ESP Mooring Analysis for Catalina Island Deployment

Feb 18, 2014

The ESP deployment at Catalina Island is to be in deeper water than has previously been done with the current mooring design. This report outlines analysis performed on the existing mooring design in a range of water depths. The analysis performed has used “WHOI-Cable” to numerically model the behavior the mooring in a range of conditions. Due to the expected mild sea states at this location, the analysis has concentrated on the static behavior of the system (i.e. it’s response to wind and currents) and only sample computations have been performed that include wave forcing and the resulting dynamic forces in the system.

Location

The primary site is on the north-east side of Catalina Island at 33.484 deg N/ 118.5388 deg W. The alternative site is nearby at 33.4775 deg N/118.5133 deg W.

There have been some discrepancies in the reported depth at the primary location, ranging from 90m to 200m. The NOAA charts indicate a depth of about 150m, with a mean bottom slope of about 12 degrees. The analysis run below is for depths of 50m, 100m, 150m, and 200m to cover the range and allow comparisons with deployments at shallower depths where there is more experience with the system.

Environmental Conditions

The currents at this location are not well characterized; the best estimates that have been found are from HF radar data collected by SCOOS over the past several years. The radar installations that cover this area spend a lot of time down so the data is spares. Nevertheless surface currents above 0.75 m/s have not been observed. Plots attached below show the data availability, histograms of the observed surface currents at the primary and alternative sites.

There are no current profiles available at this location, for the analysis two profiles have been assumed, a linear case in which the specified surface current decays linearly to zero at the bottom, and a constant current profile in which the current is constant throughout the water column. This later is considered an estimate of the worst case (although presumably the subsurface currents could be greater than the surface currents…).

Mooring Design

The mooring design is the same as has been deployed many times in shallower water and consists of a floated EM cable to a small submersible float above the instrument, a compliant “shackle” element below the instrument, and polyester rope down to a deadweight anchor. Traditionally a 7/8” polyester rope has been used but is overkill in terms of strength. For these analyses this element has been reduced to 5/8” diameter to reduce current loading. The 5/8” size has a breaking strength of 13,900lbs which is plenty of strength margin compared to the expected loads.

Mooring Modelling

The mooring behavior has been simulated by constructing a numerical model using the “WHOI-Cable” modelling software. The attached documentation shows the node arrangements for this finite-difference solution, as well as the material properties used throughout. Due to limitations in the software, the ESP instrument, mounting platform, and associated “bail” is not well modelled and therefore the details of this devices positions and motions are not characterized in detail, but the net effect of the instrument on the mooring position should be acceptable.

Numerical Results

Static Results

The static results across a range of current profiles and depths are presented in the attached plots. The “buoy freeboard” shows the point at which the surface expression submerges for each depth and current profile. Also shown are the ESP instruments depth and the resulting forces on the anchor, tension in the shackle (and polyester rope), etc.

Dynamic Results

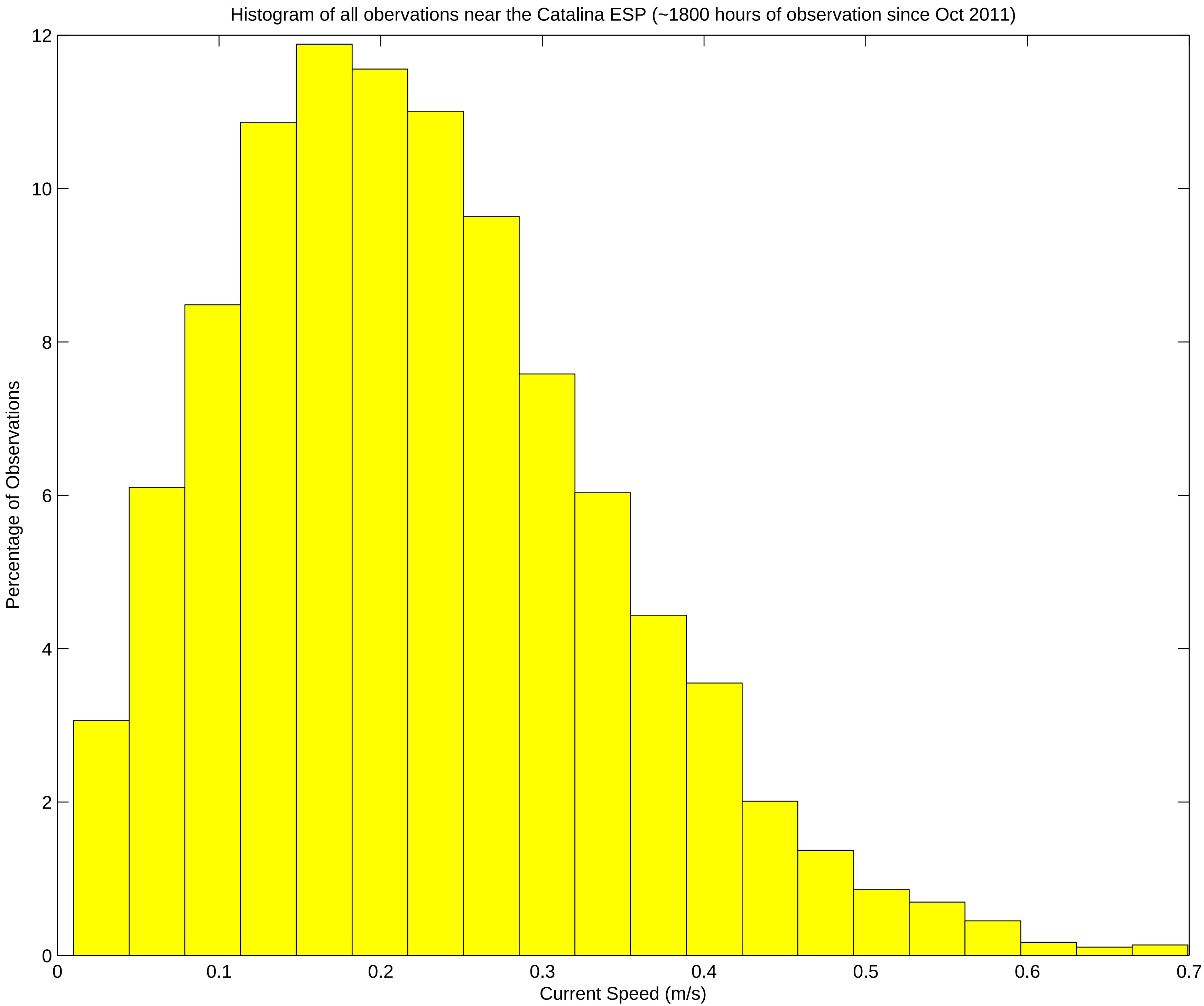
A single dynamic analysis was performed as an example for the 150meter mooring in 0.5m/s linear and waves with a 4 meter significant wave height and peak period of 10s. This was selected based on the assumption that the sea conditions inside of Catalina will remain relatively mild. The peak tensions in this case were less than twice the mean tensions and the time domain record of these forces are shown in a figure below.

