UK port mitre gates - time for modernisation

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Abstract

Mitre gates remain an important element of ports throughout the world and will remain so for the foreseeable future. For ports around the coast of the United Kingdom the design and details used for replacement mitre gates have changed little in the 43 years since the publication of Cornick's Dock and Harbour Engineering, Volume I The Design of Dock Gates. Indeed, many port engineers still regard this as the manual with which all mitre gates should comply.

These views are not shared in other countries that depend on maritime transport and continue to use mitre gates, such as the United States of America. However, not all mitre gates in UK ports have stuck to the established details for the three key areas of watertight seals, heel, mitre and sill, and yet these developments are generally unpublished. As a result of the lack of communication, combined with the relatively low frequency for replacement, engineers who are about to engage on a replacement gate project tend to stick to the "tried and test" principles of Cornick's book. Although the established details are not incorrect they are often based on inaccurate design assumptions. The objective of this paper is to draw the attention of port engineers, principally in the UK, to the developments in mitre gate details that have taken place, not only in other countries but also in UK ports where innovations have been introduced. In addition, a more appropriate design methodology will be presented to improve effective water retention for mitre gates.

1. What is Cornick's book?

Since the publication of Cornick's[1] book in 1958 there have been significant changes in the maritime transport industry of the UK. The use of small vessels for commercial transportation of goods around the coast has been increasingly replaced by road transport. In addition, although seaborne transport to the UK...
continues to be an important part of the national economy, the form of dock facilities for sea-going vessels has progressively transferred from the enclosed impound dock to deep-water sites, such as Felixstowe, to cope with the larger vessels.

In his book *The Major seaports of the United Kingdom* Bird [2] gives a historical view of the situation in 1969. The majority of the ports discussed in this book have experienced significant changes. For example, major areas of industry and commerce such as Glasgow and London no longer have a port within the city limits and depend on road and rail links to make use of a number of larger centralised ports that are remote from the city. Although most ports are now servicing different customer today from those they had in 1969 a number of impound docks are still in operation.

These developments in the transportation system have resulted in the core impound dock utilities, such as the quay wall and the dock gates of these ports, functioning with very few new developments. New mitre gates in UK ports have been predominantly replacement gates as part of a maintenance strategy. Often gates would be replaced because of leakage passing around, or through, the gate was such that the efficiency of the impound dock was being compromised. Such an event would not be suitable for innovation. It is not unreasonable to assume that the port management’s main concern would be to have the facility operational as soon as possible with a minimum level of risk.

To assess the number of ports that continue to use mitre gates, a questionnaire survey to collect associated data was posted to 60 ports in 1996. The chosen ports were those listed in *Lloyd's Ports of the World* [3] which appeared to be have an impound dock, therefore, which might have mitre gates.

There was a response from 35 ports (58.3%), which is a significant response to an unsolicited questionnaire. Of the 35 that responded, 21 had impound docks but two did not have mitre gates. Therefore, 54.3% of the 35 respondents used mitre gates. This shows the importance of these gates to the seaborne transport system.

Of those ports that did have operational mitre gates, the average expected life of the heel/mitre post was approximately 28 year and the structural steelwork just over 60 years. Therefore, it is reasonable to assume that it is probable that a port engineer may have responsibility for 1 replacement gate project in the whole of their working life. With such statistics it is understandable that port engineers, tend not to be innovative when specifying replacement mitre gates. As a number of ports are independent single commercial units, such as the Port of Sunderland that is owned by the City of Sunderland, the port engineer may not have the opportunity to discuss his/her specific situation with other port engineers. With commercial pressures of modern ports it is also unlikely a port engineer would willing seek assistance from an engineer based at a rival port. Communication on technical developments in mitre gates between those who have an interest has therefore been scarce.
2. **Source of leakage**

In the questionnaire previously referred to in section O, port engineers were asked to identify areas of leakage in the mitre gates they have at their port. The three areas of potential leakage, i.e. the heel, the mitre and the sill, were separated to help categorise not just the leakage as an effect but also to help identify the cause. The collated responses are listed in Table 1.

