Antifouling performance and mechanism of elastic graphene-silicone rubber composite membranes

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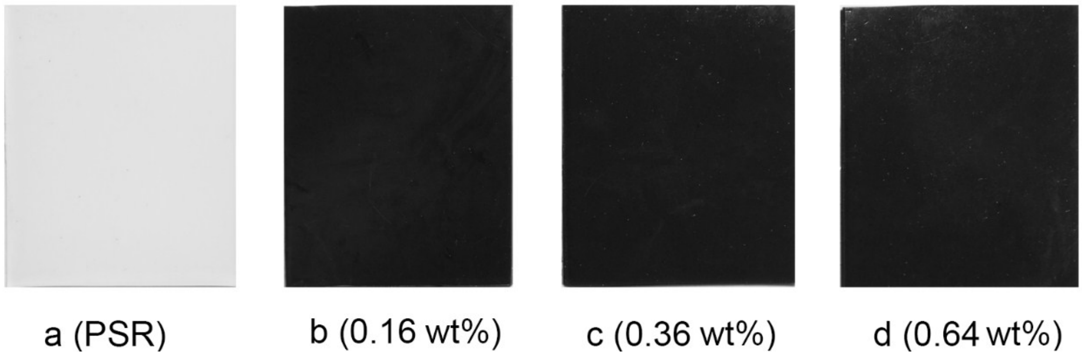
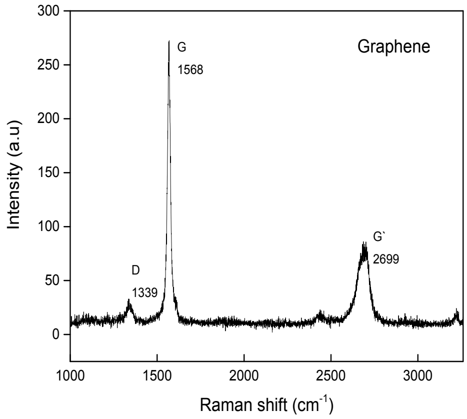
S1. Characterization of materials and membranes

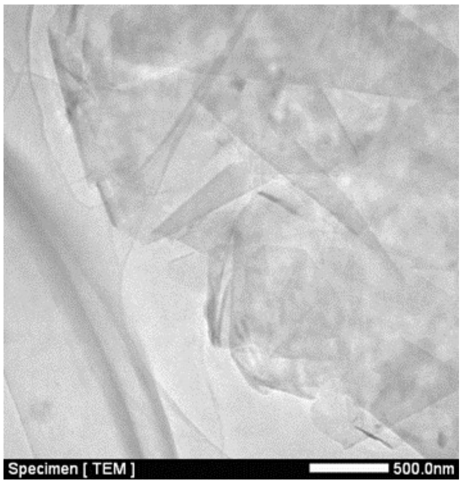
(a)



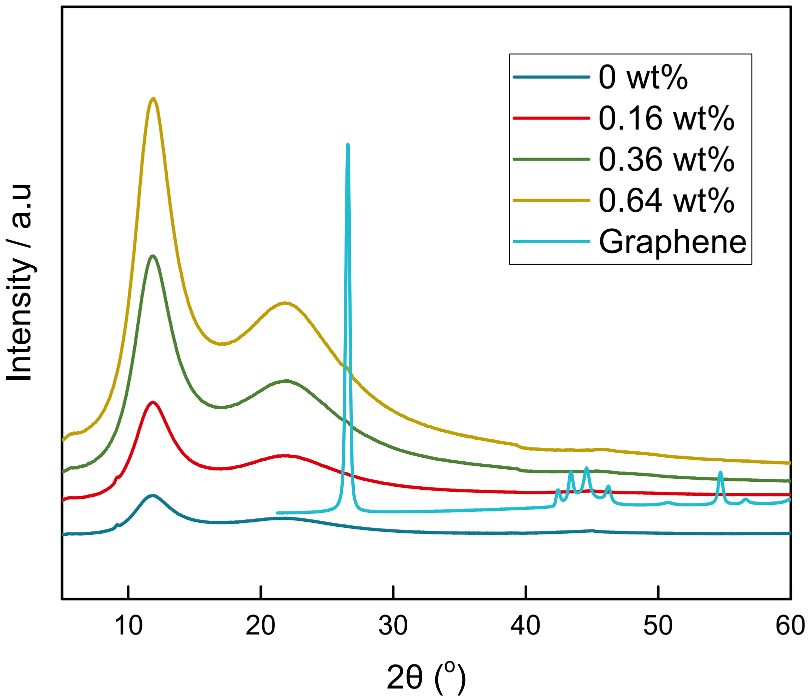
(b)



