附件 10：问题 3 中，各点水速相同、水流与风同向时，锚链长度、型号、重物球质量的 Matlab 求解程序

附件 11：问题 3 中，各点水速相同、水流与风同向时，钢桶和钢管的倾斜角度、锚链形状的 Matlab 求解程序

## 九、附件

附件 1：风力方向与水流力方向同向时的刚体力学方程组

以水流力与风力同向为例，对模型 1 中的刚体力学方程组罗列如下：

锚链：

$$\text{无沉底：}\begin{cases}\int_0^{x_1}\sqrt{1+y'^2}\,dx=s,y_1=y\left(x_1\right)\\ y'|_{x_1}=\tan\alpha_2\end{cases}$$

$$\text{有沉底：}\begin{cases}\int_{x_0}^{x_1}\sqrt{1+y'^2}\,dx=s-x_0,y_1=y\left(x_1\right)\\ y'|_{x_1}=\tan\alpha_2\end{cases}$$

钢桶及重物球：

$$\begin{cases}x:F_1\sin\gamma_1=F'\\ y:G_{bucket}+G_{ball}+\dfrac{F'}{\cos\alpha_2}\sin\alpha_2=f_{ball}+f_{bucket}+F_1\cos\gamma_1\\ G_{ball}L\sin\beta+F_1L\sin\left(\beta-\gamma_1\right)=\dfrac{F'}{\cos\alpha_2}L\sin\left(\dfrac{\pi}{2}-\alpha_2-\beta\right)\end{cases}$$

钢管 1：

$$\begin{cases}G_{pipe}+F_1\cos\gamma_1=f_{pipe}+F_2\cos\gamma_2\\ F_1\sin\gamma_1=F_2\sin\gamma_2++F_{wat\_pipe}\\ F_1L\sin\left(\gamma_1-\theta_1\right)=F_2L\sin\left(\theta_1-\gamma_2\right)\end{cases}$$

钢管 2：

$$\begin{cases}G_{pipe}+F_2\cos\gamma_2=f_{pipe}+F_3\cos\gamma_3\\ F_2\sin\gamma_2=F_3\sin\gamma_3+F_{wat\_pipe}\\ F_2L\sin\left(\gamma_2-\theta_2\right)=F_3L\sin\left(\theta_2-\gamma_3\right)\end{cases}$$

钢管 3：

$$\begin{cases}G_{pipe}+F_3\cos\gamma_3=f_{pipe}+F_4\cos\gamma_4\\ F_3\sin\gamma_3=F_4\sin\gamma_4+F_{wat\_pipe}\\ F_3L\sin\left(\gamma_3-\theta_3\right)=F_4L\sin\left(\theta_3-\gamma_4\right)\end{cases}$$

钢管 4：

$$\begin{cases}G_{pipe}+F_4\cos\gamma_4=f_{pipe}+F_5\cos\gamma_5\\ F_4\sin\gamma_4=F_5\sin\gamma_5+F_{wat\_pipe}\\ F_4L\sin\left(\gamma_4-\theta_4\right)=F_5L\sin\left(\theta_4-\gamma_5\right)\end{cases}$$

浮标：

$$\begin{cases}\pi\left(\dfrac{2}{2}\right)^2dg\rho=G_{buoy}+F_5\cos\gamma_5\\ F_5\sin\gamma_5=0.625\times2\times\left(2-d\right)v^2+374\times2\times d\times v^2\end{cases}$$

总高度：$H=y_0+l_{bucket}\cos\beta+l_{pipe}\left(\cos\theta_1+\cos\theta_2+\cos\theta_3+\cos\theta_4\right)+d$

其中 $F'=F_{wind}+4F_{wat\_pipe}+F_{wat\_bucket}+F_{wat\_float}$

$$y=\frac{F'}{\sigma g}\cosh\left(\frac{\sigma g}{F'}x+\sinh^{-1}(\tan\alpha_1)\right)-\frac{F'}{\sigma g}\cosh\left(\sinh^{-1}(\tan\alpha_1)\right)$$

游动区域的最大半径：$R = x_0 + l_{bucket}\sin\beta + l_{pipe}\left(\sin\theta_1 + \sin\theta_2 + \sin\theta_3 + \sin\theta_4\right)$
其中 20 个方程中的符号含义同模型一，上述方程是以水流力与风力同向为例，水流力与风力反向、垂直时，对上述方程组的更改方式如(40)-(45)式，或(46)-(52)式。

附件 2：问题 3 中，各点水速相同、水力与风力反向时的求解结果

表 7 各点水速相同、水力与风力反向时的系泊系统参数表

| 深度 H | H=16m | H=17m | H=18m | H=19m | H=20m |
|---|---|---|---|---|---|
| 钢桶与竖直线夹角 $\beta$ | 4.2767° | 4.2466° | 4.2174° | 4.1891° | 4.1615° |
| 钢管 1 倾斜角度 $\theta_1$ | 4.2296° | 4.2001° | 4.1715° | 4.1438° | 4.1168° |
| 钢管 2 倾斜角度 $\theta_2$ | 4.2206° | 4.1913° | 4.1629° | 4.1352° | 4.1084° |
| 钢管 3 倾斜角度 $\theta_3$ | 4.2118° | 4.1825° | 4.1542° | 4.1267° | 4.1000° |
| 钢管 4 倾斜角度 $\theta_4$ | 4.2029° | 4.1738° | 4.1456° | 4.1183° | 4.0916° |
| 浮标吃水深度 $d$ | 1.7569m | 1.7673m | 1.7775m | 1.7876m | 1.7975m |
| 游动区域最大半径 $R$ | 17.8246m | 17.2931m | 16.7433m | 16.1768m | 15.5948m |
| 锚链与海床夹角 $\alpha_1$ | 0° | 0° | 0° | 0° | 0° |