Table 1 Percentage of all mitre gates surveyed that have significant leakage in particular zones

<table>
<thead>
<tr>
<th>Location</th>
<th>Abbreviation</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower heel</td>
<td>LH</td>
<td>78.9%</td>
</tr>
<tr>
<td>Upper heel</td>
<td>UH</td>
<td>31.6%</td>
</tr>
<tr>
<td>Lower mitre</td>
<td>LM</td>
<td>63.2%</td>
</tr>
<tr>
<td>Upper mitre</td>
<td>UM</td>
<td>26.3%</td>
</tr>
<tr>
<td>Sill at heel</td>
<td>SH</td>
<td>68.4%</td>
</tr>
<tr>
<td>Sill at mitre</td>
<td>SM</td>
<td>73.7%</td>
</tr>
</tbody>
</table>

Clearly there is a predominance of problems in the lower heel, lower mitre and sill areas which are not functioning satisfactorily. Discounting damage as a cause of leakage, given the design principle of mitre gates as defined by Cornick's book, and accepted by most port engineers, these zones should be the most effective due to the high hydrostatic pressure and not the worst. To assess the cause of these leaks it is necessary to consider the details and assumptions made for these areas of the standard mitre gate.

2.1 **Heel post**

Heel posts of mitre gates have two objectives in the operation of a mitre gate; load bearing and watertight seal. In addition the detail is required to allow the gate to swing freely during the opening/closing process. To achieve these objectives heel posts have traditionally been constructed using a hardwood, such as greenheart or ekki, and fixed to the gate in a manner similar to that indicated in Figure 1.

The detail shown is that used for the construction of the replacement gates for Granville Dock at Dover in 1943. The same detail was used in 1998 when the gate was modified for a change of use in the dock. Traditional heel post details are generally perceived to have the advantages of:

- Being tried and tested
- The effectiveness of the post as a watertight seal increases as the hydrostatic pressure increases, and
- Hardwoods such as greenheart and ekki are resistant to marine borers and other form of decay.
However, for the gate to function as perceived there are a number of disadvantages that should be considered.

- The ability of the heel post to act as a watertight seal requires direct contact with the masonry hollow quoin, but clearance is necessary to allow the gate to swing open or closed.
- Once installed the gate has no allowance for adjustment that would be required to address wear on the heel post during normal opening and closing. The wear on the heel post tends to be uneven due to the load caused by the swinging weight of the gate being concentrated on the area adjacent to the lower gudgeon.
- Environmental issues that could argue the use of such hardwoods are more beneficial by encouraging a managed form of felling for sustainability than the alternative of using a manmade material. Unfortunately, due to the limited quantity of such hardwoods, and the long time period for maturity, it could be argued that their use should be limited to such a level to maintain the originating forests.
- To achieve the quality of product that can best satisfy the requirements of a mitre gate, skilled personnel is required. With the reduced frequency of new or replacement gates, this resource base is declining and is likely to reach an unsatisfactory level within the foreseeable future.

2.2 Mitre post

As with the heel post, the mitre post has the same two objectives, load bearing and a watertight seal. Traditional mitre post design details made use of greenheart or ekki as is shown in Figure 2. This detail is of Tilbury lock gate, which Cornick [4] described as "new" in 1958. These were replacement gates that were installed post World War II and are an example of the UK "state of the art" mitre gate design in the 1950's.

Given the arrangement of a typical mitre post it was on occasions possible to make use of a single log rather than the two or more necessary for the heel post.
In addition the shaping of the contact face of the mitre post, which is angled but flat, was less involved than the cylindrical surface of the heel post. However, given the accepted design principle of a three-pin arch, the design loading on the mitre post was the same as the heel post. Traditional mitre post details are generally perceived to have the same advantages as the heel post, however there are a number of additional points of concern specific to mitre posts that should be considered by the design engineer.

- As previously stated the accepted design principle of the mitre gate is that the meeting face of the mitre posts will act as a hinge. This would require the facility of rotation therefore the face pressure cannot be consistent.
- The flat contact face of the mitre post should be sufficient indication if the gate leaves misalign but the detail does not ensure a satisfactory alignment. In practice misalignment, although small, is normal, therefore a point contact will result rather than the perceived full-face contact.
- The faces are manufactured to meet at the appropriate angle but this depends on the gates being the correct length. Of a gate leaf is short than the pair will either not meet, or if they do, the mitre face contact will be at a point on the dock side of the gate. A similar but opposite affect would result if the gate leaf is manufactured longer than necessary.
- There is no facility to make maintenance adjustments to the mitre to allow for wear and tear due to normal operation of the gate.

