		20 FEET DEEP.	
	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimen- sions of Square Timber necessary to bear three times that strain.
FEET.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.
5	1.601	4.86	2.134	5.35	2.668	5.77	3.202	6.13	3.735	6.45	4.269	6.74	4.803	7.01	5.336	7.26
6	1.921	5.49	2.561	6.05	3.201	6.52	3.842	6.92	4.482	7.29	5.123	7.62	5.763	7.93	6.403	8.21
7	2.241	6.09	2.987	6.70	3.735	7.22	4.483	7.67	5.229	8.07	5.976	8.45	6.724	8.78	7.470	9.10
8	2.561	6.66	3.414	7.32	4.268	7.89	5.123	8.39	5.976	8.83	6.831	9.23	7.685	9.60	8.538	9.94
9	2.882	7.20	3.841	7.92	4.802	8.54	5.763	9.07	6.723	9.55	7.684	9.98	8.645	10.38	9.600	10.75
10	3.202	7.72	4.268	8.50	5.336	9.16	6.404	9.73	7.470	10.24	8.538	10.71	9.606	11.14	10.672	11.54
11	3.522	8.23	4.695	9.06	5.869	9.76	7.044	10.37	8.217	10.92	9.392	11.41	10.566	11.87	11.739	12.30
12	3.842	8.72	5.122	9.60	6.402	10.34	7.684	10.98	8.964	11.57	10.246	12.10	11.526	12.58	12.806	13.03
13	4.162	9.20	5.548	10.12	6.937	10.90	8.325	11.59	9.711	12.20	11.099	12.76	12.488	13.27	13.874	13.74
14	4.482	9.67	5.974	10.64	7.470	11.46	8.966	12.18	10.458	12.82	11.952	13.40	13.448	13.94	14.940	14.44
15	4.803	10.12	6.402	11.14	8.064	12.00	9.606	12.75	11.205	13.42	12.807	14.03	14.409	14.55	16.008	15.12
16	5.122	10.56	6.828	11.63	8.536	12.53	10.246	13.31	11.952	14.01	13.662	14.65	15.370	15.24	17.076	15.78
17	5.443	11.00	7.255	12.11	9.071	13.05	10.887	13.86	12.699	14.60	14.514	15.26	16.330	15.86	18.142	16.43
18	5.763	11.43	7.683	12.58	9.603	13.55	11.526	14.40	13.446	15.16	15.369	15.85	17.289	16.48	19.209	17.07
19	6.083	11.85	8.109	13.04	10.138	14.04	12.167	14.93	14.195	15.72	16.222	16.43	18.251	17.09	20.277	17.70
20	6.404	12.26	8.536	13.49	10.672	14.54	12.808	15.45	14.940	16.26	17.076	17.00	19.212	17.68	21.344	18.31

In making use of the above Table, for obtaining the necessary dimensions of the lower timbers, it has to be considered that a great support is afforded by the sill of the Gate, which will of course permit with safety the use of less timber than the Table will give. The influence of this support cannot, however, extend beyond the second timber from the bottom, as the deflection of the planking will allow the whole of the pressure to be effective.

Curved Lock Gates.

In locks of large dimensions in this country, a curved figure is given to the gates, so that when united they resemble a Gothic arch; this figure, by giving greater strength, permits a reduction to be made in the dimensions of the timber, and the gates are thereby rendered lighter, and more readily movable. The degree of curvature which will give the greatest strength, and the necessary dimensions of the timber in different sized locks, are of course points of considerable importance, not only on the score of economy, but from the greater degree of lightness that may be thus obtained; the opening and shutting can be performed with greater ease, and consequently a greater number of ships can be permitted to pass in a given time.

In order to estimate the degree of curvature which will give the greatest strength, it is first necessary to consider the nature and amount of the strains to which the Gothic shape gives rise, we may then perceive what variations, with respect to the degree of curvature and amount of salience, will tend to increase the strength, or vice versâ.

