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Design, Construction, Reliability and Hydraulic Performance of an Innovative Wave Overtopping Device

P. Frigaard[1], T. Lykke Andersen[1], L. Margheritini[1] and D. Vicinanza[2]

[1]Aalborg University, Department of Civil Engineering, Soil & Water, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark.
[2] Second University of Naples, Via Roma n.29 – 81031 – Aversa - Italy

Abstract

The SSG (Sea Slot-cone Generator) is a wave energy converter of the overtopping type. The structure consists of a number of reservoirs one on the top of each others above the mean water level, in which the water of incoming waves is stored temporary. In each reservoir, expressively designed low head hydro-turbines are converting the potential energy of the stored water into power. A yearly energy production of 320 MWh is foreseen for a 10 meter wide section.

A key to success for the SSG will be the low cost of the structure and its robustness. During the last 2 years such a 1350 tonnes concrete structure has been under detailed design in Norway. The construction was planned to be installed during spring and summer 2008 at a small island Kvitsoy situated near Stavanger. Unfortunately environmental issues have demanded a movement of the project to another location. The actual situation is that some breakwaters under design are being investigated as a possible places for integrating the SSG structure.

The paper describes the concept of the SSG wave energy converter, the structure and the studies that led to its design.

Keywords: *Wave Energy; Climate changes, Overtopping, Turbines, Concrete Structure, Caisson Breakwater.*

1 Introduction

As recently expressed by top European heads of states, the climate change is the biggest challenge that we are facing today. In the short term, the Kyoto protocol and the RES directive promotes the use of renewable energy sources (RES), and in the long term the decreasing reserve of fossil fuels will urge the use of RES.

Wave Energy is a renewable and pollution free energy source that has the potential to contribute with 2000 TWh/year of the worlds energy production. Sea waves have one of the highest energy densities among the RES. Today, the largest problem in harvesting wave energy is obtaining reliability of the technology and at the same time bringing cost down.

The SSG concept is based on the known principle of overtopping and storing the wave energy in a reservoir above sea level. Examples of such devices are the Danish concept “Wave Dragon” and the Swedish concept “Sea Power”.

Nevertheless, the SSG concept is a further development of the overtopping principle. The incoming wave will run uphill a slope and on its return it will flow into reservoirs. After the wave is captured inside the reservoirs, the water will run through the patented multi stage turbine. Using this method practically all waves regardless of size and velocity, can be captured for energy production.

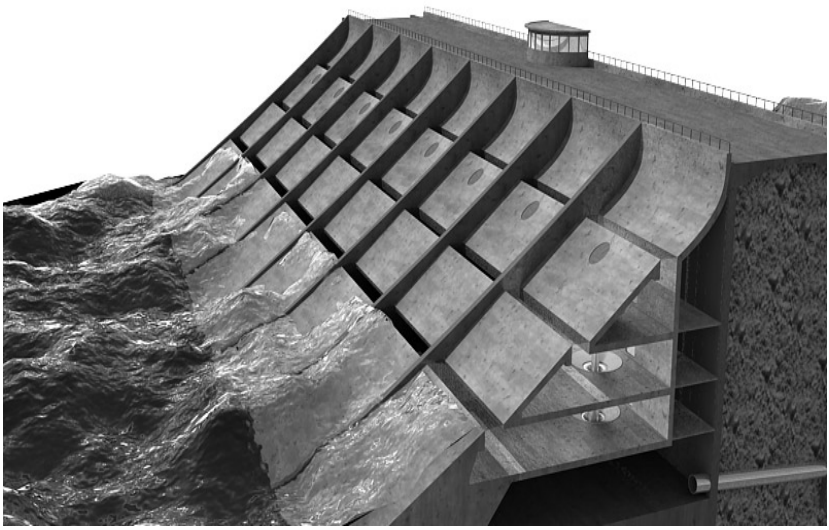

Figure 1. Cross Section of a SSG Wave Energy Converter.

2 Design of the SSG Wave Energy Converter for Kvitsoy

Wave Energy A/S (WEAS) is a private company with will and means to develop Wave Energy in Norway. In the period from 2006 to 2008 WEAS has carried out a pilot project of the SSG Wave Energy Converter at the island of Kvitsoy, near Stavanger, Norway.

The Kvitsoy municipality has 520 inhabitants and is one of 10.000 islands in Europe where wave energy quickly can be developed into a cost-effective energy production alternative to existing diesel generators.

