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## Coping with the wash

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Transverse waves

# Coping with the wash

## *The nature of wash waves produced by fast ferries*

**D**uring the past decade there has been a rapid growth in the number of fast ferries operating around our coasts and on inland waterways. These craft are popular with travellers, as journey times can be reduced by 50% or more. However, there has also been increasing public concern about the additional risk to users of the coastal zone from the wash waves produced by these vessels, and the potential impact on the environment. There have been several reported incidents on calm days of large unexpected surging waves on beaches, shallow sand banks and against sea walls. In the British Isles there has been a fatality where the wash of a fast ship has been a contributory factor.

### **The problem with fast ships**

Most fast ferries are capable of speeds of around 40 knots in water depths less than 10 m. This is a result of their high power to weight ratios. A large fast ferry with a displacement of 4000 tonnes might have 75 MW of installed power, while a conventional ferry with over twice

the displacement might have only 20% of the installed capacity. Consequently, most conventional ferries can achieve speeds of only around 15 knots in shallow water as a result of the rapid increase in resistance which occurs beyond this speed, in conjunction with the ferries' lack of power.

Compared to a conventional ship, the fast ship produces very-long-period low-amplitude waves, which are more energetic. These build in height rapidly close to the shore and then break. Consequently, these waves are not particularly visible until they are very close to the shoreline, unlike the short steep waves produced by the slower ship, which are visible from a distance offshore. Thus the primary danger is that the general public can be caught unawares by sudden steep-breaking waves surging up the beach when previously the seas had been calm. The waves arrive without warning, often after the fast ferry is out of sight, and by the time the waves are observed it is too late to avoid the uprush on the beach or spray over a sea wall. A similar risk occurs for small craft fishing over shallow banks, particularly if the

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*With the growth in the use of fast ferries on routes previously served by conventional ships, increasing numbers of wash problems have been reported. Here, we describe these problems and explain the differences between different vessels' wash characteristics. Measures are described which can be used to manage the resultant risk to the users of the coastal environment.*

sea bed topography is such that the wash is focused.

From an environmental viewpoint, the long-period waves are unnatural and occur regularly on a daily basis. Although they are not as energetic as storm waves, even in relatively sheltered estuaries, their high frequency of occurrence and the induced movement of water over the sea bed can result in the movement and regrading of the sea bed material. Such changes can also affect the marine ecology of an area.

### **Wash waves produced by ships**

The forward motion of a ship disturbs the water around it. The resulting pressure gradients produce a set of waves with a distinctive pattern. This was studied by Froude (1877) and later by Lord Kelvin (1887). The wash pattern produced by a ship in deep water is named after Lord Kelvin and comprises many waves with a range of lengths, speeds and directions of travel. The longest and fastest waves travel at the same speed and in the same direction as the ship and are known as the

transverse waves. The shorter slower waves travel at an angle to the track of the ship and are known as the divergent waves. The transverse and divergent wave components interact at the cusp locus and fit within what is known as the Kelvin wash pattern. Figure 1 shows the Kelvin wash pattern, which is steady relative to the ship and moves with the ship.

When a ship travels quickly in shallow water the characteristics of the wash change dramatically. This results from the fact that the long waves cannot travel at their desired speed in shallow water, as the resulting fluid motion is significantly influenced by the close proximity of the sea bed. The speed of the longest waves is governed by the water depth and not by the velocity of the ship. Another important difference is that, in shallow water, energy is largely conserved in the individual waves, while in deep water the energy spreads over an increasing number of waves with the passage of time. This spread or dispersion of energy in deep water waves can be observed in the simple experiment of dropping a stone into a deep pond. Initially there is one wave travelling out from the disturbance but a few moments later there are two and then three, and so on as time progresses. If the experiment were repeated by dropping the stone into a shallow puddle, then a single primary wave would be observed travelling outwards.

The wash produced by ships in shallow water was described by Havelock (1908). He classified the wash characteristics in terms of depth Froude number, which is simply defined as the ratio of the ship's velocity to the maximum speed a wave can travel in a given depth of water. When the speed of the ship equals the maximum wave speed in the given water depth it is known as the critical depth Froude number. When the ship's velocity is less than or greater than the depth-limited wave velocity it is known as either the sub-critical or the super-critical depth Froude number, respectively. The Kelvin wash pattern occurs at sub-critical

