

UNIVERSITA' DI PISA

**Facoltà di Scienze Matematiche, Fisiche e Naturali
Corso di Laurea in Scienze e Tecnologie per l'Ambiente ed il Territorio**



Tesi di Laurea:

**STUDIO DELLE MODIFICHE INDOTTE AL MOTO ONDOSONO
DALLA PRESENZA DI UN IMPIANTO EOLICO IN MARE.**

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Candidato: Stefano Monti

ANNO ACCADEMICO 2009/2010

SCOPO DELLA TESI

STUDIO DELL'INTERAZIONE TRA UN CAMPO DI MOTO ONDOSO ED UN IMPIANTO EOLICO OFFSHORE MEDIANTE L'APPLICAZIONE DI MODELLI NUMERICI 2D DEL SOFTWARE MIKE21.

Analisi delle caratteristiche dei singoli aerogeneratori e delle geometrie dei parchi eolici esistenti (*wind farm*).



Individuazione di schemi progettuali di singola torre e di impianto da studiare con le simulazioni numeriche.



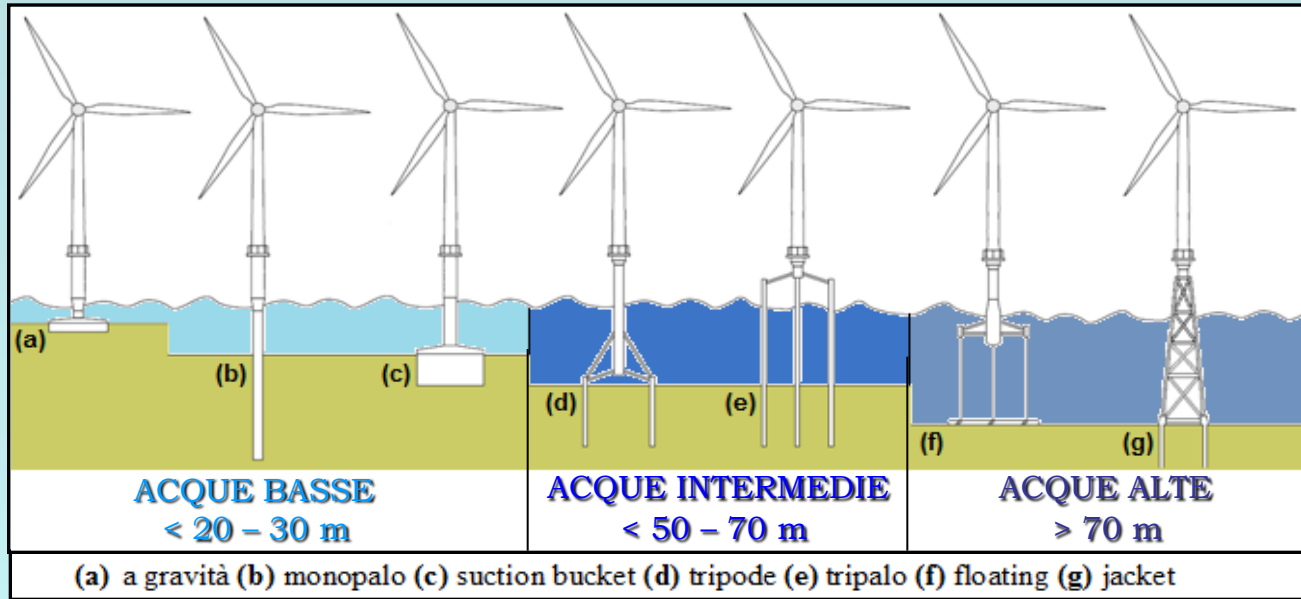
Applicazione dei modelli numerici per lo studio del moto ondoso, correnti e trasporto di sedimento



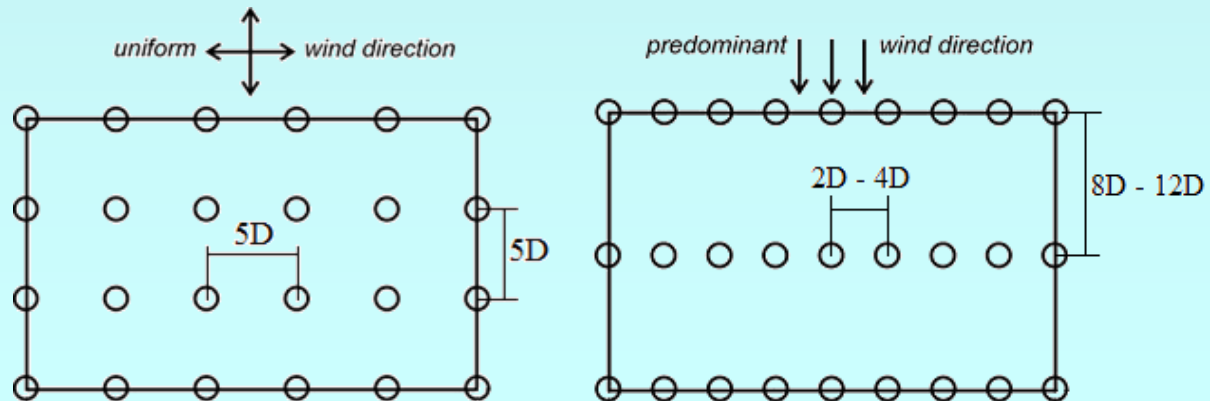
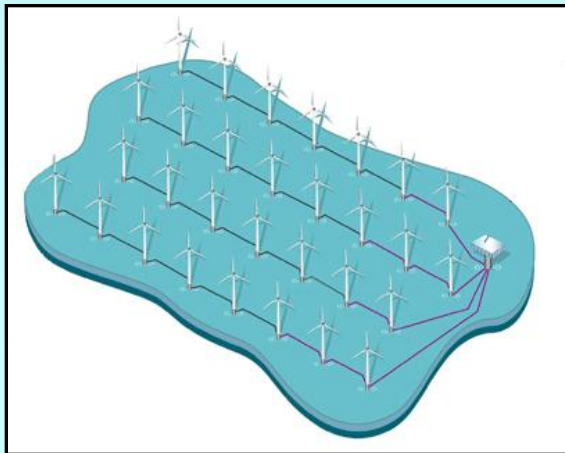
singola turbina su batimetria ideale
parco eolico su batimetria ideale
parco eolico su batimetria reale

TIPOLOGIE DI FONDAZIONE E LAYOUT DI IMPIANTO

Tipologie di fondazione :

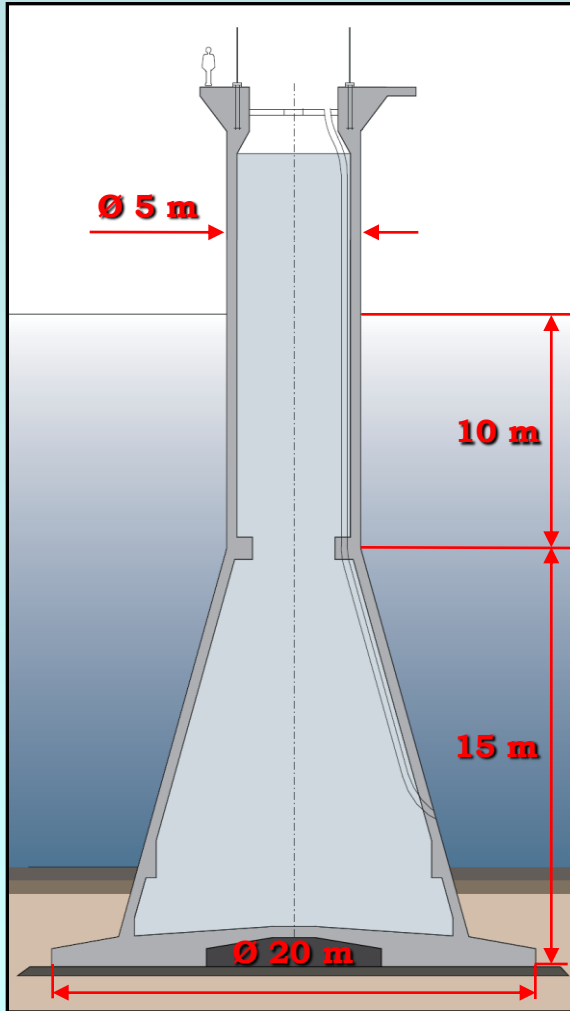


Layout di impianto:

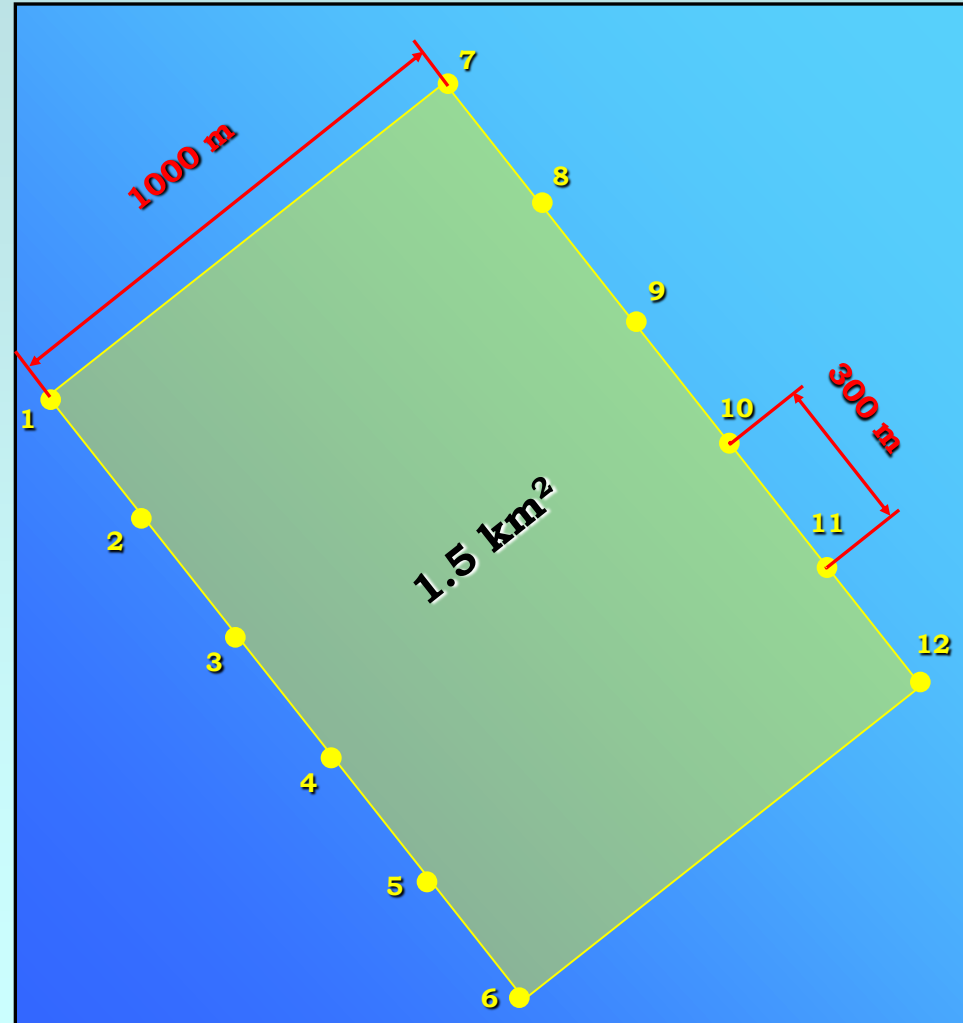


SCELTA DELLE FONDAZIONI E DEL LAYOUT DI IMPIANTO

Geometrie delle fondazioni:



Geometrie dell'impianto:



MODULI UTILIZZATI



MODULO ELLITTICO (EMS)

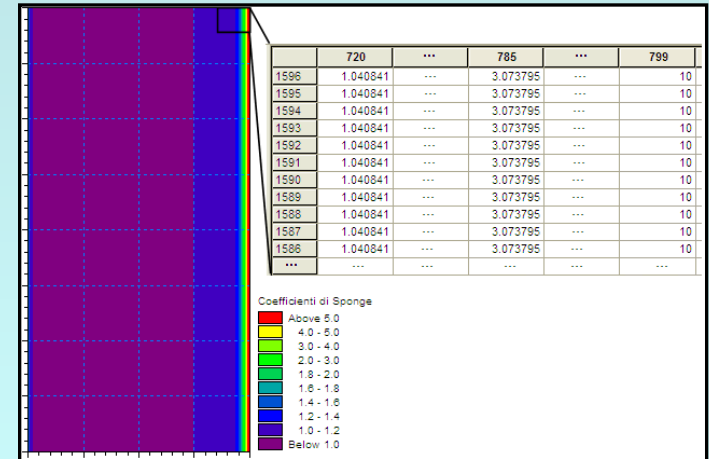
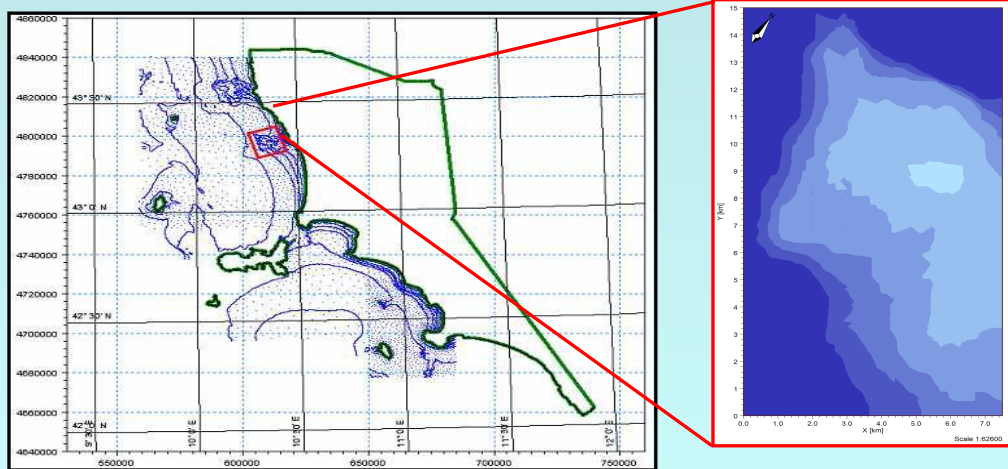
Basato sulla soluzione numerica dell'equazione di tipo ellittico proposta da *Berkhoff*:

$$\nabla(C \cdot C_{sg} \cdot \nabla \cdot \zeta) - \frac{C_{sg}}{C} \frac{\partial^2 \zeta}{\partial t^2} = 0$$

DATI DI INPUT:

➤ Mappa digitalizzata delle batimetrie

➤ Mappa degli strati assorbenti

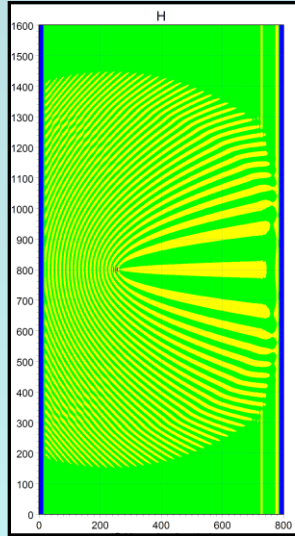


- Procedura iterativa
- Modello di frangimento di Battjes & Janssen
- Forze di attrito al fondo (Nikuradse)
- Altezza, periodo e direzione dell'onda

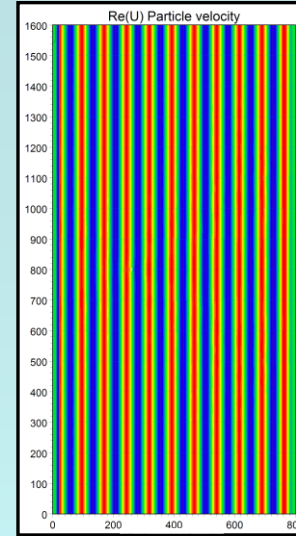
MODULO ELLITTICO (EMS)

DATI DI OUTPUT:

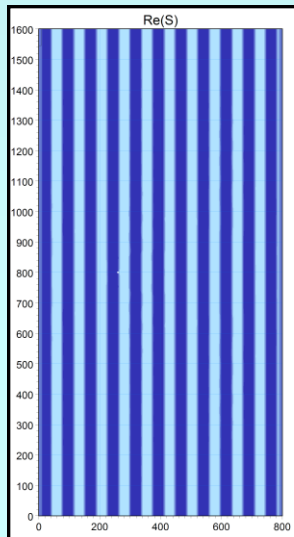
➤ Mappa delle altezze d'onda



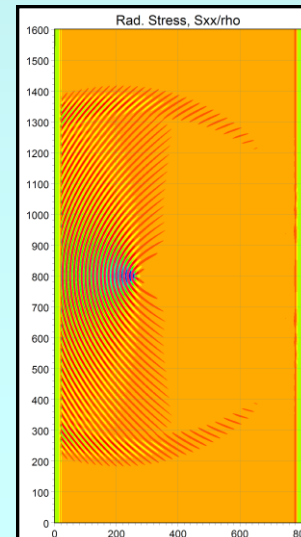
➤ Mappa delle velocità orbitali



➤ Mappa delle elevazioni

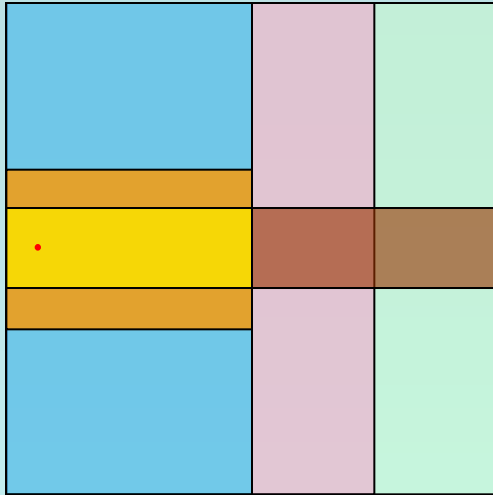


➤ Mappa dei *radiation stress*



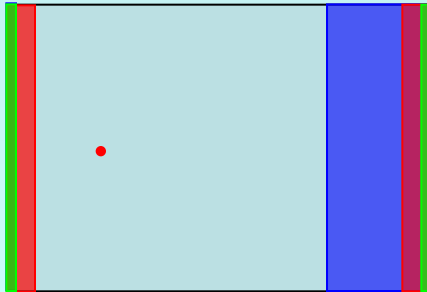
Metodologia:

- Prove preliminari con diverse dimensioni del dominio



Tipo Dominio	Dimensioni [m]		Passo [m]	
	L_x	L_y	D_x	D_y
<i>Singola torre</i>	800	260	1	1
	1600	260	1	1
	800	520	1	1
	1000	1600	1	1
	1600	1600	1	1
	800	1600	1	1
<i>Parco eolico su batimetria ideale</i>	1800	3100	1	1
<i>Parco eolico su batimetria reale</i>	1500	3000	5	5

- Prove di sensibilità con alcuni spessori di Sponge Layer



Strati Sponge inizio dominio	Strati Sponge fine dominio
20	20
20	200
50	50

- Prove definitive

Nome Onda	Altezza [m]	Periodo [s]
0	1	4
1	3	7
2	6	10

MODULO IDRODINAMICO (HD)

Risolve numericamente le equazioni di continuità e della quantità di moto in un caso 2D piano:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2 + q^2}}{C^2 h^2} - \frac{E}{\rho} \left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} \right) - \frac{I}{\rho} \left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{yx}}{\partial y} \right) - fq = 0$$

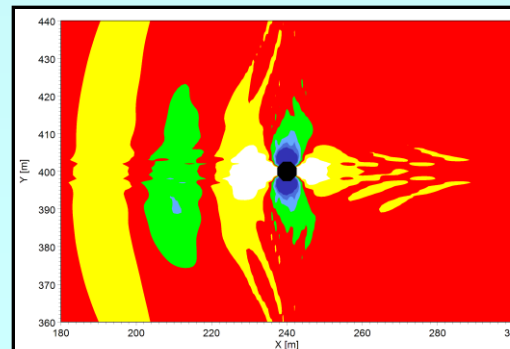
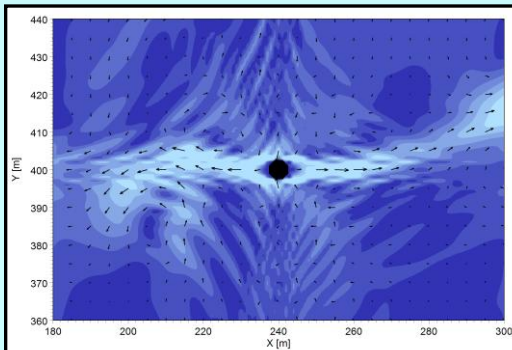
$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2 + q^2}}{C^2 h^2} - \frac{E}{\rho} \left(\frac{\partial^2 q}{\partial x^2} + \frac{\partial^2 q}{\partial y^2} \right) - \frac{I}{\rho} \left(\frac{\partial S_{yy}}{\partial y} + \frac{\partial S_{xy}}{\partial x} \right) + fp = 0$$

DATI DI INPUT:

- Mappa digitalizzata delle batimetrie
- Viscosità (coefficiente di Smagorinsky)
- Mappa dei *radiation stress*
- Scabrezza al fondo (numero di Manning)
- Durata della simulazione

DATI DI OUTPUT:

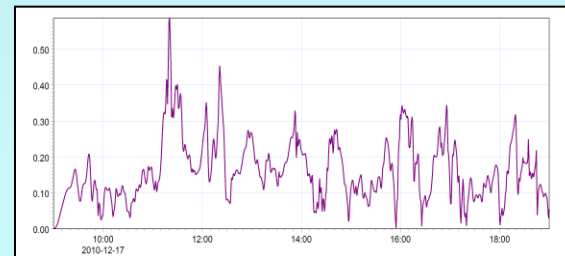
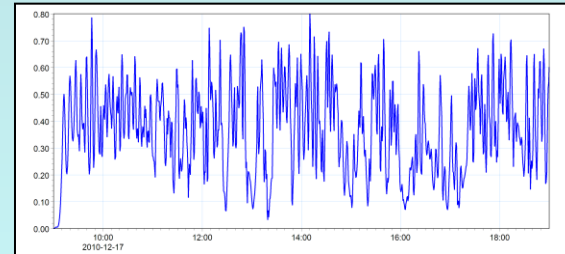
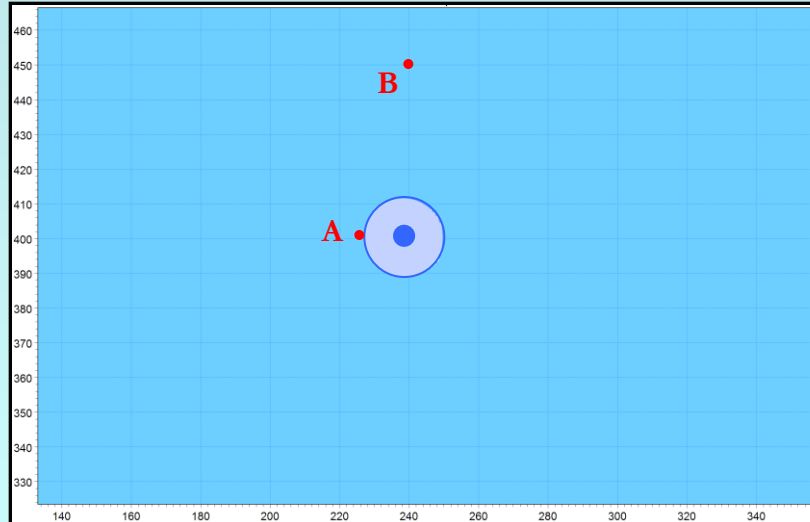
- Mappa delle velocità di corrente
- Mappa dei livelli idrici



Metodologia:

➤ Test di sensibilità per i parametri di viscosità e scabrezza al fondo

Codice Prova	Coefficiente di Smagorinsky	Costante di Manning
1	0.5	32
2	0.5	30
3	1	30



➤ Prove definitive

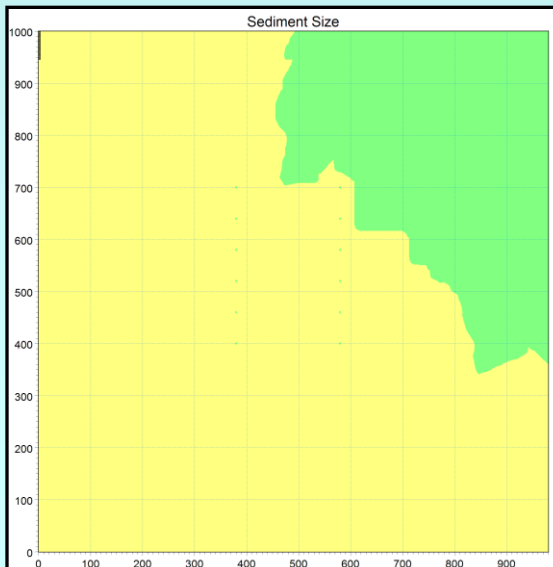
MODULO TRASPORTO SEDIMENTI (ST)

Basato sulla teoria di *Bijker* secondo cui il trasporto totale è dato da due componenti:

$$q_t = q_b + q_s = q_b \cdot (1 + 1.83Q) \quad (\text{m}^3/\text{s}/\text{m})$$

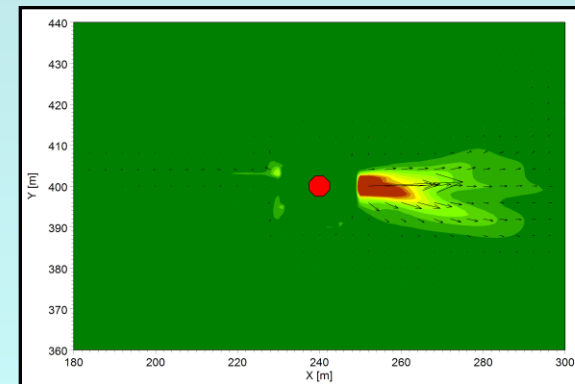
DATI DI INPUT:

- Mappa delle velocità di corrente
- Scabrezza al fondo (numero di Manning)
- Parametro di Shield θ
- Mappa delle caratteristiche del sedimento:



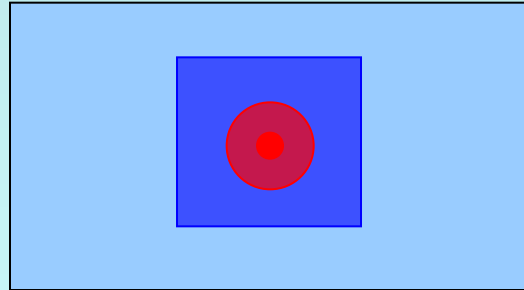
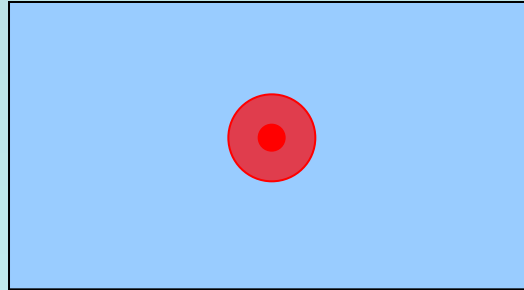
DATI DI OUTPUT:

- Mappe del flusso medio di sedimento:



Metodologia:

- Prove effettuate in assenza ed in presenza di protezione al piede della fondazione

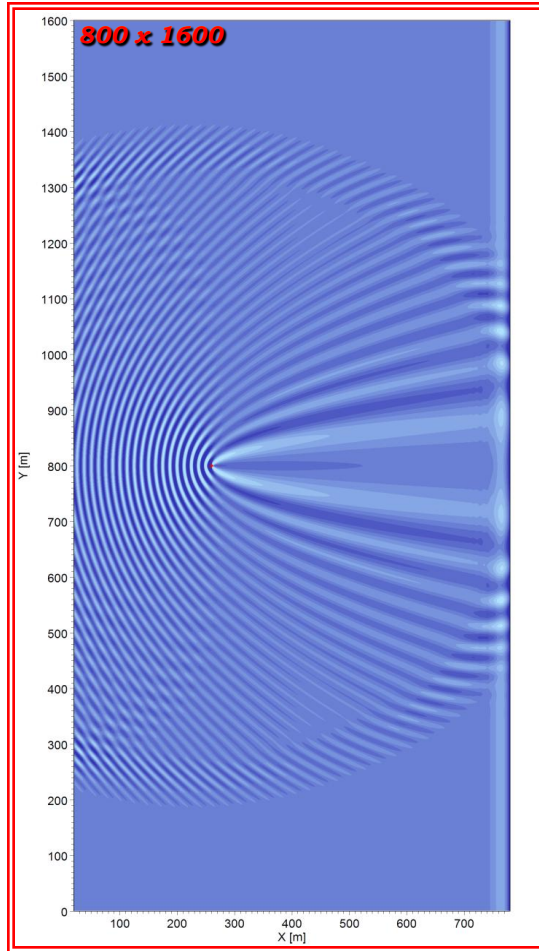


- Prove definitive

MODULO EMS – SINGOLA TORRE

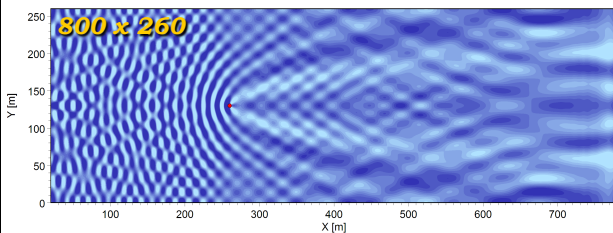
Prove preliminari sulle dimensioni del dominio:

1600 x 1600



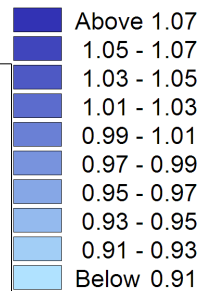
1000 x 1600

800 x 520

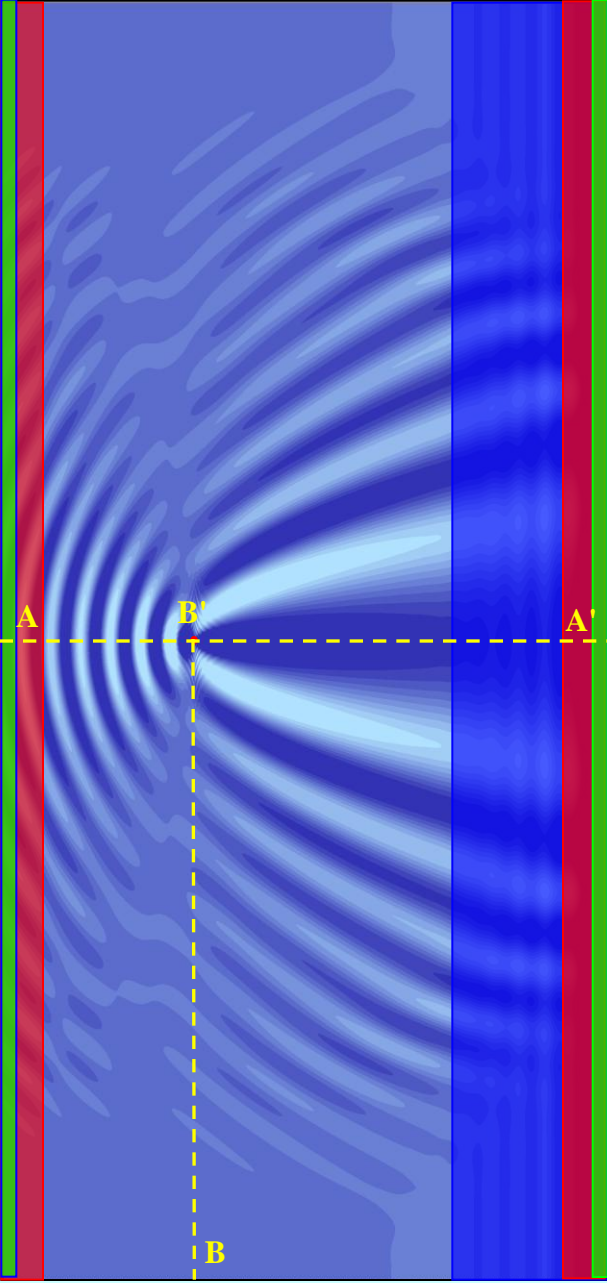


1600 x 260

Altezza d'Onda [m]



Prove di sensibilità con lo spessore degli strati assorbenti :

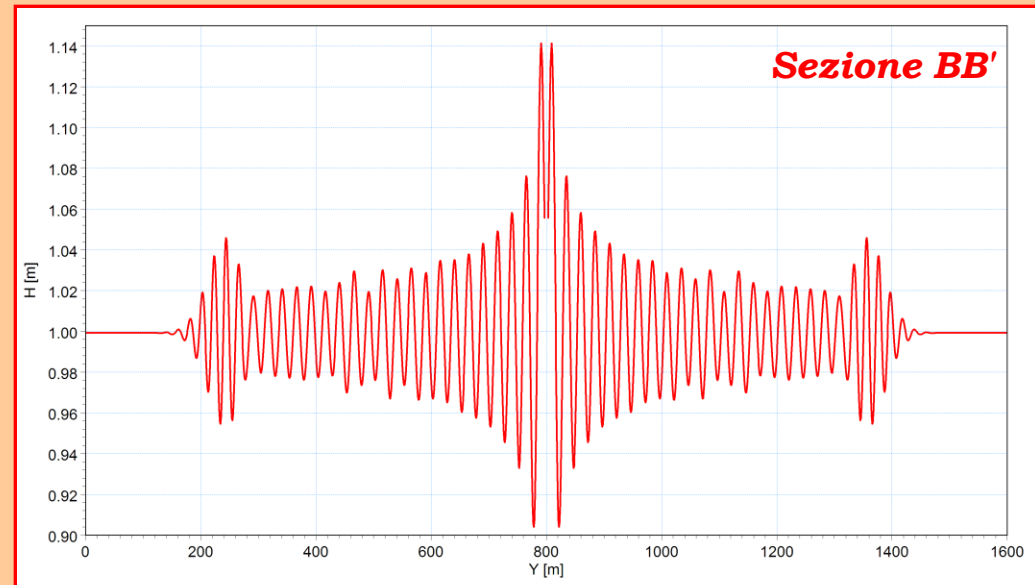
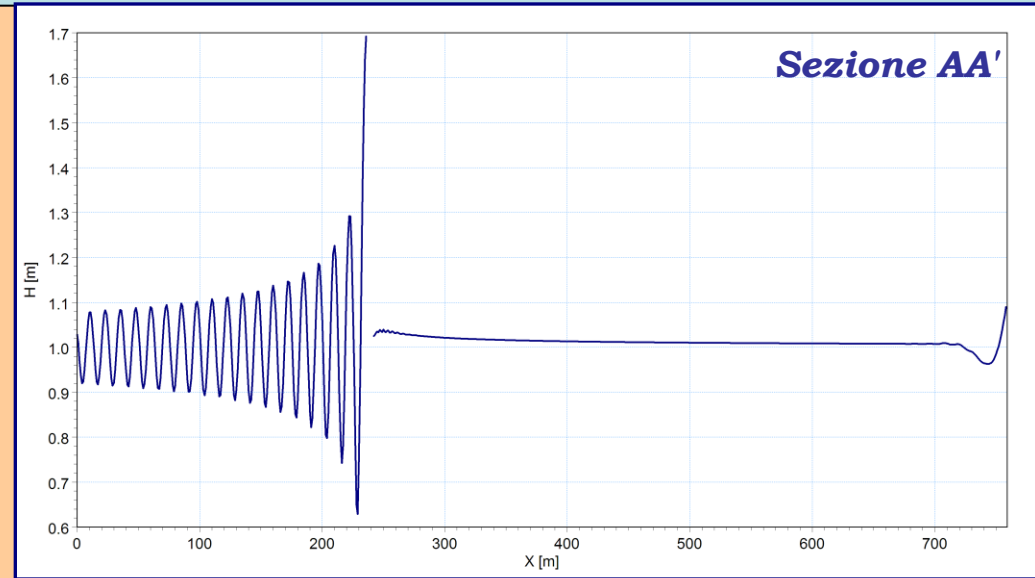
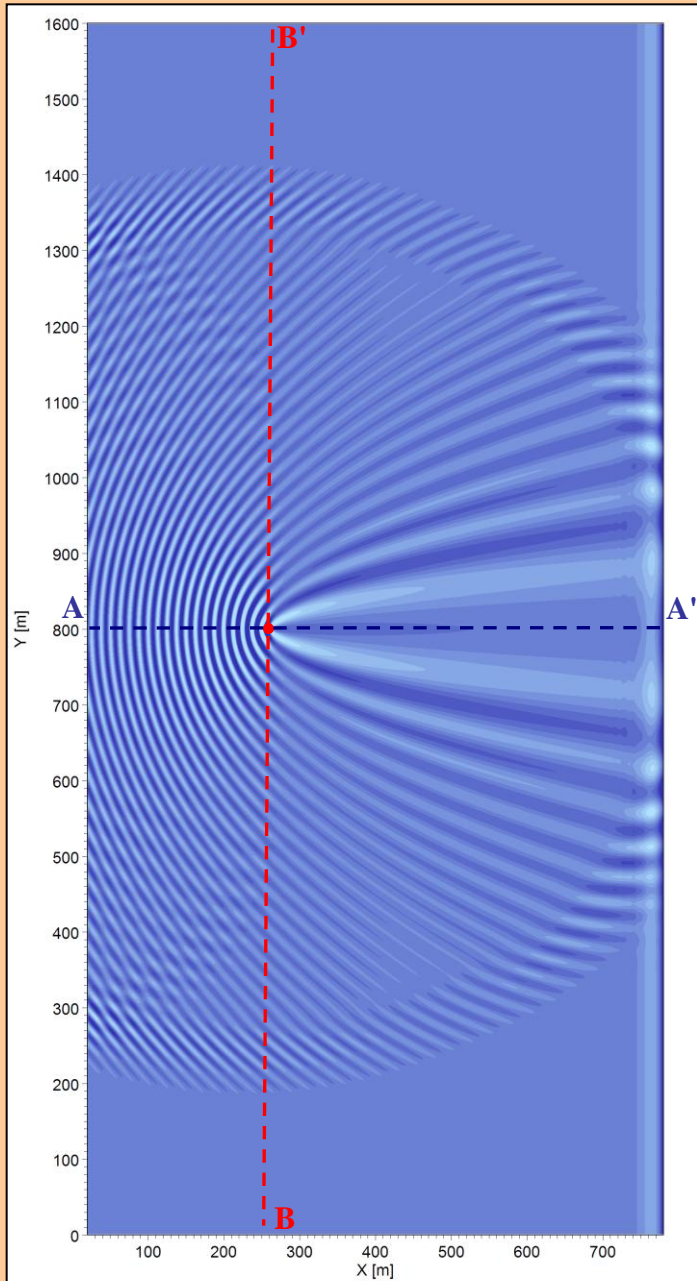


Sezione AA'

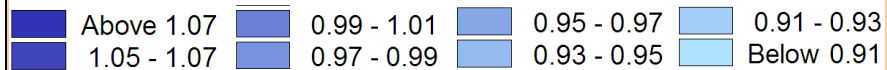
Sezione BB'

Spessore Sponge 20 – 20 50 – 50 20 – 200

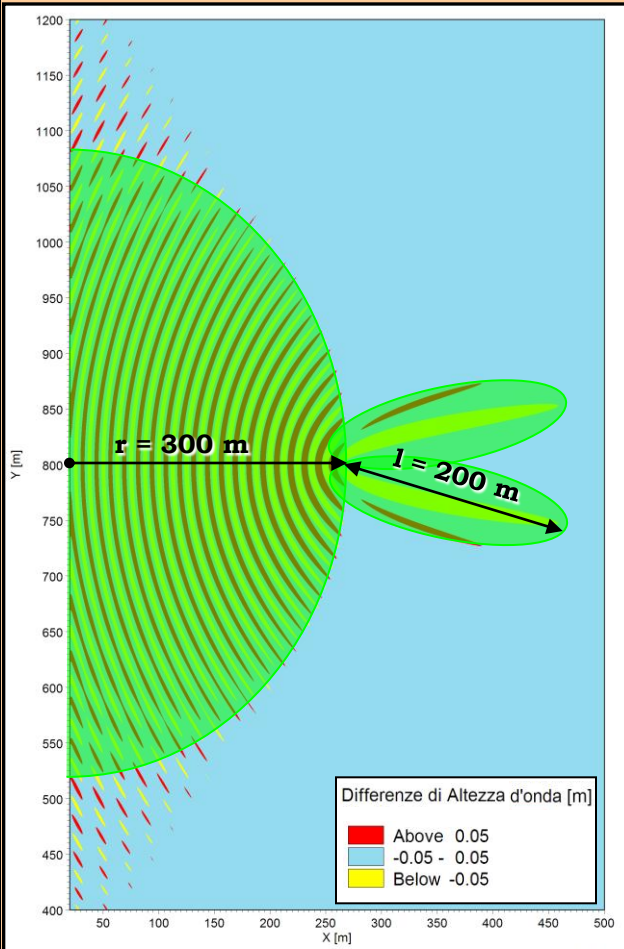
Onda 0 ($H = 1\text{m}$, $T = 4\text{s}$)



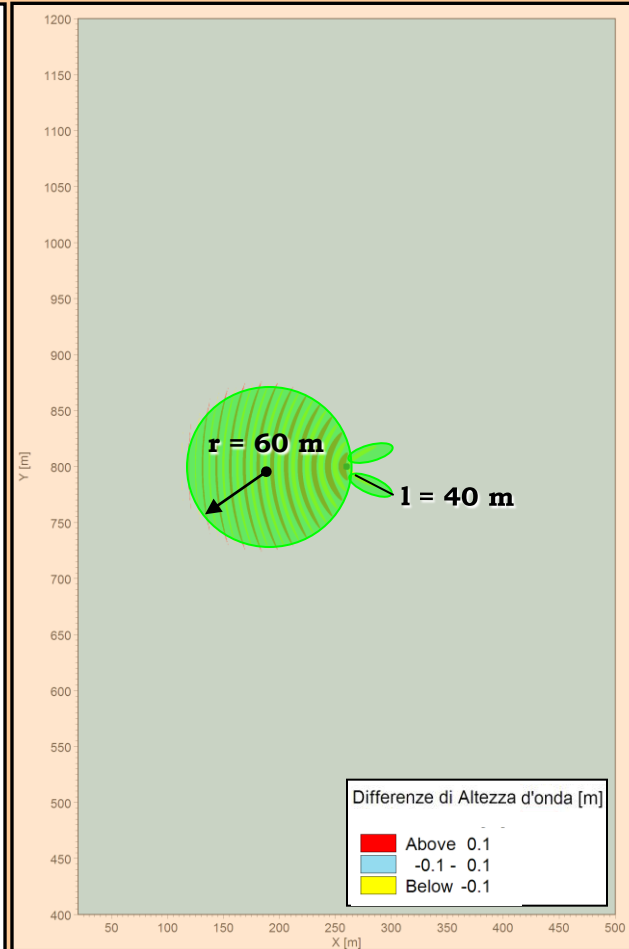
Altezza d'onda [m]



