## Appendix III: Engineering Interpretation of Large-Scale Test Data

**Francisco Grajales**
**December 13, 2010**

# CHAPTER 1: Introduction

THE TEST

The test consists primarily in a model anchor towed by a carriage structure, as shown in Figure 1.1 . Both, the model anchor and the carriage, are connected by the tow line and a support truss. As the carriage advances, the anchor moves forward and theoretically should embed into the mud.

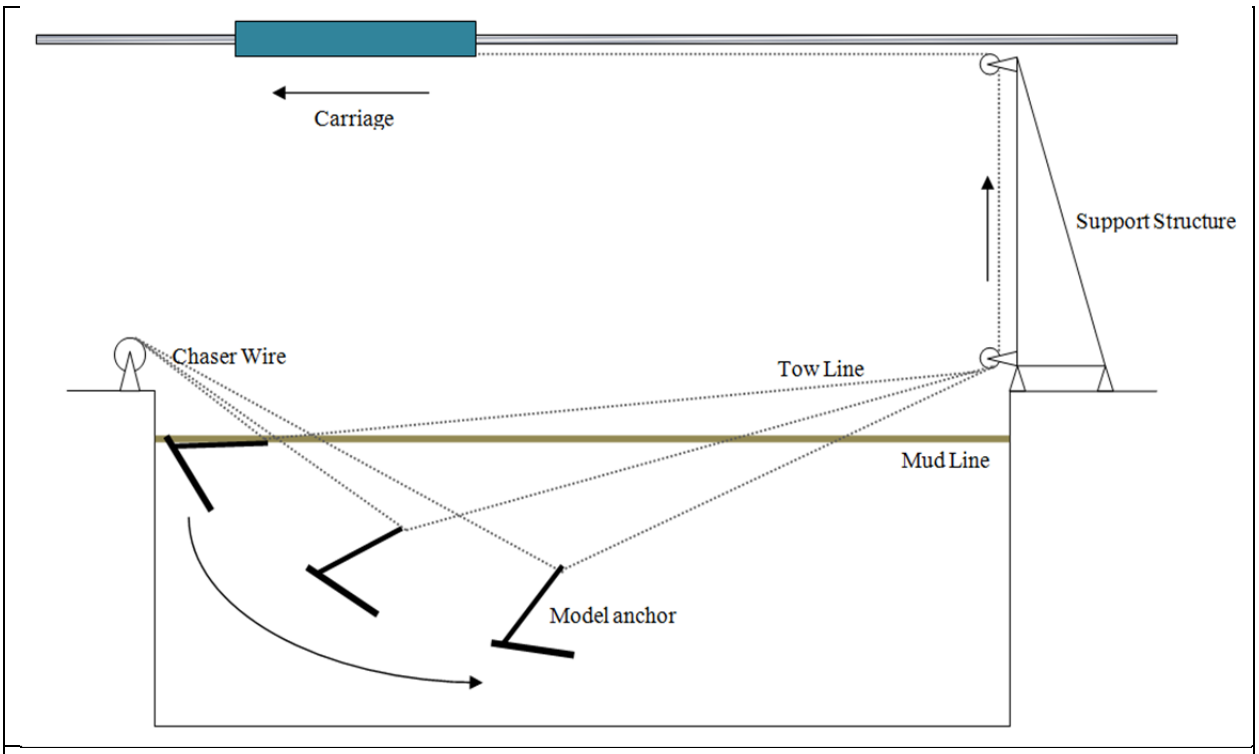



**Figure 1.1 Geometry of the Test (Not to Scale)**

The model anchor, which can be seen in Figure 1. 2 and Figure 1. 3, is equipped with a pressure transducer and an inclinometer. The pressure transducer measures the depth at which the anchor is supposed to be located. On the other hand, the inclinometer determine the fluke angle, between the fluke and the shank

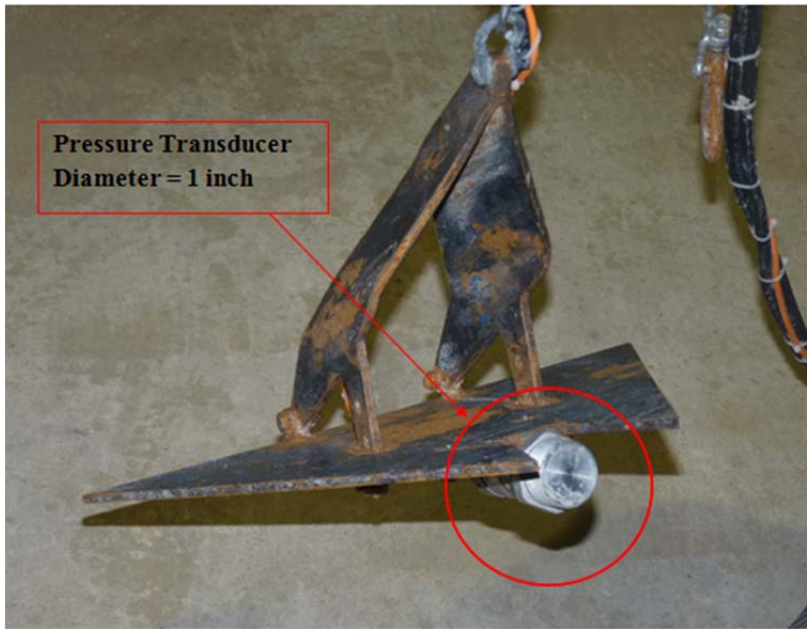



**Figure 1. 2: Model anchor and pressure transducer.**

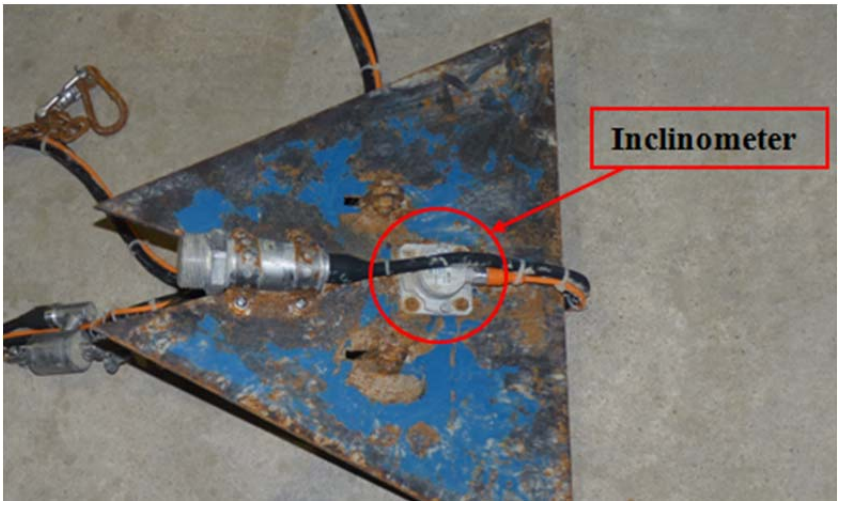



**Figure 1. 3: Model Anchor and Inclinometer**

At the end, as a result of the tests, one can obtain many tables with very useful data, which can be used to determine important parameters such as the trajectory and the bearing capacity.

# CHAPTER 2: Basic Definitions

SCOPE

This section is intended to provide some useful definition of the most common terms that are going to be commonly used in this document. For graphical reference, the reader can also check Figure 2. 1 which is a diagram of the different parts of the experiment.

