Estimation of elastic properties of H313_HTI sample

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Introduction

Some bla bla bla here))

Add MLIB library

```
clear; close all; clc;
mlibfolder = '/home/ivan/Desktop/MLIB';
path(path, mlibfolder);
add_mlib_path;
```

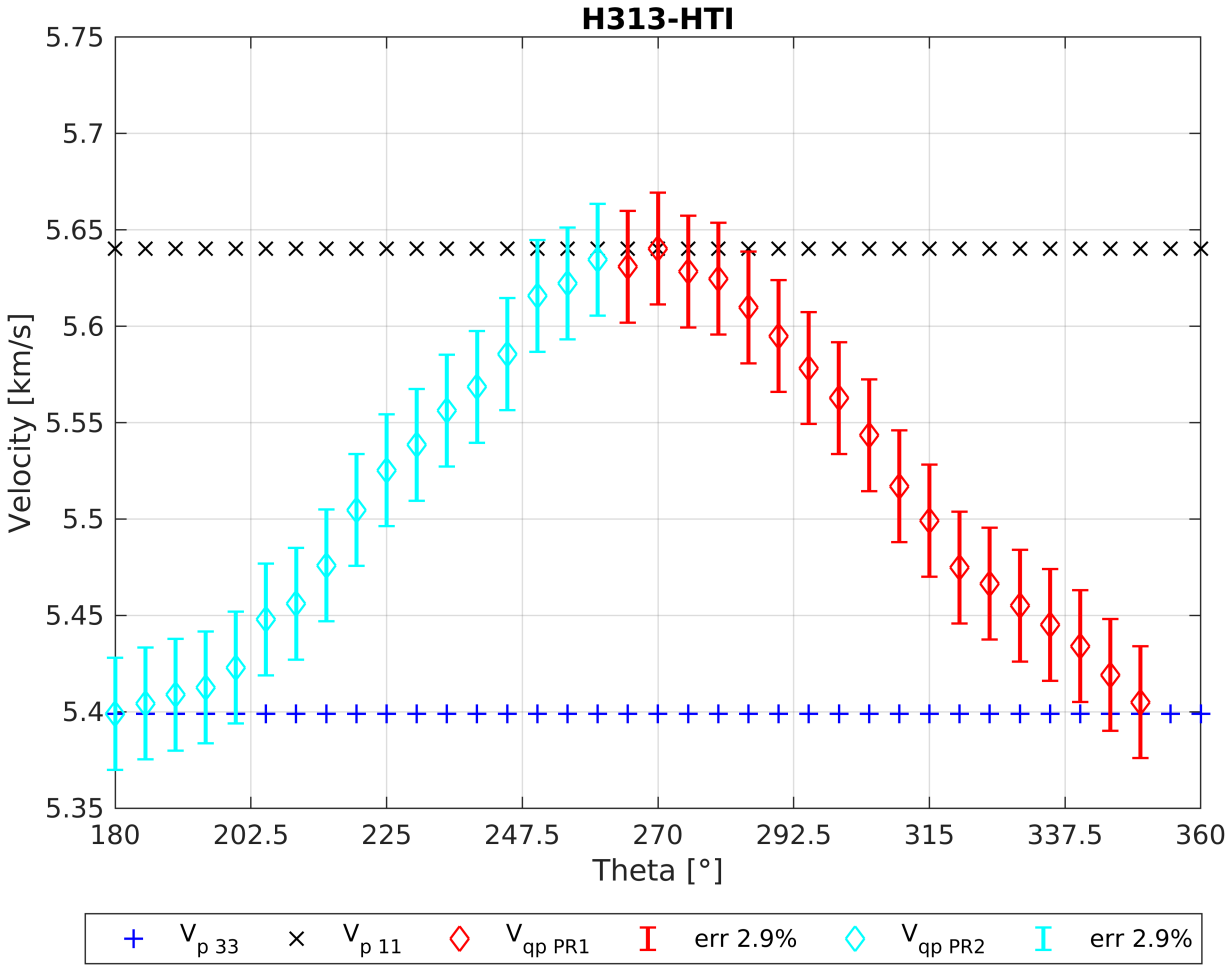
1. Upload the data

```
Sample = MLD('/remote/data/ivan/Ultrasonic_data/H313_HTI_ivan/Sample_H313_HTI_data.mat
Sample.Theta = Sample.Theta+90;
Sample.Theta(Sample.Theta>360) = Sample.Theta(Sample.Theta>360)-360;

%ind1 = [1:9 13:35];          % seria of measurements
%ind2 = [38:48 54:72];            % another at 90 degree
ind1 = 18:35;          % seria of measurements
ind2 = 56:72;            % another at 90 degree
ind = [ind1 ind2];

Sample.Vp11 = max(Sample.Vqp(ind))*ones(size(Sample.Vqp));
Sample.Vp33 = min(Sample.Vqp(ind))*ones(size(Sample.Vqp));
Sample.Vs31 = Sample.Vp33/1.7;
Sample.Vs23 = Sample.Vp11/1.7;
```

Plot velocities

```
figure(1733)       % P velocities
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1), Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1),Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidth',
plot (Sample.Theta(ind2), Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2),Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidth',
```

```
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp PR1}','err 2.9%','V_{qp PR2}','err 2.9%', 'Location
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
axis([180 360 5.35 5.75]);
grid on
```