H 分别为 16m、17m、18m、19m、20m 时绘制的锚链形状图形如下：

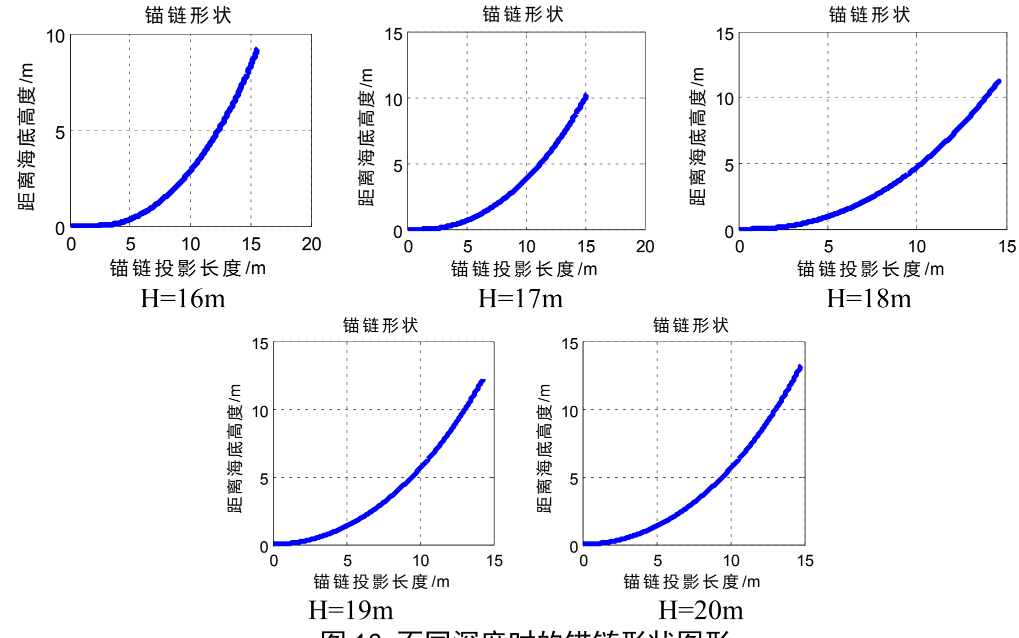



图 13 不同深度时的锚链形状图形

附件 3：问题 3 中，各点水速相同、水力与风力垂直时的求解结果

表 8 各点水速相同、水力与风力垂直时的系泊系统参数表

| 深度 H | H=16m | H=17m | H=18m | H=19m | H=20m |
|---|---|---|---|---|---|
| 钢桶与竖直线夹角 $\beta$ | 3.8142° | 3.8056° | 3.7974° | 3.7895° | 3.7820° |
| 钢管 1 倾斜角度 $\theta_1$ | 3.7719° | 3.7637° | 3.7559° | 3.7484° | 3.7412° |
| 钢管 2 倾斜角度 $\theta_2$ | 3.7639° | 3.7558° | 3.7480° | 3.7406° | 3.7334° |
| 钢管 3 倾斜角度 $\theta_3$ | 3.7560° | 3.7479° | 3.7402° | 3.7329° | 3.7258° |

| | | | | | |
|---|---|---|---|---|---|
| 钢管 4 倾斜角度 $\theta_4$ | 3.7480° | 3.7400° | 3.7324° | 3.7252° | 3.7182° |
| 浮标吃水深度 $d$ | 1.7506m | 1.7610m | 1.7713m | 1.7814m | 1.7914m |
| 游动区域最大半径 $R$ | 17.6114m | 17.0670m | 16.5060m | 15.9300m | 15.3403m |
| 锚链与海床夹角 $\alpha_1$ | 0° | 0° | 0° | 0° | 0° |

