The British Airways London Eye

Part 5: pier and impact protection system

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Access to the Wheel is catered for by public transport systems such as the tube, but, in line with the overall plan for London, river access is also provided via the new Waterloo Pier. This takes the form of a 100m-long floating pontoon connected to Queen's Walk by two bridges, each consisting of a short, fixed length linked into an articulated brow. The brows act as twin radial arm struts restraining the pontoon laterally while cables supported on floating booms provide longitudinal restraint. Visual design of the pontoon and bridges was developed to match the architectural style of the Eye.

The Thames is still tidal at the site, with current flows up and down river of about 2m/s and a tidal range of about 7m. These factors determine the drag forces acting on the pier, together with the articulation required within its components. Modest berthing loads from docking river vessels also apply, though the energy from these is mostly absorbed by fendering on the berthing face.

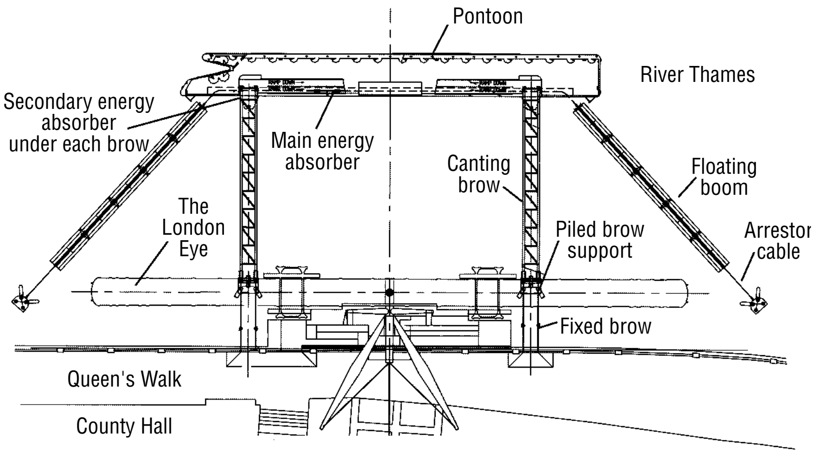

Fig 1. Waterloo Pier general arrangement

The Eye is aligned over the Thames, a busy highway for both freight and passenger shipping, making its structure potentially vulnerable to an impact. At certain tides, it is physically possible to position some of the known larger vessels in a manner that would clash with the lowest capsules. To counteract this threat, the pontoon and brows, together with their set of mooring cables, double up as an impact protection system, with the general arrangement shown in Fig 1.

Determination of an appropriate design impact force or energy was difficult, since there are no codified values. Moreover, conservatively designing for the energy of the largest vessel capable of using the river was known to be unpractical. Heavy vessel impact was considered a plausible, but slight, threat, since aggregate carrying ships, which are the largest regularly passing verssels, travel near the opposite bank when travelling upstream loaded. Lighter passenger craft crisscross the river, and some of these do dock at the pontoon; so the impact risk from these craft is clearly greater, though involving less energy. The need was to assign a design impact energy linked to vessel mass and speed.

To determine this energy rationally, a probabilistic approach was adopted. The more important variables are:

- types of craft (mass and speed) using the river
- numbers of craft in any category over a set period
- defined shipping routes
- shipping usage (with or against the tide, upstream laden, downstream light, etc.)
- water depth limitation at various tidal states
- physical constraints imposed by distance to the bridges and by route constraint through the spans.

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Fig 2. Floating boom carrying the arrestor cable

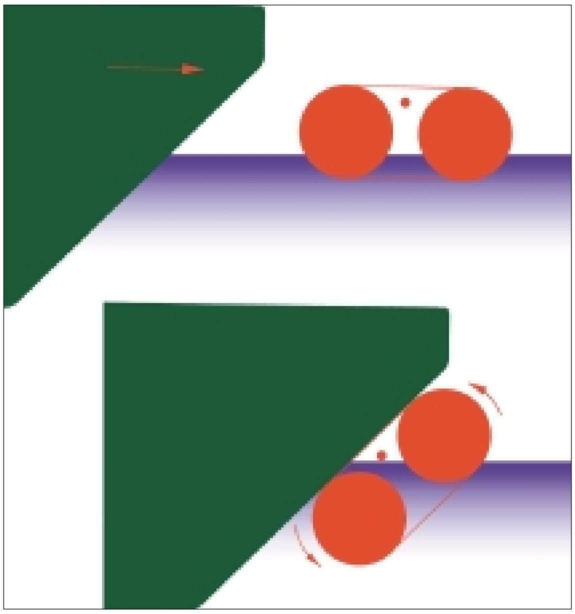

Fig 3. Rotation of twin cylinder boom under impact

Thus, for example, a transiting vessel can only travel towards the Eye by mechanical failure or human error. If a postulation is made that these can occur, then, possible vessel routes may be calculated, including the numerical probability of those routes meeting the Eye.