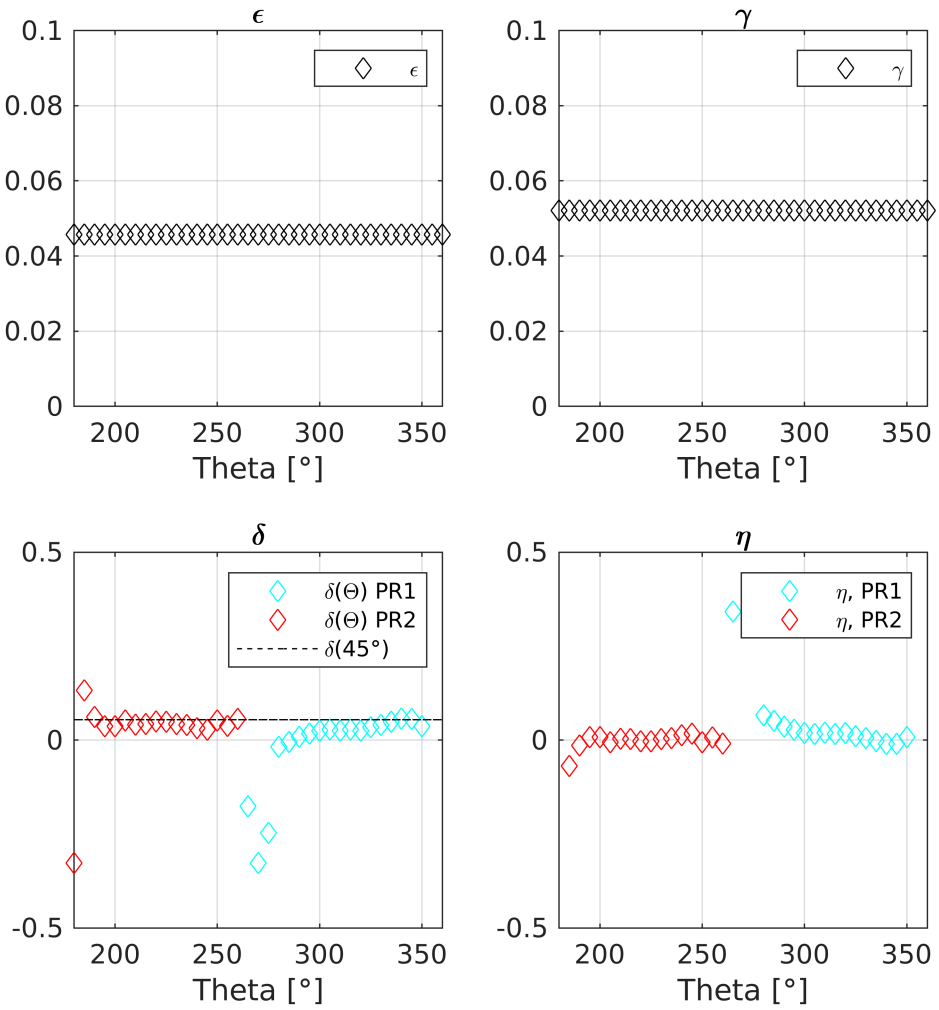


2. Conventional analyses of Thomsen's parameters

```
C11 = Sample.rho*Sample.Vp11.^2;
C33 = Sample.rho*Sample.Vp33.^2;
C44 = Sample.rho*Sample.Vs31.^2;
C66 = Sample.rho*Sample.Vs21.^2;
Cqp = Sample.rho*Sample.Vqp.^2;
C12 = C11 - 2*C66;

ST2 = (sin(Sample.Theta/180*pi)).^2;
```

```
CT2 = (cos(Sample.Theta/180*pi)).^2;

A = (C11 + C44).*ST2 + (C33 + C44).*CT2;
B = (C11 - C44).*ST2 - (C33 - C44).*CT2;

C13 = sqrt(((2*Cqp-A).^2 - B.^2)./(4*ST2.*CT2)) - C44;

gamma   = (C66 - C44)./(2*C44);
epsilon = (C11 - C33)./(2*C33);
delta = ((C13+C44).^2 - (C33-C44).^2)./(2*C33.*(C33-C44));
eta = (epsilon-delta)./(1+2*delta);

ind = ((Sample.Theta == 45) + (Sample.Theta == 135) + (Sample.Theta == 225)+ (Sample.Th
delta45.mean = mean(delta(ind));
delta45.std = std(delta(ind));


figure(21);
fig = figure('Position', [1 1 550 550]);

subplot(2,2,1)
plot(Sample.Theta,epsilon,'kd');
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 0 0.1]);
legend('\epsilon')
grid on
title('\epsilon')

subplot(2,2,2)
plot(Sample.Theta,gamma,'kd');
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 0 0.1]);
legend('\gamma')
grid on
title('\gamma')

subplot(2,2,3)
plot(Sample.Theta(ind1),delta(ind1),'cd');
hold on
plot(Sample.Theta(ind2),delta(ind2),'rd');
plot(Sample.Theta,delta45.mean*ones(size(Sample.Theta)),'k--');
legend('\delta(\Theta) PR1', '\delta(\Theta) PR2', '\delta(45\circ)')
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 -0.5 0.5]);
grid on
title('\delta')

subplot(2,2,4)
plot(Sample.Theta(ind1),eta(ind1),'cd');
hold on
plot(Sample.Theta(ind2),eta(ind2),'rd');
xlabel('Theta [\circ]','LineWidth', 2)
legend('\eta, PR1','\eta, PR2')
```

```
axis([180 360 -0.5 0.5]);
grid on
title('\eta')
```

