

Infrastructure Access Report

Infrastructure: Wave-Current flume of the University of Florence
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User-Project: WAECO

OPTIMIZATION OF WAVE OVERTOPPING IN NEARSHORE WAVE ENERGY CONVERTER SYSTEMS WAECO (WAVE ENERGY CONVERTER)



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ABOUT MARINET

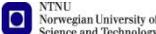
MARINET (Marine Renewable Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The aim of the initiative is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See www.fp7-marinet.eu for more details.

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	<p>Belgium 1-Tech (1_TECH)</p>		

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ABOUT THIS REPORT

One of the requirements of the EC in enabling a user group to benefit from free-of-charge access to an infrastructure is that the user group must be entitled to disseminate the foreground (information and results) that they have generated under the project in order to progress the state-of-the-art of the sector. Notwithstanding this, the EC also state that dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground.

The aim of this report is therefore to meet the first requirement of publicly disseminating the knowledge generated through this MARINET infrastructure access project in an accessible format in order to:

- progress the state-of-the-art
- publicise resulting progress made for the technology/industry
- provide evidence of progress made along the Structured Development Plan
- provide due diligence material for potential future investment and financing
- share lessons learned
- avoid potential future replication by others
- provide opportunities for future collaboration
- etc.

In some cases, the user group may wish to protect some of this information which they deem commercially sensitive, and so may choose to present results in a normalised (non-dimensional) format or withhold certain design data – this is acceptable and allowed for in the second requirement outlined above.

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EXECUTIVE SUMMARY

In recent years, there is an increasing interest amongst researchers about novel hybrid concepts of wave energy converters incorporated into coastal structures, such as breakwaters and seawalls. The concept of wave energy conversion by wave overtopping into a reservoir, thereby effectively creating very low-head hydropower, is a promising option towards this purpose. The WAECO Project's main objective has been the construction of an overtopping structure, and the testing of the overtopping water volume into a basin, with respect to its performance characteristics. Special consideration was given on the determination of the geometrical characteristics leading to the optimum performance of the structure, the minimization of the wave-induced loads, ensuring at the same time the maximization of the converter's hydraulic response (wave power capturing capacity). All tests conducted included wave conditions representative of the Mediterranean area. The test results will be used for the design optimization of an overtopping ramp that will be used as part of a coastal structure that will be able to effectively collect seawater and convert wave energy into electricity.



CONTENTS

1	INTRODUCTION & BACKGROUND	7
1.1	INTRODUCTION	7
1.2	DEVELOPMENT SO FAR	7
1.2.1	<i>Stage Gate Progress</i>	8
1.2.2	<i>Plan For This Access</i>	9
2	OUTLINE OF WORK CARRIED OUT	10
2.1	MODEL	10
2.2	TESTS	13
2.2.1	<i>Physical tests on the flume</i>	13
2.3	ANALYSIS & CONCLUSIONS	16
3	MAIN LEARNING OUTCOMES	16
3.1	PROGRESS MADE	16
3.1.1	<i>Progress Made: For This User-Group or Technology</i>	16
3.1.2	<i>Progress Made: For Marine Renewable Energy Industry</i>	16
3.2	KEY LESSONS LEARNED	17
4	FURTHER INFORMATION	17
4.1	WEBSITE & SOCIAL MEDIA	17

1 INTRODUCTION & BACKGROUND

1.1 INTRODUCTION

In recent years, along with the development of wave power applications, there is an increasing interest amongst researchers about novel hybrid concepts of wave energy converters incorporated into coastal structures, such as breakwaters and seawalls. The concept of wave energy conversion by wave overtopping into a tank, thereby effectively creating very low head hydropower, is a promising option towards this purpose.

