Effect of Clay Content on Sediment Suspension over Liquefied Sand-clay Mixed Bed under Waves

Jun Zhang[a], Qin Jiang[a,*] , Changkuan Zhang[a], Lizhu Wang[b]

a. College of Harbor, Coastal and Offshore Engineering, Hohai University. Nanjing, Jiangsu, China

b. School of Marine Science and Engineering, Nanjing Normal University, Nanjing, Jiangsu, China

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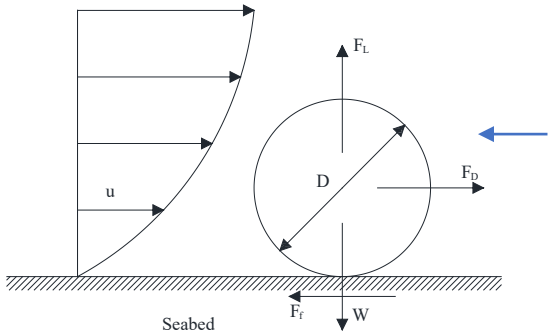
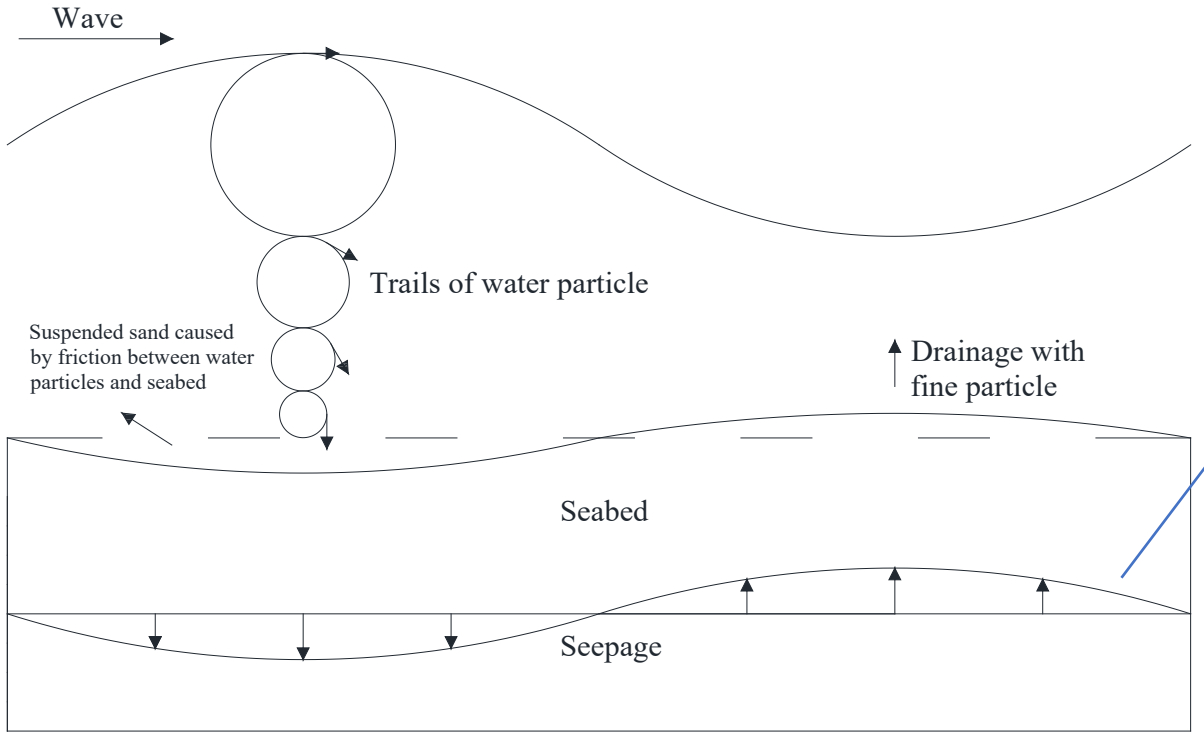
Introduction

Waves play a crucial role in sediment transformation

Previous studies focused on sediment incipient motion on clayey seabed surface



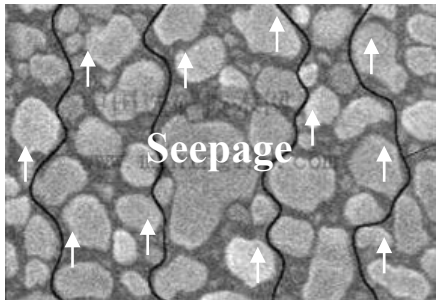
Mehta and Lee (1992) pointed out that sediment particles were moved by the lifting force, drag force, buoyant weight and cohesive force



However!