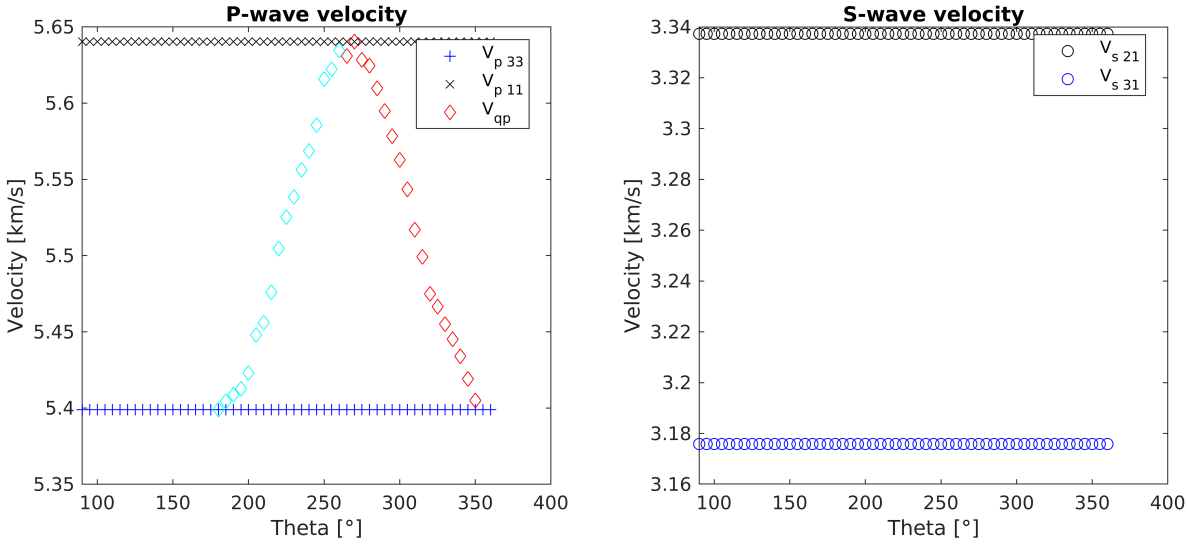


3. Least squares analysis of Thomsen's parameters

Visualize the data

```
figure(122)
fig = figure('Position', [1 1 1000 400]);
subplot(1,2,1)
plot(Sample.Theta, Sample.Vp33, '+b');
hold on
plot(Sample.Theta, Sample.Vp11, 'xk');
plot(Sample.Theta(ind1), Sample.Vqp(ind1), 'dr');
plot(Sample.Theta(ind2), Sample.Vqp(ind2), 'dc');
xlabel('Theta [\circ]')
ylabel('Velocity [km/s]')
```

```
legend('V_{p 33}', 'V_{p 11}', 'V_{qp}','Location','best')
title('P-wave velocity')

subplot(1,2,2)
plot(Sample.Theta, Sample.Vs21, 'ko');
hold on
plot(Sample.Theta, Sample.Vs31, 'bo');
xlabel('Theta [\circ]')
ylabel('Velocity [km/s]')
legend('V_{s 21}','V_{s 31}','Location','best')
title('S-wave velocity')
```



Assign C values

```
Sample.C11 = C11;
Sample.C33 = C33;
Sample.C44 = C44;
Sample.C66 = C66;
Sample.Vqp = Sample.Vqp;

ind = [ind1 ind2];
iSample.Theta = Sample.Theta(ind);
iSample.Vp33 = Sample.Vp33(ind);
iSample.Vp11 = Sample.Vp11(ind);
iSample.Vs31 = Sample.Vs31(ind);
iSample.Vs21 = Sample.Vs21(ind);
iSample.Vqp = Sample.Vqp(ind);
iSample.C11 = Sample.C11(ind);
iSample.C33 = Sample.C33(ind);
iSample.C44 = Sample.C44(ind);
iSample.C66 = Sample.C66(ind);
iSample.rho = Sample.rho;
```

Find optimum delta

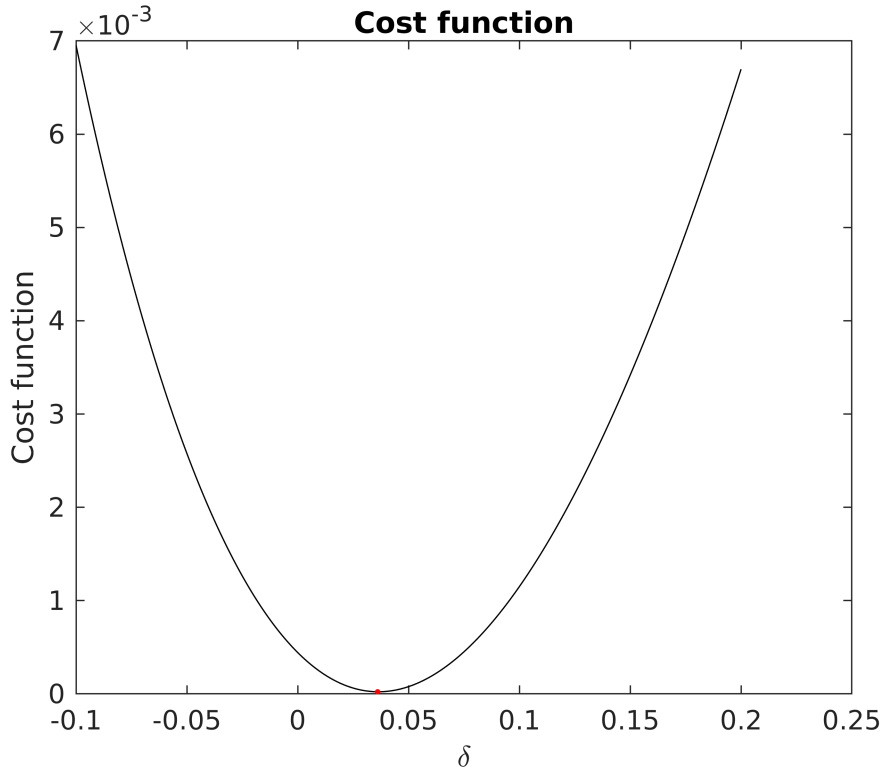
```
testdelta = -0.1:0.001:0.2;
dtheta = -10:0.1:10;
tic
nSample = iSample;
JJ = zeros(length(dtheta),length(testdelta));
for i=1:length(dtheta)
    nSample.Theta = iSample.Theta + dtheta(i);
    J = costFunction_delta(nSample,testdelta);
    JJ(i,:) = J;
end
toc
```

```
Elapsed time is 0.240275 seconds.
```