- Anchor Fluke: refers to the base of the anchor.
- Anchor Shank: refers to the part of the anchor that is connected to the tow line.
- Tow Line: metallic cable. Its function is to tow the anchor along the mud tank.
- Chaser wire: is a metallic wire, used basically to measure the length and inclination of this wire itself. This is one of the keys for the geometrical analysis.
- Fluke Angle: is the angle between the fluke and the shank. The model anchor is adjustable, in way that each test can be performed with a different fluke angle.
- Chaser angle V: is the vertical angle of the chaser wire
- Chaser angle H: is the horizontal angle of the chaser wire

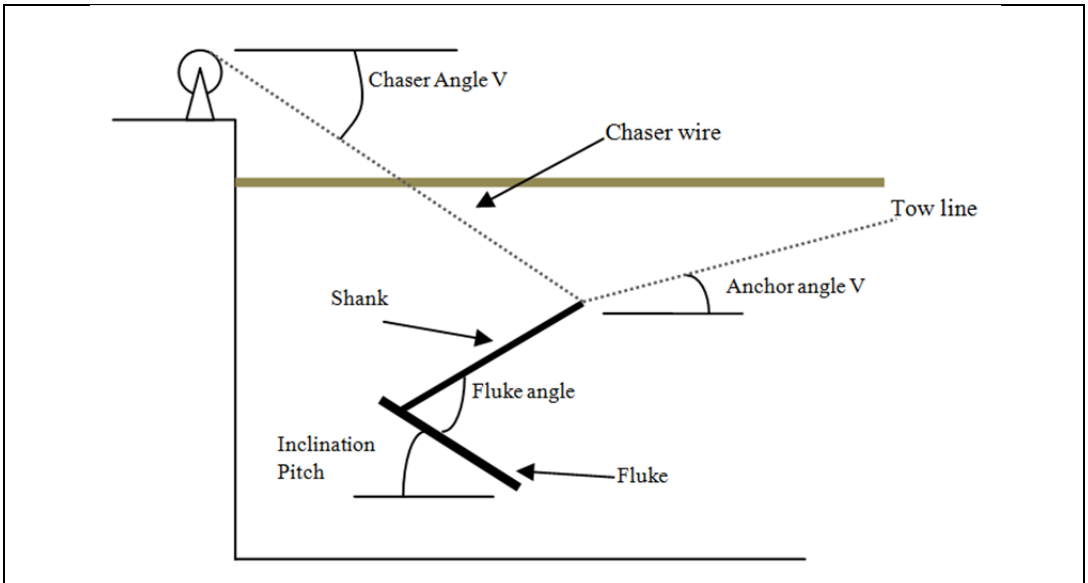



**Figure 2. 1: Diagram of the model anchor (not to scale)**

- Chaser displacement: displacement of chaser line connected to the anchor shank

- Anchor angle V: is the vertical angle of tow line at the pulley. (Support Truss)
- Anchor angle H: is the horizontal angle of tow line at the pulley. (Support Truss)
- Pressure: is the depth of anchor in feet of mud measured by pressure transducer mounted under the fluke (Refer to Figure 1. 2.).
- Inclinometer Pitch: is the angle (backward forward angle) measured by inclinometer mounted under the fluke
- Inclinometer Roll: is the angle (right left angle) measured by the inclinometer mounted under the fluke
- Anchor force: refers to the force measured by the load cell that is attached between the tow line and the anchor shank (measured in lb).
- Carriage force: refers to the force measured by the load cell attached between the tow line and the carriage (lb)

# CHAPTER 3: Geometrical analysis of the in plane testing

SCOPE

The purpose of the geometrical analysis is to obtain the position of the anchor at each measured time. In other words we are attempting to compute the trajectory of the anchor. Once the trajectory have been computed, one can be able to make a comparison between the geometrical trajectory (which we are computing), and the measured trajectory, taken with the pressure transducer.

ASSUMPTIONS

Many assumptions were made in order to obtain results, they are:

- The distance between the mud line and the chaser is approximately 32.75" (or 2.73 ft).
- It is assumed that there is no catenary in the chaser wire, therefore the length of the wire is going to give us the position.

VARIABLE DEFINITION

The following variables are going to be used along this chapter. Some of them can be identified in Figure 3. 1 and Figure 3. 2, shown below. Others will be shown during the explanation of the calculations.

$d_c$ = distance between the mud line and the chaser's pulley

$L_L$ = Chaser wire's length

$\theta_L$ = Chaser's vertical angle (with the horizontal line)

$L_{LX}$ = Horizontal component of chaser length

X = Horizontal component of the transducer displacement

$L_{LZ}$ = Vertical component of chaser length

Z = Vertical component of the transducer displacement

$\Delta x$ = Chaser's horizontal displacement

$\Delta z$ = Chaser's vertical displacement

$L_S$ = Length of the shank = 1.23 ft.

$L_T$ = Length of the fluke, where the pressure transducer is located = 1ft.

$\theta_P$ = Inclination pitch, measured by the inclinometer.

β = Fluke angle (22, 36 and 50 degrees)

Dx = Additional horizontal displacement produced by the anchor rotation during the test

Dz = Additional vertical displacement produced by the anchor rotation during the test

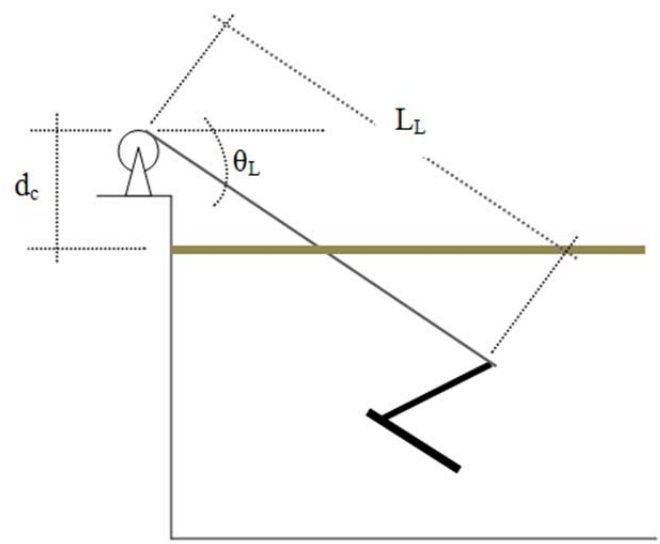



**Figure 3. 1 Side view of the system and variable definition**

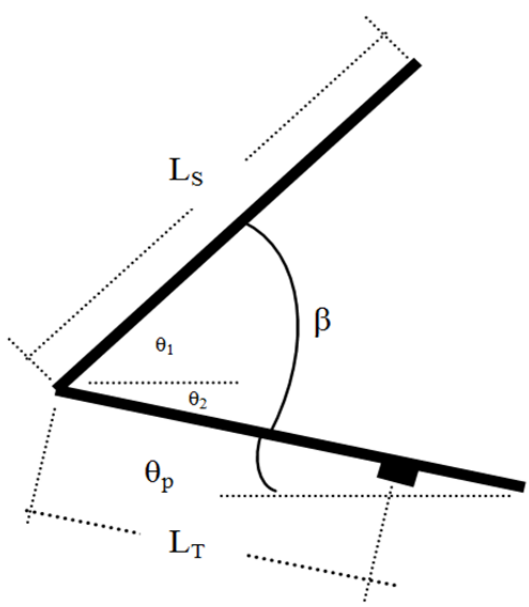



**Figure 3. 2 Model Anchor, variable definition**

GEOMETRICAL ANALYSIS

Step 1: fixing the initial chaser's displacement

The anchor initial position in every test was supposed to be with the shank parallel to the surface of the mud line. Since we know that $d_c$ = 32.75 in, we can compute our initial chaser length $L_{Lo}$ by taking the initial chaser vertical angle $\theta_{Lo}$ and working with trigonometry as follow:

$$\sin(\theta_{Lo}) = \frac{d_c}{L_{Lo}}$$

$$\text{Then } L_{Lo} = {d_c}/{\sin(\theta_{Lo})}$$

Step 2: Computation of the horizontal and vertical components of the chaser length $L_{LX}$ and $L_{LZ}$.

By multiplying the chaser length $L_L$ times the sine and cosine chaser vertical angle $\theta_L$ we can obtain the rectangular components of the chaser's length. Those can be computed as follow:

$$L_{LX} = L_L * \cos(\theta_L) \text{ and } L_{LZ} = L_L * \sin(\theta_L)$$

If we repeat the same procedure to the rest of the data we can obtain the next expression:

$$L_{LX(i+1)} = (L_{Li} + \Delta x) * \cos(\theta_{L(i+1)}) \quad \text{and} \quad L_{LZ(i+1)} = (L_{Li} + \Delta y) * \sin(\theta_{L(i+1)})$$

Step 3: Calculation of the distances induced by the position of the anchor

Once we have the vertical and horizontal component of the chaser length, we have to add to both, the distances produced by the rotation of the anchor itself (Dx and Dz). To do that one have to consider two cases: $\theta_P < 0$ and $\theta_P > 0$. Both cases are illustrated in Figure 3. 3 and Figure 3. 4.

The main reason for separating the behavior in two cases is because both, Dx and Dz, change depending on the geometry of the anchor.