Let AB, BC represent two gates meeting in the point B, and let the angle of salience, BAC, be equal to ϕ , also the angle DBE of a tangent to the curve of the gate, with the cord BA = θ , and the pressure of water upon each gate = w . The gate AB, being loaded equally all over, will exert a pressure in the direction of the tangent, to the extremity of the gate, which will be represented by the line DB, (the perpendicular DE being equal to $\frac{1}{2}w$,) or equal $\frac{1}{2}w \operatorname{cosec} \theta$.

This force is partly resisted by the compressive force of the opposite gate, which now, instead of adding to the transverse strain, as in the straight gates, is the means of diminishing it in proportion as it counteracts or destroys the

tangential force DB. In order therefore to estimate the amount of strain, it becomes necessary to get an expression for this force, which may be done as follows. Let BF represent the force acting at right angles to the extremity of the gate BC, tending to turn it upon the point C, which is of course equal to half the pressure of water. Resolving this into the direction of the tangent of the curve AB, by drawing FG parallel to BC, and producing DB, we obtain the line BG, which represents the compressive force of the gate BC in the direction of the tangent DB, and which is equal $\frac{1}{2}w \operatorname{cosec} (2\phi - \theta)$.

As the diminution of strain owing to this force is, in proportion it destroys the tangential force DB, the amount of the transverse strain at any angle, ϕ and θ may be found by the following proportion:

$$\begin{aligned} \frac{1}{2}w \operatorname{cosec} \theta &: \frac{1}{2}w \{ \operatorname{cosec} \theta - \operatorname{cosec} (2\phi - \theta) \} :: \frac{1}{2}w : x \\ \text{Or, } x &= \frac{\frac{1}{2}w \{ \operatorname{cosec} \theta - \operatorname{cosec} (2\phi - \theta) \}}{\operatorname{cosec} \theta} = \frac{1}{2}w \left\{ 1 - \frac{\operatorname{cosec} (2\phi - \theta)}{\operatorname{cosec} \theta} \right\} \\ &= \frac{1}{2}w \left\{ 1 - \frac{\sin \theta}{\sin (2\phi - \theta)} \right\} \end{aligned}$$

which is the true expression of the transverse strain or weight applied transversely in the middle of the length, which would have equal effect in breaking the timber.

It will at once be seen that when the gates united form a complete arch, that is, when the angles ϕ and θ become equal, the expression vanishes, the tangential force being then resisted by an equal compressive force in the opposite gate.

In this position, therefore, if the curve was mathematically true, the strain perfectly equal and regular, and the material also of an uniform density, the loading the arch would have no other effect than that of direct compression in the direction of the fibres, a description of strain which timber possesses great power to resist, as appears from the experiments of Girard. In practice this cannot, however, take place; the curve can neither be perfectly true nor the density of the material uniform, either of which defects would lead to a transverse strain, which, if sufficient weight was put on, would ultimately destroy the gate. In the former case, the flatter parts of the curve would naturally have a transverse strain upon the bottom fibres, from the abutments or terminations of it not being resisted with an equal degree of compressive force; the fibres would in consequence in some measure yield, and the relative position of the gates at the point of meeting would be changed, so as not to touch equally

throughout ; an increased compression would be brought upon particular fibres, which must of course yield, and the evil would continue to increase until fracture ultimately took place. In a similar manner, an irregular density of the material, by causing a yielding in some parts more than others, would bring on a change of shape which would ultimately produce the same results.

It therefore appears that in either case the cause which ultimately leads to fracture is the transverse strain produced from the irregularity of the curve, brought on by circumstances which cannot be controlled. Hence the nearer the curve can be preserved in the true figure of an arc of a circle, the greater the strength of the gates.