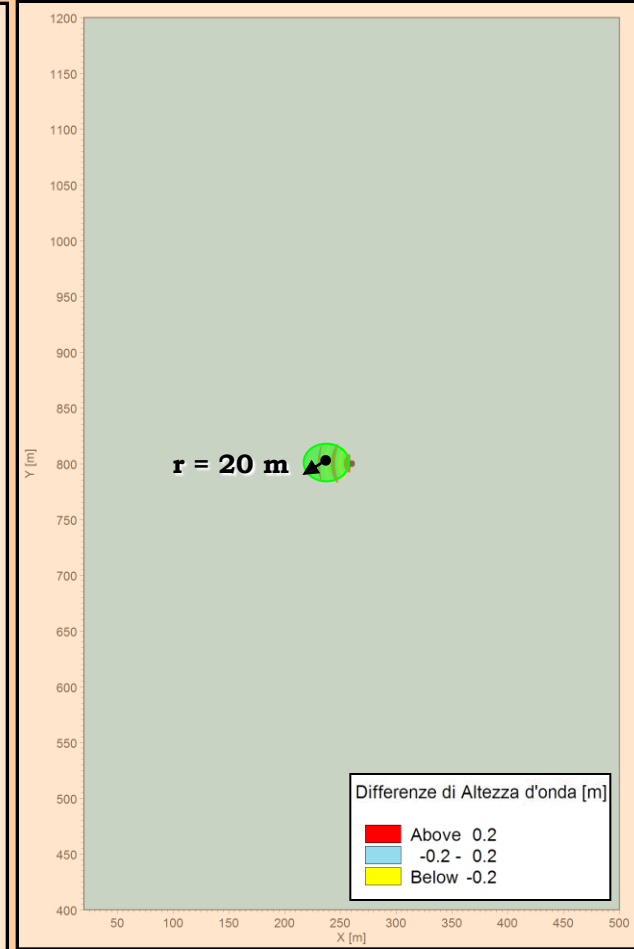
Differenze di H al 5 %



Differenze di H al 10 %



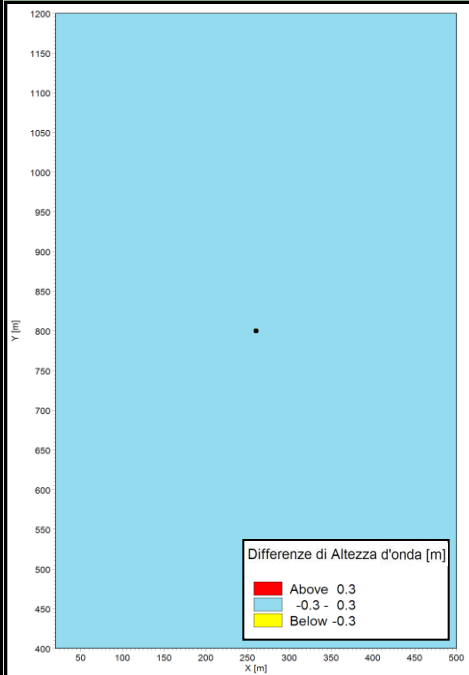
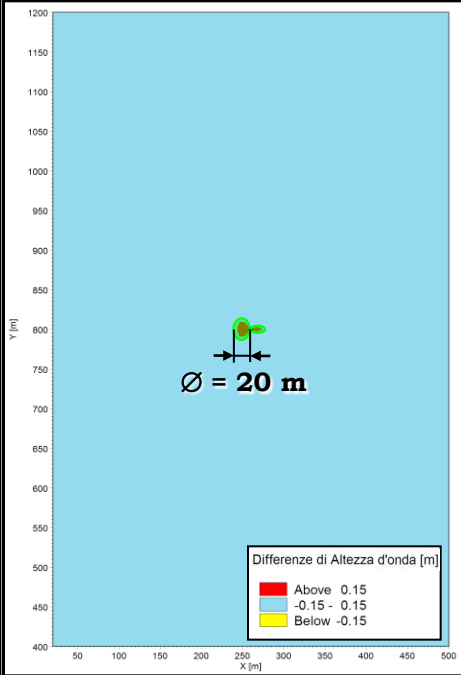
Differenze di H al 20 %



Onda 1 (H = 3m, T= 7s)

Differenze di H al 5 %

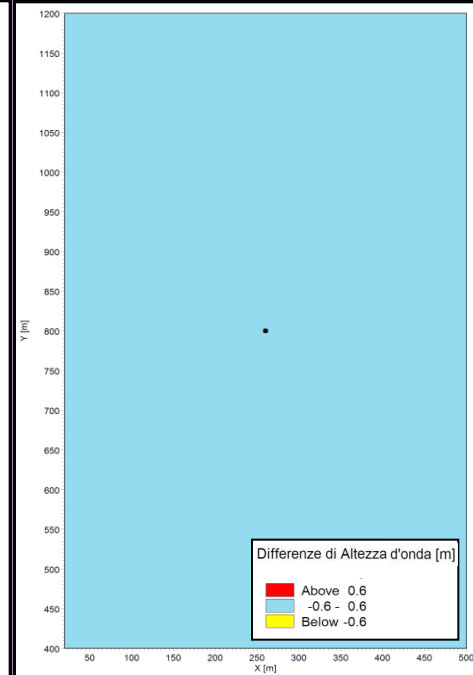
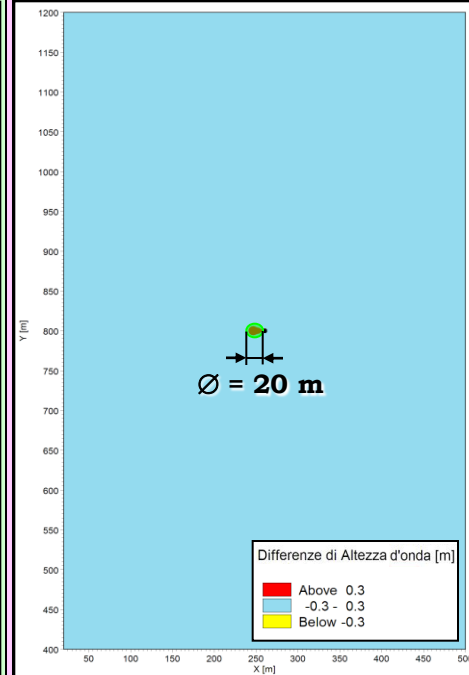
Differenze di H al 10 %



Onda 2 (H = 6m, T= 10s)

Differenze di H al 5 %

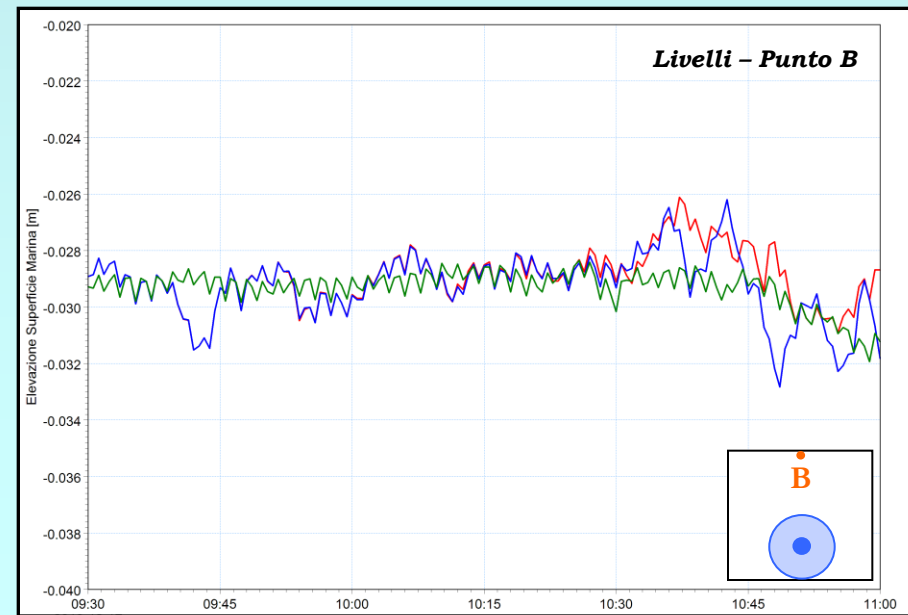
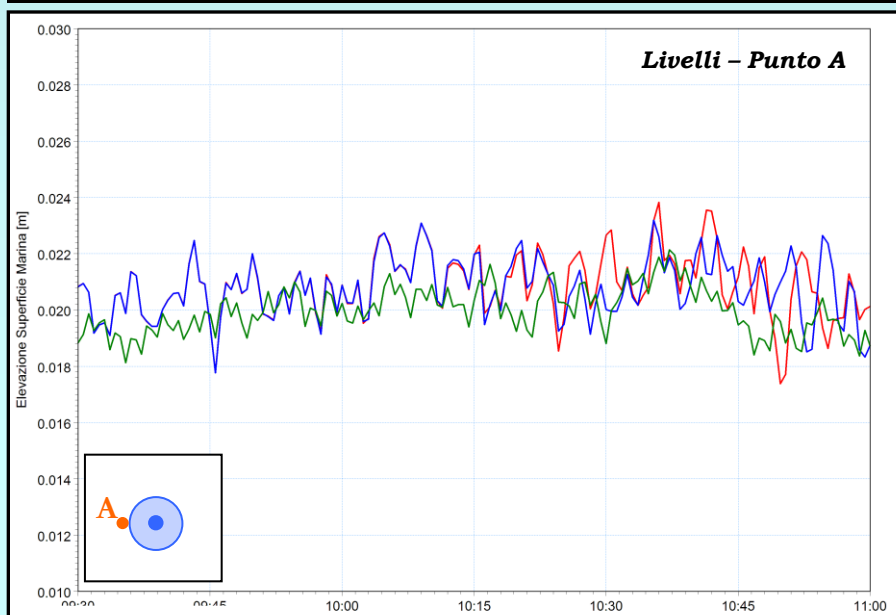
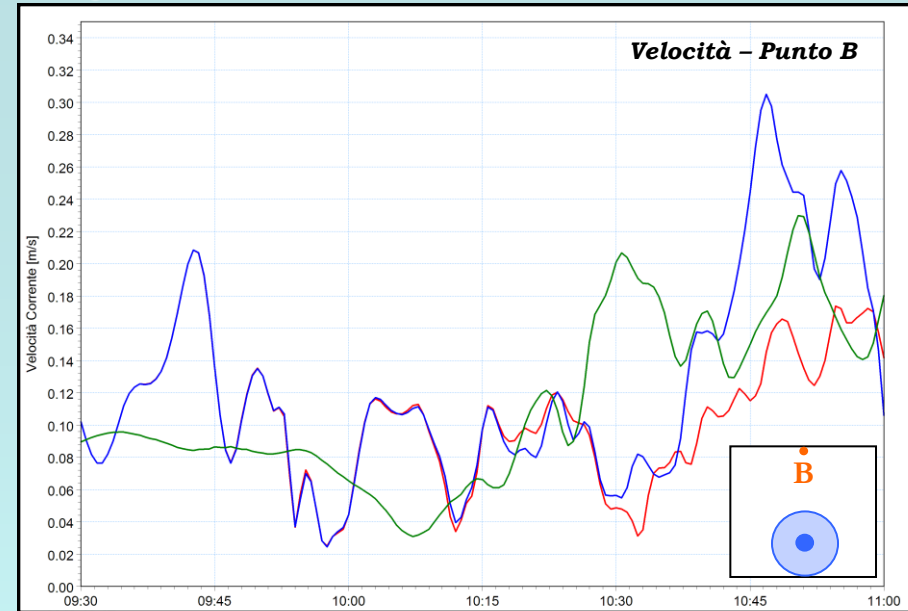
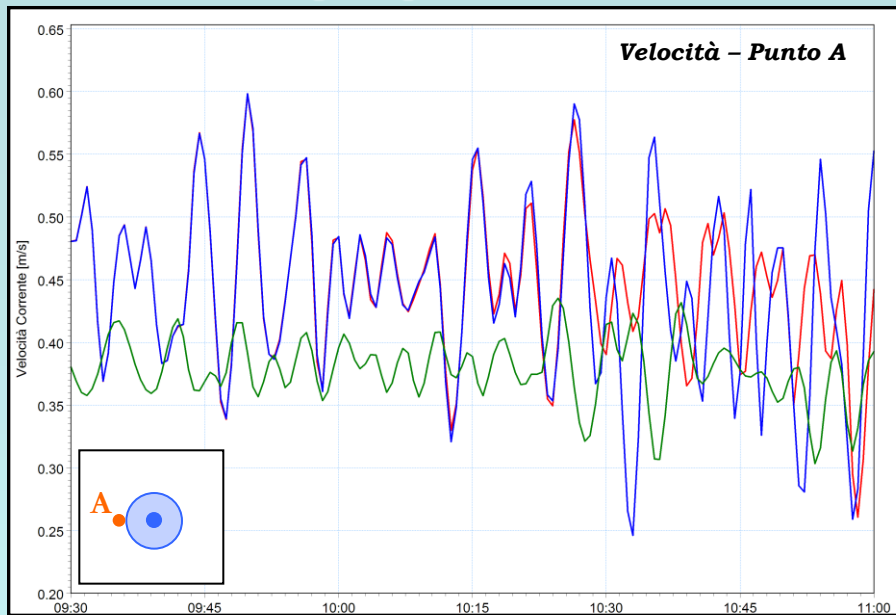
Differenze di H al 10 %



Onda	Differenze 5%		Differenze 10%		Differenze 20%	
	Davanti	A tergo	Davanti	A tergo	Davanti	A tergo
0	r = 300 m	l = 200 m	r = 60 m	l = 40 m	r = 20 m	-
1	r = 20 m	l = 5 m	-	-	-	-
2	r = 20 m	-	-	-	-	-

MODULO HD – SINGOLA TORRE

Test di sensibilità per i parametri di viscosità e scabrezza al fondo:



Smagorinsky = 0.5 Manning = 32



Smagorinsky = 0.5 Manning = 30



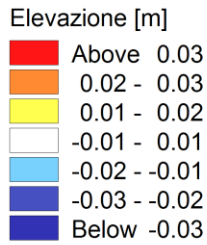
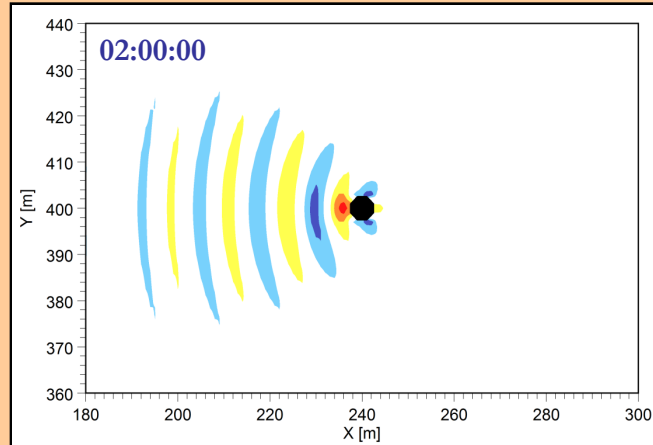
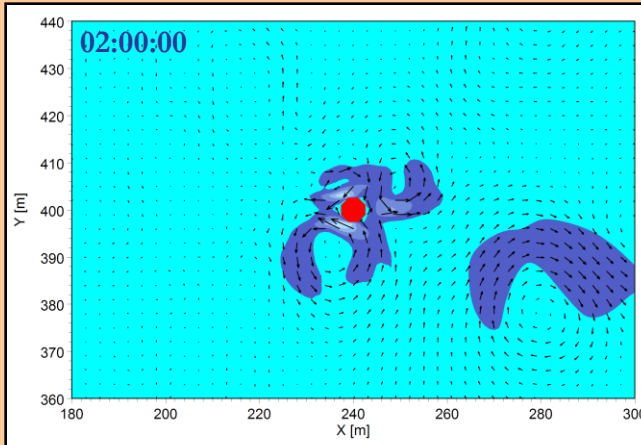
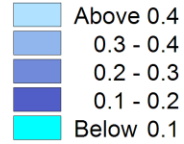
Smagorinsky = 1 Manning = 30

Onda 0

($H = 1\text{m}$, $T = 4\text{s}$)

→
0.5 m/s

Velocità [m/s]

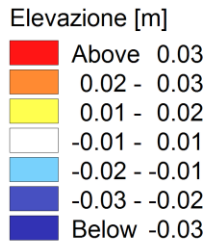
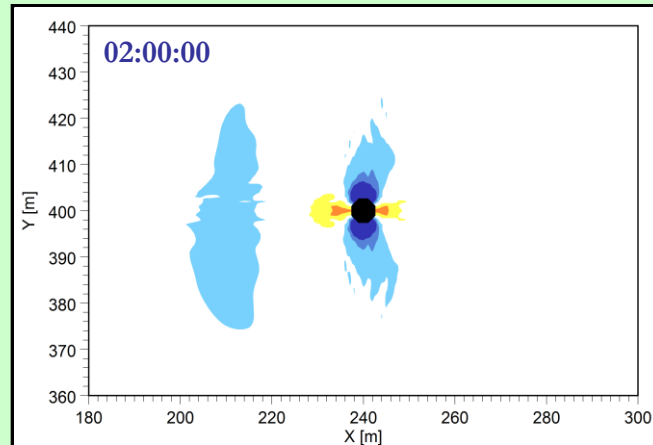
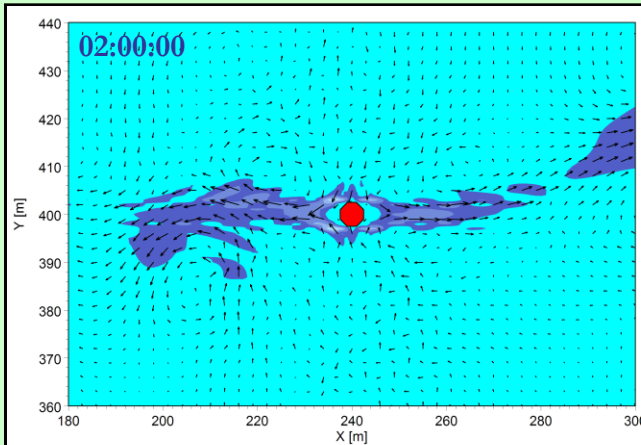
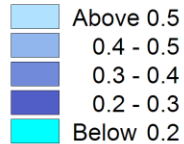


Onda 1

($H = 3\text{m}$, $T = 7\text{s}$)

→
0.5 m/s

Velocità [m/s]

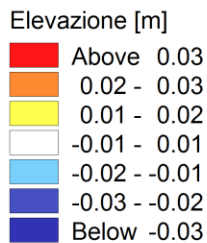
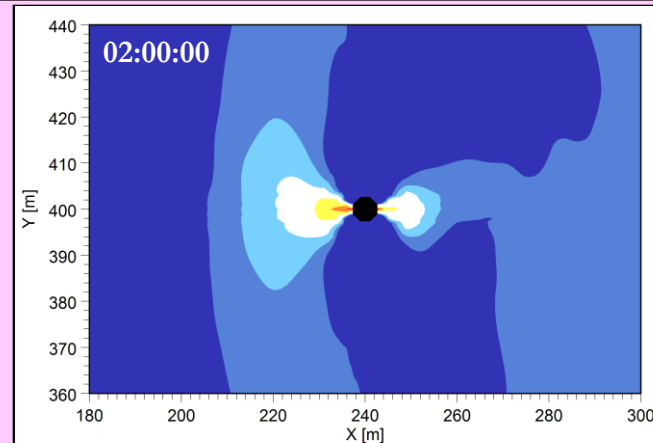
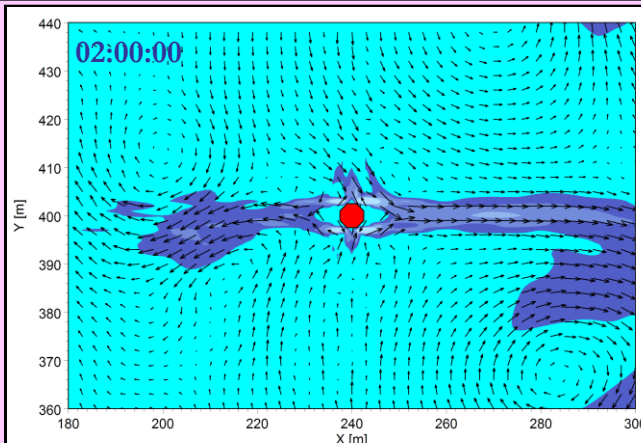
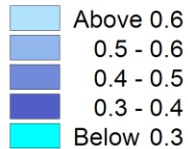


Onda 2

($H = 6\text{m}$, $T = 10\text{s}$)

→
0.5 m/s

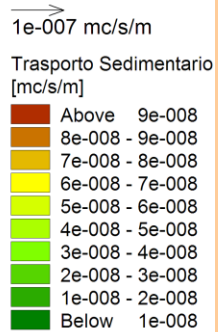
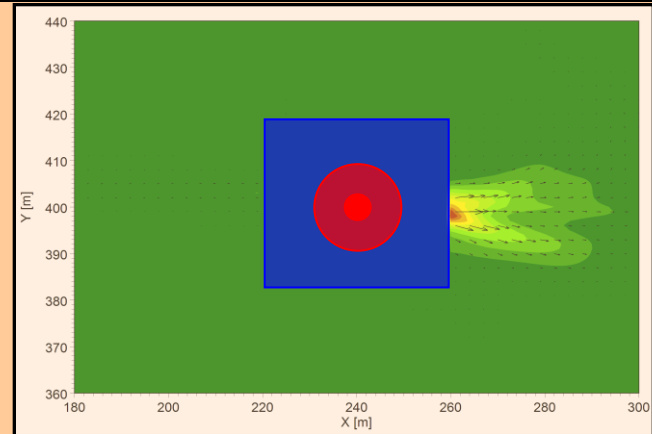
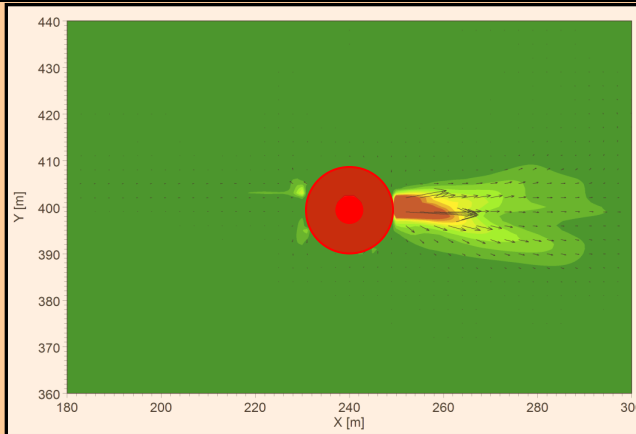
Velocità [m/s]



MODULO ST – SINGOLA TORRE

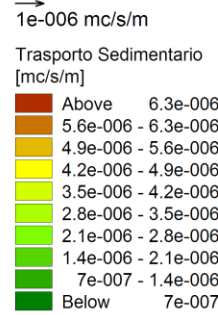
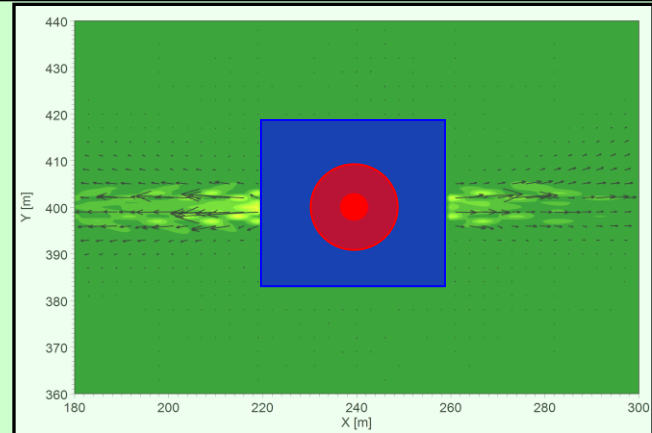
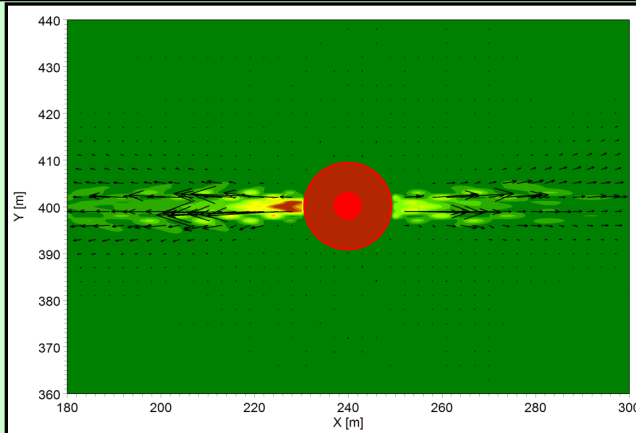
Onda 0

($H = 1m, T = 4s$)



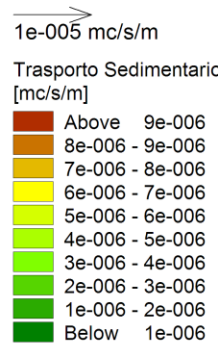
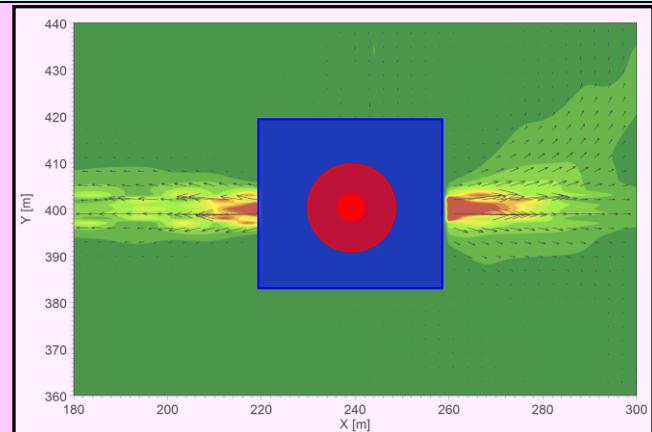
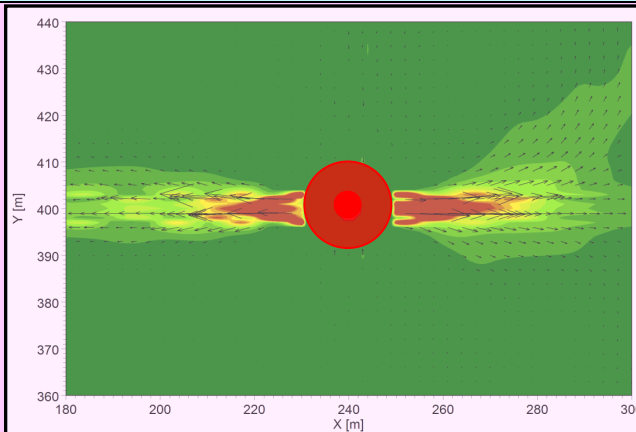
Onda 1

($H = 3m, T = 7s$)