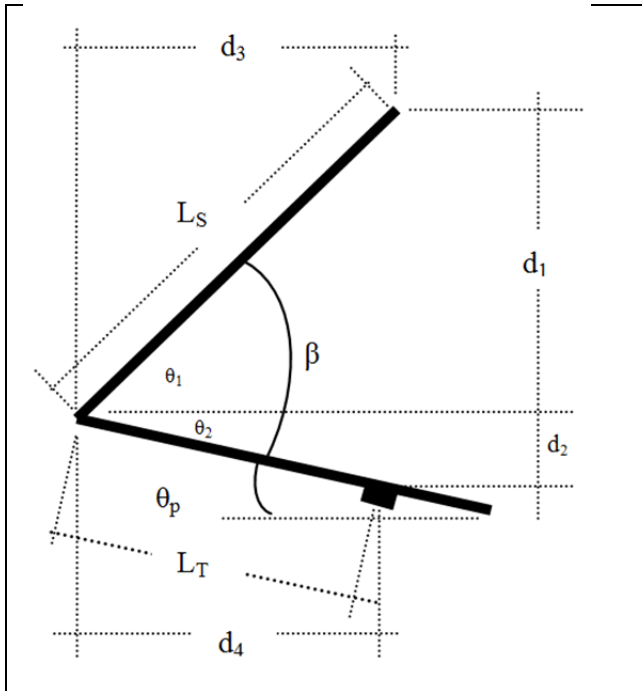



**Figure 3. 3 Case A: $\theta_P < 0$**

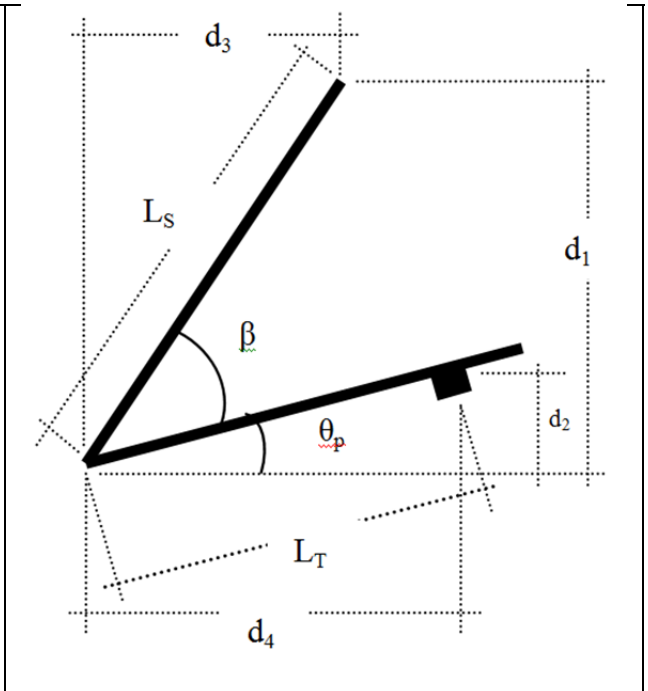



**Figure 3. 4 Case B: > 0**

**<u>Case A</u>**

The horizontal distance (Dx) can be computed as follow:

$$Dx = d_4 - d_3$$

$$Dx = L_T * \cos(\theta_p) - L_S * \cos(\theta_2)$$

Since $\theta_2 = \theta_p$ we can define $\theta_1$ as:

$$\theta_1 = \beta - \theta_p$$

Therefore:

$$Dx = L_T * \cos(\theta_p) - L_S * \cos(\beta - \theta_p)$$

The vertical distance (Dz) can be computed as shown below:

$$Dy = d_1 + d_2$$

Where

$$d_1 = L_S * \sin\theta_1 \quad \text{and} \quad d_2 = L_T * \sin\theta_2$$

Which can be defined also as:

$$d_1 = L_S * (\beta - \theta_p) \quad \text{and} \quad d_2 = L_T * \sin\theta_\mathrm{p}$$

At the end, the vertical distance is defined as shown below:

$$Dz = L_S * \left(\beta - \theta_p\right) + L_T * \sin\theta_\mathrm{p}$$

<u>Case B</u>

The horizontal distance (Dx) can be computed as follow:

$$Dx = d_4 - d_3$$

$$Dx = L_T * \cos\left(\theta_p\right) - L_S * \cos(\beta + \theta_p)$$

The vertical distance (Dz) can be computed as shown below:

$$Dy = d_1 - d_2$$

Where

$$d_1 = L_S * \sin(\theta_\mathrm{p} + \beta) \quad \text{and} \quad d_2 = L_T * \sin\theta_\mathrm{p}$$

At the end, the vertical distance is defined as shown below:

$$Dz = L_S * \sin(\theta_p + \beta) - L_T * \sin\theta_p$$

Step 4: Compute the vertical and horizontal components of the transducer displacement

Once we have the components of the chaser length ($L_{LX}$ and $L_{LY}$) and the distances produced by the anchor position, we can compute the final projections of the transducer's displacement.

Horizontal projection (X):

$$X = L_{LX} + Dx$$

Vertical projection (Z):

$$Z = L_{LZ} + Dz$$

It is important to remark that, the vertical trajectory that have to be measured from the mudline. In order to achieve that, we have to subtract the vertical component (Z) minus the distance from the mudline to the chaser's position (dc).

At the end, the horizontal and vertical component of the trajectory are going to be given by the equations stated below.

For Case A:

$$X = L_L * \cos(\theta_L) + L_T * \cos(\theta_p) - L_S * \cos(\beta - \theta_p)$$

$$Z = L_L * \sin(\theta_L) + L_S * (\beta - \theta_p) + L_T * \sin\theta_p - dc$$

For Case B:

$$X = L_L * \cos(\theta_L) + L_T * \cos(\theta_p) - L_S * \cos(\beta + \theta_p)$$

$$Z = L_L * \sin(\theta_L) + L_S * \sin(\theta_p + \beta) - L_T * \sin\theta_p - dc$$

Step 5: fix the pressure (ft) measured by the pressure transducer.

Theoretically, the pressure measured by the transducer (load cell), represents the depth below the mudline (ft) at which the transducer is.

However during our calculations we realized that the readings made during the test actually include the hydrodynamic resistance (pressure) generated by the mud in the face of the pressure transducer because of the movement of the transducer. This resistance was estimated to be around 1.5 ft of mud.

Since our geometrical calculations were made in order to compare the calculated depth to the measured depth, we need to subtract those 1.5 ft from the pressure readings.

For example, if a reading at a certain time show that the transducer is at a depth of 2 ft, the real depth is going to be equal to (2 – 1.5) = 0.5 ft.

RESULTS

The final results of this first stage are the graphs that show the comparisons of the calculated transducer trajectory versus the measured transducer trajectory. Also the chaser displacement at the shank upper part is shown in all the plots.

The tests were performed in different conditions such as the tow velocity, fluke angle and tow angle. The test plan is presented in

Table 3. **1** below.

**Table 3. 1 Test Plan - In Plane Testings**

| Date | Test Number | Fluke angle (β) deg | Tow angle (α) deg | Tow speed (V) m/s |
|---|---|---|---|---|
| 3/17/10 | 1 | 36 | 5 | 0.13 |
| 3/22/10 | 2 | 36 | 5 | 0.13 |
| 3/22/10 | 3 | 36 | 5 | 0.19 |
| 3/22/10 | 4 | 36 | 5 | 0.13 |
| 3/22/10 | 5 | 36 | 5 | 0.19 |
| 3/23/10 | 6 | 22 | 5 | 0.13 |
| 3/23/10 | 7 | 22 | 5 | 0.19 |
| 3/23/10 | 8 | 22 | 5 | 0.13 |
| 3/23/10 | 9 | 22 | 5 | 0.19 |
| 3/24/10 | 10 | 50 | 5 | 0.13 |
| 3/24/10 | 11 | 50 | 5 | 0.19 |
| 3/24/10 | 12 | 50 | 5 | 0.13 |
| 3/24/10 | 13 | 50 | 5 | 0.19 |
| 3/24/10 | 14 | 50 | 10 | 0.13 |
| 3/24/10 | 15 | 50 | 10 | 0.19 |
| 3/24/10 | 16 | 50 | 10 | 0.13 |
| 3/24/10 | 17 | 50 | 10 | 0.19 |
| 3/25/10 | 18 | 36 | 10 | 0.13 |
| 3/25/10 | 19 | 36 | 10 | 0.19 |
| 3/25/10 | 20 | 36 | 10 | 0.13 |
| 3/25/10 | 21 | 36 | 10 | 0.19 |
| 3/25/10 | 22 | 22 | 10 | 0.13 |
| 3/25/10 | 23 | 22 | 10 | 0.19 |
| 3/25/10 | 24 | 22 | 10 | 0.13 |
| 3/25/10 | 25 | 22 | 10 | 0.19 |
| 3/25/10 | 26 | 22 | 20 | 0.13 |
| 3/25/10 | 27 | 22 | 20 | 0.19 |
| 3/26/10 | 28 | 22 | 20 | 0.13 |
| 3/26/10 | 29 | 22 | 20 | 0.19 |
| 3/26/10 | 30 | 36 | 20 | 0.13 |
| 3/26/10 | 31 | 36 | 20 | 0.19 |
| 3/26/10 | 32 | 36 | 20 | 0.13 |
| 3/26/10 | 33 | 36 | 20 | 0.19 |