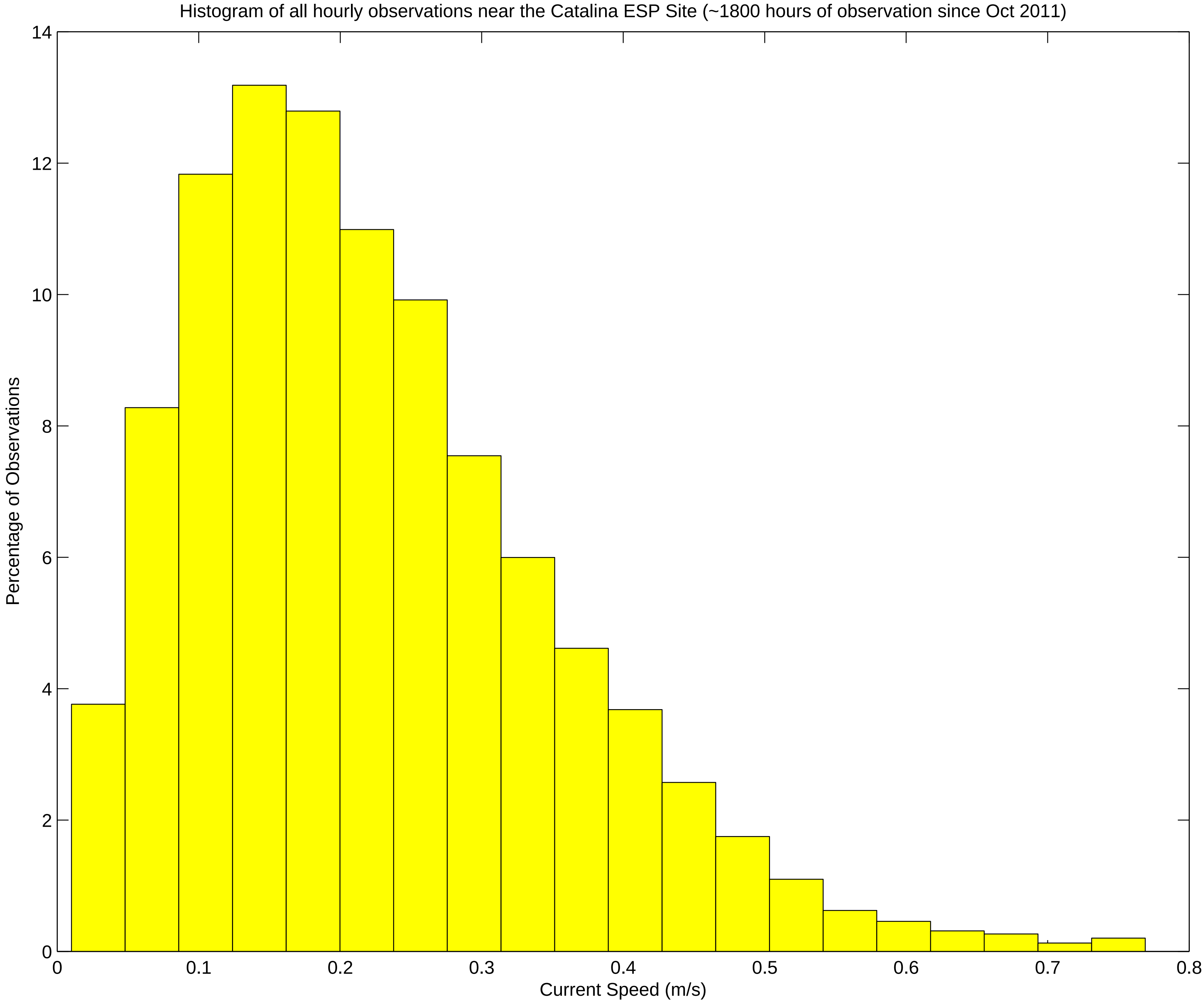
Conclusions

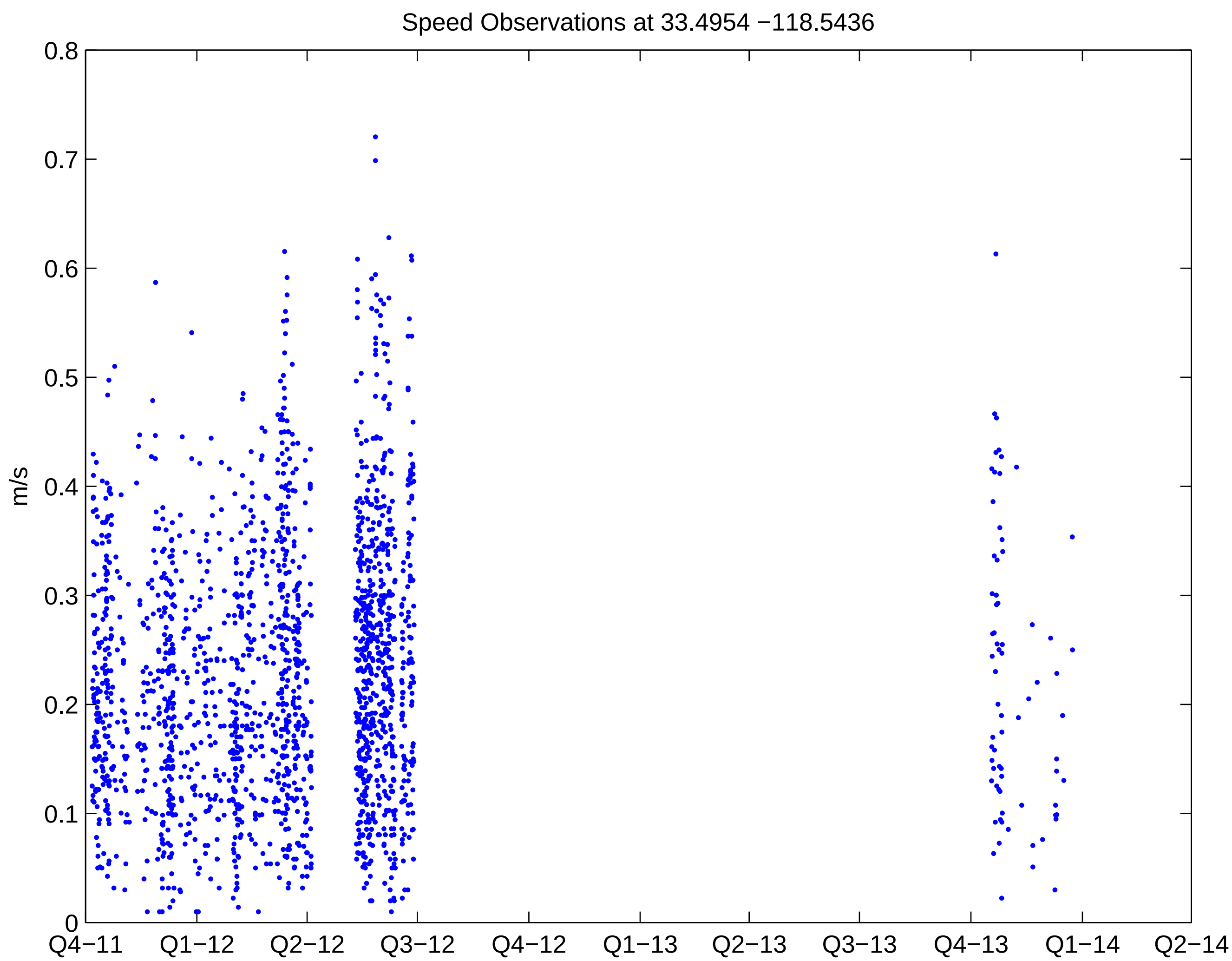
In the worst case expected current conditions (Constant current profile of 0.75m/s extending down to 200m), the surface buoy is likely to be on the verge of submerging and the ESP instrument itself will be at depth of 20m (down from 7m in calm conditions). Mooring tensions at the anchor in this condition will be about 350lbs, evenly split between horizontal and vertical forces.

Dynamic loads due to wave forcing have not been carefully characterized in this study but an estimate is that the peak loads in the system will be about 2 times the static loads, still well below the strength of the materials used throughout, but high enough that the anchoring system will need to rely on being stuck in the mud to keep from dragging .