Few studies paid attention to the liquefaction (EPP accumulation) on sediment suspension of clayey bed

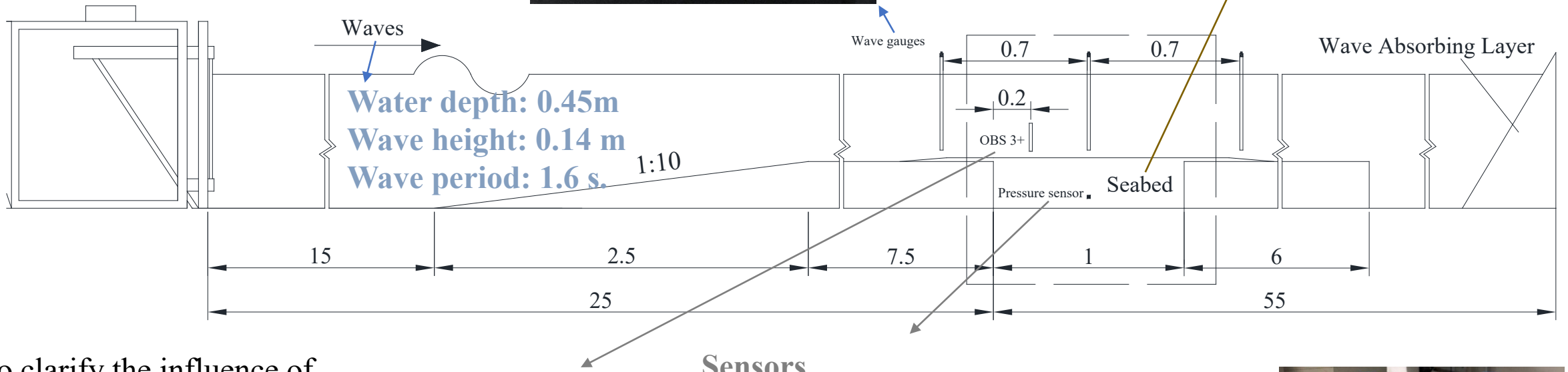
Some studies found the influence of pore pressure inside sandy seabed on sediment suspension



Tzang et al. (2009), Cheng et al. (2012) and Jia et al. (2014) considered that excess pore-water pressure (EPP) accumulated under waves would cause not only seabed liquefaction but also net upward seepage flow. The seepage flow would take fine particles within bed to the water.

Methods

Wave flume experiments



CC of sand-clay bed: 2.4%, 4.9%, 7.7%, 9.9% and 14.2%

To clarify the influence of clay content (CC) on SSC above sand-clay seabed. Flume experiments were executed with fixed wave condition and various CC.

Sensors

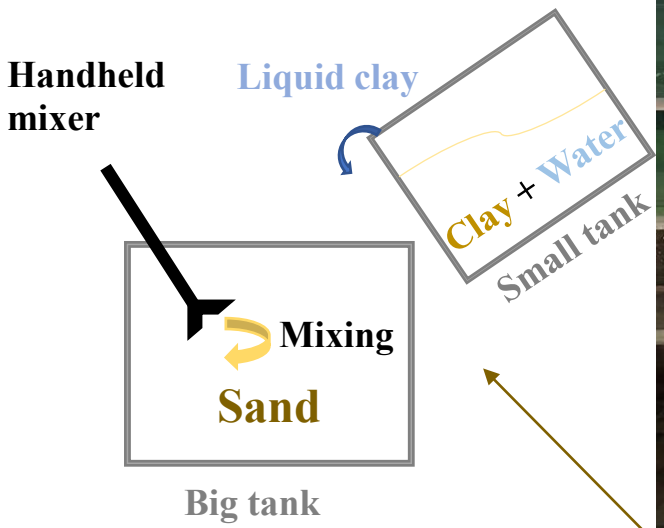
To record sediment suspension concentration (SSC)

