

Occasional Paper 128 – Brindley gates, safety gates, stop gates and stop planks

Introduction:

In his book *Lives of the Engineers* Samuel Smiles advises

As one of the great objections made to the construction of the canal had been the danger threatened to the surrounding districts by the bursting of the embankments, Brindley made it his object to provide against the occurrence of such an accident by an ingenious expedient.

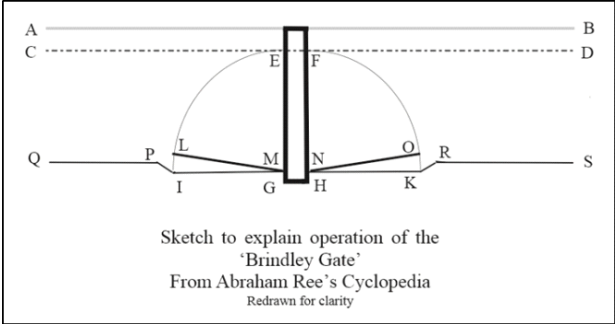
He refers to the Duke of Bridgewater's Canal built in the 1760s to carry coal from his mines at Worsley to Manchester.

Some twenty years after the opening of the Duke's canal, John Phillips, in his "Phillips Inland Navigation" writes that there were many stops, or floodgates, designed to automatically shut in the event of a breach built into the Duke's canal. There are suggestions that some of the other early canals were also built with these automatic gates, now generally known as a "Brindley Gates, after the Bridgewater Canal's engineer, James Brindley but, so far, no positive evidence has come to light. However, recent excavations during several canal restoration projects have identified a derivative of the automatic gate which was manually operated and will be discussed later.

The Brindley Gate, (or Safety Gate):

Historical Information

There is no illustration in Smiles' volume but a sketch and description of such an expedient can be found in *The Cyclopaedia or Dictionary of Arts, Science and Literature* by Abraham Rees. His sketch, redrawn for clarity as Fig 1, is explained as follows:

 <p>Sketch to explain operation of the 'Brindley Gate' From Abraham Rees's Cyclopaedia Redrawn for clarity</p> <p>Fig 1</p>	AB	Represents the top of the wall, or height of the towing path under a bridge.
	CD	The surface of the water.
	QS	The bottom of the canal
	EFGH	Is a pair of hewn stones, or a piece of formed oak timber let into the wall, its face being flush therewith
	IEG & HFK	Are recesses about two inches deep in the wall; similar provision is made in the opposite wall, for receiving counterbalanced doors or gates LM and NO across the canal, turning on centres or hollow quoins at M and N.

Under normal conditions the counterbalanced gates LM and NO would be arranged to rest in the position shown on the sketch. In the event of a breach the increased flow should be sufficient to raise the gate facing the flow to the vertical position hence stopping the flow of water. The depressions at I and K across the bed beneath the gates are probably there to facilitate starting the initial movement of the gate. The back to back arrangement shown would allow strategically

placed gates at each end of an embankment to effectively stop loss of water from both ends of the canal.

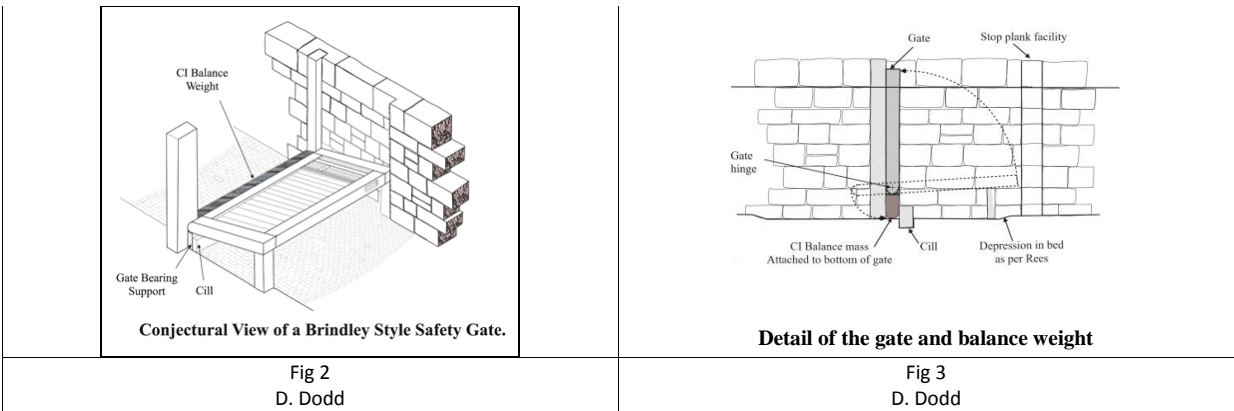
Some doubt as to the effective operation of these gates is frequently expressed and as far back as 1781 Matthew Boulton, a Birmingham industrialist, wrote ‘How easy it is to pin down a Stop Gate, or how probable it is that bungling contrivance should not rise if the Canal should break down is very obvious.’ He was very worried about the canal leaking/bursting and taking the water which powered his already substantial manufactory and he was certainly not impressed with rising stop gates. In the first instance the mechanism had to be kept clear of silt and other debris in order for it to work at all. Not always easy under normal canal operating conditions. Then there was the problem of making a very heavy, near horizontal gate even if counterbalanced, start to rise as soon as the flow rate increased.