| | | | | |
|---|---|---|---|---|
| 3/26/10 | 34 | 50 | 20 | 0.13 |
| 3/26/10 | 35 | 50 | 20 | 0.19 |
| 3/26/10 | 36 | 50 | 20 | 0.13 |
| 3/26/10 | 37 | 50 | 20 | 0.19 |

**There were many good results, basically those test performed with a fluke angle of 36 and 50 degrees, gave very good approximations between both the calculated and the measured displacement. On the other hand, most of the bad approximations are the results of the tests performed with a fluke angle of 22 degrees.**

After obtained the trajectory of all the in plane tests, a bearing capacity analysis was performed in those test that showed a good geometrical behavior. The most variable parameter in the bearing capacity factor is the shear strength of the mud.

Many T-bar testings were performed in order to obtain an approximation of Su as the depth varies. The T-bar test results are shown in Figure 3.4. It can be seen that there is a likely range of Su for different days. All the values used for Su were selected within this range.

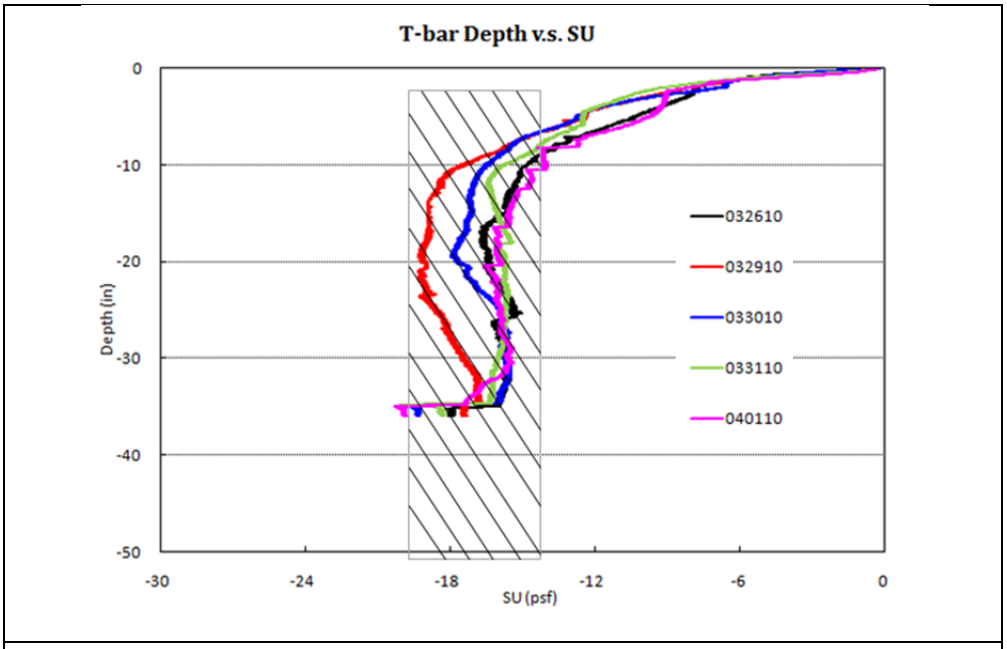


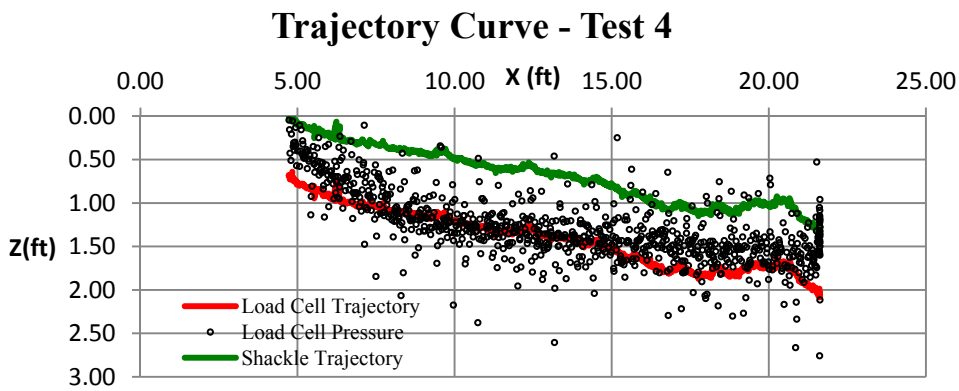

**Figure 3.4: T bar test and range**

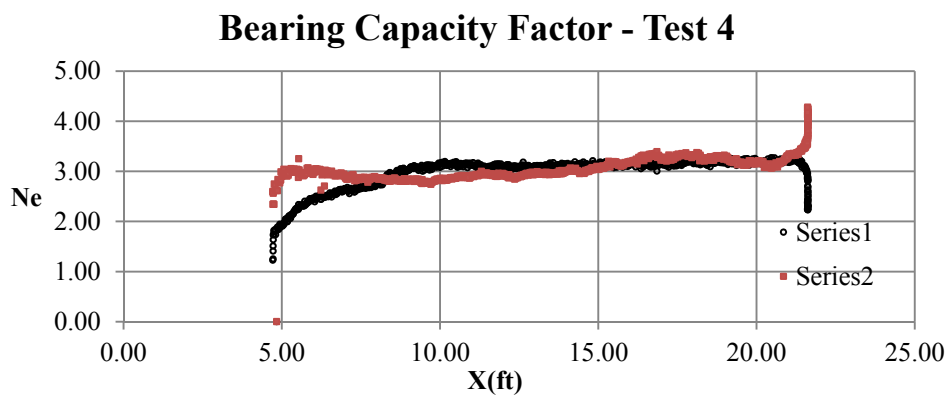
Table 3.2 shows the best results obtained from the testings. For each test we have included the three plots (trajectory, bearing capacity and fluke + anchor angle), and many other useful data for a correct interpretation of the results.

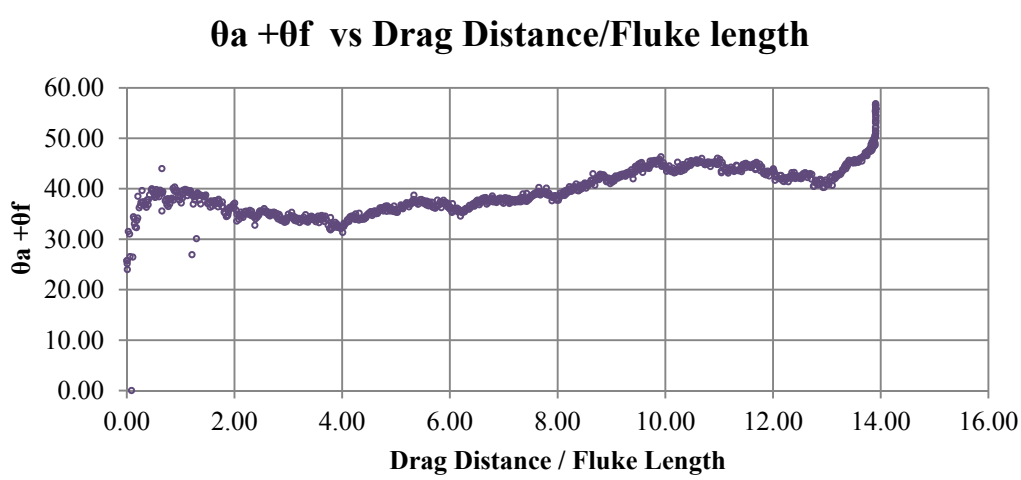
On the other hand, Table 3.3 is showing those fair test approximations, in which the calculated trajectory doesn't match the measured trajectory of the load cell. Most of the tests with this behavior are those performed with a fluke angle of 22 degrees.

