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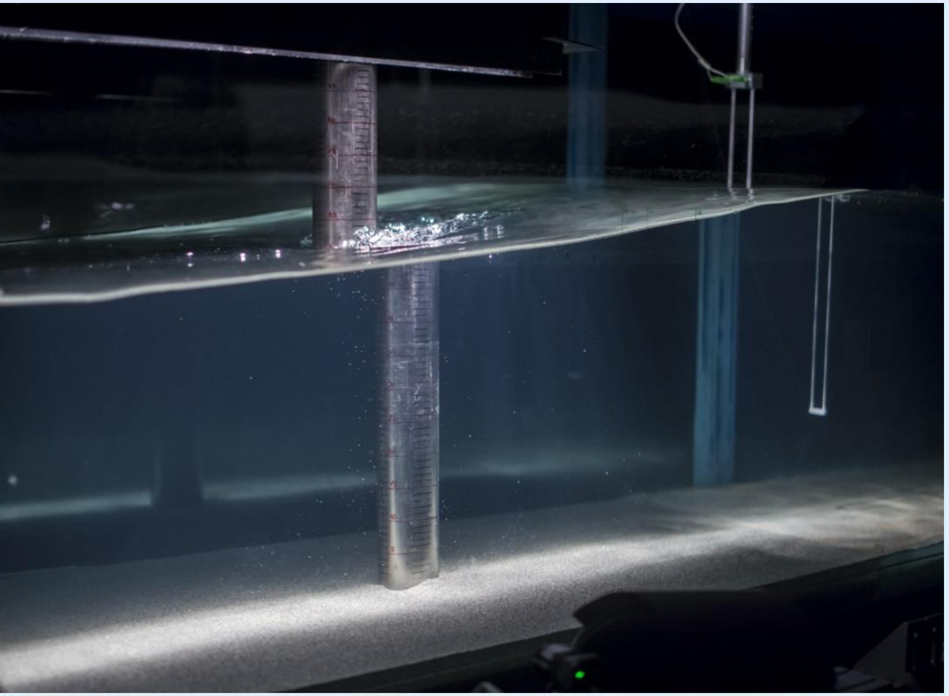
The State of the Art and Science of Coastal Engineering



Scour Protection around a single slender pile exposed to waves

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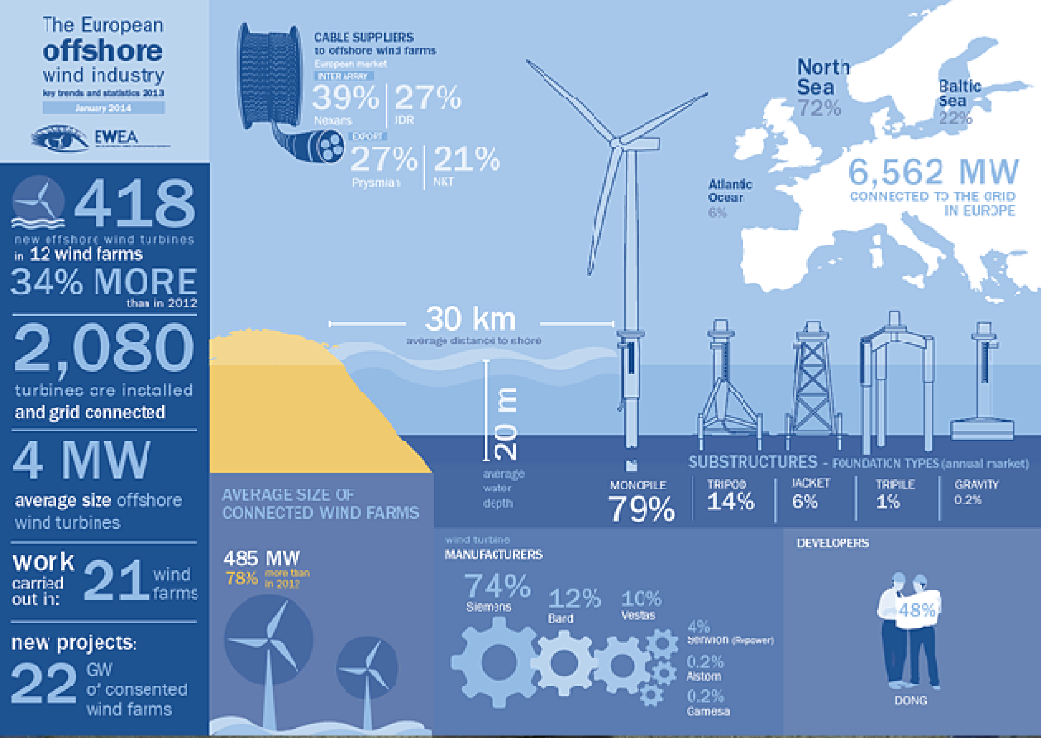


Aims & Motivations

A monopile is the most common foundation type used for wind turbine systems. In the marine environment the interaction between flows, structures and sediments leads to erosion at the base of the structures.

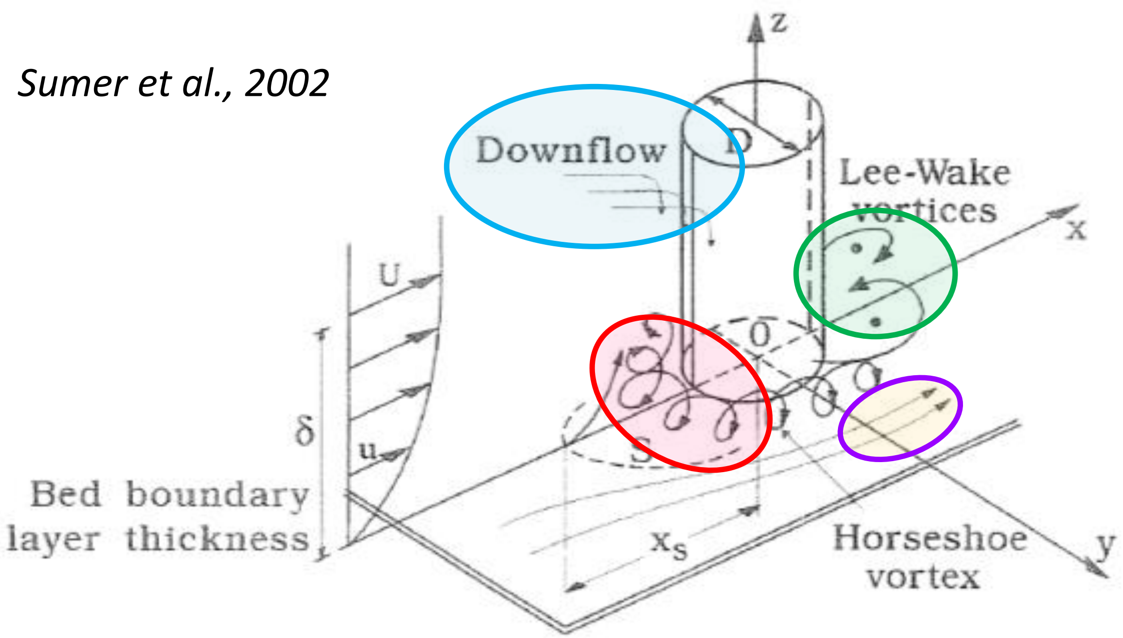
The aim of the research is on an experimental analysis on the hydro- and morpho-dynamics induced by a vertical slender pile exposed to waves. Here the focus is:

- on the analysis of the scour around a monopile foundation;
- on the evaluation of the performance of alternative scour protection systems made of geotextile sand containers (GSCs).

Provide useful information for the design of the scour protections made of GSCs

Introduction

Sumer et al., 2002



- Downflow
- Horseshoe vortex
- Lee-wake vortex flow
- Contraction of streamlines

There is substantial risk for the stability of the structure and solutions must be found to minimize the effects of seabed scouring at foundation.

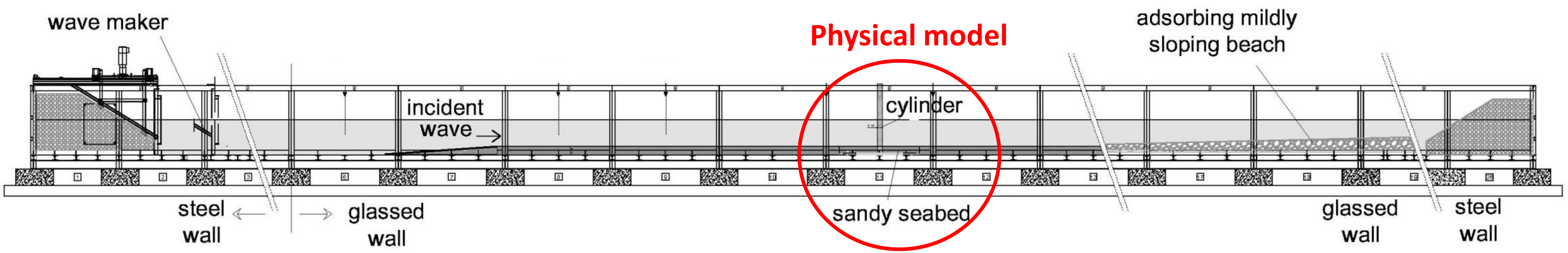
SCOUR PROTECTION
A typical protection system is made with **armour rocks.**
MAIN PROBLEMS:
- rock availability;
- seabed material suction;
- sinking of the scour protection.