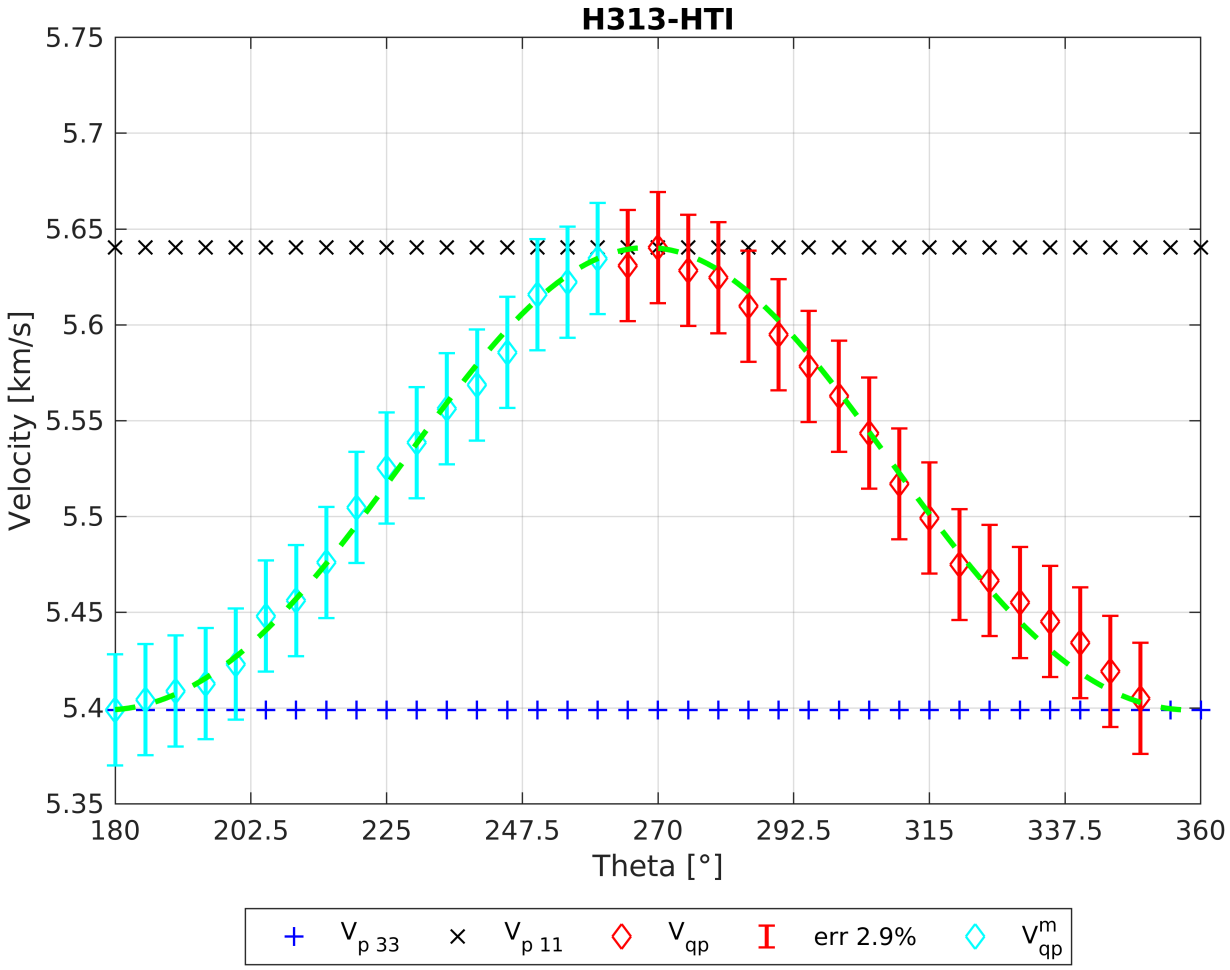
```


[~, minind] = min(JJ(:));
[inda, indd] = ind2sub(size(JJ),minind);

thetapl = dtheta(inda);
delta = testdelta(indd);
```

Plot final results

```
figure(343)
fig = figure('Position', [1 1 500 400]);
plot(testdelta, squeeze(JJ(inda,:)), 'k-');
hold on
plot(testdelta(indd), JJ(inda,indd), 'r.','MarkerSize', 7);
xlabel('\delta')
ylabel('Cost function')
title('Cost function')
```




```
nSample.Theta = 0:1:360;
Vqp = get_Vqp_VTI(nSample,delta);


figure(147)
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1), Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1),Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidth', 1
plot (Sample.Theta(ind2), Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2),Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidth', 1
plot(nSample.Theta-thetapl, Vqp, 'g-', 'LineWidth', 2)
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp}','err 2.9%','V_{qp}^m', 'Location', 'southoutside
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
axis([180 360 5.35 5.75]);
grid on
```



3. Least squares analysis of Thomsen's parameters (weak anisotropy approximation)

```
Alpha   = linspace(5.35,5.45,101);
Delta   = linspace(-0.0,0.10,101);
Epsilon = linspace(0.02,0.12,101);
dTheta  = linspace(-5,5,26);

tic
J = costFunction_delta_weak(iSample,Alpha,Delta,Epsilon,dTheta);
toc
```

```
Elapsed time is 60.048427 seconds.
```

```
[~, ind] = min(J(:));
[inda,indd,inde,indt] = ind2sub(size(J),ind);
```

```
result.alpha = Alpha(inda);
result.delta = Delta(indd);
result.epsilon = Epsilon(inde);
result.dtheta = dTheta(indt);
```

