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Impounding gates for marina and harbour navigation use

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Abstract

There are a range of design options available when choosing to impound water in a harbour. The choice of gate type will depend on a wide range of considerations. This paper attempts to briefly review the various issues to be considered and gate options available.

1. Introduction

With the increase in leisure activities in recent times, there has been much investment in Marinas, whether within existing harbours or as stand alone facilities. The purpose of this paper is to review the various gate designs often employed for marinas and leisure related harbours. Also, to cover some of the factors that influences their application. Common criteria for such gates are that they seal in one (closed) position and are navigable when open.

Considerations as to the type of gate to employ will depend on a number of performance criteria including

- The tidal range
- The speed of operation required
- The consequences of failure
- A requirement to navigate at varying tide levels

2. Design basis

The design basis for impounding gates for harbour and marina navigation is an intriguing one. At one level they have been employed for hundreds of years and everyone is familiar with their use. At another level, British Standards or Codes of Practice poorly cover these installations and many areas are in effect a 'black art'.

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In addition, there has been a general reduction in the number of 'specialist design and build' Contractors with in-depth knowledge and experience in this field. Similarly the number of 'expert' Consultants has also reduced in recent years.

The combination of the increasing use of functional specifications for 'design and build' contracts, the absence of Standards and codes of practice and reducing Contractor knowledge has led to a number of problem installations in recent years.

3. Design standards applicable

The design of dock gates is covered within BS 6349 part 3. This represents the only British Standard reference work relating to the design of water control gates of any type.

Unfortunately users will find that it is difficult to obtain practicable guidance on many of the elemental loads involved. In particular advice on ship impact and friction often leaves the Designer uncertain as to the values to be adopted.

Thereafter, calculations are performed, based on either BS5950 or BS 5400. Thus in the United Kingdom, a gate has to be considered as a building or a bridge, though it is patently neither of these structures. In any case many gates are designed for deflection criteria rather than stress.

BS 6349 also provides no useful assistance on the design of gate details such as bearings, rollers, seals etc, i.e. those details that effectively turn a structure into a gate.

A more specific standard is DIN 19704, which was re-issued in 1998 in the 'limit-states' format. This is a useful and specific reference covering hydraulic structures. Specifiers should note that this standard lays a great deal of emphasis on the Client for specifying design requirements. DIN 19705 also provides good guidance on specific gate details.

Elsewhere there are reasonable standards from the United States of America, India and Japan.

4 Functionality considerations

4.1 Consequences of failure

Each site is different and engineers must evaluate the causes and consequences of operational failure when determining the type of gate to be employed and the design specification to be developed. In most harbour/marina installations, the consequences of a failure of the gates to close would mean the eventual emptying of the harbour. The financial consequences of damage to vessels could in these circumstances be severe.

Whilst many larger installations can financially justify an effective team of lock keepers and maintenance staff to deal with emergencies, smaller harbours cannot economically sustain twenty-four hour personnel cover and call out. In

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the former it may be appropriate to include alarm dial-out facilities and manual intervention equipment. In the latter cases a simpler system would be appropriate, perhaps float operated or based on occasional gate operation. Other harbours have adopted a duplicated gate approach to increase the probability of correct functioning.

Wherever possible duplicated operating systems should be considered, so that no single failure can cause the gate to be inoperable. Where appropriate, a considerably higher level of redundancy needs to be employed.

4.2 Vibration

All gates are prone to vibration due to the passage of high velocity water flowing past the structure. Special consideration needs to be given to ensure that vibration is designed-out at the detailing stage. Design to avoid vibration is an essential part of the gate development process.

4.3 Speed of operation

There are two distinctly separate aspects of the speed of operation of a gate. How fast does it open and close and, in the case of navigable locks, how fast does it allow water equalisation.

Typically, power operated gates open and close in around one to two minutes, though there are no rules in this area and wide variations exist.

Intelligent sluicing is beginning to be adopted in some marinas so as to vary the sluicing area in proportion to the differential head of the water levels. This enables a near constant throughput of water.

4.4 Control options

The development of control options is very site-dependent and only general advice can be given within a paper such as this.

Control systems should be designed so as to fail-safe where-ever possible.

Consideration should be given to the inclusion of back-up systems; appropriate to the implications of gate failure. Such provisions can include:

- Duplicated electric motors;
- Auxiliary power supplies;
- Manually operated valves so as to overcome electrical control failures;
- Trolley mounted emergency hydraulic systems with snap-on connectors.

