contract nr: SES6-CT2005-019969

SEEWEC

Sustainable Economically Efficient

Wave Energy Converter

Specific Targeted Research Project
Sixth Framework Programme
Priority 6-1 : Sustainable Energy Systems

SEEWEC – Publishable Final Activity Report

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Author(s) and organisation name(s): Julien De Rouck (UGent),Vincent Meirschaert (Ugent)

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Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contract n°:	SES6-CT2005-019969	**Reporting period:**	T_0 till T_{0+42}
Title:	Sustainable Economically Efficient Wave Energy Converter (SEEWEC)		

Participant name	**Country**
Ghent University (coördinator)	Belgium
Spiromatic NV	Belgium
ABB	Sweden
Standfast Yachts*	The Netherlands
Brevik Engineering A.S.	Norway
Marintek (SINTEF)	Norway
Norwegian University of Science and Technology	Norway
Instituto Superior Técnico	Portugal
Chalmers University of Technology	Sweden
Fred Olsen Ltd.	UK
Natural Power Consultants Ltd.	UK

*The cooperation with STY has been stopped as described in section 3.2.

For additional information and follow up on the SEEWEC project, please take a look at the project's website : www.SEEWEC.org or contact the project's coordinator :

Prof. Dr. ir. Julien De Rouck
Ghent University
Department of Coastal Engineering
Technologiepark 904
9052 Zwijnaarde
Tel : +32 9 264 54 89
Fax : +32 9 264 58 37
Email : julien.derouck@ugent.be

Project objectives:

The SEEWEC project is built up around the FO^3: a robust **floating wave energy converter**, meant to be installed **near shore** and intended to lead to **competitive and economically effective exploitation of wave energy** along (European) coasts. The basic concept of the FO^3 device consists of several (12 or 21) point absorbers placed under a floating platform. This concept combines experience from the offshore industry with knowledge of wave-energy conversion by use of point absorbers.

The general objective of SEEWEC is to assist in the further development of the FO^3 wave energy converter through extensive use of the experience from monitoring the 1:3 laboratory rig Buldra and the single system test station (SSTS) at Løkstad. The project will focus on robust cost effective solutions and design for large scale (mass) manufacturing.

SEEWEC supports the development of a new, sustainable technology for renewable energy production that over time will have the potential to :

- produce electricity without the combustion of carbon;
- reduce dependency on fossil fuels;
- increase the availability of renewable energy;
- contribute to diversify and secure the European energy supply;
- minimize the environmental impact of energy production;
- increase the economical sustainability of the renewable energy technologies.

The results achieved during the project suggested a modification of the objective of the SEEWEC project. While the original FO^3 point absorber concept was platform-based, the results showed that it was worthwhile to pursue an alternative based on a single point absorber moored directly to the seabed rather than attached to a platform.

One reason for looking at the adapted concept was the fact that initial estimates of the energy capture ratio of the purely platform-based absorbers have proven to be too optimistic. While a full-scale platform was initially expected to capture enough energy to justify an installed power of 1,5 MW (with 3000 full-load equivalent hours), we now (March 2009) have more realistic calculations deriving an installed capacity of 0,4-0,6 MW (again with 3000 full-load equivalent hours). This led directly to the requirement for an adapted concept. The new concept also led to significant improvements in manufacturing cost per kW installed capacity.

The final device aims for simplicity in design, flexibility in deployment and relatively low costs throughout the development, testing, manufacturing, operation and decommissioning processes.

However we would like to emphasize that significant new knowledge was acquired regarding the serviceability (energy capture) and safety (structural integrity of hull, mooring system) as well as the electrical off-take and control system, which will be useful in further developments in the organizations involved as well as others.