In order to achieve the differential pressure required for the system to work it is necessary to have water flow above and below the gate. The velocity below will be less than that above the gate because of drag along the canal bottom whereas that above will accelerate as the breach continues to discharge water. It should behave rather like an aeroplane wing with the lower and higher pressures on top and bottom respectively.

In order to meet these dynamic conditions it is necessary to design a gate to include the following features:

- The gate must include a counterbalance.
- The gate hinge must be above the canal bottom. (To allow for the counterbalance).
- The gate must seal off the water flow when closed.

Figs 2 and 3 show possible arrangements for the necessary features.



Rees described gate assemblies of this sort as *safety gates*, but they are often referred to as Brindley Gates although how much Brindley had to do with the design is not known.

Rees then continues to describe two more isolating arrangements, namely *stop gates* which are simple, unbalanced gates resting on the bottom of the canal with chains attached so that they can be manually hauled into the vertical position when required. They are simply safety gates without a counterbalance, and finally *stop planks*, where an appropriate number of planks are

dropped into vertical recesses or guides in walls either side of the canal to stop the flow of water. The second two arrangements are used when planned isolation of a section for maintenance is required and are usually found adjacent to or as part of a lock or bridge hole where the necessary masonry structures would be required anyway

Stop Gates

In recent years several well preserved examples of horizontal style stop gates of the kind described by Rees have been excavated on the Kennett & Avon Canal (K&AC) and the broad section of the Grand Western Canal (GWC) in Devon. Both canals were engineered by John Rennie, being completed in 1810 and 1814 respectively.

The Kennet and Avon Canal (John Rennie), built 1794-1810

In 2000, during relining of a section of the canal to the east of the Dundas Aqueduct, an almost complete gate assembly was uncovered together with another almost rotted away. They were both hinged horizontally along the bottom, each installed so that canal flow could be controlled from either direction (i.e. left and right handed). The best example included a paddle assembly, which would have been opened during gate operation to reduce the resistance created by its movement through the water. A block and tackle arrangement or perhaps horse power would have been used to raise and lower the heavy gates which would have been installed at a reduced width part of the canal, very likely in conjunction with a bridge hole or at either end of an embankment.



Plate 1
Limpley Stoke Stop Gate
from *Waterways World*, Feb 2001 P35

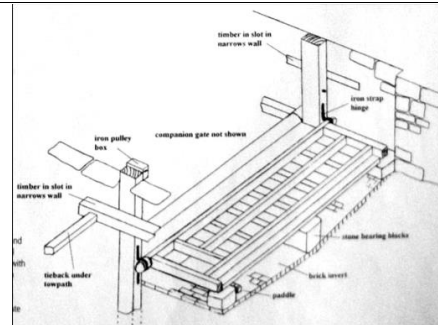


Fig 4.
Conjectural View of the Gate,
from *Narrow Boat*, Spring 2010 P.11

The gate shows no evidence of a counterbalance so was probably installed as a stop gate as were the ones on the Grand Western Canal. A block holding the gate clear of the canal bottom at a positive angle of about 5 degrees is evident under the centre, there to allow water to flow under the gate to assist when raising or lowering it, and to prevent silt from covering the assembly when in the open position. The gate is now on display at the Kennet and Avon Canal Museum, Devizes, Wiltshire

The Grand Western Canal, Devon. (John Rennie), built 1810-1814

In November 2012 the north side of the canal embankment at Halberton between the Swing and

Rock Bridges breached after a period of exceptional rainfall. The breach was very serious and immediately attended to by Devon County Council. The following repair work and the upgrading of that section of the canal revealed the existence of one very well preserved stop gate at Swing Bridge and evidence of a gate installation at Rock Bridge, similar in arrangement and construction to the ones on the Kennet & Avon Canal at Limpley Stoke.