Although several investigations on the optimization of overtopping type energy converters exist, they either mainly referred to floating energy converters or they were focused on optimizing the angle of the overtopping ramp. As such, the research aims of the proposed project focus on:

1. evaluation of the overtopping characteristics;
2. optimization of the ramp shape;
3. survivability of the device;

For this, two different model ramps were tested under a variety of representative wave conditions. The use of the specific infrastructure led to the evaluation of the overtopping characteristics of a medium/small-scaled prototype front reservoir model that can be incorporated into a breakwater structure.

The main objectives are the performance and survivability analysis and optimization of retrofitting near-shore wave converter systems (composite seawall). Special consideration was given on the determination of the geometrical characteristics leading to optimum seawall performance, minimization of wave induced loads and in the same time maximization of the converter's hydraulic response (wave power capturing capacity). All these, for wave conditions representative of the Mediterranean area. The high quality data collected are used for the calibration, validation and extension of two CFD and Boussinesq type numerical codes, aiming on the development of a design tool appropriate for such applications. In addition, a number of tests will refer to extreme wave conditions and variable water depths. Those tests are expected to significantly contribute on the preliminary evaluation of the anticipated global warming effects and specifically on the implications of high waves, the rising sea water level and the increased storminess. Nevertheless, the primary function of the device will remain the harbor/coastal protection, but with the principal aim of costs reduction. The new design should be capable of adding a revenue generation function to a breakwater while adding cost sharing benefits due to integration of a wave energy conversion utility.

1.2 DEVELOPMENT SO FAR

Our previous work was been focused mainly into a number of numerical modelling tasks which were related to the wave propagation and modelling in overtopping structures. Work has also been carried out with the analysis of Boussinesq formulas, including a set of parameters that are representative of the Mediterranean Sea wave conditions. The outcomes of the numerical analysis helped us to proceed with the determination of a number of key parameters, such as the crest freeboard and the wave period, which were used for the purposes of our laboratory tests.

The exact values of incident wave heights and periods that will be used for each test, and also the value of the freeboard, were determined after the runs of Computational Fluid Dynamics (CFD) codes. CFD codes runs also helped us to obtain numerically the two optimum slopes and the curve shape of the overtopping ramp. Numerical modeling and calibration using CFM codes and an existing Boussinesq model for wave overtopping were also used as preliminary work prior to the facility tests that took place at DICEA.

1.2.1 Stage Gate Progress

Previously completed: ✓

Planned for this project: ➡

	Status
Stage 1 – Concept Validation	
• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)	✓
• Finite monochromatic waves to include higher order effects (25 –100 waves)	✓
• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)	
• Restricted degrees of freedom (Doff) if required by the early mathematical models	
• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)	✓
• Investigate physical process governing device response. May not be well defined theoretically or numerically solvable	➡
• Real seaway productivity (scaled duration at 20-30 minutes)	
• Initially 2-D (flume) test programme	➡
• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them	
• Evidence of the device seaworthiness	
• Initial indication of the full system load regimes	
Stage 2 – Design Validation	
• Accurately simulated PTO characteristics	
• Performance in real seaways (long and short crested)	➡
• Survival loading and extreme motion behaviour.	
• Active damping control (may be deferred to Stage 3)	
• Device design changes and modifications	
• Mooring arrangements and effects on motion	
• Data for proposed PTO design and bench testing (Stage 3)	
• Engineering Design (Prototype), feasibility and costing	
• Site Review for Stage 3 and Stage 4 deployments	
• Over topping rates	
Stage 3 – Sub-Systems Validation	
• To investigate physical properties not well scaled & validate performance figures	
• To employ a realistic/actual PTO and generating system & develop control strategies	
• To qualify environmental factors (i.e. the device on the environment and vice versa) e.g. marine growth, corrosion, windage and current drag	
• To validate electrical supply quality and power electronic requirements.	
• To quantify survival conditions, mooring behaviour and hull seaworthiness	
• Manufacturing, deployment, recovery and O&M (component reliability)	
• Project planning and management, including licensing, certification, insurance etc.	
Stage 4 – Solo Device Validation	
• Hull seaworthiness and survival strategies	
• Mooring and cable connection issues, including failure modes	
• PTO performance and reliability	
• Component and assembly longevity	

