2.0 RPT SUMMARY AND RECOMMENDATIONS

Background to the Study

This report follows on from the development work on the Circular Clam by Coventry Polytechnic between 1983 and 1986, which was reviewed by RPT for the Department of Energy. Until this year no further funds have been available for development of the scheme. In January of this year RPT were approached by Coventry Polytechnic and asked to implement, with funding from the Department of Energy, the recommendation of the 1986 RPT report that the reference frame design should be developed further.

Two hull schemes were developed; one in steel and one in concrete. The steel hull concept was based closely on the scaled-up dimensions of the model tested at Loch Ness. The concrete hull concept was developed along similar lines but had to be made slightly wider to provide sufficient buoyancy to support the additional dead weight. The tubular steel concept, reviewed by RPT in 1986, was compared with the outline steel hull design. It was found that the steel hull concept was only 5% heavier than the tubular design (including RPT's 1986 revisions) whereas the cost per tonne of shipyard hull fabrication was between 30% and 50% lower than that for tubular construction. The tubular steel concept was not therefore developed further.

Loads

A more sophisticated wave load analysis method was developed from the method used by RPT in 1986 allowing rapid assessment of the forces imposed by waves of different height and length. The 1986 study only looked at waves with a critical wave length of 120m. The developed analysis method was used in a parameter study to determine the critical wave length (which was found to be very similar to that assumed in the 1986 report) and was used in the fatigue analysis to determine forces from waves of arbitrary wave length. Wave forces from the revised analysis method were found to agree well with the values predicted by Coventry Polytechnic and the scaled values measured on the model.

Main Device Parameters

		Concrete	Steel
Max. Device Width		60m	60m
Hull Width		4.500m Ave	4.000m Ave
Hull Depth		7.900m	8.000m
Displacement (t)			
- structural wt		5,005t	922t
- ballast wt		235t	3567t
- total		5,240t	4489t
Draft (Bags Deflated)		7.400m	7.400m
Reserve Buoyancy (t) (Bags Deflated)		388t	330t
Volume of Power Tube (m^3)		$320m^3$	$320m^3$
Quantities	Concrete	$1,900m^3$	-
of	Reinforcement	290-310t	-
Materials	Prestressing	50t	-
	Structural Steel	(duct) 32t	920t

Steel Hull

The cross section of the steel hull concept was found to be very similar to the side buoyancy space of a hopper dredger and fabrication is considered to be well within the capability of a number of medium sized shipyards. Launching of the device will require a wide clear area either side of the slipway but the weights and draft involved are comparatively small. The steel hull has therefore been costed on the basis of ship fabrication rates from the structural steel weight with an allowance for fitments.

The steel hull section design was found to be governed by fatigue, as was the 1986 tubular design, but because of the simpler connections and lower stresses the problems were less severe.

The steel hull is ballasted down with inert water in all compartments except the power duct and the cell surrounding the turbine. This method of ballasting limits transverse stresses on hull plates and allows the device to be de-ballasted to give access for maintenance and bag change-out.

Cost estimates for the outline steel hull concept fall in the range £1.17m to £1.62m per device excluding design costs. This range represents the expected variation in tender prices and includes no estimating tolerance which might be expected to be of the order of -10%, +20%. The lower price is expected to be achievable but would be sensitive to market forces. The upper cost range encompasses a greater number of yards and is therefore not likely to be exceeded. The cost quoted for steel construction is basically independent of the number of devices ordered although a single device may be expected to attract a slight premium and a very large order some discount.

Concrete Hull

The concrete hull device was developed with hoop prestress around the circumference as a Class I structure to BS 8110, i.e., no tension under service loads, and ordinary reinforcement in the transverse section with crack widths limited to 0.1mm. Wall thicknesses were kept to a minimum of 300mm which was considered to be the minimum practical to accommodate internal prestressing tendons and through-thickness shear reinforcement. Two types of prestressing systems were investigated; internal and external. Internal stressing uses special stressing anchors developed for circular structures where each tendon passes completely around the device and is anchored against itself using a special steel anchor block. In external stressing the tendons would be outside the hull wall but within the hull cross section and protected from the marine environment. The internal stressing system was preferred on cost.

Several different construction facility types were considered. A feasible construction programme was developed for each facility but a preferred construction method was not selected because of the small number of suitable facilities of each type and the sensitivity of the price to market forces. Costs for the concrete device construction were developed by adding material, labour and plant costs to facility rental costs and adding allowances for supervision, and other overheads as is standard practice with civil engineering projects.