H 分别为 16m、17m、18m、19m、20m 时绘制的锚链形状图形如下：

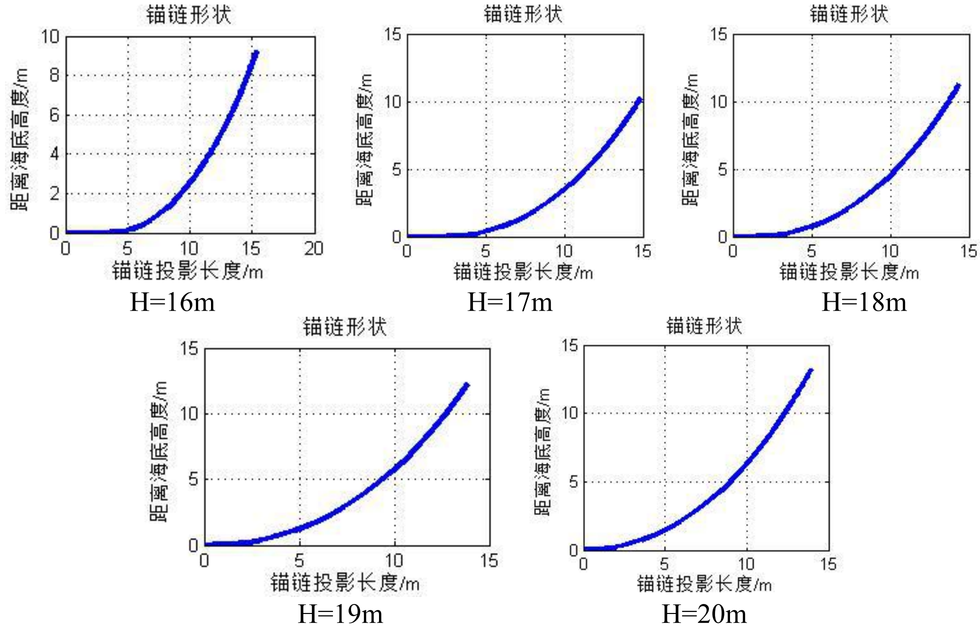


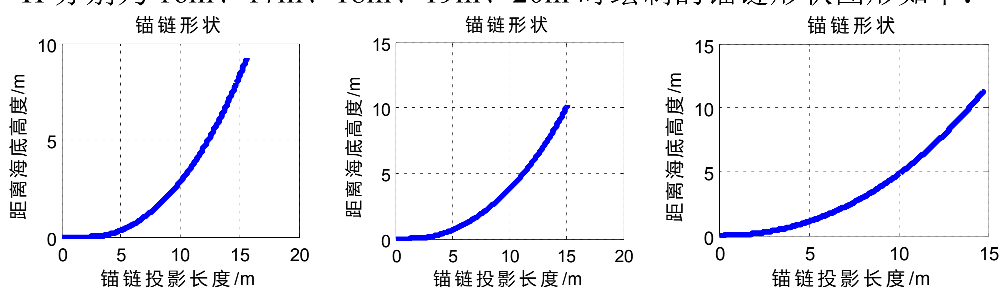

图 14 不同深度时的锚链形状图形

附件 4：问题 3 中，各点水速不同、水力与风力同向时的求解结果

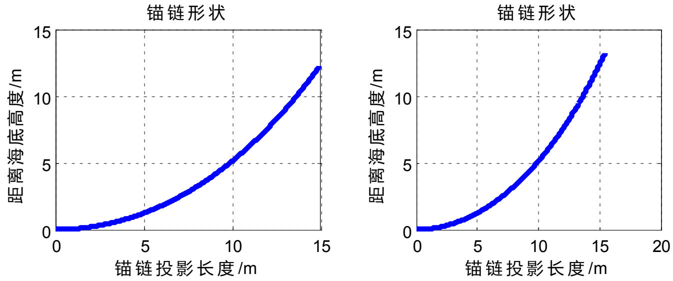
表 9 各点水速不同、水力与风力同向时的系泊系统参数表

| 深度 H | H=16m | H=17m | H=18m | H=19m | H=20m |
|---|---|---|---|---|---|
| 钢桶与竖直线夹角 $\beta$ | 4.4417° | 4.4105° | 4.3803° | 4.3511° | 4.3226° |
| 钢管 1 倾斜角度 $\theta_1$ | 4.3632° | 4.3324° | 4.3026° | 4.2737° | 4.2455° |
| 钢管 2 倾斜角度 $\theta_2$ | 4.3150° | 4.2846° | 4.2552° | 4.2267° | 4.1990° |
| 钢管 3 倾斜角度 $\theta_3$ | 4.2671° | 4.2372° | 4.2081° | 4.1800° | 4.1526° |
| 钢管 4 倾斜角度 $\theta_4$ | 4.2142° | 4.1847° | 4.1560° | 4.1283° | 4.1014° |
| 浮标吃水深度 $d$ | 1.7612m | 1.7718m | 1.7821m | 1.7923m | 1.8024m |
| 游动区域最大半径 $R$ | 17.9413m | 17.4212m | 16.8888m | 16.3368m | 15.7695m |
| 锚链与海床夹角 $\alpha_1$ | 0° | 0° | 0° | 0° | 0° |

H 分别为 16m、17m、18m、19m、20m 时绘制的锚链形状图形如下：



H=16m H=17m H=18m

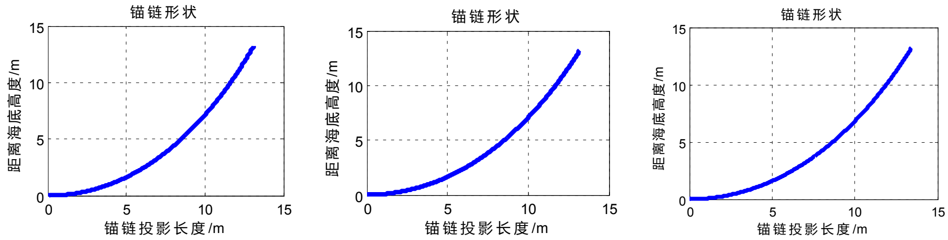



H=19m H=20m

图 15 不同深度时的锚链形状图形

附件 5：水流力与风力夹角为任意角度时，锚链形状

水流力与风力夹角为任意角度$\eta$，按照模型三中所求解得到的三个决策变量，锚链取五号，长度 20.9m，重物球质量 4635.24kg,当水深为 20m 时，锚链线形状：