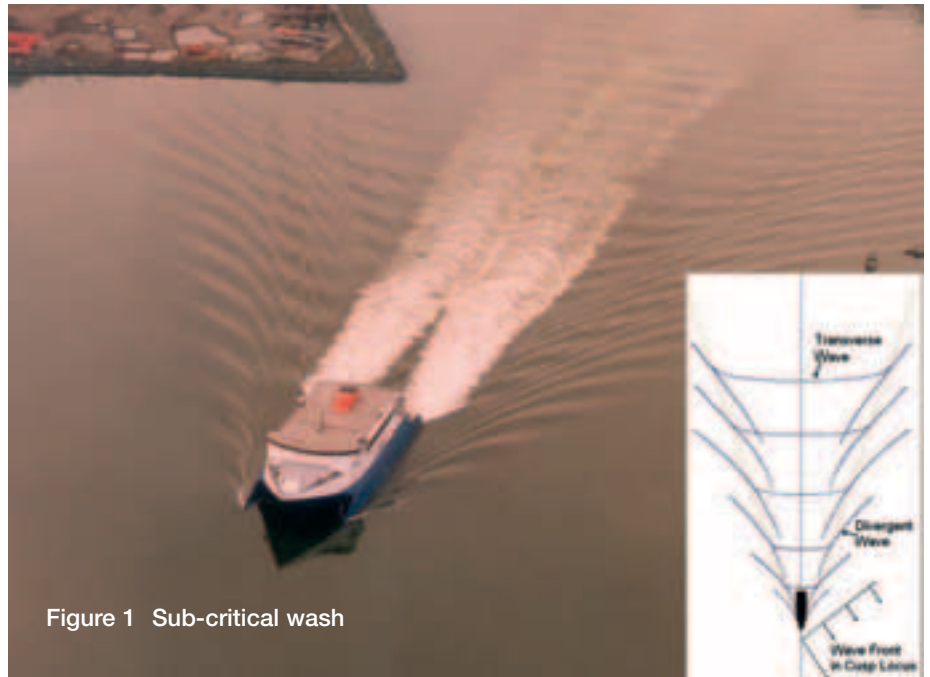


Figure 1 Sub-critical wash

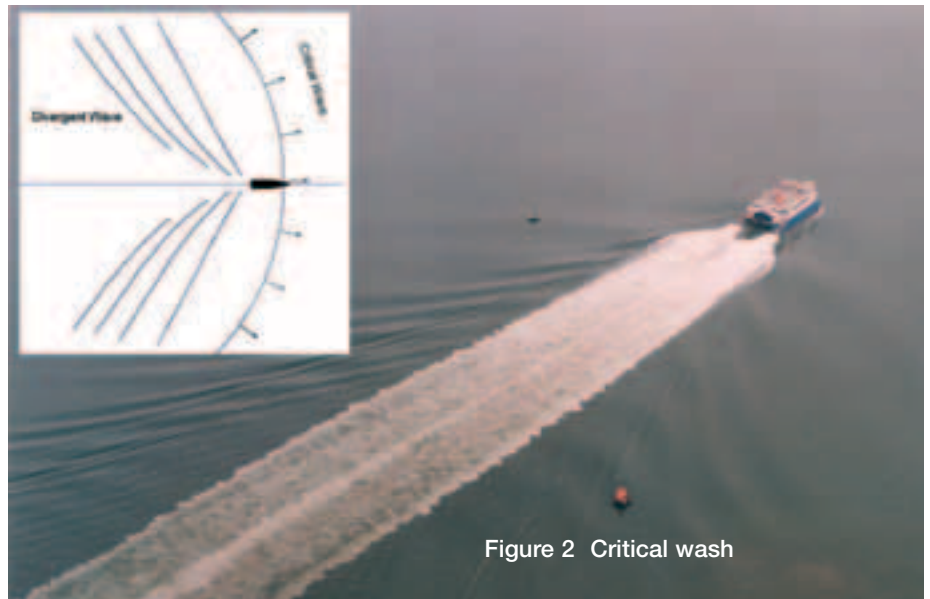


Figure 2 Critical wash

depth Froude numbers of less than 0.57 and these are deep water waves. This is the wave pattern produced by most conventional ships in all operational water depths.

As the ship either increases speed or travels into shallower water, the depth Froude number increases and the fluid particle motion resulting from the longer wave components is increasingly disturbed by the sea bed. Between depth Froude numbers of 0.57 and 1, the long waves become steadily less dispersive: their energy is increasingly conserved in individual waves and does

not disperse back along the wave train aft of the ship, unlike the deep water waves in the sub-critical wash. This is clearly shown in the diagram and aerial photograph presented in Figure 2. Now a significant proportion of the propulsive power is converted into wave energy in a few waves on either side of the ship, with fronts nearly perpendicular to the track. As the crests spread out at a similar rate to the forward velocity of the ship, the wash could quickly extend across the full width of an estuary if the ship's speed and the water depth remained constant for several minutes.