	Status
• Electricity supply quality (absorbed/pneumatic power-converted/electrical power)	
• Application in local wave climate conditions	
• Project management, manufacturing, deployment, recovery, etc	
• Service, maintenance and operational experience [O&M]	
• Accepted EIA	
Stage 5 – Multi-Device Demonstration	
• Economic Feasibility/Profitability	
• Multiple units performance	
• Device array interactions	
• Power supply interaction & quality	
• Environmental impact issues	
• Full technical and economic due diligence	
• Compliance of all operations with existing legal requirements	

1.2.2 Plan For This Access

The tests include a number of sets of waves attacks, generated at the DICEA laboratory facilities. For each test, a regular wave train was generated, and the overtopped volume of water collected in the reservoir was measured. The water collected, after the measurements, returned into the flume through the existing recirculation system.

The wave motions were measured by seven ultrasonic type wave gauges which were installed in a distance each along the wave flume. For the purposes of our experiments, a set of four load cells were installed below the water reservoir to measure the weigh of the overtopped water volumes, and three pressure transducers were installed at the overtopping ramp for the determination of its survivability in wave load conditions.

The duration of the tests was two weeks:

Day 1-3: Preparation of test 1 (setup, calibration)

Day 4-8: Test S1 (ramp slope 1/3,)

Day 9: Preparation of test 2

Day 10-14: Test S2 (ramp slope 1/2,)

2 OUTLINE OF WORK CARRIED OUT

2.1 MODEL

The tests were performed in the wave-current flume at the the Laboratory of Maritime Engineering of the Civil and Environmental Department (DICEA) of Florence University (www.labima.unifi.it). The flume s is 37.0m long, 0.80m wide, and it can accommodate a water depth of up to 0.60m. The model tested in the UNIFI wave-current flume is the Overtopping Device reported in Figure 2.1.



Figure 2.1. Picture of the model.

The model of the Overtopping device was located about 30m far from the wave maker (the 26th sector of the wave-current flume). Two ramps with different slopes were tested, respectively S1 (1:3) and S2 (1:2). The toe of the ramp named S1 was located at a distance of 31.5m from the wave maker, instead the toe of the ramp S2 was placed at a distance of 32.2m far. Moreover three different freeboards (the vertical distance from the still water level to the upper part of the ramp) equal to 0.16m, 0.14m and 0.12m were tested. They are respectively named F160 (water depth 0.50m), F140 (water depth 0.52m) and F120 (water depth 0.54m).

The ramp model was equipped with differential pressure sensors in order to measure the wave-induced pressure on the ramp. The pressure sensors used are submersible capacitive transmitters (Series 46X, by KELLER) with a full scale (FS) of 100mbar and an accuracy of $\pm 0.1\%$ FS (see Figure 2.2).

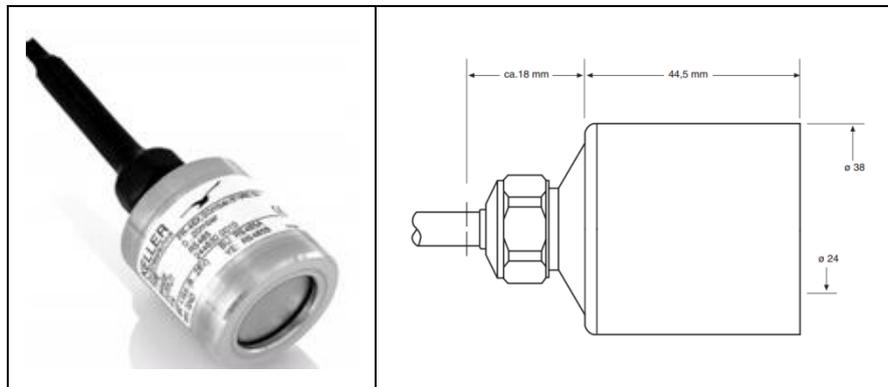


Figure 2.2. Pressure transducer- KELLER Series 46X. Picture and technical drawing.