$\eta=30°$时锚链线形状： $\eta=45°$时锚链线形状： $\eta=45°$时锚链线形状：

图 16 水流力与风力不同夹角时锚链形状

附件 6：问题 1 中，系泊系统参数求解的 Matlab 程序

```
function question1
x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
options=optimset('MaxFunEvals',1e4,'MaxIter',1e4);
format long
[x,fval,exitflag]=fsolve(@fangcheng,x0,options)%设置初值
x(9:18)=x(9:18)/pi*180
function F=fangcheng(x)
Fwind=x(1);%风力
unuse=x(2);
alph1=0;%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);theta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=24;%风速
H=18;%水深
p=1025;%海水密度
sigma=7;
g=9.8;%重力加速度
```

```
Mball=1200*0.869426751592357;%重物球质量
maolian=22.05;%锚链长度
maolian=maolian-x(2);%减去沉在海底的长度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)(Fwind/sigma/g*cosh(sigma*g*t/Fwind+asinh(tan(alph1)))-Fwind/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/Fwind+asinh(tan(alph1)))).^2));
xx=0:0.001:x1;
yy=y(xx);
xx=[0:0.001:unuse,xx+unuse+0.001];
u=length(0:0.001:unuse);
yy=[zeros(1,u),yy];
plot(xx,yy,'LineWidth',3,'markersize',8)
set(gca,'xtick',[0:x1+unuse+1],'ytick',[0:yy(end)+1])
title('锚链形状')
xlabel('锚链投影长度/m')
ylabel('距离海底高度/m')
grid on
R=sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)+xx(end)-0.001
F(1)=quad(Dy,0,x1)-maolian;%锚链长度
alph2=atan(sinh(sigma*g*x1/Fwind+asinh(tan(alph1))));
y1=y(x1)
%钢桶
F(2)=F1*sin(gama1-beta)+Fwind/cos(alph2)*sin(pi/2-alph2-beta)-Mball*g*sin(beta);
%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-Fwind*tan(alph2);% 竖直受力平衡
F(4)=F1*sin(gama1)-Fwind;%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-Fwind;
F(10)=F3*sin(gama3)-Fwind;
F(11)=F4*sin(gama4)-Fwind;
F(12)=F5*sin(gama5)-Fwind;
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
```

```
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
```

附件 7：锚链部分沉底情况下，系泊系统参数求解的 Matlab 程序

```
function question1_luodi
x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
options=optimset('MaxFunEvals',1e4,'MaxIter',1e4);
format long
[x,fval,exitflag]=fsolve(@fangcheng,x0,options)%设置初值
x(9:18)=x(9:18)/pi*180
function F=fangcheng(x)
Fwind=x(1);%风力
unuse=x(2);
alph1=0;%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);theta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
H=18;%水深
p=1025;%海水密度
sigma=7;
g=9.8;%重力加速度
Mball=4090*0.869426751592357;%重物球质量
maolian=22.05;%锚链长度
maolian=maolian-x(2);%减去沉在海底的长度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)(Fwind/sigma/g*cosh(sigma*g*t/Fwind+asinh(tan(alph1)))-Fwind/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/Fwind+asinh(tan(alph1)))).^2));
xx=0:0.001:x1;
yy=y(xx);
xx=[0:0.001:unuse,xx+unuse+0.001];
u=length(0:0.001:unuse);
yy=[zeros(1,u),yy];
```

```
plot(xx,yy,'LineWidth',3,'markersize',8)
set(gca,'xtick',[0:x1+unuse+1],'ytick',[0:yy(end)+1])
title('锚链形状')
xlabel('锚链投影长度/m')
ylabel('距离海底高度/m')
grid on
R=sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)+xx(end)-0.001
F(1)=quad(Dy,0,x1)-maolian;%锚链长度
alph2=atan(sinh(sigma*g*x1/Fwind+asinh(tan(alph1))));
y1=y(x1)
%钢桶
F(2)=F1*sin(gama1-beta)+Fwind/cos(alph2)*sin(pi/2-alph2-beta)-Mball*g*sin(beta);
%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-Fwind*tan(alph2);% 竖 直 受
力平衡
F(4)=F1*sin(gama1)-Fwind;%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-Fwind;
F(10)=F3*sin(gama3)-Fwind;
F(11)=F4*sin(gama4)-Fwind;
F(12)=F5*sin(gama5)-Fwind;
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
```