The development of permeable and resistant materials as geotextile increases its diffusion in different fields such as the maritime environment.

Geotextile Sand Containers (GSCs)

- *flexible*
- *permeable*
- *high resistance*
- *low transport cost*
- *filled with in situ material*

Laboratory: the wave flume



The wave flume of the **Università Politecnica delle Marche** (AN, Italy) is **50m long, 1.3m height and 1.0m width.** A piston-type wavemaker operates up to a maximum run of 0.5m (semi-stroke). Max velocity 0.8 m/s. T he sidewalls are glassed for the central 36m. A permeble seabed, made of small stones (D_{50}=4 cm), with slope 1:20 was used to reduce wave reflection at the end of the flume.

The physical models

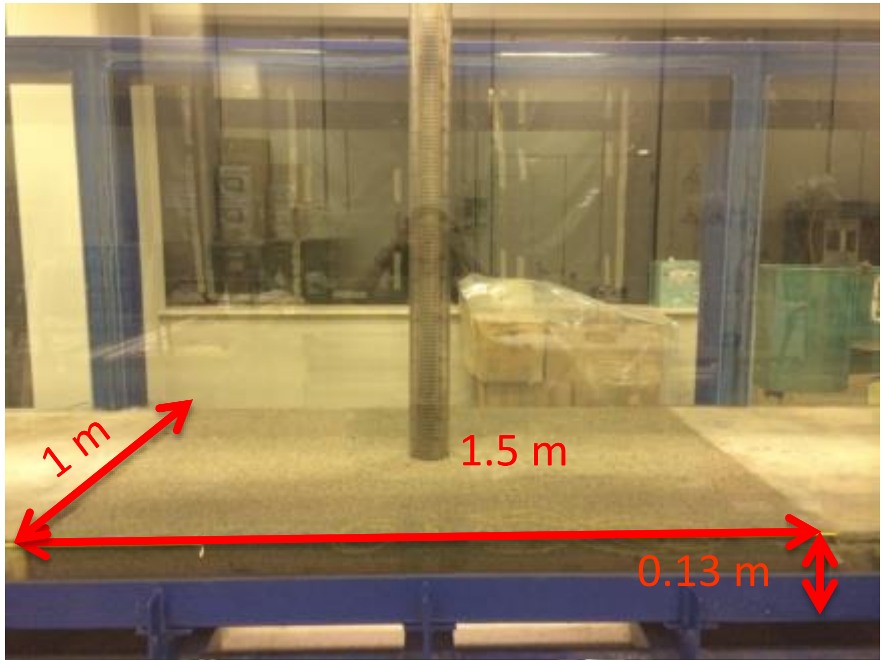
Two different experimental campaigns have been carried out:

1. **Mobile seabed**
2. **Rigid seabed**

1) MOBILE SEABED

The mobile seabed made of sand d_{50}=0.6 mm; ρ_s=2.63g/cm³ (w_s=0.085m/s, θc =0.04). The diameter of the pile is ***D*=100mm.** The water depth over the physical model is of *h*=0.40m and 0.50m.

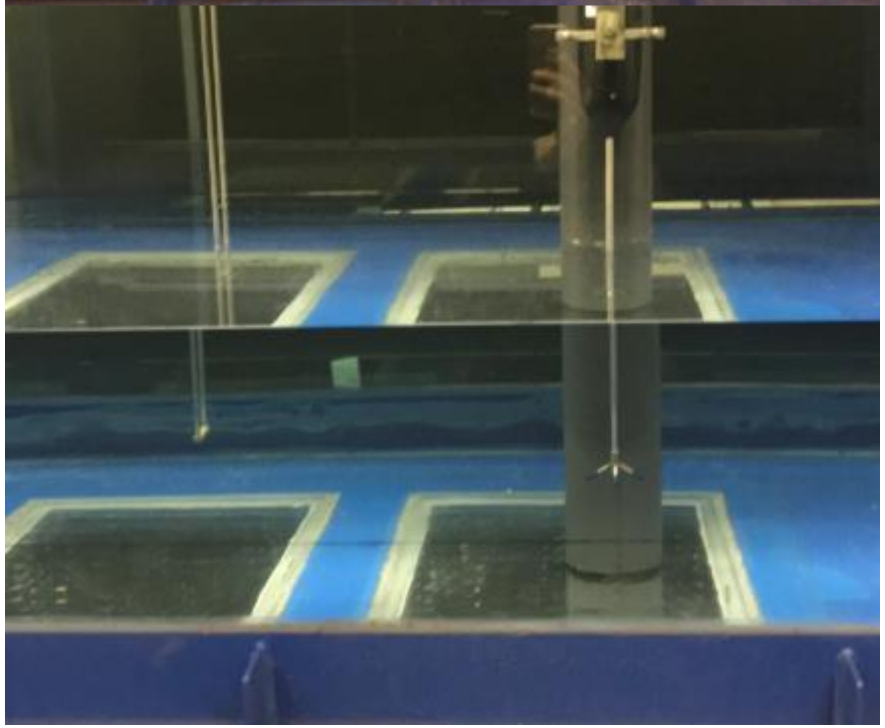
Seabed morphology and scour protections (different configurations)



2) RIGID SEABED

The diameter of the pile made of PVC is **DN100** (external diameter 110 mm). *h*=0.50m and 0.75m

Hydrodynamics and scour protections (performance)



Wave Charateristics

MOBILE SEABED

	Wave	h (m)	H (m)	T (s)	KC	ReD (x10^4)
REGULAR WAVES	R0	0.5	0.12	1.83	4.0	2.2
	R1	0.5	0.14	2.74	8.1	3.0
	R2	0.5	0.21	2.74	11.7	4.3
	R3	0.5	0.28	2.74	15.7	5.7
	R4	0.5	0.35	2.74	19.6	7.1
	R5	0.5	0.20	1.83	6.7	3.7
	R6	0.5	0.25	1.83	8.0	4.4
	R7	0.5	0.16	1.83	5.2	2.9
	R8	0.5	0.16	2.19	6.8	3.1
	R9	0.5	0.19	2.19	8.1	3.7
	R10	0.5	0.23	2.19	9.9	4.5
	R11	0.5	0.14	2.19	6.1	2.8
	R12	0.5	0.36	2.74	20.2	7.4
	R13	0.4	0.17	2.74	10.8	3.9
	R14	0.4	0.19	2.74	12.3	4.5
	R15	0.5	0.17	2.74	9.8	3.6
	R16	0.4	0.14	2.19	6.7	3.1
	R17	0.5	0.19	2.74	10.6	3.9
	R18	0.4	0.16	2.19	8.0	3.7
	R19	0.4	0.21	2.19	10.4	4.8
RANDOM WAVES	NR1	0.5	0.12	2.74	6.4	2.4
	NR2	0.5	0.15	2.74	8.0	3.0
	NR3	0.5	0.19	2.74	10.1	3.7
	NR4	0.5	0.21	2.74	10.7	4.0
	NR5	0.5	0.16	1.83	5.7	3.0
	NR6	0.5	0.18	1.83	6.0	3.3
	NR7	0.5	0.14	2.19	6.3	2.8
	NR8	0.5	0.17	2.19	6.8	3.2
	NR9	0.5	0.20	2.19	7.7	3.7