In particular, for each ramp tested, three pressure transducers were arranged at distance of about 0.20m from the toe of the ramp (PT1), in the middle of the central axis of the ramp (PT2) and close to the free surface (PT3) (see Figure 2.3).

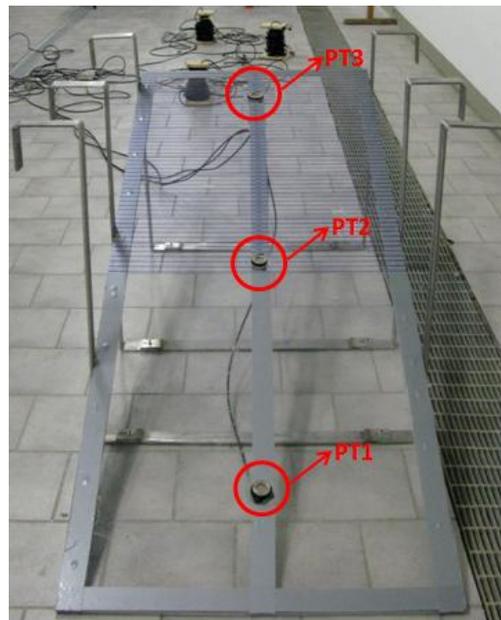


Figure 2.3. Location of the Pressure transducers on the ramp S1.

To measure the incident, reflected and transmitted waves, ultrasonic distance sensors (Series 943-M18 F4V-2D-1C0-330E by HONEYWELL) were used (see Figure 2.4). The ultrasonic sensors measure the free surface displacements with an accuracy of 1mm at a distance from the sensor within the range of 60mm and 500mm.

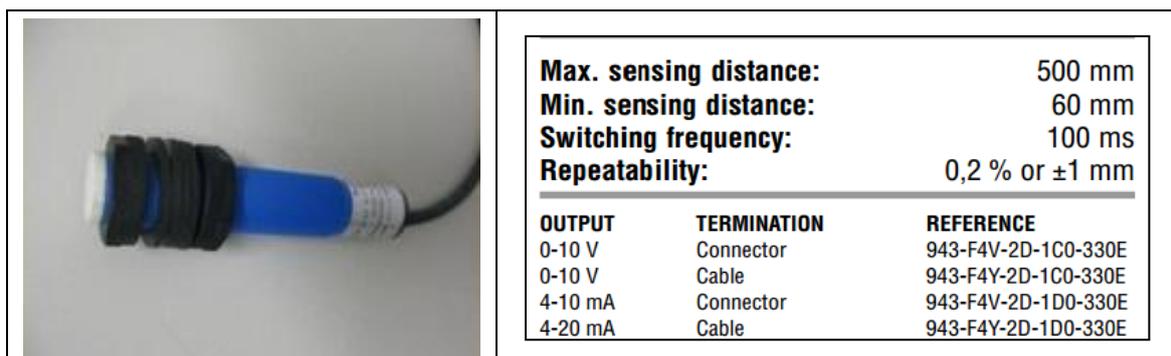


Figure 2.4. Ultrasonic wave probe HONEYWELL Series 943-M18 F4V-2D-1C0-330E. Picture and technical data sheet.

Seven ultrasonic wave probes were deployed in two arrays along the wave-current flume as reported in Figure 2.5.