It has however to be considered that the arch is not composed of one complete timber, but that the fibres are disunited at the point of meeting, and consequently if that part from any cause should become flattened there are no fibres to resist the transverse strain thus produced ; and as the flattening of this part of the arch is an effect which might probably arise from any yielding of the abutments, or wear of the heel posts in the hollow quoin, this would evidently be the weakest part of the curve. It therefore becomes necessary to deviate in a small degree from the true curve of the arch, by giving the gates greater length, and causing them to meet at a point a short distance from the curve, or in fact rendering them slightly Gothic ; but as the security to the point is obtained at the expense of a constant transverse strain upon each of the gates, the deviation from the true arched figure should be as little as possible, consistently with the object in view, and by no means so great as is commonly employed in lock gates : I should think a deviation of one foot or eighteen inches quite sufficient for the purpose of locks of from forty to fifty feet wide.

General Remarks.

It was my intention to have concluded the preceding part of the article with a Table of the requisite dimensions of timber for gates of different sizes, both of the curves commonly employed, and of those which I should recommend ; I find, however, that these calculations would require a greater length of time than I can at present devote to the subject, and I therefore conclude with a few general remarks on the results arrived at.

In the first place, with respect to the proper angle of straight gates, this being a subject naturally calculated to excite the propensities of the mathema-

tician to set his maxima and minima to work, a great number of solutions to the problem have been given; but I must remark, with every respect for that useful class of men, that they are frequently too anxious to commence investigations without sufficient data, and consequently arrive at results totally incorrect, which has certainly been the case in those investigations I have had an opportunity of examining on the subject.

It seems to me perfectly impossible to arrive at correct results, without first ascertaining the amount of transverse strain produced by the end pressure, which does not seem to have been done before; but having obtained this from Girard's experiments to be one-tenth of the effect of an equal weight in the middle of the length, I have little doubt that the angle $19^{\circ} 25'$ would be found, by experiments, to be very nearly that in which the greatest strength would be obtained with a given quantity of timber.

The angle commonly adopted in this country, is considerably more than $19^{\circ} 25'$, amounting generally to between 30 and 40 degrees, which is said to be preferred from the direction of the thrust being met by a larger quantity of brick-work. I cannot, however, conceive this to be a matter of much importance, particularly as there are locks on the continent, of large dimensions, where the angle is considerably less, which have stood perfectly well. The angle of the celebrated sea-lock of Muyden is only $16^{\circ} 30'$, and the ancient lock of Sparendam, which was built in 1568, and has stood many storms without injury, has a sally of not more than one-sixteenth:—the angle ought certainly to be in some measure guided by the circumstances in which the gate is placed; at the same time, I consider the angle commonly made use of in England, to be decidedly larger than necessary, and a useless weight of material employed, which increases one of the evils of canal navigation,—the time consumed in passing the locks.

The employment of curved timber is undoubtedly advantageous, but its application is evidently made upon no fixed principles, as may be seen from the differences of the curves which have been adopted; some being so great as to very nearly approach the figure I have pointed out as the best, while others are so exceedingly flat that they possess little advantage over the straight gate.

To illustrate these differences in wooden gates, I have represented, in the accompanying drawing, the curves employed in the gates of the St. Katharine's, London, and West India Docks. The dimensions are as follows:—

ST. KATHARINE'S DOCKS.

Width of the lock		45 feet.
Projection		11
Radius of the gate		117

Consequently the angle $\phi = 29^{\circ} 16'$, and $\theta = 6^{\circ} 8'$.

LONDON DOCKS.

Width of the lock		40 feet.
Projection		9
Radius of the gate		50

Angle $\phi = 23^{\circ} 35'$, and $\theta = 13^{\circ} 54'$.

WEST INDIA DOCKS.

Width of the lock		45 feet.
Projection		10
Radius of the gate		120

Angle $\phi = 26^{\circ} 24'$, and $\theta = 5^{\circ} 53'$.

With the aid of the preceding formulæ I have calculated the amount of transverse strain in each case, (half the pressure of water upon one gate being unity,) and the same, if they were of straight timber, having an equal salient angle. These formulæ are arranged in the following Table.