附件 8：锚链不存在沉底的情况下，系泊系统参数求解的 Matlab 程序

```
function question1_weiluodi
x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.09,0.
09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
options=optimset('MaxFunEvals',1e4,'MaxIter',1e4);
format long
[x,fval,exitflag]=fsolve(@fangcheng,x0,options)%设置初值\
x(9:18)=x(9:18)/pi*180
function F=fangcheng(x)
```

```
Fwind=x(1);%风力
alph1=x(2);%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);theta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
H=18;%水深
p=1025;%海水密度
sigma=7;
g=9.8;%重力加速度
Mball=2010*0.869426751592357;%重物球质量
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)(Fwind/sigma/g*cosh(sigma*g*t/Fwind+asinh(tan(alph1)))-Fwind/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/Fwind+asinh(tan(alph1)))).^2));
Y=y(x1)
xx=0:0.001:x1;
yy=y(xx);
plot(xx,yy,'LineWidth',3,'markersize',8)
set(gca,'xtick',[0:x1+1],'ytick',[0:yy(end)+1])
title('锚链形状')
xlabel('锚链投影长度/m')
ylabel('距离海底高度/m')
grid on
% pause
F(1)=quad(Dy,0,x1)-22.05;%锚链长度
% alph2=atan((y(x1+0.001)-y(x1-0.001))/0.002);
alph2=atan(sinh(sigma*g*x1/Fwind+asinh(tan(alph1))));
y1=y(x1);
R=x1+sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)
%钢桶
F(2)=F1*sin(gama1-beta)+Fwind/cos(alph2)*sin(pi/2-alph2-beta)-Mball*g*sin(beta);
%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-Fwind*tan(alph2);%竖直受力平衡
F(4)=F1*sin(gama1)-Fwind;%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
```

```
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-Fwind;
F(10)=F3*sin(gama3)-Fwind;
F(11)=F4*sin(gama4)-Fwind;
F(12)=F5*sin(gama5)-Fwind;
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
```

附件 9：问题 2 中，系泊系统参数求解的 Matlab 程序

```
function question2
global Mball
G=[];beta=[];alph1=[];d=[];R=[];
for Mball1=1700:10:5000
    Mball=Mball1*0.869426751592357;
    [x,fval,exitflag,r,Unuse]=fun;
    if (Unuse==0&x(2)>0.279)|x(3)>1.5|x(13)>0.087%只选取阿发 1 小于 16°，浮标深度小于 1.5 米，β小于 5 度的解
        continue
    elseif Unuse==0%代表没有落在地面的锚链
        alph1=[alph1;x(2)];G=[G;Mball1];beta=[beta;x(13)];d=[d;x(3)];R=[R;r];
    else%代表有落在地面的锚链
        alph1=[alph1;0];G=[G;Mball1];beta=[beta;x(13)];d=[d;x(3)];R=[R;r];
    end
end
G,beta=beta/pi*180,alph1=alph1/pi*180,d,R
figure(1)
plot(G,beta)
title('β随重物球质量变化图')
xlabel('重物球质量/kg')
ylabel('β/°')
grid on
figure(2)
plot(G,R)
title('区域半径随重物球质量变化图')
xlabel('重物球质量/kg')
```

```
ylabel('半径/m')
grid on
figure(3)
plot(G,d)
title('吃水深度随重物球质量变化图')
xlabel('重物球质量/kg')
ylabel('深度/m')
grid on
figure(4)
plot(G,alph1)
title('α1 随重物球质量变化图')
xlabel('重物球质量/kg')
ylabel('α1/°')
set(gca,'ytick',[0:16])
grid on
figure(5)
k=[0.1,0.8,0.1];%吃水深度：β：区域半径=0.1：0.8:0.1
y=d/max(d)*k(1)+beta/max(beta)*k(2)+R/max(R)*k(3);
plot(G,y)
title('优化目标随重物球质量变化图')
xlabel('重物球质量/kg')
ylabel('目标值')
grid on
[a,place]=min(y)
G(place),beta(place),alph1(place),d(place),R(place)
end
function [x,fval,exitflag,R,Unuse]=fun
global R Mball
options=optimset('MaxFunEvals',1e4,'MaxIter',1e4);
format long
x0=[1372.4,0.18,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.0
9,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
[x,fval,exitflag]=fsolve(@fangcheng2,x0,options);
Unuse=0;%代表没有落在地面的锚链
if x(2)<0

x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.09,0.
09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
    [x,fval,exitflag]=fsolve(@fangcheng1,x0,options);
    Unuse=1;%代表有落在地面的锚链
end
end
function F=fangcheng1(x)
global R Mball
```

```
Fwind=x(1);%风力
unuse=x(2);
alph1=0;%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);th
eta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
H=18;%水深
p=1025;%海水密度
sigma=7;
g=9.8;%重力加速度
% Mball=1200;%重物球质量
maolian=22.05;%锚链长度
maolian=maolian-x(2);%减去沉在海底的长度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)(Fwind/sigma/g*cosh(sigma*g*t/Fwind+asinh(tan(alph1)))-Fwind/sigma/g*co
sh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/Fwind+asinh(tan(alph1)))).^2));
R=sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)+x1+unuse;
F(1)=quad(Dy,0,x1)-maolian;%锚链长度
alph2=atan(sinh(sigma*g*x1/Fwind+asinh(tan(alph1))));
y1=y(x1);
%钢桶
F(2)=F1*sin(gama1-beta)+Fwind/cos(alph2)*sin(pi/2-alph2-beta)-Mball*g*sin(beta);
%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-Fwind*tan(alph2);% 竖 直 受
力平衡
F(4)=F1*sin(gama1)-Fwind;%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-Fwind;
F(10)=F3*sin(gama3)-Fwind;
F(11)=F4*sin(gama4)-Fwind;
F(12)=F5*sin(gama5)-Fwind;
```

```
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
end
function F=fangcheng2(x)
global R Mball
Fwind=x(1);%风力
alph1=x(2);%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);th
eta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
H=18;%水深
p=1025;%海水密度
sigma=7;
g=9.8;%重力加速度
% Mball=1200;%重物球质量
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)(Fwind/sigma/g*cosh(sigma*g*t/Fwind+asinh(tan(alph1)))-Fwind/sigma/g*co
sh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/Fwind+asinh(tan(alph1)))).^2));
R=x1+sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4);
F(1)=quad(Dy,0,x1)-22.05;%锚链长度
alph2=atan(sinh(sigma*g*x1/Fwind+asinh(tan(alph1))));
y1=y(x1);
%钢桶
F(2)=F1*sin(gama1-beta)+Fwind/cos(alph2)*sin(pi/2-alph2-beta)-Mball*g*sin(beta);
%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-Fwind*tan(alph2);% 竖 直 受
力平衡
F(4)=F1*sin(gama1)-Fwind;%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
```

```
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-Fwind;
F(10)=F3*sin(gama3)-Fwind;
F(11)=F4*sin(gama4)-Fwind;
F(12)=F5*sin(gama5)-Fwind;
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
```

