H1 STRUCTURAL DEVELOPMENT OF THE SEA CLAM

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ABSTRACT

The Energy Systems Group (ESG) at Coventry University in conjunction with Sea Energy Associates Ltd (SEA) have been researching wave energy and developing wave energy devices since 1975. Recently, the Group was involved with consulting engineers at Rendel Palmer & Tritton (RPT) on a joint project aimed at developing the structural design for the reference frame of a circular SEA Clam wave energy device. This paper arises from that project and covers all aspects of the structural design, cost of construction, launching and production methods.

The paper reviews the development of the SEA Clam wave energy converter to its present circular configuration and identifies the key features which make it a leading device in the recent ETSU review report [1]. The requirements of the floating toroidal structure are assessed and the three main design options; steel tubular framework, steel hull and concrete hull, are evaluated. The chosen steel and concrete hull designs are described in detail and costings based on quotations presented. Construction methods are considered and the maintenance requirements assessed.

1. INTRODUCTION

From 1979 to 1983 the ESG/SEA team at Coventry worked on the development and testing of the linear spine Clam [2]. At the conclusion of this work the design was assessed as having many good features, including low structure cost and mechanical simplicity, but the linear reference frame had little inherent pitch stability. This resulted in a power take off stiffness which compromised efficiency to achieve stability. It was noted at that time that a much more stable frame could potentially lead to considerable increase in efficiency. It was also noted that a scaled down device optimised for low cost of power rather than for maximum use of the resource, would be more relevant to the early practical application of wave energy to power generation. The result of this thinking was the 1984 circular Clam [3], based on a twelve sided reference frame only 60m in breadth, optimised for the 120m wave length as illustrated in Fig. 1.

The ESG/SEA team sought help with the design of a suitable reference frame from an offshore construction company and were provided in 1986 with a frame design based on offshore tubular technology. RPT were engaged by the Energy Technology Support Unit (ETSU), to assess and cost this design. RPT included in their report an indication that further design work on the circular frame could yield very significant improvements in both cost and structural performance and subsequently in 1991 were contracted with the SEA team, as part of the wave energy review, to investigate alternative structural configurations in steel and concrete, to produce an improved, costed design.

The outline specification for the structural design was based on a deployment of 10 Clam units sited 2km off the Scottish coast in 50m water depth. The principal dimensions were taken as; diameter = 60m, hull width = 4m (steel) and 4.5m (concrete), hull depth = 8m, which gives operating displacements of 4500 tonnes (steel) and 5,250 tonnes (concrete).

Other key requirements relating to safety, serviceability and maintenance were established as objectives to be studied and optimised as far as possible during the design process, as described elsewhere in this paper. There was no perception as to whether steel or concrete or some combination of the two was likely to come out 'best'. Clearly steel, being much lighter and amenable to one-off construction could have advantages at the prototype stage, and concrete, with its higher set up costs would be most competitive with larger numbers.

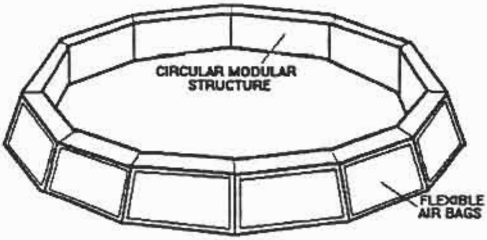

Fig. 1 The SEA Clam

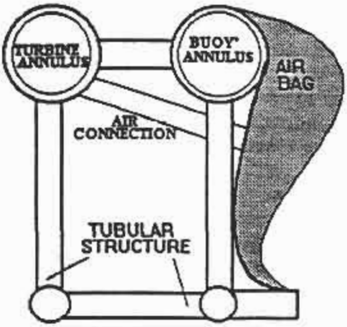

Fig. 2 Tubular Steel Design - 1986

2. STEEL HULL DESIGN

The first concept tubular steel design is illustrated in Fig. 2. Based on the established technology of offshore jacket construction, the feasibility of the design was assured, but cost is relatively high. Tubular construction in a fatigue environment is inherently expensive, particularly when, as in this case, there is a high proportion of joint to tube connections. The back plate to the bag is not utilised as part of the section which means wasted material and the structure is vulnerable to slamming forces on the flat section at the top between the two main tubes. This tubular design was re-examined by RPT, and checked out with full fatigue analysis, and it was decided that the design was not worth pursuing further.

Sketch exercises and preliminary calculations suggested that the section shown in Fig. 3 might provide the basis for an optimum structure. The functions of providing the housing for the bag, providing buoyancy, and providing requisite structural strength are combined in this simple skin structure. In developing the concept much attention was paid to minimising transverse welding, which is inherently weak in fatigue. The 30° changes of direction in the main section however are the natural locations for the site of construction joints, where some transverse welding in unavoidable. By using folded plates to move welds away from the positions of peak stress, and locally increased plate thicknesses to reduce stresses, the problem of fatigue has been contained within an acceptable tonnage of steel.

The resemblance of Fig. 3 to a double skin ship section is deliberate; in fact, the whole section is seen to closely resemble one half of the hull section of a cutter-suction dredger, with which craft RPT are very familiar. It was a rule for the detail design that the finished design should be capable of being made and launched in a shipyard, so that advantage could be taken of the low price of shipyard construction. Design development included on site discussions with the design team at Camell Laird, and RPT's in-house naval architects were involved at all stages.

The all steel design requires extensive ballast for it to float at the required submergence. Water, with appropriate additives, is the obvious cheap ballast, and was finally selected. It has the advantage that the structure can be wholly or partially deballasted at any time to aid launching, towage, maintenance, and repair and to provide extra buoyancy in the event of an accident.