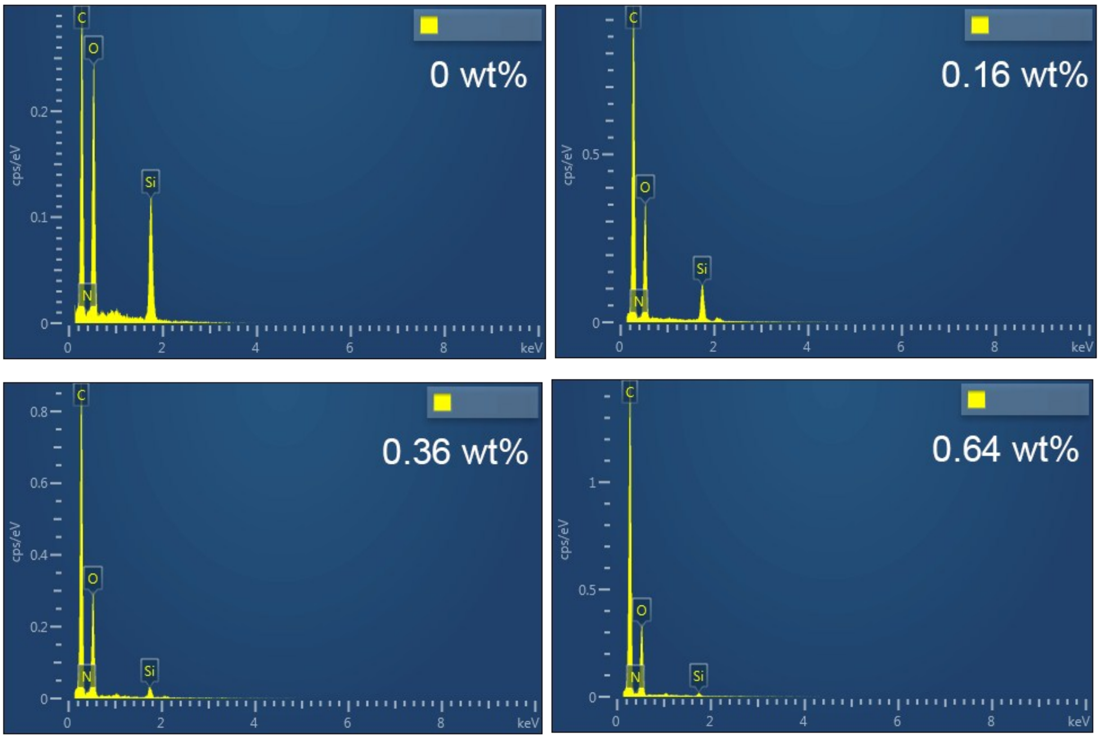
(c)