The starting point was a tabulation of defined energies associated with the known river traffic profile. Taking account of the variables scheduled above, the study then aimed to evaluate the likelihood of impact in various energy bands on a numerical basis. The consequences of impact were taken as serious (i.e. potential severe injury or death) and, from approaches used in this type of work elsewhere (dealing with societal risk tolerability), an impact energy band value could be selected of an acceptably (low) probability. Intuitively, we know that there must be a high probability of low energy impact, but only a very low probability of high energy impact. The numerically based approach aids the decision-making process of where to define an acceptable boundary. In practice, once the numerical study was complete, mitigating arguments were also marshalled to support the view that the probability of a major impact was indeed very low: e.g. the Eye is on the inside of the river bend, so if a vessel was to lose steering control it would be more likely to continue in a straight line and impact on the opposite bank.

Fig 4. The main Jarret energy absorber unit mounted in the pontoon

Apart from misjudged berthing manouveres, the likeliest impact comes from an errant vessel drifting with the tide off its intended route; if this route were aligned towards the Wheel, the vessel would have to cross the protective boom before it could cause damage. Other impact alignments are possible such as end- or side-on to the pontoon, and the probabilistic study assigned different energy bands to each location.

The arresting medium for a boom impact is a 64mm diameter steel cable and, to stop the vessel, this cable must be kept above the water surface. This is achieved by attachment to a floating boom (Fig 2). It has to be assured that any vessel striking the boom will not ride over it, hence the use of twin cylinders for the floatation units. Any vessel striking and depressing the first cylinder would cause the whole unit to twist axially around the arrestor cable, presenting greater blockage from the second cylinder as shown in Fig 3. The potential for oversailing depends to some extent on the vessel's bow shape, sharply raked swim bows pose the highest risk.

An early design decision was not to rely on the ductility of the cable to absorb energy but to provide for this positively by incorporating energy absorbers both at the pontoon end of the cable and on each brow-to-pontoon connection (Fig 4). These absorbers, made by Jarret in Paris, take the form of a piston loosely fitted in a tube filled with silicone putty that deforms at constant pressure under load. As in a dashpot, the energy absorption is a function of the tube and piston cross-section (force) and of the unit's stroke length (displacement). The main units on the pontoon have a capacity of 10.6MJ with a stroke of 5.9m and a weight of 2t. The smaller units on each brow have capacities of 3.6MJ with a 2m stroke and weigh 1t. A 'fuse' is included on each unit such that the system is rigid until the applied force exceeds the critical value.

If a vessel were to strike the boom along its length, the cable is allowed to displace up to 10m, a limit determined by the need to prevent contact with the brow. The geometry of the displaced cable, its stretch, extension of the energy absorbers and axial resistance by the brow, form a complex, but coherent, strut–tie resistance system. In the case of Waterloo Pier, maximum system capacity is limited by the brow's axial strength of 260t. Thereafter the capacities of separate components are tuned to ensure that the cable will not break.

A particular detail problem arises with the connection of the brow to the pontoon. The connection here has to be capable of sliding in the event of a severe impact exceeding the energy absorber's fuse capacity. But it also has to articulate in three degrees of freedom and absorb some twist to cope with relative pontoon movements imposed by everday tidal changes.

The pontoon iself was designed in the manner of a traditional ship structure using frame stiffened plate. Sizing was done in accordance with the empirical Lloyd's rules. Protection against failure of the pontoon itself is assured by the internal compartmentalisation.

The pontoon was fabricated on the Tyne, delivered to Tilbury by heavy lift ship for finishing and then towed to site where it was held on temporary moorings; the linking brows and fixed bridges were installed using a floating crane, the booms were connected and temporary mooring then removed. The pier was put into service for passenger boats to the Dome on 2 January 2000.

Acknowledgements

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