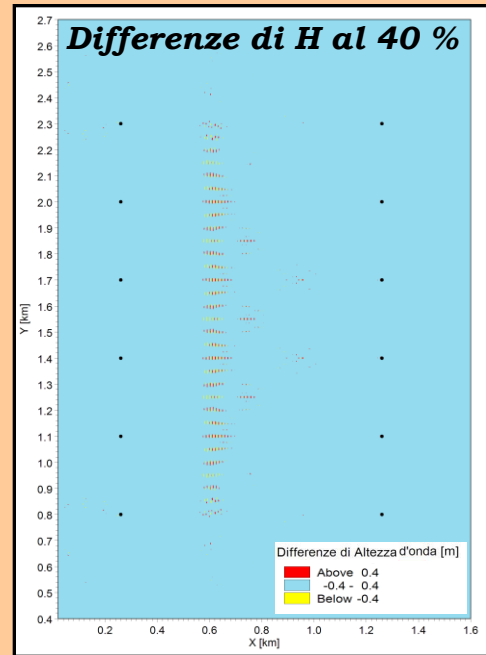
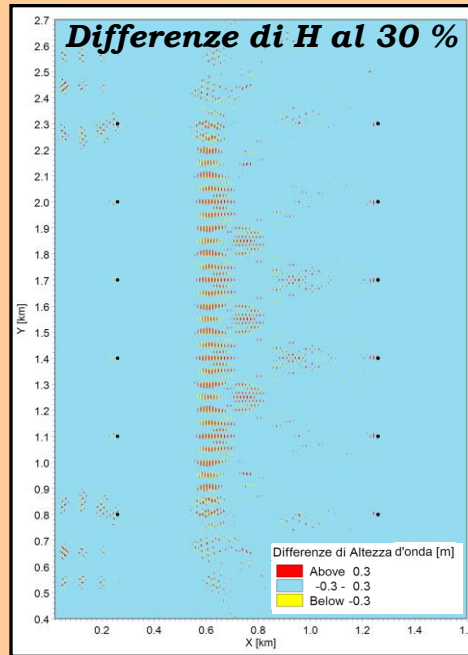
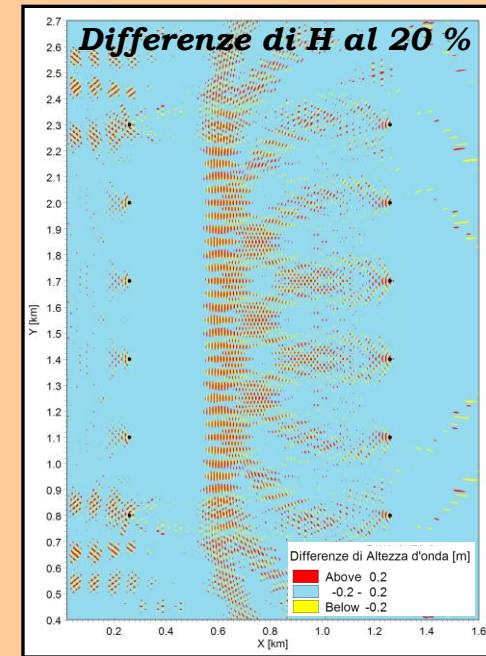
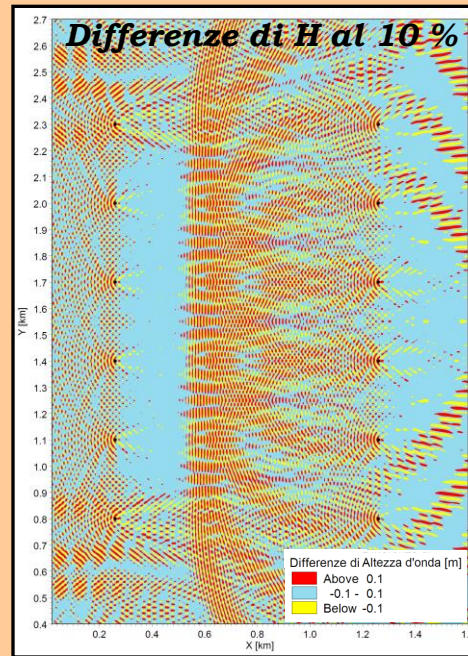
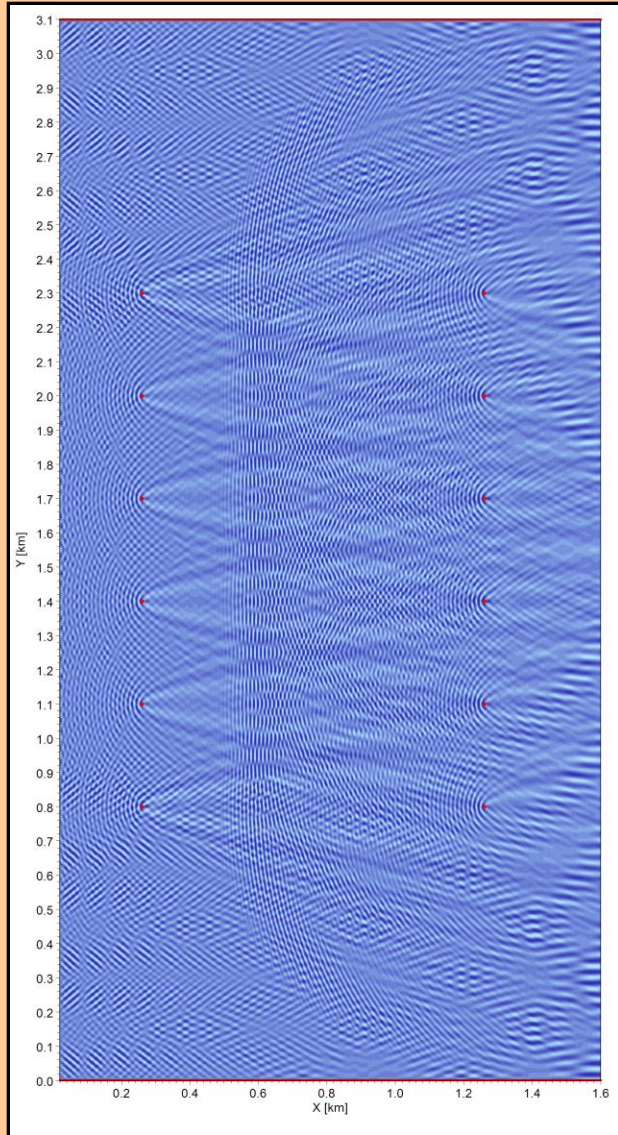
Onda 2

($H = 6m, T = 10s$)

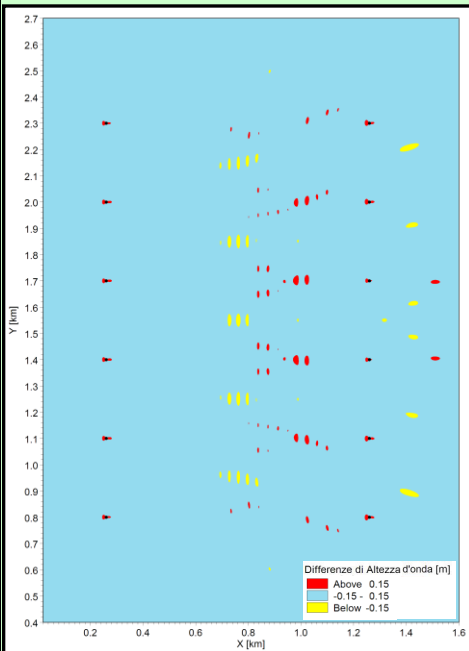


MODULO EMS – PARCO IDEALE

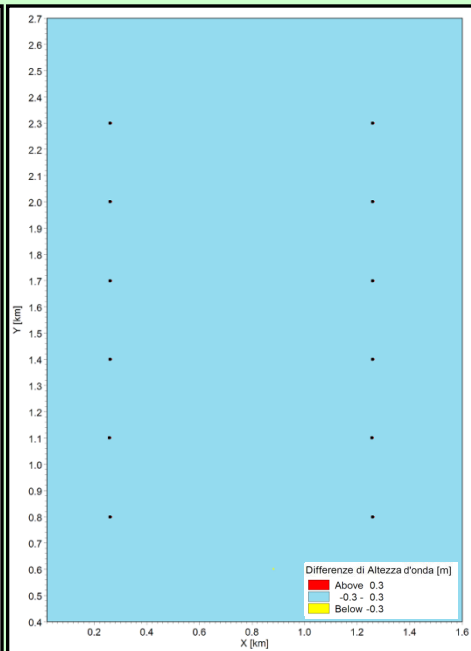
Onda 0 ($H = 1m$, $T = 4s$)



Onda 1 ($H = 3m$, $T = 7s$)

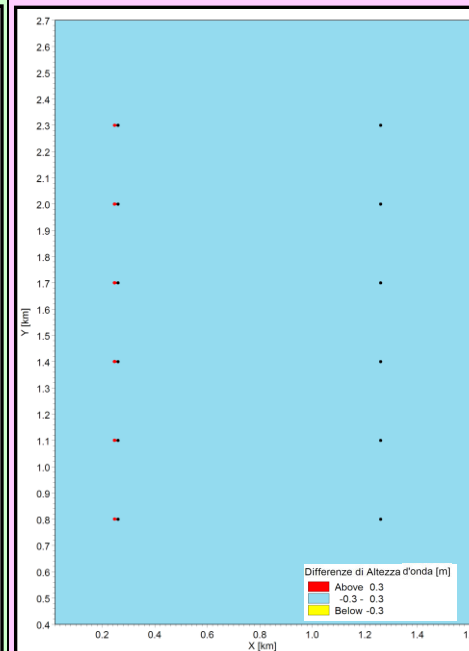


Differenze di H al 5 %

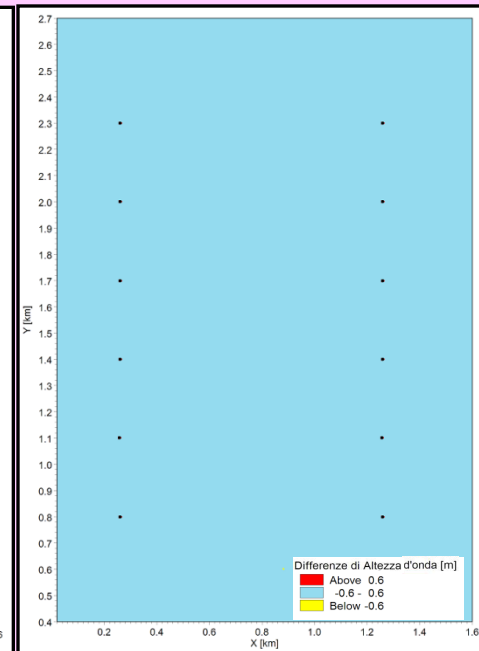


Differenze di H al 10 %

Onda 2 ($H = 6m$, $T = 10s$)



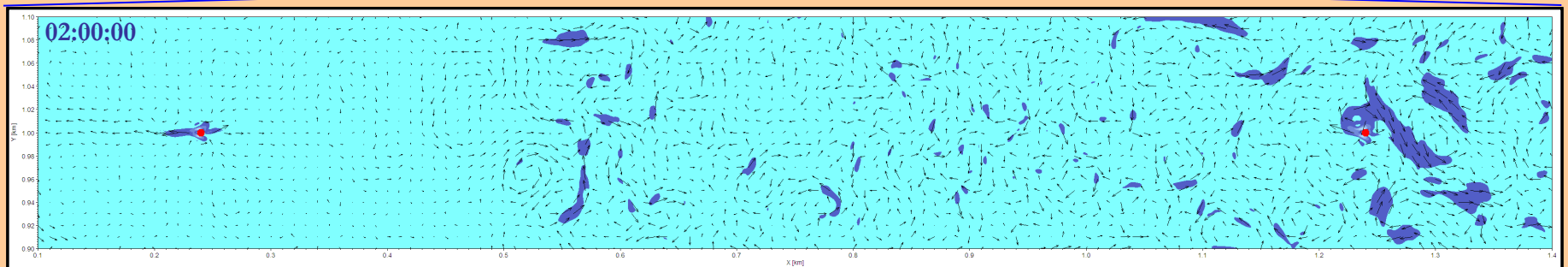
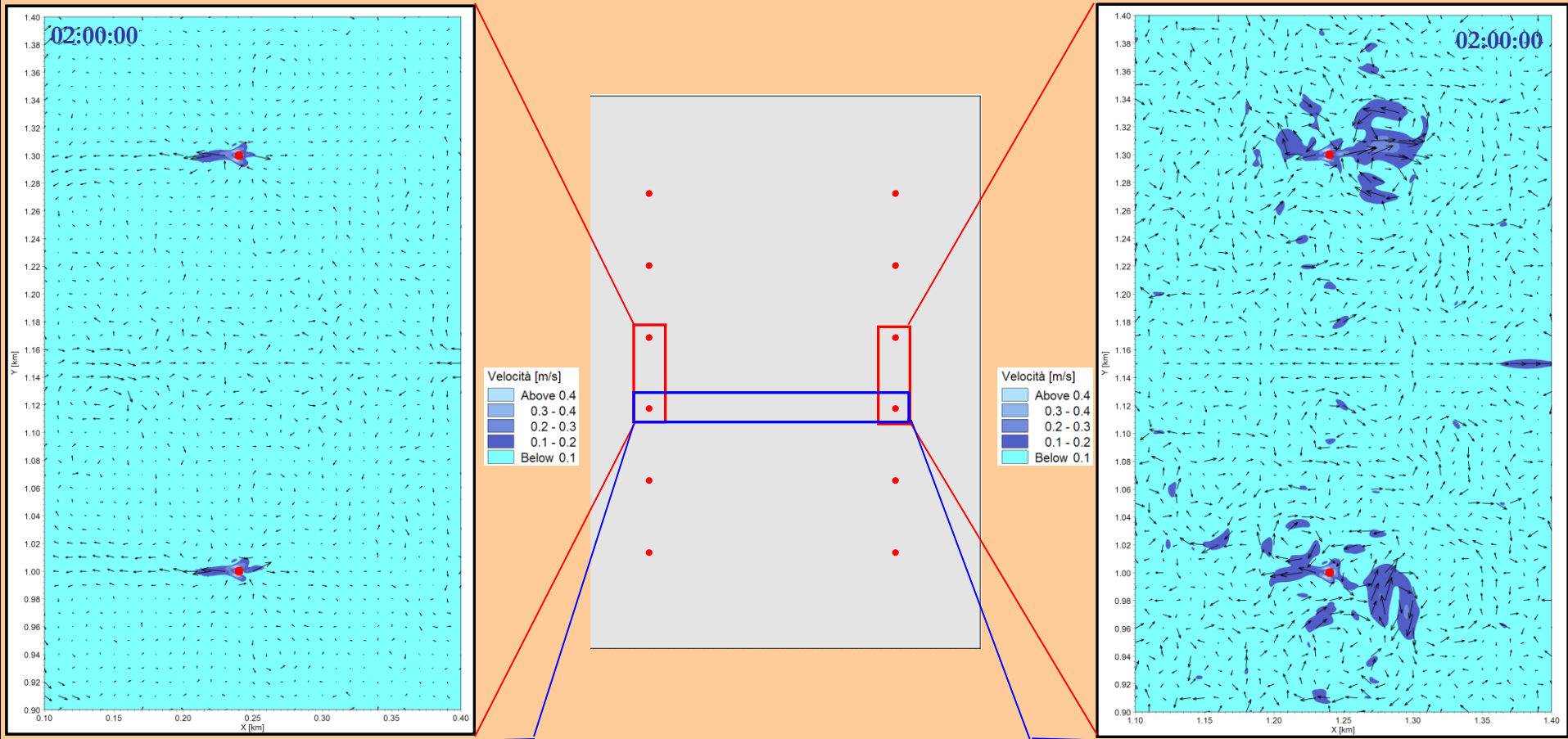
Differenze di H al 5 %