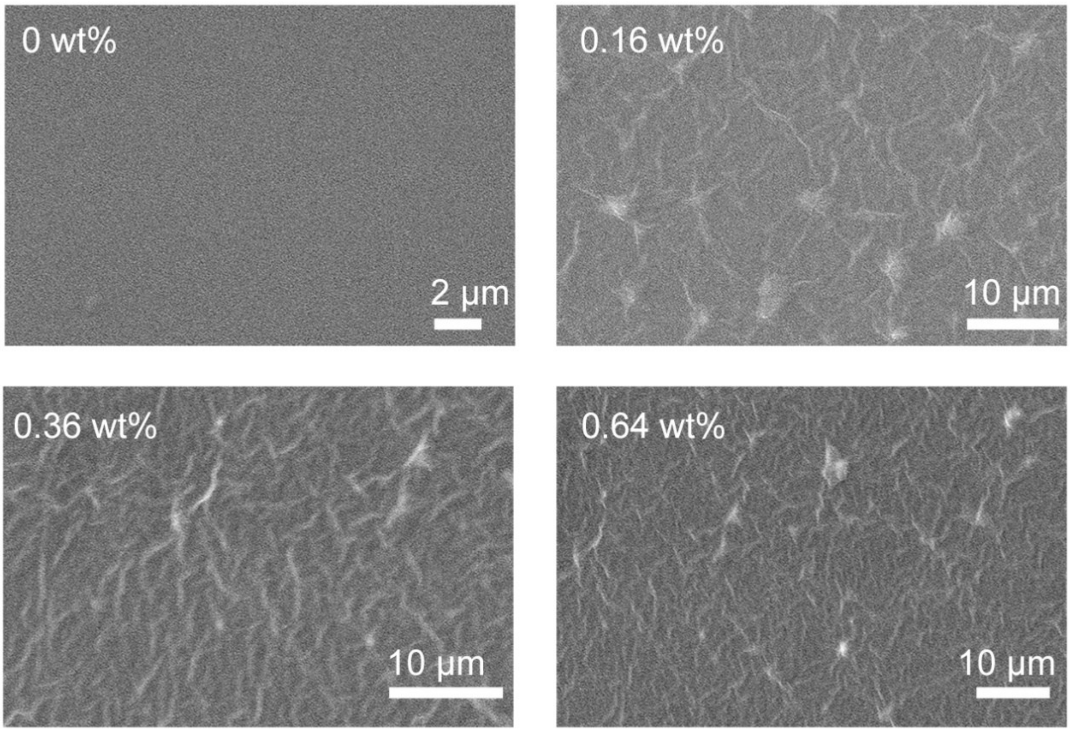
(d)



