6. STEEL HULL DESIGN

6.1 Main Features of the Design

The general arrangement of the steel hull design is shown on drg DEA8/1. The plan dimensions and elevation are as agreed with the device team at progress meetings.

The steel hull cross section resembles the side buoyancy space of a suction hopper dredger and has been detailed with generally similar scantlings. However larger plate thicknesses are required locally from considerations of fatigue and strength because of the additional global bending moments about the vertical axis (surge bending).

The hull consists of twelve modules separated by watertight bulkheads each forming one of the sides of the dodecagon. Each module supports one flexible membrane "bag" and contains one turbine cell which is accessed through a hatch in the deck. The turbine cell occupies the upper section of the central third of each hull module. Each turbine cell is isolated from the rest of the hull module by watertight bulkheads and a floor. The remainder of the hull within each module forms a single ballast cell which will be fully ballasted with inert water when the device is operational to bring the device to the correct operating draft.

A continuous power duct passes through all bulkheads with branches off to each air "bag". The duct has a diameter of 1.5m generally through the ballast tanks and is terminated in a flange within the turbine cell for attachment to a 1.8m diameter turbine pod. An overall diameter of 2.0m has been allowed for the external clearance dimensions of the turbine generator pod. Switchgear, oil coolers and other ancillaries will have to be located within the turbine cell around the turbine pod. More space could be provided if required by substituting dense solid ballast for some water ballast and thus allowing a larger buoyant turbine cell.

TABLE 6.1 ANNUAL FATIGUE DAMAGE AND FATIGUE LIFE OF THREE TYPICAL DETAILS

Wave Height (m)	Wave Period (Secs)	Nr of Occurrences p.a.	½ Range of Hull Bending Moment (MNm) Heave	Surge	DETAIL A Damage	DETAIL B Damage	DETAIL C Damage
1	6.2	3618981	2.6	0.55	0.000062	0.000726	0.000284
3	8.2	828085	6.8	7.9	0.019029	0.022090	0.028195
5+	9.8	252934	6.1	8.7	0.010197	0.007134	0.010270
		TOTAL DAMAGE pa			0.029288	0.029950	0.038749
		LIFE (YRS)			34	33	25

The reverse curved front of the module forms a recess to suit the wave power extraction requirements. To enable the bag to be rapidly changed the rim of the recess is shaped to accept a steel bag attachment frame. This forces the hull plate to be kept back from the front of the recess thus reducing the reserve buoyancy at the top of the hull. The "lost" buoyancy is made up by a section of closed cell foam attached to the outside of the hull plate within the bag recess. This buoyancy is necessary to provide a reserve in the event of damage to the power tube.

6.2 Strength and Fatigue Life

Lloyds rules were followed in sizing stiffeners, plates and bulkheads to carry local hydrostatic and hydrodynamic loads.

The longitudinal bending stresses were calculated at a series of points around the hull section using a simple spreadsheet. This allowed the plate thicknesses to be adjusted round the section of trial and error so that permissible stress limits were not exceeded. The spreadsheet was also extended to calculate the fatigue damage so that the fatigue life could be calculated. It was found that the fatigue wave climate could be represented adequately by only three different combinations of wave height and period. This is because the wave forces do not increase significantly with wave heights in excess of 3m for waves of normal steepness. The extreme wave loads are only found with excessively steep waves which are considered to be on the point of breaking and whose frequency of occurrence is not sufficient to cause significant fatigue damage.

Typical spreadsheets for extreme environmental conditions and fatigue life assessment are included in Appendix B. The maximum permissible stress under extreme environmental conditions was taken as $120 N/mm^2$ and the maximum stress calculated for the final design was only $85\ N/mm^2$. This apparent conservatism arises because fatigue governs the design.

The fatigue spreadsheets have been run for three classes of weld detail (Ref 4). The different classes of detail each have different stress concentrations and give different S-N relationships. The three classes represent different types of welded attachments which form stress raisers and different methods of welding, the hull modules together at the vertices. It should be noted that fatigue lives are calculated for all three classes of detail at each location but only those details which are noted were used in the final design. All details used in the final design had fatigue lives greater than 25 years.