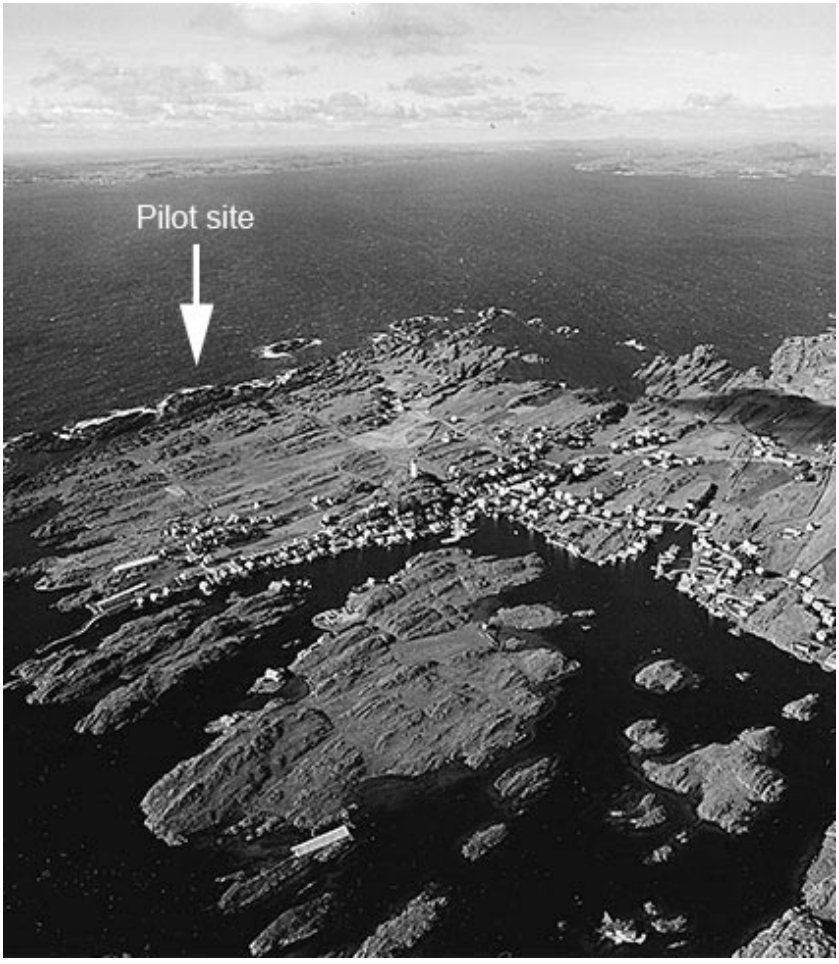

Figure 2. The Island of Kvitsoy (located at Bokna Fjord, near Stavanger, Norway) with the pilot site facing west against the North Sea.

The pilot project regards a 10 meter wide concrete civil structure module of the SSG equipped with a multistage turbine as well as some conventional Kaplan turbines. The objective of this project was to demonstrate at full scale, the operation and energy production of the SSG Wave Energy Converter in 15-20 kW/m wave climate, including turbine (150 kW), generator and control system, and to connect the system to the public grid for electricity production for some households.

A detailed description of the project can be found on www.waveenergy.no. This web page has also some nice videos showing the location and the waves on the location.

The design and construction of the SSG Wave Energy Converter for Kvitsoy has been supported by the European Union under the Sixth Framework program priority 6.1 (Sustainable Energy System), contract 019831, titled "Full-scale demonstration of robust and high-efficiency wave energy converter" (WAVESSG).

This project has covered the following activities related to the technical prototype at Kvitsoy:

- Planning and measurement of water level data in three SSG reservoirs for turbine design input
- Planning and measurement of forces on the full scale technical prototype for reliability assessment input
- Design, manufacturing, testing and installation of a full scale technical prototype of the MST multi-stage turbine with installed capacity of 150 kW
- Design, production, testing and installation of electricity generator
- Grid connection, long term testing and performance evaluation of the SSG Wave Energy Converter

The specific objectives of the project have been:

- To design the SSG civil structure for maximum energy capture in such a way that these structure can handle the wave loads
- To develop and install a full-scale 150 kW technical prototype of the innovative MST turbine technology into the SSG civil structures
- To develop a full-scale generator and control system equipment for grid connection and production of 200.000 kWh of renewable and pollution free electricity
- Measure performance data of the SSG Wave Energy Converter including the structure in a period of up to six months for reliability and life time assessment

The international group of partners working with the project has been from the following institutions:

- Wave Energy A/S, Norway
- Municipality of Kvitsoy, Norway
- Aalborg University, Denmark
- Ganz Trans electro, Hungary
- Technical University of Munich, Germany
- Norwegian University of Science and Technology, Norway
- IKM Elektro A/S, Norway

This group of research institutions has developed the project during the last 3 years and final design was ready autumn 2007, and call for tenders related to the construction were ready when the project was stopped due to some environmental reasons.

One single local inhabitant managed to claim some negative environmental impact. His claim was mainly about visual impact from the device, and possible cultural values at the sea bottom at the site in front of the Wave Energy Converter.

It is likely that the consortium lead by Wave Energy A/S would have been able to win a trial and go on, but the 'green' people behind the company did not want to operate against the local environmental opinion. Therefore, the project was stopped early 2008 and the consortium is now looking for a new location for the project to go on. Among different options is the integration of a SSG Wave Energy Converter into an outer breakwater. Some breakwaters under design are being considered.