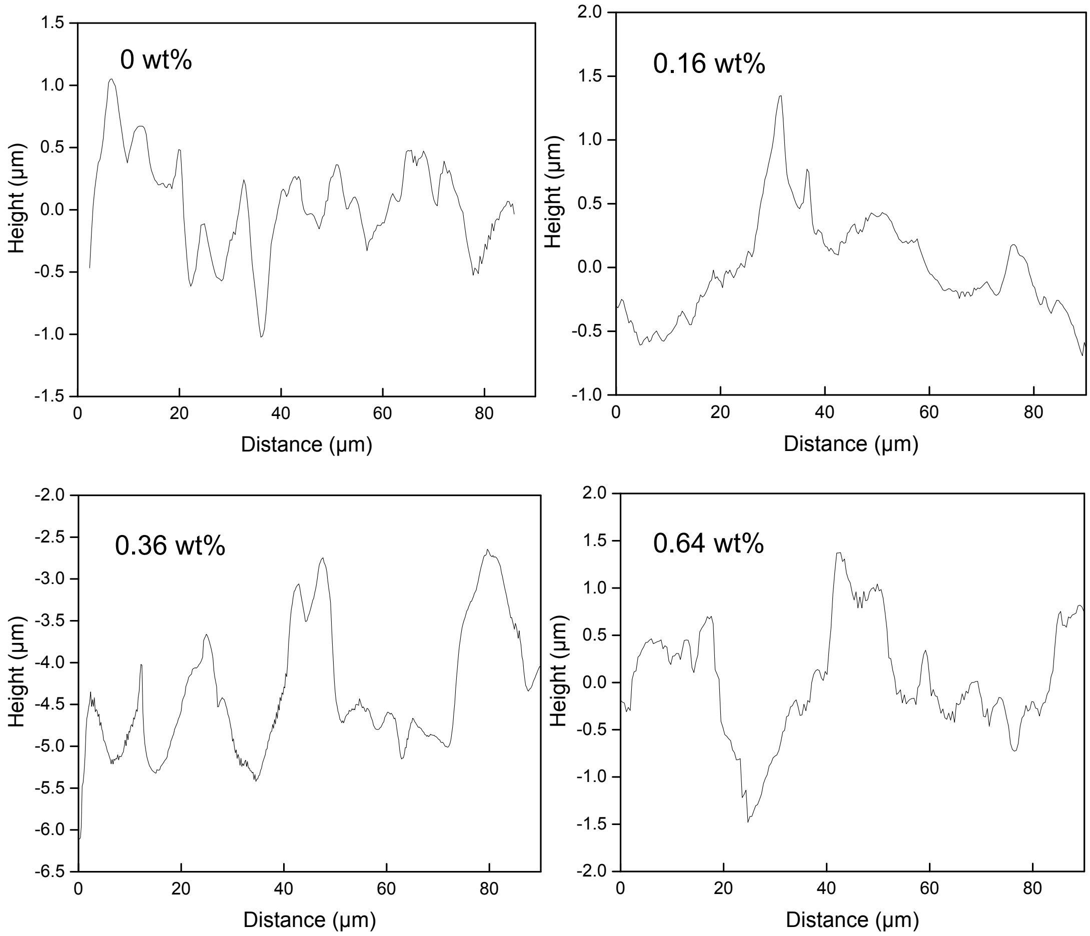
(e)


0 wt%
0.16 wt%
0.36 wt%
0.64 wt%
C
O
N
Si
cps/eV
keV
0
2
4
6
8

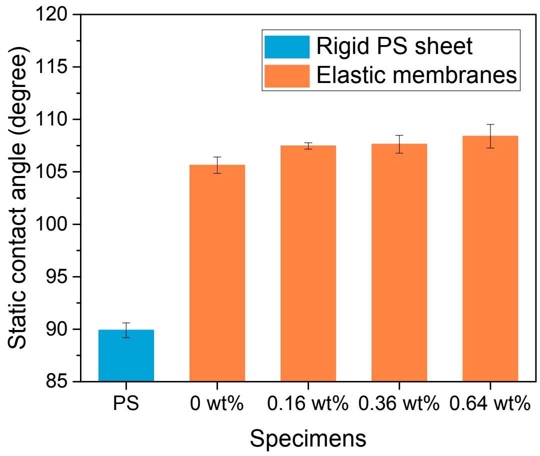
(f)


0 wt%
2 μm
0.16 wt%
10 μm
0.36 wt%
10 μm
0.64 wt%
10 μm

(g)



(h)



(i)

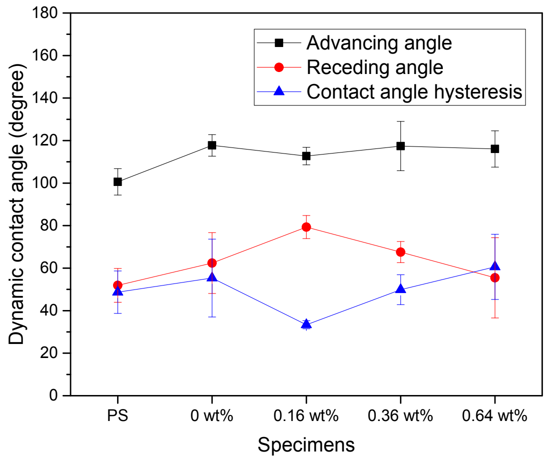


Fig. S1 (a) Colors of the membranes; (b) Raman spectra of the multi-layer graphene nanosheets; (c) TEM measurement of the graphene nanosheets; (d) XRD patterns of graphene and elastic membranes; (e) SEM measurement of the pristine membranes; (f) surface topography images of the prepared surfaces measured by the AFM; (g) measurement of elements in the elastic membranes by EDS; (h) Static contact angle of the specimens; (i) Dynamic contact angle of the specimens.

