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DESIGN AND CONSTRUCTION OF GREENWAVE ENERGY CONVERTER FOR SHALLOW WATERS

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This paper describes the structural design and construction of the oscillating water column “greenWAVE Energy Converter”, constructed during 2013 and planned to be deployed in shallow water off the South Australian coast in 2014. Rated initially at 1 MW, the greenWAVE unit will be dedicated to electricity production, although an option is available to also produce desalinated seawater. The unit base is constructed from reinforced concrete designed to international maritime codes, and will be founded in approximately 10-15m of water. The upper portion of the device extends above sea level, housing the airwave turbine and electrical control systems.

Keywords: Wave energy, Oscillating water column, Design wave.

1 INTRODUCTION

Ocean waves are a huge largely-untapped energy resource, and the potential for extracting energy from waves is considerable. Research in this area is driven by the need to meet renewable energy targets, although it has remained relatively immature compared with other renewable technologies.

There are various concepts for wave energy conversion. WECs (Wave Energy Converters) are generally categorized by energy conversion mechanism. Oscillating Water Column (OWC) devices are known as one of the more efficient ways to capture and convert the wave energy to electricity.

The greenWAVE Energy Converter (GEC) consists of a chamber with an opening to the sea below the waterline. As waves approach the device, water is forced into the chamber, applying pressure on the air within the chamber. This air escapes to the atmosphere through a turbine. As the water retreats, air is then drawn in through the turbine. A low-pressure “Wells” turbine is often used in this application, as it rotates in the same direction irrespective of the flow direction, removing the need to rectify the airflow. It has been suggested that one of the advantages of this concept is its simplicity and robustness.

Such robustness needs to be assured in recognition of the severe and variable-load regime associated with the in-service location of the GEC. The unit is planned to be located approximately 10-12 km offshore from the South Australian Coast in the Great Australian Bight.

The GEC described in this paper comprises a reinforced concrete substructure (below sea level), a reinforced concrete superstructure housing the turbine, and a generator set and electrical control system (above sea level), as shown in Figure 1 below.

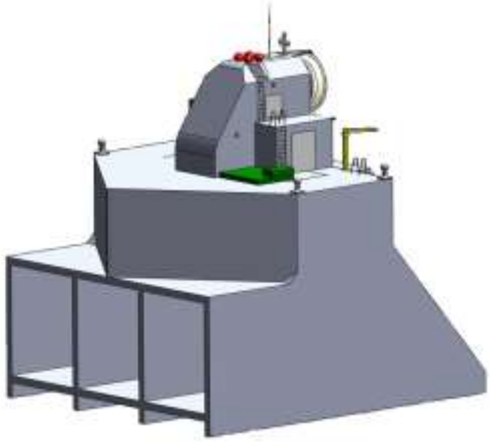

Figure 1. Isometric View of GEC.

2 DESIGN REGIME

The GEC is intended for a design service life of 25 years.

Current Australian Standards provide only limited design guidance for maritime structures and offshore structures in general. The Australian Standard AS 4997-2005 (AS 4997) is entitled “Guidelines for the Design of Maritime Structure”, the emphasis being on “Guidelines”. Equation 5.9.2 of AS 4997-2005 defines the design wave for offshore structures as H_1, as it is the average of the highest 1% of all waves for the design storm event. Simplistically, AS 4997 suggests:

$$H_1 = f H_s \tag{1}$$

Where H_s = significant wave height
= Average height of highest 1/3
of waves in any given time interval
as estimated by “an expert observer”.

More relevantly, AS 4997 suggests: *“The design wave conditions may be determined by more specific modelling.”*

2.1 Selection of Design Wave

Wave data was available from a variety of sources, which—when considered together—resulted in a fairly-broad scatter, with H_s varying between 6.5m and 10.0m based on the modified Goda (1974) relationship.

This broad scatter of H_s values was of limited value, given the range of design outcomes for concrete section sizes and reinforcement density, and—of course—the resulting construction cost.

2.2 Model Tank Testing

As recommended in AS 4997, a series of model trials was conducted at the Australian Maritime College facilities in Launceston, Tasmania. The final report recommended that design should proceed on the basis of a design wave for which:

$$H_{max} = 9.25\text{M and } T_s = 12 \text{ seconds} \qquad (2)$$

However, the largest wave able to be generated in the tank testing was the equivalent of 6.0m. Therefore, any extrapolation of design loads from 6.0m to 9.5m would require further validation.

While considered to be of some value, the model testing was in fact limited in direct relevance to the design regime for the GEC.

3 LITERATURE REVIEW

An extensive literature review was conducted with valuable guidance found from well-known researchers, including Cuomo *et al* (2010).

All of the available data was re-plotted and a “correlation band” was recognized as reproduced in Figure 2 below.