A survey was carried out and presented by AC Archaeology in March 2014.

The upper surface of the sound gate was cleaned up and the construction details and other features recorded. A heavy chain was attached to the off side which presumably had been used for lifting the gate. Rather than the paddle arrangement described on the K&AC gates a type of hinged flap was used. It was difficult to fully assess the construction of the flap gear as a decision was made not to lift the gate but to leave it in its nearly horizontal position, resting on a short post which may have had the same purpose as the stone blocks at Limpley Stoke.



Plate 2,
Swing Bridge viewed from East.
Shows post projecting through the gate. AC Archaeology

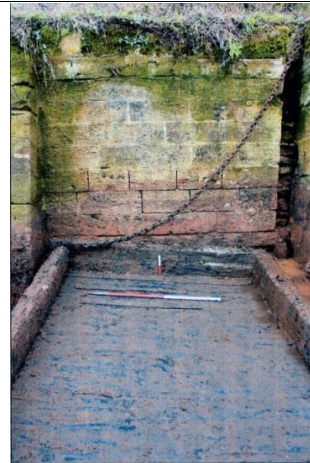


Plate 3,
Swing Bridge viewed from the South
showing recess in North abutment. AC Archaeology

Installation of the Rennie Stop Gates

The *Narrow Boat* article of Spring 2010 mentions two slots, one in each side wall and facing in opposite directions, adjacent to the vertical timber gate jamb. It was concluded that their function was to facilitate installation of the gate by lowering it in askew and twisting it into the working position. It is assumed that the gate was then secured by inserting wooden wedges into the slots.

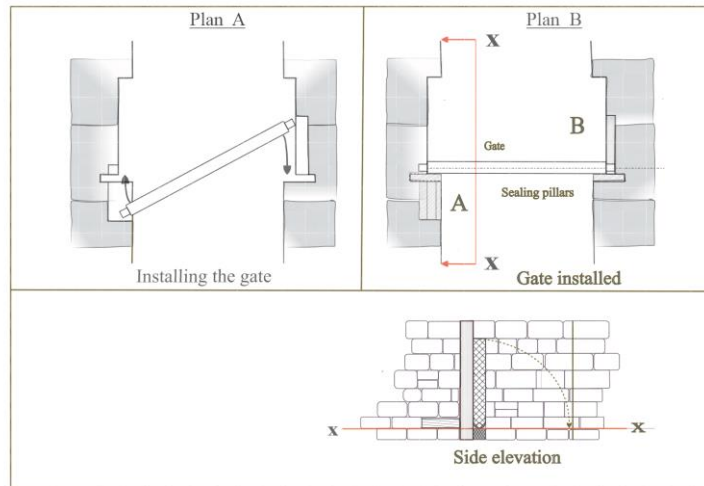


Fig 5
Conjectural view of Limpley Stoke arrangement. D. Dodd

Fig 5 indicates that the gates could just as easily be installed with the slots A and B on the same side of the gate with A opposite to B. It would also make for a cheaper construction and evidence of this arrangement was seen at Rock Bridge during the repair work. See Plates 4, 5, 6 & 7.

Plates 4 and 5 of the Rock bridge site show how the gate jamb grooves have been utilised as a stop plank facility and a steel beam inserted as a cill and a stop plank in position above it. The wedge slots are clearly visible and suggest that the arrangement was simplified as described above as they are opposite each other..





Plate 6
D. Dodd



Plate 7
D. Dodd

Plate 6 shows damage to the original bridge stone invert and Plate 7 shows a mason's mark at Rock Bridge.

