Appendix IV: Delmar DEA Investigation

A.1.0 IN-PLANE TESTS

A.1.1 Test Matrix

TABLE II.1.1: In-plane Tests

Date	Test Number	Fluke angle (β) deg	Tow angle (α) deg	Tow speed (V) m/s
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
3/29/10	38	36	5	0.13
3/29/10	39	36	5	0.19
3/29/10	40	36	5	0.13
3/29/10	41	36	5	0.19

A.1.2 In-plane Results

Figure 6-17 illustrate equivalent anchor capacity factor versus anchor embedment and pitch angle resulting from in-plane tests. The equivalent anchor capacity factor N_{eq} is defined as

$$N_{eq} = \frac{F_{anchor}}{S_u * A} \quad (1)$$

where F_{anchor} is the anchor shackle tension plus the anchor self-weight effect, S_u is the soil shear strength and A is the fluke area.

Since T-bar was only conducted to 3 ft of depth, for 50° fluke angle, soil shear strength at depth of more than 3 ft was estimated from existing data. The corresponding capacity factors may be not accurate and are covered with a blue box in figures. To be concise, two towing speeds are not separated with colors, but the difference can be noticed in the plots of some cases.

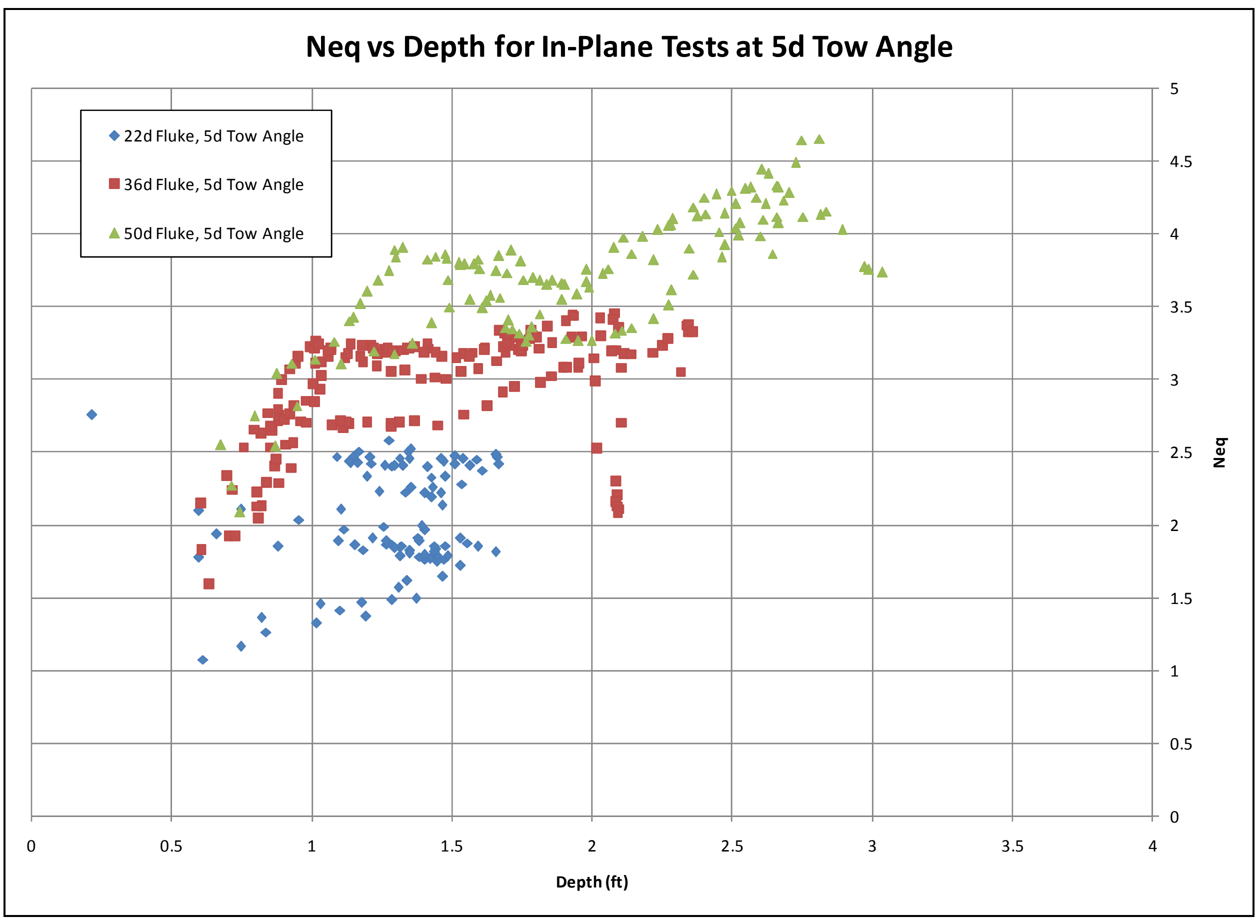

Figure II.1.2: Neq vs. Depth for In-plane Tests at 5° Uplift Angle

- For 5° tow angle, N_{eq} and maximum embedment both increase as the fluke angle increases. This shows that large fluke benefits the anchor capacity and embedment.
- Anchor capacity factor is found to increase as the anchor embedment increases, but only vary within small a range for each fluke setting.

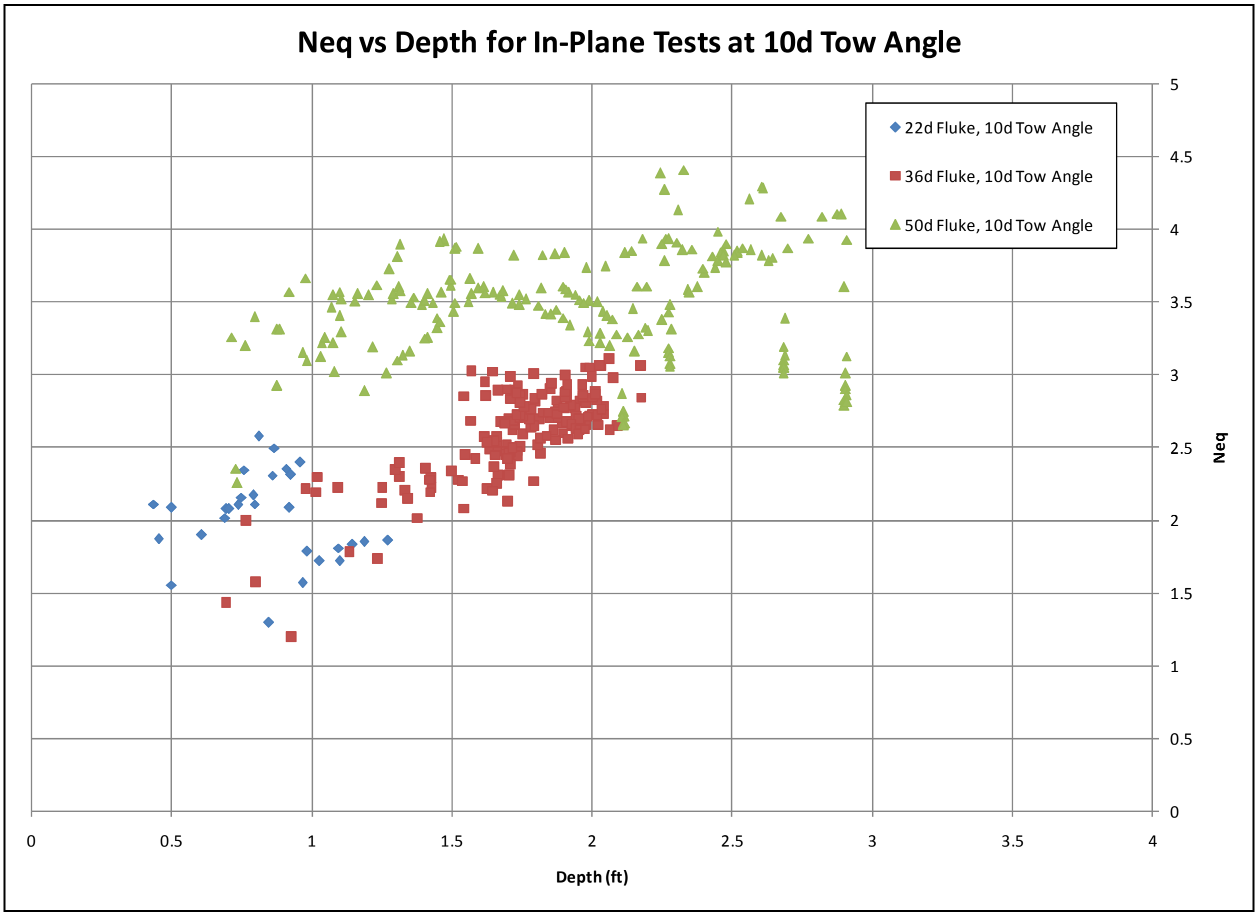

Figure II.1.3: Neq vs. Depth for In-plane Tests at 10° Uplift Angle

- For 10° tow angle, N_{eq} and maximum embedment both increase as the fluke angle increases. This matches the observation for 5° tow angle.
- Anchor capacity factors concentrate in small range for each fluke setting at large depth.
- 22° fluke settings depth data may be not accurate. The chaser reading and pressure reading have large gap. The plot is the best guess based on both of them.

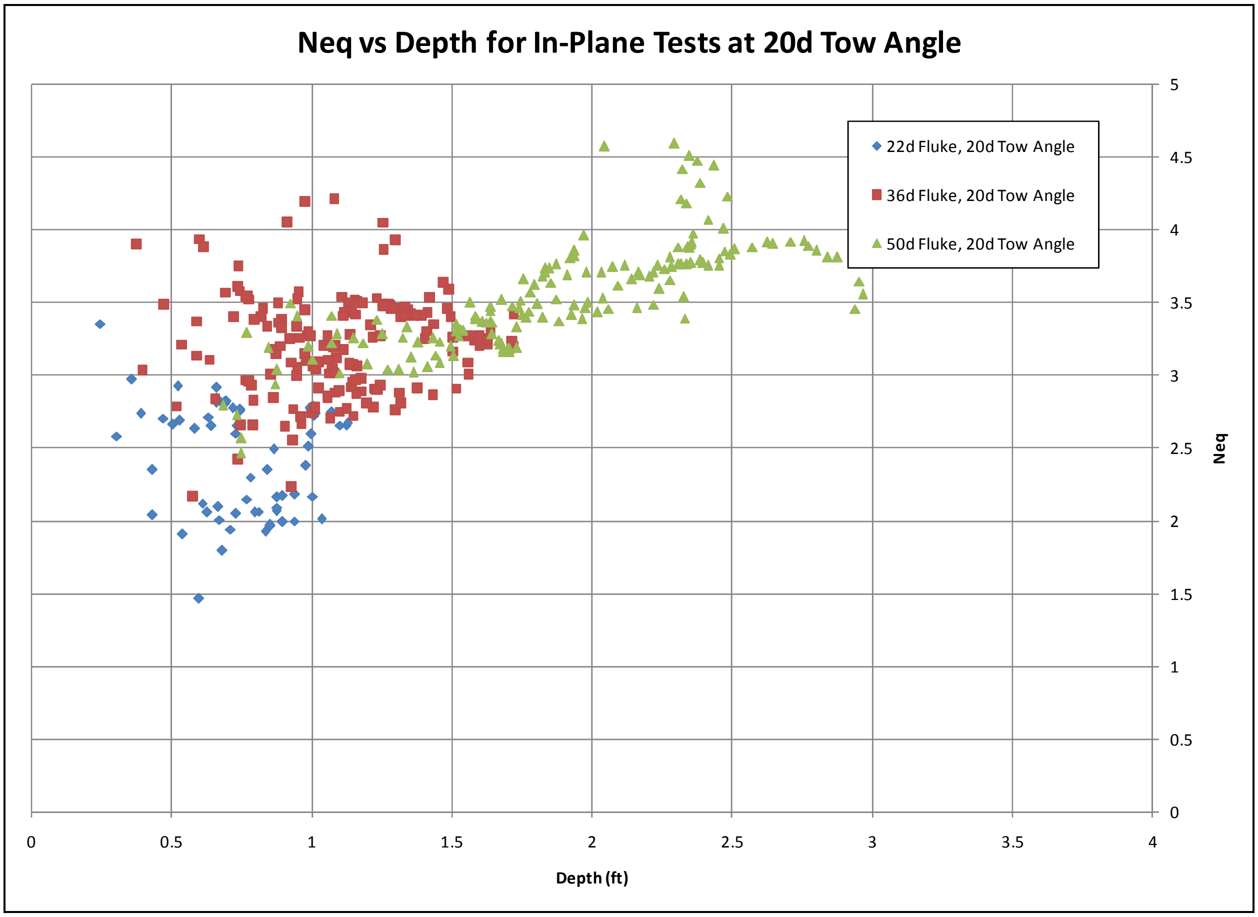

Figure II.1.4: Neq vs. Depth for In-plane Tests at 20° Uplift Angle

- For 20° tow angle, maximum embedment both increase as the fluke angle increases. This matches the observation for 5° and 10° tow angle.
- The difference of N_{eq} is much smaller between each fluke setting, which means the benefit of very large fluke angle is not seen at this large tow angle in terms of N_{eq}.
- Anchor capacity factors concentrate in small range for each fluke setting at large depth.