MOBILE SEABED

h=0.40m and 0.50m

RIGID SEABED

h=0.50m and 0.75m

H=0.18m-0.28m

T=1.83s-2.74s

Keulegan-Carpenter number

$$KC = \frac{U\,T}{D}$$

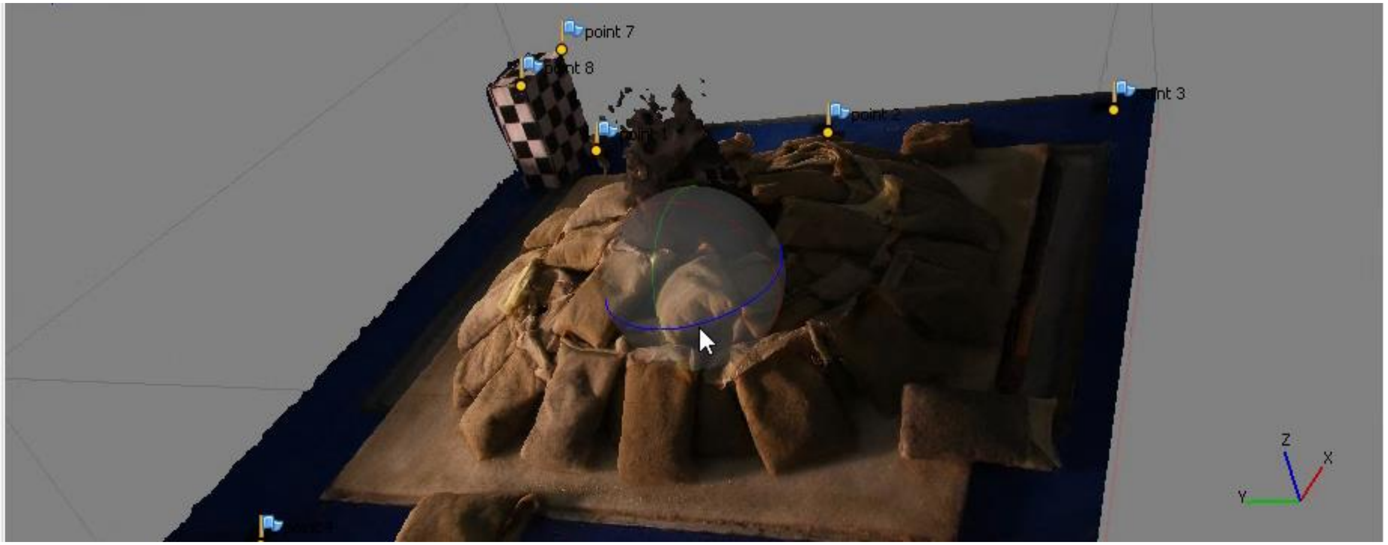
pile Reynolds number

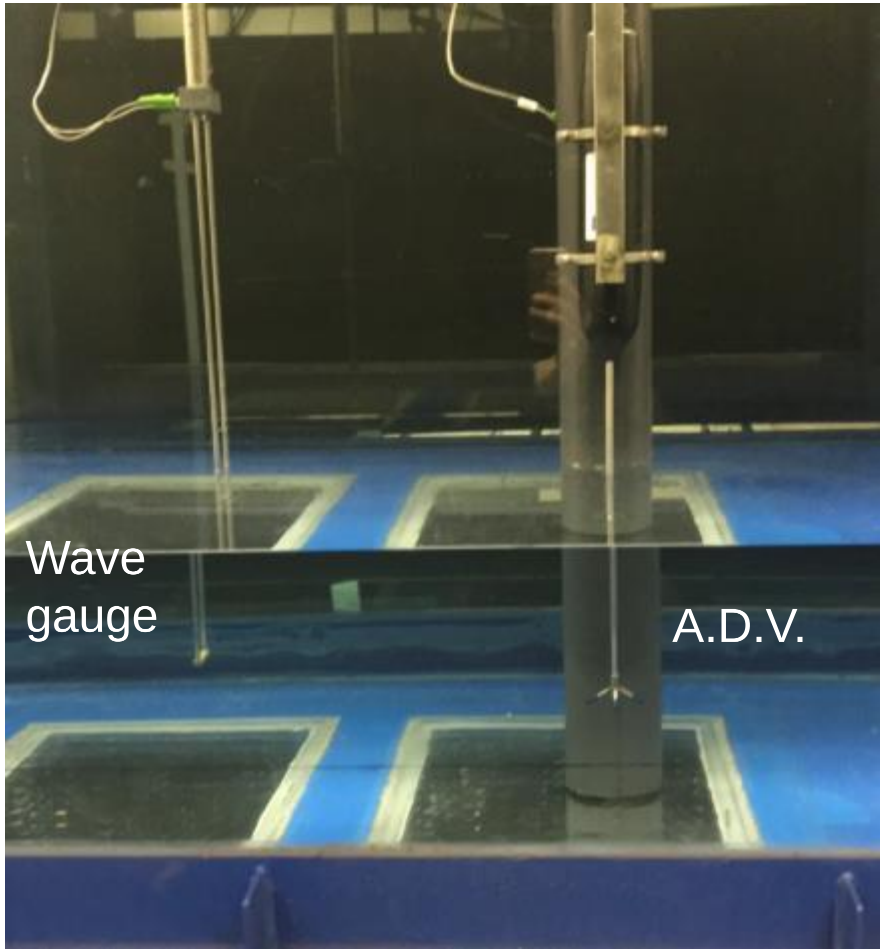
$$Re_D = \frac{U\,D}{\nu}$$

Laboratory: instruments

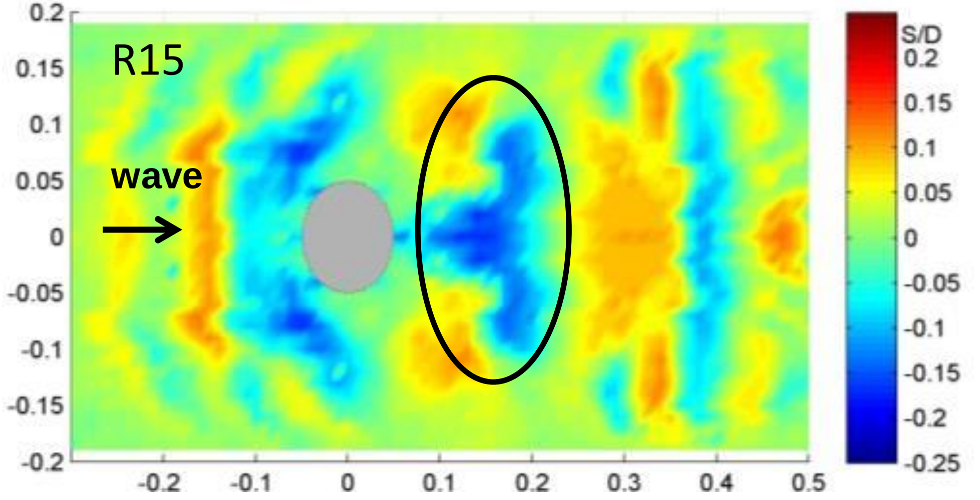
Syncronized experimental instruments system: *WaveLogger* software

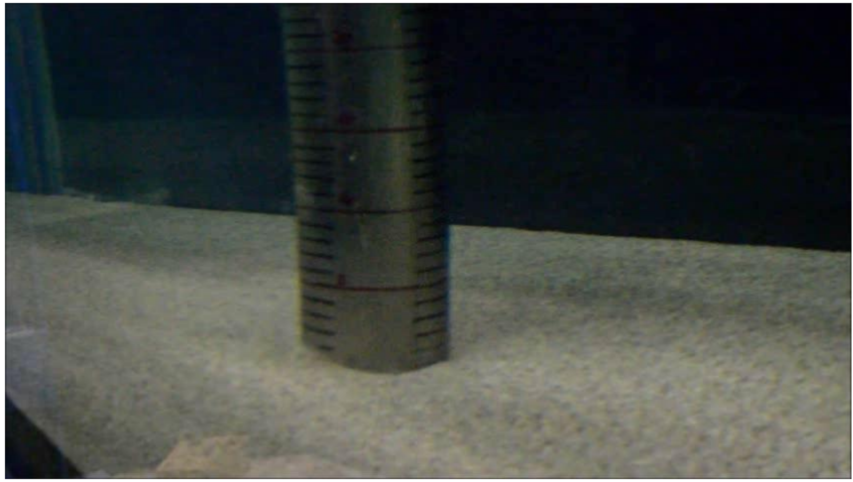
- Electroresistive wave gauges;
- Acoustic Doppler Velocimeter A.D.V.;
- Laser Distance-meter;
- Pressure sensors;
- 3D graphical reconstruction of the scour protection