Table S1. The weight percentage (wt %) of atoms in the membranes by the EDS.

Element (wt%)	PSR (0 wt%)	GSR (0.16 wt%)	GSR (0.36 wt%)	GSR (0.64 wt%)
C	43.73	61.81	67	74.18
O	29.13	24.28	27.71	23.95
Si	27.14	13.91	5.29	1.87

S2. Flowing water system

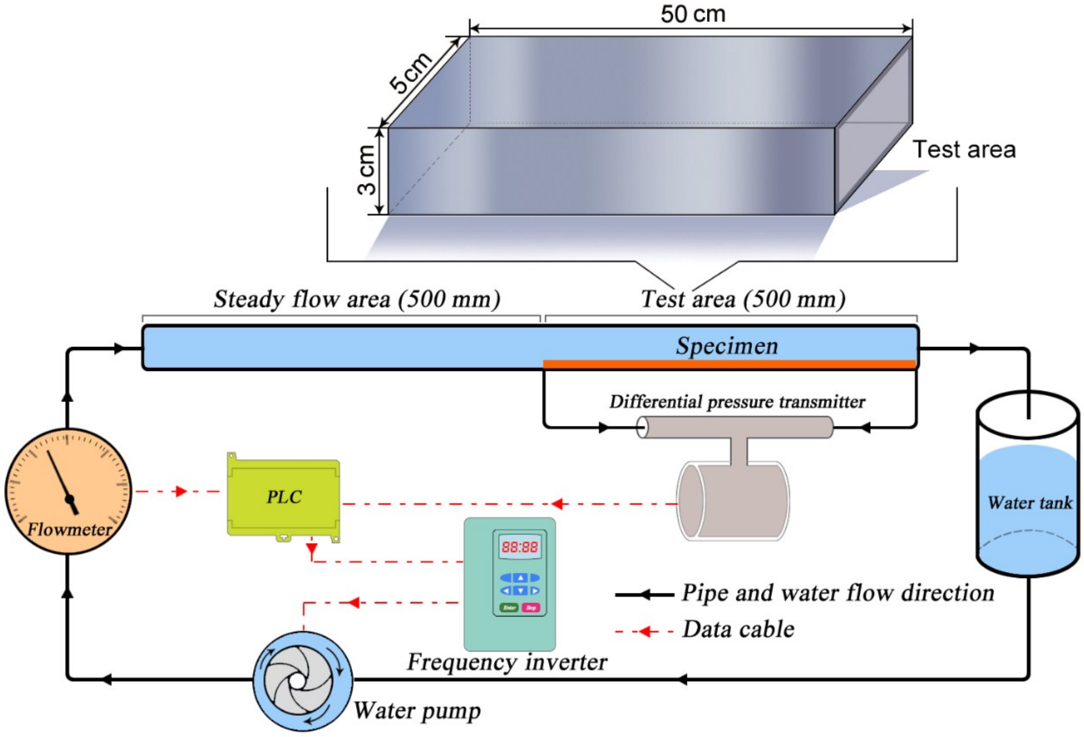


Fig. S2 Schematic diagram of the flowing water system.