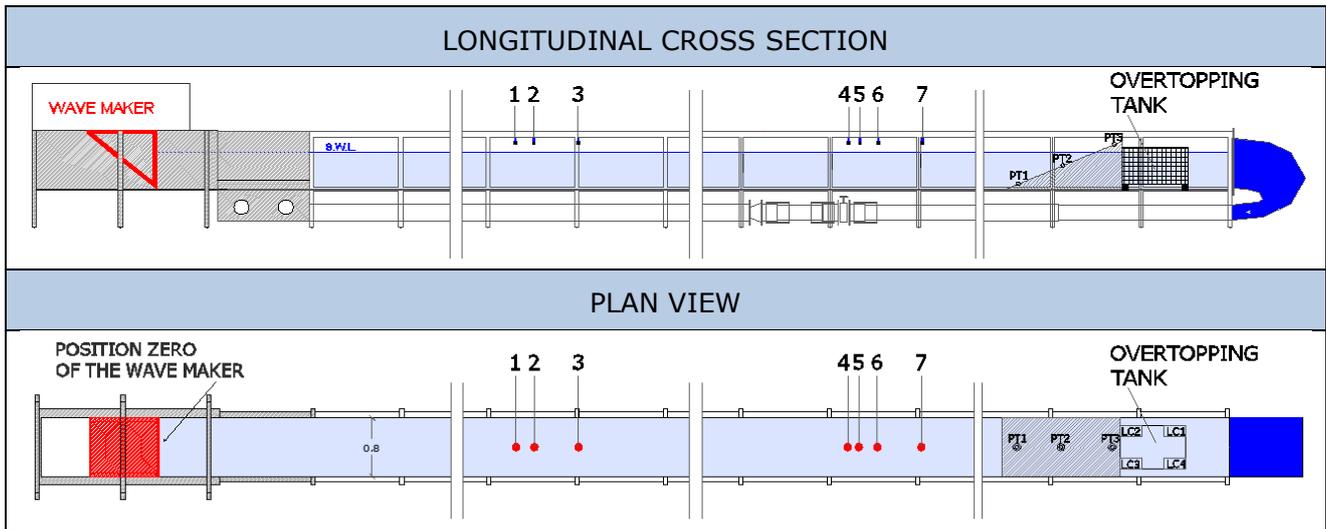


Figure 2.5. Location of the ultrasonic sensors along the UNIFI wave-current flume.

The distance of each probe from wave generator is reported in Table 1. The minimum distance between the ramp and the last wave gauge (WG7) was kept equal to 4.10m for the ramp S1 and 4.80m for the ramp S2.

Table 1: Distances of the ultrasonic probes along the UNIFI wave-current flume.

ARRAY	ULTRASONIC PROBE	Distance from the wavemaker [m]	Relative Distances [m]
Array 1	WG1	18.10	18.10
	WG2	18.35	0.25
	WG3	18.95	0.60
Array 2	WG4	26.40	7.45
	WG5	26.55	0.15
	WG6	26.80	0.25
	WG7	27.40	0.60

In order to collect the overtopping discharges, a tank 0.50m height, 0.60m wide and 0.90m long was placed behind the device (see Fig 2.6).