Provision is required for navigation lights. Advice should be sought from the Harbour Master and Trinity House. Generally they will favour the standards adopted by the International Association of Lighthouse Authorities (I.A.L.A.). Whilst these are very appropriate for large installations, smaller marinas may wish to adopt a simpler system of red or green lights, which may be better understood by 'week-end sailors'.

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Marinas with a permanent lock keeper may require manual control. Small installations without manual intervention may rely on a simple timer controlling the direction of access to the harbour entrance.

Larger marinas are now providing event logging equipment so as to protect them from false litigation in the event that a vessel becomes damaged.

4.5 Free flow

Many harbours work on the basis of a period of free flow (gates fully open when the tide levels match the range of operating levels within the harbour/marina). This is particularly so around the top of the tide. When this can occur, special considerations relating to loading and controls come into play.

Great care should be taken to evaluate the maximum water velocity that may be present when the harbour empties or fills under such conditions. Larger harbours cannot usually adopt such a regime.

4.6 Flood defence

Some gate installations are required to provide a flood defence for the immediate inland area. Such gates must be capable of reverse loading.

In addition, detailed consideration needs to be given to ensuring that the gates are capable of closure even under the most advanced levels of component failure such as electrical power failure, motor failure, transmission failure, hydraulic pipeline bursts, etc.

4.7 Water leakage

In most harbour installations the degree of water leakage is not an especially big issue as later high tides can be used to top them up. In some places this is not the case and the cost of impounding pumps is a significant operating cost.

There is, however, a maintenance cost associated with specifying a low-leakage seal as the Contractor response is usually to jack the seals hard onto their respective sealing faces leading to accelerated wear.

5 Gate types

5.1 Mitre gates

5.1.1 Introduction

Mitre gates are the traditional means of impounding water within a commercial harbour. Large gates are normally floated into position and allowed to settle in position over a pintle pin, by opening tidal chambers. Such gates typically incorporate a combination of tidal and buoyancy chambers so as to regulate the net forces on the pintle.

Access to the internal parts of the gates bring into play issues relating to confined spaces which require minimum dimensions and safe means of ingress and egress, as well as facilities for air injection.

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The larger gates are arranged with a timber heelpost, which fits within a civil engineering quoin and forms a three-point arch when closed.

Smaller mitre gates can be designed with traditional bearings and incorporate neoprene seals against a stainless-steel frame.

Mitre gates are simple, well proven and are the traditional means of impounding water in harbours. Typically they incorporate sluice valves to enable water levels to be equalised across the gate prior to their operation.

Problems with mitre gates are well documented and include a vulnerability to trapping submerged debris between the lower clapping seal and it's mating face.

In addition, mitre gates cannot operate against reverse heads, hence there is a range of tides for which the gates must be open and a limitation on the range at which the gates may be opened or closed. The lack of resistance to reverse loading also makes them vulnerable to severe wave loading in their standard form.

5.1.2 Operating Systems

Historically, mitre gates were opened and closed using chain systems driven by capstans. Many gates remain today using variations of this system, however most modern gates have moved over to an oil hydraulic system.

Larger gates often employ a hydraulic cylinder running on a cross-head system with a separate strut linked to the gate leaf. This system limits the vulnerability of the cylinder to damage from ship impact.

Mitre gates normally incorporate sluices/penstocks that can be used to equalise water levels across the gate prior to operation. Alternatively such equipment is built into the civil engineering which allows water to bypass the gates.

5.2 Vertical Sector gates

5.2.1 Introduction

Sector gates have become very popular in the United Kingdom for marina use, mostly because of their ability to operate against a maximum unbalanced head from either side. As such, these gates can provide locked access to a marina for all navigable tide levels.

The gates are relatively expensive because they require accurate fabrication jigs and the general construction detail is of a more complex nature. However, they give the maximum flexibility to marina operation.

Water levels are synchronised by partially opening the gate leaves so that water flows around the recess. A secondary seal system prevents flow through the centre of the gates, which may be dangerous to boats within the lock and would promote vibration.

Sector gates are normally based on a pair of gates; however it is possible to base the installation on a single gate in the event that the design vessel width is small. This saves considerable cost and space in terms of recess construction.

As a consequence of the ability to withstand a load from either direction, the sealing systems are more complex. The seals for Sector gates need to be set very

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accurately. Unfortunately modern extruded neoprene seals cannot be manufactured to tight tolerances. For this reason the best designs incorporate seal sub-frames which can be finely adjusted by jacking in at least two planes.

A design that simply mounts the seal onto a surface that can be jacked in and out in one plane is unlikely to provide good service in the long term.