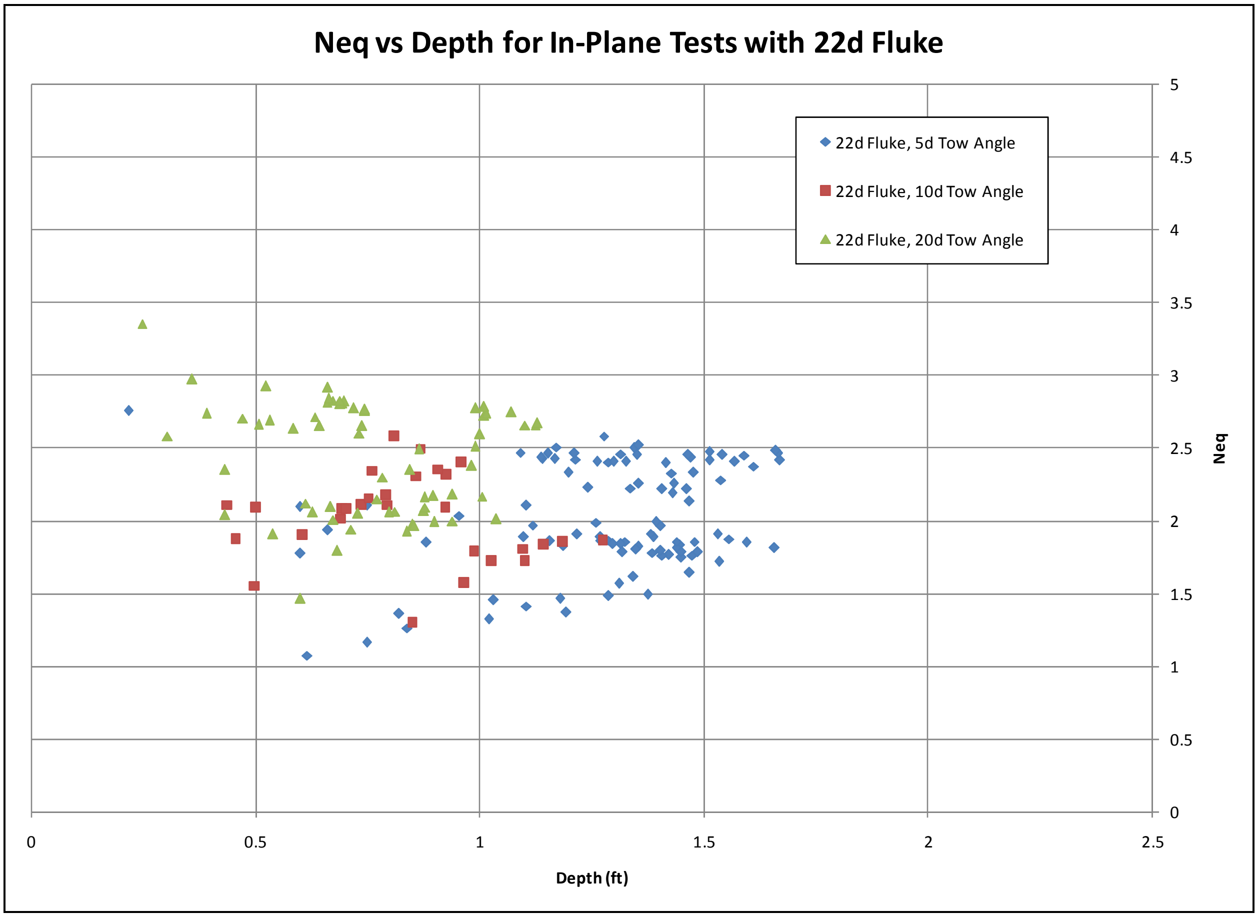

Figure II.1.5: Neq vs. Depth for In-plane Tests at 22° Fluke Angle

- N_{eq} for different tow angles are close to each other.
- Small tow angle is seen to have deeper embedment. Tow angle mainly matters the anchor trajectory rather than anchor capacity factor which is mainly affected by fluke setting.

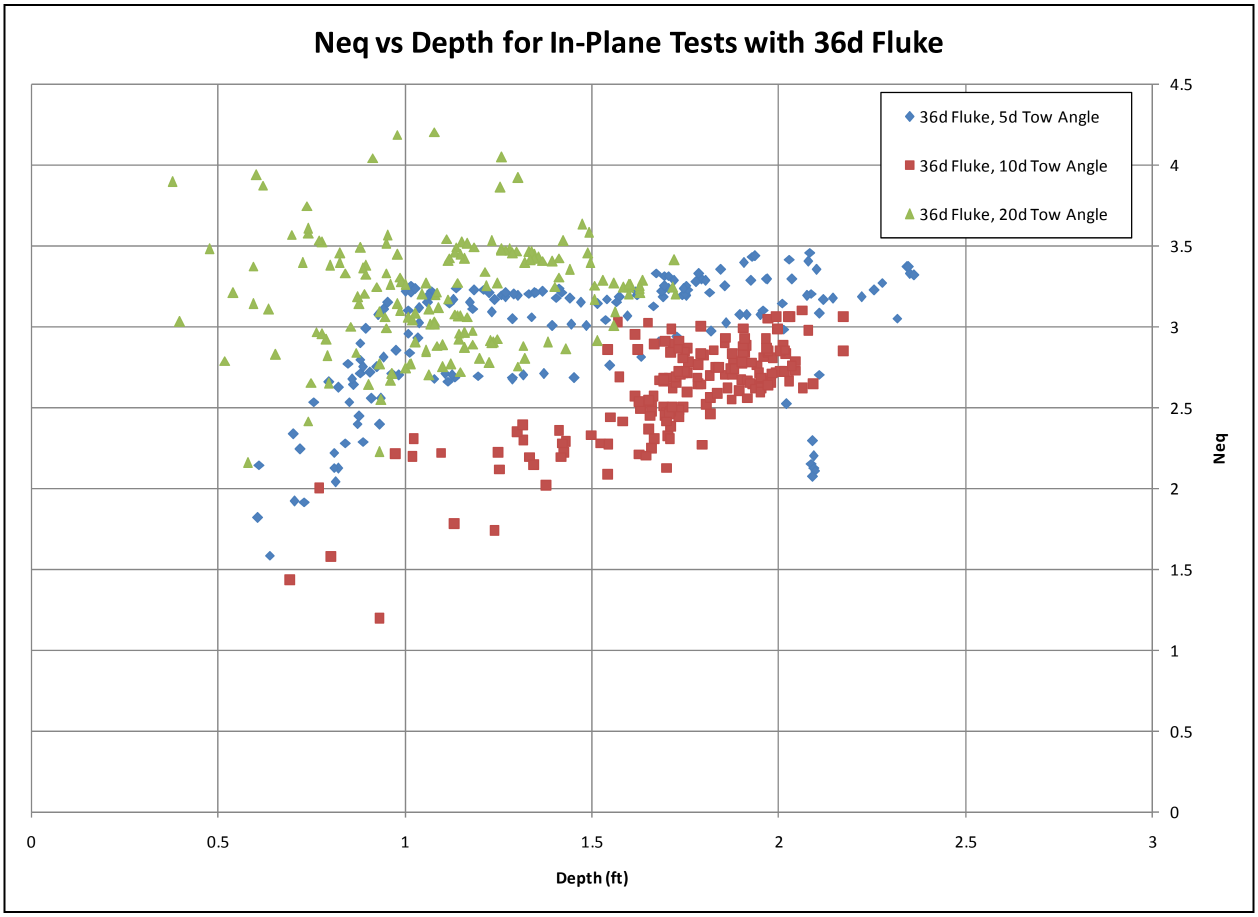

Figure II.1.6: Neq vs. Depth for In-plane Tests at 36° Fluke Angle

- N_{eq} for different tow angles are close to each other. Slightly higher capacity factor is seen on 20° tow angle.
- Smaller tow angle is seen to have a slightly deeper embedment.
- Anchor capacity factors are in a small range during the embedment.

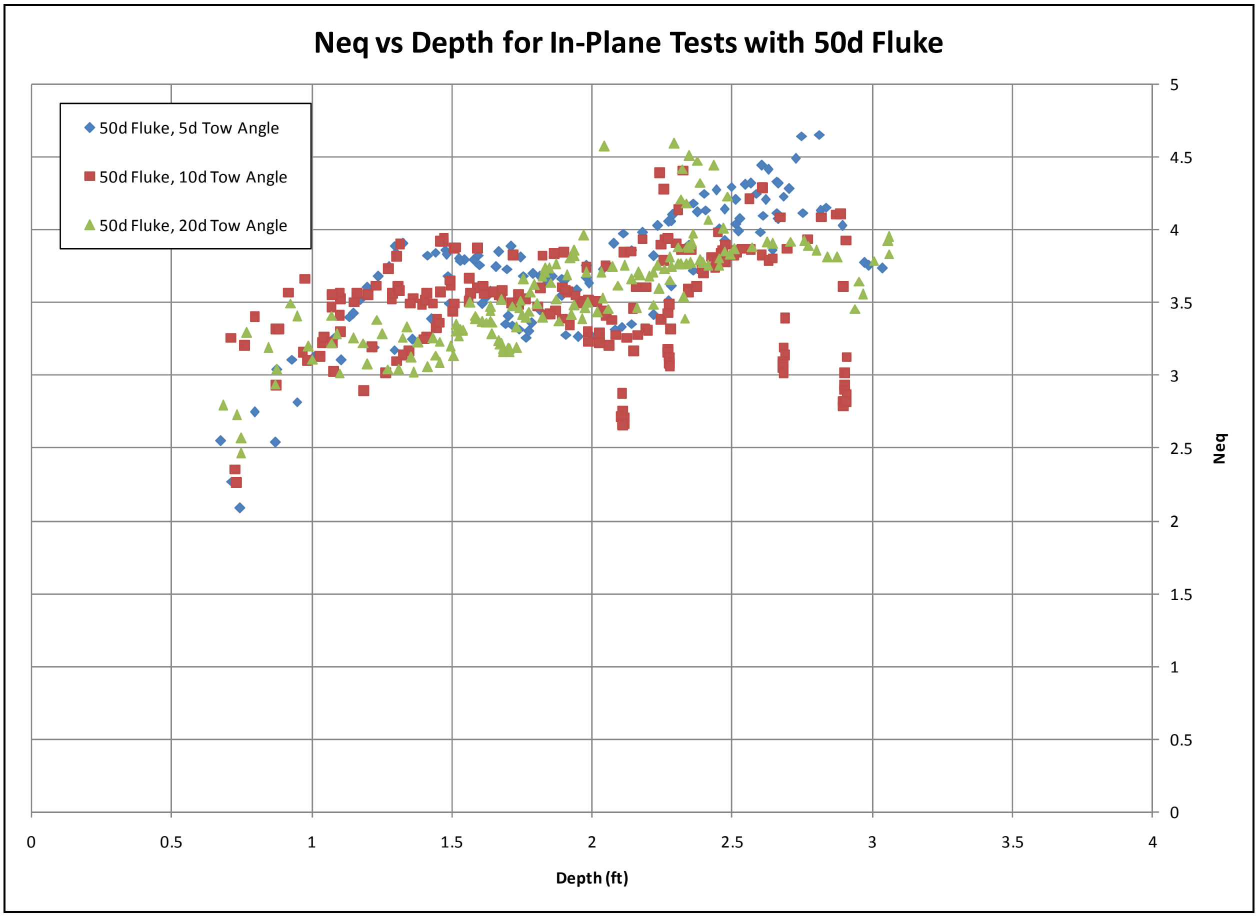

Figure II.1.7: Neq vs. Depth for In-plane Tests at 50° Fluke Angle

- For 50° fluke angle, no impact from uplift on embedment or anchor capacity factor is observed.
- Anchor capacity factors distribute in a small range during the embedment.

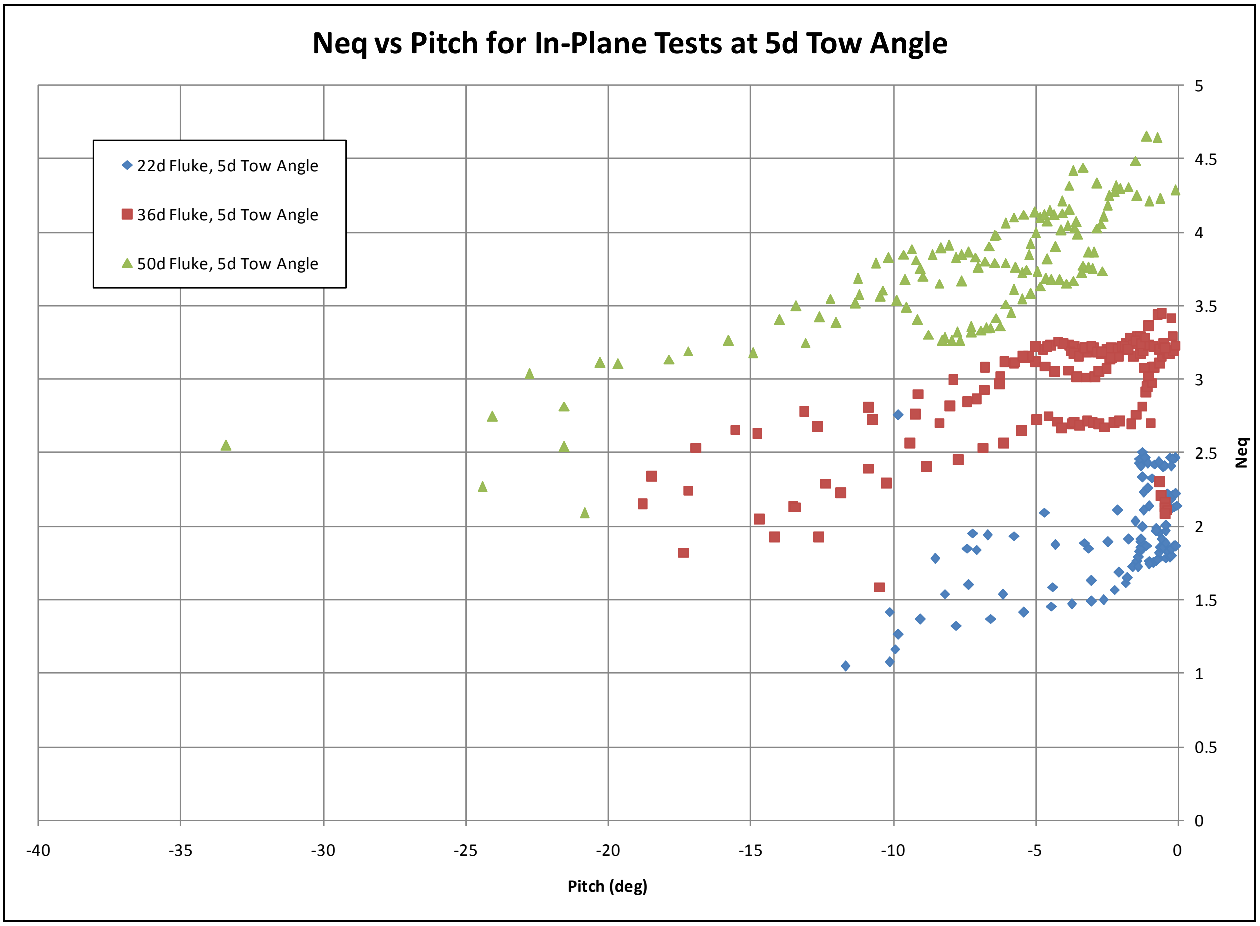

Figure II.1.8: Neq vs. Pitch for In-plane Tests at 5° Uplift Angle

- For 5° tow angle, anchor capacity factor N_{eq} clearly increases as the fluke angle increases. This shows that large fluke benefits the anchor capacity and matches previous observation.
- Anchor capacity factor is found to increase slightly as pitch angle decreases.