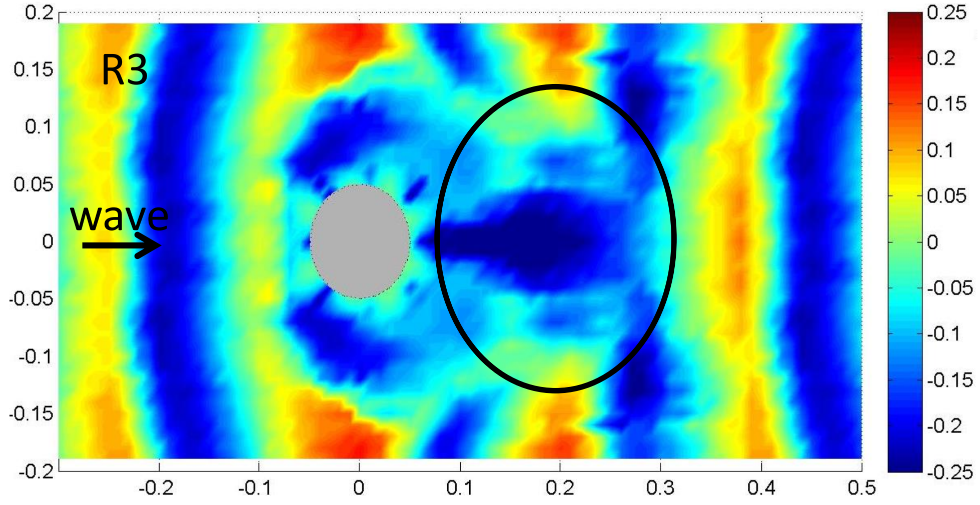


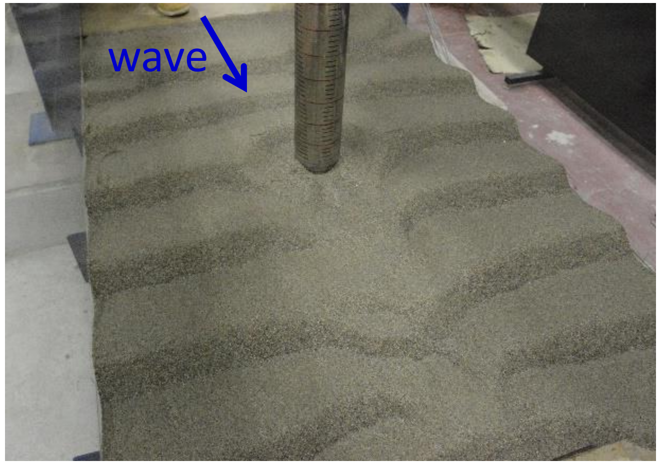
Experimental results: scour

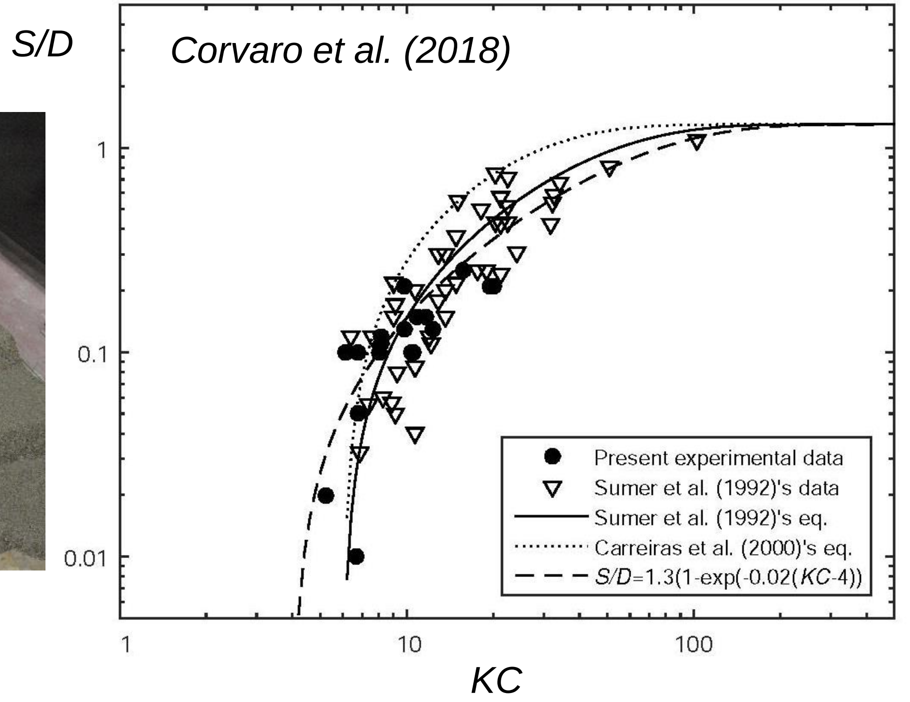




Wave R15 – KC=10

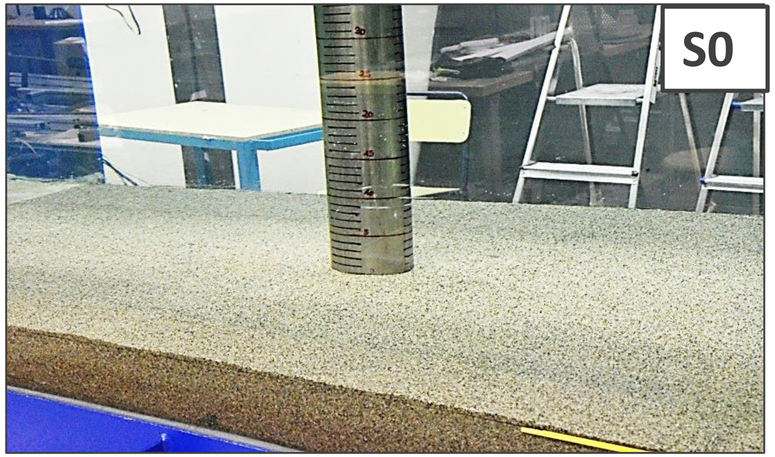






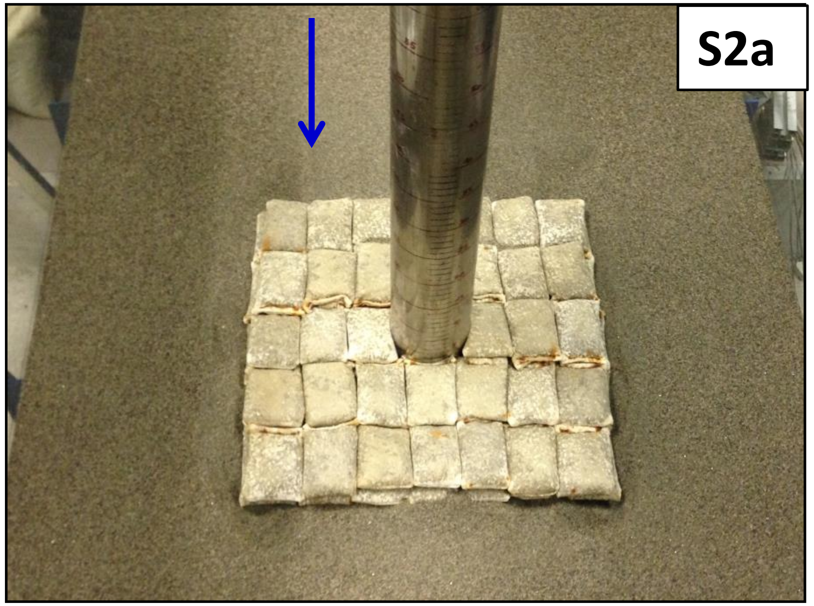
Wave R3 – KC=16

Different scour protection configurations

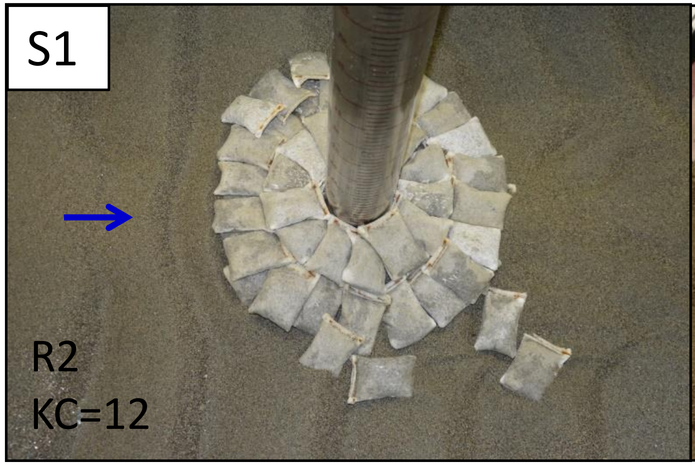


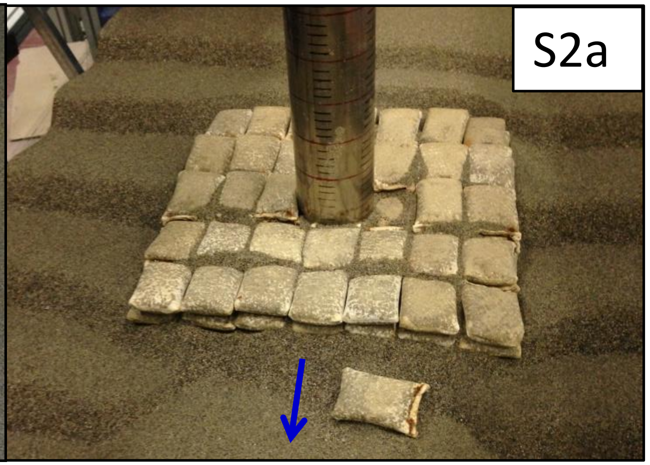
Geocontainer:
- Dimensions: 8cm x 6cm x 2cm
- Mass: 130g
- Fill ratio: 80%