附件 10：问题 3 中，各点水速相同、水流与风同向时，锚链长度、型号、重物球质量的 Matlab 求解程序

```
function question3_junyunshuili %水力与风力同向
clc
clear
tic
global Mball sigma maolian H G BETA ALPH1 D RR A
SIGMA=[3.2,7,12.5,19.5,28.12];
G=[];BETA=[];ALPH1=[];D=[];RR=[];A=[];XX=[];THETA=[];
H=20;
    for xinghao=5:5
        sigma=SIGMA(xinghao);
        for maolian=21.1:0.1:22
            for Mball=4000:1:4002
                [x,fval,exitflag,r,Unuse]=fun;
                if
         (Unuse==0&x(2)>0.279)|x(3)>1.8|x(3)<0|x(13)>0.087|exitflag<1|(Unuse==1&x(2)<0)%只选取阿发 1 小于 16°，浮标深度小于 1.5 米，β 小于 5 度的解
                    continue
                elseif Unuse==0%代表没有落在地面的锚链

         ALPH1=[ALPH1;x(2)];G=[G;Mball];BETA=[BETA;x(13)];D=[D;x(3)];RR=[RR;r];A=[A;sigma,maolian,Mball];XX=[XX,[Unuse;x]];THETA=[THETA,x(12:15)];
                else%代表有落在地面的锚链
```

```
            ALPH1=[ALPH1;0];G=[G;Mball];BETA=[BETA;x(13)];D=[D;x(3)];RR=
            [RR;r];A=[A;sigma,maolian,Mball];XX=[XX,[Unuse;x]];THETA=[THET
            A,x(12:15)];
                    end
                end
            end
        end
G,BETA=BETA/pi*180,ALPH1=ALPH1/pi*180,D,RR,A,XX%sigma,maolian,Mball
k=[0.1,0.8,0.1];%吃水深度：β：区域半径=0.1：0.8:0.1
y=D/1.5*k(1)+BETA/5*k(2)+RR/30*k(3);
[aim,place]=min(y)
D(place),BETA(place),RR(place),A(place,:)%sigma,maolian,Mball
sigma_cu=A(place,1)
maolian_cu=A(place,2)
Mball_cu=A(place,3)
aim_cu=aim
THETA=THETA
toc
end
function [x,fval,exitflag,R,Unuse]=fun
global R
format long
x0=[1372.4,0.18,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.0
            9,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
[x,fval,exitflag]=fsolve(@fangcheng2,x0)
Unuse=0;%代表没有落在地面的锚链
if x(2)<0

            x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,
            0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
    [x,fval,exitflag]=fsolve(@fangcheng1,x0)
    Unuse=1;%代表有落在地面的锚链
end
end
function F=fangcheng1(x)
global R Mball sigma maolian H
Fwind=x(1);%风力
unuse=x(2);
alph1=0;%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);th
            eta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
```

```
%%
Vwind=36;%风速
p=1025;%海水密度
g=9.8;%重力加速度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)((Fwind+42.075*4+252.45+2*d*374*1.5*1.5)/sigma/g*cosh(sigma*g*t/(Fwi
        nd+42.075*4+252.45+2*d*374*1.5*1.5)+asinh(tan(alph1)))-(Fwind+42.0
        75*4+252.45+2*d*374*1.5*1.5)/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/(Fwind+42.075*4+252.45+2*d*374*1.5*1.5)+asin
        h(tan(alph1)))).^2));
R=sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)+x1+unuse;
F(1)=quad(Dy,0,x1)-(maolian-x(2));%锚链长度
alph2=atan(sinh(sigma*g*x1/(Fwind+42.075*4+252.45+2*d*374*1.5*1.5)+asinh(tan
        (alph1))));
y1=y(x1);
%钢桶
F(2)=F1*sin(gama1-beta)+(Fwind+42.075*4+2*d*374*1.5*1.5)/cos(alph2)*sin(pi/2-
        alph2-beta)-Mball*g*sin(beta);%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-(Fwind+42.075*4+252.45+2*
        d*374*1.5*1.5)*tan(alph2);%竖直受力平衡
F(4)=F1*sin(gama1)-(Fwind+42.075*4+2*d*374*1.5*1.5);%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-(Fwind+42.075*3+2*d*374*1.5*1.5);
F(10)=F3*sin(gama3)-(Fwind+42.075*2+2*d*374*1.5*1.5);
F(11)=F4*sin(gama4)-(Fwind+42.075*1+2*d*374*1.5*1.5);
F(12)=F5*sin(gama5)-(Fwind+2*d*374*1.5*1.5);
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
end
function F=fangcheng2(x)
```

```
global R Mball sigma maolian H
Fwind=x(1);%风力
alph1=x(2);%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);th
        eta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
p=1025;%海水密度
g=9.8;%重力加速度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
f=2*d*374*1.5*1.5;
%%
y=@(t)((Fwind+42.075*4+252.45+f)/sigma/g*cosh(sigma*g*t/(Fwind+42.075*4+25
        2.45+f)+asinh(tan(alph1)))-(Fwind+42.075*4+252.45+f)/sigma/g*cosh(asi
        nh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/(Fwind+42.075*4+252.45+f)+asinh(tan(alph1)))).^
        2));
R=x1+sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4);
F(1)=quad(Dy,0,x1)-maolian;%锚链长度
alph2=atan(sinh(sigma*g*x1/(Fwind+42.075*4+252.45+f)+asinh(tan(alph1))));
y1=y(x1);
%钢桶
F(2)=F1*sin(gama1-beta)+(Fwind+42.075*4+f)/cos(alph2)*sin(pi/2-alph2-beta)-Mba
        ll*g*sin(beta);%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-(Fwind+42.075*4+252.45+f)*
        tan(alph2);%竖直受力平衡
F(4)=F1*sin(gama1)-(Fwind+42.075*4+f);%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-(Fwind+42.075*3+f);
F(10)=F3*sin(gama3)-(Fwind+42.075*2+f);
F(11)=F4*sin(gama4)-(Fwind+42.075*1+f);
F(12)=F5*sin(gama5)-(Fwind+1683);
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
```

```
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
end
```