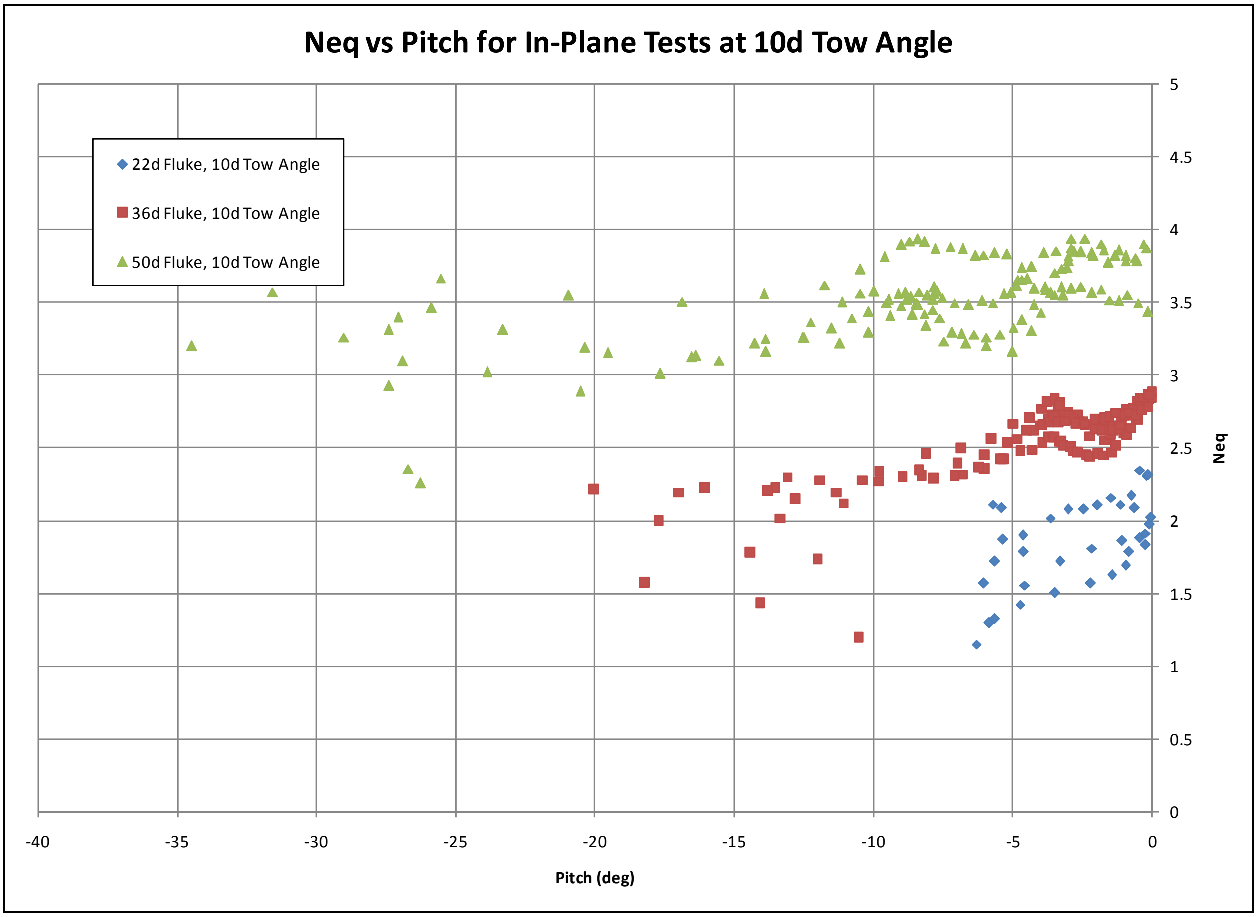

Figure II.1.9: Neq vs. Pitch for In-plane Tests at 10° Uplift Angle

- For 10° tow angle, anchor capacity factor N_{eq} increases as the fluke angle increases. Again, this shows that large fluke benefits the anchor capacity and matches previous observation.
- Anchor capacity factors stay in a very small range for each fluke setting, and slightly increase as pitch angle decreases to zero.

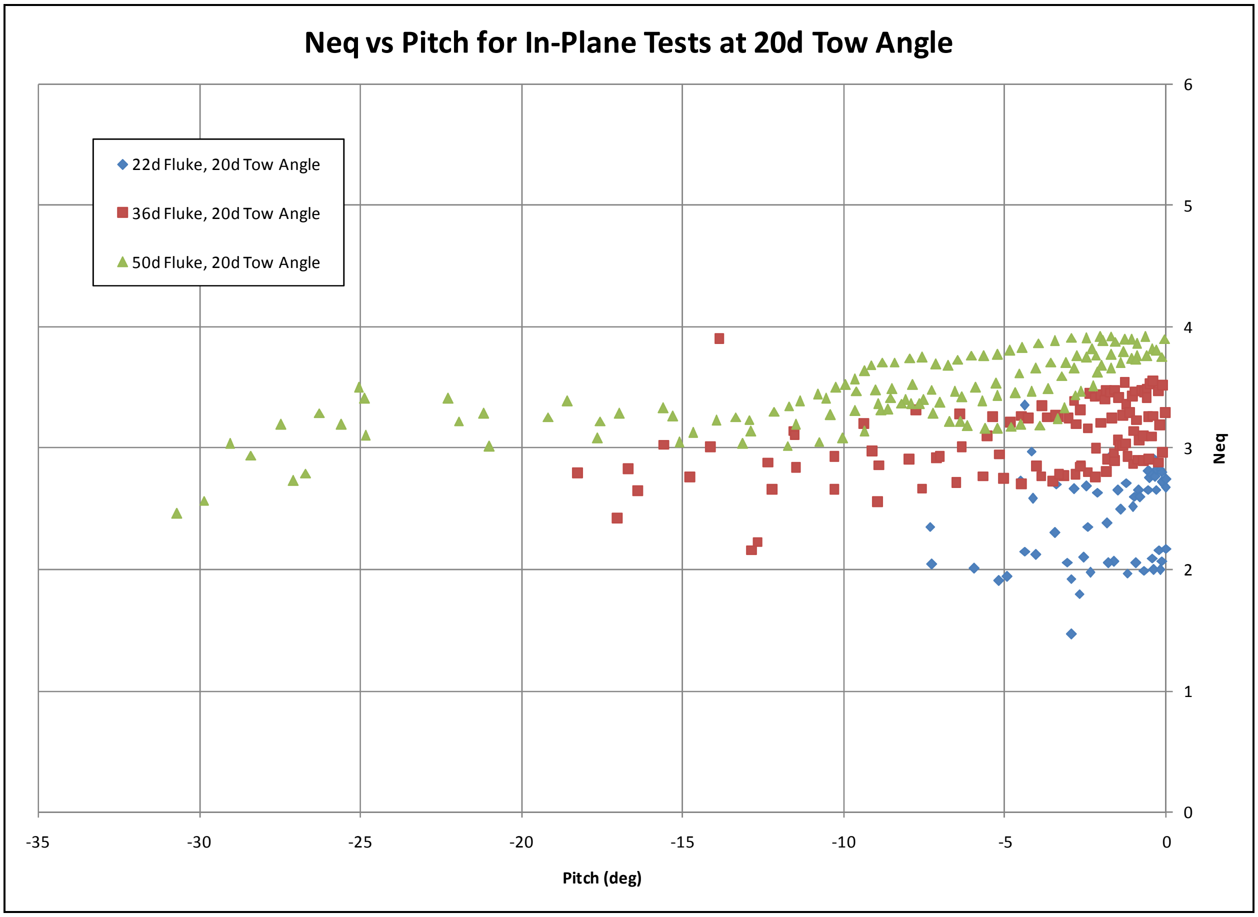

Figure II.1.10: Neq vs. Pitch for In-plane Tests at 20° Uplift Angle

- For 20° tow angle, anchor capacity factor N_{eq} increases as the fluke angle increases. This shows that large fluke benefits the anchor capacity and matches all previous observation. But the effect of fluke setting is not as large as small tow angles.
- Anchor capacity factors stay in a very small range for each fluke setting, and slightly increase as pitch angle decreases to zero.

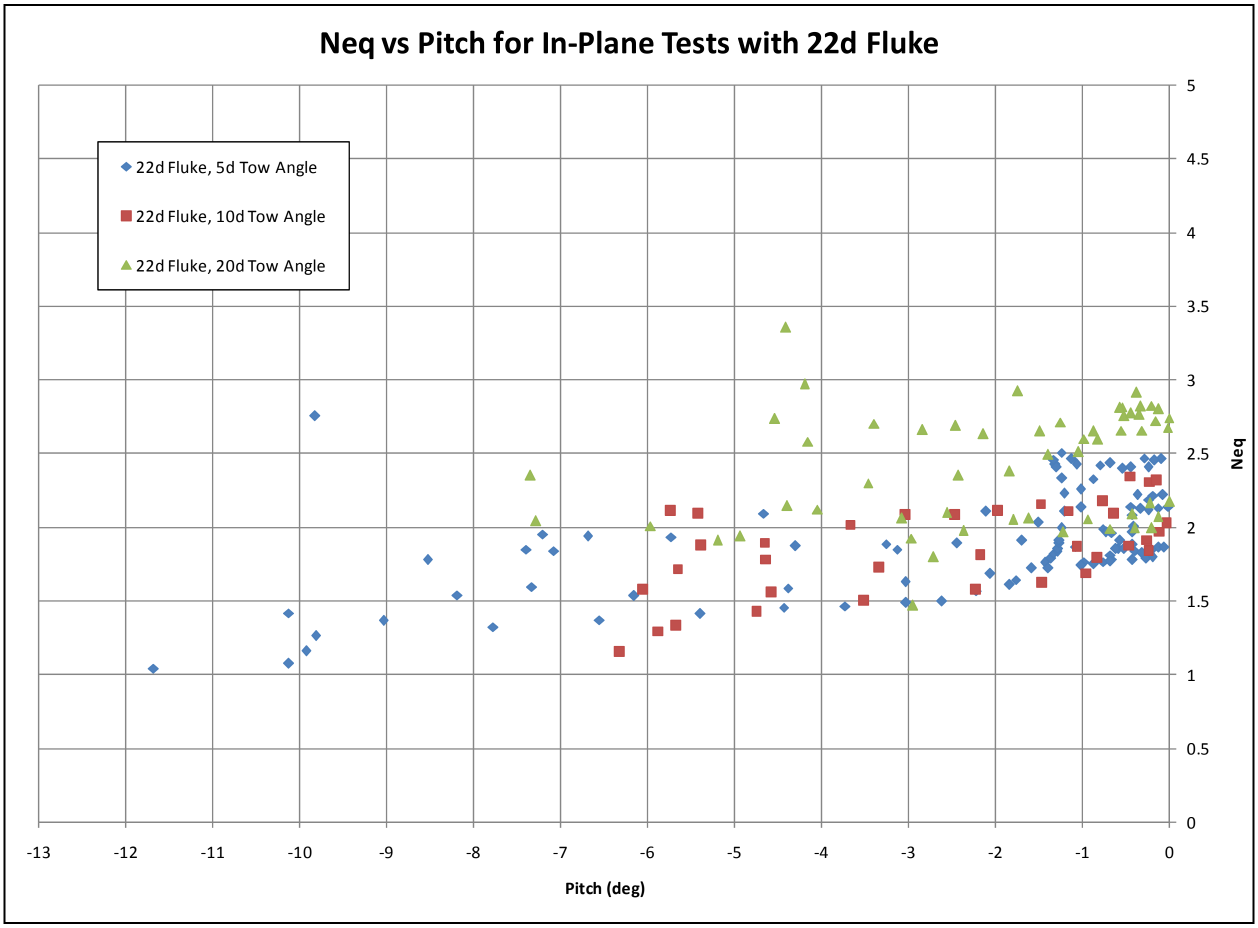

Figure II.1.11: Neq vs. Pitch for In-plane Tests at 22° Fluke Angle

- N_{eq} for different tow angles are close to each other. Slightly higher capacity factor is seen on 20° tow angle.
- Anchor capacity factors stay in a very small range for each fluke setting.

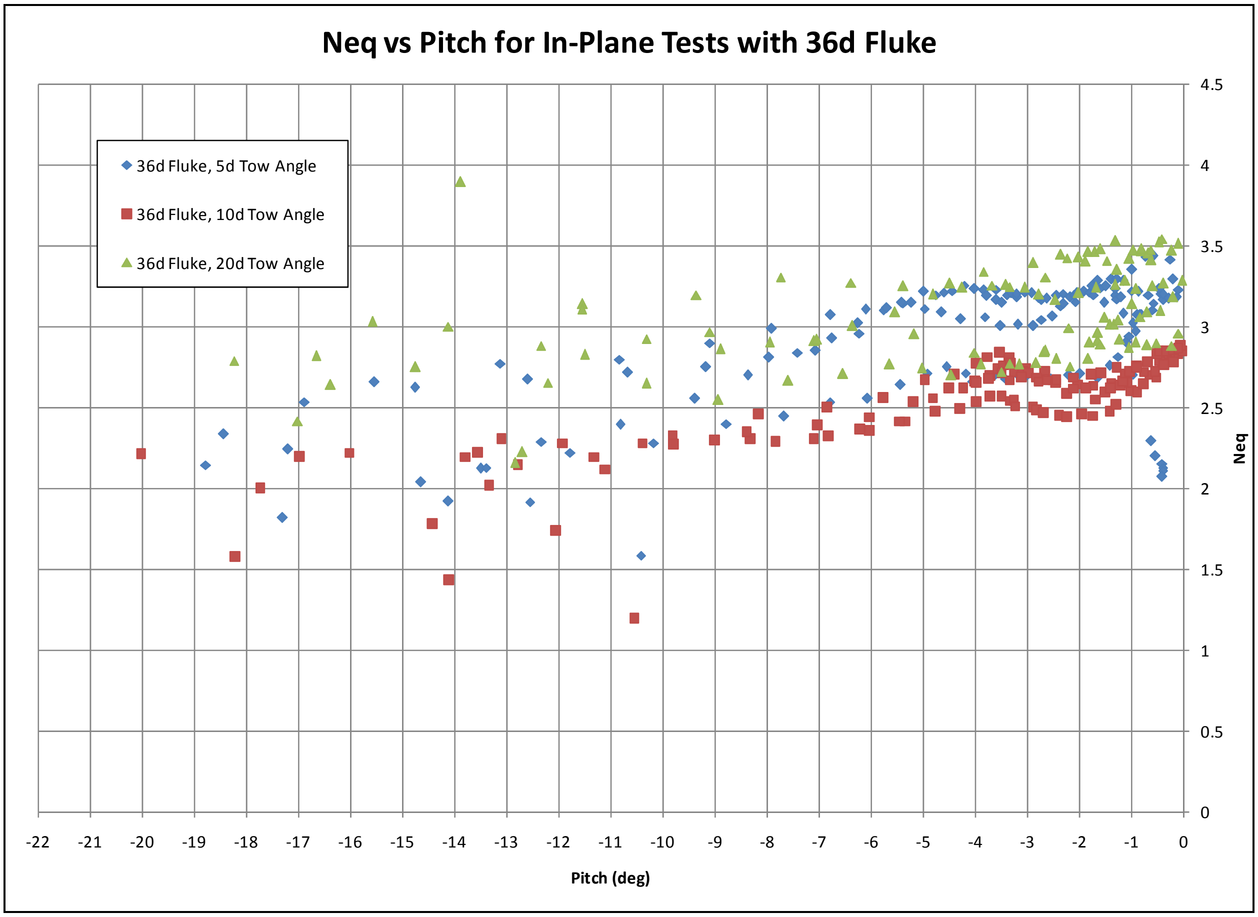

Figure II.1.12: Neq vs. Pitch for In-plane Tests at 36° Fluke Angle

- N_{eq} for different tow angles are close to each other. Slightly higher capacity factor is seen on 20° and 5° tow angle.
- Anchor capacity factors stay in a very small range for each fluke setting.