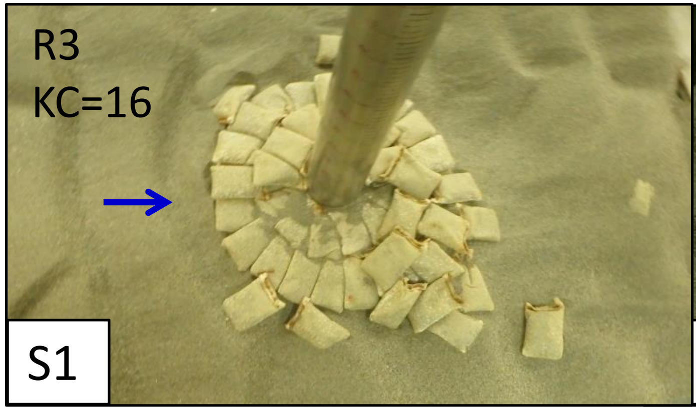
Scour protection:
- Layers: 2
- Extension: 5D

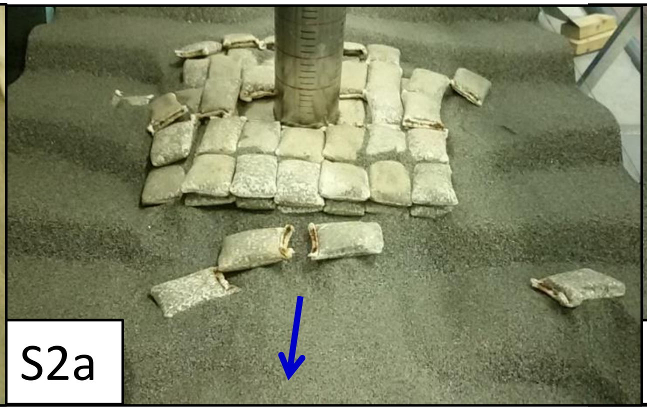


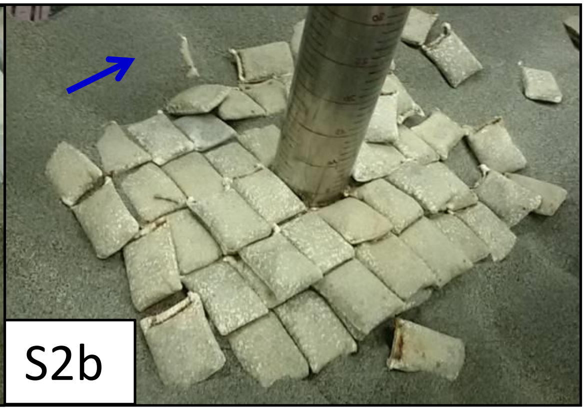
Comparison of the performace of different scour protection configurations







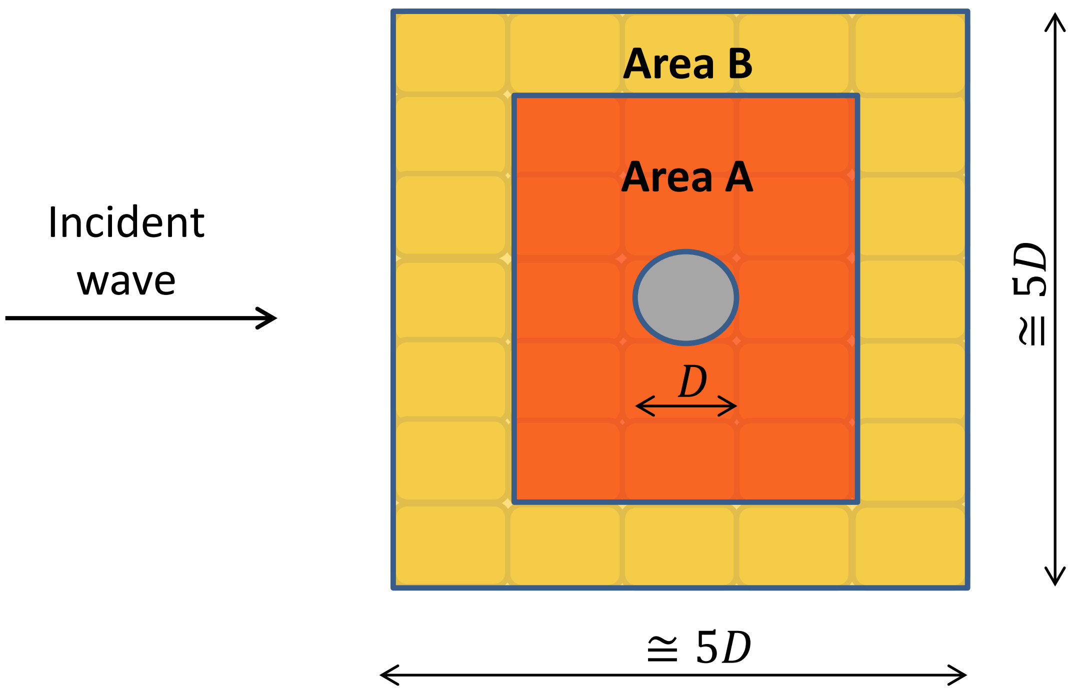




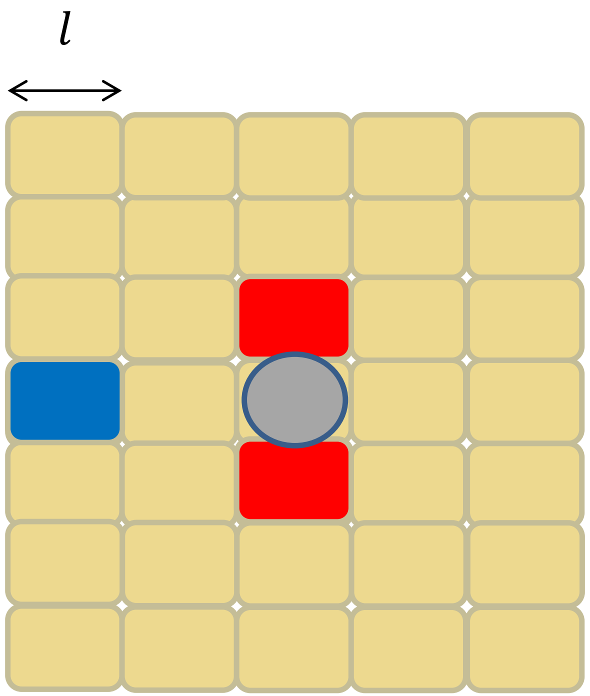
Mobilizing Forces	Resisting Force
$F_D = 0.5\rho_w u^2 C_D A_S$ $F_M = C_M \rho_w V \dfrac{\partial u}{\partial t}$ $F_L = 0.5 C_L \rho_w A_T u^2$	$F_{GSC} = \rho_{GSC} g V$ with $\rho_{GSC} = (\rho_s - \rho_w)$

The GSC failure modes are two: **sliding** and **overturning**

Damage parameter definition



$$l = \left(\frac{W}{k_W \gamma_s}\right)^{1/3}$$



Damage 0: no movements of GSCs

Damage 1: movement of GSCs in Area B

Damage 2: relevant movement of GSCs (Area A and Area B)