	Nomenclature	Value
ρ	water density	1.024 g/cm^3 (20°C, salinity 35‰)
V	the rate of water flow	0.2－0.5 m/s
d_H	hydraulic diameter of rectangular tube (full filled)	
μ	dynamic viscosity	0.00108 Ns/m^2 (20°C, salinity 35‰)
a, b	width and height of the section of the tube in test area	a = 5cm and b = 3cm

The Reynolds number (Re) is an important dimensionless quantity in fluid mechanics used to help predict flow patterns in different fluid flow situation. *Re* is determined by

$$Re = \frac{\rho V d_H}{\mu}$$

$$d_H = \frac{2ab}{a + b}$$

The results show *Re* in the range of 0.71×10^4—1.78×10^4 which is bigger than 4000, so that it is turbulent flow in test area, namely, its`s a turbulence generator.

S3. Calculation method of the surface energy.

The correlation of contact angle and surface energy is given by[1]

$$\cos\theta = -1 + 2\sqrt{\frac{\gamma_S}{\gamma_L}}\,[1-\beta(\gamma_L - \gamma_S)]$$

where θ stands for contact angle, γ_S and γ_L represents surface energy of solid and liquid, respectively. β is a constant with the value 1.057×10^{-4} m^2/mJ.

Surface energy of the liquid is given by the following table:

Liquid	γ_L (mJ•m^{-2})
DI Water	72.8

According the equation and the table above, it easy to get surface energy of the four membranes (Fig. S3b).

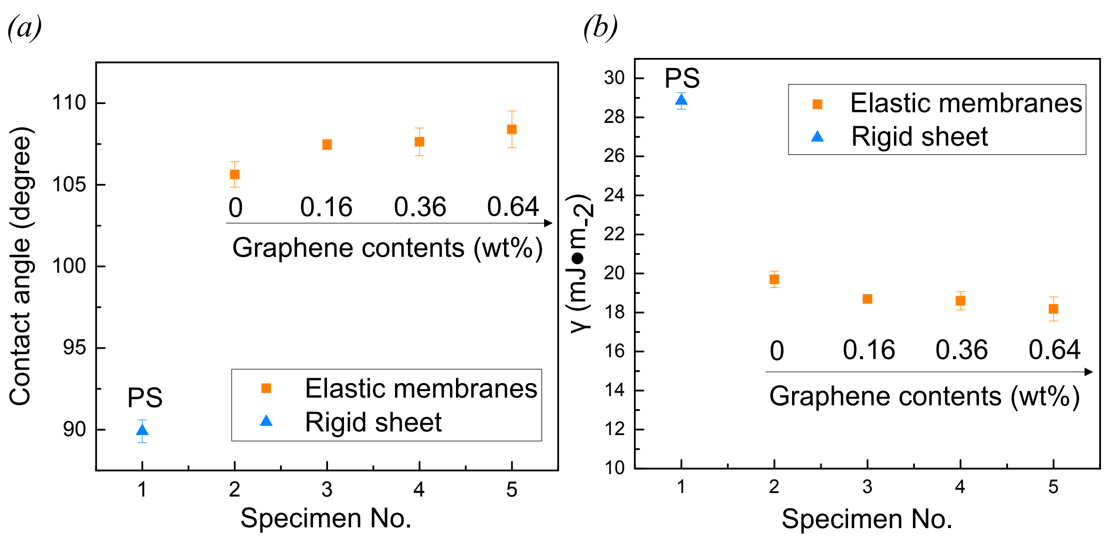


Fig. S3 (a) Water contact angle of the rigid PS sheet and PSR/GSR membranes for various graphene contents at 20°C. (b) Surface energy of the rigid PS sheet and

PSR/GSR membranes for various graphene contents at 20°C. (Error bar: standard deviation, n=3)