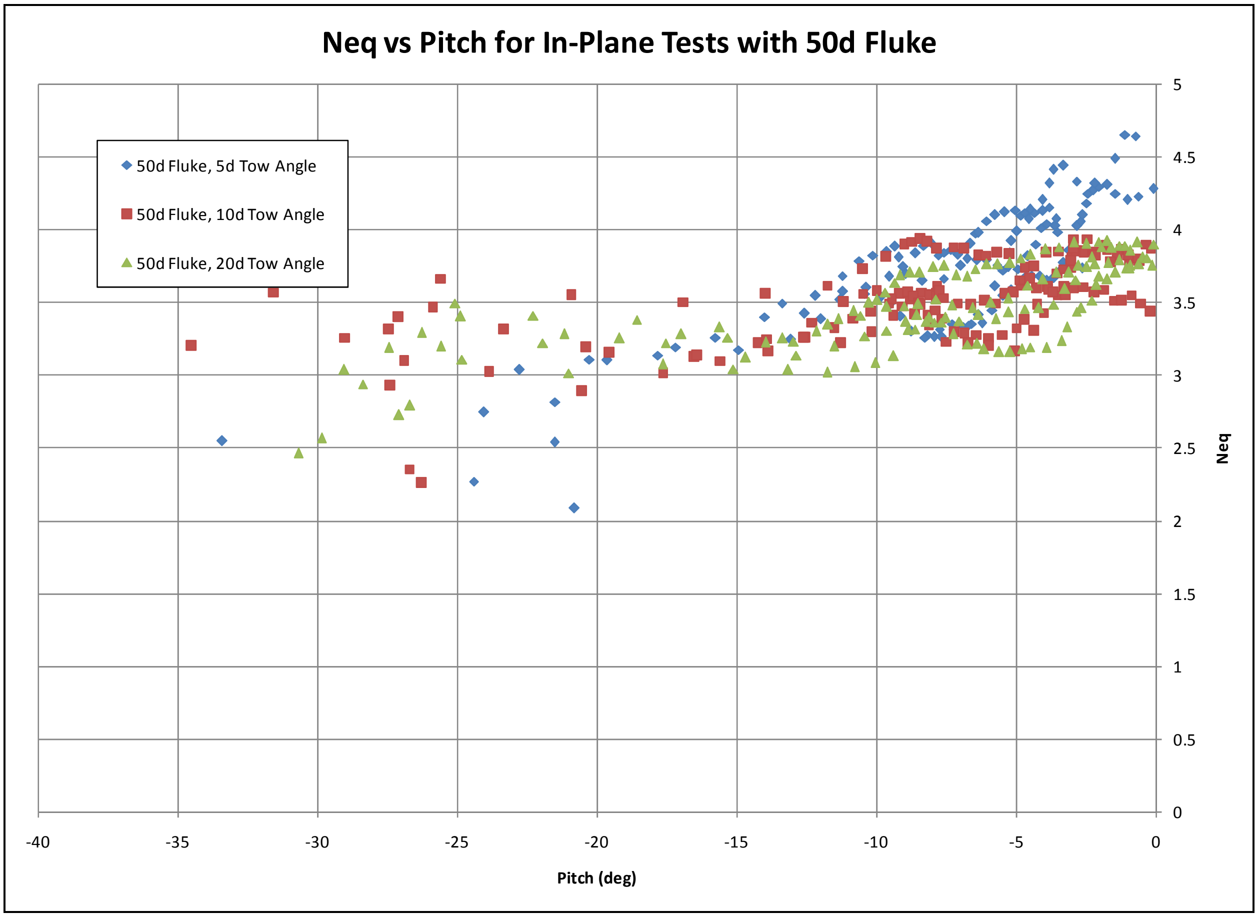

Figure II.1.13: Neq vs. Pitch for In-plane Tests at 50° Fluke Angle

- For 50° fluke angle, it is slightly observed anchor capacity factor N_{eq} increases as tow angle decreases.
- Anchor capacity factors stay in a very small range for each fluke setting.
- For 5° tow angle, the capacity factor increases slightly as the pitch angle decreases.

Figure 19-21 illustrates fluke-shackle angle versus anchor capacity factor. The fluke-shackle angle is calculated from anchor mudline angle using reverse catenary program.