The fatigue lives for three typical details used to connect hull plates from adjacent hull modules across the main bulkhead are summarised in table 6.1. Detail A represents a cruciform fillet weld. Detail B represents an improved detail for this connection using an insert plate which passes through the main bulkhead (as shown in Detail 1 of Drg DEA8/1). This detail is used in the most highly stressed region which is the outer top corner. This detail can only be used economically if the insert plate is only curved in one plane. Details C represents a reinforced version of Detail A where the stresses are reduced to increase the fatigue life. This detail is used where detail B would involve a doubly curved plate.

Table 6.1 shows that a minimum fatigue life of 25 years has been achieved and that most of the fatigue damage (60%) is caused by 3m high waves.

Within the main hull section all plates with welded attachments will have the same classification as detail B and the minimum fatigue life is also estimated to be 25 years (Appendix B).

The sensitivity study described in section 4.2.3 demonstrated that the alternative fatigue wave climate reduced the minimum life of the existing design to 21 years. However a redesign to achieve a 25 year life with the alternative wave climate increased the device weight by only 0.6%. Since the cost of the device is more or less proportional to its weight it can be seen that the device cost is not very sensitive to the fatigue wave climate. Nevertheless this study also demonstrates the importance of selecting an appropriate fatigue wave climate for the site chosen to prevent premature local fatigue failure.

The fatigue calculations have all been made assuming that the device is at the same orientation to each wave and that the same critical section is most highly stressed in each case. The assumption is clearly very conservative because of both wave spreading and device yaw. By rotating the device by 30° every three years or so to ensure that the fatigue damage is spread around the device it would be possible to make some small structural weight savings.

It has been assumed that the paint system will be regularly maintained and will prevent sea water coming into contact with any welded joint and therefore no environmental reduction factor has been applied to the calculated fatigue lives. If subsequent detailed analysis shows it to be advisable then additional protection can be provided to specific welded joints at negligible extra cost.

6.3 Construction Considerations

It is intended to follow normal shipbuilding practice as closely as possible. Discussions have been held with Cammel Lairds Shipbuilders Ltd to discuss the preferred construction method. It was established that the most economical method of construction would be to make as much use as possible of the automatic welding facilities of a panel line. The panel line at Cammel Lairds can currently accommodate flat panels up to a maximum size of 14m wide by 15m long but could be extended to cope with panels up to 15m wide.

With the extension described above it would be possible to fabricate the plates forming the front and back panels of each hull module in one piece on the panel line at Cammel Lairds except for a small insert piece at the extreme outer edge. The flat panels would then be lifted into jigs and pulled down to form the required shape. Partial frames would be added to maintain the shape while the front and back panels were lifted up and assembled with the intermediate frames and one end bulkhead.

Assembly of six hull modules into two device halves and attachment of the bag recess side assemblies could all take place under cover at Cammel Lairds in the assembly hall. The two halves would then be skidded outside onto the slipway for the last joints to be made.

In order for the final assembly of the two halves to proceed without delay the tolerances on the assembly of the individual hull modules would have to be carefully controlled. It is proposed that all modules will be fabricated slightly oversize and the ends accurately trimmed before assembly to eliminate problems of predicting weld shrinkage. With experience it may be possible to eliminate this operation and cut the flat panels with a margin for weld shrinkage. All tolerances on the bag recess will have to be carefully controlled since the bag attachment frames are intended to be interchangeable.

The joint between adjacent hull modules will generally be made by welding the open end of one module to the bulkhead at the closed end of the adjacent module. The tolerance on the eccentricity of the shell plates on opposite sides of the bulkhead has been assumed to be less than half the thickness of the bulkhead in making the fatigue life assessment. Generally the shell plates will be attached to the bulkhead using a cruciform fillet or partial penetration butt weld which in certain areas will need to be reinforced. In the most highly stressed areas an insert plate will be used to extend the fatigue life.

Assembly undercover would allow all mechanical and electrical fitting out (apart from the final interconnection between halves), ductwork, painting and testing to take place in a controlled environment. However, other shipyards may not have this facility and may require more work to be carried out outside. In any event the construction has been shown to be a relatively small extrapolation from existing shipbuilding practice.