In order to make the comparison of the straight and curved gate more direct, there is also added a column of the amount of transverse strain on the latter, that on the straight gate being unity.

The fourth column illustrates the reduction of the dimensions of square timber which may be permitted owing to the diminished strain.

TABLE III.

GATE.	Transverse strain, $\frac{1}{2}$ to being unity.	Transverse strain of straight timber having the same salient angle, $\frac{1}{2}$ to being unity.	Transverse strain, that on the straight gate being unity.	Dimensions of timber having equal strength, that on the straight gate being unity.
At St. Katharine's Docks .	·86	1.178	·73	·900
London Docks . . .	·56	1.229	·45	·766
West India Docks . .	·86	1.201	·72	·896

It thus appears that a considerable advantage is gained in each case from the curvature, but that in the London Docks, from the radius being less, and the two gates in consequence approaching nearer the curve of a complete arch, the advantage is much greater, and the transverse strain in consequence reduced to less than half that of straight gates having the same salient angle.

The difficulty of obtaining timber of sufficient curvature has been urged as a reason for the flatness of the curves employed in wooden gates; this is certainly a consideration which must be attended to, but as similar curves are employed when the material made use of is cast iron, I cannot conceive this to be a point which has materially influenced the choice of the figure.

In the accompanying drawing (Plate XIII.) are given the curves of the gates of the Caledonian Canal, Dundee Docks, and Sheerness Basin, which are of cast iron: they will be found to differ very materially from each other, being in one instance nearly as flat as in the West India and St. Katharine's Docks.

The following are the dimensions:—

CALEDONIAN CANAL.

Width of the lock		40 feet.
Amount of projection		10
Radius of curvature		75

Angle of sally $\phi = 30^\circ$, and $\theta = 8^\circ 3'$.

DUNDEE DRY DOCKS.

Width of entrance		40 feet.
Amount of projection		7 feet 6 inches.
Radius of curvature		67 feet.

Angle of sally $\phi = 22^\circ 2'$, and $\theta = 9^\circ 12'$.

SHEERNESS BASIN.

Width of entrance		58 feet.
Amount of projection		12 feet 6 inches.
Radius of curvature		55 feet.

Angle $\phi = 24^\circ 5'$, and $\theta = 16^\circ 55'$.

To make a comparison of these curves, I have calculated a Table, as in the case of the wooden gates, containing the amount of the transverse strain which straight gates would have under similar circumstances.

The same formula is employed for this purpose as for the wooden gates, which may not be strictly true with cast iron ; but I should not conceive the difference to be sufficient to affect materially the comparison.

TABLE IV.

GATE.	Transverse strain, half the pressure of water being unity.	Transverse strain of a straight gate, with the same sa- lient angle.	Transverse strain, that of the straight gate being unity.	Dimension of iron of similar section with the straight gate, that of the latter being unity.
At Caledonian Canal . .	·82	1.173	·700	·887
Dundee Docks . . .	·72	1.247	·58	·834
Sheerness Basin . . .	·44	1.215	·35	·704

It thus appears that in the gates of the Caledonian Canal the transverse strain is nearly as great as in the West India and St. Katharine's Docks. In those of the Dundee Docks and Sheerness Basin, a considerable improvement is made, particularly in the latter, where the strain amounts to little more than one-third of that which straight gates would have in the same situation ; but I conceive that by slightly diminishing the salient angle, and increasing the curvature of the gates, the advantage might be carried still further,—the same strength produced by less weight of material, and a lightness given which would greatly facilitate the passing and repassing of vessels.

CURVES OF LOCK-GATES.

ST KATHERINES DOCKS.

CALEDONIAN CANAL.

LONDON DOCKS.

SHEERNESS BASIN.

WEST INDIA DOCKS.

PROPOSED CURVES.

DUNDEE DOCKS.

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