Damage 3: Failure of the protection

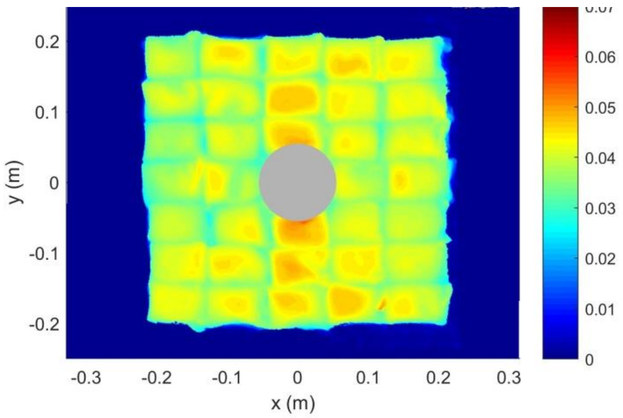
$$S_d = \frac{A_e}{A_{GSC}}$$

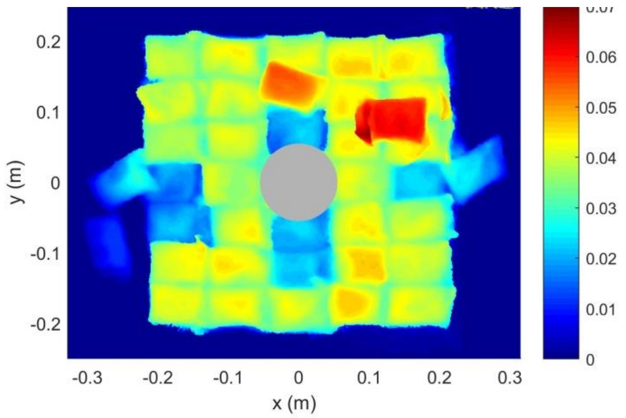
$$A_{GSC} = k_T l^2$$

$$U_{cr} = c\sqrt{l}$$

Experimental Results: eroded area for configuration S1

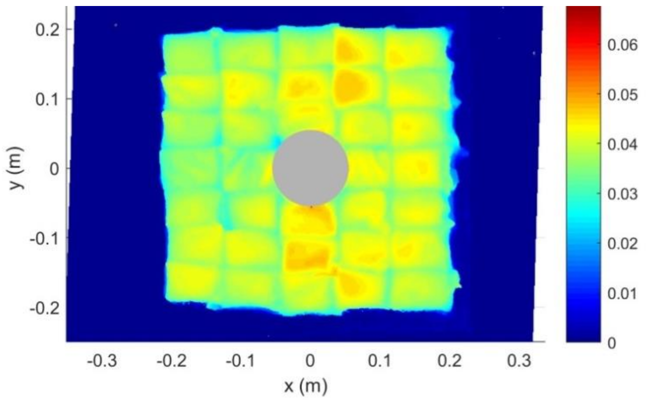
REGULAR WAVE
Wave R3
KC=16
h=50cm

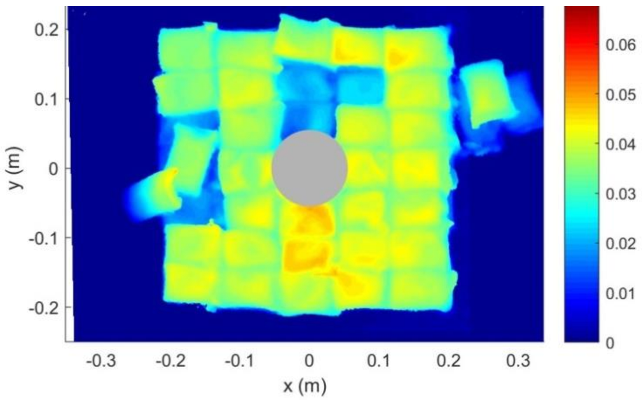




$S_d = 7.0$

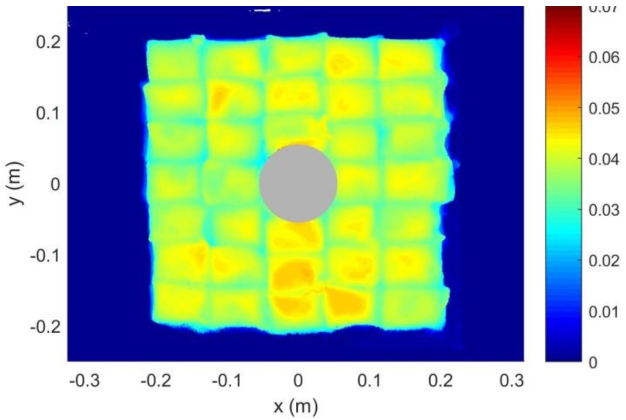
REGULAR WAVE
Wave R12
KC=20
h=75cm

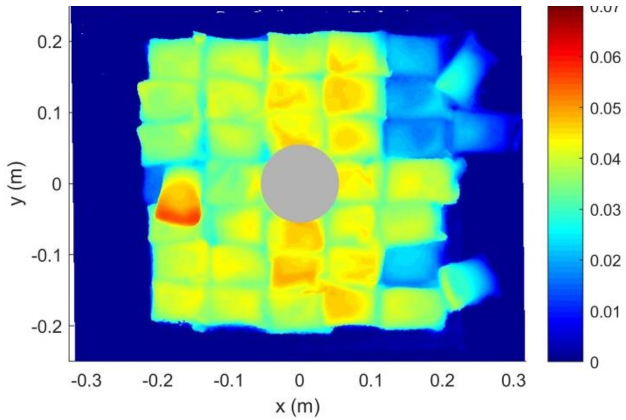




$S_d = 5.3$

RANDOM WAVE
Wave NR9
KC=8
h=50cm

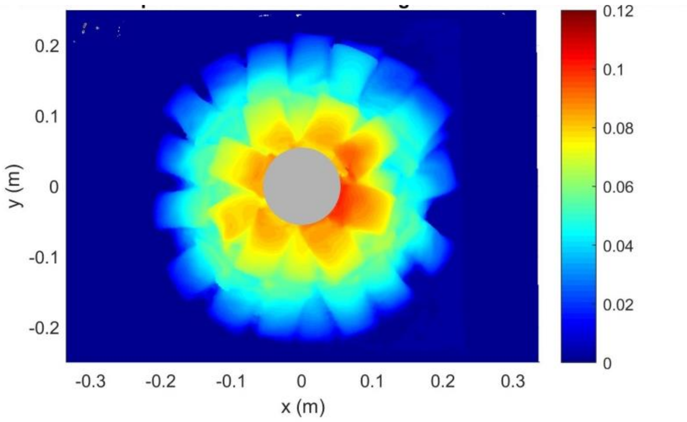


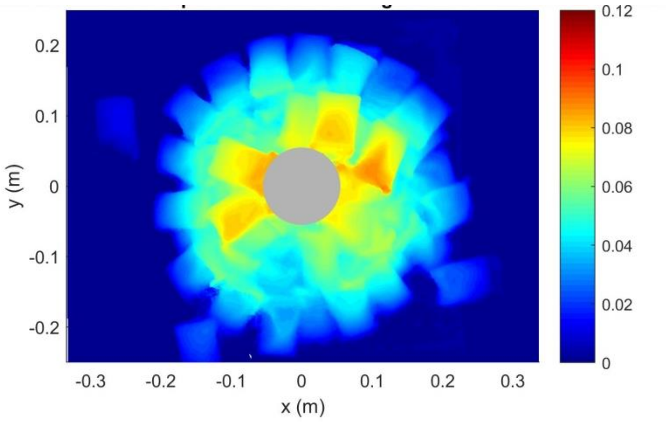


$S_d = 5.3$

Experimental Results: eroded area for configuration S3

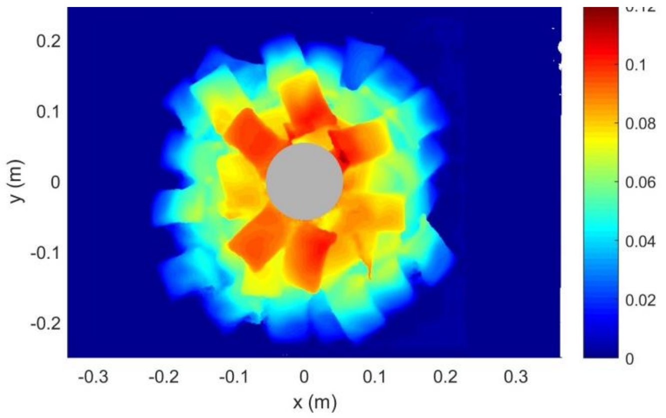
REGULAR WAVE
Wave R10
KC=10
h=50cm

