At-Sea Experiment and Site Monitoring on a New Coastal Protection Engineering Method-Artificial Marine Forest

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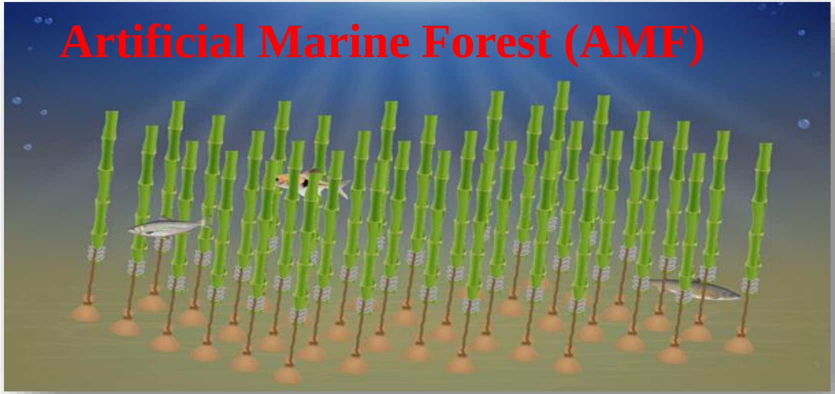
Motivation
Artificial Marine Forest

- Beach erosion is related to wave energy. Decreasing wave height is helpful to the coast protection. Natural marine plants in the coast can decrease the wave heights.
- Using the soft method can decrease rigid structures (such as build seawalls) and rebuild the natural beach.
- <u>“Bionic” apply in the real coast.</u>



■Problems

- **Laboratory experiments had been done.**

Two points we care

1).How about the efficiency for decreasing wave heights in the open sea?

2).How about the durability of Bionic structure at the sea for long-time?

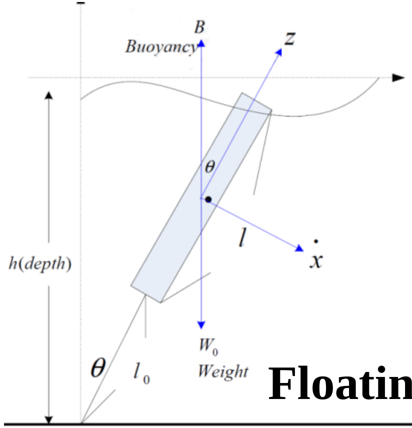
- **Prototype experiment at sea is necessary.**

Make a prototype experiment → (Observation / Measurement) → Feedback

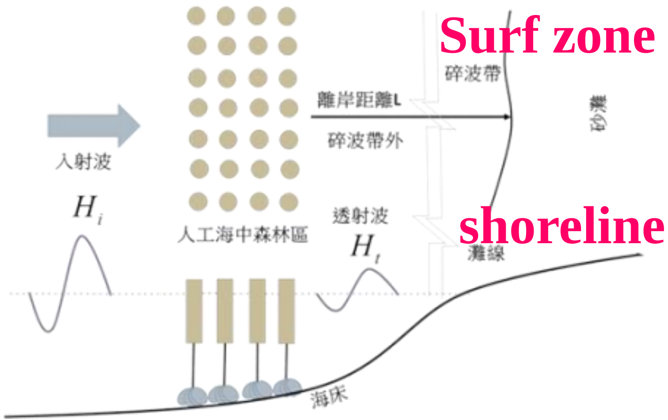
Methodology

■ Floating Unit and Artificial Marine Forest (AMF)

The concept is to make an artificial buffer zone between the beach and offshore waves for decreasing wave energy, coastal erosions and protecting the natural beach.



Floating Unit



$$A\ddot{\theta} + B\dot{\theta} + C\theta = E\cos\sigma t + F\sin\sigma t$$

$$A = \left(\frac{\frac{ml^2}{3} + ml_0(l_0 + l)}{(l_0 + \frac{l}{2})} + \rho_w C_{ax} V (l_0 + \frac{l}{2}) \right)$$

$$B = \left(\frac{1}{2}\rho_w C_{dx} D (l_0 + \frac{l}{2}) (\frac{Hgk}{\pi \cosh(kh)}) (\frac{\sinh(kh) - \sinh(k(h-l))}{k}) \right)$$

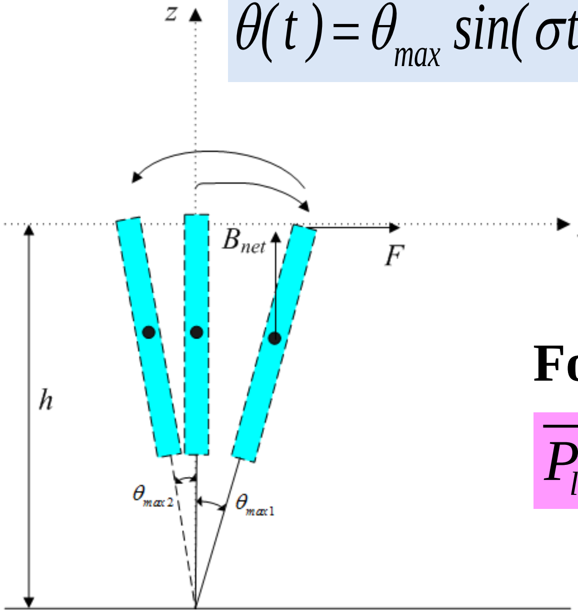
$$C = (\rho_w - \rho_s) V g$$

$$F = \left(\rho_w C_{dx} D (\frac{Hgk}{2\sigma \cosh(kh)})^2 (\frac{2kl + \sinh(2kh) - \sinh(2k(h-l))}{3k}) \right)$$

$$E = \left(-\rho_w (C_{ax} + 1)(\frac{\pi D^2}{4}) \frac{Hgk(\sinh(kh) - \sinh(k(h-l)))}{2\cosh kh} \right)$$

Considering the Work-Energy principle, Morison equation and Superposition theorem

$$\theta(t)=\theta_{max}\sin(\sigma t-\beta)$$



$$P=\int_{-l}^{0}dF\times x' dz=\int_{-l}^{0}\frac{1}{2}C_D\rho_w D|u|u\cdot x' dz$$

For wave motion

$$\overline{P_{loss}}=M\times P$$

$$M=\frac{\left(\frac{2}{\pi}\sqrt{(a-b\cos\beta)^2+(b\cos\beta)^2}\right)^3}{\left(\frac{gHk}{\pi\sigma}\frac{\cosh k(h+z)}{\cosh kh}\right)^3}$$