3a. Alternative idea with L-BFGS-B method

```
save('/home/ivan/Desktop/MLIB/UMM/TempSample.mat','iSample');


x0  = [5.40 0.05 0.07   0];   % The starting point.
lb  = [5.35 0.0  0.02 -10];  % Lower bound on the variables.
ub  = [5.45 0.1  0.12 +10];  % Upper bound on the variables.

tic
x = lbfgsb(x0,lb,ub,'ComputeObjectiveSample','ComputeGradientSample',...
               [],'genericcallback','maxiter',80,'m',4,'factr',1e-12,...
               'pgtol',1e-5);
```

```
  1  0.000179
  2  0.000145
  3  3.79e-05
  4  3.1e-05
  5  2.82e-05
  6  2.82e-05
  7  2.82e-05
  8  2.82e-05
  9  2.82e-05
 10  2.82e-05
 11  2.81e-05
 12  2.81e-05
 13  2.79e-05
 14  2.71e-05
 15  2.55e-05
 16  2.27e-05
 17  2.01e-05
 18  1.84e-05
 19  1.76e-05
 20  1.7e-05
 21  1.59e-05
 22  1.5e-05
 23  1.5e-05
 24  1.49e-05
 25  1.49e-05
 26  1.48e-05
 27  1.48e-05
 28  1.48e-05
 29  1.48e-05
 30  1.48e-05
```

```
toc
```

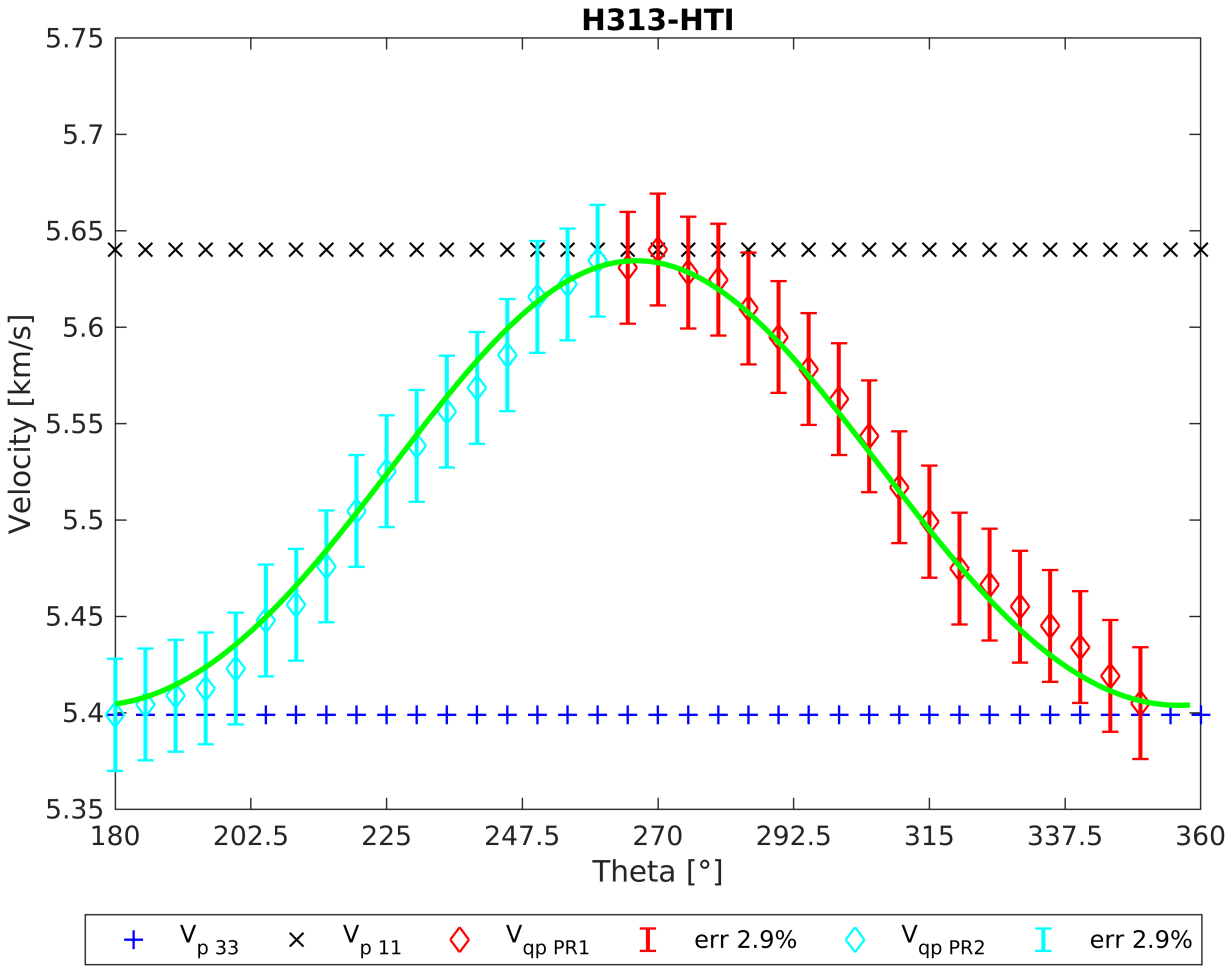
```
Elapsed time is 3.883095 seconds.
```

```
result.alpha = x(1);
result.delta = x(2);
```

```
result.epsilon = x(3);
result.dtheta = x(4);
```

Plot the result:

```
figure(27)
fig = figure('Position', [1 1 1200 800]);

nSample.Theta = 0:1:360;
Vqp = get_Vqp_VTI_weak(nSample,result.alpha,result.delta,result.epsilon,result.dtheta)

figure(144)
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1), Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1),Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidth', 1
plot (Sample.Theta(ind2), Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2),Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidth', 1
plot(nSample.Theta-result.dtheta, Vqp, 'g-', 'LineWidth', 2)
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp PR1}','err 2.9%','V_{qp PR2}','err 2.9%', 'Location
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
axis([180 360 5.35 5.75]);
```