1056 Obs
1894 Obs
1776 Obs
1863 Obs
871 Obs
1385
1579
0 Obs
ESP : 33.484 -118.5388
0 Obs
0 Obs
0 Obs
668 Obs
Data CSUMB SFML, CA OPC
Image © 2014 DigitalGlobe
Google
1994
Imagery Date: 8/31/2011
33°28'58.32" N 118°32'22.05" W elev -329 ft


Histogram of all obervations near the Catalina ESP (~1800 hours of observation since Oct 2011)
Percentage of Observations
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Current Speed (m/s)

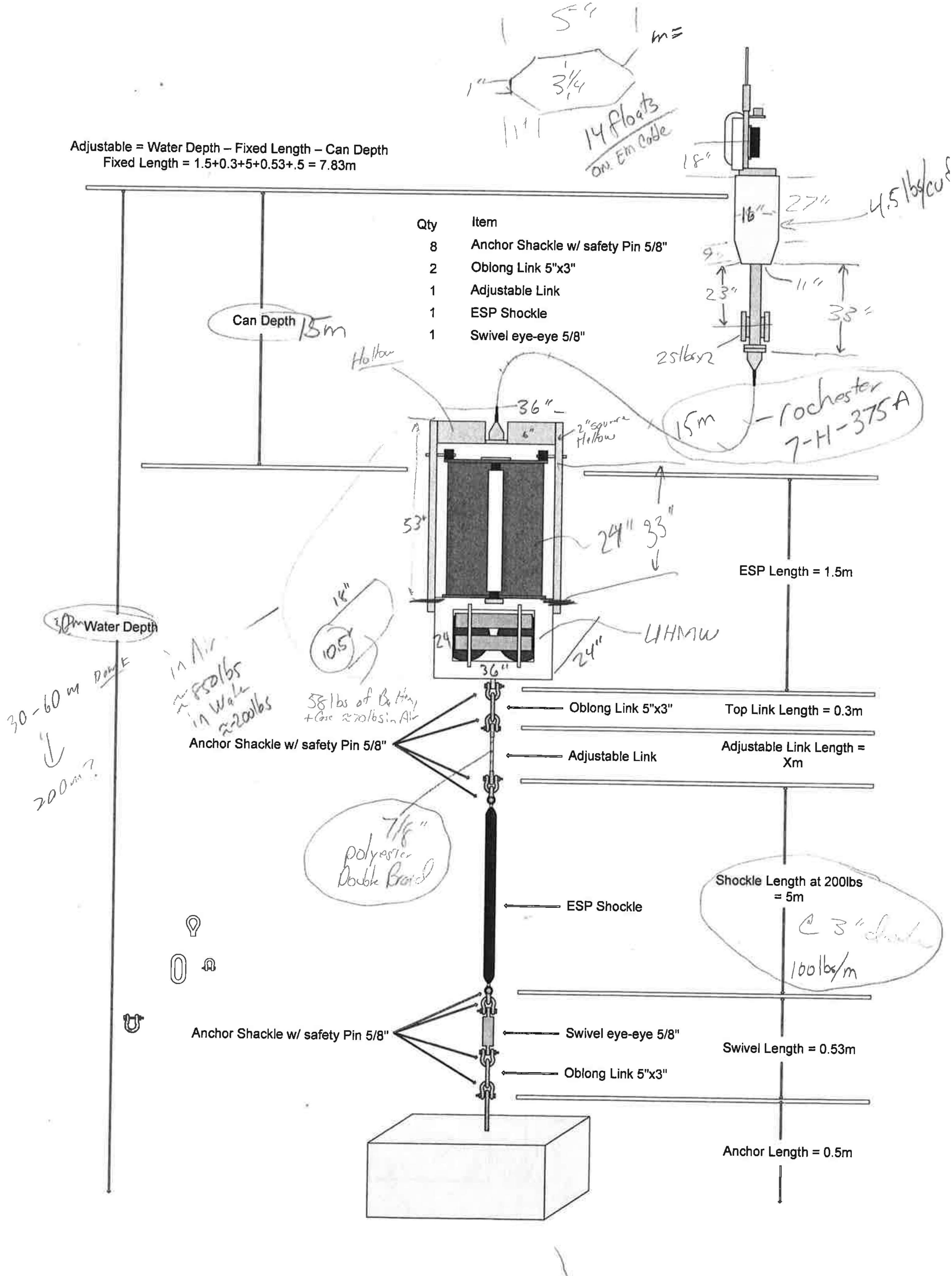

Histogram of all hourly observations near the Catalina ESP Site (~1800 hours of observation since Oct 2011)
Percentage of Observations
Current Speed (m/s)
0
2
4
6
8
10
12
14
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8



Speed Observations at 33.4954 −118.5436
m/s
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Q4−11
Q1−12
Q2−12
Q3−12
Q4−12
Q1−13
Q2−13
Q3−13
Q4−13
Q1−14
Q2−14

Adjustable = Water Depth – Fixed Length – Can Depth
Fixed Length = 1.5+0.3+5+0.53+.5 = 7.83m

Qty	Item
8	Anchor Shackle w/ safety Pin 5/8"
2	Oblong Link 5"x3"
1	Adjustable Link
1	ESP Shockle
1	Swivel eye-eye 5/8"



ESP MOORING WHOI CABLE MODEL

BUOY

mass = 34 kg (75 lbs)

Axisymmetric

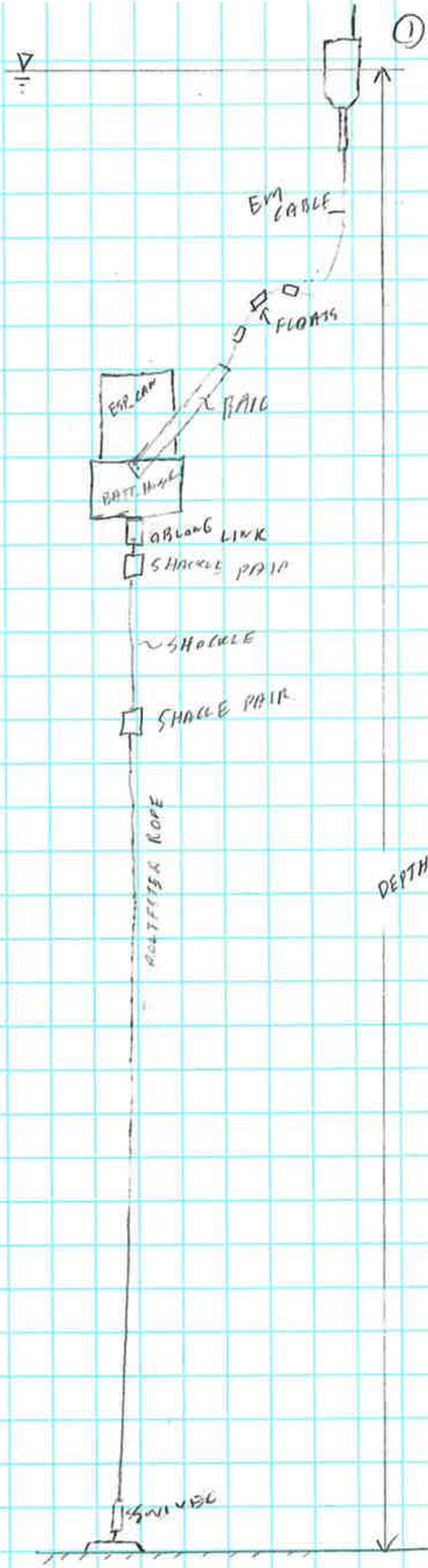
z	d
0	3"
33"	3"
33"	11"
42"	16"
69"	16"

$S_w = .15\ m^2$

$C_{dw} = 0.75$

$C_{dn} = 1.0$

$C_{dt} = 0.1$



ESP ASSEMBLY

- THERE ISN'T A GREAT WAY TO MODEL THIS BAIL ARRANGEMENT IN WHOI CABLE. TWO APPROACHES ARE USED:

A) SIMPLEST, AND WRONG B/C IT DOESN'T INCLUDE THE BAIL HINGED DOWN LOW

→ MODELED AS A CYLINDER OF APPROPRIATE SIZE WITH A MOMENT RELEASING CONNECTOR AT THE TOP AND BOTTOM.