S4. Theory for the laser-displacement sensor in underwater measurement

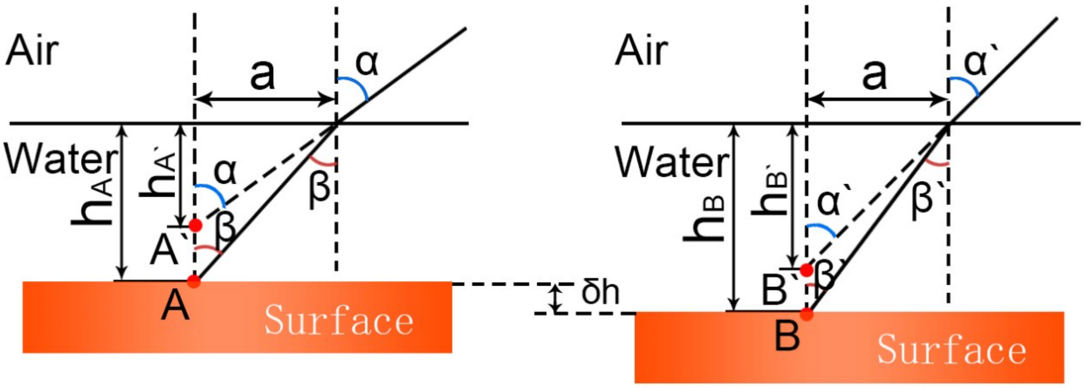


Fig. S4 Displacement of the surface from *A* to *B*.

In Fig. S4, left: The initial position is *A*, incident angle is *α*, and refraction angle is *β*. According to the geometrical relationship, the virtual image position is *A*`, $h_A$ is the distance between *A* and water surface, and $h_{A`}$ is the distance between *A*` and water surface; right: The position is *B*, incident angle is *α*`, and refraction angle is *β*`. According to the geometrical relationship, the virtual image position is *B*`. The distance between the sender and receiver of the sensor is *a*. Refractive index is *n*. We can get the following relationships:

$$n=\frac{sin\alpha}{sin\beta} \tag{S4.1}$$

$$h_A=\frac{a}{tan\beta} \tag{S4.2}$$

$$h_{A`}=\frac{a}{tan\alpha} \tag{S4.3}$$

When the surface displacement occurred, *A* reached *B* with the displacement *δh*. Similarly, we can get the following equations

$$h_B=\frac{a}{tan\beta`} \tag{S4.4}$$

$$h_{B`} = \frac{a}{tan\alpha`} \quad \text{(S4.5)}$$

The actual displacement: $\delta h = h_B - h_A = a\,(\frac{1}{tan\beta`} - \frac{1}{tan\beta})$ (S4.6)

The virtual image displacement: $\delta_H = h_{B`} - h_{A`} = a\,(\frac{1}{tan\alpha`} - \frac{1}{tan\alpha})$ (S4.7)

By combining equations(S4.1) and (S4.6, S4.7), we can get

$$\delta_H = \frac{1}{n}\,\delta h \quad \text{(S4.8)}$$

Hence, the measurement results (δ_H) multiply by n equal the actual displacement (δh).

S5. Simulations in ANSYS

Two simplified models were established in the ANSYS Mechanical APDL software package. The first one (Fig. S5a) shows a fouler that was glued on the elastic surface with no gap in attachment area. The second one (Fig. S5b) shows a fouler that was glued on elastic surface with some flaws in attachment area. Elastic modulus of the elastic surface $E=1\ MPa$. Elastic modulus of the fouler was listed in the following table[2].

Fouler	Elastic modulus E
Cell[3-5]	0.1-100 kPa
Alga[6, 7]	2-10 MPa
Barnacle[8]	0.2-5 MPa

In our models, we assumed the fouler was a cell, therefore elastic modulus of the fouler $E=100\ kPa$ was used in the simulations. The two elastic surfaces were 10 m long, and 4 m wide, with a thickness of 2 m, and the fouler with the size of 2 m long and 4 m wide, with a thickness of 0.5 m. Pressure $F=100\ N$ was applied to the edge of the membrane. After the models were meshed, they were solved.