As either the speed of the ship increases or the water depth diminishes, the transverse waves in the critical wash are left behind, as shown in Figure 2. Now the super-critical region is reached where the long waves are non-dispersive and the wash pattern takes on a different appearance, as shown in Figure 3. The long waves cannot travel in the direction of the ship as the water depth limits their speed. Therefore the wave fronts radiate out in lines from the ship in a delta-like formation. The longer faster waves are on the outside of the wash, while the slower shorter waves with crests swept further back are on the inside. The leading wave crest is straight in plan view and the subsequent wave crests are concave, particularly close to the ship where they are pulled along at a greater speed than they can physically sustain because of the limited water depth.

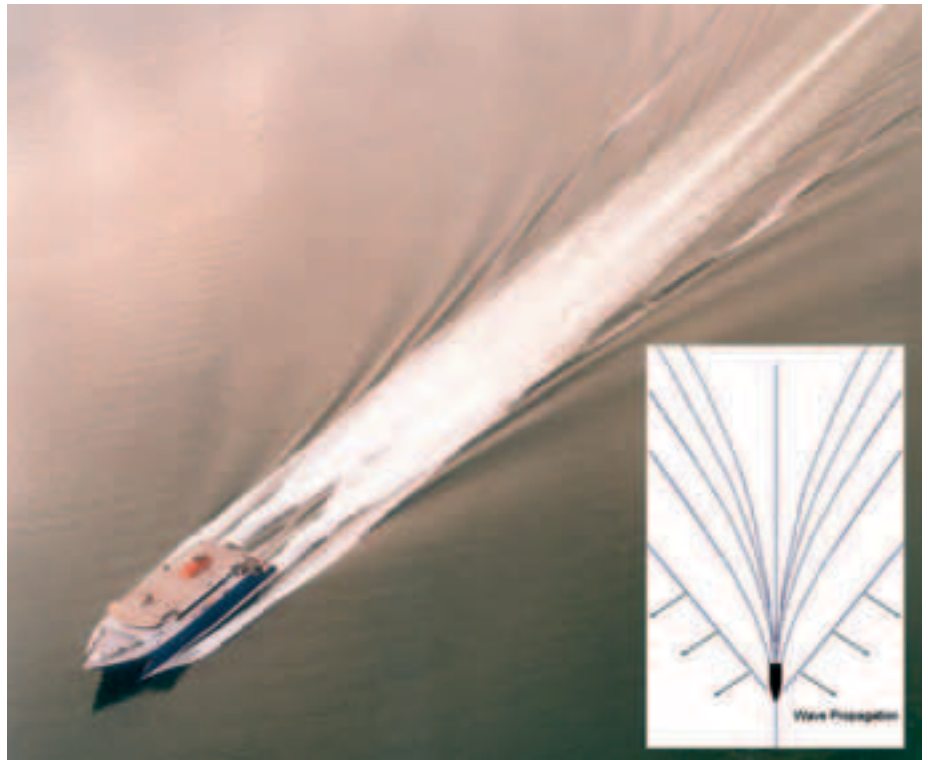


Figure 3 Super-critical wash

### How fast-ferry wash compares with natural waves

Figure 4 shows an example of a wash measurement taken 2.7 km from a large catamaran high-speed ferry operating at 40 knots at a water depth of 15 m. It should be noted that the precise distribution of wave periods and heights would vary with distance from the track and with the hull form and size of ship. In this example there are three obvious groups of wave periods designated as zones 1, 2 and 3, caused by the interference pattern resulting from the wash of each hull. In comparison, a high-speed monohull would have a more continuous spread of wave heights and periods.

The initial group of waves, shown in zone 1, does not exist in a conventional ferry wash and is peculiar to a vessel operating in the super-critical range. The first wave has a period of 40 s and a height of over 0.3 m; the second and third waves are the highest at 0.5 m with periods of 20 s and 16 s, respectively; followed by a wave group which steadily reduces in height and wave period to 0.2 m and 8 s, respectively.

