23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

REDESIGN OF A WAVE ENERGY CONVERTER IN FERROCEMENT

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Abstract: *The case study for the redesign of a floating device able to produce electric energy from sea waves is presented. In particular, the steel hull of the ISWEC set up by the spin off "Wave for Energy" of the Politecnico di Torino has been converted in ferrocement without changing the total mass displacement and the position of the centre of gravity. Moreover, the essential ferrocement technology is illustrated, stressing the main differences with respect to the reinforced concrete. A reference guide useful for the early stage design scantling of small ferrocement crafts has been adopted for the specific case studied.*

Keywords: Wave Energy Converter, WEC, ISWEC, Ferrocement, Gyroscopic floating device.

1. Introduction

Over 70 % of the globe is covered by water containing a large amount of energy, which constitutes one of the largest unexploited source of renewable energy. Comparing the various technologies for the exploitation of this renewable energy, the capacity of devices for wave energy conversion is significantly greater than wind and solar farms. This stems from the fact that water is a high density source of energy, in fact, the potential energy of waves, in terms of energy transport, is about five times higher than the one generated by the wind and 10 ÷ 30 times higher than solar one. Over the years a wide range of Wave Energy Converters (WEC) has been developed, and more than one thousand of prototypes among Japan, North America and Europe (Clément et al., 2002) has been installed. As it is known, steel is the main ship construction material, which over the years has been improved in its mechanical characteristics. Such a material has no processing problems, but presents high costs of maintenance. In order to overcome the maintenance costs of WECs ferrocement can be used as hull construction material. In this paper, a case study regarding the redesign in ferrocement of the ISWEC, which is a WEC built by "Wave for Energy" a spin off Company of the Politecnico di Torino and installed offshore from Pantelleria, is presented.

2. Wave Energy Converters

The classification of WECs can be done according to both the distance from the shore of the installation location and its working principle. Considering the distance, they can be:

- *Onshore devices*: installed on the seabed in shallow waters, or integrated into breakwaters or cliffs.
- *Nearshore devices*: installed in moderate water depths (10 ÷ 25 m) a few hundred meters from the shore, can be either floating structures or rested on the seabed without mooring.
- *Offshore devices*: installed in deep water (> 40 m), are floating or submerged structures moored to the seabed. These are the devices exploiting the more powerful waves far from the shore.

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If the working principle is considered the WECs can collected as follows:

- *Attenuators*: use the oncoming waves energy to induce an oscillatory motion between two (or more) adjacent structural components. The energy can be captured by hydraulic motors or direct drive Power Take Off (PTO).
- *Point absorbers*: are floating structures that can absorb energy from all directions. They use buoyant forces to induce heaving motion of the top body with respect to the fixed base. The base can be moored to the seabed, or held in place by gravitational forces through a large foundation mass.
- *Oscillating wave surge converters*: energy is obtained from the wave motion and the movement of water inside the device by means an arm mounted on a pivot coupling that swings like a pendulum.
- *Oscillating water columns*: the wave generates a water column oscillating inside a closed vessel and compresses the contained air, which in turn moves a turbine connected to an electric generator.
- *Overtopping/terminator devices*: the device are floating or fixed to the shore. They have a reservoir which is filled by overtopping waves, so accumulating potential energy. Then the water is released back to the sea through a conventional low-head turbine coupled with an electric generator.
- *Submerged pressure differential devices*: attached to the seabed, have a top component, which rises and falls when waves move over it, so capturing energy from the hydrodynamic pressure changes.
- *Rotating mass devices*: electricity is produced by the rotation of an eccentric mass or a gyroscope connected to an electric generator inside a floating device oscillating with waves.

3. Inertial Sea Wave Energy Converter (ISWEC)

ISWEC (Bracco et al., 2011) is an *active* floating system where pitch motion produces electric energy by means of a gyroscope. The system is defined *active* because requires the presence of a rotating mechanical member powered by an electric motor. The energy produced by an ISWEC can be estimated equal to 250 MWh/year, with a saving of 68 t of CO_2 if the same energy had been produced by fossil fuels. Therefore, considering that the average consumption of a family is about 3000 kWh/year, a single device would be able to meet the energy needs of more than 50 families (Bracco et al., 2015). Currently, the hull of ISWEC system contains two 130 kW gyroscopic groups having a mass equal to 25 tons each. The steel hull has the following dimensions.