Finally, Table 3.4 is a summary of the results obtained in the tests mentioned on Table 3.2.

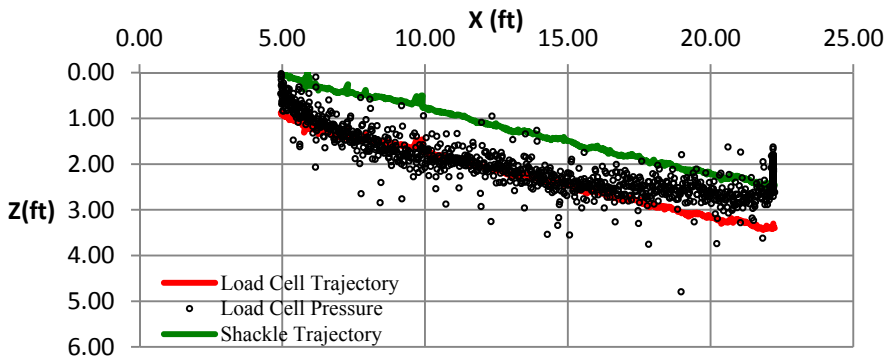
| Table 3. 2 Excellent Test Results | | |
|---|---|---|
| **TEST 04** | **DATE: March 22, 2010** | |
| β = 36 deg | Tow Angle = 5 deg | Tow Speed = 0.13 m/s |
| Selected Su = 20 psf | $\theta f_{Initial}$ = -19.34 deg | $\theta f_{Final}$ = 1.97 deg |
| Final Shackle Depth = 1.34 ft | Drag Distance = 21.64 ft | Bearing Cap. Factor (avg)= 2.98 |
| Initial Roll = -3.72 deg | Final Roll =-7.52 deg | Bearing Cap Range: 1.74 – 3.28 |

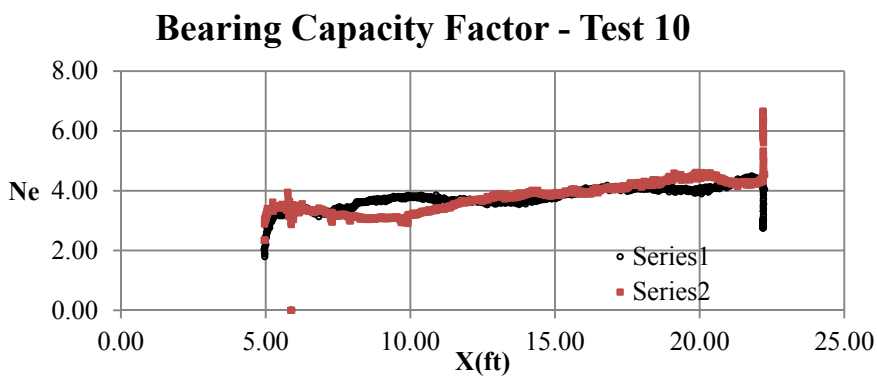


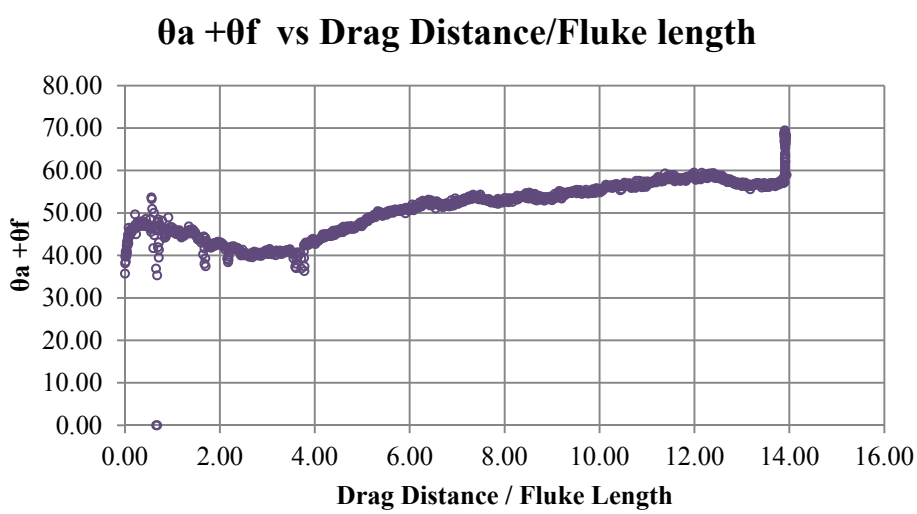



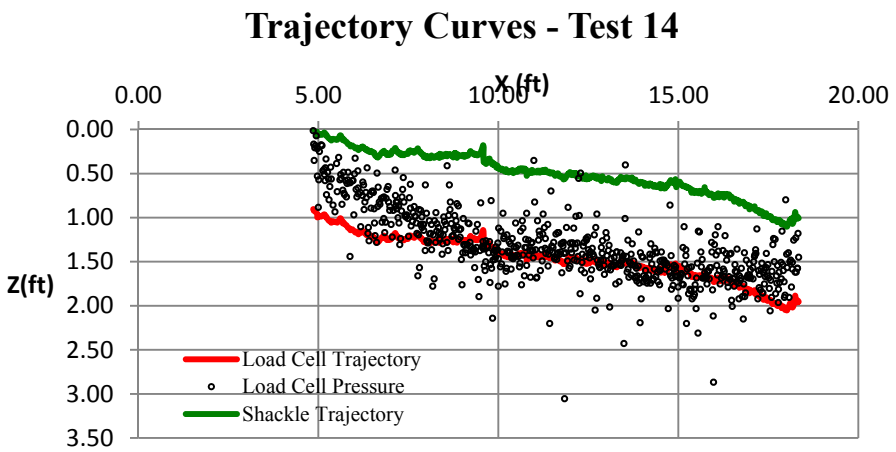
| TEST 10 | DATE: March 24, 2010 | |
|---|---|---|
| β = 50 deg | Tow Angle = 5 deg | Tow Speed = 0.13 m/s |
| Selected Su = 16 psf | $\theta f_{Initial}$ = -33.51 deg | $\theta f_{Final}$ = -2.31 deg |
| Final Shackle Depth = 2.23 ft | Drag Distance = 19.90 ft | Bearing Cap. Factor (avg)= 3.6 |
| Initial Roll = 2.20 deg | Final Roll =8.61 deg | Bearing Cap Range: 1.79 - 4.49 |