附件 11：问题 3 中，各点水速相同、水流与风同向时，钢桶和钢管的倾斜角度、锚链形状的 Matlab 求解程序

```
function question3_fenxi_junyunshuili
global Mball H maolian sigma
Mball=4030;H=input('输入海深 H：');maolian=20.9;sigma=28.12;
 [x,fval,exitflag,r,Unuse]=fun;
if Unuse==0%代表没有落在地面的锚链
        alph1=x(2);beta=x(13);d=x(3),R=r;
else%代表有落在地面的锚链
        alph1=0;beta=x(13);d=x(3);R=r;
end
beta=beta/pi*180,alph1=alph1/pi*180,d,R
x(9:13)/pi*180
end
function [x,fval,exitflag,R,Unuse]=fun
global R Mball
format long
x0=[1372.4,0.18,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.0
9,0.09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
[x,fval,exitflag]=fsolve(@fangcheng2,x0)
Unuse=0;%代表没有落在地面的锚链
if x(2)<0

x0=[1372.4,6,0.78,14496.80,14592.35,14687.92,14783.49,14879.07,0.09,0.09,0.09,0.
09,0.09,0.09,0.09,0.09,0.09,0.09,17.75]';
     [x,fval,exitflag]=fsolve(@fangcheng1,x0)
     Unuse=1;%代表有落在地面的锚链
end
end
function F=fangcheng1(x)
global R Mball sigma maolian H
Fwind=x(1);%风力
unuse=x(2);
alph1=0;%弧度<0.2793
d=x(3);%吃水深度 0.5
```

```
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);th
eta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
p=1025;%海水密度
g=9.8;%重力加速度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
%%
y=@(t)((Fwind+42.075*4+252.45+2*d*374*1.5*1.5)/sigma/g*cosh(sigma*g*t/(Fwi
nd+42.075*4+252.45+2*d*374*1.5*1.5)+asinh(tan(alph1)))-(Fwind+42.075*4+252.
45+2*d*374*1.5*1.5)/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/(Fwind+42.075*4+252.45+2*d*374*1.5*1.5)+asin
h(tan(alph1)))).^2));
R=sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4)+x1+unuse;
F(1)=quad(Dy,0,x1)-(maolian-x(2));%锚链长度
alph2=atan(sinh(sigma*g*x1/(Fwind+42.075*4+252.45+2*d*374*1.5*1.5)+asinh(tan
(alph1))));
y1=y(x1);
xx=0:0.001:x1;
yy=y(xx);
xx=[0:0.001:unuse,xx+unuse+0.001];xx=(xx-xx(1))*0.89;
u=length(0:0.001:unuse);
yy=[zeros(1,u),yy];
plot(xx,yy,'LineWidth',3,'markersize',8)
% set(gca,'xtick',[0:x1+unuse+1],'ytick',[0:yy(end)+1])
title('锚链形状')
xlabel('锚链投影长度/m')
ylabel('距离海底高度/m')
grid on
%钢桶
F(2)=F1*sin(gama1-beta)+(Fwind+42.075*4+2*d*374*1.5*1.5)/cos(alph2)*sin(pi/2-
alph2-beta)-Mball*g*sin(beta);%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-(Fwind+42.075*4+252.45+2*
d*374*1.5*1.5)*tan(alph2);%竖直受力平衡
F(4)=F1*sin(gama1)-(Fwind+42.075*4+2*d*374*1.5*1.5);%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
```

```