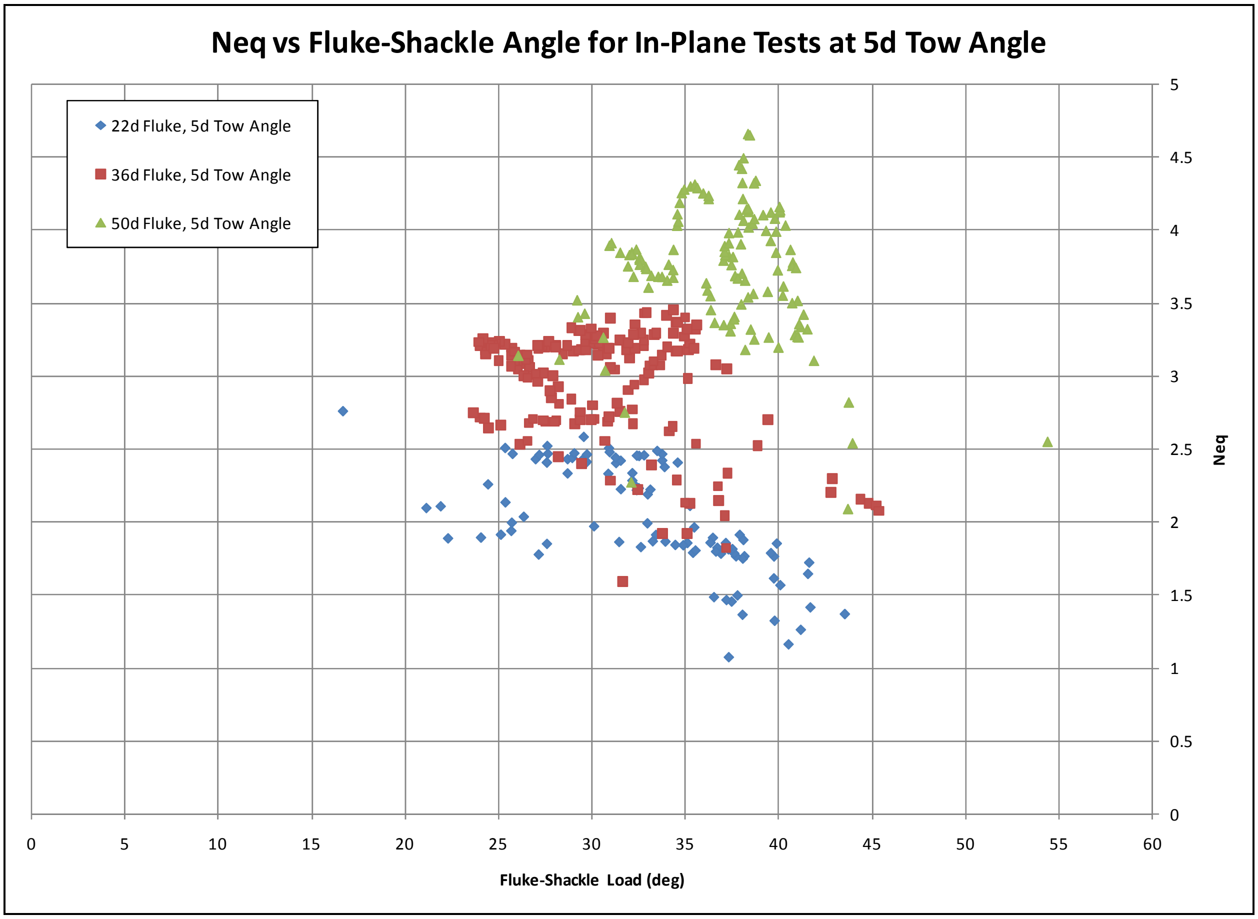

Figure II.1.14: Neq vs. Fluke-shackle Angle for In-plane Tests at 5° Tow Angle

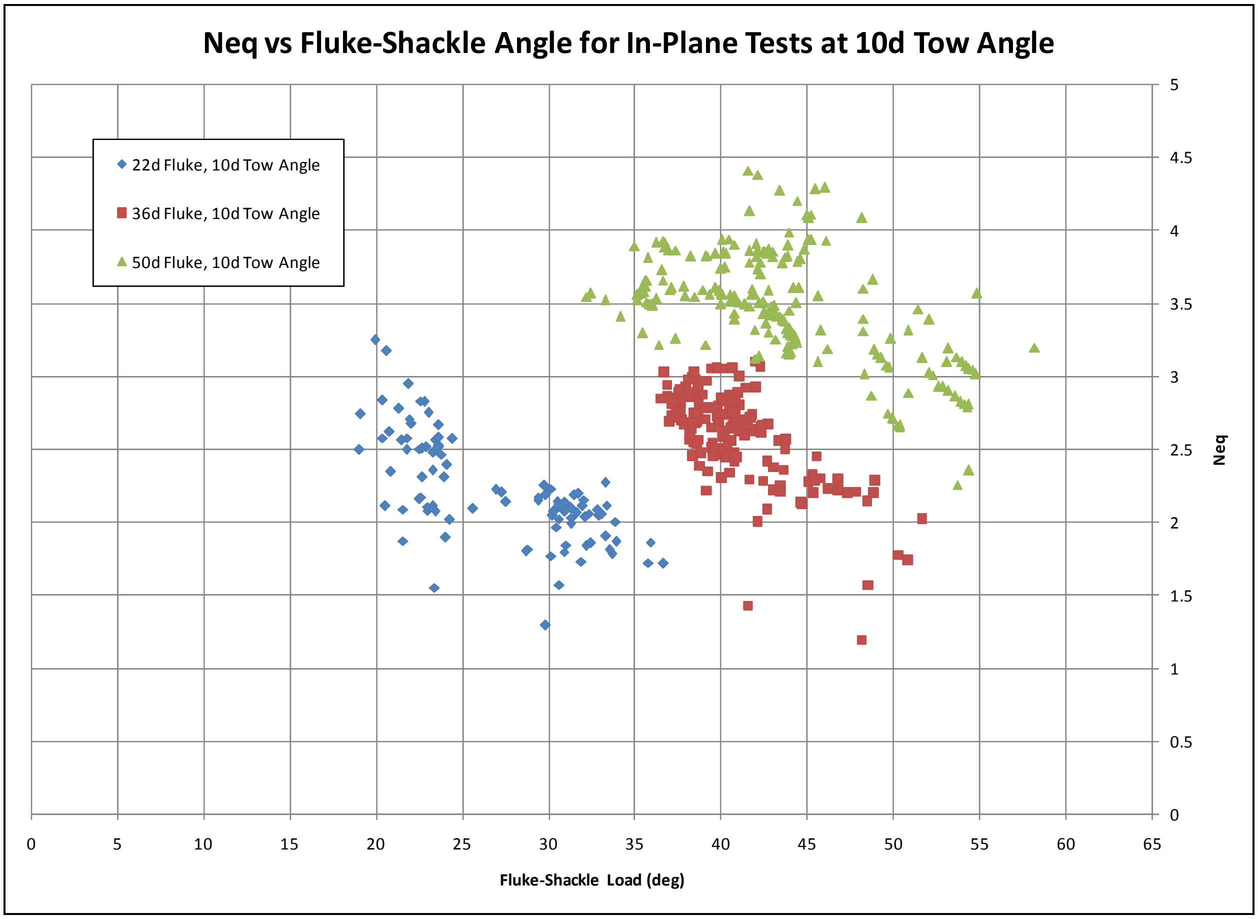

Figure II.1.15: Neq vs. Fluke-shackle Angle for In-plane Tests at 10° Tow Angle

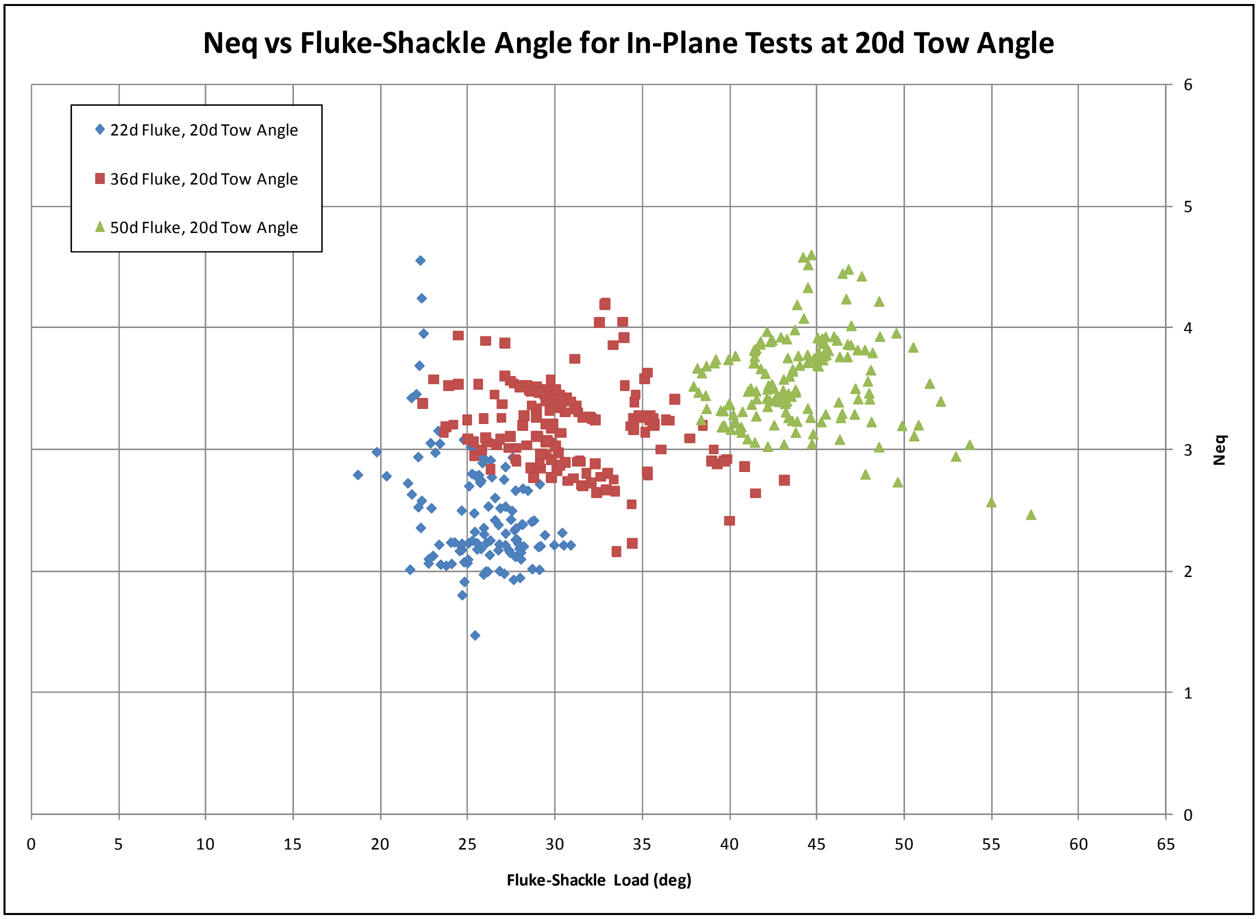

Figure II.1.16: Neq vs. Fluke-shackle Angle for In-plane Tests at 20° Tow Angle

- Like anchor capacity factor, fluke-shackle angle varies in a small range for each test. This matches the assumption in the anchor trajectory programs we are currently using.
- For small uplift with 22° fluke anchor, fluke-shackle angle scatters more than other angles. This may be due to bad data (for 22° fluke tests, the chaser reading deviates a lot from pressure reading).
- Generally, larger fluke-shank angle results in larger fluke-shackle angle and higher capacity factor. On average, the fluke-shackle angle is close the fluke-shank angle, but for anchor with small fluke angle, the fluke-shackle angle is always larger than fluke angle. In practice, small fluke angle anchor can also achieve fluke-shackle angle larger than fluke angle. This can be used in anchor prediction program.

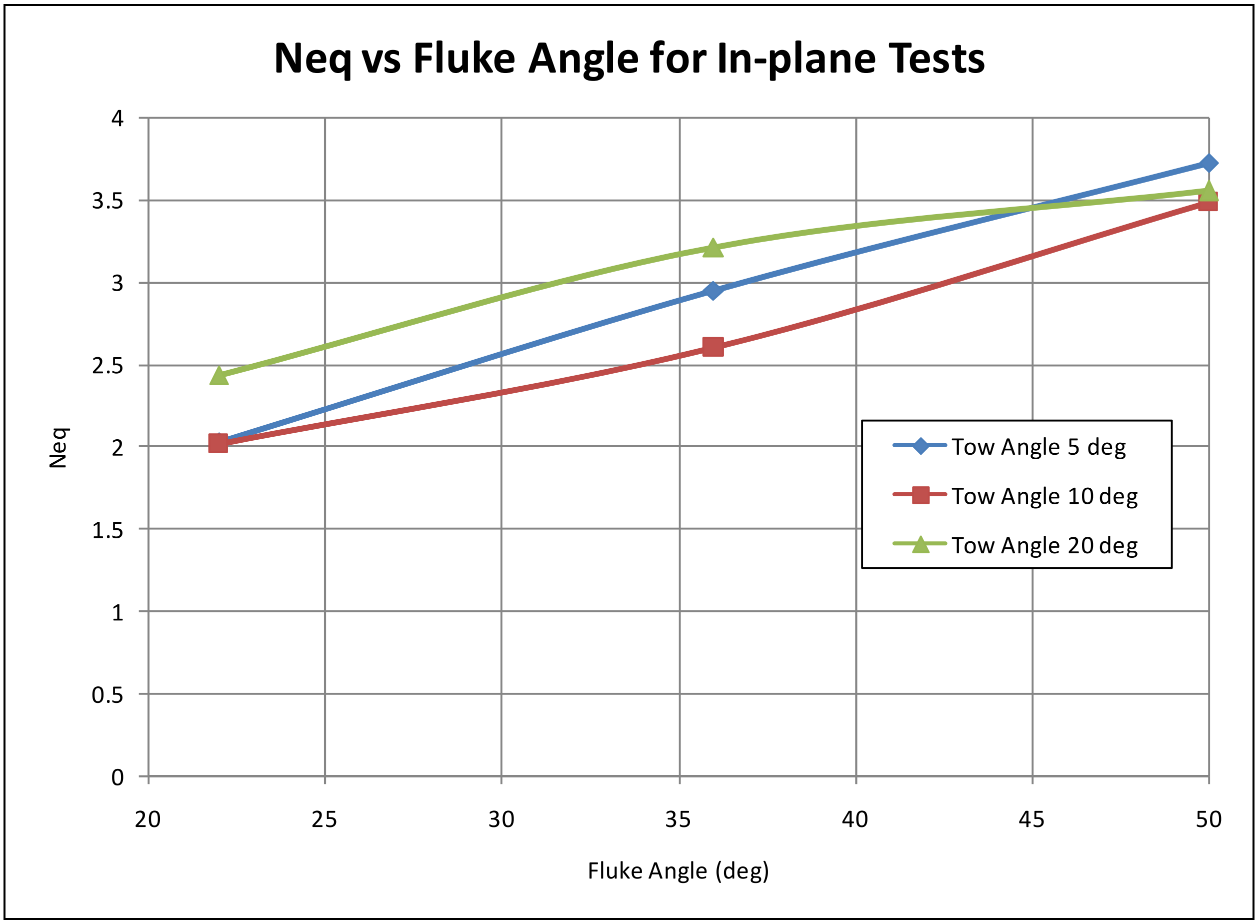

Figure II.1.17: Average Neq vs. Fluke Angle for All In-plane Tests

- Anchor Capacity Factor increases as fluke angle increases.
- Tow angle doesn't show any trend to affect anchor capacity factor.

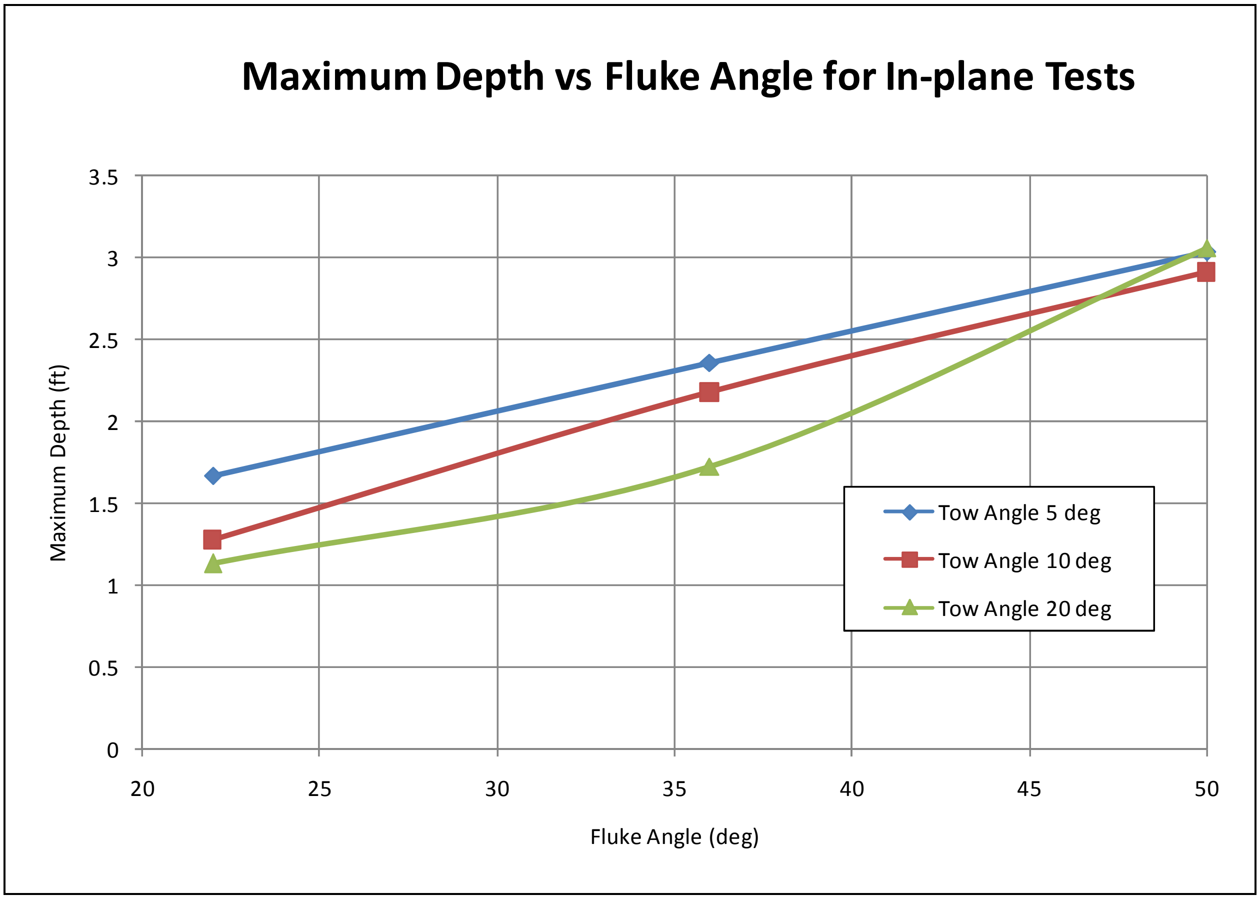

Figure II.1.18: Maximum Depth vs. Fluke Angle for All In-plane Tests

- Maximum embedment increases as fluke angle increases.
- Smaller tow angle tends to lead to deeper embedment. For 50° fluke angle, tow angle doesn't affect the maximum embedment.

A.1.3 Conclusions of In-plane Testing

1. Higher fluke angle is expected to result in larger embedment and stronger anchor capacity factor.
2. Tow angle has less impact on anchor capacity factor, but it affects the anchor trajectory and embedment, and thus affects the dimensional anchor capacity.
3. Anchor capacity factor is close to a constant for each test setting.
4. Fluke-shackle angle is stable for large and medium uplift anchor, because the rotation resistance is usually the controlling resistance for anchor capacity. Generally, large fluke angle results in large fluke-shackle angle and large anchor capacity factor. The value of fluke-shackle angle is close to the fluke angle of the model.
5. For small fluke-shackle angle (<10°), the anchor may experience a different capacity factor and an increasing fluke-shackle angle, because the controlling resistance is the tangential resistance for small fluke-shackle angle. But these tests have not recorded any small fluke-shackle even at the beginning stage. So this makes sense that fluke-shackle angle, and capacity factor tend to keep constant for each run.