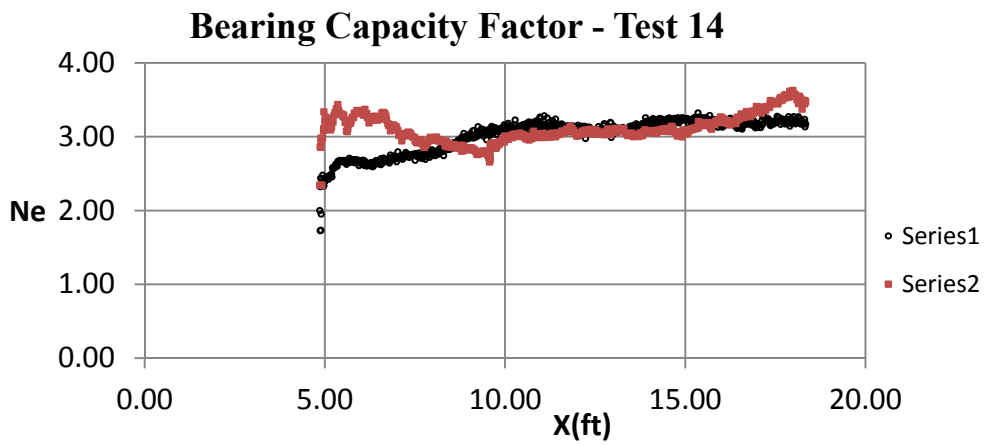


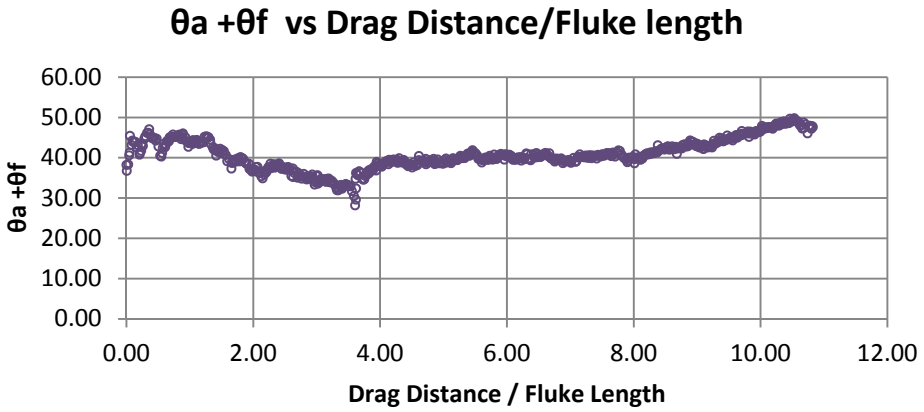



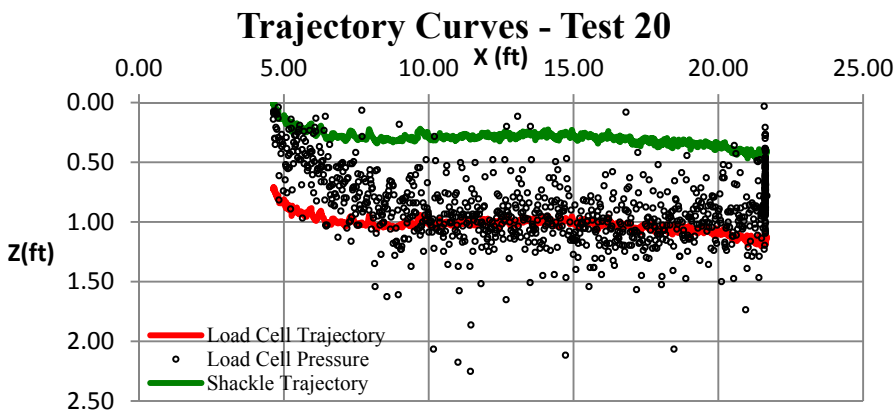
| TEST 14 | DATE: March 24, 2010 | |
|---|---|---|
| β = 50 deg | Tow Angle = 10 deg | Tow Speed = 0.13 m/s |
| Selected Su = 19 psf | $\theta f_{Initial}$ = -29.84 deg | $\theta f_{Final}$ = -2 deg |
| Final Shackle Depth = 1.01 ft | Drag Distance = 18.17 ft | Bearing Cap. Factor (avg)= 3.02 |
| Initial Roll = -3.66 deg | Final Roll =4.09 deg | Bearing Cap Range: 1.73 – 3.32 |

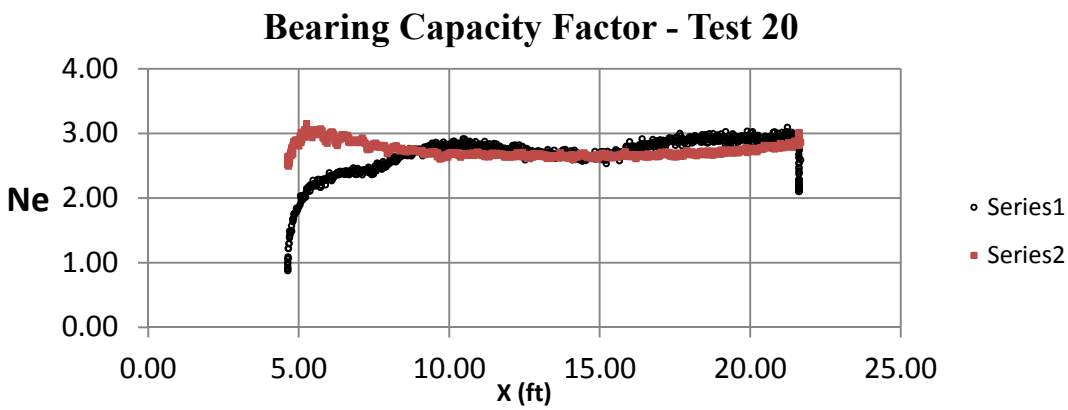


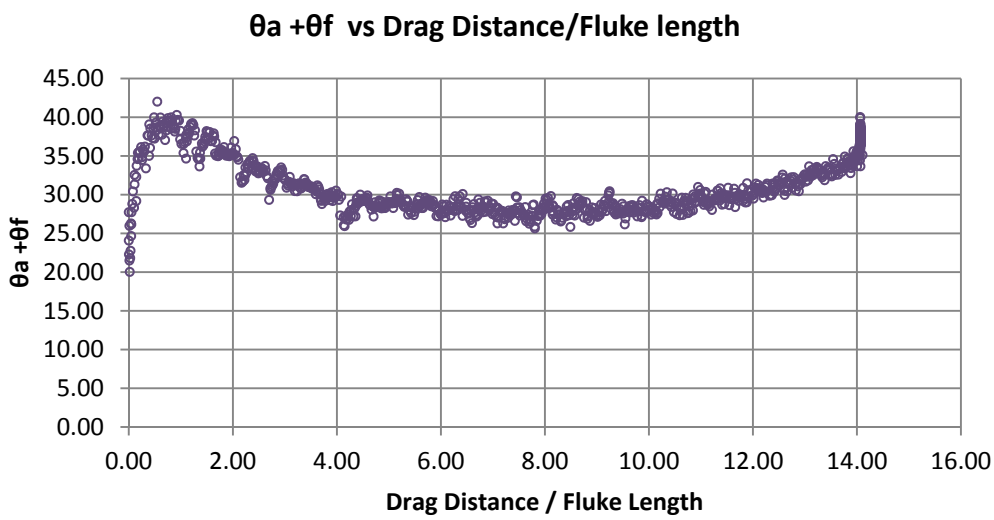



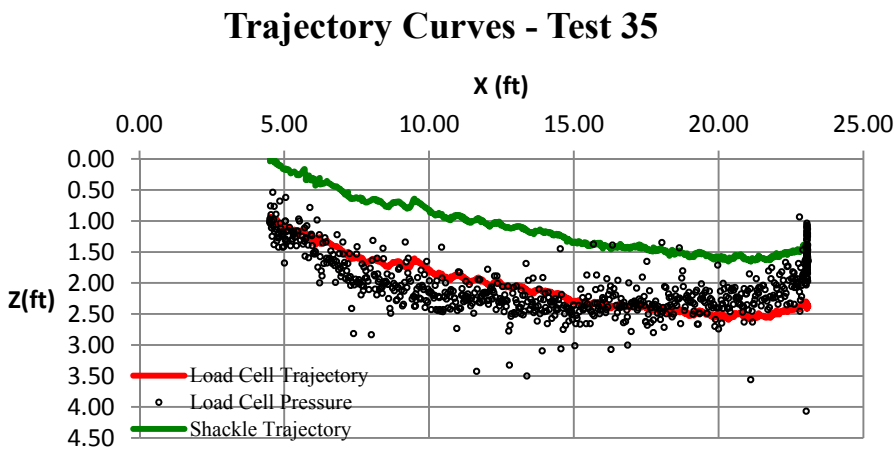
| TEST 20 | DATE: March 25, 2010 | |
|---|---|---|
| β = 36 deg | Tow Angle = 10 deg | Tow Speed = 0.13 m/s |
| Selected Su = 18 psf | $\theta f_{Initial}$ = -10.72 deg | $\theta f_{Final}$ = 2.50 deg |
| Final Shackle Depth = 0.44 ft | Drag Distance = 21.66 ft | Bearing Cap. Factor (avg)= 2.61 |
| Initial Roll = -2.13 deg | Final Roll =12.65 deg | Bearing Cap Range: 0.88 – 3.09 |