Tab. 1: Main dimension ISWEC

Main Dimension		
Length	15.33	m
Width	8.04	m
Depth	4.5	m
Draft	3.25	m
Displacement	313	t

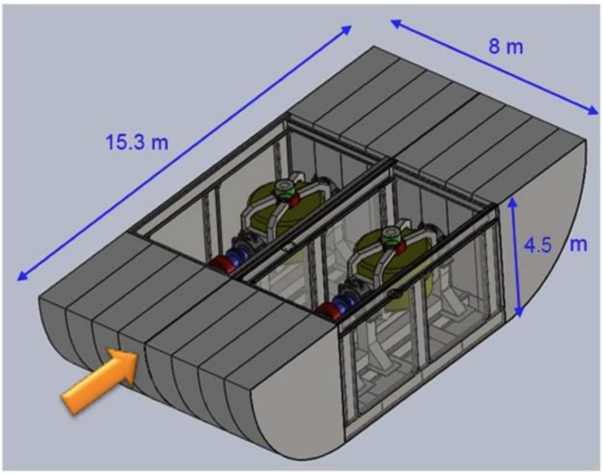

Fig. 1: ISWEC.

4. Ferrocement

Ferrocement is a composite material consisting of mortar reinforced by a number of steel wire meshes and bars. The mechanical properties of such a composite material are determined by the individual properties of matrix (mortar) and reinforcements (meshes and bars).

The mortar used for ferrocement is a mixture of cement, additives, aggregates and water. The cement must comply with either the ASTM C150-85a (Portland cement), the ASTM C 595-85 (blended hydraulic cement), or other equivalent Standards. Mineral additives, such as Pulverised Fly Ash (PFA), silica fume or blast furnace slag, may be used in order to improve workability and long-term mechanical properties

(Housing and Building Research Institute, 2015). If mineral additives are used, they must be in accordance with either ASTM C 618-85 or ASTM C 989-85a Standards. The aggregate used for ferrocement is sand, which must comply with the ASTM C33-86 Standard or equivalent. The maximum sand particle size depends on the constructional criteria, i.e., the size of the metal meshes and the distance between them. However, the most used sand size is the Sieve Number 16 (equivalent to 1.19 mm). The suggested mix proportion ranges of mortar for ferrocement are: sand-cement ratio by weight 1.4 ÷ 2.5 and water-cement ratio by weight 0.3 ÷ 0.5 (Balaguru et al., 1997). In most cases, the compression resistance evaluated by a cylindrical test after 28 days of curing, it was found to be not less than $35\ N/mm^2$.

The reinforcing mesh can be of different kinds, but the main required property is the flexibility. The meshes most commonly used are:

- *Hexagonal wire mesh*, is the most easy and cheap to be used, but is not efficient as much as meshes with square opening, because the wires cannot be oriented along the direction of tensions.
- *Square welded wire mesh*, is more rigid than the previous reinforcement and has got an increased resistance to cracking.
- *Square woven wire mesh*, is similar to the previous one, but is a bit more flexible and easy to work.
- *Expanded metal lath*, has the same strength of the welded mesh, but is stiffer, providing greater resistance to impact and a better control of cracking. It is difficult to be used in corners.
- *Bars*, may be used in combination with wire mesh, complying with ASTM A615-86, A616-86 or A617-84. Bars must be made of steel with minimum yield strength $410\ \mathrm{N/mm^2}$ and tensile strength $615\ \mathrm{N/mm^2}$.
- *Fibers*, added to the mortar mix, are short steel wires or other fibrous materials used to control cracking and to increase impact resistance.

The substantial difference between reinforced concrete and ferrocement is the presence in the latter of steel wire meshes. As findings of experiments (Alwash, 1982) comes out that both crack spacing and width decrease with a greater number of wire meshes layer, Fig. 2. Moreover, by ferrocement it is possible to reduce the thickness of plates with respect to reinforced concrete.