$m = 386$ kg (850 lbs) [193 kg/m]

WET WEIGHT = -890 N (-200 lbs) [-445 N/m]

$d = .762$ m (30")

$L = 2.0$ m (79")

$C_d = 1.0$ $\quad C_{an} = 1.0$

$C_t = 1.0$ $\quad C_{at} = 1.0$

B) MORE COMPLICATED, MODEL ASSEMBLY AS THREE COMPONENTS, BATTERY CASE, BAIL CONNECTED TO TOP OF BATTERY CASE, with a moment releasing connector AND ESP AS "ATTACHMENT" ADDING DRAG/MASS/WET-WEIGHT TO TOP NODE OF BATTERY CASE. SUM OF THE MASS AND WEIGHT OF THE THREE ELEMENTS SUM TO THE APPROPRIATE TOTAL VALUE.

B (cont)

BATTERY CASE

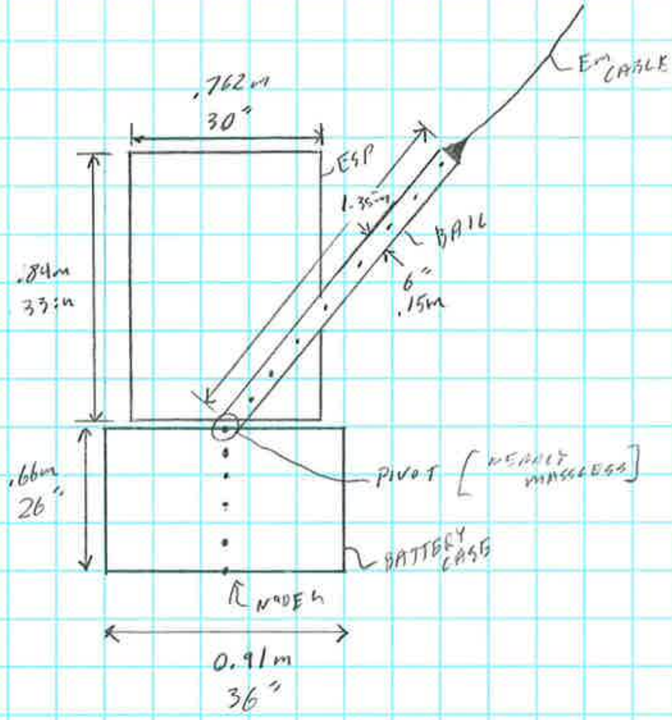
$EA = 1e7$ $EI = 5e5$

$m = 120$ kg 181.8 kg/m

264 lbs

WET WEIGHT = 647 N 980 N/m

145 lbs



BAIL

$EA = 1e7$ $EI = 1.4e4$

$m = 30.4$ kg 22.9 kg/m

68 lbs

WET WEIGHT = 0 N } CONSIDER IT
0 lbs } NEUTRAL.

ESP CAN

$m = 235$ kg = 517 lbs

wet weight = −1540 N = −346 lbs

SUMS

$m = 120$ kg + 30.4 kg + 235 kg = 386 kg = 849 lbs

WET WEIGHT =

POLYESTER ROPE

$EA = 1\times10^6$ N [FROM SPEC SHEET THA INDICATES 1.1% ELONGATION @ 2540 lbs]

$EI = 31$ N·m^2 [EQUIVALENT ROD]

$d = .022$ m [7/8"]

$m = .403$ kg/m

wet weight = 1.53 N/m [FROM SPECIFIC GRAVITY = 1.38 SPEC]

ROCHESTER EM CABLE

$EA = 3.226\times10^6$ N [FROM SPEC SHEET]

$EI = 18$ N·m^2 [EQUIVALENT ROD]

$d = .0096$ m

$m = .370$ kg/m

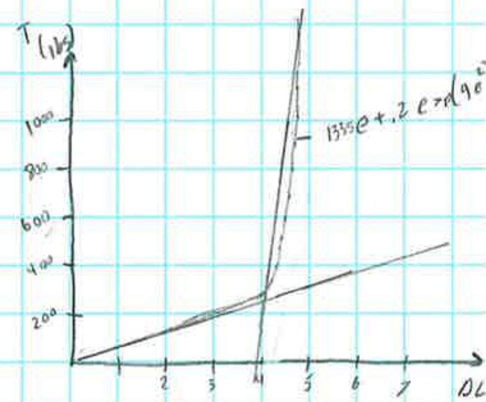
wet weight = 2.97 N/m [FROM SPEC SHEET, ADJUSTED FOR SEAWATER]

SYNTACTIC FLOATS - MODELED AS CYLINDERS

$d = .0762\,m$ [3"]
$length = .1016\,m$ [4"]
$m = .230\,kg$ [MEASURED FROM SAMPLE]
wet-weight: $-2.17\,N$ [COMPUTED FROM MEASURED MASS AND COMPUTED VOLUME]

SHACKLE → 3m LONG
-5m LONG @ 200 lbs [DL = 2m]
@7m LIMITER TAKES OVER [DL = 4m]

LINEAR OPTION:
$m = .909\,kg/m$ [6 lbs FOR 3m LENGTH]
$d = .052\,m$ [~2" DIAM]
$EA = 1335\,N$ [200 lbs STRETCHES 3m LENGTH TO 5m]
$EI = .226\,N\cdot m^2$ [BASED ON ROD EQUIVALENT, NOT A GREAT ASSUMPTION...]
wet weight = 0 [NEUTRAL]



NON-LINEAR OPTION → LOCUS
$m = .909\,kg/m$ [6 LBS FOR 3m Length]
$d = .052\,m$ [~2" DIAM]
wet_weight = 0

$T(e) = 1335e + .2\exp(4e^2)$ ← SIMULATE SPECTRA STIFFNESS ABOVE 5m LENGTH
$T'(e) = 1335 + .16e\exp(4e^2)$
$T''(e) = (.16e)^2\exp(4e^2) + .16\exp(4e^2)$
$= .16[.16e^2 + 1]\exp(4e^2)$

SWIVEL AT ANCHOR
$m: 5\,kg$ [9.43 kg/m]
$L: .53\,m$
$d: .0508\,m$ (2")
wet-weight: 20 N [37.7 N/m]

SHACKLE PAIR
$m: 2\,kg$
$L \approx 0$ } CONNECTOR
wet_weight = 8 N

OBLONG LINK
$m: 3\,kg$ (10 kg/m)
$L = .3\,m$
wet-weight = 12 N [40 N/m]

POLYESTER ROPE (5/8")

$EA = 560{,}000\,N$ [SPEC SHEET INDICATES 11% ELONGATION AT 1390 lbs

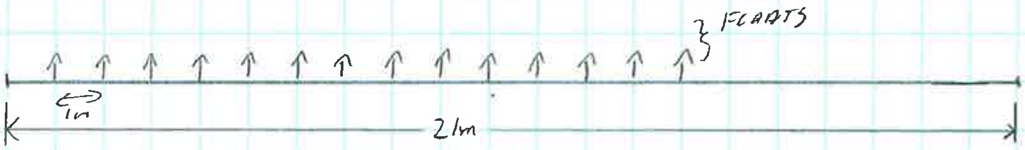
$EI = 22\,N \cdot m^2$ [EQUIV ROD]

$d = .0159\,m$ [5/8"]