The design of the seal mounting frame also requires careful thought as the seals need to be protected from fast moving flotsam during sluicing.

5.2.2 Operating Systems

Sector gates can be operated by winch or by hydraulic cylinder. Cylinders have tended to predominate in the last decade in view of their direct action, ability to accelerate and decelerate a load and their general robustness.

The design of the cylinder construction is important and the installed position needs to take tide levels into consideration, as there may be occasions when it is immersed.

The design of load control valves for Sector Gate use is of significance because there are considerable fluctuations of pressure in the cylinder during an opening/sluicing cycle, which can lead to hydraulic instability.

Recent Sector gates have included 'intelligent sluicing' equipment. This system senses the water level difference across the gate leaf and automatically adjusts the gate position to increase the sluice opening as the differential falls. This system can maintain a relatively even rate of water transfer and thus substantially reduces the time required to lock through the system.

5.3 Horizontal Rising Sector gates

5.3.1 Introduction

A rising sector gate can also be used to impound water and be navigable. Such arrangements are similar to the Thames Barrier in principle (see figure 3).

The gates are capable of accepting a hydraulic load from either direction and have the advantage that they take up a smaller 'footprint' than conventional Sector gates.

The turbulence caused when such gates are equalising water and their cost when compared to a tilting gate has generally meant that their take-up has been restricted. However they do have some advantages within certain limited site constraints and should not be immediately discounted when first considering options.

In view of the need to design an underwater recess to lower the gates into, some thought needs to be given to the incidence of siltation. In general, gates which open and close on each tide tend to stay untroubled from an accumulation of silt. Where this may not be the case, provision can be made for a means of fluidising the silt via air or water pipeline systems.

5.3.2 Operating Systems

Sector gates can be operated by winch or by hydraulic cylinder. Cylinders have tended to predominate in the last decade in view of their direct action. Also the

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use of a winch requires careful design of the centre of gravity and buoyancy so that the rope remains in tension through all points of operation.

5.4 Delta gates

5.4.1 Introduction

Delta gates are similar in principle to Vertical Sector gates. They differ in so far as the gate leaf is flat.

Delta gates offer the advantage that the gate leaves are cheaper to manufacture because they can be made on the fabrication workshop floor and thus do not require special jigs. They have one major disadvantage in that the bottom seals have a part sweeping and part scuffing action and experience has tended to show that failure rates are high. For this reason they have not been widely adopted.

5.4.2 Operating systems

Because Delta gates operate in a similar manner to Sector gates, the points previously raised, apply identically here.

5.5 Tilting gates

5.5.1 Introduction

Tilting gates are normally flat structures, hinged along their lower edge and are raised or lowered when the tide level equates to the natural gate impoundment level. In so doing the gate is effectively operated under near balanced head conditions.

This being the case, Tilting Gates provide the cheapest form of gate impoundment. This is so because the gate leaf is flat and the operating equipment does not have to be rated for large differentials.

In view of their design, simple Tilting Gates cannot take a high degree of reverse loading and it is necessary to open and close them at specific water levels over the tidal cycle.

Tilting gates can provide an element of wave or flood protection by introducing mechanical latches at the top outside edges. Special attention should be given with such devices, as they are located at a position where flotsam can be a problem.

Care needs to be taken when applying Tilting Gates to large Harbours as high water velocities may be engendered at certain phases of the tide.

On large tilting gates it is often cost effective to build some measure of buoyancy into the structure; this has the advantage of reducing the forces necessary for articulation.

Special attention needs to be paid to protecting the bottom edge of the gate. Tilting gates are vulnerable to debris falling down the leaf as it is raised and becoming jammed between the gate leaf and frame, where the considerable mechanical advantage of the operating equipment can cause structural damage.

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Typically this problem is addressed by the introduction of a flap, which spans the gap between the gate and its sealing frame.

The Designer should take steps to protect vessels during gate operation as they may be unaware of a large structure rising just below the water level. In this respect a Tilting gate is at a disadvantage to say a Sector Gate in that the gate leaf is often invisible to mariners.

Tilting gates can be arranged to include pedestrian walkways along the top edge. Special risk assessment needs to be undertaken as there are often difficulties in clearing the structure prior to operation, particularly with the need to regulate the precise time at which such a gate is operated.

In view of the need to design an underwater recess to lower the gates into, some thought needs to be given to the incidence of siltation. In general, gates which open and close on each tide tend to stay untroubled from an accumulation of silt. Where this may not be the case, provision can be made for a means of fluidising the silt via air or water pipelines.