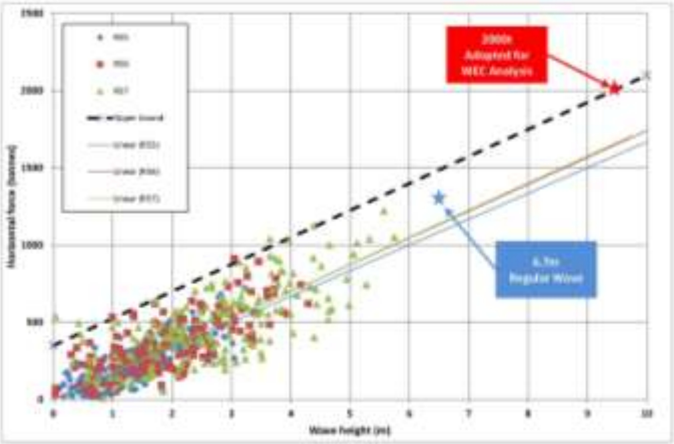

Figure 2. Wave Height/Load Scatter Band.

4 STRUCTURAL DESIGN REGIME

As with all maritime structures, durability (commensurate with a 25-year design life) was the primary focus for the structural design of the GEC.

4.1 Crack Control

AS 4997-2005 provides for crack control in maritime structures being achieved by limiting tensile stresses in carbon steel reinforcement to a figure between 150 MPa and 185 MPa, depending on bar diameter.

4.2 Cover to Reinforcement

It was decided that it was appropriate to adopt two (2) exposure classifications for the GEC based on AS 4997-2005. Classification B2 was adopted for the lower (submerged) portion of the structure, and classification C2 for the upper (superstructure) portion. In addition, galvanized reinforcement was specified for all areas of maximum moment transfer and other critical locations throughout the structure. The balance of the reinforcement was non-galvanized, all reinforcement stress limits limited as noted previously.

4.3 Fatigue

AS 4997-2005 provides only limited guidance with regard to fatigue, noting: “The magnitude of the repeated loadings when designing such structures, or elements of structures, for fatigue performance should be determined from in-service cyclic actions.” A figure of 10^6 cycles per annum is suggested for wave periods of 2-4 seconds.

This figure is generally in line with other literature including a valuable paper by Waagaard (1977) which states: “No endurance limit is found up to 10^7 cycles on testing of plain concrete.” Further, it is accepted in the offshore gravity structure area that the cycling frequency of such structures is low, generally in the region of 0.05 H_z to 0.30 H_Z. Accumulated experimental data indicates that frequencies up to 10.0 H_z do not affect fatigue strength of concrete (plain or reinforced).

4.4 Buoyancy and Towing Actions

The GEC was constructed at the Common User Facility at Techport north of Adelaide, South Australia.

Buoyancy for the unit during deployment from Techport to Port MacDonnell (approximately 400 kms) was to be provided by:

a) Fitting a removable steel bulkhead across the major openings at the front of the structure, and
b) Fitting a number of air filled buoyancy bags around the perimeter of the unit in locations determined by the naval architect for the project.

The planned towing speed for deployment of the GEC was 4 knots.

Cast-in items were provided throughout the concrete substructure and superstructure to accommodate the buoyancy and towing loads.

4.5 *In Situ* Stability

Two (2) main failure modes for the *in situ* GEC were considered, based on the ultimate limit state design wave discussed at sections 2 and 3 above.

4.5.1 Overturning

Considering the total submerged mass of the structure as the only resistance against overturning, a safety factor of 2.3 was adopted.

4.5.2 Sliding

Extensive iterations were conducted to determine a “comfortable” value for sliding resistance.

It was acknowledged that small (say 0-0.5 m) horizontal movements by the GEC could be accommodated without any impact on the power generating efficiency of the unit.

This enabled relaxation of sliding factors of safety below those which would be required for assurance of fixity in location. Detailed dynamic analysis suggested that with a friction coefficient as low as 0.5, the GEC would undergo a horizontal translation of less than 100mm for a wave load of 25,000 kN (at 1.25 times the design wave load).

Figure 1

Figure 2

Photographs of the GEC, nearing completion in September 2013.

5 CONCLUSION

Construction of the GEC was completed in early 2014 and the unit was launched in early March 2014 (see Figures 1, 2, and 3):

Figure 3. GEC following Launch.

Shortly after towing the unit was commenced, a problem was detected with the buoyancy air bags, resulting in an unstable state, and the unit was towed to shallow water south of Adelaide for repairs to be made prior to final deployment.

Acknowledgement

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References

Cuomo G., Allsop W., Bruce T., and Pearson J., *Breaking wave loads at vertical seawalls and breakwaters*, in Coastal Engineering 57, 424-39, 2010.

Goda, Y., *New wave pressure formulae for composite breakwaters*, Proc. Int. Conf., Coastal Engineering, Copenhagen, No. 14 Vol 3, 1702-20, 1974.

Standards Australia, AS 4997-2005, *Guidelines for the Design of Maritime Structures*, 2009.

Waagaard, K., *Fatigue of offshore concrete structures – design and experimental investigations*, Offshore Technology Conference, Houston, Texas, 1977.