$m = 0.14 \frac{lbs}{ft} \cdot \frac{1ft}{12in} \cdot \frac{1in}{.0254m} \cdot \frac{1kg}{2.21lbs} = 0.2088\,kg/m$

wet weight $= 0.778\,N/m$ } BASED ON S.G = 1.38

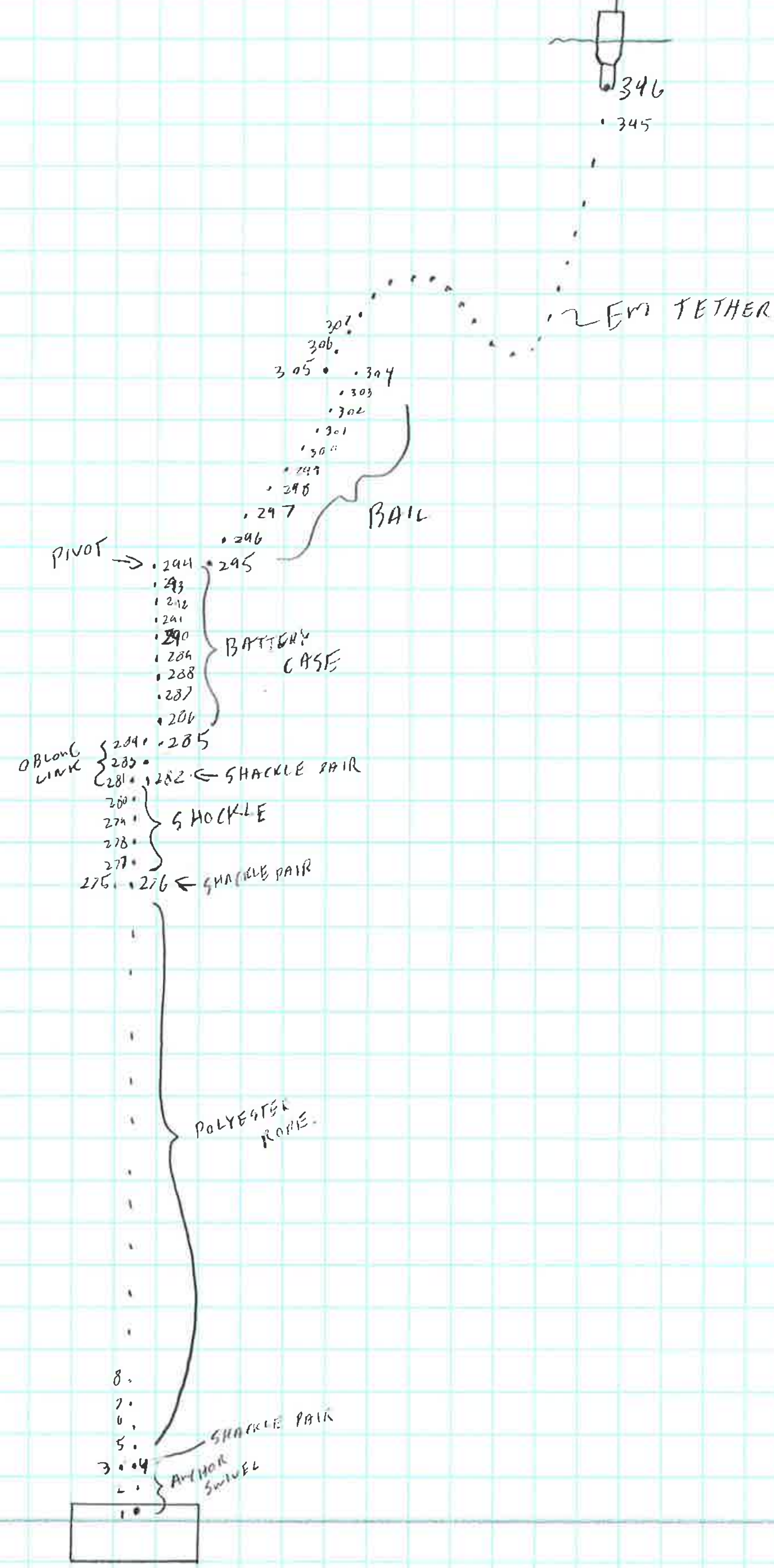
EM CABLE WITH FLOATS



→ CABLE WET WEIGHT = $2.97\,N/m$ = $62.4\,N$ TOTAL

→ FLOAT WET WEIGHT = $-2.17\,N$/FLOAT = $30.4\,N$ TOTAL

→ MEAN WEIGHT OF FLOATED SECTION: $\approx 0.8\,N/m$



346
345
2EM TETHER
BAIL
PIVOT
BATTERY CASE
OBLONG LINK
SHACKLE PAIR
SHACKLE
SHACKLE PAIR
POLYESTER ROPE
SHACKLE PAIR
ANCHOR SWIVEL

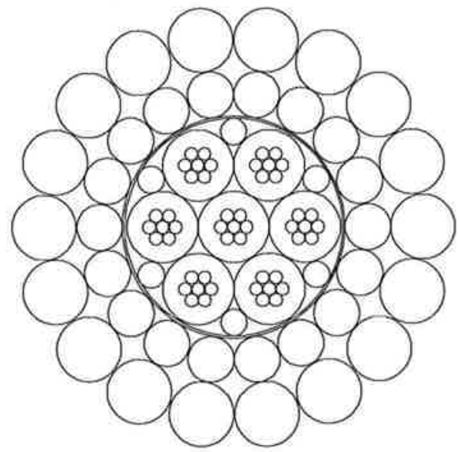
751 Old Brandy Road
Culpeper, Virginia 22701

Tele: 540 825-2111
Fax: 540 825-2238

DATALINE®

Description

	mm	Inch
CONDUCTORS (7) #20 AWG, 7/0.0121" (0.31 mm) Bare Copper	0.91	0.036
INSULATION 0.016" (0.41 mm) Wall EPC	1.73	0.068
CORE 6 insulated cdrs around 1 with fillers as necessary. Voids filled with free-stripping semiconductive material. Semiconductive tape over core.	5.05	0.199
ARMOR: Special GIPS Wire		
Inner: 18/0.0375" (0.95 mm)	6.96	0.274
Outer: 18/0.052" (1.32 mm)	9.60	0.378



CABLE CHARACTERISTICS
(Nominal Values @ 20℃)

		Metric	English
PHYSICAL			
Overall Dimensions		9.60 mm	0.378 in
Weight in Air		370 kg/km	249 lb/kft
Weight in Freshwater		310 kg/km	208 lb/kft
Temperature Rating,	normal	135℃	275℉
	intermittent	149℃	300℉
MECHANICAL			
Breaking Strength		57.8 kN	13,000 lbf
Bend Diameter		53 cm	21 in
Elongation (approximate)		0.31 m/km/kN	1.4 ft/kft/klbf
ELECTRICAL			
Voltage Rating		600 Vdc	600 Vdc
Insulation Resistance @ 500 Vdc		15,000 MΩ•km	50,000 MΩ•kft
dc Resistance			
cdr		36.8 Ω/km	11.2 Ω/kft
armor		5.8 Ω/km	1.8 Ω/kft
Capacitance (cdr-armor)		197 pF/m	60 pF/ft
Velocity of Propagation @ 1 MHz		67%	67%

Tyco Electronics *The Rochester Corporation*

Rochester Stock Type 7-H-375A (18 x 18 Armor)			
Date	**Page**	**Revision**	**Part No.**
06/11/2010	1	X	A276374

Where People and Technology Make the Difference

Stable Braid

DOUBLE BRAID CLASS I

PRODUCT CODE: 506/806

A time proven, tough 100% polyester double braid with excellent controlled working elongation

FEATURES AND BENEFITS

- High strength
- Low stretch
- Durable
- Flex-fatigue resistant
- Pro-Gard Marine Finish

Stable Braid has a braided core and cover, both contributing to its strength and firm hand, while remaining fully spliceable. It works very well on winch drums and has the non-rotational flexibility to be flaked on deck. Stable Braid is a proven, tough rope with excellent controlled working elongation.