For the group of researchers has it been very annoying to see the project being stopped just before construction. The wave energy sector is not used to cooperate with companies with the necessary means actually to build a Wave Energy Converter. Nevertheless, Wave Energy A/S will continue the project at another location.

The lessons learnt from Kvitsoy are to have full control of all environmental aspects. To take all locals into the planning phase as early as possible.

3 Main findings from the Kvitsoy project

The research related to the Kvitsoy project covers several man years, and it is totally impossible to cover every detail in this paper. Nevertheless, the next pages will briefly list some main findings related to SSG Wave Energy Converter designed for Kvitsoy.

- Energy capture
  Comprehensive 2D and 3D hydraulic model tests were carried out at the Department of Civil Engineering, Aalborg University (DK). The model scales used were 1:60 and 1:20. The foreshore was modelled in detail following a survey from Kvitsoy 2006.
  The front slope, the levels of the reservoirs and in general the entire geometry of the structure was optimised in order to find the cross section with the maximum energy capture.
  Several hundreds of tests with changing geometry were performed. Margheritini (Margheritini et al., 2007) reported energy captures up to 40% in irregular short crested waves for the optimized geometry.

- Wave loads / Wave Pressures
  Information on the wave loading acting on the SSG Wave Energy Converter is essential for a proper design of the civil structures. Remember, that the device is facing the highest waves in order to have maximum energy capture.
  During the project period waves were measured at the location. The highest wave measured was 15.7meter, which is an enormous wave, but such waves are to be expected every year at the location.
  Comprehensive 2D and 3D hydraulic model tests were carried out at the Department of Civil Engineering, Aalborg University (DK). The model scales used were 1:60 and 1:20. The foreshore was modelled in detail.
  Maximum wave pressures (from breaking waves) in the order of $500 kN/m^2$ were measured. The results of the model tests have been compared with predictions by Tanimoto and Kimura, (Tanimoto and Kimura, 1985).
  Vicinanza 2008 reported the measured wave pressures.

- Civil Structures (Concrete Structures)
  The reported wave loads resulted in a 1300 tonnes concrete structure for a 10 meter wide section. The typical thickness of the concrete elements was 0.30 meter.

- Generator and Control system
  IKM has with success developed and tested a full scale generator and corresponding control system to be built into the Multi-stage turbine.

- The Multi-stage turbine
  The Multi-stage turbine has been tested at NTNU in Trondheim. An overall efficiency is found to be in the order of 60%. This might seem rather low, but overtopping based wave energy converters have the problem that they loose a lot of energy during start and stop operations needed in order to keep the water levels in the reservoirs.

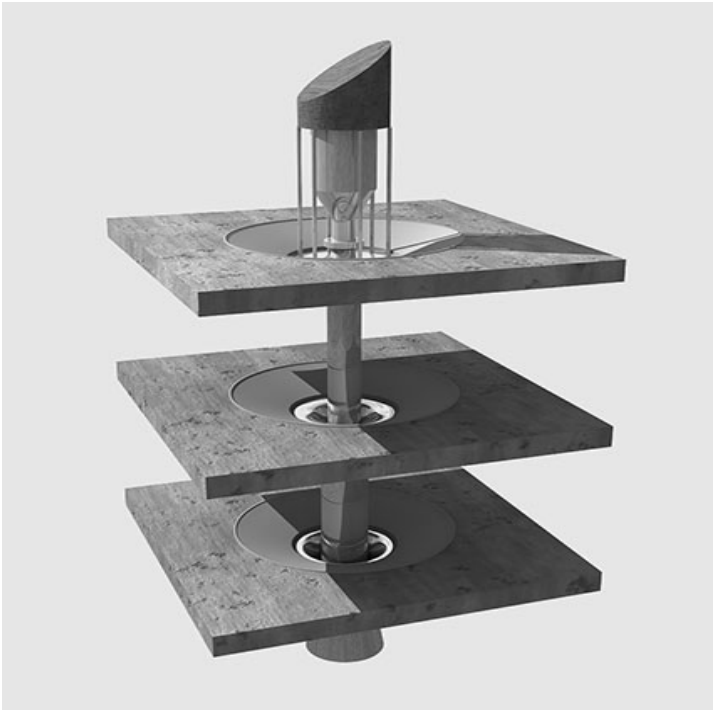

Figure 3. The Multi-stage turbine.

- Yearly energy production.
  Taking into account energy losses in the reservoir, the turbines and the generators a 10 meter wide section of the SSG Wave Energy Converter will be able to bring 200.000 kwh electricity to the grid if situated in a 19 kW/m wave climate like the one near Kvitsoy.

4 Conclusions

During the last years a group of research institutions has developed a new and innovative Wave Energy Converter. Wave Energy A/S in Norway is

leading the process to commercialise the concept. A structure was designed, financed and ready to be built at Kvitsoy, 2008. The project was unfortunately stopped due to environmental reasons, but the development of the concept will go on at another location.

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