Other Examples of Safety / Stop Gates

Cromford Canal, built, Built 1789-1794

Curious remains were found during the relining a section of canal under the Leashaw Bridge north of Whatstandwell. Unfortunately they were covered over before authorities were informed but a sketch generated from the contractor's recollection indicated the presence of an horizontally hinged gate. There is evidence of at least five other sites along the canal and it is hoped that future archaeological excavation will be possible.

Basingstoke Canal, built 1788-1794

There is evidence of a crescent shape cut into the stonework under the Mychett Place Bridge which could be construed as a safety device constructed to provide protection in the event of a breach in the nearby Ash Embankment

Brecon and Abergavenny Canal, built 1796-1812

Reconstruction work after a major breach in October 2007 exposed the remains of a wooden structure lying on the canal bed by Bridge 106 near Gilwern. It also had all the characteristics of a stop or 'rising' gate. The archaeology revealed nothing new but canal records referred to a 'rising gate' costing £3.00 to build at another site along the canal.

Bridgewater Canal built, built 1759-1761

Samuel Smiles refers to them being installed on the Duke of Bridgewater's Canal.

Droitwich Canal, completed 1771

Drawbridge type gates, referred to as 'Brindley gates', were found on the canal bed during restoration in the 1970s. They were located at disused swing bridges, each about half a mile to either side of Salwarpe Village. There is a steep embankment in the three mile long pound. They had chains attached suggesting they were designed as stop gates.

A Vertically Hinged Safety Gate?

In June 2002 The Waterway Recovery Group (WRG) were engaged to dredge 300 m of cutting

along the tub boat section of the Grand Western Canal near Cothay Manor in Somerset, known locally as Jay's Cutting. To the east there are 300 m of canal embankment where the canal is infilled. The Tithe Map showed a restriction in the canal at the feature change and the WRG were instructed to use their plant judiciously and hand dig where appropriate. Flat stones at ground level provided a path over the canal line but beneath them was a grid of stones and timber set to fill in the depression: Plates 8, 9, and 10. Some of the stones were fashioned to provide a typical lock arrangement including stop plank grooves and gate hinge features. Finally, the base was exposed showing various grooves for timber components and the remains of a vertically hinged gate lying at about 45 degrees across the canal bed: Plate 11. Working conditions were difficult because of continued ingress of water.

The gate hinge was on the south side of the chamber, Plate 13 and a recess in the wall accommodated it when open, Plate 12. The north side vertical wall was curved, Plate 14, to accommodate the gate as it swung into the closed position. The stop plank grooves were on the downstream side of the gate.

Much of the masonry had been robbed out but most of the large stones containing the gate hinge, recesses and grooves were randomly deposited close by the gate location. The gate appeared to fit snugly in the recess and may have moved due to increased flow. A gate projecting into the main channel and possessing similar design features described by Rees would have been be exceptionally prone to damage and probably possess a mind of its own anyway.

Beyond the embankment to the east the canal line crossed over a road, entered a short cutting and followed an escarpment contour to the top of the Wellsford Inclined plane where there is an 81 ft (24 m) drop to the next level. The incline is some 900 m beyond Jay's Cutting. The Tithe map shows another canal narrows just above the incline which may have included a gate. This has not been explored as access is problematical.

Plates 15 and 16 show all that remained of the gate after removal. Plates 17, 18, 19, 20 and 21 show the excavated stones.