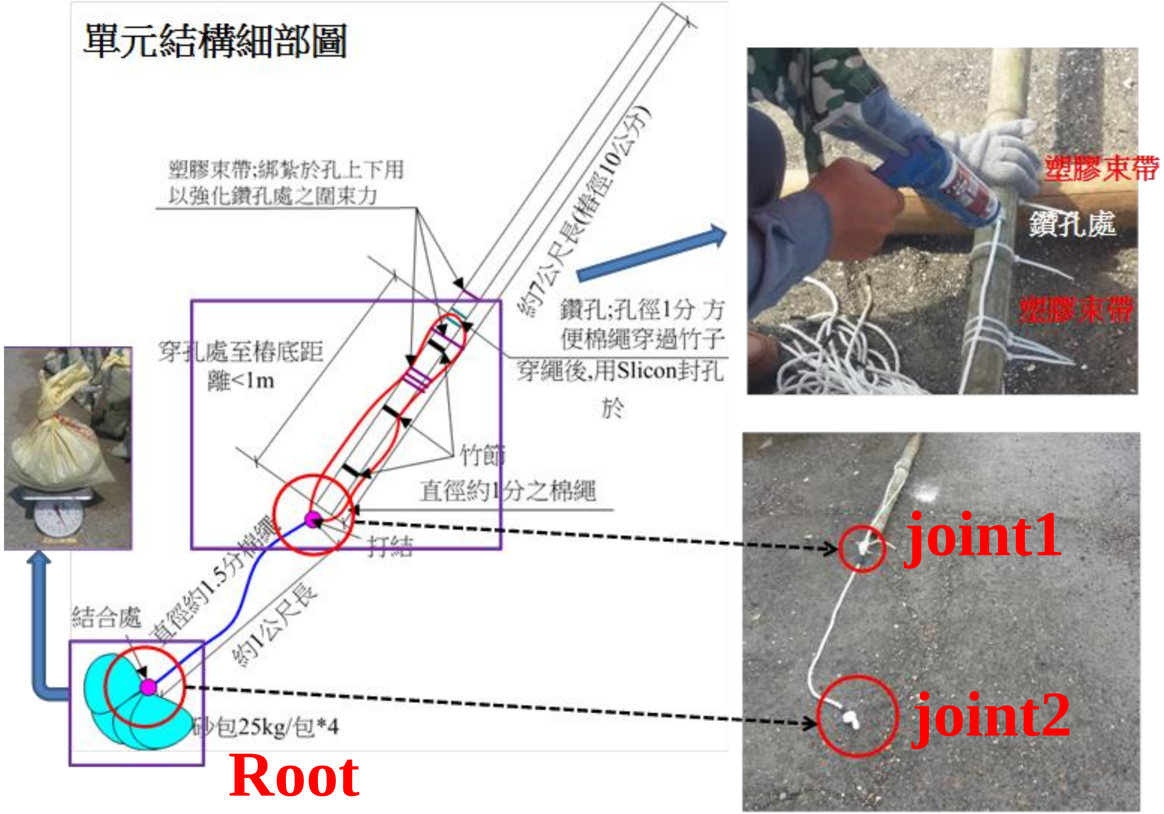
The interaction between the wave and structure induced the averaged dissipated power during one period

$$\overline{P_{loss}}=M\frac{2\pi^2}{3T^3}C_D\rho_w D[(l_0+l)^4-l_0^4]\theta_{max}^3$$

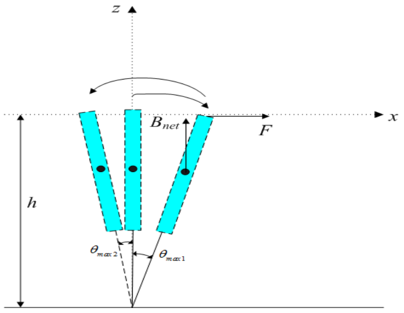
Related factors：wave condition, wave period, fluid density, the diameter of body, C_D, the length of body, the length of rope and angle

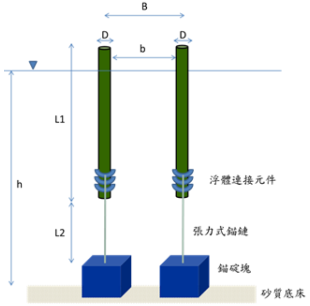
■ Design a Floating Unit

Components：bamboos, cables and sand-bags (Green materials)



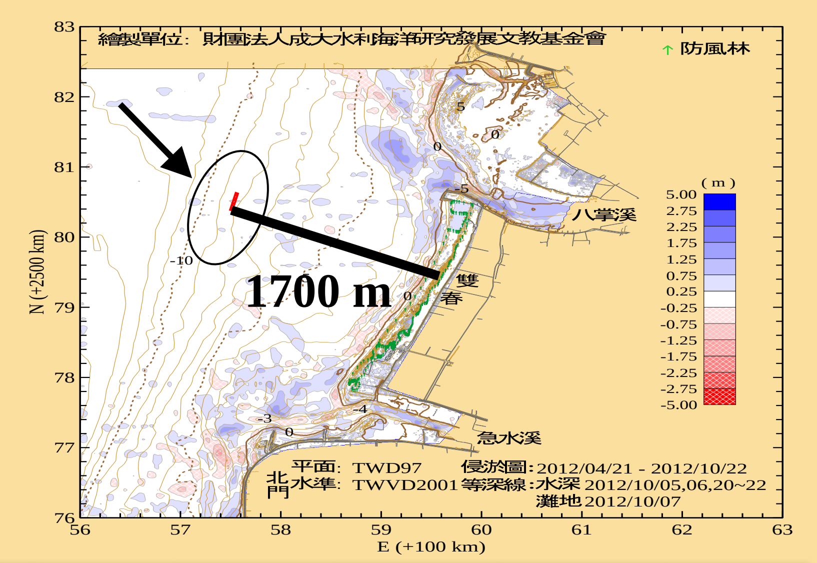
- **Cylinder floating**： Bamboos with 0.1m diameter and 7m long.
- **Anchors**： made by 4 sand -bags with 100 kgw.
- **Cable**： Diameter 1/8” with tension force 200 kg.