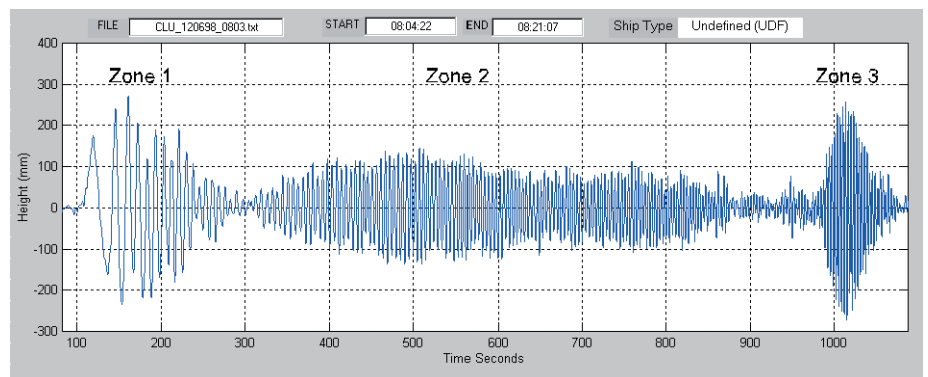


Figure 4 Super-critical wash wave time trace

The second zone of waves, with periods of between 8 s and 4 s, is similar to the complete wash produced by a conventional ferry of similar displacement and results from the divergent sub-critical waves. However, conventional ferries are substantially heavier and will produce a greater wave height in this zone compared to fast ferries.

The third zone has a small group of very steep waves with a period of 3 s and is peculiar to fast ferries with transom sterns and water jet propulsion.

Consequently it is the leading and tail group of waves that make the wash

of fast ships different to that of conventional ships and it is mainly these waves that have caused public concern. The wave periods found naturally in inland seas and estuaries are in the same range as those produced by fast ships in zone 2 or those produced by conventional ships. However, storm waves in these areas could be ten times higher and one hundred times as energetic. Therefore infrequent storm events will have a greater impact on erosion and sediment movement than the much smaller but frequent wash wave events.

### Wash transformation from ship to shore

The leading long-period waves in the super-critical fast-ship wash are unnatural in most areas where this type of vessel operates. They are like ocean swells in terms of period, length and speed of propagation, although only a fraction of the height and energy. To someone sitting in a small boat in open water, the leading wash waves would be barely noticeable, having a length of several hundred metres and a height of only half a metre. However, on the sea bed, water movement would be noticeable up to a depth of 100 m. On reaching shallow water of about 2 m, these waves change dramatically due to the process of shoaling. The waves build in height several times and shorten, producing breakers. The forward momentum of the breakers surges the water a substantial distance up a gentle sloping beach at such a speed that most people will not react quickly enough to avoid getting their feet wet.

As has been shown, the wash pattern is three-dimensional and when it leaves the ship, the waves from which it is composed change in characteristics. The divergence of the leading wave crests and the increasing number of waves due to energy dispersion of the shorter components spreads the total energy over a larger area, thus exponentially reducing the wave height with distance from the track of the ship. In addition, variations in the sea bed topography also change the waves because of the process of refraction. Figure 5 presents a contour plot of wave height for a particular component of the wash and clearly shows 'hot spots' in red where wave energy is focused.

### The effect of operational procedure on wash

Wave focusing can also result from course alterations at speed in the confines of an estuary. For example, the wash produced before and after a high-speed turn can superimpose on the inside of the bend, increasing the local