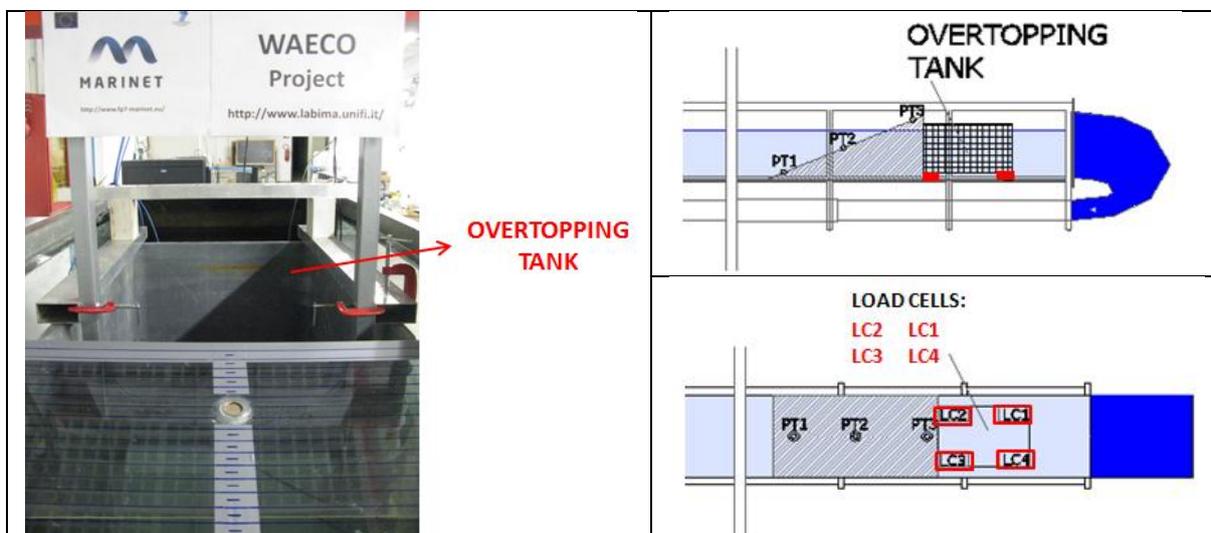


Figure 2.6. Location of the tank behind the Overtopping device and schematization of the load cells placements.

The tank was posed on four bending load cells (TYPE 54-100-C3 by CELMI s.r.l.), which measure loading capacity with a full scale (FS) of 100Kg and an accuracy of $\pm 0.01\%$ FS (see Figure 2.7).

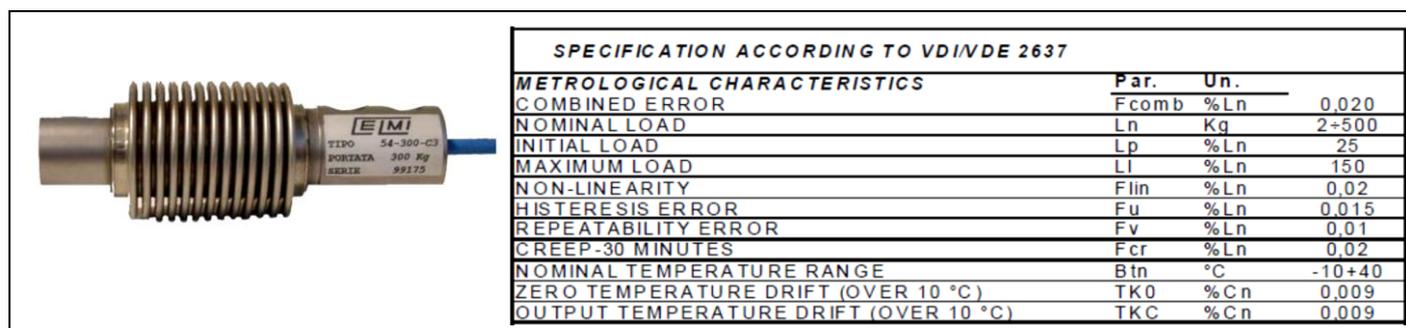


Figure 2.7. Bending Load Cells TYPE 54-100-C3 by CELMI s.r.l. Picture and technical data sheet.

The four bending load cells were located under the tank (see Figure 2.6), providing the trend of the overtopping volumes during the wave attacks. Moreover, the number of overtopping volumes was acquired by video records.

2.2 TESTS

2.2.1 Physical tests on the flume

The experimental tests were performed simulating 3 regular waves for each freeboard. The tested wave conditions were characterized by the wave parameters reported in **Errore. L'origine riferimento non è stata trovata.** for the slope ramp S1 and in Table 3 for the slope ramp S2. Moreover were tested 8 random waves for each freeboard, characterizing by the wave parameters reported in Table 4 for the slope ramp S1 and in Table 5 for the slope ramp S2.

Table 2: Wave Parameters of the tested wave condition for the slope ramp S1.