4. Find errors of estimated parameters

```
% angle error std: 3 grad  =>> error in velocity 25 m/s
% error in velocity due to measurements =>> 15 m/s
% total error: 30 m
%                                       37 mrasurement 73
% variance for velocity error 30 m = 0.010;   0.0060
% variance for velocity error 100 m = 0.030   0.020

Alpha   = linspace(5.35,5.45,26);
Delta   = linspace(-0.0,0.10,26);
Epsilon = linspace(0.02,0.12,26);
dTheta  = linspace(-5,5,11);

x0  = [5.40 0.05 0.07   0];   % The starting point.
lb  = [5.35 -0.05  0.02 -10];  % Lower bound on the variables.
ub  = [5.45  0.1  0.12 +10];  % Upper bound on the variables.
```

```
Theta = iSample.Theta;
iiSample = iSample;

clear test;

for i=1:1:200

    iiSample.Theta = Theta + 1*randn(size(Theta));
    Vqptrue = get_Vqp_VTI_weak(iiSample,result.alpha,result.delta,result.epsilon,result

    VqpE = Vqptrue.*(1+0.015*randn(size(Vqptrue)));
    iiSample.Vqp = VqpE;
    iiSample.Theta = Theta;

    %J = costFunction_delta_weak(iSample,Alpha,Delta,Epsilon,dTheta);

    %[~, ind] = min(J(:));
    %[inda,indd,inde,indt] = ind2sub(size(J),ind);



    %test.alpha(i) = Alpha(inda);
    %test.delta(i) = Delta(indd);
    %test.epsilon(i) = Epsilon(inde);
    %test.dtheta(i) = dTheta(indt);

    save('/home/ivan/Desktop/MLIB/UMM/TempSample.mat','iiSample');


    x = lbfgsb(x0,lb,ub,'ComputeObjectiveSample','ComputeGradientSample',...
               [],'genericcallback','maxiter',20,'m',4,'factr',1e-12,...
               'pgtol',1e-5);


    test.alpha(i) = x(1);
    test.delta(i) = x(2);
    test.epsilon(i) = x(3);
    test.dtheta(i) = x(4);

end
```

```
 1  0.00306
 2  0.00303
 3  0.00282
 4  0.00281
 5  0.00281
 6  0.00281
 7  0.00281
 8  0.00281
 9  0.00281
10  0.0028
11  0.0028
12  0.00279
13  0.00276
14  0.00272
```

```
15  0.00268
16  0.00268
17  0.00265
18  0.00265
19  0.00265
20  0.00265
 1  0.00268
 2  0.0026
 3  0.00241
 4  0.00241
 5  0.00241
 6  0.00241
 7  0.00241
 8  0.00241
 9  0.00241
10  0.00241
11  0.00241
12  0.00241
13  0.00241
14  0.00241
15  0.00241
16  0.00241
17  0.00241
18  0.00241
19  0.00241
20  0.00241
 1  0.00265
 2  0.00261
 3  0.00246
 4  0.00244
 5  0.00235
 6  0.00235
 7  0.00234
 8  0.00234
 9  0.00234
10  0.00234
11  0.00234
12  0.00234
13  0.00233
14  0.00232
15  0.0023
16  0.00229
17  0.00229
18  0.00229
19  0.00229
20  0.00229
 1  0.00263
 2  0.00259
 3  0.00245
 4  0.00243
 5  0.00235
 6  0.00234
 7  0.00234
 8  0.00234
 9  0.00234
10  0.00234
11  0.00234
12  0.00234
13  0.00234
14  0.00234
15  0.00234
16  0.00234
17  0.00234
18  0.00233
19  0.00232
```

```
20  0.00232
 1  0.00363
 2  0.0036
 3  0.00352
 4  0.00352
 5  0.00352
 6  0.00352
 7  0.00352
 8  0.00352
 9  0.00352
10  0.00352
11  0.00352
12  0.00352
13  0.00352
14  0.00352
15  0.00352
16  0.00352
17  0.00352
18  0.00352
19  0.00352
20  0.00352
 1  0.00849
 2  0.00315
 3  0.00311
 4  0.00301
 5  0.00301
 6  0.003
 7  0.003
 8  0.003
 9  0.003
 1  0.00264
 2  0.00261
 3  0.00254
 4  0.00254
 5  0.00253
 6  0.00253
 7  0.00253
 8  0.00253
 9  0.00253
10  0.00253
11  0.00253
12  0.00253
13  0.00252
14  0.00251
15  0.00249
16  0.00249
17  0.00248
18  0.00248
19  0.00248
20  0.00248
 1  0.00284
 2  0.00282
 3  0.00271
 4  0.00271
 5  0.0027
 6  0.0027
 7  0.0027
 8  0.0027
 9  0.0027
10  0.0027
11  0.0027
12  0.0027
13  0.0027
14  0.0027
15  0.0027
```

```
16  0.00269
17  0.00269
18  0.00269
19  0.00269
20  0.00269
 1  0.00469
 2  0.00457
 3  0.00414
 4  0.00412
 5  0.00406
 6  0.00406
 7  0.00406
 8  0.00406
 9  0.00406
10  0.00406
11  0.00406
12  0.00406
13  0.00405
14  0.00402
15  0.00399
16  0.00395
17  0.00395
18  0.00395
19  0.00395
20  0.00395
 1  0.00511
 2  0.005
 3  0.00468
 4  0.00468
 5  0.00467
 6  0.00467
 7  0.00467
 8  0.00467
 9  0.00467
10  0.00467
11  0.00467
12  0.00467
13  0.00467
14  0.00467
15  0.00467
16  0.00467
17  0.00467
18  0.00467
19  0.00466
20  0.00466
 1  0.00366
 2  0.00365
 3  0.00363
 4  0.00362
 5  0.00361
 6  0.00361
 7  0.00361
 8  0.00361
 9  0.00361
10  0.00361
11  0.00361
12  0.00361
13  0.00361
14  0.00361
15  0.00361
16  0.00361
17  0.00361
18  0.00361
19  0.0036
20  0.0036
```

```
 1  0.00377
 2  0.00374
 3  0.00362
 4  0.00361
 5  0.00359
 6  0.00359
 7  0.00359
 8  0.00359
 1  0.00381
 2  0.00364
 3  0.00304
 4  0.00303
 5  0.00296
 6  0.00296
 7  0.00296
 8  0.00296