APPLICATIONS

VESSEL MOORING
- General working line
- Secondary mooring line

TUG
- Shock line

COMMERCIAL FISHING
- Gilnet line
- Purse seine line
- Trawl or bridle line

SIZE DIAMETER INCHES	SIZE CIRC. INCHES	WEIGHT PER 100 FT. POUNDS	SAMSON MBS* POUNDS	SIZE DIAMETER MILLIMETERS	WEIGHT PER 100 m KILOGRAMS	SAMSON MBS* METRIC TONS	ISO 2307 STRENGTH** METRIC TONS
1/4"	3/4"	2.1	2,000	6	3.1	0.89	0.99
5/16"	1"	3.2	3,100	8	4.8	1.4	1.5
3/8"	1-1/8"	4.5	4,800	9	6.7	2.2	2.4
7/16"	1-1/4"	6.1	6,500	11	9.1	3.0	3.3
1/2"	1-1/2"	8.2	8,800	12	12.2	4.0	4.5
9/16"	1-3/4"	11.0	11,300	14	16.4	5.1	5.7
5/8"	2"	14.0	13,900	16	20.8	6.3	7.0
3/4"	2-1/4"	18.0	17,300	18	26.8	7.9	8.7
7/8"	2-3/4"	27.1	25,400	22	40.3	11.5	12.8
1"	3"	34.0	33,300	24	50.6	15.1	16.8
1-1/8"	3-1/2"	45.3	41,000	28	67.4	18.6	20.6
1-1/4"	3-3/4"	53.9	48,700	30	80.2	22.1	24.5
1-5/16"	4"	60.8	55,000	32	90.5	24.9	27.7
1-1/2"	4-1/2"	73.3	63,800	36	109	29.0	32.2
1-5/8"	5"	85.9	74,100	40	128	33.6	37.4
1-3/4"	5-1/2"	104	88,400	44	155	40.1	44.6
2"	6"	124	105,000	48	185	47.8	53.1
2-1/8"	6-1/2"	147	123,000	52	219	55.9	62.1
2-1/4"	7"	173	141,000	56	257	64.0	71.1
2-1/2"	7-1/2"	196	162,000	60	292	73.3	81.4
2-5/8"	8"	225	180,000	64	335	81.7	90.8
2-3/4"	8-1/2"	246	199,000	68	366	90.2	100
3"	9"	300	236,000	72	446	107	119
3-1/4"	10"	375	292,000	80	558	132	147
3-5/8"	11"	450	346,000	88	670	157	174
4"	12"	525	400,000	96	781	181	201
4-1/4"	13"	589	453,000	104	876	206	228
4-5/8"	14"	689	524,000	112	1025	238	264
5"	15"	788	593,000	120	1173	269	299

*Spliced strength **This standard replaces BS EN 919 and ISO 2307:1995 and is for unspliced strengths.

SPECIFICATIONS[1]

FIBER (CORE/COVER): **Polyester / Polyester**

SPECIFIC GRAVITY: **1.38**

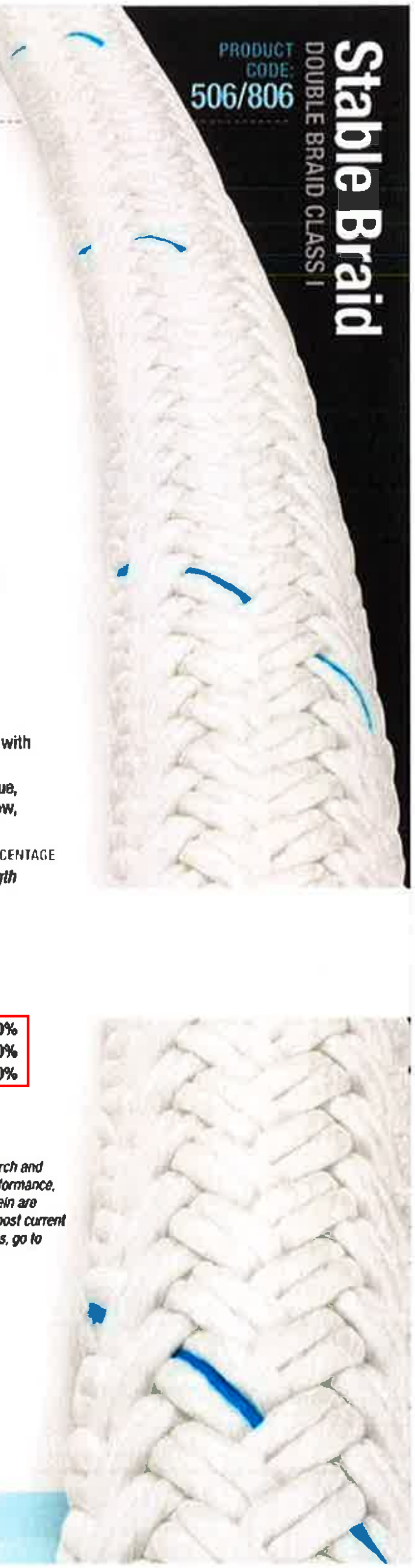
STANDARD COLORS:
UNCOATED (506): White with blue ID, black
COATED (806): Black, blue, green, orange, red, yellow, and clear with blue ID

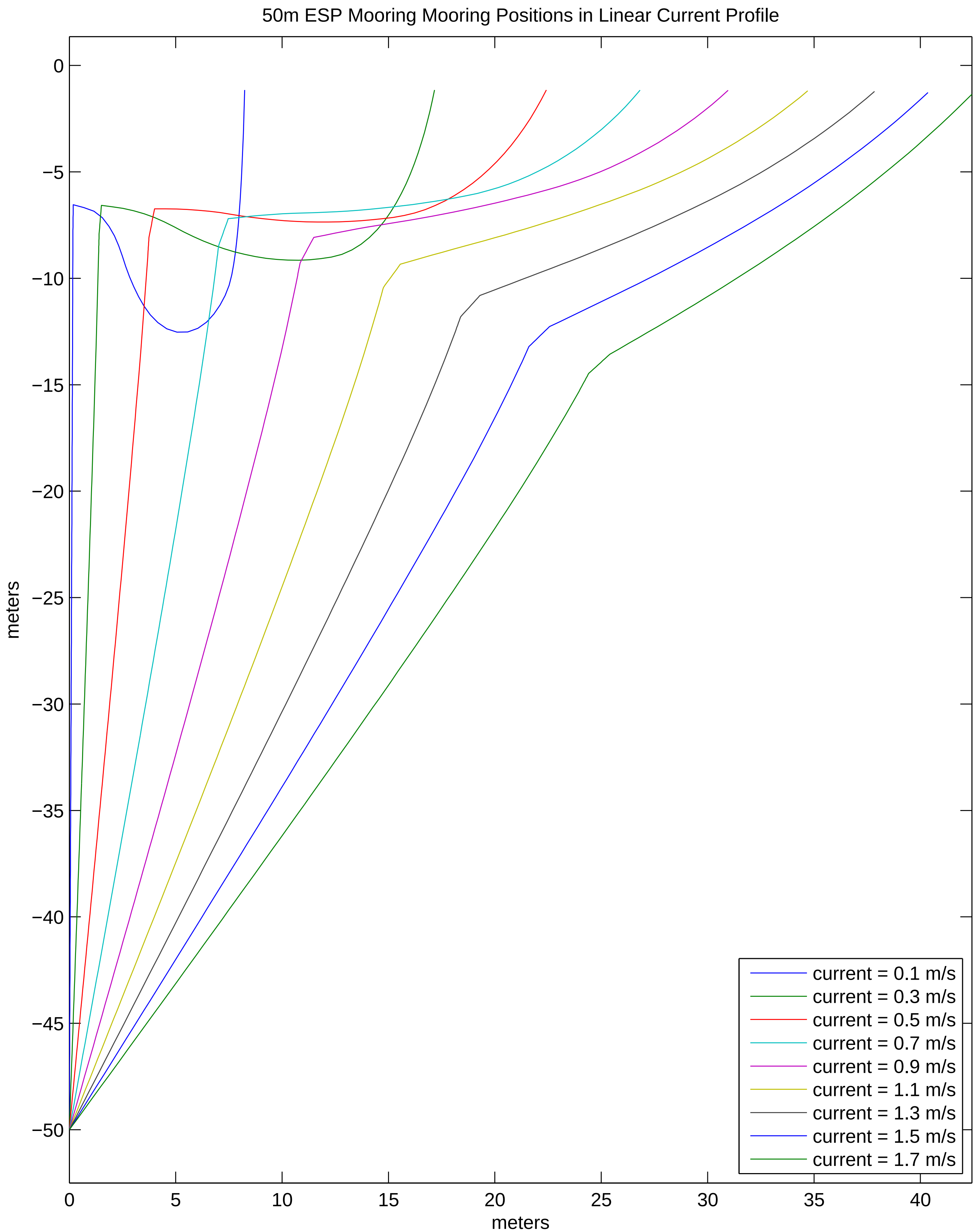
ELASTIC ELONGATION PERCENTAGE
At % of break strength