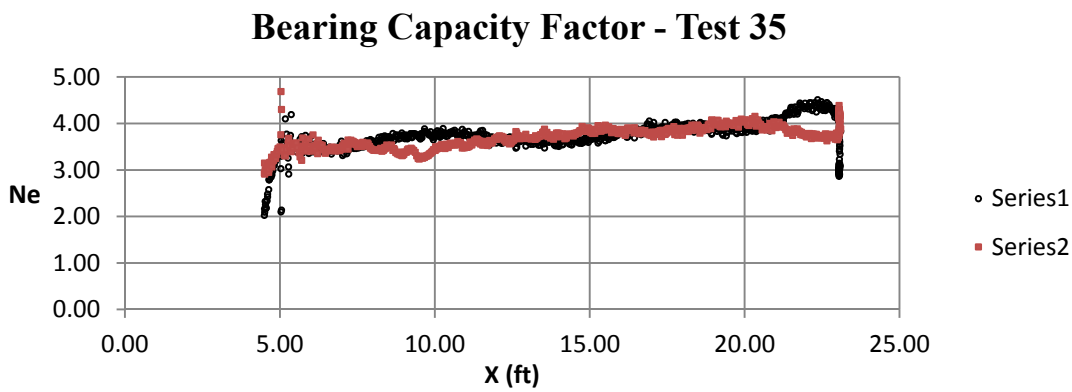


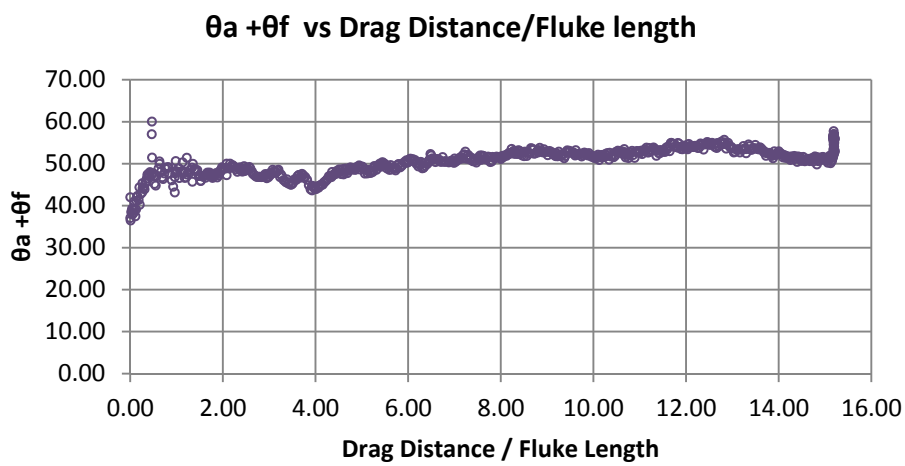



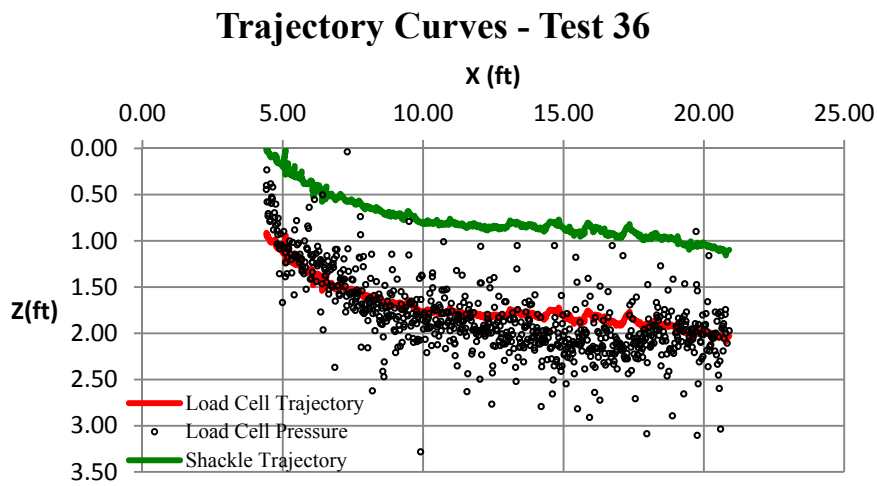
| TEST 35 | DATE: March 26, 2010 | |
|---|---|---|
| β = 50 deg | Tow Angle = 20 deg | Tow Speed = 0.19 m/s |
| Selected Su = 16.5 psf | $\theta f_{Initial}$ = -26.98 deg | $\theta f_{Final}$ = 7.57 deg |
| Final Shackle Depth = 1.44 ft | Drag Distance = 21.64 ft | Bearing Cap. Factor (avg)= 3.66 |
| Initial Roll = -2.94 deg | Final Roll =-5.05 deg | Bearing Cap Range: 2.02 – 4.51 |

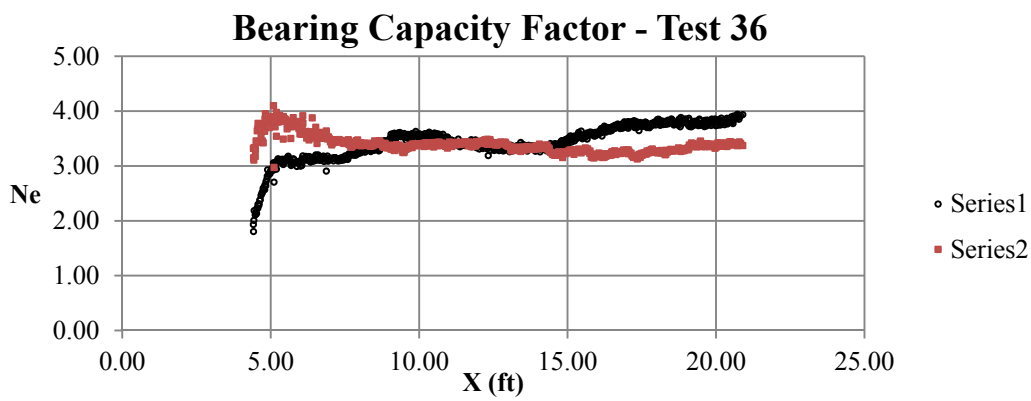


| TEST 36 | DATE: March 26, 2010 | |
|---|---|---|
| β = 50 deg | Tow Angle = 20 deg | Tow Speed = 0.13 m/s |
| Selected Su = 17.5 psf | $\theta f_{Initial}$ = -30.84 deg | $\theta f_{Final}$ = 2.18 deg |
| Final Shackle Depth =1.10ft | Drag Distance = 20.73 ft | Bearing Cap. Factor (avg)= 3.44 |
| Initial Roll = -5.04 deg | Final Roll =-8.88 deg | Bearing Cap Range: 1.80 – 3.94 |