Scientific achievements and results:

1. Field testing and data collection have been done on different test sites:
   - Results and data from the initial model tests carried out by Marintek were made available for the SEEWEC project and have been used extensively.
   - Two wave rider buoys have been installed to collect wave data for two sites under consideration.
   - Tests have shown that it is possible to efficiently extract useful energy from ocean waves using a direct drive mechanically / electrical PTO (Power Take Off).
   - The design and control of the wave energy capture systems at Buldra (Figure 1) and Løkstad (Figure 2) have been investigated and improved continuously.

Figure 1: 1:3 Laboratory rig Buldra.

Figure 2: Løkstad test facility.

   - At the end of the project an efficiency of power production up to 65% (with an average of 40%) of the incoming power was obtained.

2. An identification of suitable areas for wave energy deployment was performed:
   - In a first phase, criteria (e.g. wave period, significant wave height, water depth, grid connection, environmental designations, other marine users, construction facilities) were defined as basis for the global method for the evaluation of the sites.
   - Secondly, coastal areas were defined in UK, Ireland, Spain, Portugal and France meeting basic requirements for deployment of FO^3 devices from the viewpoint of wave energy climate, bottom bathymetry, distance to shore, grid connection, environmental restrictions, etc.

3. Material design for large scale manufacturing of point absorbing buoys and platform structure has been investigated:

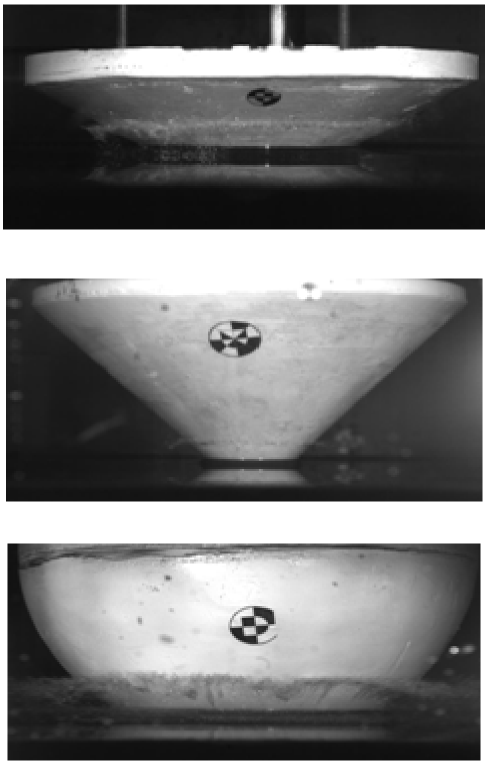

Figure 3: Small scale (1/16) drop tests (resp.: cone 20°, cone 45° and hemisphere).

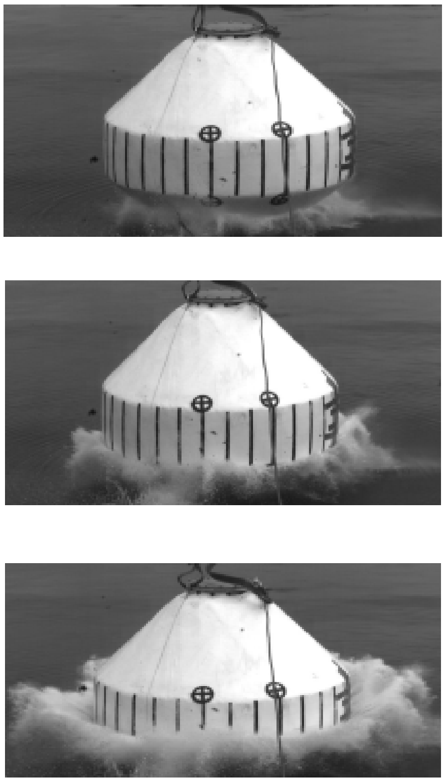

Figure 4: Large scale (1/3) drop tests.

- The basic fiber reinforced composite and basic mechanical characteristics have been determined. Required thickness, stacking sequences, stiffeners, joining, limits in geometry for manufacturing, have been studied and determined.
- A concept of optimal fabrication process, in view of automated large scale production, was studied and evaluated by construction of two large scale point absorbers (diameter 1,75 m).
- The basic mechanical characteristics have been controlled by fatigue tests, small scale and large scale drop tests (respectively Figure 3 and Figure 4), a fracture test and a FEM-analysis.