 9  0.00296
10  0.00295
11  0.00294
12  0.00294
13  0.00292
14  0.0029
15  0.00289
16  0.00288
17  0.00288
18  0.00288
19  0.00288
20  0.00288
 1  0.00283
 2  0.00281
 3  0.0027
 4  0.0027
 5  0.0027
 6  0.0027
 7  0.0027
 8  0.0027
 9  0.0027
10  0.0027
11  0.0027
12  0.0027
13  0.0027
14  0.00269
15  0.00269
16  0.00268
17  0.00268
18  0.00267
19  0.00267
20  0.00267
 1  0.00473
 2  0.00463
 3  0.00421
 4  0.0042
 5  0.00414
 6  0.00414
 7  0.00414
 8  0.00414
 9  0.00414
10  0.00414
11  0.00414
12  0.00414
13  0.00413
14  0.00412
15  0.00408
16  0.00405
17  0.00404
```

```
18  0.00403
19  0.00403
20  0.00403
 1  0.00298
 2  0.00286
 3  0.00243
 4  0.00243
 5  0.00242
 6  0.00242
 7  0.00242
 8  0.00242
 9  0.00242
10  0.00242
11  0.00242
12  0.00242
13  0.00242
14  0.00242
15  0.00242
16  0.00242
17  0.0024
18  0.00238
19  0.00236
20  0.00234
 1  0.00392
 2  0.0039
 3  0.00387
 4  0.00384
 5  0.00383
 6  0.00383
 7  0.00383
 8  0.00383
 9  0.00383
10  0.00383
11  0.00383
12  0.00383
13  0.00383
14  0.00383
15  0.00383
16  0.00382
17  0.00382
18  0.00382
19  0.00382
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17  0.00379
18  0.00379
19  0.00377
20  0.00377
 1  0.00584
 2  0.00568
 3  0.00562
 4  0.00562
 5  0.00562
 6  0.00562
 7  0.00562
 8  0.00562
 9  0.00562
10  0.0056
11  0.00558
12  0.00553
13  0.00545
14  0.00496
15  0.00489
16  0.00485
17  0.00485
```

```
18  0.00485
19  0.00485
 1  0.00328
 2  0.0031
 3  0.00245
 4  0.00245
 5  0.00245
 6  0.00245
 7  0.00245
 8  0.00245
 9  0.00245
10  0.00245
 1  0.00278
 2  0.00274
 3  0.00246
 4  0.00245
 5  0.00245
 6  0.00245
 7  0.00245
 8  0.00244
 9  0.00244
10  0.00244
11  0.00243
12  0.00241
13  0.0024
14  0.00239
15  0.00238
16  0.00238
17  0.00238
18  0.00238
19  0.00238
20  0.00238
 1  0.00382
 2  0.00352
 3  0.00339
 4  0.00337
 5  0.00331
 6  0.00331
 7  0.00331
 8  0.00331
 9  0.00331
10  0.00331
11  0.00331
12  0.00331
13  0.00331
14  0.00331
15  0.00331
16  0.0033
17  0.00327
18  0.00324
19  0.00323
20  0.00321
 1  0.0029
 2  0.00286
 3  0.00272
 4  0.00272
 5  0.00269
 6  0.00269
 7  0.00269
 8  0.00269
 9  0.00269
10  0.00269
11  0.00269
12  0.00269
13  0.00269
```

```
14  0.00268
15  0.00267
16  0.00265
17  0.00263
18  0.00263
19  0.00262
20  0.0026
 1  0.00311
 2  0.00308
 3  0.00295
 4  0.00294
 5  0.00289
 6  0.00289
 7  0.00289
 8  0.00289
 9  0.00289
10  0.00289
11  0.00289
12  0.00289
13  0.00289
14  0.00289
15  0.00289
16  0.00289
17  0.00289
18  0.00289
19  0.00289
20  0.00289
 1  0.00299
 2  0.00291
 3  0.00271
 4  0.00267
 5  0.00264
 1  0.00372
 2  0.00367
 3  0.00355
 4  0.00355
 5  0.00355
 6  0.00355
 7  0.00355
 8  0.00355
 1  0.00335
 2  0.00332
 3  0.00322
 4  0.00322
 5  0.00322
 6  0.00322
 7  0.00322
 8  0.00322
 9  0.00322
10  0.00322
11  0.00322
12  0.00322
13  0.00322
14  0.00321
15  0.00321
16  0.00321
17  0.00321
18  0.0032
19  0.0032
20  0.00319
 1  0.00344
 2  0.0032
 3  0.00241
 4  0.0023
 5  0.00226
```

```
 6  0.00226
 7  0.00226
 8  0.00226
 9  0.00226
10  0.00224
11  0.0022
12  0.00211
13  0.0021
14  0.00194
15  0.00186
16  0.00182
17  0.00181
18  0.0018
19  0.00179
20  0.00179
 1  0.00459
 2  0.00453
 3  0.00449
 4  0.00447
 5  0.00444
 6  0.00444
 7  0.00444
 8  0.00444
 9  0.00444
10  0.00444
11  0.00444
12  0.00444
13  0.00444
14  0.00444
15  0.00444
16  0.00444
17  0.00443
18  0.00443
19  0.00441
20  0.00439
 1  0.0042
 2  0.00419
 3  0.00415
 4  0.00414
 5  0.00411
 6  0.0041
 7  0.0041
 8  0.0041
 9  0.0041
 1  0.00413
 2  0.00406
 3  0.00384
 4  0.00382
 5  0.00375
 6  0.00375
 7  0.00375
 8  0.00375
 9  0.00375
10  0.00375
11  0.00375
12  0.00375
13  0.00375
14  0.00375
15  0.00375
16  0.00375
17  0.00375
18  0.00374
19  0.00373
20  0.00373
 1  0.00394
```

```
  2  0.00391
  3  0.00373
  4  0.00366
  5  0.00356
  6  0.00356
  7  0.00356
  8  0.00356
  9  0.00356
 10  0.00356
 11  0.00356
 12  0.00356
 13  0.00356
 14  0.00356
 15  0.00356
 16  0.00355
 17  0.00352
 18  0.0035
 19  0.00349
 20  0.00349
  1  0.0035
  2  0.00344
  3  0.00329
  4  0.00327
  5  0.00326
  6  0.00326
  7  0.00326
  1  0.00435
  2  0.00418
  3  0.00403
  4  0.00396
  5  0.00388
  6  0.00388
  7  0.00387
  8  0.00387
  9  0.00387
 10  0.00387
 11  0.00387
 12  0.00387
 13  0.00386
 14  0.00386
 15  0.00385
 16  0.00381
 17  0.00378
 18  0.00377
 19  0.00377
 20  0.00377
```