A.2.0 OUT-0F-PLANE TESTS

A.1.4 Test Matrix

TABLE II.2.1: Out-of-plane Tests

Date	Test Number	Fluke angle (β) deg	Tow angle (α) deg	Tow speed (V) m/s	Out of plane angle (θ) deg
3/30/10	42	36	5	0.13	45
3/30/10	43	36	5	0.19	45
3/30/10	44	36	5	0.13	45
3/30/10	45	36	5	0.19	45
3/31/10	46	22	5	0.13	45
3/31/10	47	22	5	0.19	45
3/31/10	48	22	5	0.13	45
3/31/10	49	22	5	0.19	45
3/31/10	50	50	5	0.13	45
3/31/10	51	50	5	0.19	45
3/31/10	52	50	5	0.13	45
3/31/10	53	50	5	0.19	45
3/31/10	54	50	5	0.13	90
3/31/10	55	50	5	0.19	90
3/31/10	56	50	5	0.13	90
3/31/10	57	50	5	0.19	90
3/31/10	58	36	5	0.13	90
3/31/10	59	36	5	0.19	90

3/31/10	60	36	5	0.13	90
3/31/10	61	36	5	0.19	90
3/31/10	62	22	5	0.13	90
3/31/10	63	22	5	0.19	90
4/1/10	64	22	5	0.13	90
4/1/10	65	22	5	0.19	90
4/1/10	66	50	5	0.13	90 imbed
4/2/10	67	50	5	0.19	90 imbed
4/2/10	68	50	5	0.13	90 imbed
4/2/10	69	50	5	0.19	90 imbed
4/2/10	70	50	5	0.13	45 imbed
4/2/10	71	50	5	0.19	45 imbed
4/2/10	72	50	5	0.13	45 imbed
4/2/10	73	50	5	0.19	45 imbed
4/7/10	74	36	5	0.13	90 imbed
4/7/10	75	36	5	0.19	90 imbed
4/7/10	76	36	5	0.13	90 imbed
4/7/10	77	36	5	0.19	90 imbed
4/7/10	78	36	5	0.13	45 imbed
4/7/10	79	36	5	0.19	45 imbed
4/7/10	80	36	5	0.13	45 imbed
4/7/10	81	36	5	0.19	45 imbed
4/8/10	82	36	5	0.13	15

4/8/10	83	36	5	0.13	15
4/8/10	84	36	5	0.13	15
4/8/10	85	36	5	0.13	15
4/9/10	86	36	5	0.13	30
4/9/10	87	36	5	0.13	30
4/9/10	88	36	5	0.13	30
4/9/10	89	36	5	0.13	30
4/8/10	90	36	5	0.13	45
4/8/10	91	36	5	0.13	45
4/8/10	92	36	5	0.13	45
4/8/10	93	36	5	0.13	45
4/8/10	94	50	5	0.13	15
4/8/10	95	50	5	0.13	15
4/8/10	96	50	5	0.13	15
4/8/10	97	50	5	0.13	15
4/8/10	98	50	5	0.13	30
4/8/10	99	50	5	0.13	30
4/8/10	100	50	5	0.13	30
4/8/10	101	50	5	0.13	30
4/9/10	102	50	5	0.13	45
4/9/10	103	50	5	0.13	45
4/9/10	104	50	5	0.13	45
4/9/10	105	50	5	0.13	45

5/2/10	145	50	5	0.13	15,30,45
5/2/10	146	50	5	0.13	15, 30, 45
5/2/10	147	50	5	0.13	15,30,45
5/2/10	148	50	5	0.13	15, 30, 45

A.1.5 Out-of-plane Results

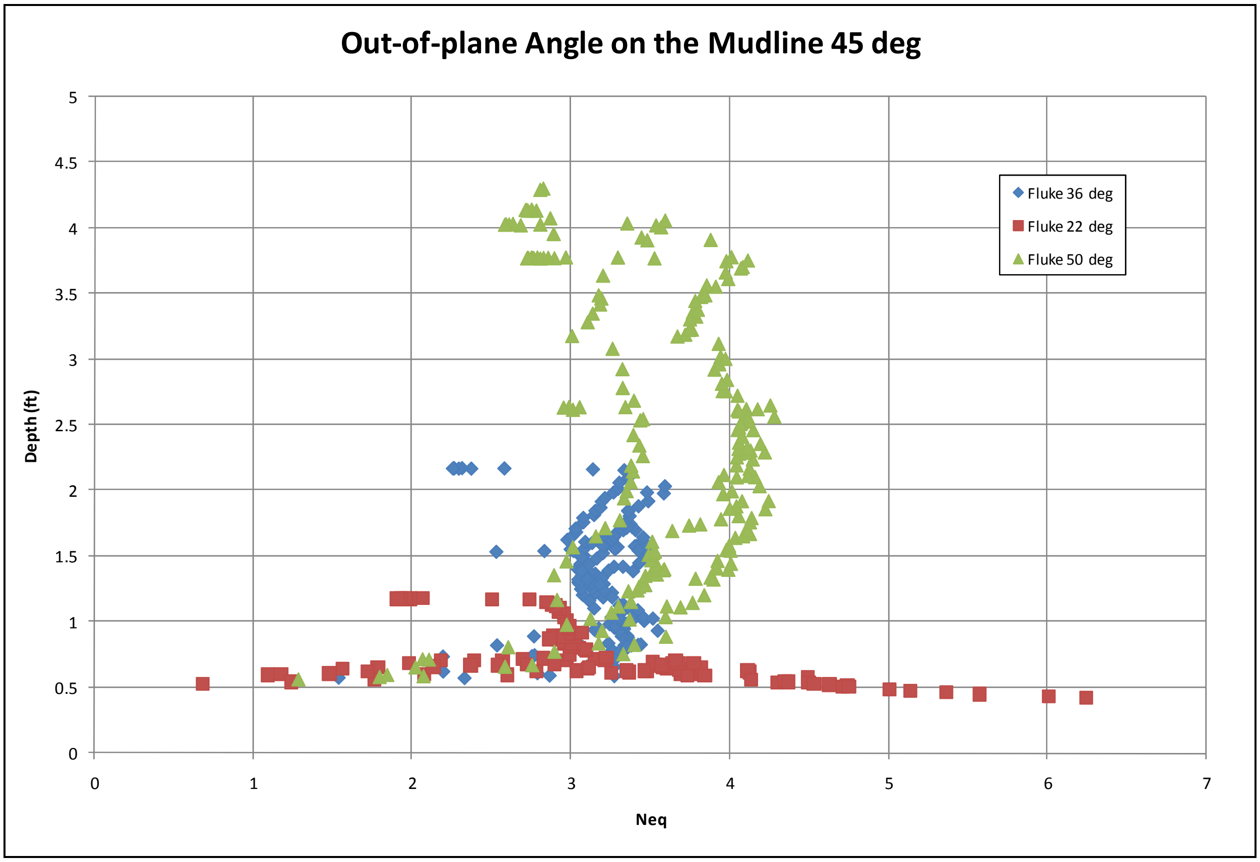

Figure II.2.1: Neq vs. Depth for OOP Angles 45°on the mudline

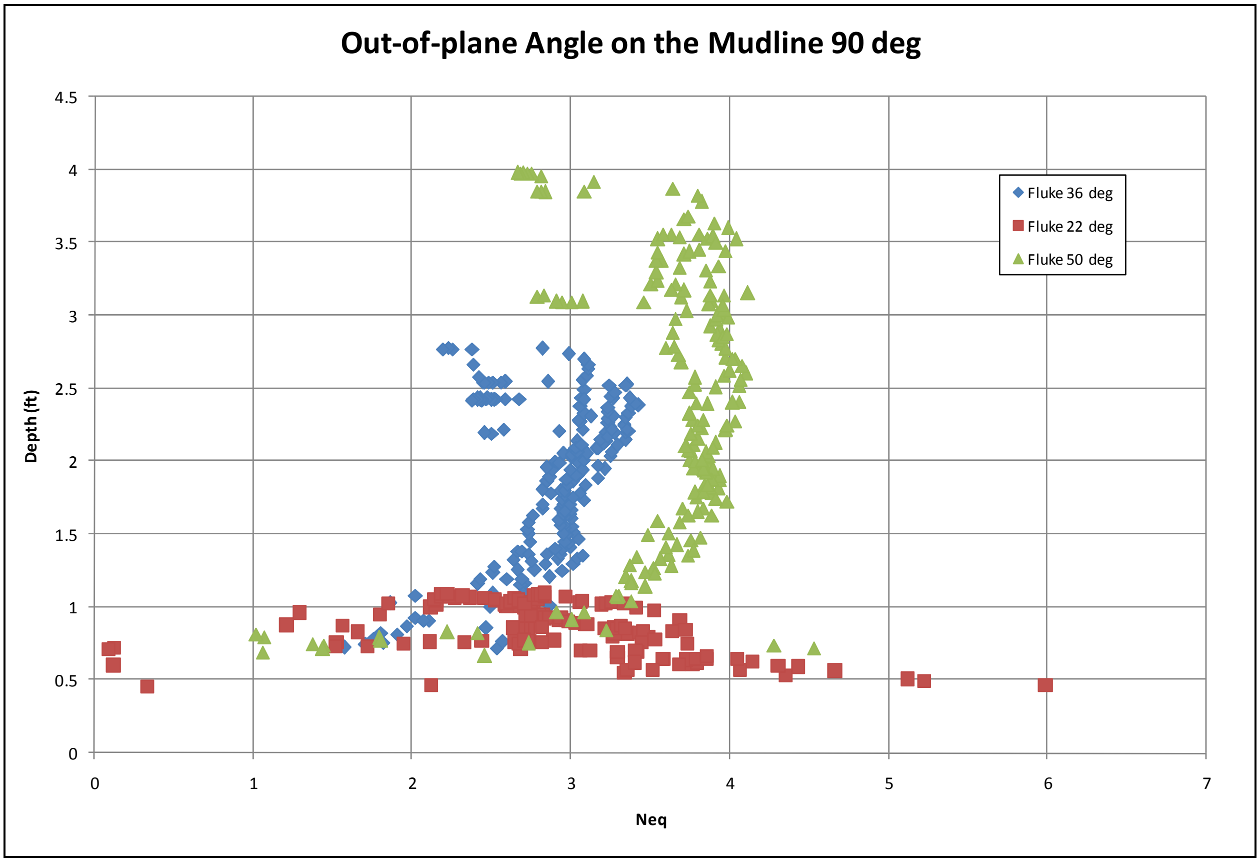

Figure II.2.2: Neq vs. Depth for OOP Angles 90°on the mudline

- Large Anchor Capacity factors are seen when the 22° fluke anchor is pulled out. For normal cases, larger fluke angles result in deeper embedment and higher capacity factor.
- OOP angle does not show any obvious effects on anchor capacity factor, but 90° OOP angle has deeper embedment on 36° fluke anchor than 45° OOP angle.

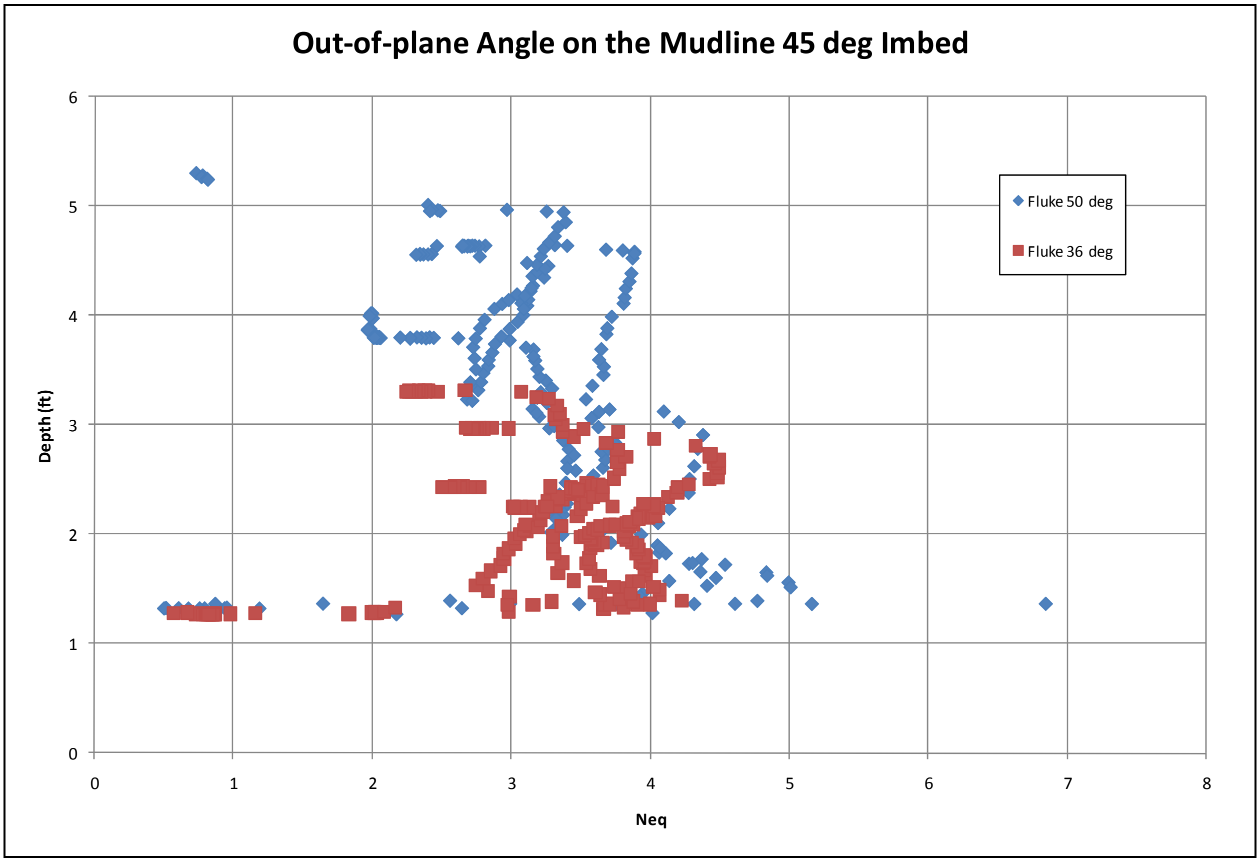

Figure II.2.3: Neq vs. Depth for OOP Angles 45°, Imbed 14" below Mudline

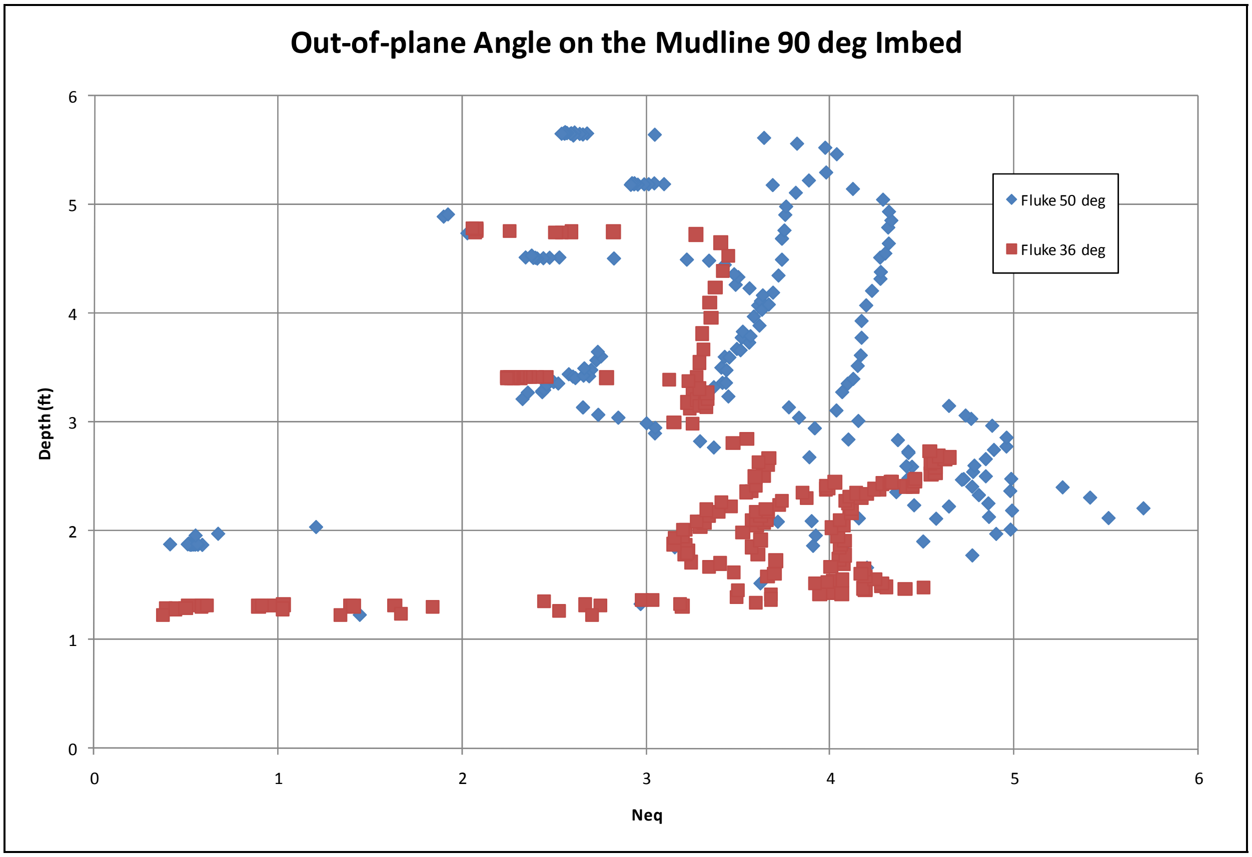

Figure II.2.4: Neq vs. Depth for OOP Angles 90°, Imbed 14” below Mudline

- Higher capacity at 90° OOP angle than 45° OOP
- Higher fluke angle results in slight higher embedment and capacity factor