It has been suggested that there may be further benefit to be derived from optimisation of the device diameter in the next stage of work. The concrete hull cross-section design is governed by buoyancy and local shear stresses and the concrete cross section cannot be reduced. The concrete is not highly stressed longitudinally and the diameter of the device could therefore be scaled up without changing the cross section, but with increase in prestress. The concrete scheme may therefore become more economical at a larger device diameter. A brief sensitivity study of the variation of device cost with device diameter for concrete structures is given in Appendix C. The benefit to be obtained by increasing device diameter would have to be assessed in conjunction with device productivity studies.

Cost estimates for the concrete hull concept are in the range of £1.25m to £1.9m per device excluding design costs depending upon type of construction facility adopted. Costs close to the lower bound estimate were obtained for a number of different construction options and the upper bound estimate was obtained using a purpose made construction facility. The cost estimate is sensitive to the number of devices constructed and, since all facility options require some fixed capital expenditure, the cost of a single device would be expected to be greater than the estimate. On the other hand a large production run would justify setting up a purpose made facility which could lead to a significant cost reduction for this particular option and possible overall savings of up to 10% on the cheapest option.

Recommendations

The reductions in the cost of the circular Clam reference frame which were predicted by RPT in 1986 have now been demonstrated. Subject to other aspects of the design being satisfactory Rendel Palmer and Tritton (RPT) recommend that the next stage of development should lead to a prototype design.

The steel concept is more flexible and can be scaled up or down more readily than the concrete design since it is not governed by buoyancy. In this respect the steel hull design would be more suitable than the concrete hull for a small scale demonstration device. However the cost estimates are so close and the number of suitable construction facilities or yards is so small that it is recommended that a prototype design should be developed in both steel and concrete to widen the number of possible construction options.

The following programme of work leading towards a prototype design is tentatively proposed for the next stage of development.

1. Determine suitable site for prototype design - obtain necessary permissions.
2. Obtain local environmental data.
3. Choose site which, though sheltered, sees sufficiently vigorous conditions occasionally to properly monitor prototype performance. Site would need to provide a good weather window access for maintenance and modification.
4. Develop detailed designs for - structure
   M + E
   transmission
   membranes
5. Draw up tender documents.
6. Detailed discussions with possible suppliers to determine tender list.

3. STABILITY CONSIDERATIONS

3.1 Intact Stability

The intact stability was investigated for a service condition. The air bags were assumed to be deflated resulting in a minimum freeboard of 0.5m.

The righting moment curve was calculated by using the British Maritime Technology Programs HYDRE and WSTAB. The Clam was modelled as a series of hull sections and negative portions to model the central opening (see Figure 3.1). The programmes calculate the righting moment at a series of inclinations or heel angles after first adjusting the trim to obtain the correct buoyancy.

The stability curve for still water conditions is shown on fig 3.2. The effect of waves on the stability was not investigated since it is assumed that this will be covered by the model test programme.

Clam stability is judged to be satisfactory, in this state by inspection, since windage is negligible. It is assumed that operational requirements - ie providing a stable reference frame- will govern the intact stability.

3.2 Damage Stability

Two cases of damage were considered:

1) Flooding of the power tube
2) Flooding of two adjacent compartments

In both cases the bags were assumed to be deflated.

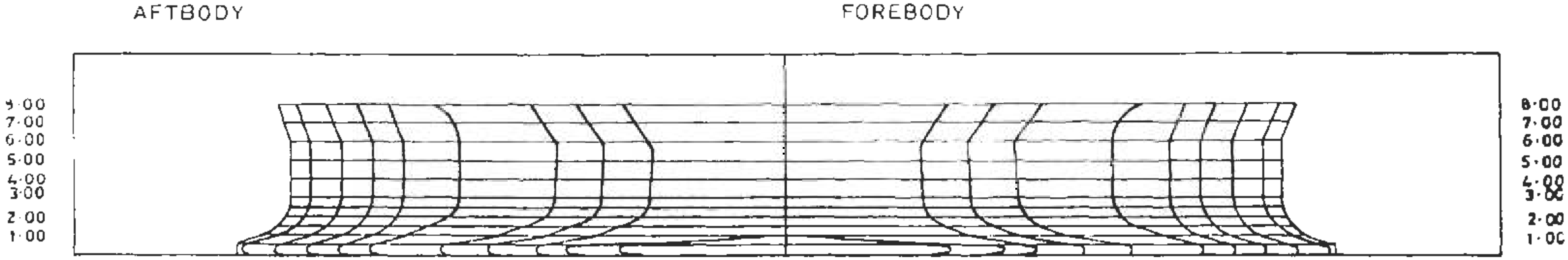
CASE 1

The maximum volume of water in the power tube is 280m^2. This significantly reduces the reserve buoyancy. The associated reduction in stability is shown on fig 3.2. The maximum righting moments reduce from 77 MNm for the intact case to 19 MNm.