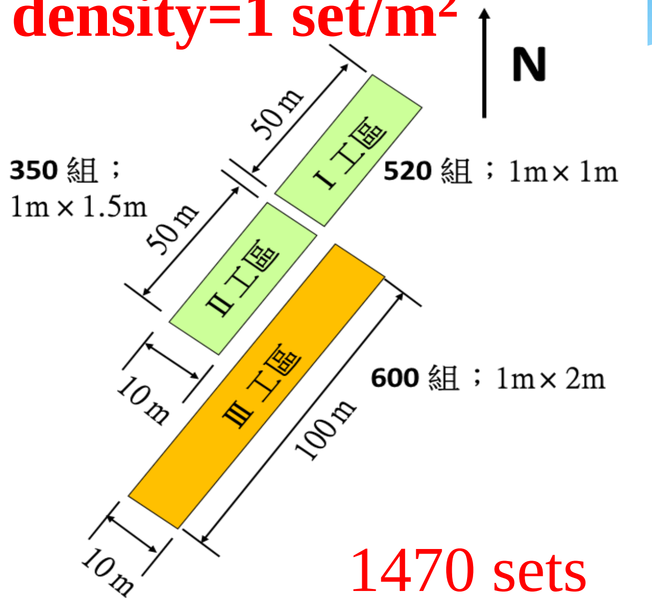
Construction

■ Experimented Site



Site for prototype experiment

Setting density=1 set/m²



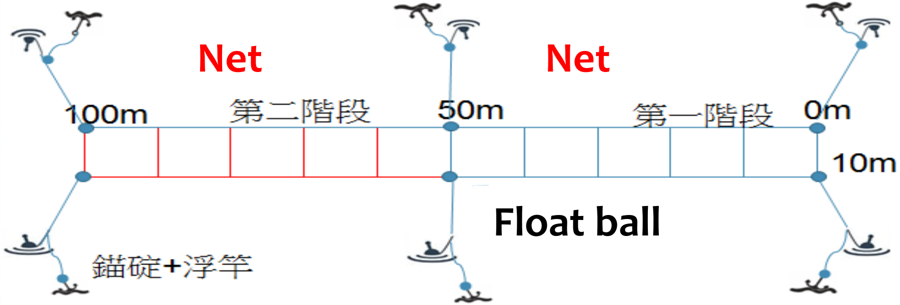
Arrangement for AMF

- **The site is located on the offshore of Shuangchun coast (southwest of Taiwan) with 7m water depth and 1.7 km offshore distance.**
- **Total 1470 sets were constructed in the 3 zones, respectively.**

Working program

- **Grid marked and position at the sea**

Loading → Transport → Supply → Setting up → Finish



Building-1st zone

項目	時間	施放組數/趟數	布置長度	備註
測試	2016/08/23	44組/1趟	4m	-
航次1	2016/08/26	115組/2趟	約12m	中午低潮過低
航次2	2016/08/27	116組/2趟	約12m	中午低潮過低
航次3	2016/09/01	119組/2趟	約12m	-
航次4	2016/09/02	64組/1趟	約6m	浪大、打雷
航次5	2016/09/06	56+6組/1趟	約6m	此6組為只綁結無打洞
累計		520組	50m	第二階段還再評估

Building-2nd zone

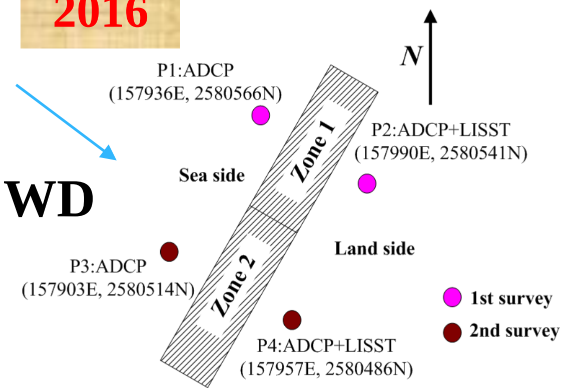
項目	時間	施放組數/趟數	布置長度	備註
航次6	2016/10/25	60組/1趟	約9m	
航次7	2016/10/27	60組/1趟	約9m	
航次8	2016/10/28	60組/1趟	約9m	
航次9	2016/11/04	60組/1趟	約9m	
航次10	2016/11/05	60組/1趟	約9m	
航次11	2016/11/06	50組/1趟	約7m	
累計		350組	50m	

Aerial View by the drone

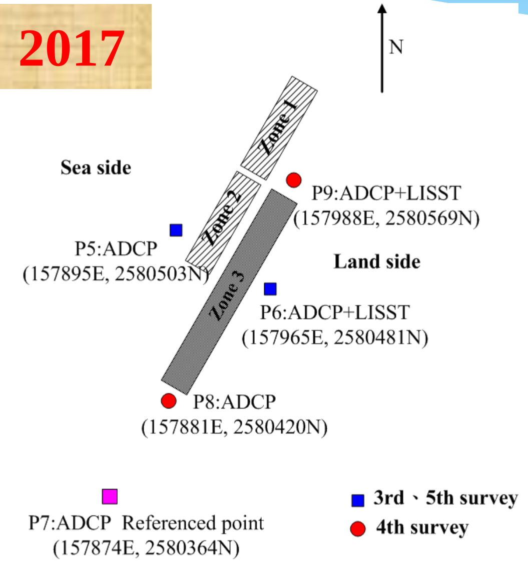
Monitoring

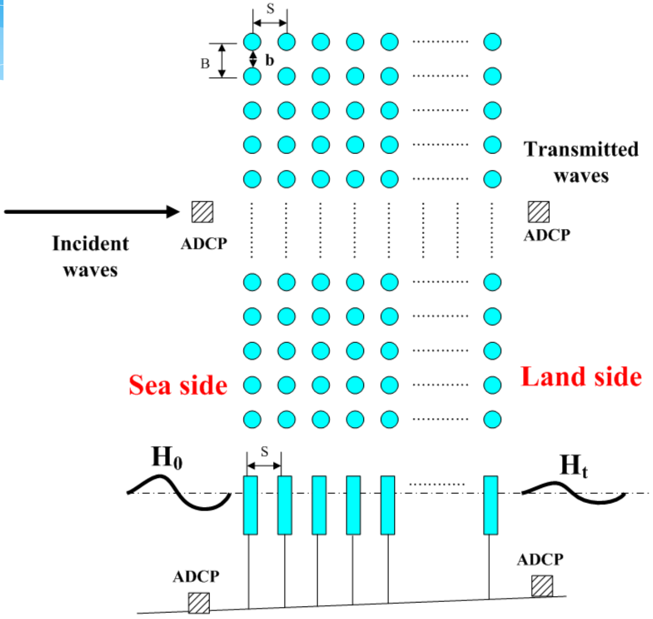
- **The evaluation on the wave energy elimination**