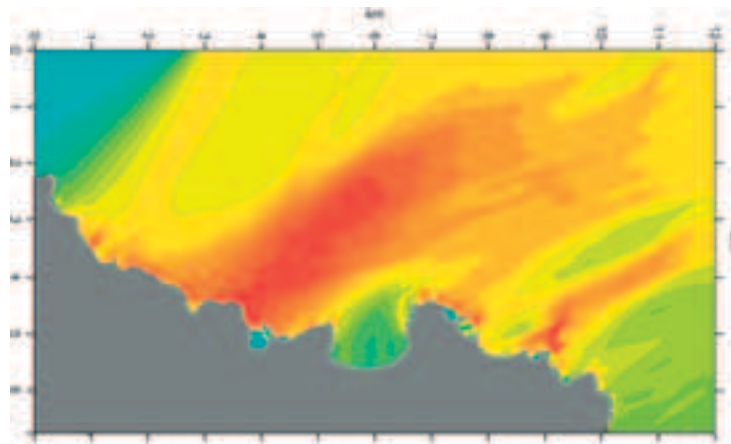


Figure 5  
Contour plot of wave heights

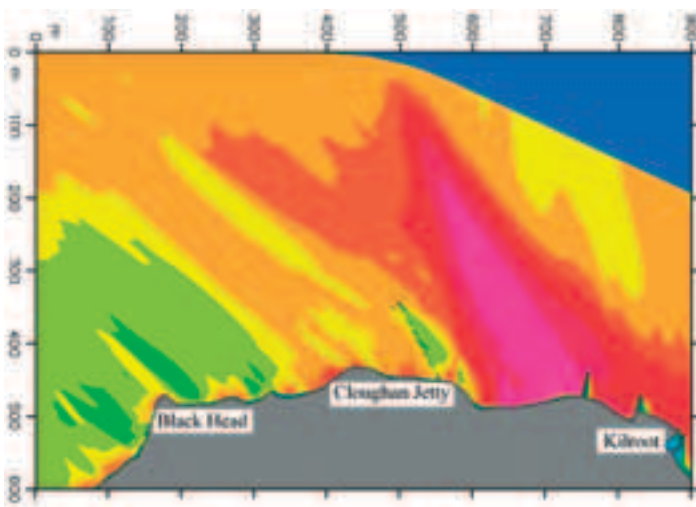


Figure 6  
Wave focusing on inside of turn

wave height. In the example in Figure 6, the focal area coincided with an open jetty where ships moor. This caused excessive surging in the long-period waves and damage to the ship, jetty and mooring ropes. The problem was resolved by altering course in deeper water and running the ship straight into the estuary, avoiding wave amplification at the jetty. Also, better mooring procedures ensured that loads were more evenly distributed across the ropes, reducing the incidence of breakage.

The largest wash is produced at the critical depth Froude number, so operators try to minimise the time spent in this zone. However, factors such as heavy loads, hull fouling and engines down on power can result in vessels struggling to accelerate through this high-resistance zone, causing large waves due to the time spent accelerating. In addition, ships

accelerate faster in shallow water but sometimes such acceleration is not allowed, because of operational constraints such as speed limits set to avoid excessive wash generation at high-risk locations in estuaries. Approaching shallow estuaries from deep water can also cause problems, as ships must transcend the critical zone as the depth reduces. For example, a ship travelling at 33 knots and approaching the 30 m depth contour can become stuck in the critical zone, with the resistance hump causing the vessel to slow with reducing depth. If there are insufficient reserves of power either to maintain or increase speed, then the only option is to slow the speed to the sub-critical range and for the ship to operate like a conventional ship at less than 20 knots.

It is important to avoid carrying excessive weight on a fast ship, since displacement has a direct bearing on

wash height. With some ships on certain routes it can be prudent to reduce the payload carried as cargo in order to maximise performance and limit wash.

## Risk management

If a ship operates at speed in shallow water then the production of long-period waves in the leading part of the wash is unavoidable. However, there are several ways of reducing the potential risk to coastal users. The most important starting point is the realisation by operators that vessels can produce wash waves that can pose a risk to others. For example, in the United Kingdom the Maritime & Coastguard Agency ensures that ferry operators prepare a route assessment with regards to wash; this must be approved to obtain a permit to operate. This entails a detailed submission specifying the operation of the vessel from port to port, giving information such as speed, course, way points, locations of acceleration and slow-down to and from cruising speed, and the wash that will be produced at each stage. Potential risk points are identified, such as bathing beaches, open harbours or jetties, slipways, low coastal paths or promenades and shallow banks, and the wash at these locations assessed.

It is necessary to establish the wash generated by the ship operating at different speeds in the range of water depths encountered and then predict how the waves change from the track line of the ship to the point of risk. This is not an exact science and is the subject of extensive research. At present it is accomplished by a combination of model testing, field measurement and mathematical modelling. A risk assessment can then be undertaken by assigning a score to both the magnitude of the problem and the level of risk. Although this is a subjective process it does provide a relative measure of potential problems. The risk assessment is a live document and must be updated if incidents as a result of wash are reported. If the risk is deemed to be too

high then the ship is forced to slow and operate like a conventional vessel prior to reaching the location in question.

## Conclusions

High-speed ships produce long-period waves in shallow water which are unnatural in many operational locations. Consequently the risk must be managed by careful route planning and an appreciation of the nature of the problem. This can be achieved by good route planning with careful control of the locations for acceleration, slow-down, alteration of course, the course itself and distance from high risk. If the risk is still unacceptably high then the only remaining option is to slow down. Informing users of the coastal environment about the problems of wash from ships has resulted in a reduction of reported incidents on several routes.

In the future it will be possible to build lower-wash high-speed ships but this still leaves the problem of the existing vessels. However, the wash produced by new conventional ships must also be considered, as there is a trend to install more power, enabling them to enter the critical speed range in estuaries. ■

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