Because tilting gate bearings are permanently immersed it is wise to ensure that they are sealed from silt ingress. In addition, provision may be necessary to be able to change the bearings with the gates insitu.

5.5.2 Operating systems

The two principle means of operating an impounding tilting gate is by wire rope winch or hydraulic cylinder.

The wire rope arrangement is relatively cheap and consists of the dead ended rope on one side of the civil works passing over a number of pullies mounted on the gate leaf and finally onto a winch.

Winch pullies should be arranged so that the wire rope cannot disengage from a pulley in the event of a slack rope condition.

Consideration should be given to the means by which a rope can be changed in an emergency.

Limit switch arrangements need to consider the effect of long-term rope stretch.

Hydraulic arrangements can employ either one or two cylinders.

A single cylinder can be used for gate operation provided that sufficient torsional stiffness is built into the gate structure. Such stiffness usually takes the form of a box type structure. A single cylinder is cheaper and avoids the need to synchronise hydraulic operation. In addition it can also mean that the hydraulic system does not need to be routed across the lock and this avoids potential pollution hazards.

Where the lock is too wide, it may be necessary to use two cylinders. This arrangement can also have the advantage of providing an element of cylinder redundancy for emergency use.

On small harbour entrances, it may be possible to employ a displacer-operated gate. These have been used successfully over a number of years and their simplicity helps to reduce the risk of a failure to operate at the appropriate time.

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One small problem with such installations is that since the gate operates according to tide level, it is not possible to print a definitive timetable as to when the gate will operate. Also the relative uncertainty as to the specific operating point leads to navigation being curtailed sooner than would be the case for powered systems.

5.6 Caisson Gates

5.6.1 Introduction

A caisson gate is a large single span structure, sometimes referred to as a free-floating gate. The gate is flooded with water to sink it into position or pumped out to enable it to float. Once floating, it is possible to winch the caisson out of the way.

When in the closed position, the gate seals against vertical sealing faces and a lower sill.

Caisson gates are seldom used for access purposes because they are expensive to manufacture and only effectively operate under controlled opening and closing conditions associated around a single tidal condition. In most cases Caisson gates are employed to act as dry or wet dock entrance gates, however there are notable exceptions to this.

5.6.2 Operating Systems

The conventional Caisson gate is winched in a lateral direction so as to clear the dock entrance. Under these circumstances the arrangement often employs guide rails to ensure that the gate is delivered and retrieved in a controlled manner.

It is possible to arrange for a Caisson gate to be hinged at one end so as to enable opening and closing via winch systems. Such an arrangement is being successfully employed at Milford Haven to enable regular access to the harbour by pleasure craft.

6 Relative Costs

It is not possible to provide consistently accurate comparisons for the costs of impounding gates. Typical cost per tonne type rates have not been found to be a good guide to project costing. Some designs are cheaper in view of their relative occurrence, which leads to some design savings.

Similarly we are all aware of 'special prices' given by Contractors who are either short of work or who have simply made mistakes in their estimating.

As a generalism, the following typical cost comparators has been assembled for a mythical gated entrance, 10 m wide, and having an 'average' level of control equipment requirements. Inevitably such an exercise is fraught with assumptions and the figures should be used for very early project assumptions only.

Note that gates which only impound water are generally shorter than those that are required to hold back the full tidal cycle.

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Gate Type	Arrangement	Assumed gate size	Typical Cost £000's
Mitre Gates	Single set	10 m wide x 8 m high	£500
Vertical Sector Gates	Single Pair	10 m wide x 8 m high	£650
Horizontal Rising Sector Gates	Single Gate	10 m wide x 3 m high	£350
Delta Gates	Single Pair	10 m wide x 8 m high	£550
Tilting Gates	Single Gate	10 m wide x 3 m high	£250
Caisson Gates	Single Gate	10 m wide x 8 m high	£1000

7 Conclusions

There are a number of choices when considering the type of gate to use for marina or harbour impoundment purposes. There is a great deal of experience of all types and each has advantages and disadvantages in particular circumstances. The best choice will depend on a myriad of criteria relating to the project and its budget. The answer to almost any question relating to water control gates seems to start with the words 'it all depends……..'.

Designers and Specifiers need to make a comprehensive and systematic assessment of the various operating requirements and constraints in order to determine the most appropriate type and functionality. Purchasing an impounding gate on a design and build basis using a simple functional specification is unwise due to the lack of detail within most standards.

In spite of their relatively mature technology, great care needs to be taken in designing gated installations as it is usually difficult to modify the equipment once installed. Purchasers should carefully consider the experience and track record of the Professionals and Contractors that they employ on such schemes.