The possibility was considered of using a proportion of concrete as ballast, built into the structure at strategic locations to reduce local stresses in regions subject to high fatigue stress. In the event however it was found to be of only marginal benefit and the idea has not been further developed.

The steel structure was costed on the basis of current rates obtained from suitable ship yards in UK, Germany and Holland and also from a steel fabricator who is generally reckoned to be one of the most competitive in Europe. The rates obtained included total fabrication and assembly, painting, and launch. The result was a price range for the reference frame between the limits £1.17m and £1.62m at February 1991 prices.

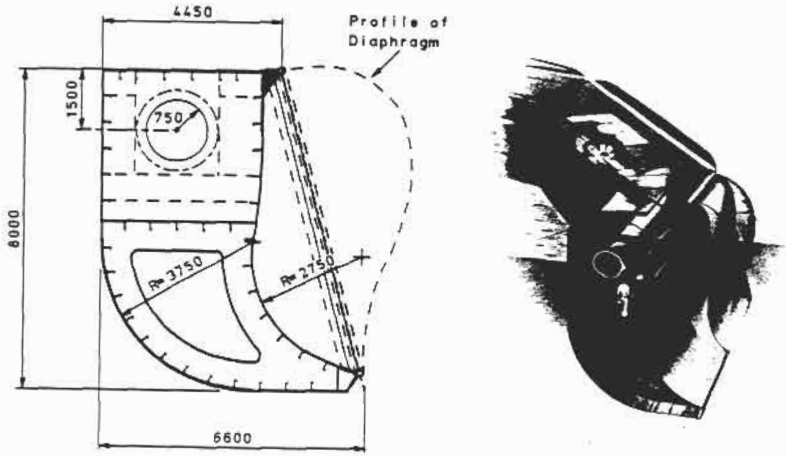

Fig. 3 Steel Hull Design

3. CONCRETE HULL DESIGN

The shape developed for the steel design lends itself very well to a prestressed concrete solution. Repetitive modular construction is inherent in the symmetrical 12 sided polygonal shape, and the size of modules required, 8m x 4.5m section, is comfortably within current practice in bridge construction and in many other applications. The inherently high mass of concrete construction, which in other areas of construction is a penalty, is here quite acceptable. Prestressed concrete is not prone to fatigue, and lends itself readily to efficient jointing on site. The material can be made durable in a marine environment and requires no maintenance.

Various systems were investigated for the prestressing, including cables within the shell wall, and 'external' prestressing, with a system of cables exposed inside the hollow shell. At this stage the former solution has been preferred. RPT had current experience in producing alternative designs in steel and prestressed concrete for a similar project, the Coulport floating dock. The process of public tender confirmed the competitiveness of concrete for this type of structure.

The section shown in Fig. 4 was adopted and the design developed to a stage which allowed relatively accurate costing to be carried out using the extensive industry data which exists for this type of construction. Methods of construction and launch were investigated and appropriate costs were developed for this element of the project. The final costing for this concrete reference frame indicates a cost in the water between £1.25m and £1.88m.

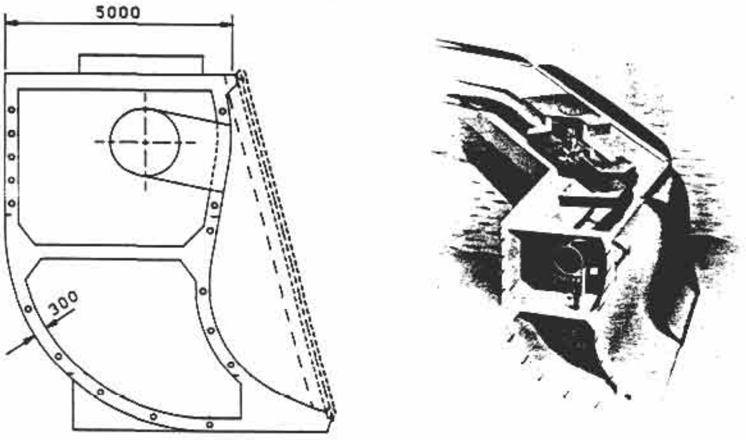

Fig. 4 Concrete Hull Design

4. OPTIMISATION OF THE CONCRETE DESIGN

The wall thickness of the concrete section for the 60m diameter Clam is determined not by first order frame bending and torsion stresses, but by the practicalities of concrete construction, and hydrostatic stress due to submergence. The concrete is under utilised in its main frame action. It follows that the concrete cross section can be made capable of sustaining significantly greater moments and shears simply by adding additional prestressing steel. No extra concrete thickness is needed. RPT extended their analytical work and established that the proposed Clam design could be stretched to an 80m diameter Clam using the same concrete section, with additional prestressing steel. The costing of this extended design can be considered secure in the sense that it is based on sound calculations and the same cost data base as the 60m Clam. No uncertain factors have been introduced, and there is no reason why cost of power estimated for this reference frame should be less reliable than the cost estimate for the 60m Clam. There are substantial benefits of stretching the Clam from 60m to 80m diameter. The power captured per metre increases by 20% for a structure cost per metre increase of 13% giving a predicted cost of electricity of 7 p/kWh.

5. CONCLUSIONS

The SEA Clam lends itself to efficient structural design by virtue of its modular circular configuration. Viable structural designs in steel and concrete have been presented which have been fully costed. These designs conform to marine requirements and may be refined to give added benefits. In particular the concrete design can be stretched to larger diameters to give higher efficiency and lower electricity costs.

ACKNOWLEDGEMENTS

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