Plot results:

```
figure(33)
subplot(2,2,1);
histfit(test.alpha',21)
xlabel('V_{P0}, [m/s]')
dist = fitdist(test.alpha(1:100)','Normal');
disp(['ALPHA: Relative error: ' num2str(abs(result.alpha-dist.mu)/result.alpha*100) '%
```

```
ALPHA: Relative error: 0.010983%
```

```
alpha_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,4) ' \sigma=' num2str(dist.sigma,2)])

subplot(2,2,2);
histfit(test.delta',11)
xlabel('\delta')
dist = fitdist(test.delta(1:100)','Normal');
disp(['DELTA: Relative error: ' num2str(abs(result.delta-dist.mu)/result.delta*100) '%
```

```
DELTA: Relative error: 1.7924%
```

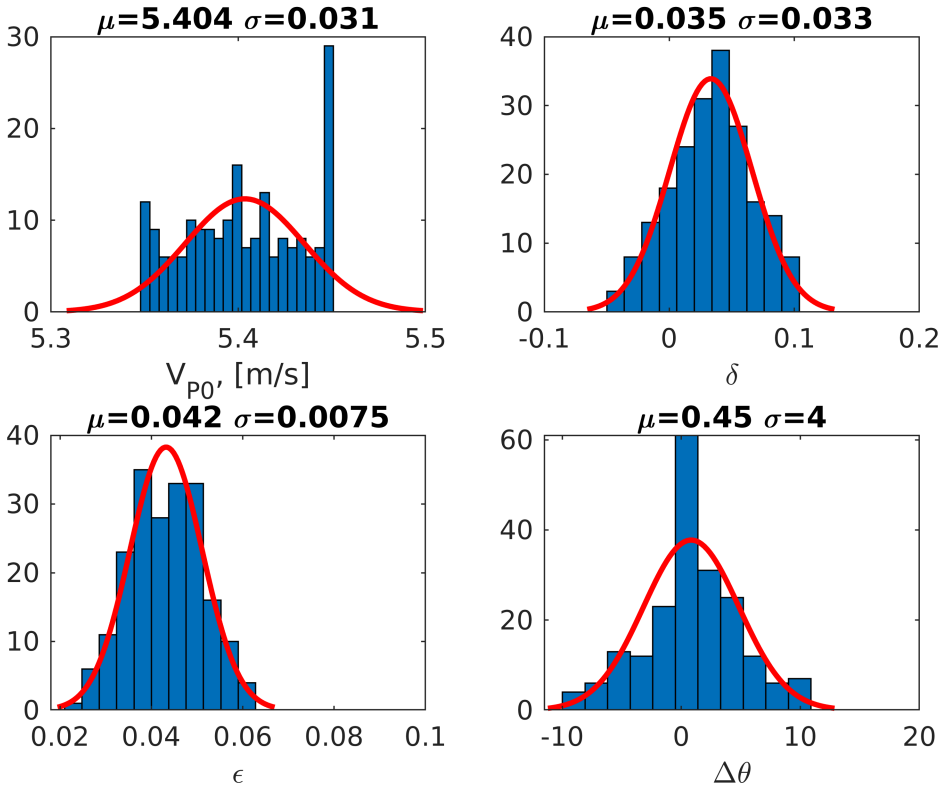
```
delta_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])

subplot(2,2,3);
histfit(test.epsilon',11)
xlabel('\epsilon')
dist = fitdist(test.epsilon(1:100)','Normal');
disp(['EPSILON: Relative error: ' num2str(abs(result.epsilon-dist.mu)/result.epsilon*10
```

```
EPSILON: Relative error: 1.2762%
```

```
epsilon_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])
%
subplot(2,2,4);
histfit(test.dtheta',11)
xlabel('\Delta\theta')
dist = fitdist(test.dtheta(1:100)','Normal');
disp(['DTHETA: Absolute error: ' num2str(result.dtheta-dist.mu)])
```

```
DTHETA: Absolute error: 1.3462
```

```
dtheta_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])
```


μ=5.404 σ=0.031
30
20
10
0
5.3
5.4
5.5
V_{P0}, [m/s]
μ=0.035 σ=0.033
40
30
20
10
0
-0.1
0
0.1
0.2
δ
μ=0.042 σ=0.0075
40
30
20
10
0
0.02
0.04
0.06
0.08
0.1
ϵ
μ=0.45 σ=4
60
40
20
0
-10
0
10
20
$\Delta\theta$