To record pore-water pressure

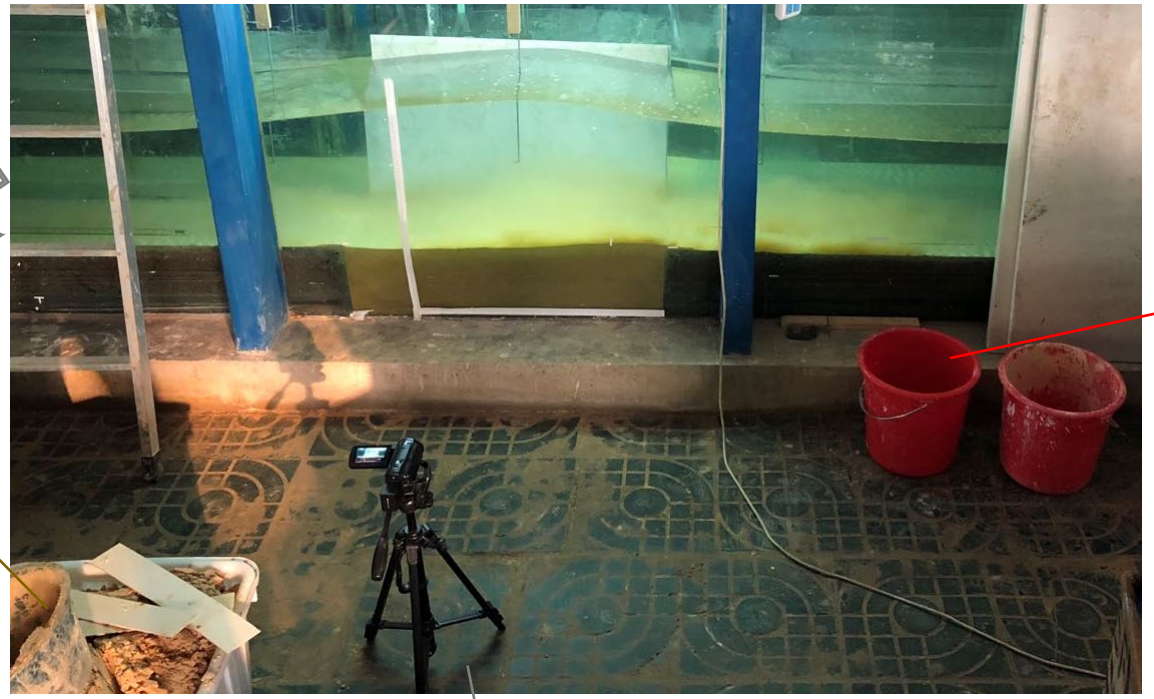
Data collector

Methods

Tanks to mix soil samples

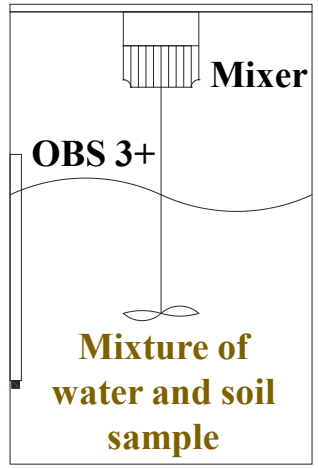


The liquid clay was added into the mixing tank and running the mixer to form a uniformed soil sample. The prepared soil sample was placed in the trench of the flume subsequently.