6.4 Launching

The light steel hull section has a draft of only 1.5m and can readily be launched down a slipway given sufficient unobstructed width and a minimum of 1.5m of water over the quay wall. These conditions are certainly met at Cammel Lairds facilities on the Mersey and also at other locations in the UK such as Scott Lithgow at Glasgow and Swan Hunter on the Tyne plus a number of the offshore rig building yards.

The launching characteristics of the device have been investigated and it is found that the device imposes a local load of 3.6 MN on the slipway at rotation if launched trimmed level. It will be possible to reduce this local load on the slipway by partially pre-ballasting the device to trim down by the head.

By suitable choice of ballast it will also be possible to reduce the bending moment on the hull during launching so that the hull stresses on launching will be less than $40N/mm^2$.

There is therefore no difficulty in launching the completed device down a suitable slipway.

6.5 **Maintenance**

It is proposed that regular structural maintenance of the steel hull should include:

- annual inspection of external surfaces and mooring attachments.

- inspection of bag recesses as bag change out allows.

- monitoring of cathodic protection of tanks

- painting of external surfaces and the bag recess at 5 yearly intervals.

Access for inspection and painting of the external surface can be obtained by deballasting all but two adjacent tanks which gives the device sufficient trim to lift the opposite section out of the water. This facility will also assist in bag replacement. The stresses imposed on the hull by this are similar to those imposed during launching and are perfectly acceptable. It is not intended to provide an integral ballasting system and any ballast adjustment for maintenance will have to be carried out with portable pumps powered from the maintenance vessel.

It must be noted that it will only be possible to carry out maintenance in fine weather since the horizontal bottom of the exposed hull section will be subjected to wave slam in other than calm conditions.

Access for internal maintenance will be effected at sea through a 700m diameter manhole at one inside corner of each power compartment. Only minor internal maintenance will be possible at sea but the turbine generator power pod can be removed for maintenance ashore through the 2m x 2m hatch provided (the internal diameter of the turbine is less than 2m - only the external clearance dimension is shown on the drawings). All major turbine and generator components will be located within the power pod. Removal of other ancillary components which are too large to be removed through the manhole will necessitate prior removal of the power pod.

6.6 Fabrication Cost

The general practice for cost estimating of steel fabrication in shipyards is to build up a data base of labour cost/ton for different types of vessels constructed. Depending on the vessel type, hull shape, size and complexity this will vary as from a tug to a cargo ship to a tanker and so on.

Labour costs when added to the current market steel price, both plate and section, will provide a rate/ton for a hull or part thereof peculiar to the vessel type under consideration. Rates will vary from shipyard to shipyard as well as nationally and internationally.

The Consultant has drawn on personal contracts in UK and in Europe for preliminary indication of the level of fabrication involved for the device under consideration and for the structural arrangements proposed.

The following representative rates for fabricated and painted (primed and undercoat) steelwork including launching but excluding project management costs have been obtained from the following sources.

a. Holland - Medium size modern shipyard building under cover.

b. Germany - Small size modern shipyard building under cover but also manufacturing high quality large pressure vessels.

c. U.K. - Small size modern shipyard building under cover.

d. Holland - Steel fabrication contractor.

The rates were given in local currency but have been converted at a rate of exchange applicable (14/2/91) and resulted:

a £1230/ton

b £1500/ton

c £1600/ton

d £1160/ton

The weight of the steel structure for the circular Clam design shown in drg DEA8/1 is estimated to be 920 tonnes. To estimate the all-in cost we have added 10% to the rates quoted above to allow for contingencies and structural fitments. Thus the range of tender costs of the steel hull, excluding mooring, mechanical and electrical equipment and the flexible membranes and their attachments is estimated to be £1.17m to £1.62m at February 1991 prices. Although the lowest tender would normally be taken, the budget costs are quite market sensitive and it suggested that the final contract price could be anywhere within this range.

Note that the figures quoted were provided by commercial organisations on the basis of a description of the type of fabrication. No breakdown of the rates into material, fabrication, painting, overheads etc is available since this information is commercially confidential. The costs include launching but exclude towing to site, moorings, mechanical and electrical plant, project management and design costs.