2016

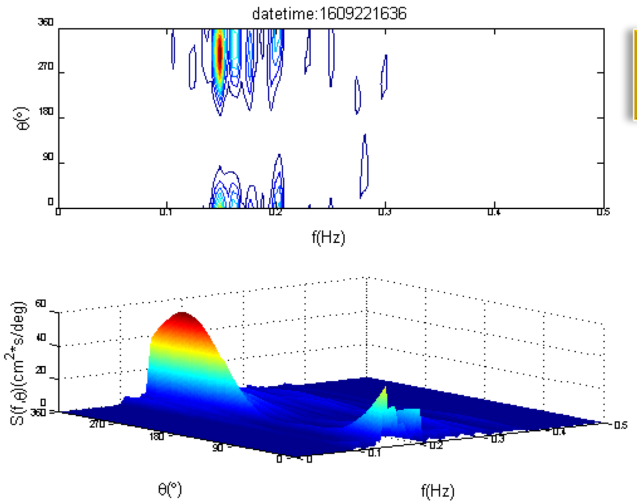


2017

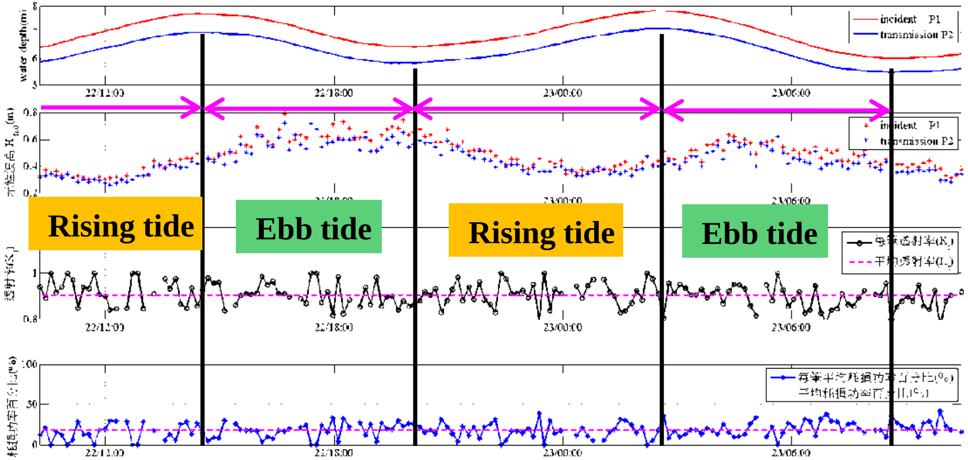




	2016		2017		
Run No.	1	2	1	2	3
Wave Direction	W～NW	WSW～NW	WSW～W	SW～W	WNW~ N
Wind Direction	NE(winter)	NE(winter)	SW (summer)	SW (summer)	NE (winter)