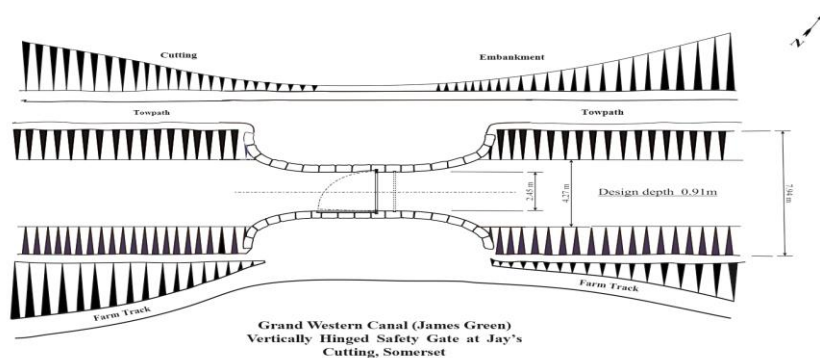


Fig 6
D. Dodd



Plate 8
D. Dodd



Plate 9
D. Dodd



Plate 10
D. Dodd



Plate 11
D. Dodd



Plate 12
D. Dodd



Plate 13
D. Dodd



Plate 14
D. Dodd



Plate 15
D. Dodd



Plate 16
D. Dodd



Plate 17
D. Dodd



Plate 18
D. Dodd



Plate 19
D. Dodd



Plate 20
D. Dodd



Plate 21
D. Dodd

Stop Planks

Stop planks are simple, and their simplicity makes them reliable. They consist of vertical slots cut into the masonry walls either side of a canal into which wooden planks are lowered to form a dam to isolate a section. They are invariably installed at a canal narrowing at either end of embankments, locks, inclined planes, lifts, bridge holes etc. – anywhere where the engineer would deem them to be useful for maintenance purposes. Plate 22 shows a typical siting under a bridge where masonry walls are necessary anyway. The canal beyond the stop planks has been drained.



Plate 22
Baker Gr07.E01.S01.P01

Experiments with a Model

Rees's explanation of the safety gate and the accompanying drawing promoted much discussion, particularly about the depression in the canal bed beneath the gate and the angle set to raise the leading. It was thought possible that the Bernoulli's principle might be relevant, so a small model (approximately 1:60 scale) that included a trough and adjustable gate was constructed that would, hopefully, replicate working conditions. An explanation and the results of the tests and a conclusion are included in Appendices I and II.

Conclusion

It is generally accepted that the Canal Age in the United Kingdom started with the Duke of Bridgewater's Canal in North West England in the 1760s. As work progressed and landowners began to realise the significance of a major breach the inclusion of some sort of protection device would have been demanded and it seems that Brindley rose to the challenge and devised the type of gate recorded in Rees's *Cyclopaedia* which was published in 1820.

Little is known about Brindley's education but he was certainly able to read, write and work calculations. There were Quaker connections and it is possible that he attended a Quaker School. He started working life as a mill wright and would have been familiar with the effects of protuberances etc. on water flow in steams and mill leats. It is unlikely that he was aware of Bernoulli's principle published 1738 but he was a practical man and his natural ability as an innovative engineer with fine observational skills would well have enabled him to design a working safety gate.

Most of the recorded finds of what may have been safety gates have been found in the first generation period of canal building in the UK – a period of about 20 years. After that, stop gates appear on the Kennet and Avon and the Grand Western Canals, horizontally hinged and lying on the canal bed until required. Stop gates are relatively easy to manually lift especially if headroom is available, as at a bridge-hole and ideal for use during maintenance operations. In the event of a long term shut down program the use of stop planks to augment the gate would be normal practice. Installing stop planks in fast flowing water is a hazardous operation as they found out in Devon two years ago. Much easier to use modern plant and clay filled dumpy bags!

It is reasonably safe to conclude that Brindley designed and installed the type of safety gate linked to his name, and that they probably worked if well maintained. However, until archaeology or supportive written evidence comes to light we cannot be completely sure. In all event they probably fell out of use because they were expensive to build and maintain and any economic benefit superseded by the introduction of stop gates.

I would also like to thank the following contributors whose names are not included in the footnotes.

Andrew Davey and Keith Westray, Droitwich Canal Trust

Andrew Denny, *Waterways World*

Christine Richardson, 'James Brindley biographer', Chesterfield Canal Trust.

John Ditchfield, for model, tests and analysis of results,

David Greenfield, Graham Laucht, Brian Goggan and Brian Murless for valuable support.

Appendix I

Further discussion introduced the idea that Bernoulli's Theorem might help to understand what was happening during the tests.

Bernoulli's Theorem

The principle behind Bernoulli's theorem is the law of conservation of energy. It states that energy can be neither created nor destroyed, but merely changed from one form to another, i.e. potential energy to kinetic energy or kinetic energy to potential energy

By using an hydrofoil as an analogy it can be demonstrated how the Theorem might be applied to a Brindley gate.

STREAMLINE FLOW over an HYDROFOIL

The following explanation is a simplified description of the actual process that provides the *lift* that occurs when an aerofoil or hydrofoil performs in fluid flow. The effects of the vortex, vortices, boundary layer and angle of attack, which also help to increase lift, are omitted for the sake of clarity.