REGULAR WAVE				
Test code	Freeboard [cm]	Slope	H [cm]	T [s]
H01S1F160	16	1/3	4.7	0.9
H02S1F160	16	1/3	9.6	0.9
H03S1F160	16	1/3	15.2	0.9
H01S1F140	14	1/3	4.5	0.9
H02S1F140	14	1/3	9.6	0.9
H03S1F140	14	1/3	14.1	0.9
H01S1F120	12	1/3	4.6	0.9
H02S1F120	12	1/3	9.5	0.9
H03S1F120	12	1/3	13.8	0.9

Table 3: Wave Parameters of the tested wave condition for the slope ramp S2.

REGULAR WAVE				
Test code	Freeboard [cm]	Slope	H [cm]	T [s]
H01S2F160	16	1/2	4.8	0.9
H02S2F160	16	1/2	9.6	0.9
H03S2F160	16	1/2	13.3	0.9
H01S2F140	14	1/2	4.6	0.9
H02S2F140	14	1/2	9.4	0.9
H03S2F140	14	1/2	14.4	0.9
H01S2F120	12	1/2	4.6	0.9
H02S2F120	12	1/2	9.4	0.9
H03S2F120	12	1/2	13.2	0.9

Table 4: Random Wave Parameters of the tested wave condition for the slope ramp S1.

IRREGULAR WAVE				
Test code	Freeboard [cm]	Slope	Hm0,i [cm]	Tp [s]
H1S1F160	16	1/3	8.0	1.2
H2S1F160	16	1/3	9.3	1.2
H3S1F160	16	1/3	10.5	1.2
H4S1F160	16	1/3	12.4	1.2
H5S1F160	16	1/3	6.6	1.4
H6S1F160	16	1/3	8.1	1.4
H7S1F160	16	1/3	10.3	1.4
H8S1F160	16	1/3	12.1	1.4
H1S1F140	14	1/3	7.7	1.2
H2S1F140	14	1/3	9.1	1.2
H3S1F140	14	1/3	10.3	1.2
H4S1F140	14	1/3	11.9	1.2
H5S1F140	14	1/3	6.9	1.4
H6S1F140	14	1/3	8.4	1.4
H7S1F140	14	1/3	10.1	1.4
H8S1F140	14	1/3	12.4	1.4
H1S1F120	12	1/3	7.8	1.2
H2S1F120	12	1/3	9.1	1.2
H3S1F120	12	1/3	10.3	1.2
H4S1F120	12	1/3	11.8	1.2
H5S1F120	12	1/3	7.1	1.4
H6S1F120	12	1/3	8.6	1.4
H7S1F120	12	1/3	10.1	1.4
H8S1F120	12	1/3	12.5	1.4

Table 5: Random Wave Parameters of the tested wave condition for the slope ramp S2.

IRREGULAR WAVE				
Test code	Freeboard [cm]	Slope	Hm0,i [cm]	Tp [s]
H1S2F160	16	1/2	7.9	1.2
H2S2F160	16	1/2	9.0	1.2
H3S2F160	16	1/2	10.2	1.2
H4S2F160	16	1/2	11.8	1.2
H5S2F160	16	1/2	8.4	1.4
H6S2F160	16	1/2	10.2	1.4
H7S2F160	16	1/2	12.2	1.4
H8S2F160	16	1/2	13.5	1.4
H1S2F140	14	1/2	7.9	1.2
H2S2F140	14	1/2	9.0	1.2
H3S2F140	14	1/2	10.3	1.2
H4S2F140	14	1/2	12.2	1.2
H5S2F140	14	1/2	7.8	1.4
H6S2F140	14	1/2	9.7	1.4
H7S2F140	14	1/2	11.4	1.4
H8S2F140	14	1/2	13.6	1.4
H1S2F120	12	1/2	8.7	1.2
H2S2F120	12	1/2	9.4	1.2
H3S2F120	12	1/2	11.4	1.2
H4S2F120	12	1/2	13.5	1.2
H5S2F120	12	1/2	7.3	1.4
H6S2F120	12	1/2	9.1	1.4
H7S2F120	12	1/2	10.6	1.4
H8S2F120	12	1/2	12.0	1.4