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-(Fwind+42.075*3+2*d*374*1.5*1.5);
F(10)=F3*sin(gama3)-(Fwind+42.075*2+2*d*374*1.5*1.5);
F(11)=F4*sin(gama4)-(Fwind+42.075*1+2*d*374*1.5*1.5);
F(12)=F5*sin(gama5)-(Fwind+2*d*374*1.5*1.5);
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
end
function F=fangcheng2(x)
global R Mball sigma maolian H
Fwind=x(1);%风力
alph1=x(2);%弧度<0.2793
d=x(3);%吃水深度 0.5
F1=x(4);F2=x(5);F3=x(6);F4=x(7);F5=x(8);theta1=x(9);theta2=x(10);theta3=x(11);theta4=x(12);
beta=x(13);gama1=x(14);gama2=x(15);gama3=x(16);gama4=x(17);gama5=x(18);
x1=x(19);%锚链末端横坐标
%%
Vwind=36;%风速
p=1025;%海水密度
g=9.8;%重力加速度
floatage_bucket=0.15*0.15*pi*p;%钢桶浮力
floatage_pipe=0.025*0.025*pi*p;%钢管浮力
F=ones(19,1);
f=2*d*374*1.5*1.5;
%%
y=@(t)((Fwind+42.075*4+252.45+f)/sigma/g*cosh(sigma*g*t/(Fwind+42.075*4+252.45+f)+asinh(tan(alph1)))-(Fwind+42.075*4+252.45+f)/sigma/g*cosh(asinh(tan(alph1))));
Dy=@(t)(sqrt(1+(sinh(sigma*g*t/(Fwind+42.075*4+252.45+f)+asinh(tan(alph1)))).^2));
R=x1+sin(beta)+sin(theta1)+sin(theta2)+sin(theta3)+sin(theta4);
F(1)=quad(Dy,0,x1)-maolian;%锚链长度
alph2=atan(sinh(sigma*g*x1/(Fwind+42.075*4+252.45+f)+asinh(tan(alph1))));
y1=y(x1);
xx=0:0.001:x1;
yy=y(xx);
plot(xx,yy,'LineWidth',3,'markersize',8)
```

```
% set(gca,'xtick',[0:x1+1],'ytick',[0:yy(end)+1])
title('锚链形状')
xlabel('锚链投影长度/m')
ylabel('距离海底高度/m')
grid on
%钢桶
F(2)=F1*sin(gama1-beta)+(Fwind+42.075*4+f)/cos(alph2)*sin(pi/2-alph2-beta)-Mba
ll*g*sin(beta);%力矩平衡
F(3)=F1*cos(gama1)+floatage_bucket-100*g-Mball*g-(Fwind+42.075*4+252.45+f)*
tan(alph2);%竖直受力平衡
F(4)=F1*sin(gama1)-(Fwind+42.075*4+f);%水平受力平衡
%4 个钢管力矩平衡
F(5)=F1*sin(gama1-theta1)-F2*sin(theta1-gama2);
F(6)=F2*sin(gama2-theta2)-F3*sin(theta2-gama3);
F(7)=F3*sin(gama3-theta3)-F4*sin(theta3-gama4);
F(8)=F4*sin(gama4-theta4)-F5*sin(theta4-gama5);
%4 个钢管水平受力平衡
F(9)=F2*sin(gama2)-(Fwind+42.075*3+f);
F(10)=F3*sin(gama3)-(Fwind+42.075*2+f);
F(11)=F4*sin(gama4)-(Fwind+42.075*1+f);
F(12)=F5*sin(gama5)-(Fwind+f);
%4 个钢管竖直受力平衡
F(13)=F1*cos(gama1)+10*g-F2*cos(gama2)-floatage_pipe;
F(14)=F2*cos(gama2)+10*g-F3*cos(gama3)-floatage_pipe;
F(15)=F3*cos(gama3)+10*g-F4*cos(gama4)-floatage_pipe;
F(16)=F4*cos(gama4)+10*g-F5*cos(gama5)-floatage_pipe;
F(17)=F5*cos(gama5)+1000*g-pi*d*p*g;%浮标竖直受力
F(18)=y1+cos(beta)+cos(theta1)+cos(theta2)+cos(theta3)+cos(theta4)+d-H;%水深
F(19)=2*(2-d)*0.625*Vwind*Vwind-Fwind;%风力
end
```