2K camera to record experimental video

Calibration of OBS 3+ sensor

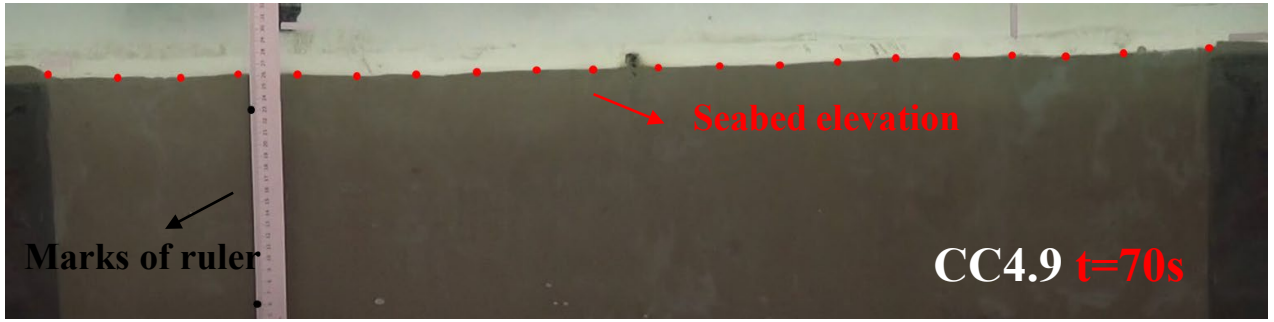


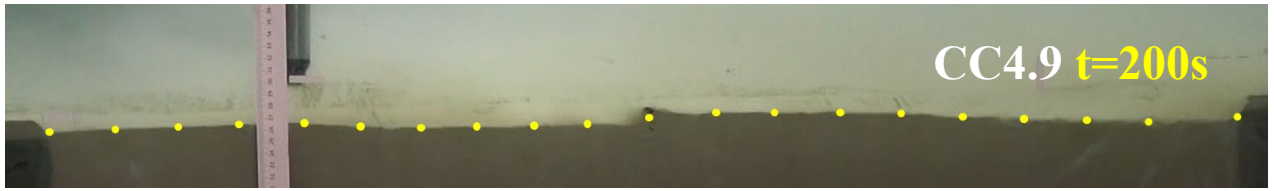
Bucket

A known quantity of well-mixed dry soil sample was dispersed into the bucket and was suspended in the water by mixer stirring. Meanwhile, OBS signal changes induced by increased SSC were recorded by the connected computer. This process was repeated with known increments of soil sample and the OBS signal were recorded and time-averaged accordingly.

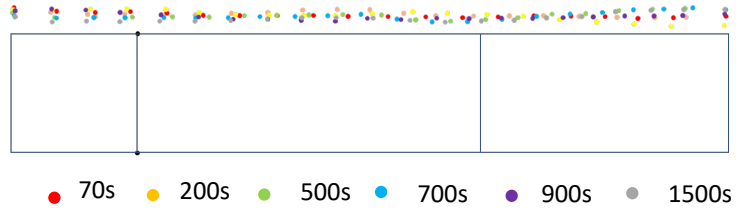
Methods

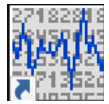
Measurement of seabed elevation





Screenshots from 2k video





GetData APP

Different time points

Coordinates of elevation points

Average elevation of CC4.9 at t=0

t=0		t=30		t=200		t=500		t=700		t=900		t=1500	
0.4	26.75	0.4	26.75	0.27	26.43	0.15	25.94	0.43	25.58	0.56	26.23	0.53	25.38
5.55	26	6.34	26.17	5.77	26.46	6.03	25.28	6.31	25.22	5.64	26.49	5.71	24.66
10.66	25.74	11.71	26	11.01	26.46	11.71	25.38	11.49	25.28	10.4	26.36	10.47	24.79
15.84	25.81	16.6	26.13	16.09	26.52	16.85	25.35	15.84	25.28	15.17	26	15.14	24.7
20.98	25.68	21.65	25.94	21.55	26.43	22.44	25.38	21.27	25.28	20.85	25.68	20.7	24.76
25.59	25.71	26.73	25.58	26.22	25.97	27.56	25.35	25.68	25.25	26.09	25.35	25.59	24.76
30.63	25.87	31.78	25.58	31.24	25.68	32.48	25.58	30.22	25.25	30.89	25.06	30.54	24.86
35.71	26	37.08	25.55	35.91	25.64	36.95	25.58	34.64	25.41	35.72	25.06	35.65	25.06
40.57	26.36	42.07	25.58	40.67	25.51	41.43	25.64	39.53	25.45	40.35	24.89	40.45	25.25
45.33	26.43	46.89	25.45	45.12	25.51	46.16	25.71	44.07	25.58	45.12	24.76	45.24	25.25
49.88	26.39	52.45	25.45	50.26	25.87	51.53	25.64	48.7	25.74	49.56	25.15	50.36	25.22
54.64	25.87	57.69	25.38	55.88	26.07	56.33	24.96	53.69	25.06	54.23	24.99	55.5	24.89
59.09	25.55	62.84	25.28	60.71	25.94	61.16	24.76	58.58	24.66	59.22	25.19	60.39	24.63
64.33	25.48	67.76	25.38	66.2	25.71	66.05	25.02	63.51	24.66	63.73	25.15	65.44	24.79
69.35	25.48	72.74	25.55	71.25	25.48	70.52	25.28	68.3	24.99	68.2	25.22	69.98	24.89
74.08	25.53	77.92	25.45	76.4	24.99	75.25	25.74	73.13	25.45	72.55	25.15	74.52	25.25
79	25.41	82.65	25.41	81.48	24.63	79.92	25.84	77.76	25.81	76.81	25.28	79.41	25.45
84.27	25.32	87.23	25.15	86.69	24.34	84.55	26.3	82.27	26	81	25.38	84.11	26.13
89.54	25.25	92.15	25.28	91.83	24.01	89.25	26.49	86.59	26.39	85.38	25.51	89.03	26.3
93.89	25.35	99.48	25.48	99.23	24.17	93.79	26.59	90.81	26.49	89.48	25.51	93.6	26.43
99.32	25.9					99.35	26.49	94.87	26.65	93.45	25.58	99.32	26.39
								99.48	26.39	99.29	25.77		
	25.80476		25.627		25.591		25.5905		25.53955		25.44364		25.23048