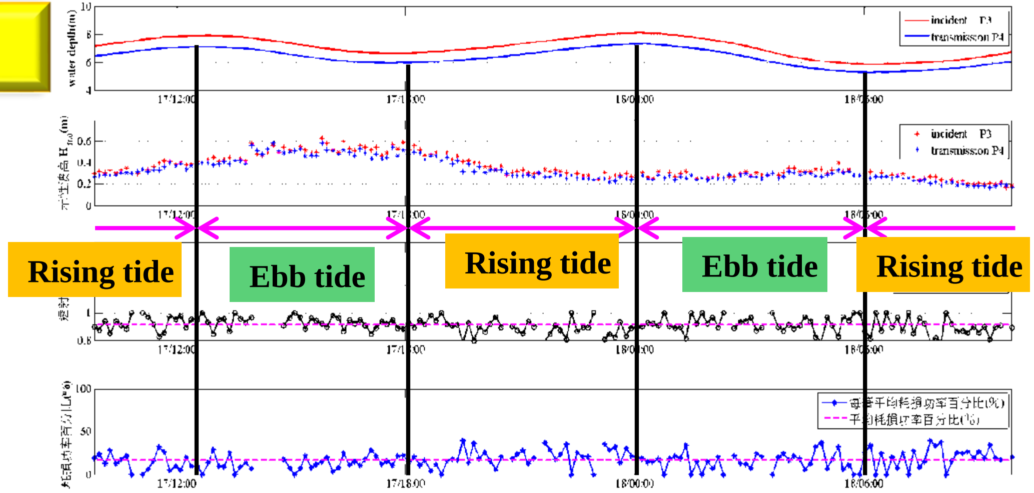


Run1



Determination of Energy Loss

Run2



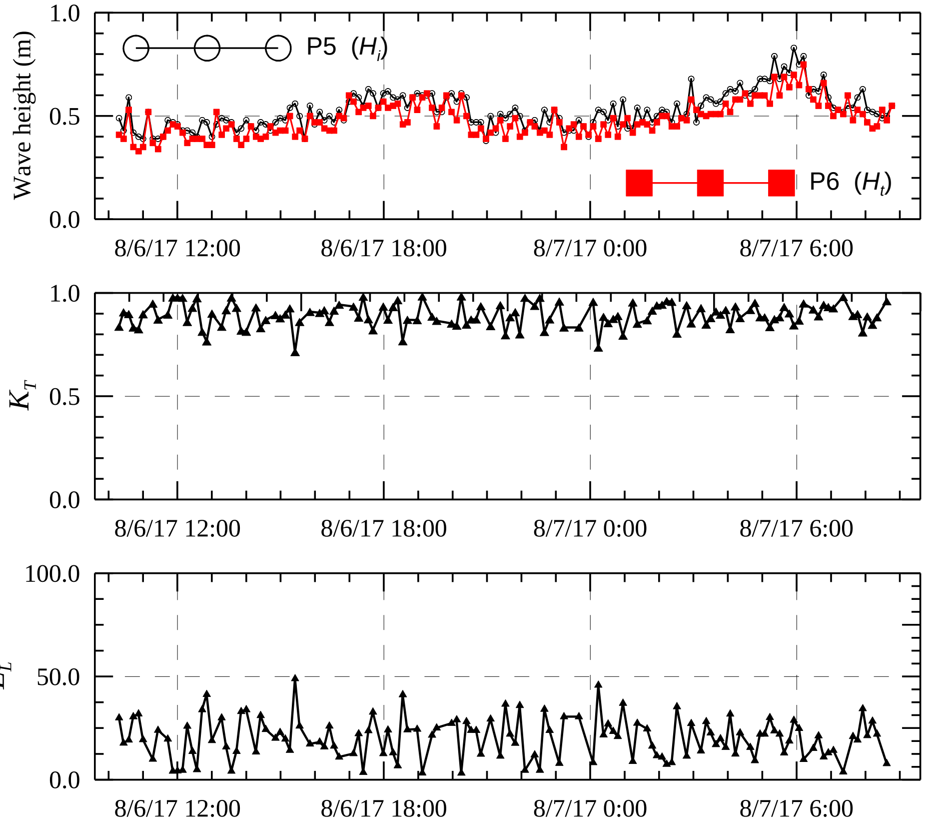
Transmission coefficient

$$K_T = H_i / H_t$$

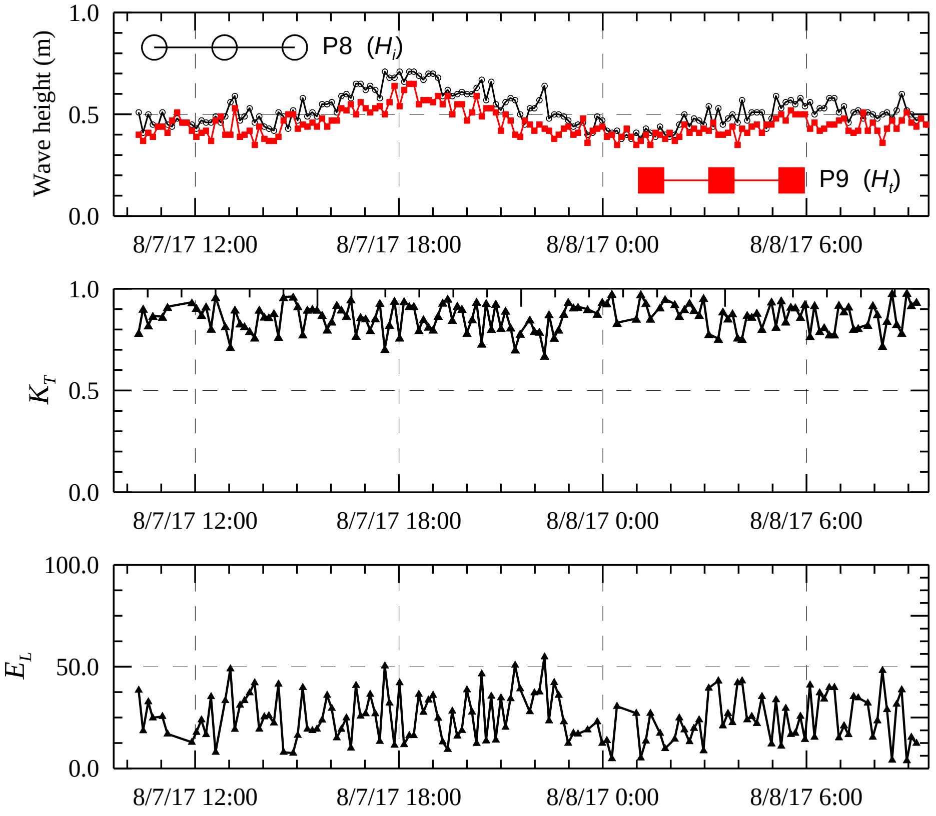
Energy Loss (%)

$$E_L = \left(1 - K_T^2\right) \times 100\%$$

Run3


1.0
0.5
0.0
Wave height (m)
P5 (H_i)
P6 (H_t)
8/6/17 12:00
8/6/17 18:00
8/7/17 0:00
8/7/17 6:00
1.0
0.5
0.0
K_T
100.0
50.0
0.0
E_L

Run4


1.0
0.5
0.0
Wave height (m)
P8 (H_i)
P9 (H_t)
8/7/17 12:00
8/7/17 18:00
8/8/17 0:00
8/8/17 6:00
1.0
0.5
0.0
K_T
100.0
50.0
0.0
E_L

Survey Result

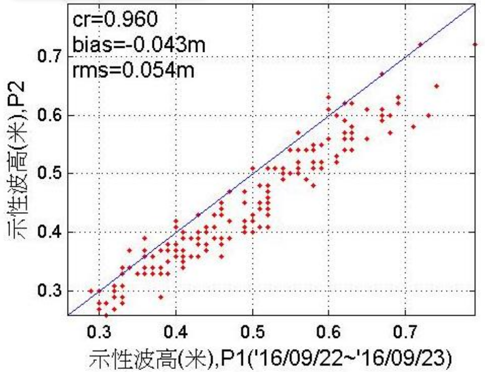
	2016		2017		
Run	1	2	1	2	3
Wave direction	W～NW	WSW～NW	WSW～W	SW～W	WNW~ N
	Winter	Winter	Summer	Summer	Winter
Wind direction	NE	NE	SW	SW	NE
Max. K_t	0.98	0.98	0.98	0.98	0.99
Min. K_t	0.78	0.77	0.71	0.67	0.71
Average K_t	0.9	0.9	0.89	0.86	0.87
Max. E_L	41%	40%	49%	54.9%	49.4%
Min. E_L	3.2%	3.8%	3.3%	3.8%	2.1%
Average. E_L	19.1%	18.9%	20.1%	25.4%	24.8%

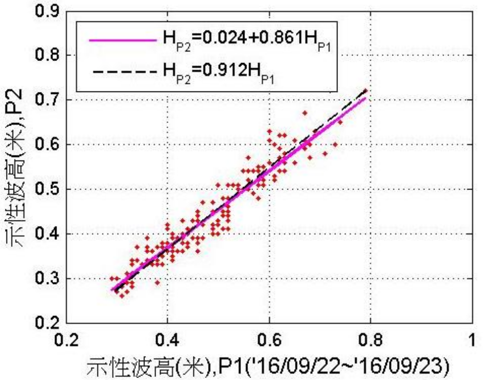
- It shows that the capability on decreasing energy almost a constant.