Differenze di H al 10 %

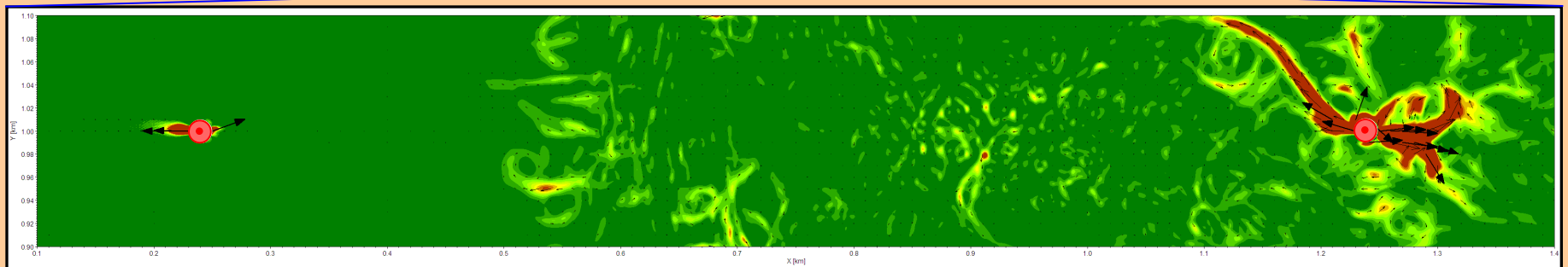
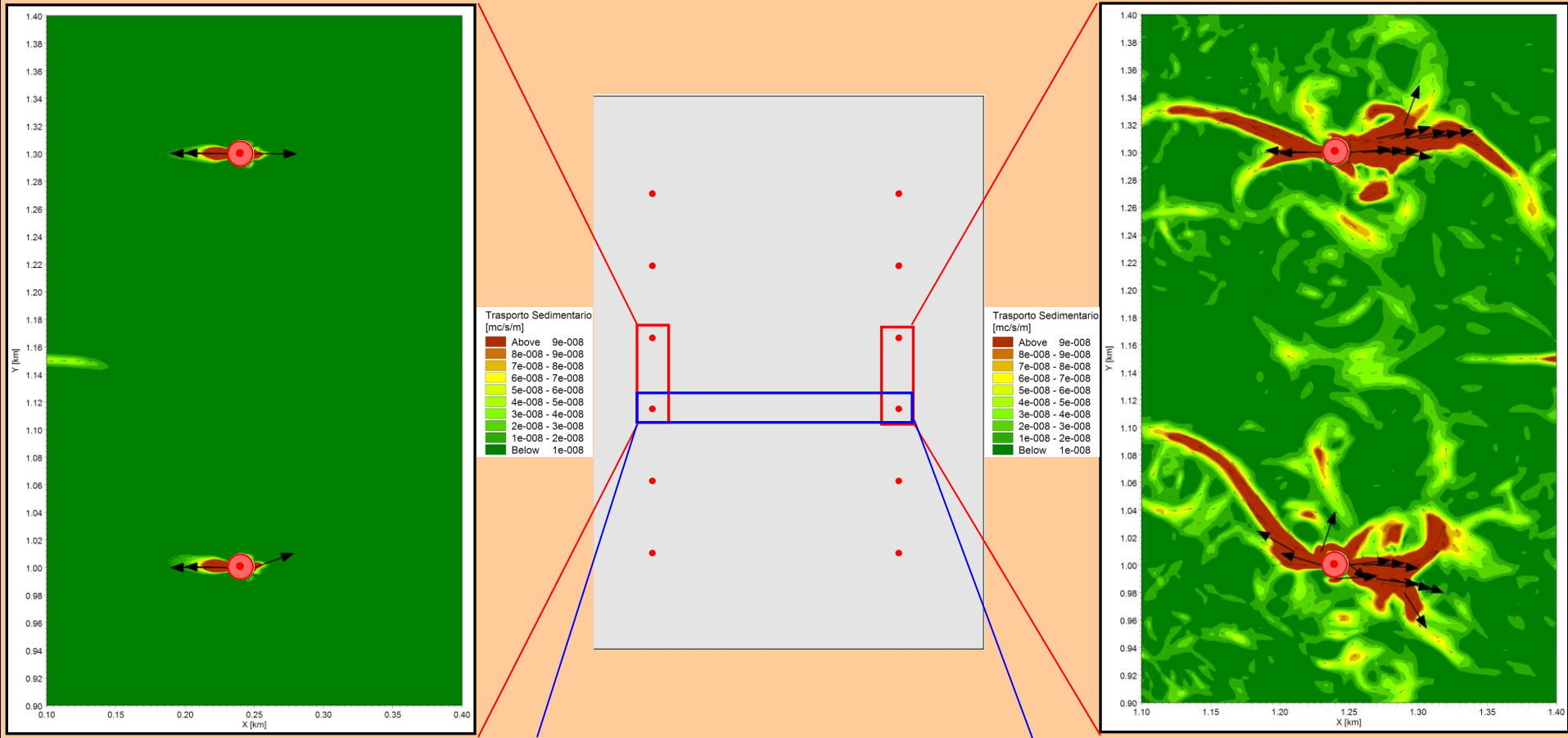
MODULO HD – PARCO IDEALE

Onda 0 ($H = 1m$, $T = 4s$)



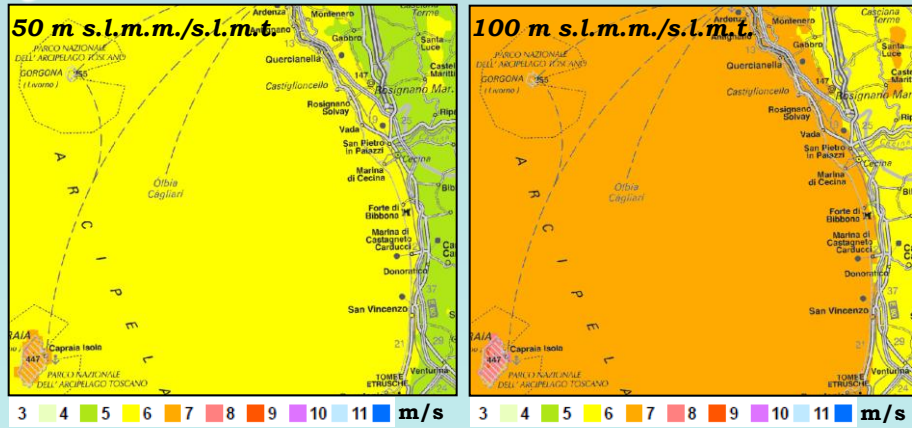
MODULO ST - PARCO IDEALE

Onda 0 ($H = 1m$, $T = 4s$)

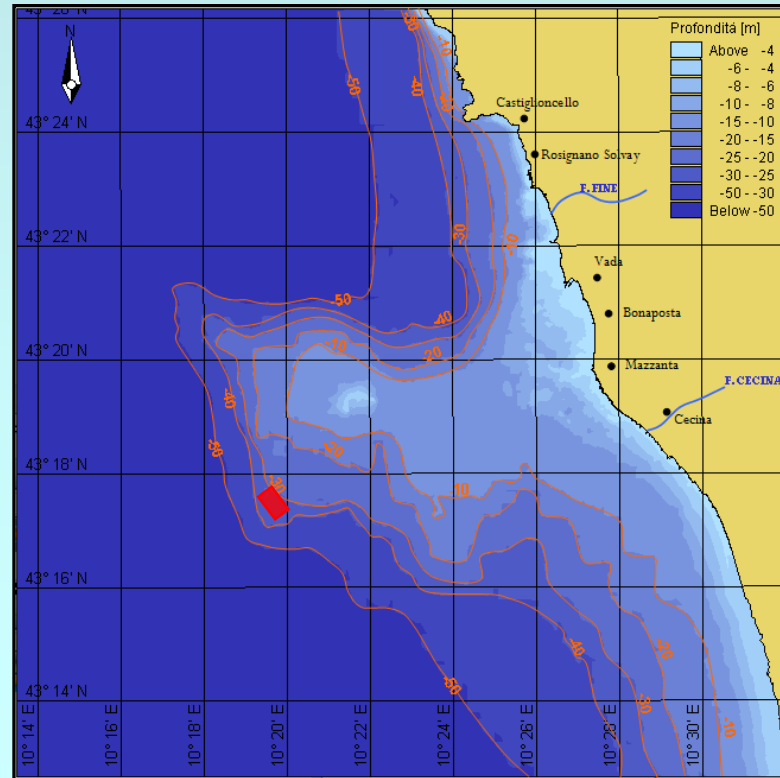
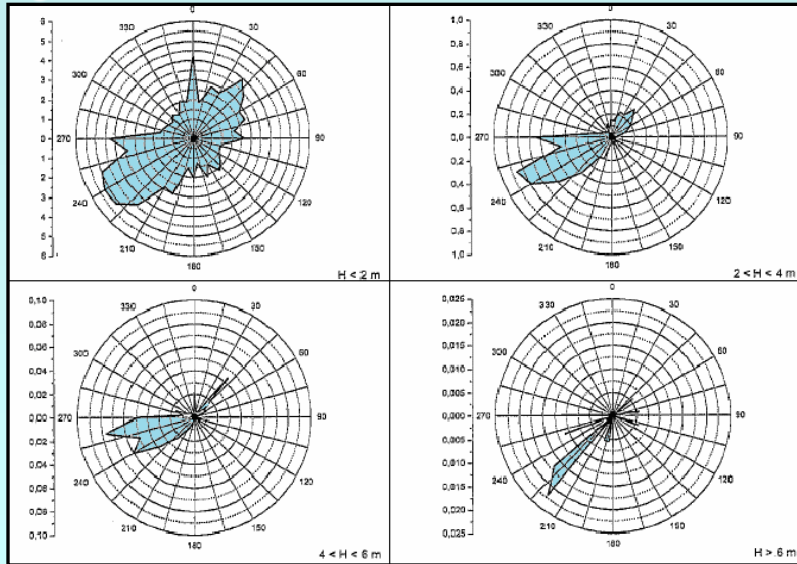


SCELTA DEL SITO SU BATIMETRIA REALE

Regime anemometrico :

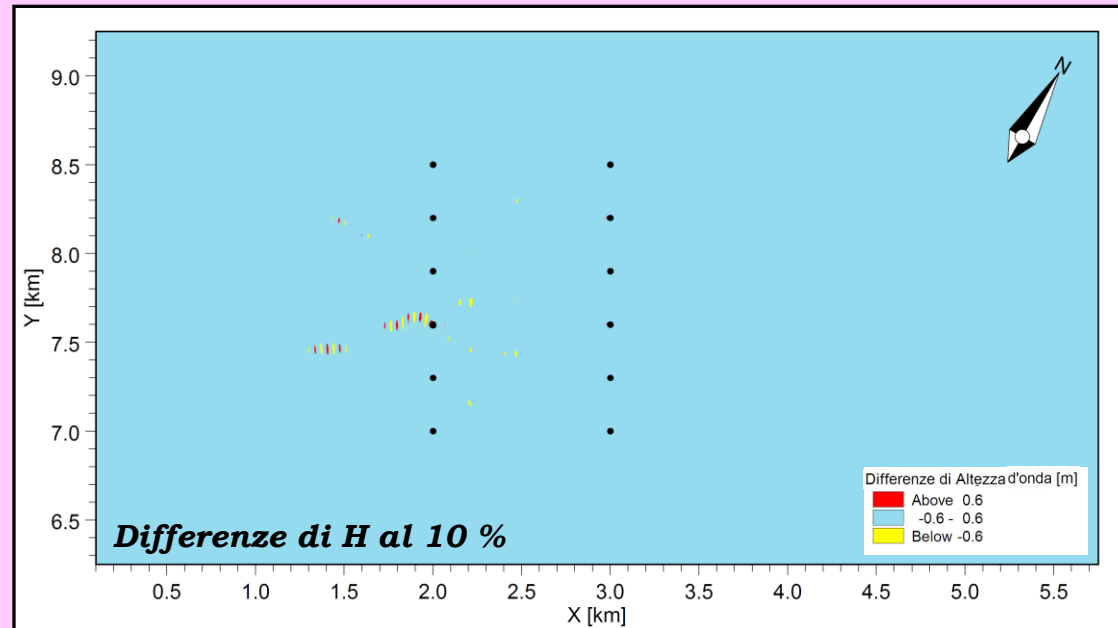
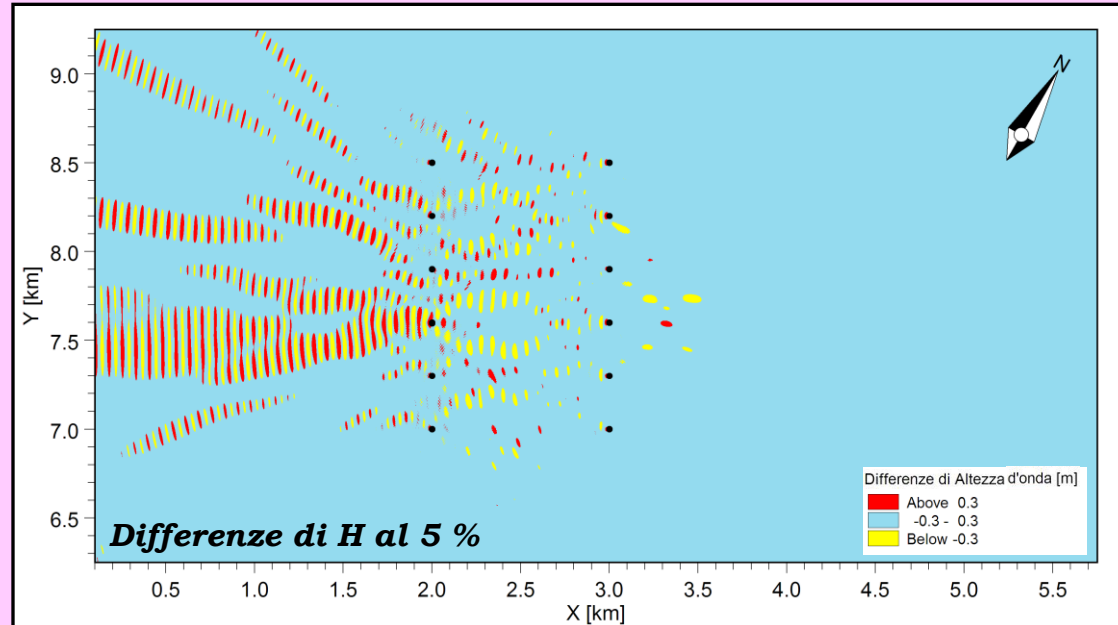
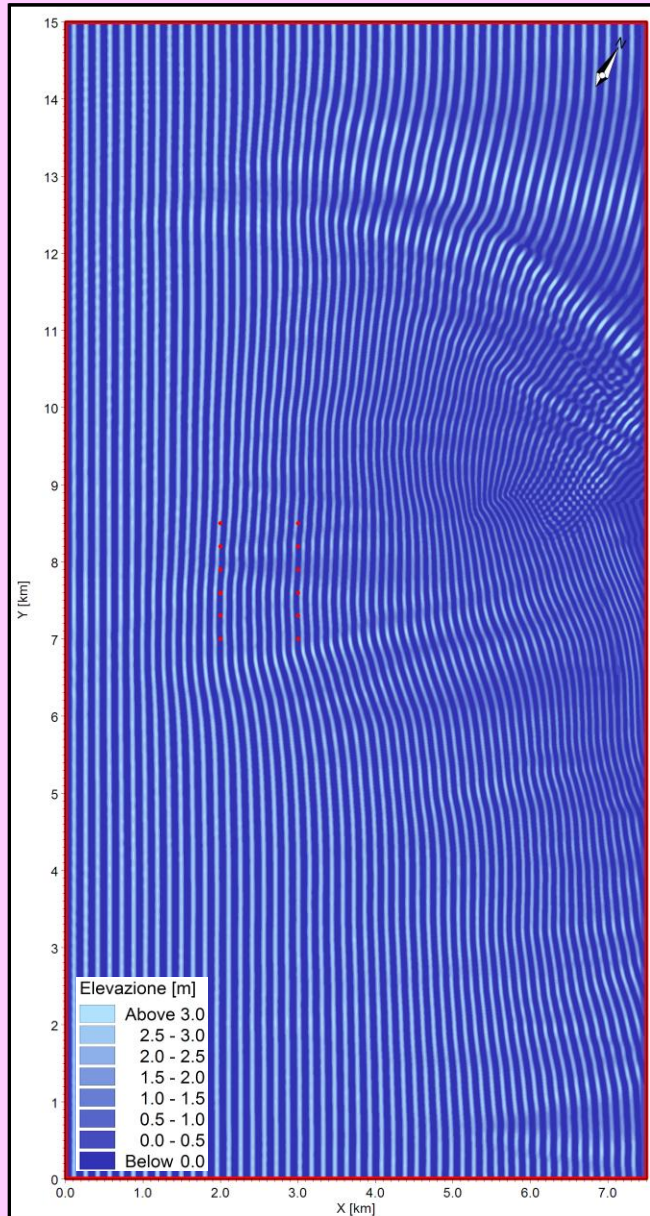