Results and Discussion

Seabed response under waves

CC (%)	P_{acc} (kPa)	σ_0 (kPa)	SSC (g/L)
0	0.067	1.226	6.629
2.4	1.705	1.154	5.879
4.9	1.544	1.118	2.651
7.7	1.519	1.096	1.952
9.9	0.928	1.065	1.033
14.2	0.622	1.023	0.32

Liquefaction occurred

Clay content of sand-clay mixed bed

Accumulation of EPP at z=0.23m in mixed bed with different CC

Critical mean normal effective stress
Seabed liquefy when P_{acc} is bigger than σ_0

Suspended sediment concentration

Tzang (2009)
Sandy bed

Cheng (2012)
Sandy and Silty bed

Jia (2014)
Silty bed

→ $SSC_{liquefied} > SSC_{non\text{-}liquefied}$

Cohesionless seabed

This study → $SSC_{liquefied} > SSC_{non\text{-}liquefied}$

CC2.4-7.7 CC9.9-14.2

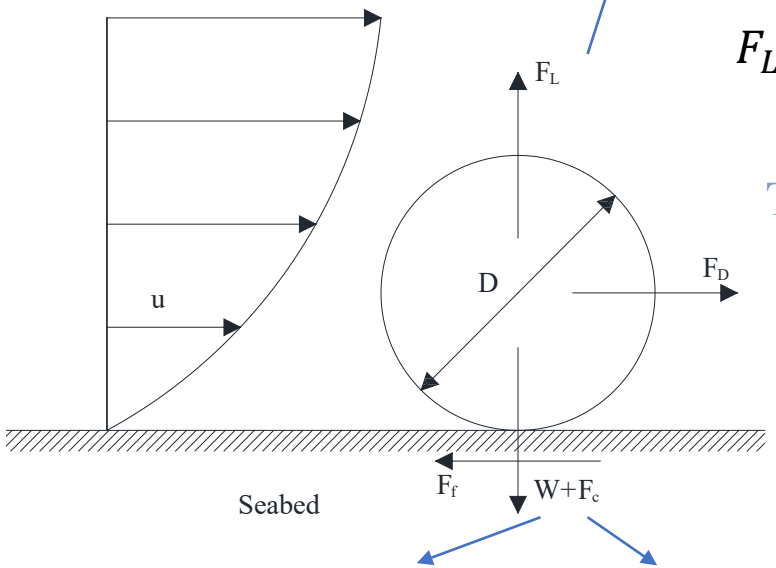
WHY?

$SSC_{liquefied} < SSC_{non\text{-}liquefied}$

CC2.4-7.7 Sand

Results and Discussion

Sediment incipient motion



The lifting force caused by EPP accumulation

$$F_L = \frac{\pi D^2}{4}\frac{P_{acc}}{z}$$

The drag force

$$F_D = C_D \frac{\pi D^2}{4}\frac{\rho_w U_{fm}}{2}$$

The buoyant weight

$$W = \frac{g\pi D^3}{6}\gamma'$$

The cohesive force Dafalla's (2013)results were used here

The horizontal force of sediment particle is almost unchanged, cause the wave condition and water depth are unchanged. So, the vertical force on particle should be analyzed.