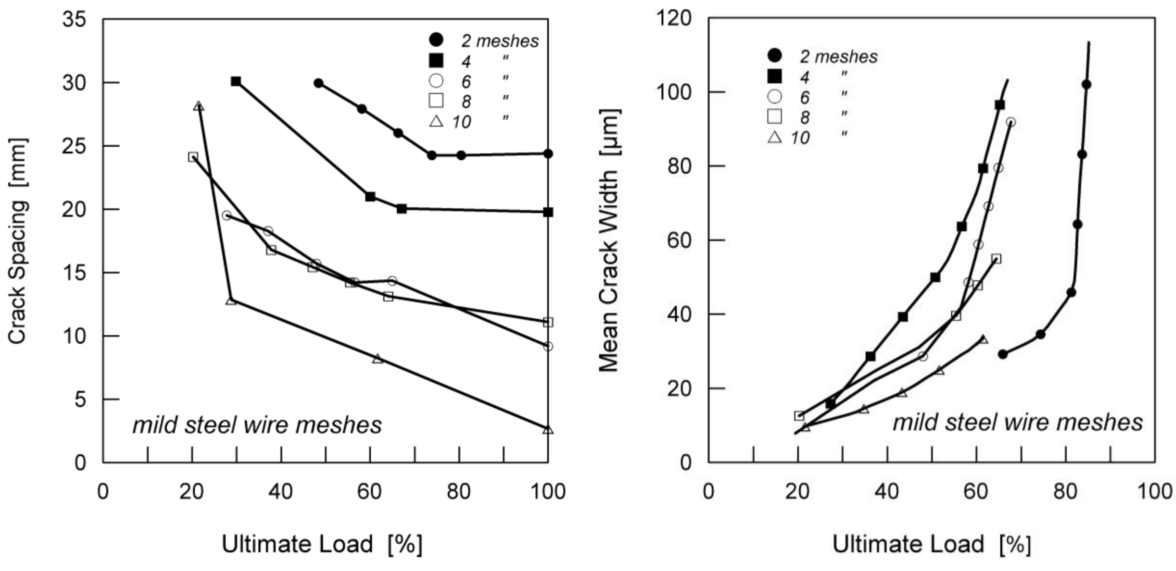

Fig. 2: Spacing and width of cracks vs percentage of the ultimate load.

5. Case study

The main advantages in using ferrocement in shipbuilding are the low costs of raw materials, the low level of skills required for manufacturing and the reduced maintenance due to the good resistance to rot and corrosion. Despite these advantages, currently ferrocement has found few applications in shipbuilding (mainly fishing vessels and pleasure crafts), consequently also the building regulations are few and quite dated (ABS, 1969). However, there is an evidence of their application in 1995 in relation to a FAO project for the construction of small fishing boats in India (Riley, 1995). In the early stage of the redesign of ISWEC in ferrocement has been used the guide for scantling of fishing boat reported in the above-mentioned FAO Technical Paper. Such a guide is valid for crafts having frame spacing in the range 600÷700 mm and mesh size between 18÷22 gauge. In particular, for a craft about 15 m long comes out a minimum thickness for hull and deck equal to 30 mm, 6 layers of square welded wire mesh (size 13 × 13 mm and wire gauge 19), longitudinal and transversal reinforcing rods with diameter 6 mm and spacing 50 mm. Fig. 3 shows the scantling plans of the ISWEC.

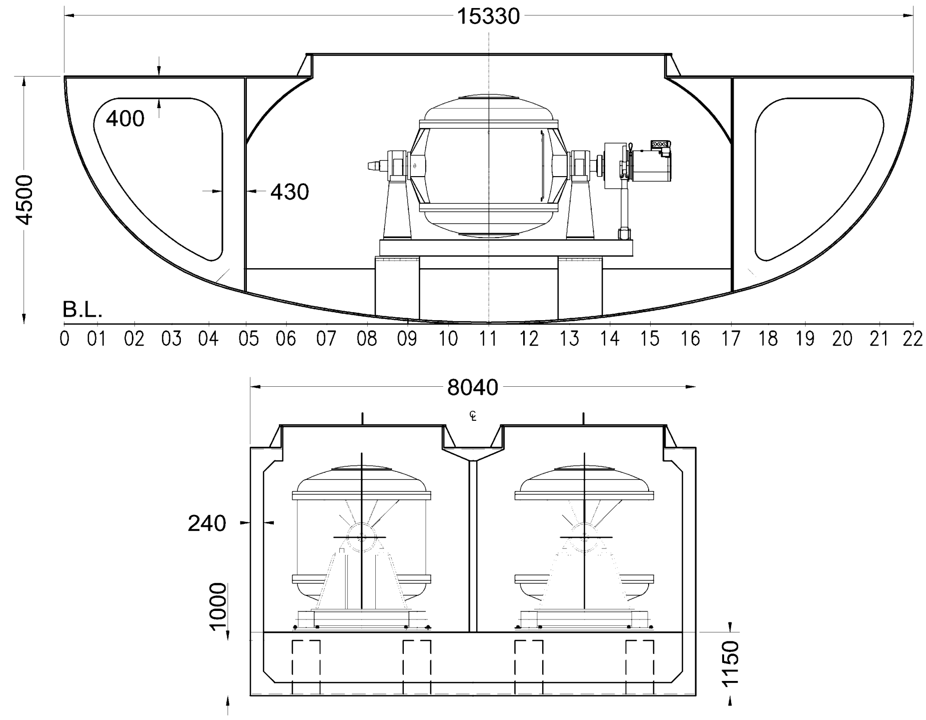

Fig. 3: Longitudinal and transversal sections of ISWEC in ferrocement.

6. Conclusions

Renewable energy from the sea represents a promising technological trajectory of European Development Strategy until 2030, aimed at reducing the greenhouse gas emissions by the use of conversion devices like the WECs. Great attention must be paid on the WECs construction, taking into account that they are constantly exposed to harsh marine environment and that it is to minimize the maintenance costs. Ferrocement, as hull construction material, would seem able to meet such requirements as well as low first costs and low skill capacity. In the case study presented the hull weight turns to be greater (196 t) than the steel solution (63 t), but this is not a problem because the ballast can be reduced without compromising the performance of the device in terms of centre of gravity and total mass displacement.

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