Regime moto ondoso :



MODULO EMS – PARCO REALE

Onda 2 ($H = 6m$, $T = 10s$)

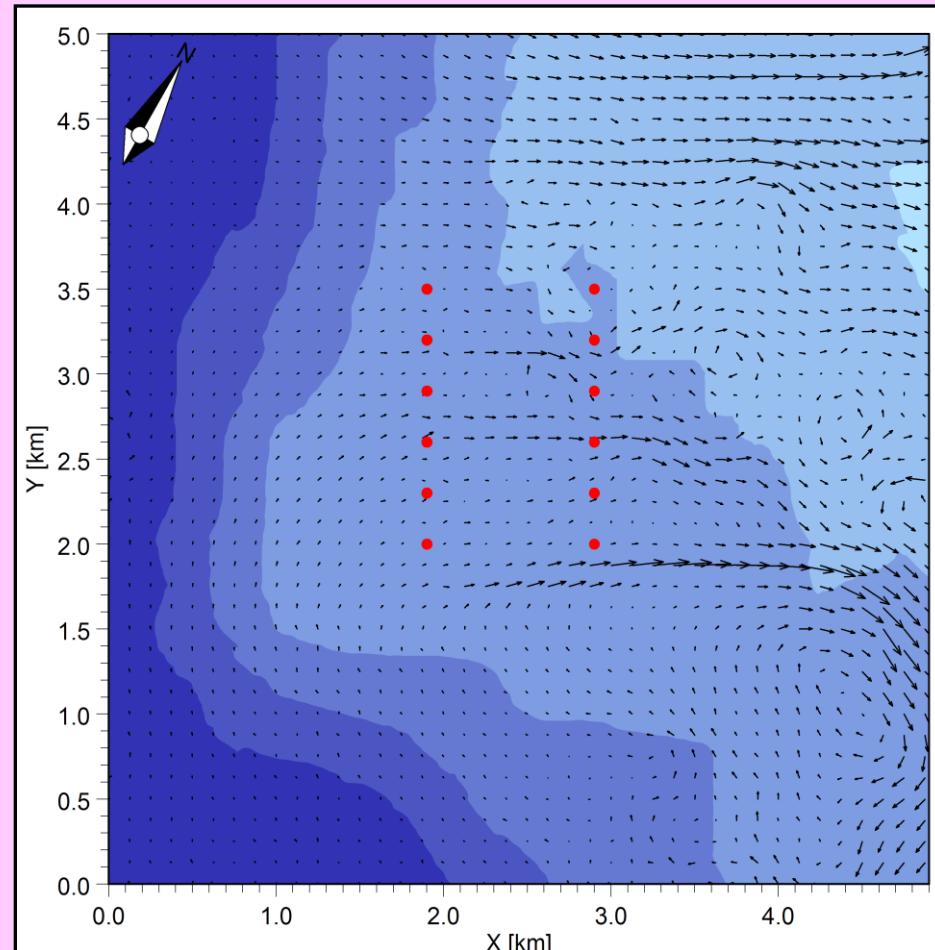
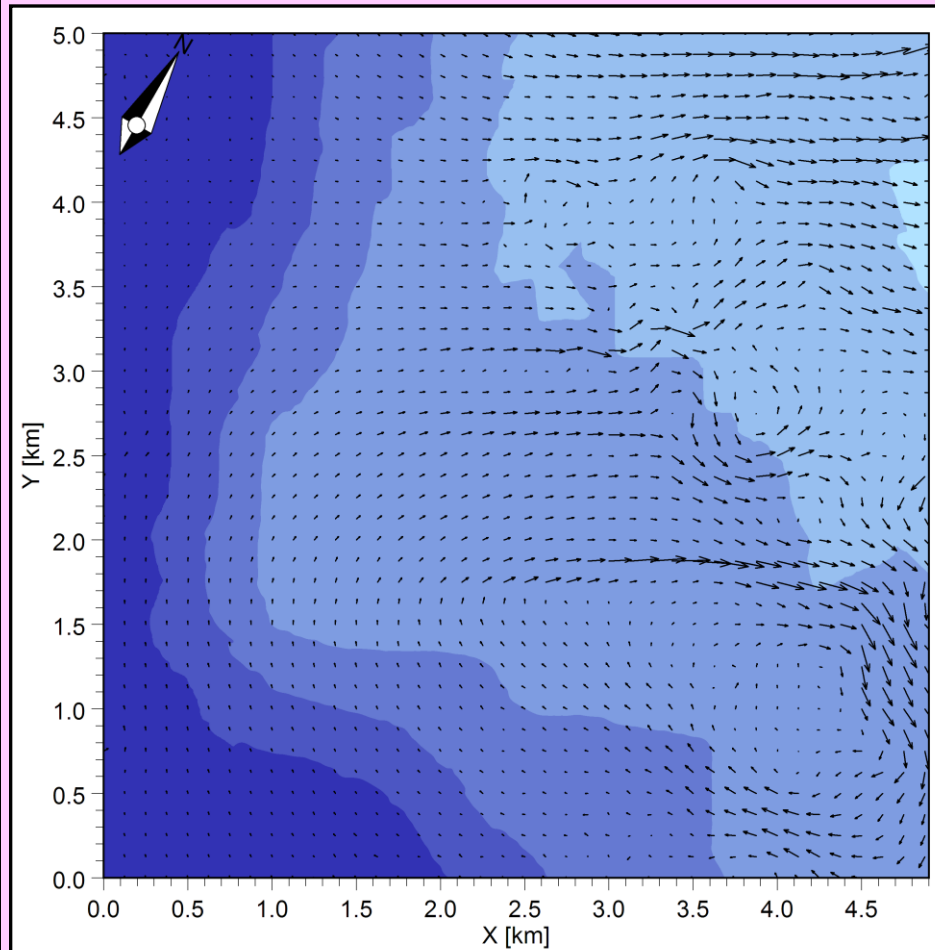


MODULO HD – PARCO REALE

Onda 2 ($H = 6m$, $T = 10s$)

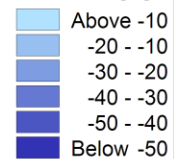
Stato attuale

Ipotesi



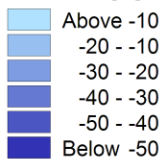
→
2 m/s

Profondità [m]



→
2 m/s

Profondità [m]

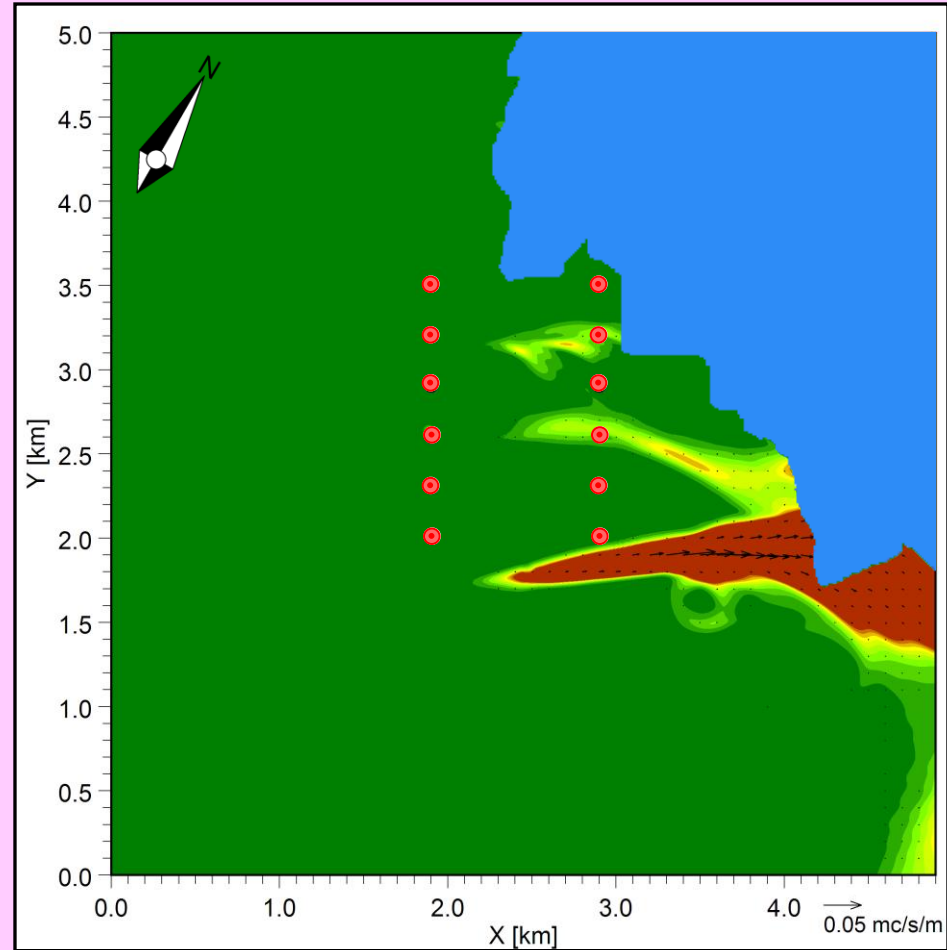
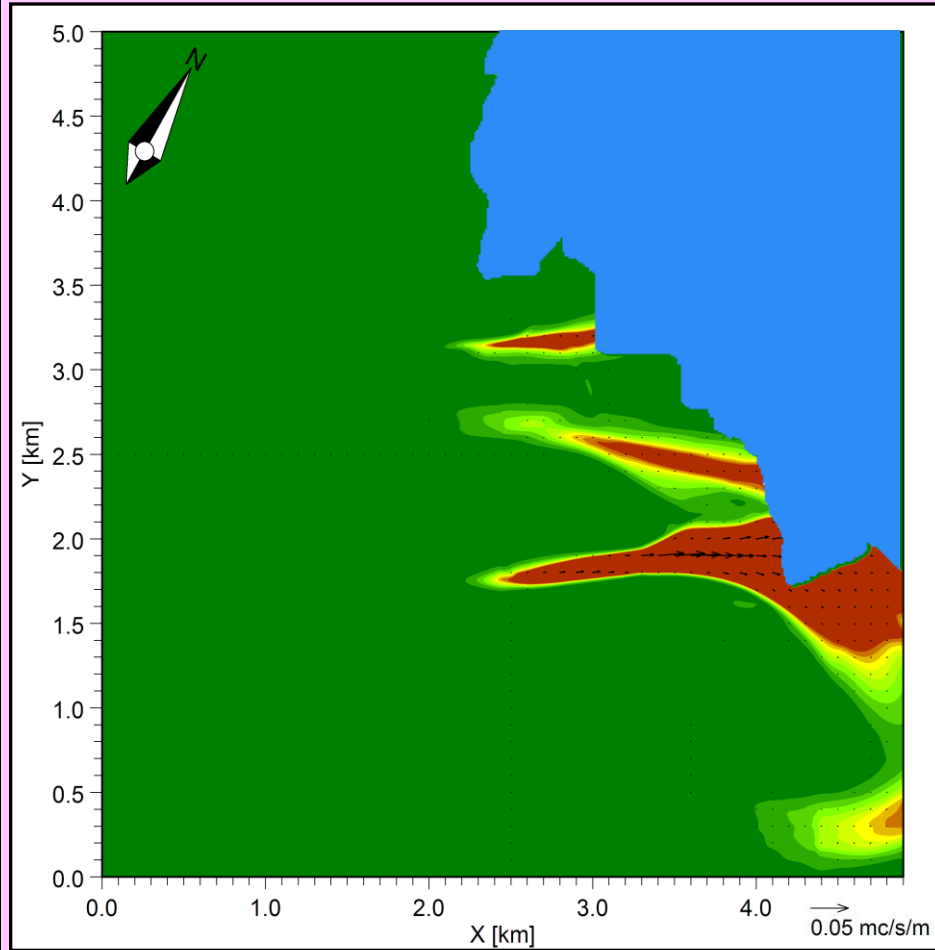


MODULO ST – PARCO REALE

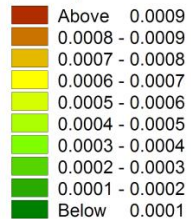
Onda 2 (H = 6m, T = 10s)

Stato attuale

Ipotesi

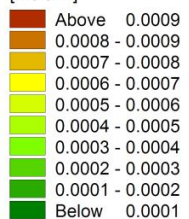


Trasporto Sedimentario [mc/s/m]



Superficie non erodibile

Trasporto Sedimentario [mc/s/m]



Superficie non erodibile

CONCLUSIONI

- I moti ondosi generati dalle onde prese in esame danno luogo a modifiche più pronunciate davanti alla struttura, meno evidenti a tergo.
- L'onda più corta è responsabile delle alterazioni più significative al moto ondoso.
- I campi di corrente sono localizzati solo attorno alle fondazioni, non c'è interazione tra perturbazioni prodotte da torri adiacenti.
- I flussi di sedimento sono intensi e localizzati attorno alle fondazioni, è quindi importante studiare sistemi per la protezione al piede della fondazione.
- I modelli numerici sono un potente strumento come ausilio al monitoraggio e alla progettazione.