Waves Scatter

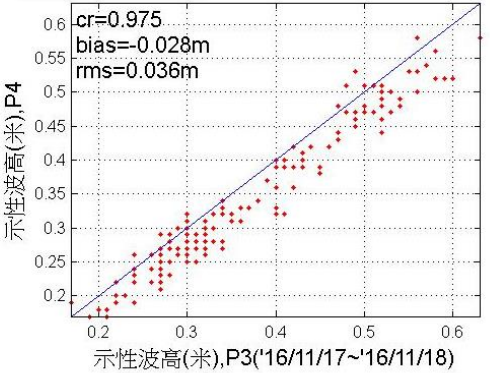
Compare with the change of wave displacement

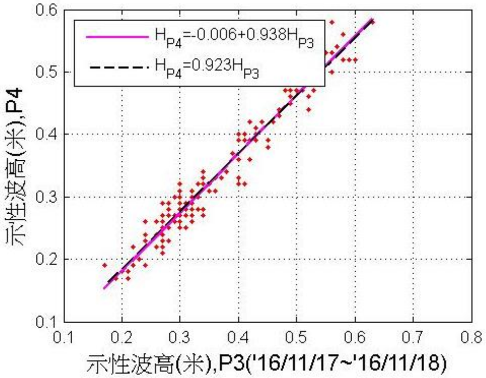
Run1





Run2



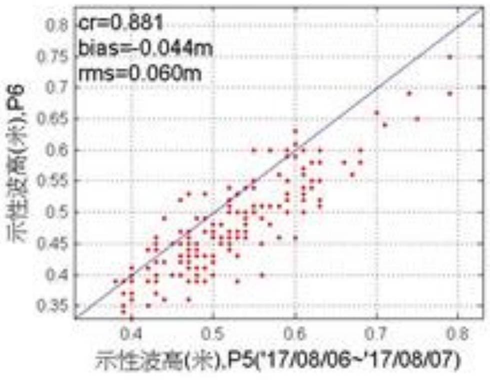


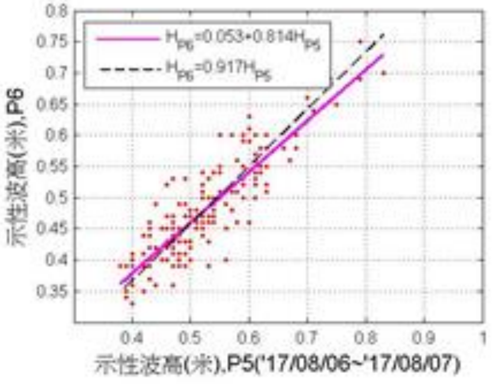
We also take every 8 min-long wave data to show wave scatter for double check.

$$H_{Ts} = 0.91 \times H_{is}$$

$$H_{Ts} = 0.92 \times H_{is}$$

Run3





$$H_{Ts} = 0.92 \times H_{is}$$

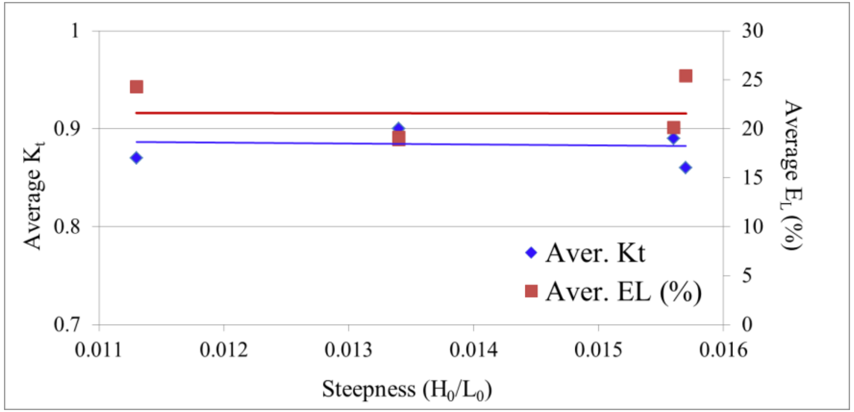
Results are similar the previous.

Run.	Wave period	H_o/L_o	d/L_o	K_t
No.1	4.9s	0.0134	0.214	0.91
No.2	4.3s	0.0134	0.264	0.92
No.3	5s	0.0156	0.203	0.92
No.4	5s	0.0157	0.208	0.88
No.5	5s	0.0113	0.164	0.87

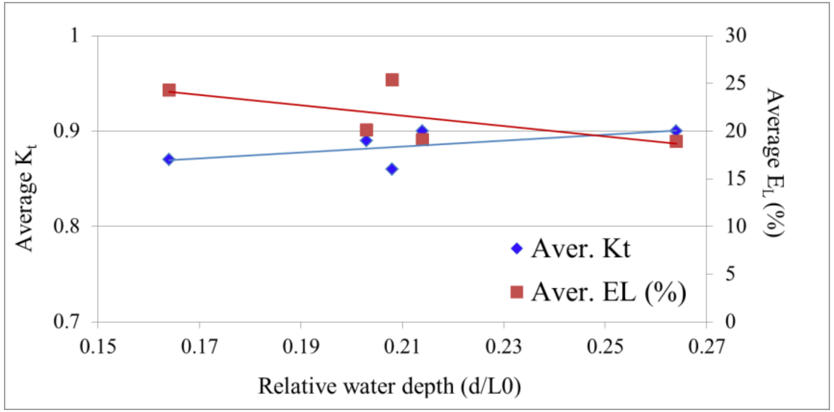
Wave condition V.S Energy Loss

Run	H_0/L_0	d/L_0	$K_t(t)$	Aver. K_t	$E_L(t)$ (%)	Aver. E_L (%)
1(NE)	0.0134	0.214	0.78~0.98	0.90	3.2~41.0	19.1
2(NE)	0.0134	0.264	0.77~0.98	0.90	3.8~40.0	18.9
3(SW)	0.0156	0.203	0.71~0.98	0.89	3.3~49.0	20.1
4(SW)	0.0157	0.208	0.67~0.98	0.86	3.8~54.9	25.4
5(NE)	0.0113	0.164	0.71~1	0.87	0~49.4	24.3