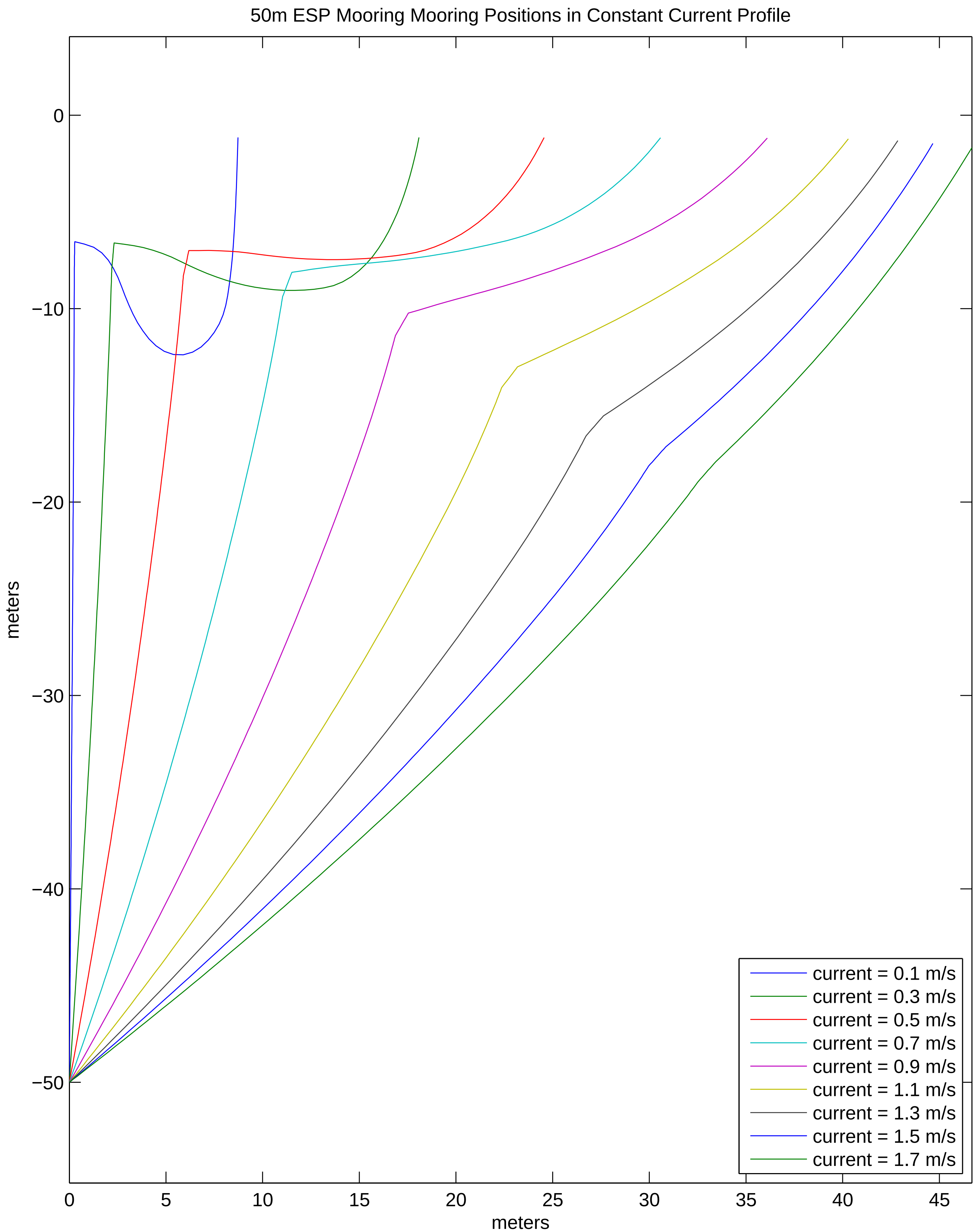
10% 1.10%
20% 1.70%
30% 2.70%

SPLICE/CLASS:
Double Braid Class I

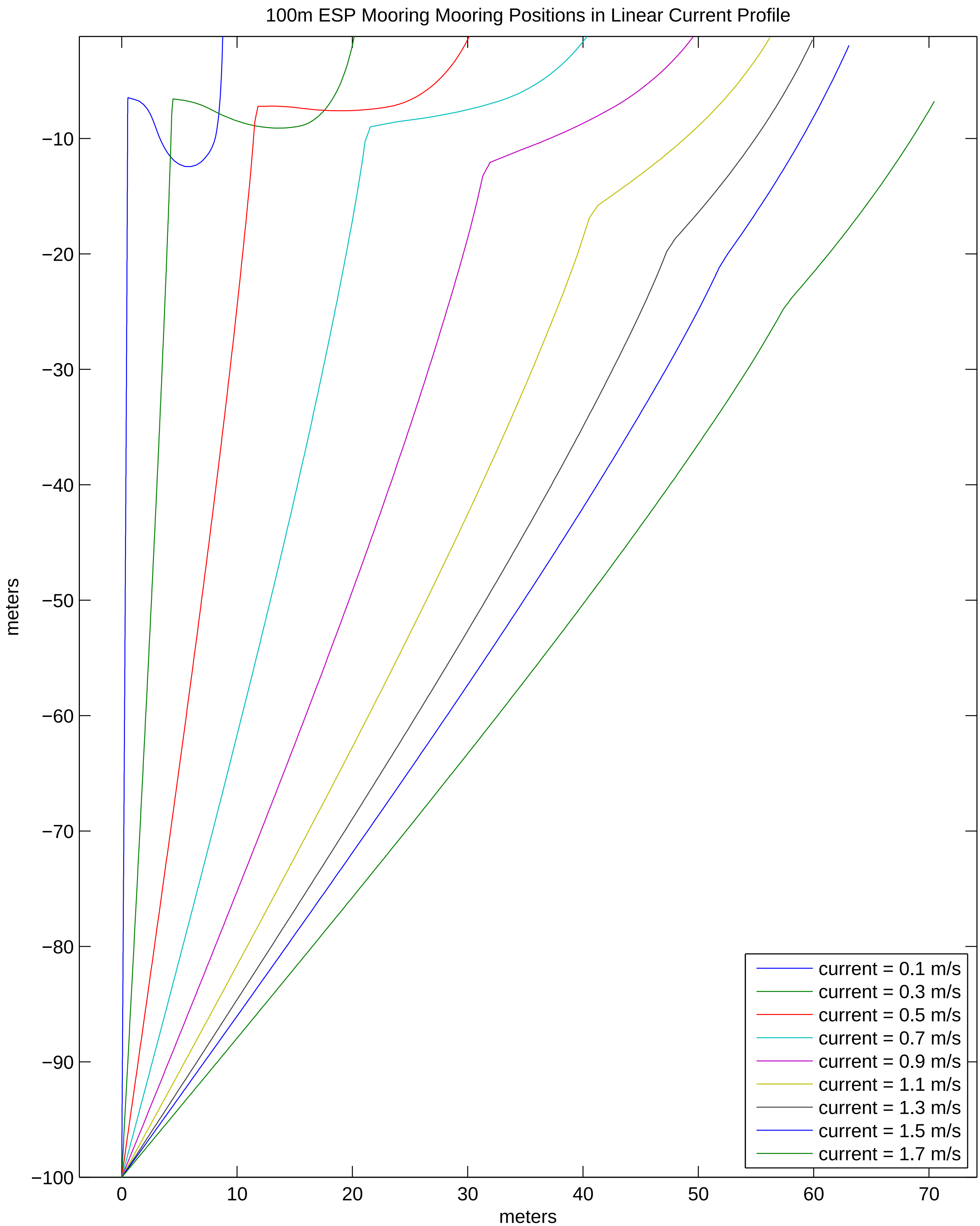
[1]Due to our continued research and development of product performance, the specifications listed herein are subject to change. For the most current sizes, weights, and strengths, go to SamsonRope.com.