Vertical forces on sediment particle

CC (%)	F_L (kPa)	F_c (kPa)	W (kPa)	F_v (kPa)
0	0.29	0	1.91	-1.62
2.4	7.41	2.35	1.86	3.2
4.9	6.71	4.73	1.83	0.15
7.7	6.60	7.11	1.82	-2.33
9.9	4.03	9.49	1.80	-7.26
14.2	2.71	13.58	1.77	-12.64

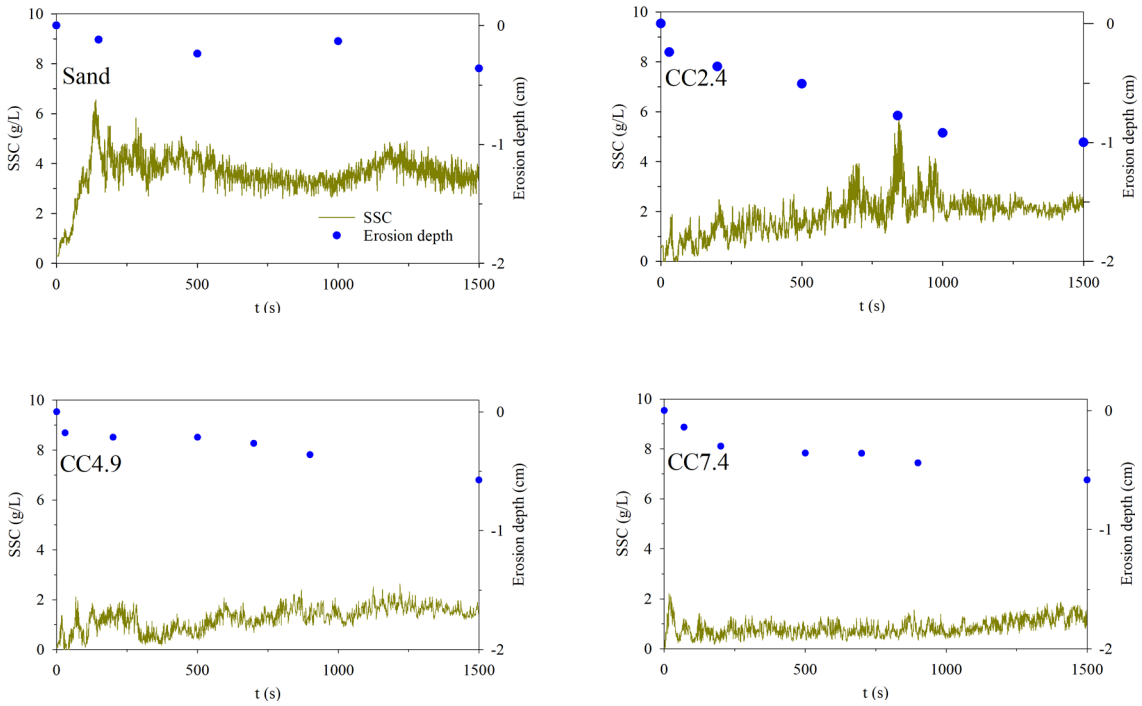
Easy to move

Hard to move

Particles on the seabed surface with 2.4% and 4.9% CC were improved to suspend to the water, particles on the seabed surface with 9.9% and 14.2% CC were hard to move, and F_v of CC7.7 is similar to that of sandy bed.

Results and Discussion

Erosion of mixed bed



Variation of SSC and seabed elevation

Seabed with 9.9% and 14.2% CC were not shown here, cause seabed elevation of these cases were unchanged.

$SSC_{Sand} > SSC_{mixed}$

$Erosion\ depth_{Sand} < Erosion\ depth_{mixed}$

The **net upward gradient** generated by EPP accumulation in the liquefied bed, which made more fine particles on bed surface or within bed suspended to the water compared with sandy bed.

But the **cohesive force** by clay made particles moved near the bed.

The sensor measured SSC in this study was set 3.5cm above the bed and it was set 1cm above bed in Tzang's study. As the result, high density suspended sediment near bed surface was not detected by the OBS sensor over the liquefied bed.

Conclusion

1) The sediment incipient motion of mixed bed was mainly influenced by the cohesive force and lifting force in this study. Particles on the mixed bed with less than 5% CC suspended easily compare with sandy bed;

2) The SSC above the mixed bed decreased with the increase of CC, and the measured SSC of mixed beds are all less than that of sandy bed;

3) The elevation of non-liquefied mixed beds (CC9.9-14.2) were almost unchanged under waves due to the high cohesive strength among particles. The erosion of liquefied beds (CC2.4-7.7) were more than that of sandy bed, because the accumulation of EPP made more sediments suspended to the water.

Thanks for watching!