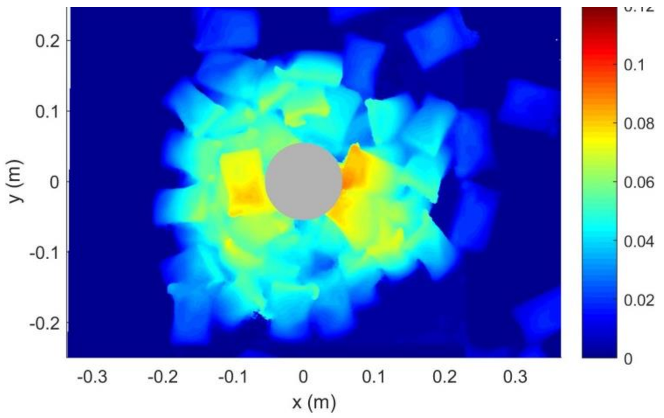




$S_d = 7.6$

REGULAR WAVE
Wave R3
KC=16
h=50cm

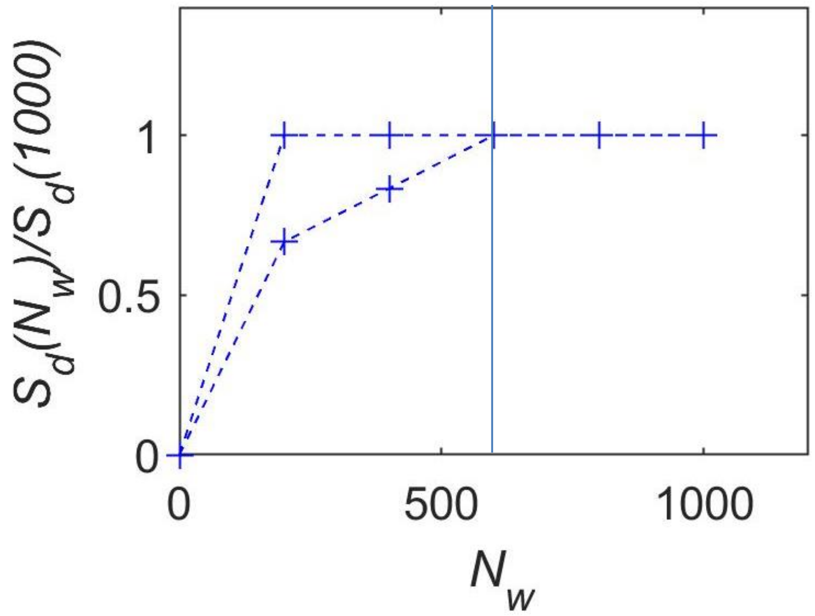


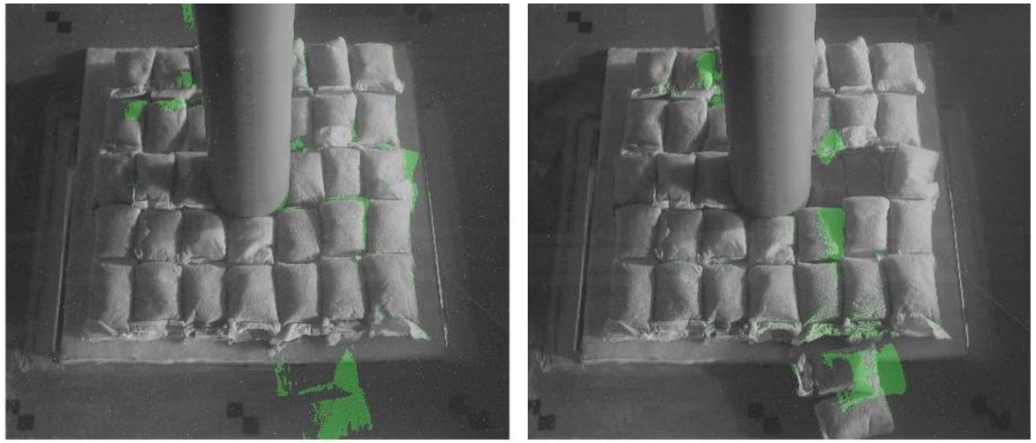


$S_d = 20.8$

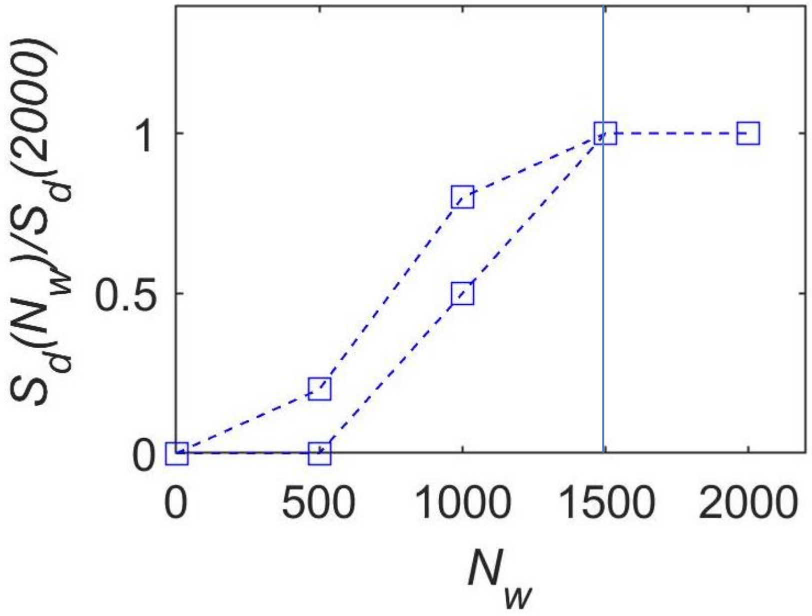
Evolution of the damage

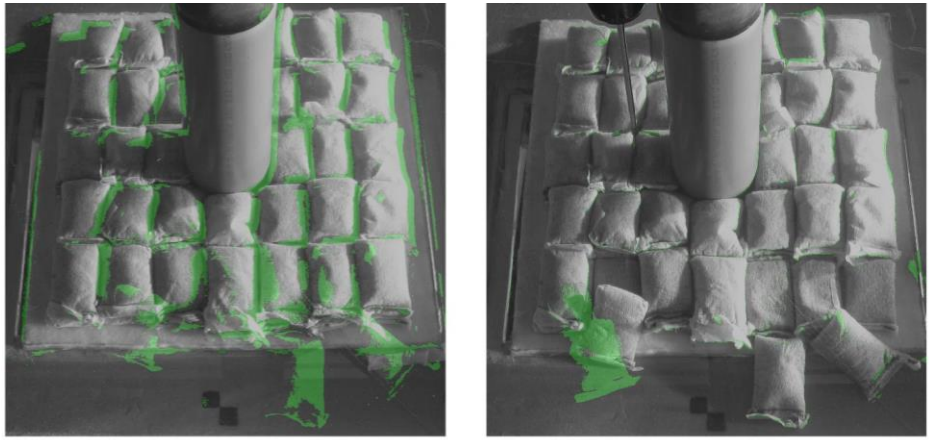
REGULAR WAVES



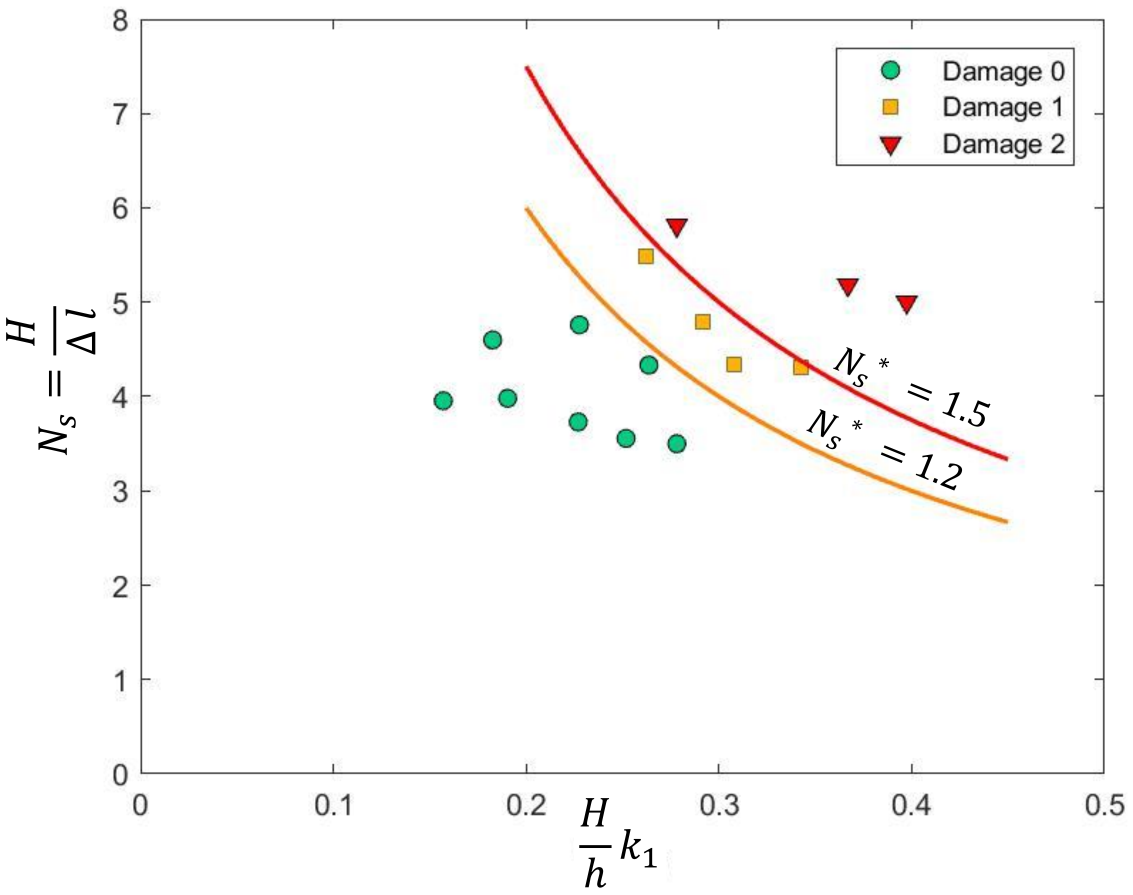


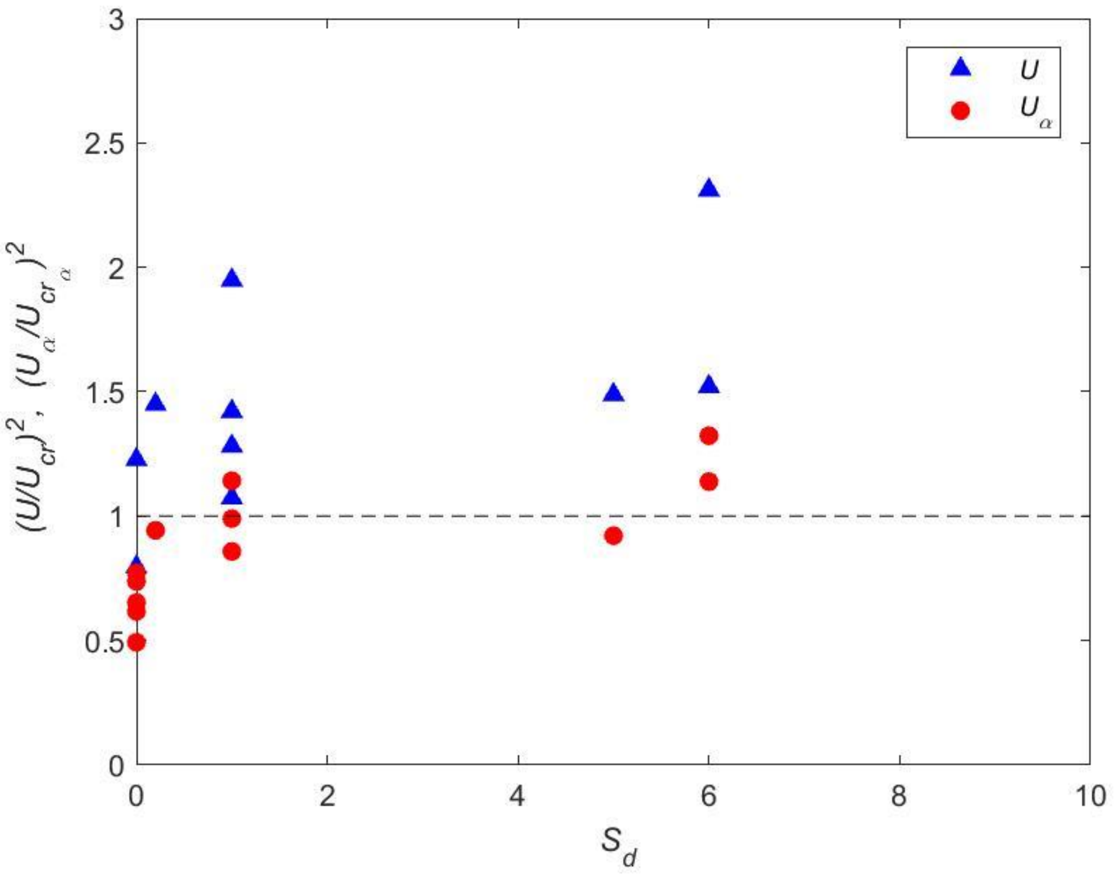
RANDOM WAVES





Modified hydraulic stability number and critical velocity





$N_s{}^* = N_s \frac{H}{h} k_1$ with k_1=*f(h,L)*

c=f(shape,Re,C_D*,*C_L*,packing)*

$U_{cr} = c\sqrt{l} = 0.9\sqrt{l}$ ⇨ $U_{cr\,\alpha} \cong 2.5 U_{cr}$

Conclusions

- The stability of geotextile sand containers (GSCs) seems to be good, no failure conditions have been observed even for waves characterized by larger wave heights and periods (nonbreaking waves);