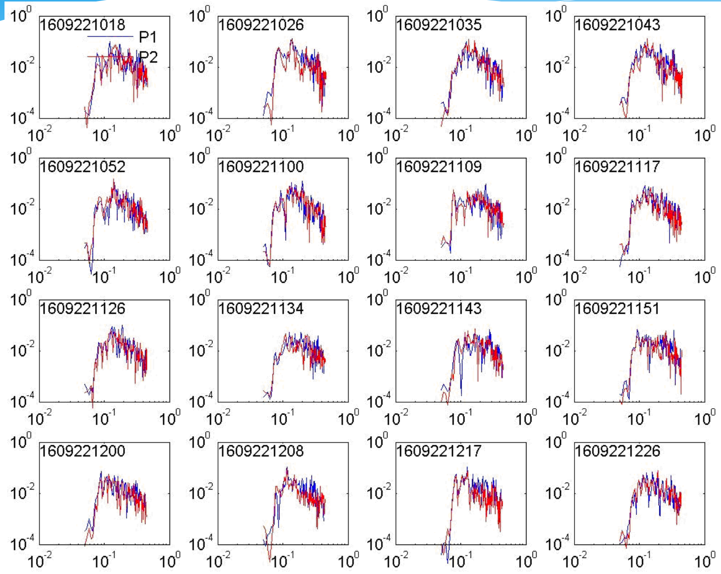
Wave steepness

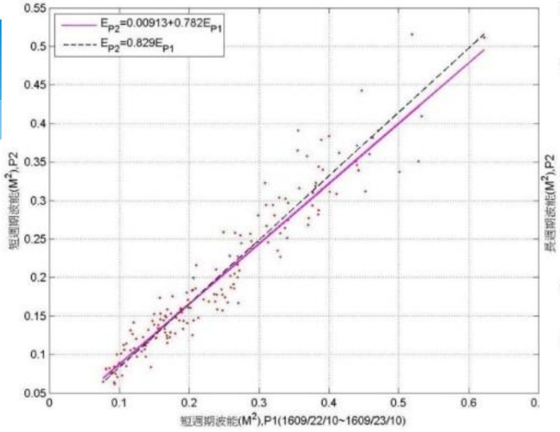


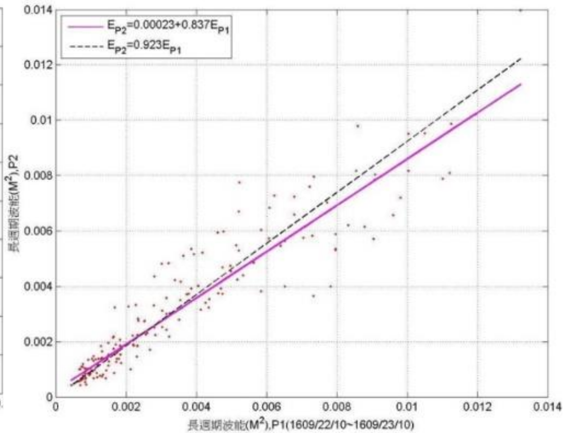
Water depth



Spectrum Analysis







Short waves(T<10s)

$$E_{is} = 0.83 \times E_{ts}$$

Long waves

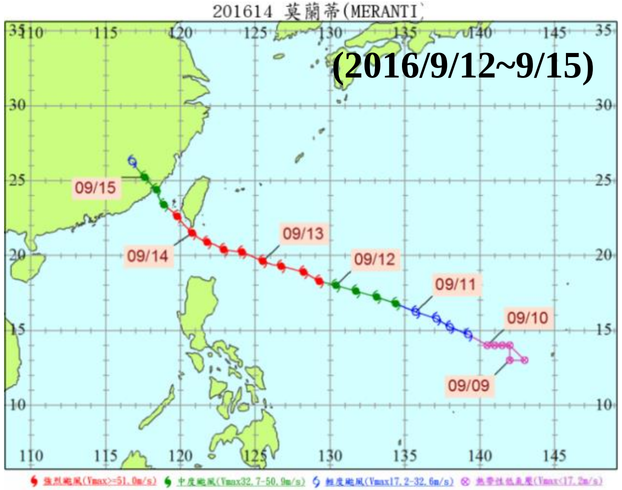
$$E_{il} = 0.92 \times E_{tl}$$

- **Transmission short waves induced the wave energy is 0.83 times of incident short wave induced that.**
- **For long wave component, Transmission waves induced the wave energy is 0.92 times of incident wave induced that.**
- **Significantly, the effective on wave decreasing for short waves is better than that for long waves (averaged higher about 6~10%)**