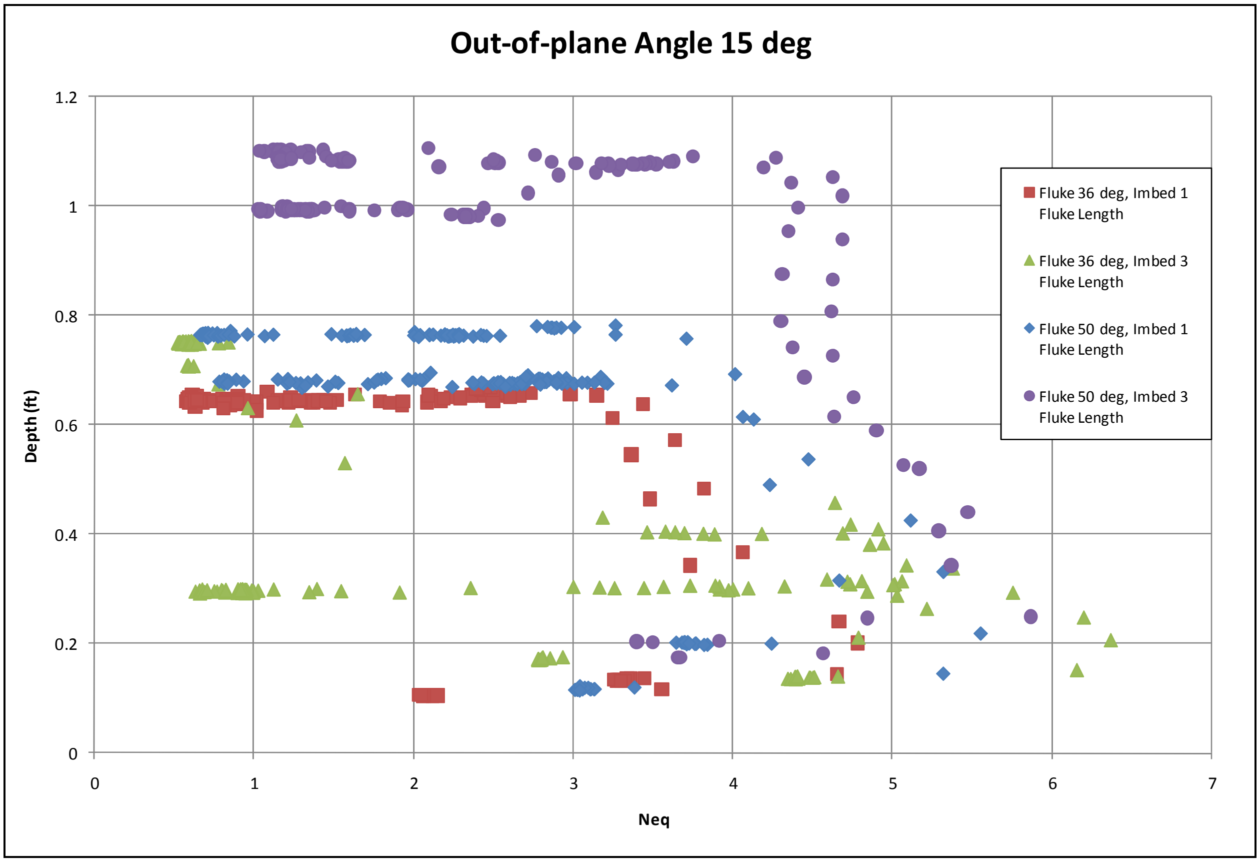

Figure II.2.5: Neq vs. Depth for OOP Angles 15°

- Anchor with higher fluke angle has deeper embedment
- Anchor pulled with OOP angle has much smaller embedment than placed on mudline with OOP angle, but anchor capacity factors are close.

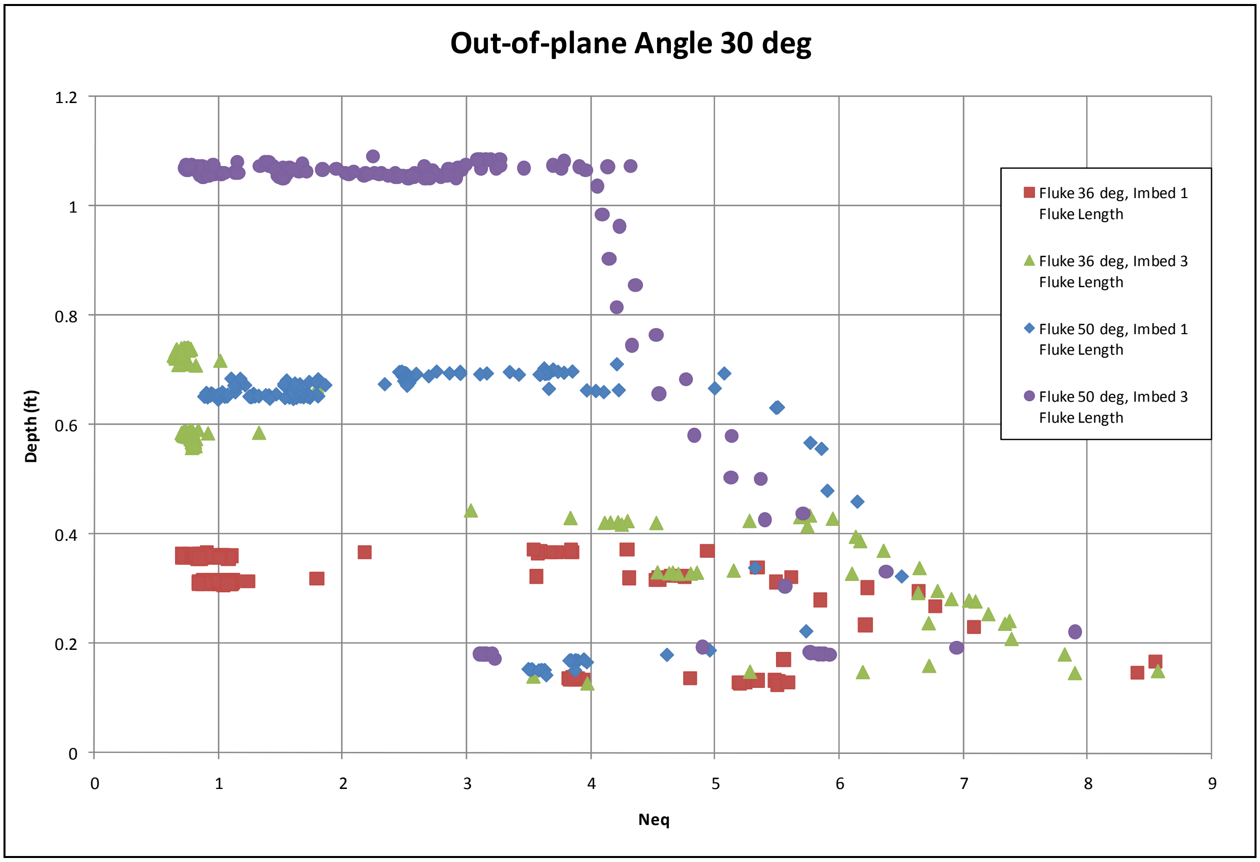

Figure II.2.6: Neq vs. Depth for OOP 15° and 30°

- Anchor with higher fluke angle has deeper embedment but slightly smaller anchor capacity factor.
- OOP pulling angle does not show any obvious impact

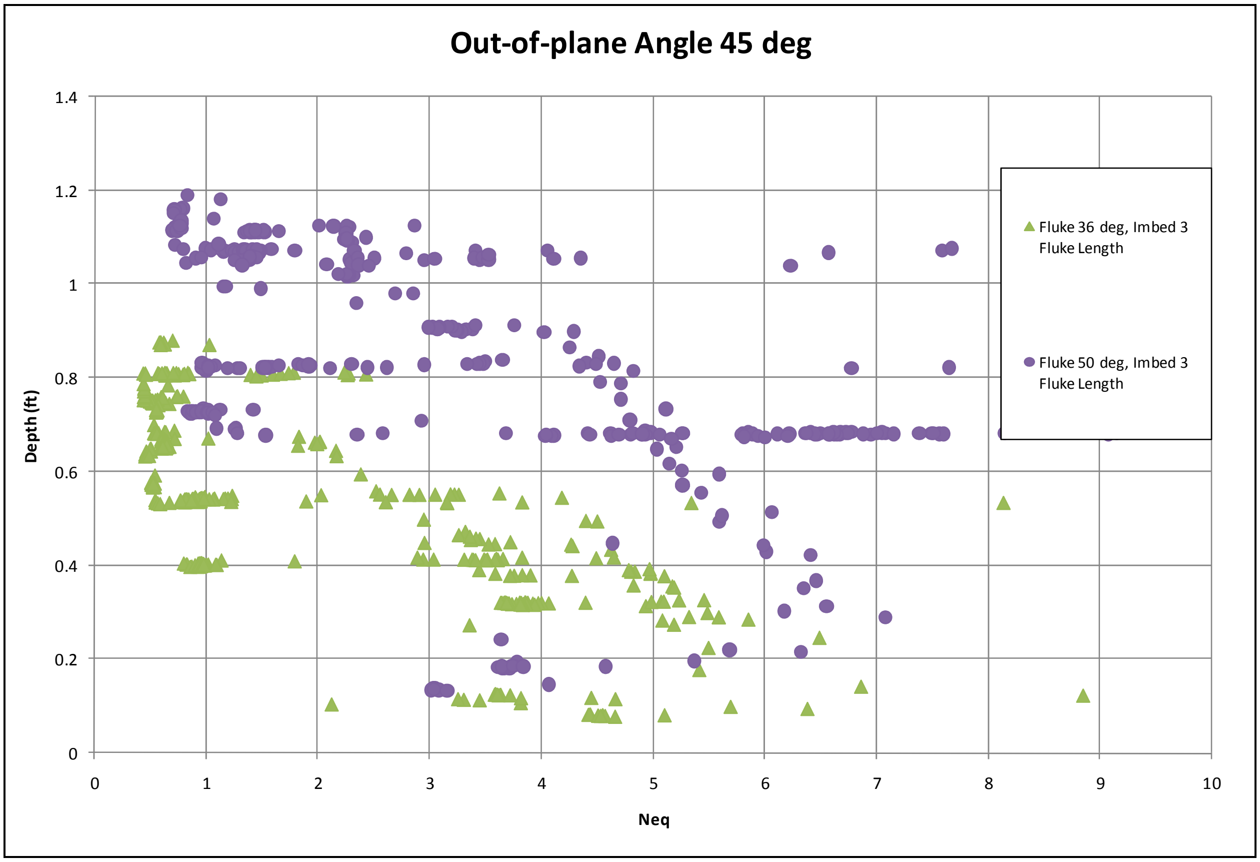

Figure II.2.7: Neq vs. Depth for OOP 15° and 30°

- Anchor with higher fluke angle has deeper embedment. Anchor capacity factor are close.
- OOP pulling angle does not show any obvious impact

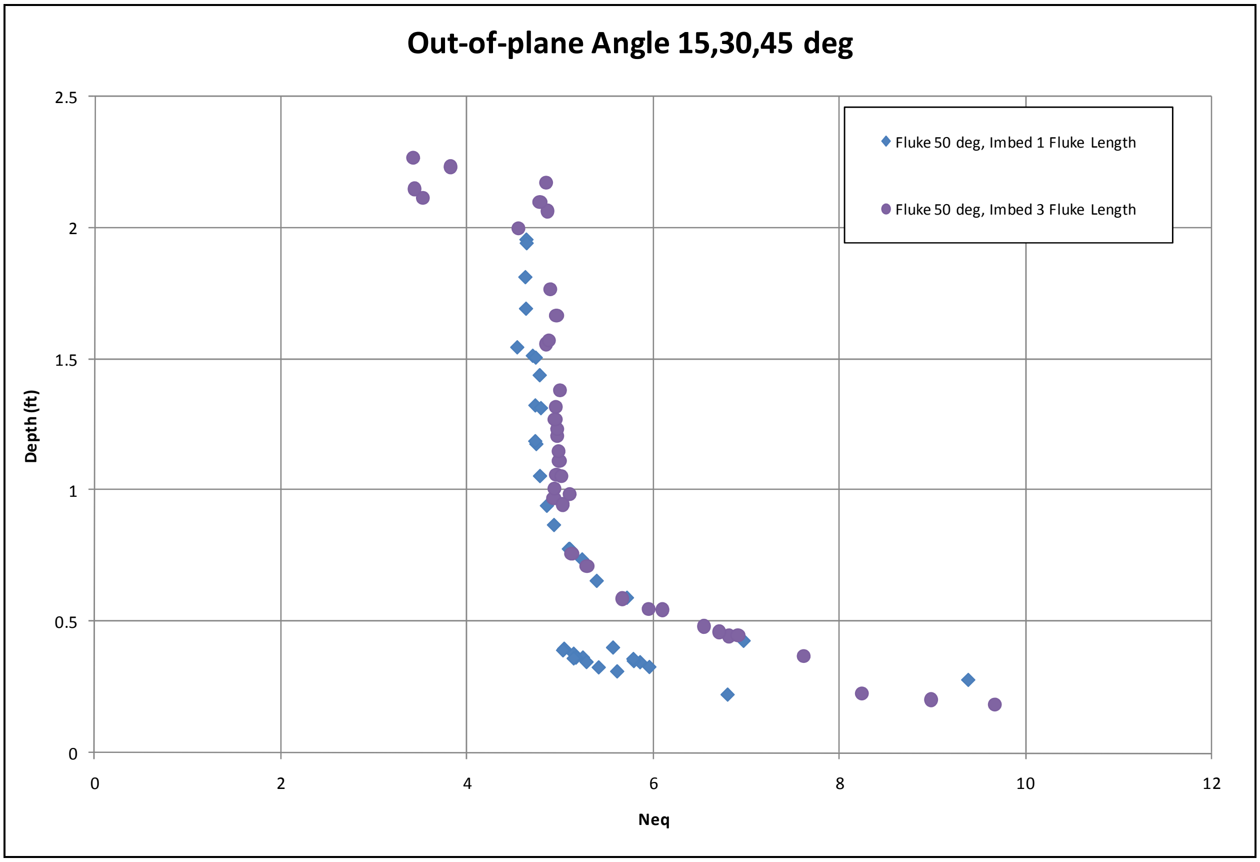

Figure II.2.8: Neq vs. Depth for OOP 15°, 30° and 45°

- Different fluke angles show similar behaviors with increasing OOP pulling angle.
- Compared to OOP tests using a fixed OOP angle, tests with mixed OOP angle achieve high embedment and capacity factor.