4. The overall design of platform and point absorber has been refined and examined:
   - The total system consisting of platform, point absorber system and power take-off system were considered with respect to the optimization of the annual energy capture. Platform geometry, dimensions, the number and size of the buoys and the arrangements of the buoys were analyzed.

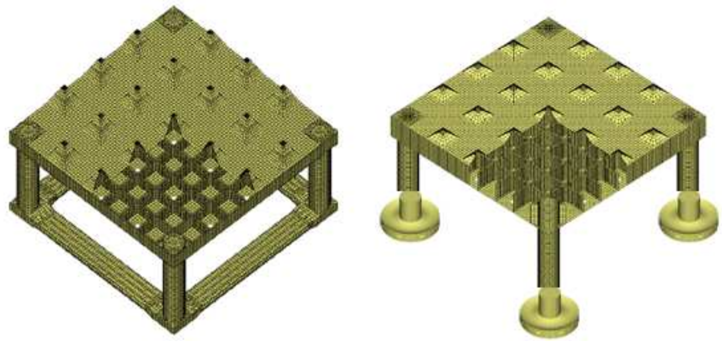

Figure 5: Two different hulls have been evaluated.

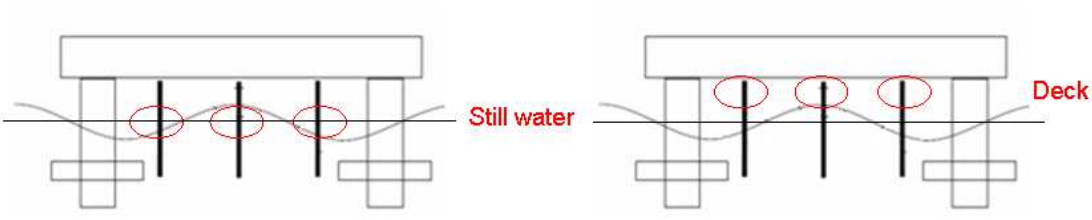

Figure 6: Two alternative locations of buoys in survival condition.

   - The optimal energy capture of point absorber buoys were determined based on sensitivity studies with respect to dimensions, mass and shape and operational sea states.
   - Hydrodynamic pressures due to bottom slamming were estimated experimentally and theoretically.
   - The structural design of the FO^3 consisting of a semisubmersible platform and point absorbing buoys was investigated with special consideration to survival in extreme environmental conditions. Two alternative main types of hulls were envisaged (Figure 5). The effect of the location of the point absorption buoys in survival conditions on the performance was studied (Figure 6).
   - The single buoy device (Figure 7) was studied based on a time-domain simulation model (Figure 8).

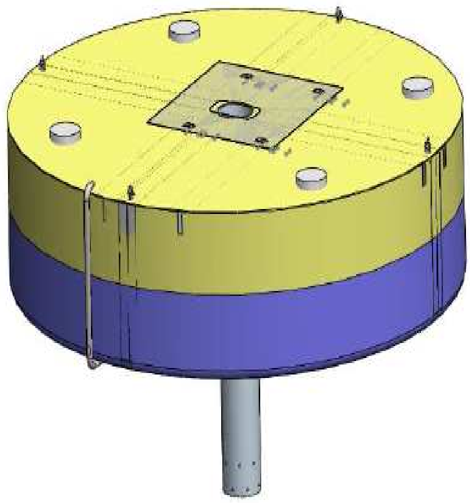

Figure 7: Sketch of the B1.