![Figure 2 Traditional Mitre post Detail](image)

2.3 Sill seal

The sill seal has a single objective: to provide a watertight seal. Traditionally, the design detail of the sill seal was to use a large section, e.g. 30cm x 30cm, or larger, of a hardwood such as greenheart, ekki, oak or elm. Figure 3 shows the detail of the sill seal used for the replacement mitre gate for Granville Dock in
Dover in 1944. This detail is typical of sill seals that have been used over a long period for new or replacement mitre gates. The perceived advantages of the traditional hardwood sill seal are:

- the hardwood is robust and will deal with debris that may become trapped between the gate and the standing sill;
- misalignment of the gate’s steel structure that is to support the timber sill seal can be allowed for in trimming of the timber to suit;
- timber sill seal can be cost effective.

Unfortunately, the operational reality of timber sill seals does not support these views and there is a point of concern that should be considered by the design engineer. The design principle of the gate acting as an arch to retain water assumes the water loading will be distributed in line with the hydrostatic pressure \((pgh)\), therefore, the thrust loading through the gate will be minimum at the higher levels of the gate and maximum at the lower levels of the gate.

Given the elastic response of the gate the stress experienced by the main structure will produce a directly proportional strain. As the gate will be experiencing compressive stress the effective length of the gate will be reduced. It would be reasonable to assume that if the length of the two leaves of the gate are shortened the location of the mitre must move forward from the dock in line with the loading applied, i.e. the lower level moves more than the higher level. As the timber sill seal is selected for its robust nature against the stationary standing sill the lower level of the gate cannot move, but the higher level of the gate can move. This can result in the loading on the gate can be the reverse of the assumed distribution.

The extent of this phenomenon is dependent on the initial unloaded length of gate. If the gate leaves are is longer than necessary, the gate will respond as designed until the sill seal makes contact with the standing sill when loading will be redistributed in line with the extent of strain available to the gate.

The specialist contractor who have experience of mitre gates often allow extra length to ensure the initial wear on the heel and mitre post is provided for by the gate responding in this manner. As the gate timbers wear the redistribution of loading increases to reach the full inverse of the design model.

Figure 3 Typical sill seal detail

This effect is evident from the figures listed in table 1 that shows the high percentage of leakage at the lower levels of both heel and mitre post. The long-
term effect of the torsional stress that results from the redistribution of loading on the gate structure is the connection of the heel post to the gate becomes loose and gaps develop. Often the gaps are sufficient to allow water to leak into the buoyancy chamber, therefore the swinging weight of the gate increases accelerating wear on the heel post.

3. Developments in mitre gate seal detail

The observations made in Section 2 may appear to be innovative and the result of modern structural analysis but this is not so. Cornick [5] refers to paper produced by Cooper of work completed for the Wilson Dam, Florence, Alabama, but implies the proposals should be discounted as too complex. In his 1926 paper Cooper [6] acknowledges the influence of the sill seal detail and produces an alternative seal design to act more in line with the perceived view of sill seals. As can be seen in Figure 4, this detail provides the facility for the gate to respond to the stress/strain by moving forward and the location of the rubber section forming the seal can vary, thus allowing for wear of the heel and mitre.

Figure 4 Innovative gate details as presented by Cooper

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Figure 4 also shows that the heel (referred to by Cooper as quoin and reaction) and mitre post are also non-traditional. However, the two objectives of load-bearing and watertight seal are still served by the same units as the traditional details but there is a form of adjustment to allow maintenance to take place without removal of the gate.

Despite there being a gap of 32 years between Comick's book and Cooper's paper, there is no evidence of such details being adopted in the construction of new or replacement mitre gates in the UK. As for the USA, where mitre gates used in the inland waterway system are designed, installed and maintained by the US Corp of Engineers, the design details presented by Cooper have been maintained and developed further as can be seen in the details contained in Figure 5.

The Corp's web site www.usace.army.mil is available to all and gives many examples of the diverse work that the Corp has completed and those that are in progress. For those that have an interest in design of mitre gates there are many details used successfully by the Corp.

![Figure 5 US Corp of engineers details of quoin, miter, quoin block and sill seal](image)

This does not mean there have been no developments in UK mitre gate construction. Rubber sill seals have been used in a number of locations but progress has been slow. Early examples of solid, rectangular synthetic rubber blocks were designed and incorporated into new and replacement mitre gates by
Head, Wrightson Teesdale Ltd., in the 1960's. Yet the use of synthetic rubber for the sill seal is only recently being accepted by port engineers in the UK as normal for dock gates, but there still remains a few to be convinced.