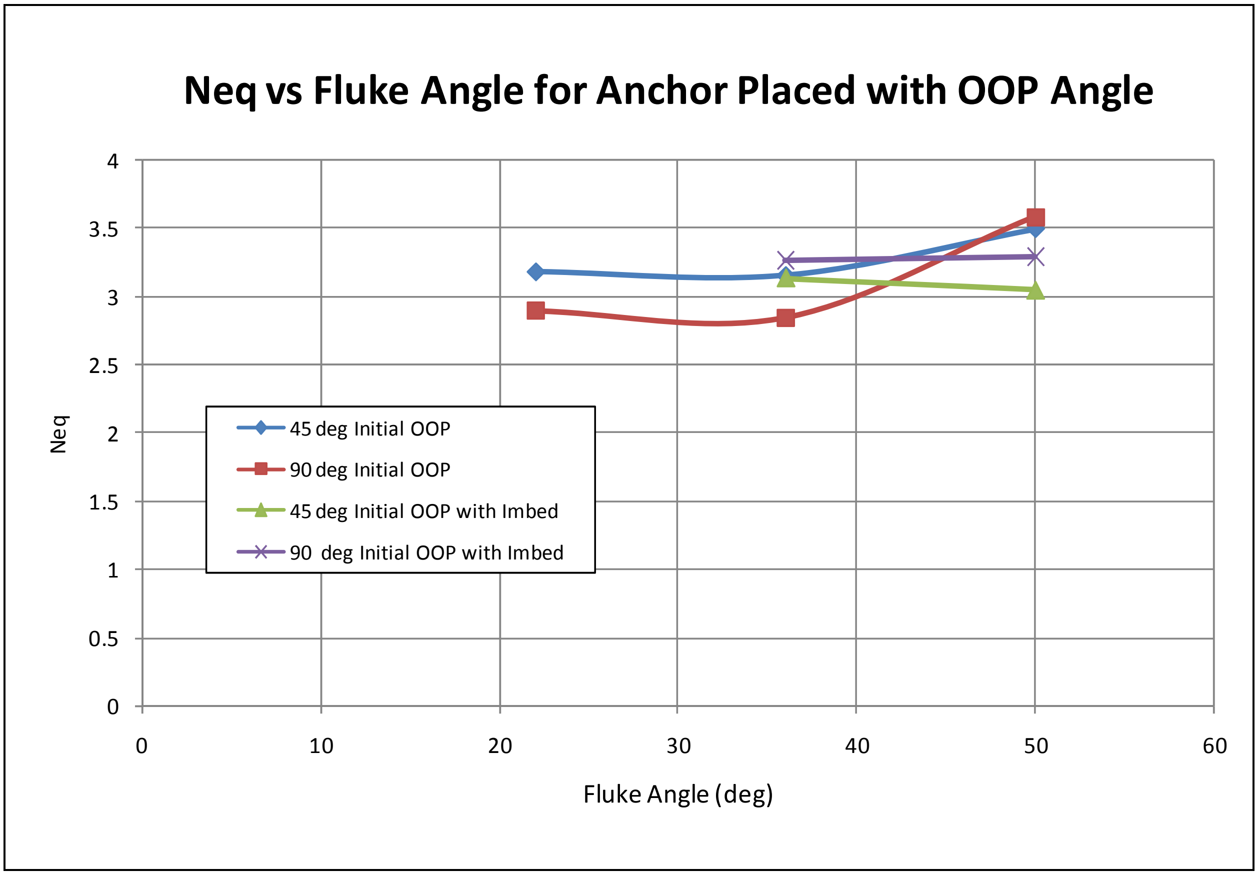

Figure II.2.9: Neq vs. Fluke Angle for All Tests with Anchors Placed at OOP Angles

- Higher capacity factor are seen in 50° fluke angle for no imbed tests.
- Compared to in-plane tests, the capacity factors of tests with initial OOP angles are close to in-plane tests and impact of fluke angle is weakened.

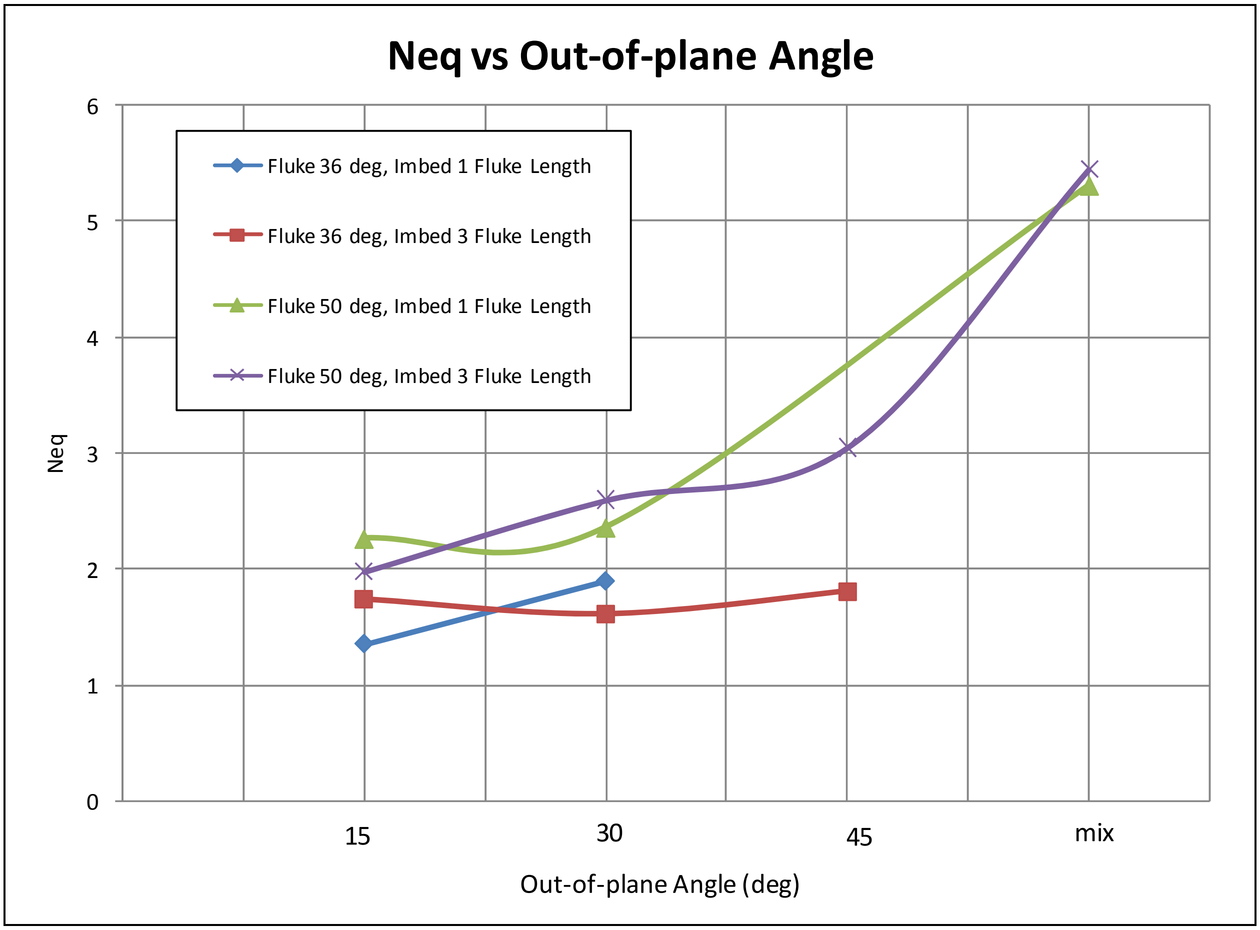

Figure II.2.10: Neq vs. Out-of-plane Angle for All Tests Pulled with OOP Angle

- Higher capacity factor are seen in larger fluke angle.
- OOP angle show little impact on capacity factor, but gradually increasing OOP angle evidently increases the capacity factor.
- Compared to in-plane tests, the capacity factors of OOP tests are smaller except for the tests with increasing OOP angle.

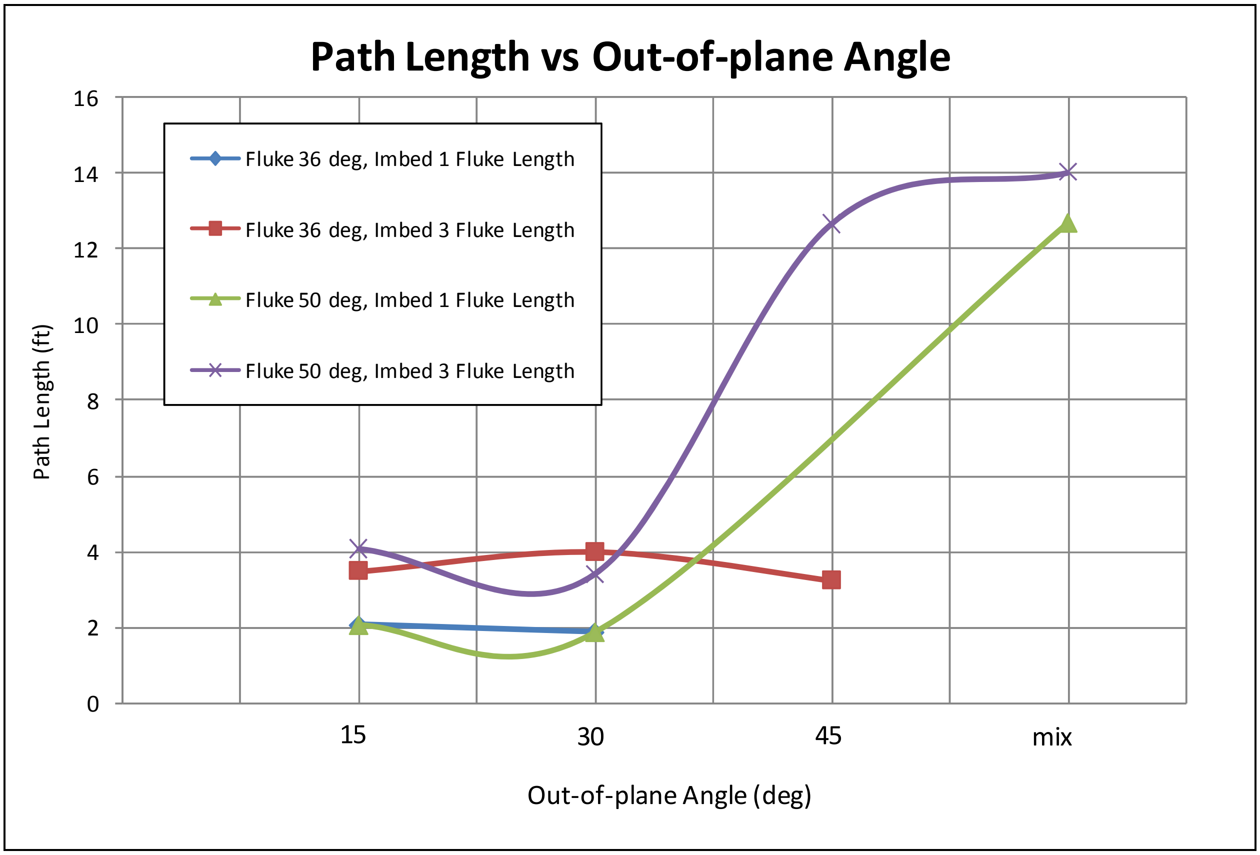

Figure II.2.11: Path Length vs. Out-of-plane Angle for All Tests Pulled with OOP Angle

- Further path length is seen at tests embedded 3 fluke length, because it takes longer path to pull them out.
- 50° fluke anchor with 45° and mixed OOP angle has much longer path length than other tests

II.2.3 Conclusions of Out-of-plane Testing

- Compared to in-plane test, anchor capacity factors of tests with anchor placed at OOP angle and tests with anchor pulled at increasing OOP angle show higher capacity factor than in-plane tests. In terms of embedment, the OOP tests always result in smaller embedment except for OOP tests with increasing pulling angle.
- For tests pulled at OOP angle, the anchor capacity reduces when OOP angle applies, but the embedment can continue to increase.

- Out-of-plane angle show little impact on embedment, capacity factor or path length. But increasing OOP angle tests result in larger capacity factor, embedment and path length than other OOP tests.
- Large fluke angle helps to increase embedment and anchor capacity factor.
- Path length of OOP tests are mostly shorter than in-plane tests, except for OOP tests with increasing pulling angle, because these tests bring about very large horizontal movement.

Note that in all OOP tests the displacements are measured by chaser line. Some tests with evidently problematic data are removed. In some in-plane tests, the displacement are measured by chaser line, but in others, the displacement are measured by adjusted pressure reading when the chaser line reading are considered problematic.