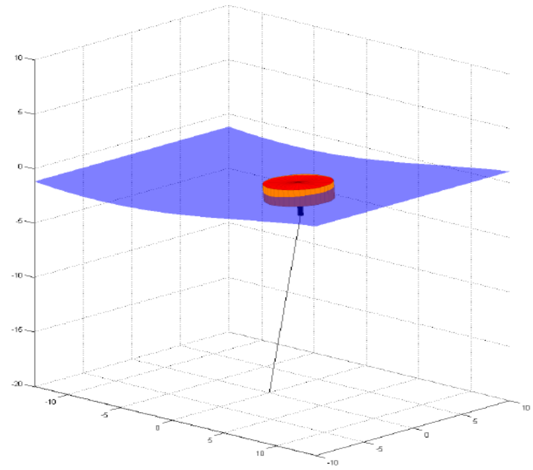

Figure 8: Time-domain simulation model of B1.

5. Layout of a farm of Wave Energy Converters.
   - The lay-out of a farm of FO^3 WECs has been determined with respect to an optimal balance between high energy capture, low wave loads on the structure and minimal use of surface.
   - A study of different mooring systems for a single FO^3 WEC and for multiple FO^3 WECs has been performed with the purpose of:
     - studying the effect of the mooring system on energy absorption (and to minimize this effect);
     - comparing mooring of individual platforms with systems where platforms share mooring.
   - The energy absorption in a farm as compared to individual WECs was studied.

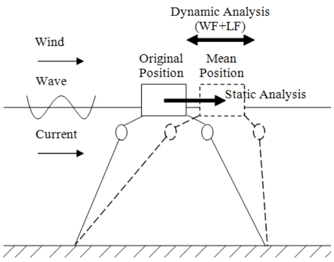

Figure 9: Outline of mooring system analysis.

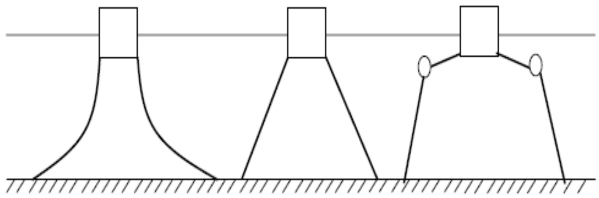

Figure 10: Different basic mooring configurations (from the left to the right: catenary, taut and taut mooring systems with buoys).

6. The power generation has been examined:
    - Different direct generation systems for a heaving buoy wave energy absorber have been developed and analyzed.
    - Three different collection systems for the platform and three different collection systems for the farm have been investigated. The influence of different parameters (voltage levels, transmission distance and number of installed buoys) on the base systems has been examined. For each case the energy production and cost of the collection and transmission system have been calculated using cost models of the components.
    - Different control strategies for optimized energy extraction were evaluated. A mathematical hydrodynamic model of the interaction between the energy extraction of one point absorber and the waves has been developed in order to evaluate the different control strategies.
    - Three aspects of grid interconnection have been studied: power smoothing, voltage regulation and low voltage ride through.

7. Several aspects of the revised concept (single buoy absorber) have been studied:
    - Before the engineering of the floater, different parameters were evaluated: back-up system in case of failure, easy maintenance, easy (dis)connecting from the mooring, reliability of equipment, low production cost, personal safety and low equipment weight.
    - Dry testing in test bench of the new power take off system in order to clarify: access and maintenance, to log energy output and energy losses and correct and modify software and mechanics.
    - A functional description of the software and a software code has been established for the revised concept. The software has been validated through several experiments.
    - The following models of the revised concept have been built.
        - First phase: the B33, in order to test the survivability and to verify the concept.
        - Second phase: the B22 which has been developed to full engineering standards and was installed at Risør (Figure 11).

- Finally: the B1, which is the revised prototype (Figure 12). The floater is built from a tank of 8 mm glass fiber reinforced epoxy. The diameter of the tank is 5.15 m, and the height is 1.45 m. Total volume of the tank is 30 m^3. Four bulkheads are integrated in the structure to carry the loads. Four ballast tanks are installed. At the end of the construction process the whole outer tank is filled with polyurethane foam and a lid is moulded on top. The total weight of the floater is approximately 6 tons. The installed capacity is 40 kW. During dry testing max produced power was 70 kW.