Consider Figure 7. This represents streamline flow over an hydrofoil showing how the streamlines close in over the top of the of the upper surface.

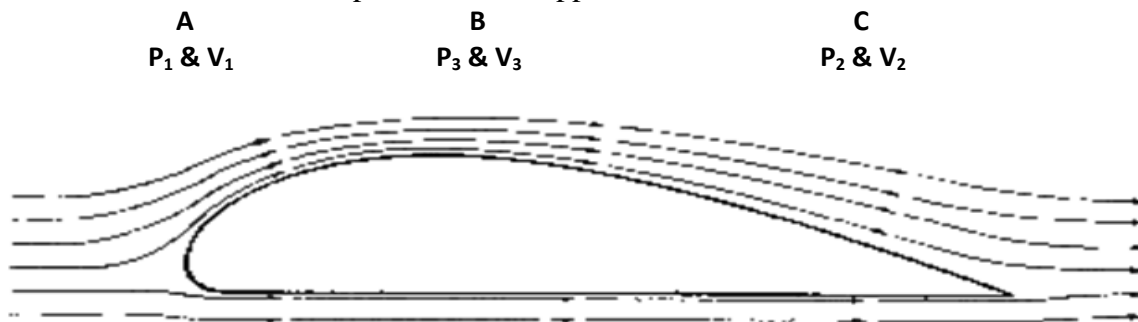


Figure 7 – Streamline flow over an hydrofoil

V = Velocity

KE = Kinetic energy (in the fluid by virtue of its motion)

P = Pressure

PE = Potential energy (in the fluid as pressure)

Total energy in system = **KE + PE**

At positions A & C **$P_1 \& V_1$** & **$P_2 \& V_2$** have the same values.

But at **B** the closing in of the streamlines constricts the flow. As a result there is an increase in **velocity** over the top of the hydrofoil resulting in a **low-pressure** area. This, being lower than the pressure beneath the hydrofoil, creates a lift.

Applying the Bernoulli concept to a Brindley gate bearing in mind that the gate is not shaped like an hydrofoil, we find:

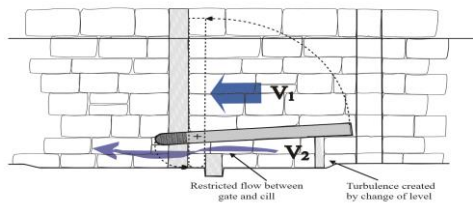


Fig 8 Gate open
D. Dodd

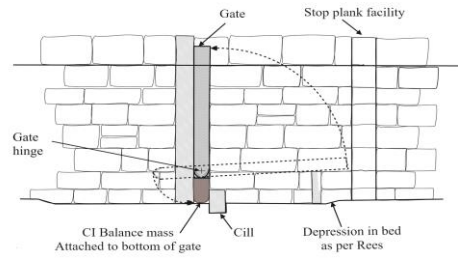


Fig 9 Gate shut
D. Dodd

Fig 8 Gate open:

As a breach occurs, flow velocity V_1 increases reducing the pressure over the gate. The restricted flow at V_2 below the gate induces a higher pressure thus creating an upward lifting force. The depression shown, as per Rees in Fig. 1, is there possibly to induce turbulence beneath the gate hence clear debris and assist the initial movement. (See comments in Appendix II, Test 6 and Conclusion.)

Fig 9 Gate shut:

Velocity V_2 decreases as the gate closes

Appendix II

The Tests & Conclusion (John Ditchfield)



Plate 1



Plate 2

FLOW



Plate 3

Views of the Test Rig
John Ditchfield

- Trough width-----90mm
- Gate weighted with a piece of sheet metal to prevent buoyancy
- Hinges A piece of slender rod passing through two eyelets.
- Photos taken from the upstream side.