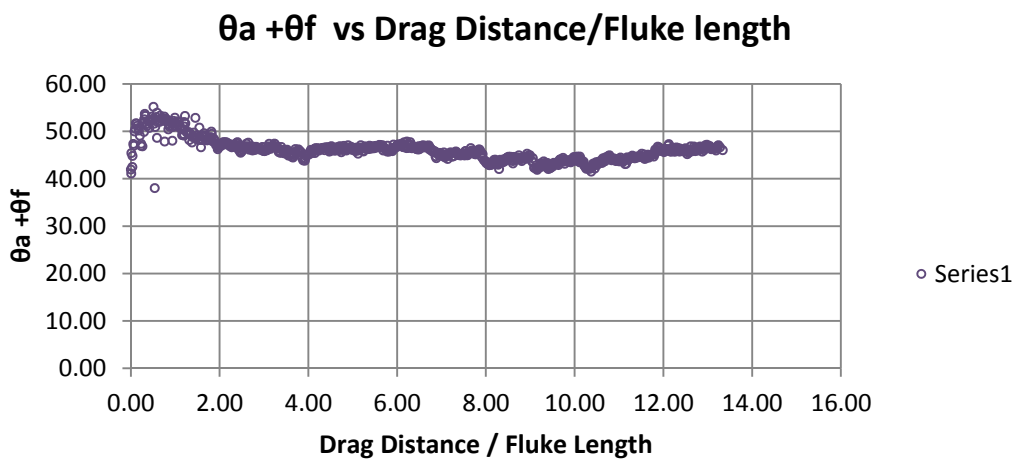
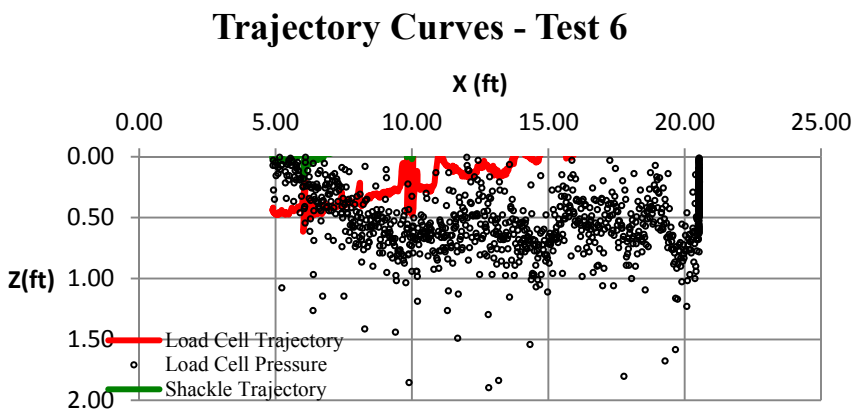
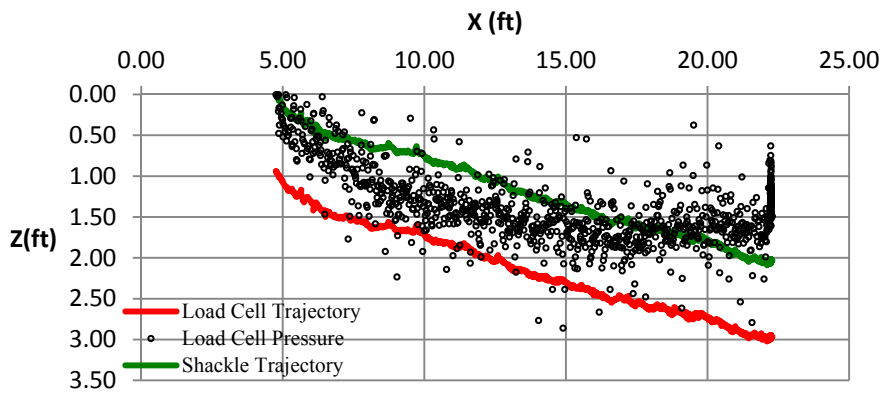
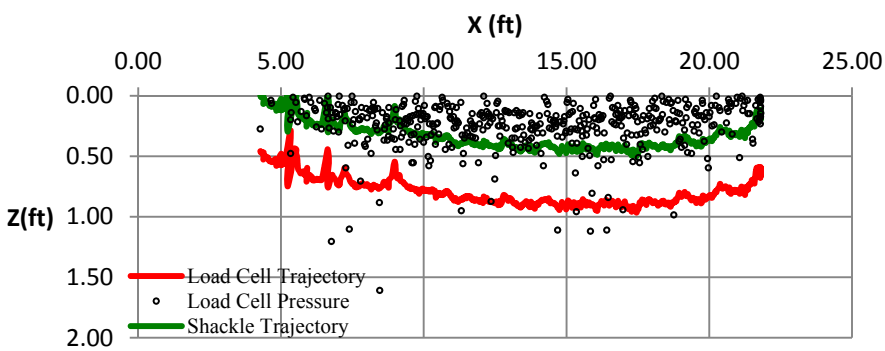
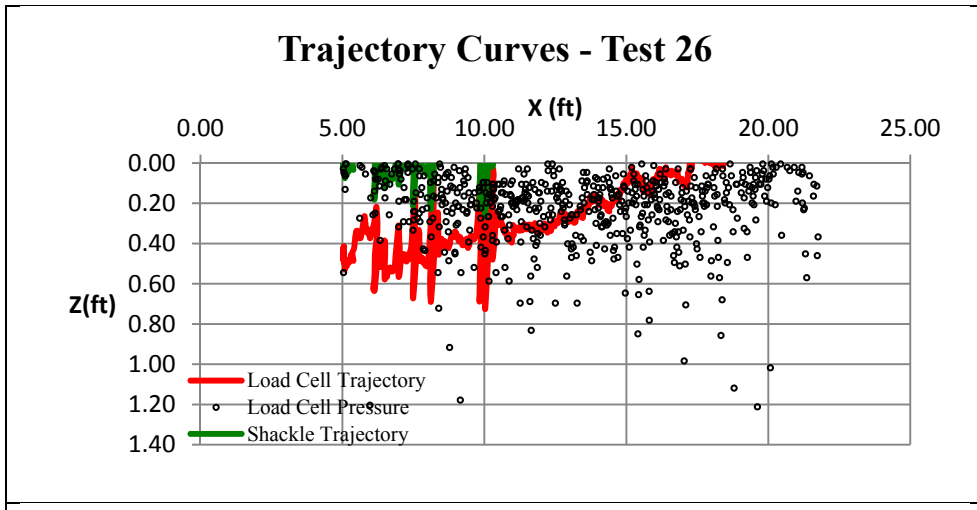
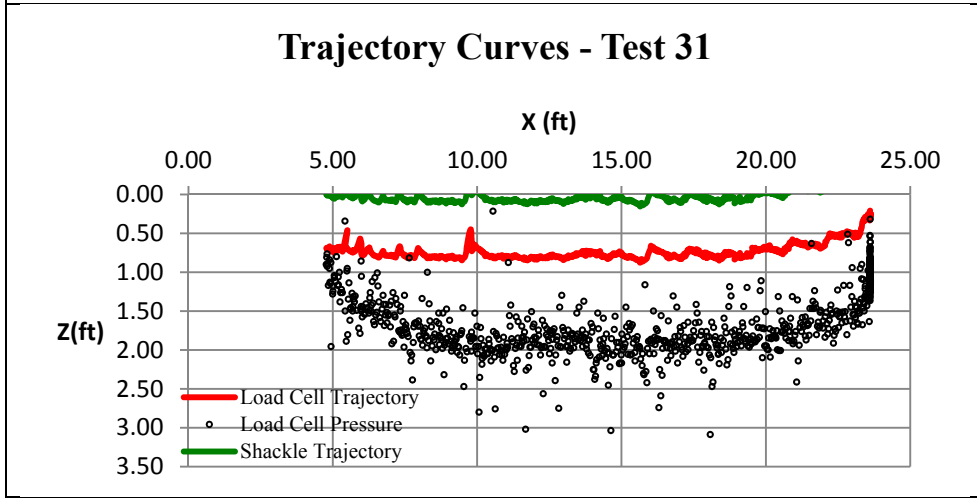



**Table 3. 3 Fair test results**

| PLOT | Fluke angle (deg) |
|---|---|
|   NOTE: tests 7 to 9 had similar results. | 22 |
|   | 50 |
|   | 22 |


Trajectory Curves - Test 26
X (ft)
0.00
5.00
10.00
15.00
20.00
25.00
Z(ft)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Load Cell Trajectory
Load Cell Pressure
Shackle Trajectory

22


Trajectory Curves - Test 31
X (ft)
0.00
5.00
10.00
15.00
20.00
25.00
Z(ft)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Load Cell Trajectory
Load Cell Pressure
Shackle Trajectory

36

**Table 3.4 Summary**

| TEST | β (deg) | Tow Angle (deg) | Tow Speed (m/s) | Su (psf) | Initial Pitch (deg) | Final Pitch (deg) | Initial Roll (deg) | Final Roll (deg) | Final shackle depth (ft) | Drag distance (ft) | Bearing Capacity Factor (Average) | Bearing Capacity Factor (Range) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04 | 36 | 5 | 0.13 | 20 | -19.34 | 1.97 | -3.72 | -7.52 | 1.34 | 21.64 | 2.98 | 1.74-3.28 |
| 10 | 50 | 5 | 0.13 | 16 | -33.51 | -2.31 | 2.20 | 8.61 | 2.23 | 19.90 | 3.6 | 1.79-4.49 |
| 14 | 50 | 10 | 0.13 | 19 | -29.84 | -2 | -3.66 | 4.09 | 1.01 | 18.17 | 3.02 | 1.73-3.32 |
| 20 | 36 | 10 | 0.13 | 18 | -10.72 | 2.50 | -2.13 | 12.65 | 0.44 | 21.66 | 2.61 | 0.88-3.09 |
| 35 | 50 | 20 | 0.19 | 16.5 | -26.98 | 7.57 | -2.94 | -5.05 | 1.44 | 21.64 | 3.66 | 2.02-4.51 |
| 36 | 50 | 20 | 0.13 | 17.5 | -30.84 | 2.18 | -5.04 | -8.88 | 1.10 | 20.73 | 3.44 | 1.80-3.94 |