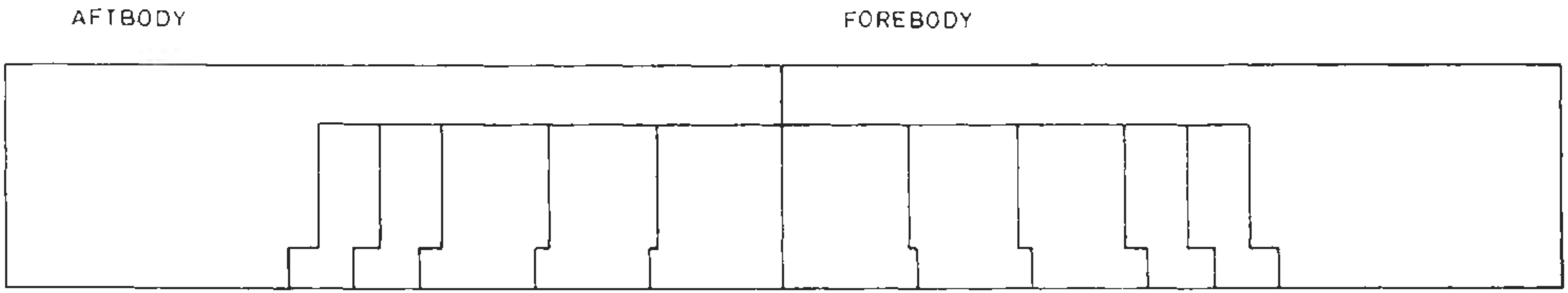
CASE 2

The extreme case was taken to be the flooding of two adjacent compartments. This case can occur in the concrete structure but not the steel structure. In the steel structure each buoyant compartment is surrounded by water ballasted compartments.

The heeling and righting moments for a structure with three water-tight compartments between bulkheads, are shown on fig 3.3. The normal criterion is that the area under the righting moment curve between the first and second intercepts is greater than the area under the heeling moment curve by a factor of safety - usually taken as 1.5. By inspection this criterion is met and therefore there is sufficient stability in the structure against accidental damage.



HULL SECTIONS



NEGATIVE PORTIONS

BASIC PARAMETERS

LBP	57·920	BEAM	57·920
DRAFT	8·000	HSIDE	·000
RISE	·000	THICK	·000

SCALE: 3·33 MMS PER UNIT LENGTH (m)