2.3 ANALYSIS & CONCLUSIONS

The collected data base is going to be used as the basis for the calibration and verification of a numerical simulation code. The measured wave overtopping volume in the water reservoir will be compared to the calculated (from the scientific literature) wave overtopping discharge. The energy collected will be determined as a function of the ramp height and the overtopping efficiencies from the model test which will be given as a function of normalized freeboard. Evaluation of the different steepness and the H/Rc ratio impacts of each into overtopping rates, and comparison to previous studies. The tests results will be compared to other previous measurements reported on wave overtopping in composite seawalls for energy production. Contribution to optimum structural design will be provided.

3 MAIN LEARNING OUTCOMES

3.1 PROGRESS MADE

3.1.1 Progress Made: For This User-Group or Technology

The data generated from the laboratory tests conducted at DICEA in Florence will significantly contribute to better evaluate the effects of different model parameters in the field of wave overtopping. Progress made in the field of wave overtopping includes the determination of the optimum combination of sea state parameters (wave period, wave height, crest freeboard, etc) and structure geometry of the overtopping ramp, with respect to the characteristics of the Mediterranean Sea. These outcomes will enrich the existing knowledge from previous similar work, and will provide a database for use in next experimental facilities about studying of the optimization of the parameters that affect the overtopping efficiency in similar structural concepts.

3.1.1.1 Next Steps for Research or Staged Development Plan – Exit/Change & Retest/Proceed?

In general, the WAECO project's results according to our pre-test hypotheses were encouraging. Therefore, our next steps for research include the proceeding of our group's work with the use of the data collected for the calibration, validation and extension of two CFD and Boussinesq type numerical codes, which will be used for the development of a design tool, which in turn will be used later for the construction of a small-scaled prototype front reservoir model that can be incorporated into a breakwater structure, including an overtopping ramp with a front reservoir for and a seawall for water collection. The small-scaled model will then be subjected to a number of 2-D tests under different sets of wave conditions parameters, in order to optimize its structural design.

3.1.2 Progress Made: For Marine Renewable Energy Industry

In the field of wave energy development, the progress made includes the generation of new data about different overtopping ramp slopes under a variety of representative wave conditions. These data will contribute to new knowledge creation about the best structural concepts that can be used for the near-shore wave energy utilization in the coasts, with a dual function of will energy conversion and harbor/coastal protection of the Mediterranean Sea in future wave energy projects from the Marine Renewable Energy Industry.

3.2 KEY LESSONS LEARNED

The wave overtopping data measured by means of the laboratory tests conducted at DICEA in Florence have been compared to the values that can be predicted by classical empirical formulations. The predicted values are quite far from the measured values thus that the use of empirical formulation leads to considerable errors in the estimation of the efficiency of a overtopping wave energy converters. On the other hand the use of laboratory experiments is quite expensive and the conduction of a parametric study by using such methodology could be not affordable. The innovative Boussinesq type numerical code that has been developed by the user group leader, is going to be validated by using the data collected to asses its accuracy and thus to use it as working tool for studies related to the overtopping wave energy converters. The key lesson learned is the need of the use of a hybrid approach based on laboratory and numerical tool in order to optimize the design characteristics of a overtopping ramp for a wave energy overtopping device.

4 FURTHER INFORMATION

4.1 WEBSITE & SOCIAL MEDIA

Website:

<http://www.labima.unifi.it/CMpro-v-p-18.html>

http://www.fp7-marinet.eu/access_user-projects.html

YouTube Link(s):

<https://www.youtube.com/user/coastlab>

<https://www.youtube.com/channel/UCtQxAiX3XOljRzbJ9v7kgpw>