At about the same time, Head, Wrightson Teesdale Ltd were showing further innovation by introducing a thrust block at the mitre on both gate leaves to carry the thrust loading and a separate, but closely located, shaped synthetic rubber block to act as the watertight seal. Both the seal and the load bearing blocks had provisions for adjustment that allowed for operational maintenance without the need to remove the gate. Examples of these details from the Falmouth N°3 Dry Dock replacement gates, which were constructed in 1968, are shown in Figure 6. The main commercial competitor of Head, Wrightson Teesdale Ltd. was Sir William Arrol Ltd., latterly part of Rolls Royce plc and they also introduced synthetic rubber sill seal details. The first rubber section sill seal detail used by Sir William Arrol Ltd. was that of the widely available neoprene 'D' shaped fender. This detail was used in replacement gates for Burntisland dock in Fife and has proven to be a reliable sill seal that give some freedom for the gate to strain as assumed in the design process.

![Figure 6 Head, Wrightson Teesdale Ltd. details of mitre and sill seal](image-url)

Unfortunately neither company is still in existence. However, perhaps the most significant development of gate seal design was the work of the prestigious consulting engineering organisation, Rendell Palmer & Tritton for Royal Royal Portbury Dock near Bristol. The gates were constructed by Fairfield Mabey Ltd. and installed in 1978. Innovative detail for the heel, the mitre and the sill were introduced for the large mitre gates that have to contend with the largest tidal range of any UK port. In the main, the design engineers considered each of the
objectives of each location and provided a solution to each objective. Perhaps the most significant change from traditional gate design was to separate the heel post's role as a watertight seal and its load-bearing objective. During the swinging action of the gate during opening and closing the heel post is not in contact with the quoin. Once mitred and the hydrostatic loading takes effect a system of spring supports are compressed to engage the heel post with the hollow quoin and the gate as a whole adopts a seating to function to the best advantage to retain water in the impound dock.

The heel post is not constructed of timber but makes use of the manmade engineering bearing material ORKOT from San Diego Plastics, Inc. mounted on a machined cast steel heel section. Similarly the mitre load-bearing objective and watertight seal objective are dealt with separately. Manmade material has also been used for thrust pads located at levels corresponding to the deck positions in the gate to deal with the load transfer and a separate, but closely located, composite rubber section to provide a water barrier. The composite rubber section continues from the mitre to the sill to ensure a continuity to create a watertight seal. The system is in regular use and the extent of leakage passed the gates is minimal.

4. What of the future?

The example of Royal Portbury Dock shows what can be achieved in mitre gate design, but in answer to the paper Design considerations for impound dock mitre gates [7] there was one response that suggested the standing sill should be replaced by a horizontal, flat sealing face. It was proposed that a sufficiently flexible yet robust synthetic rubber seal be used in conjunction with a stainless steel plate. The restraint imposed by the standing sill would no longer apply and the gate would be able to stain as assumed by the design procedure. In addition the likelihood of debris being trapped between the swinging gate and the standing sill would be minimal.

To date there is no evidence of such a detail being installed, or planned to be installed, in a mitre gate entrance to a port in the UK. The US Corp of Engineers has used approximately similar details but there are sufficient differences to reduce the likelihood of installation in a UK port.

To influence port engineers, the benefits of such a proposal would need to be proven by full scale testing over a significant period of time. The capital expenditure of such a test is likely to be prohibitive, therefore the use of such a design detail in the future is unlikely, but not impossible.

5. Conclusion

Mitre gates continue to be an important item on the itinerary of a port engineer who has an impound dock. Excessive leakage can result in the dock not functioning, which results in a loss of revenue. Despite the importance of these gates there has been limited development undertaken, or encouraged, in the UK. From the early dock gate developments of Cooper, the UK has lagged behind the
USA in applying the principles modern engineering to construct better gates with the one notable exception at Royal Portbury Dock.

To construct a new or replacement mitre gate the designer should separate and engineer a solution for each individual objective of the heel, the mitre and the sill seal. A number of good examples of how this was achieved in the past are available for engineers to witness. Unfortunately, engineers are often unaware of what these developments are, or where they are.

Communication by papers such as this paper of the developments in mitre gates that have proven to be successful (and those that have been unsuccessful) is essential to ensure their advancement in the future.

References