Figure 3.1 CLAM DEVICE STABILITY CHECK – SECTIONS & PORTIONS USED

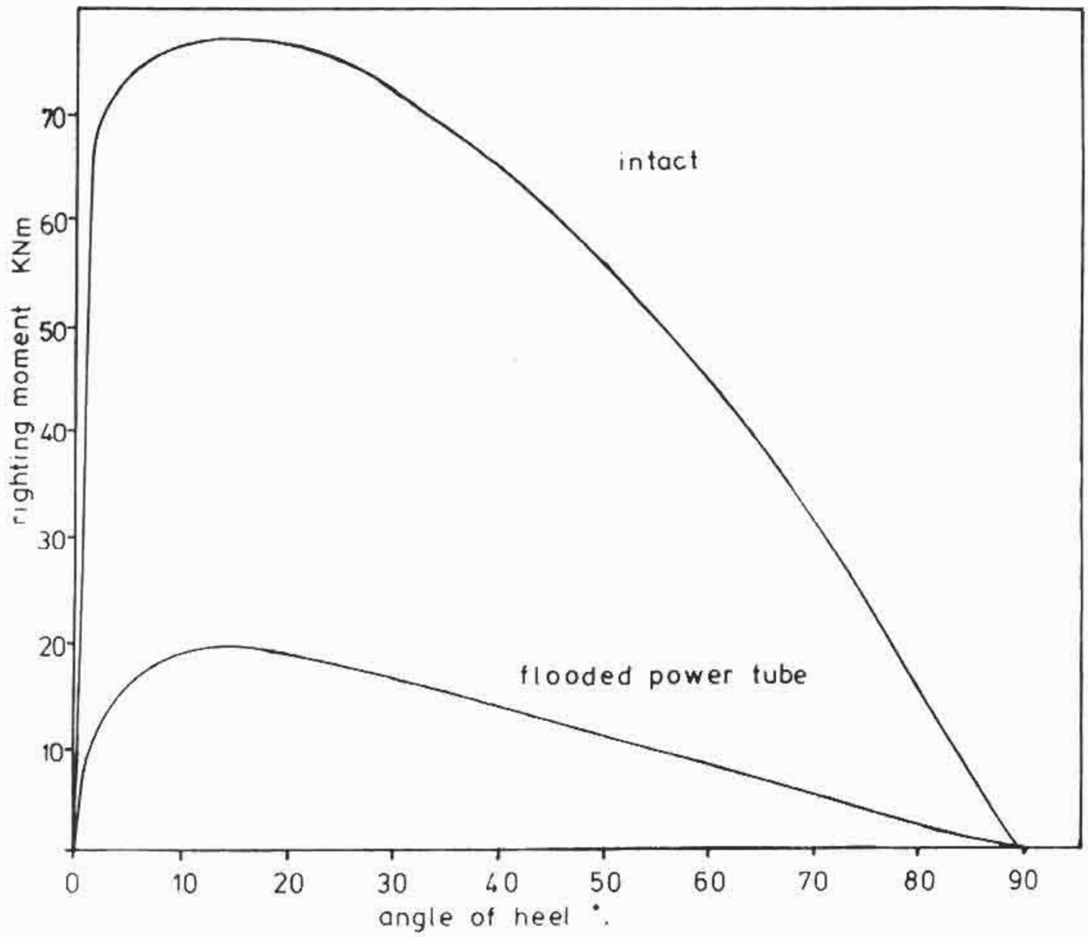


FIGURE 3.2 COMPARISON OF RIGHTING MOMENT CURVE FOR INTACT CASE AND FLOODED POWER TUBE CASE.

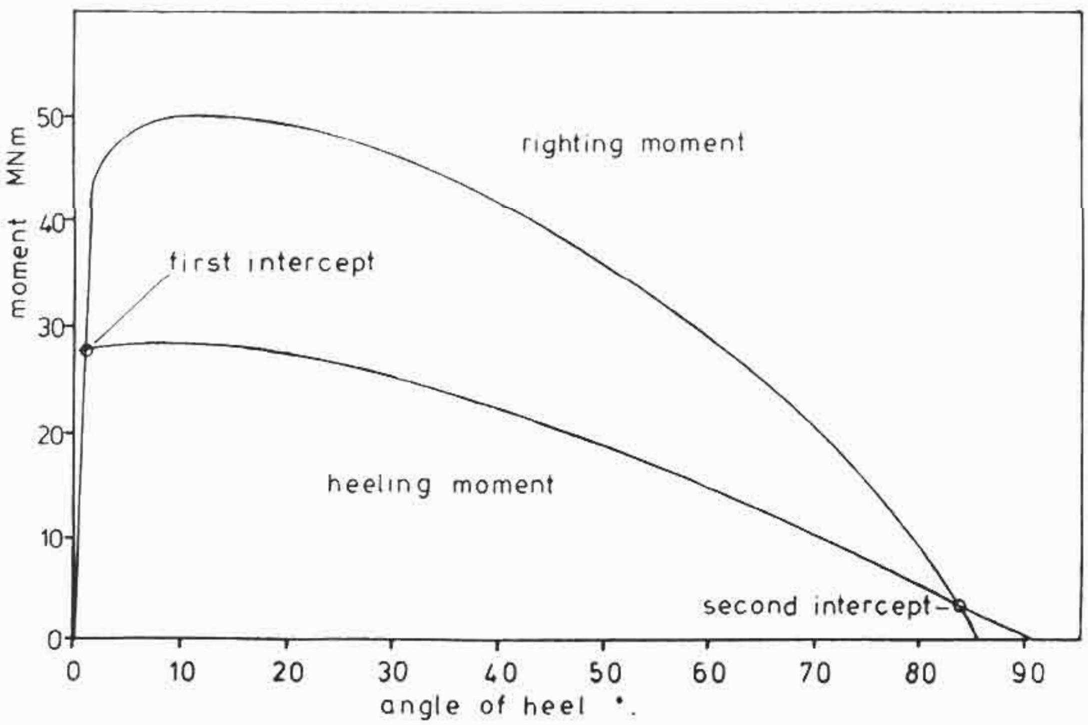


FIGURE 3.3 RIGHTING MOMENT FOR COMPARTMENT DAMAGE CASE.