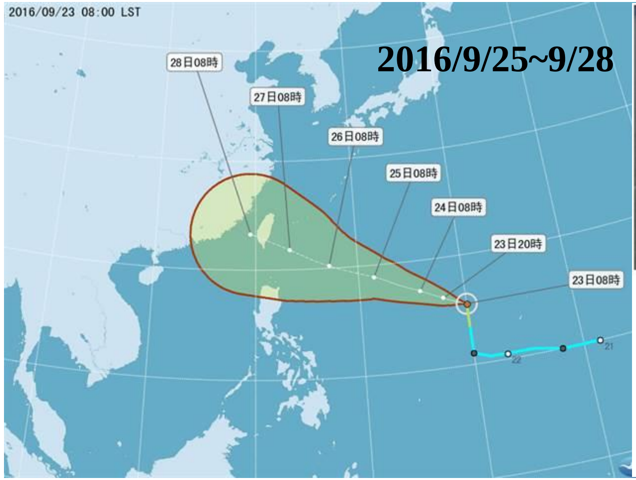
■ Durability of AMF by using drone

Regularly determination of quantities of AMF

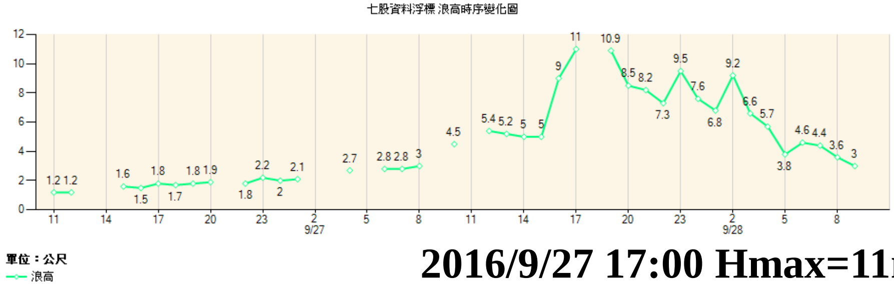
Typhoon MERANTI



Typhoon MEGI



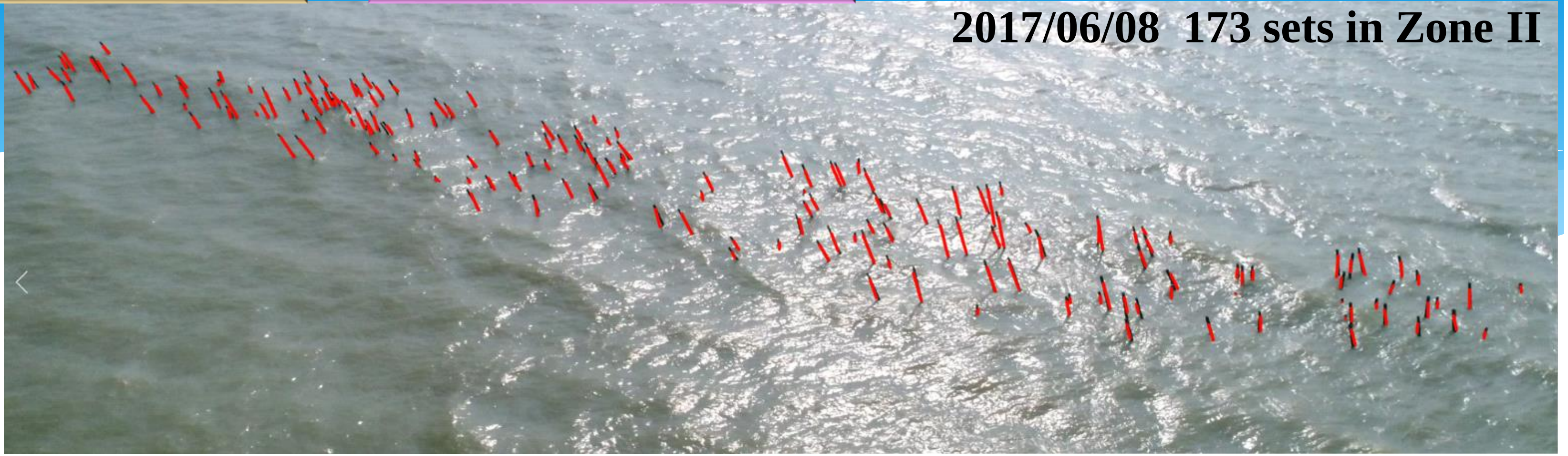
2016/9/14 19:00 Hmax=9m



2016/9/27 17:00 Hmax=11m

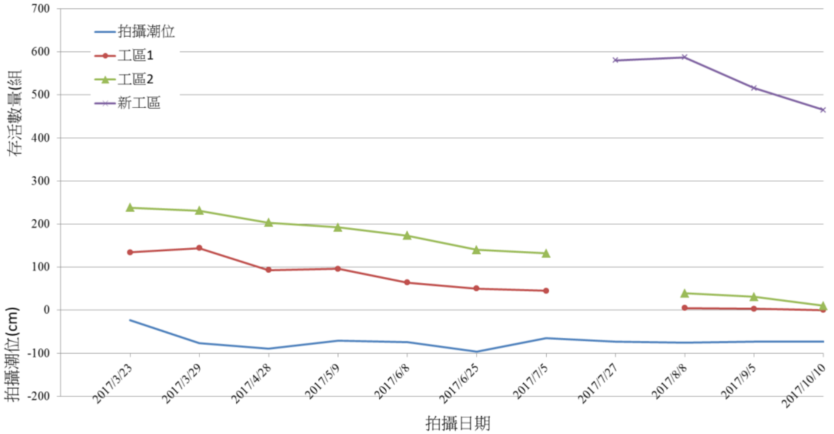
Survey Results

Image Identification



次數	年-月-日	時間	潮位(乾潮)	潮位	工區 I	工區 II	新工區	浮球	警示燈組
第一次	2017-03-23	12:35~13:18	中潮 12:42	-23	134	238	-	2	-
第二次	2017-03-29	16:54~17:27	大潮 16:52	-77	144	231	-	2	-
第三次	2017-04-28	17:10~17:25	大潮 17:20	-90	93	203	-	2	-
第四次	2017-05-09	15:21~16:04	中潮 15:22	-71	96	192	-	2	-
第五次	2017-06-08	15:26~15:41	中潮 15:39	-74	64	173	-	2	-
第六次	2017-06-25	16:45~16:57	大潮 16:55	-96	50	140	-	2	-
第七次	2017-07-05	14:11~14:53	中潮 14:11	-62	45	132	-	2	-
第八次	2017-07-27	16:52~17:25	大潮 19:06	-73	非最低潮位拍攝		580	2	8組
第九次	2017-08-08	16:58~17:31	中潮 17:02	-75	5	39	587	2	7組
第十次	2017-09-05	16:17~16:32	中潮 17:02	-73	3	31	516	2	7組
第十一次	2017-10-10	16:40~16:57	中潮 17:02	-73	0	10	465	2	7組

註:潮位(平均海平面)

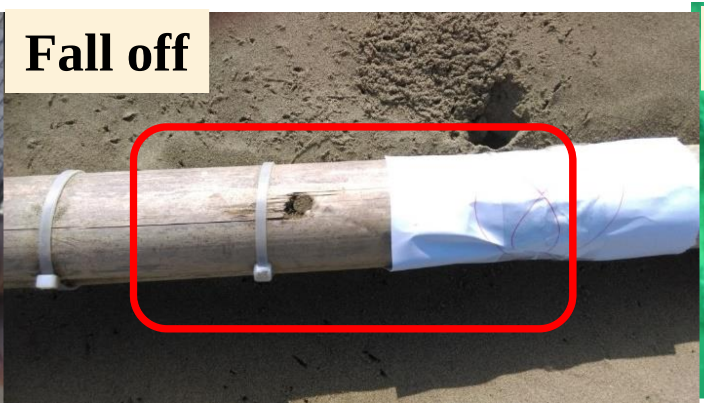


- **Averaged decrease rate 18~21 sets/month, almost constantly.**

Failure Reasons

According to the field survey,

- **The strength is insufficient on the joints.** It can’t sustain the combined wave_current induced the long-term action and the short term typhoons force.
- **The improper design** is on the joints between cables and bodies.
- Time-related **Biofouling** (**such as shellfish, algae, etc…**) induced the buoyancy loss and the structure instability.



Summary

● Apply to

1.Low disaster prevention or development coast regions

2.It's suggested that combining with other coast protection to be the first defense-line

● Material suggestion

1.Bodies(Ex.using PVC pipes)

2.Tethered system (Ex.Nylon or Steel)

3.Anchored unit(Ex. pipes)

● Applicability

1.Deep water region(out of surf zone)

2.Steep seabed slope

3.Larger wave conditions

Artificial Marine Forest

● Further Works

1.Biofouling induced the buoyancy loss.

2.Regularly clear and maintain.

3. Design in joints.

● Arrangement

1.Using the physical model to study the optimized arrangement for real cases.

Thank you for listening