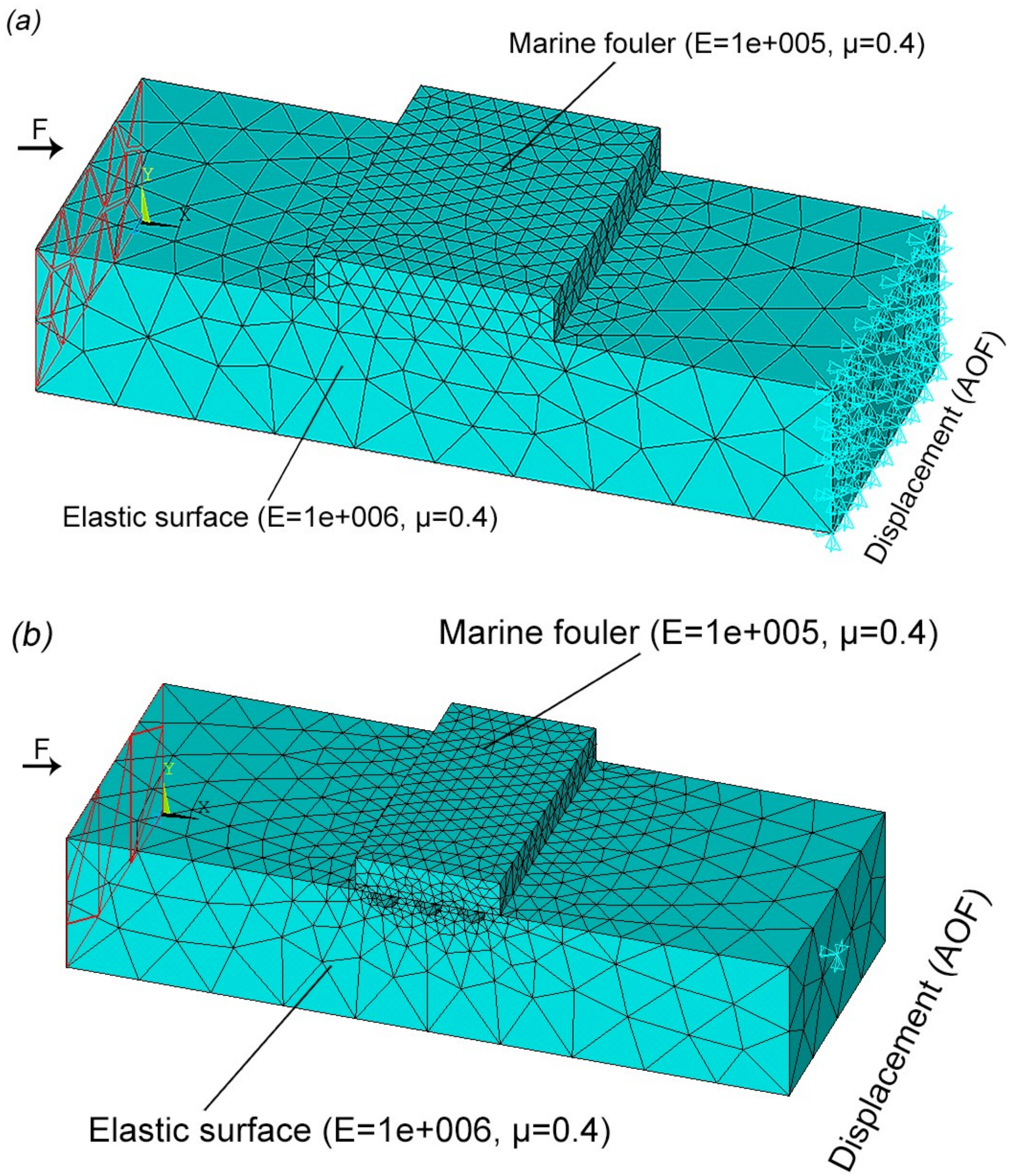


Fig. S5 (a) A fouler was glued on the elastic surface. (b) A fouler was glued on the elastic surface with some flaws in attachment area.