Figure 11: B22: Scale version of the revised concept.

Figure 12: B1: Prototype of the revised concept.

8. The financial viability was assessed:
   - Estimates were made for the costs of building a buoy-based wave farm and for the generated income that can be expected from a farm in operation.
   - A comparison between the platform based device and the individual absorber device shows that the revised design is more cost-competitive.
   - Figure 13 shows the learning curve for an increasing number of installed B1 buoys in function of the price per MW in k€. The installation cost is very site dependent and is not included.

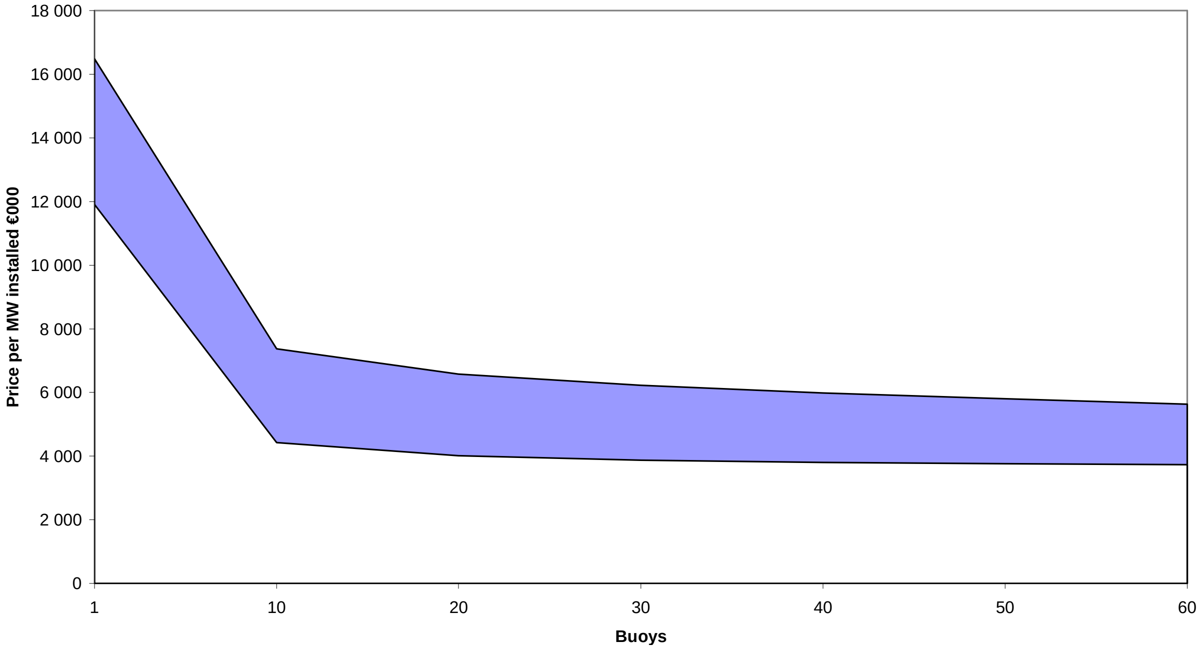

Figure 13: Learning curve for the B1 prototype.

Socio-economic relevance and policy implications:

The EU imports 53.8% of its primary energy (Eurostat, 2006) and this could rise to 66.6% in 2030 (DG TREN, 2008), which makes the EU dependent on imported energy and consequently economically vulnerable. Moreover, usage of traditional fossil fuel has been proven to cause global warming with likely climate change as a consequence in the long term.

Therefore, in 2008, the EC has set as a target to reduce greenhouse gas emissions by at least 20% (compared with the 1990 levels), to increase the share of renewable energy up to 20% and to improve energy efficiency by 20% by the year 2020. The oceans are an enormous, unexploited provider of renewable energy. A number of different technologies for wave energy conversion have been developed, but up to now a very limited number of them have resulted in first trials of commercial deployment beyond the prototype stage.