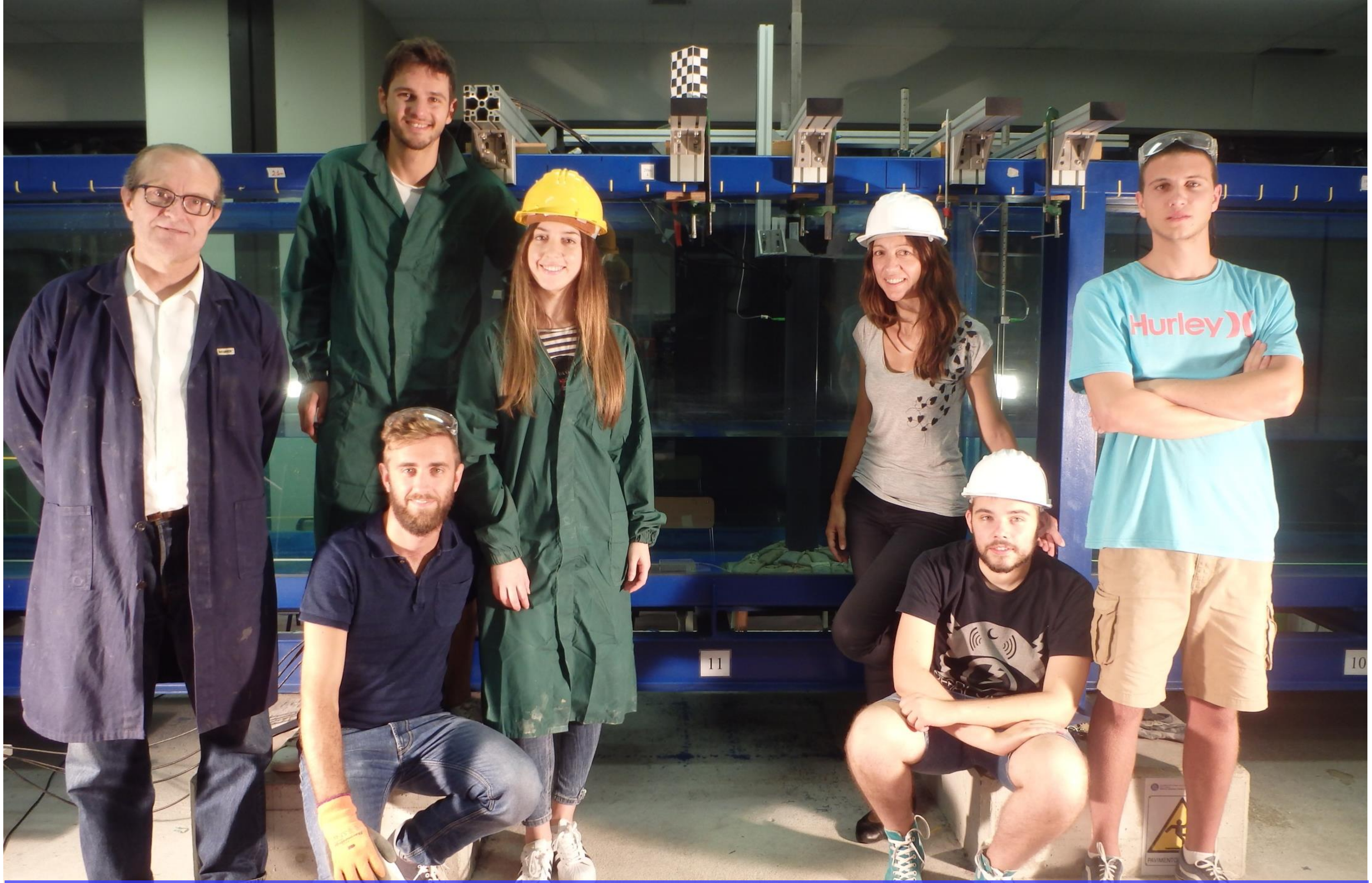
- Larger displacements occurred for configuration of geobags arranged in random ways (S3), even if it seems to have an acceptable performance. The elements arranged transversally with respect to the direction of wave propagation (configuration S2) show the lowest efficiency.

- Damage parameter has been defined in order to classified the level of risk of the scour protections;

- GSCs were found stable for a modified hydraulic stability number $N_s^* < 1.2$ (Damage level =1) and $N_s^* < 1.5$ (Damage level =2);

- The critical velocity has been obtained for geobags: $U_{cr\alpha} = 2.5\, U_{cr}$,

Therefore useful design criteria has been obtained ⇨ $N_s^*\ (H, h, L, 1/l) < 1.2$ and $U_{cr} = 0.9\sqrt{l}$



Thank you for your attention