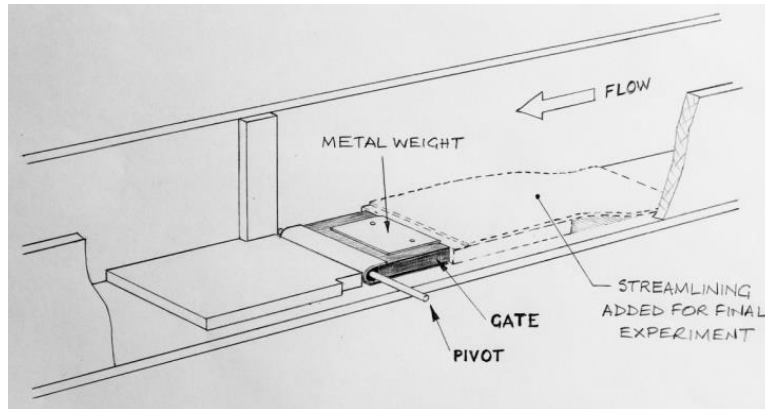
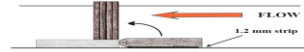


Fig 10 Test Rig Schematic
John Ditchfield

<p>1st Test</p> <p>A piece of wood the same thickness as gate placed on the floor of the canal, upstream and close to the edge of the recumbent gate.</p> <ul style="list-style-type: none"> • Canal filled, drain hole uncovered • The gate stayed put. 	
<p>2nd Test</p> <ul style="list-style-type: none"> • Piece of floor wood removed. Front edge of gate propped up by about 5 mm. Canal drained • <i>Gate lifted as water flow developed, and closed rapidly.</i> 	
<p>Piece of floor wood moved from upstream to downstream (as seen in photos), and hinge modified to minimise leakage under gate.</p>	
<p>3rd Test</p> <ul style="list-style-type: none"> • Gate propped at front by a smaller amount - about 3mm. • <i>Water released, gate worked.</i> 	
<p>4th Test</p> <ul style="list-style-type: none"> • Gap under front edge of gate reduced from 3 to 1.2 mm. • <i>Still worked OK.</i> 	

5th Test

- A 1.2 mm piece of metal strip (about 15mm wide) was then put under the full length of the gate so that the gate was ostensibly lying horizontal.
- *Surprisingly, it worked perfectly.*



In the tests, from opening the 'breach' there was a delay of a few seconds before the gate lifted. This reflects the time required for the body of water passing the gate to reach the critical velocity. In reality, the delay would depend on the distance of the breach from the stop gate. Clearly it would be desirable to put any safety gates as close as possible to likely breaching locations, and to make the gate passage as narrow as possible to maximise velocity. Clearly these requirements would also apply when more common stop planks were used. So, might the presence of narrow masonry-lined passages where there are no locks and no provision for stop planks, indicate the possible presence of safety gates?

I then returned the piece of wood to the floor of the canal upstream of the gate for further investigation, noting the step/recess shown in Rees's drawing. Before proceeding, it was clear that the gate was being restrained (to the floor) by surface tension, so I put a small spacer underneath.

6th Test

A

- To increase the velocity, I tilted the canal (not an expression you hear every day), and poured water in from a watering can.
- *To my surprise the gate did lift.*

However, on repeating the exercise, I saw that the leading edge of the false bottom was causing great disruption in the water at the edge of the gate, and the disturbance was helping the gate to lift



6th Test

B

- *When I streamlined the inserted piece of wood, the flow was smooth and the gate didn't lift.*



Conclusion

Could it be that the stepped recess shown in Rees's drawing was intended to encourage turbulence, to help unstick the gate if it was mud-bound? Or perhaps it was simply to allow the gates to

lie low, and not be hit by a boat. No matter, as it appears that the real gates as found were propped clear of the canal bed.

So, in summary, the model was far too small to be representative, and offered little prospect of proving anything beyond confirming the obvious fact that a slightly tilted gate would lift to oppose the flow if the flow was high enough: it would have been much more interesting if it had not worked!

The only surprise was that the model gate lifted even when it was nominally lying flat.

Another point arising, again obvious when you think about it, is that there is a definite time delay before the flow at the gate reaches the critical velocity following the breaching of the canal, during which time scouring damage will be developing.

What does come across is the ingenuity of the original idea. It would be interesting to know what size of leak - and hence water velocity in the narrow channel - Brindley had assumed, and what testing he had done.

Additional Information

Several 'narrows' not associated with bridges or locks identified in recently excavated parts of the Somerset Coal Canal are thought to be locations where Brindley style gates may have been installed. Unfortunately landowner considerations have prevented any in depth archaeological excavations to date.

It is extremely likely that similar automatic or manually operated stop gates were installed in many of the early canals at locations best suited to minimise flood damage in the event of a breach such as at either end of a large embankment.

D. Dodd July 2016