Scientific investigation into ocean renewable energy should therefore remain an important preoccupation of the European Community. The added value of a European approach versus only a national collaboration gives the opportunity to exchange experience and knowledge within a wide range of scientists with a different technical background from different European countries.

The collaboration between different partners is necessary to tackle future energy challenges which the EU has to deal with. The efforts which are put into research with respect to ocean energy are increasing year by year and worldwide signifying its growing importance. The possible future ability to use wave energy will result in a “greener” environment, less dependency on energy imports and will create directly and indirectly thousands of jobs.

The outcomes of this project have different socio-economic impacts:

- It is obvious that the knowledge gained within the SEEWEC project, if provided to the wider wave power industry, has the potential to accelerate the development of other similar devices being put into the sea.
- The gains are relevant within a wide range of the wave energy topic and do not only concentrate on one specific item but cover platform characteristics, buoy characteristics, power efficiency, determination for the most suitable location and farm lay-out.
- The results of these different items are also relevant for other renewable industries such as tidal energy and offshore wind energy (e.g. the model to determine the most suitable location for exploitation).

- At this moment (March 2009), the revised concept has led to a financially less risky and more viable wave energy converter which is easier to maintain, has a lower weight, can be moored directly to the seabed and has lower production costs. Therefore the revised concept has a greater possibility than the original concept to become commercially exploitable.
- Collaboration between industry, SME's, universities and research institutions has been engendered by the SEEWEC project in a positive and significant way.

Conclusions:

Various field, laboratory and numerical testing have been performed in order to optimize the original platform based FO^3 concept and in order to gain more info about the performance of the FO^3 in real sea conditions. Substantial knowledge has been gained on many fields: e.g. the mooring system for a single and multiple WECs, the design of the platform, investigation of the buoy characteristics. Both operational conditions in order to optimize the energy capture and extreme sea conditions to guarantee the survivability of the device have been studied. A lot of effort has also been put into the choice of the composite material of the eggs and manufacturing for large scale production in a cost effective way.

The research now leads us to believe that point absorbers in the shape of buoys will have qualities that are superior to purely platform-based absorbers. Also the financial risk of the evolved concept will be lower than that of the platform based device.

One of the main reasons for this is that the revised concept will allow for the avoidance of the considerable cost of building a platform, instead making it possible to opt for a lower-cost design with floating buoys moored directly to the seabed. It is expected that the revised concept will give significantly lower costs, while maintaining a similar level of effectiveness in power conversion.

The revised point absorber buoys are designed to be utilized either in conjunction with an FO^3 platform functioning as the hub of a buoy-farm, or in a pure buoy-based farm with one or more of the buoys taking the role of “mothership” for all or part of the wave farm. The PTO system is designed with capability to be used as part of a multiple PTO system onboard a platform and as a single system.

SEEWEC is a collaborative project with the objective to commercialize a new WEC. The objective was obtained through close operation between industry, SME’s, universities and research institutes. All partners hope that based on the SEEWEC results continued efforts will be done to further optimize wave energy conversion.

Acknowledgement:

As coordinator of SEEWEC, I would like to acknowledge all partners for their hard work and efforts to make SEEWEC a success.

We acknowledge the generous support of the EU Commission, which through contract SES6-CT2005-019969 gave life to the project.

I also cordially thank Mr. K. Diamantaras, Mrs A. Gigantino, Mr T. Langlois d'Estaintot who, on behalf of the commission, have followed us during the project lifetime with attention and comprehension.

Prof. Julien De Rouck

Keywords:

Wave Energy Converter (WEC), Wave Climate, Wave Farm, Power Generation Efficiency, Buoy design, Platform design, Material design, Large Scale Production, Mooring Design, FO^3.

UNIVERSITEIT GENT