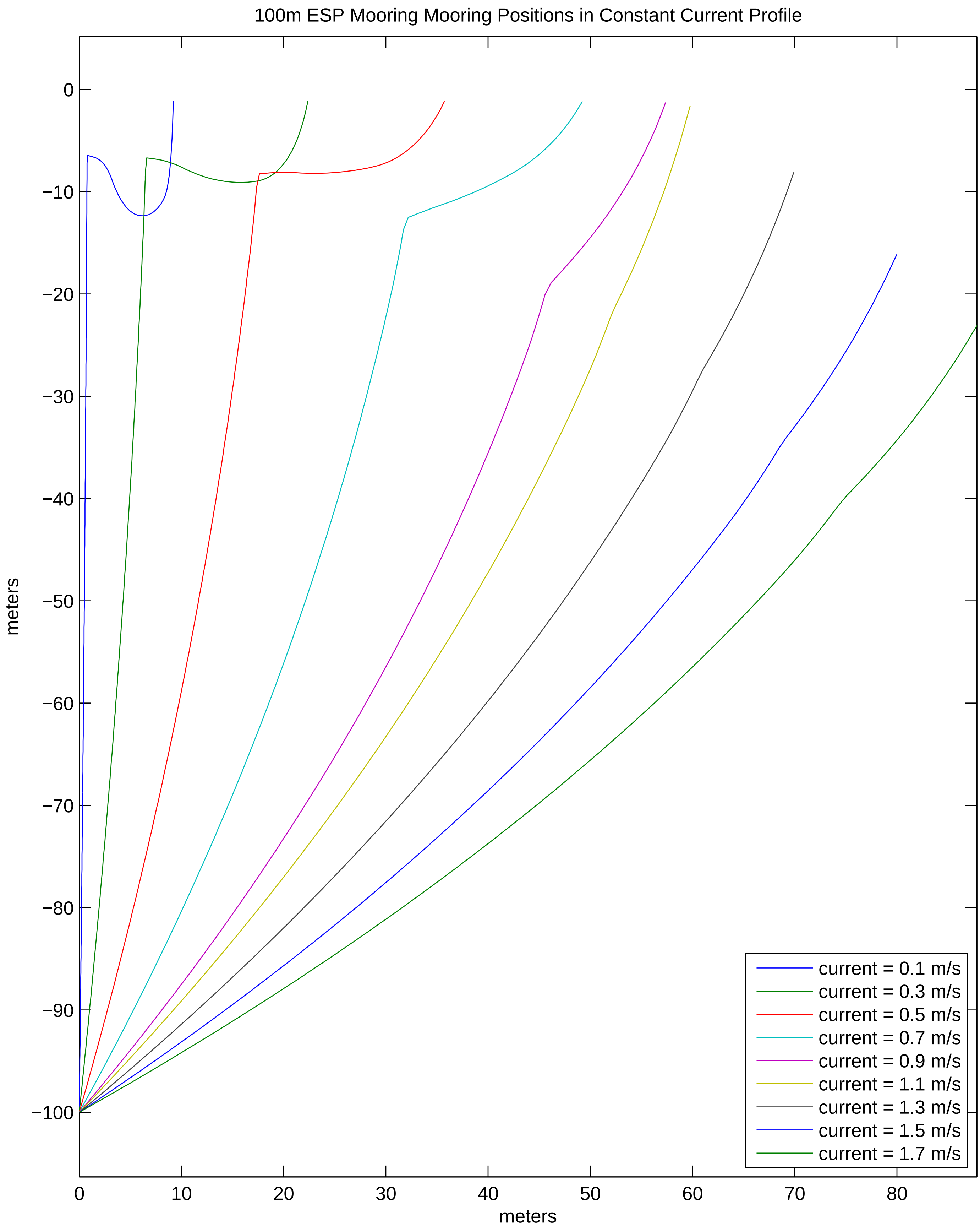


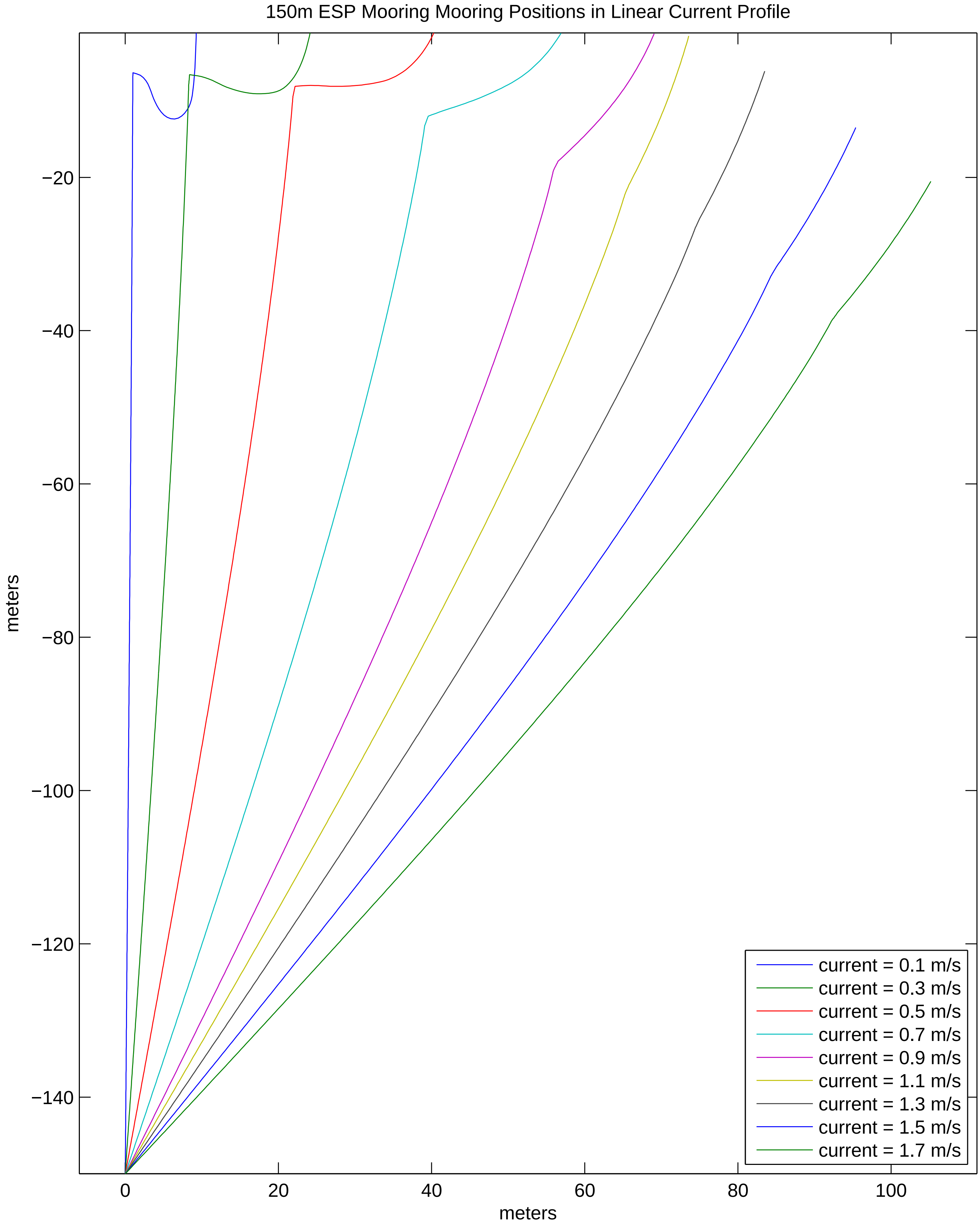

50m ESP Mooring Mooring Positions in Linear Current Profile
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
meters
0
5
10
15
20
25
30
35
40
meters
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

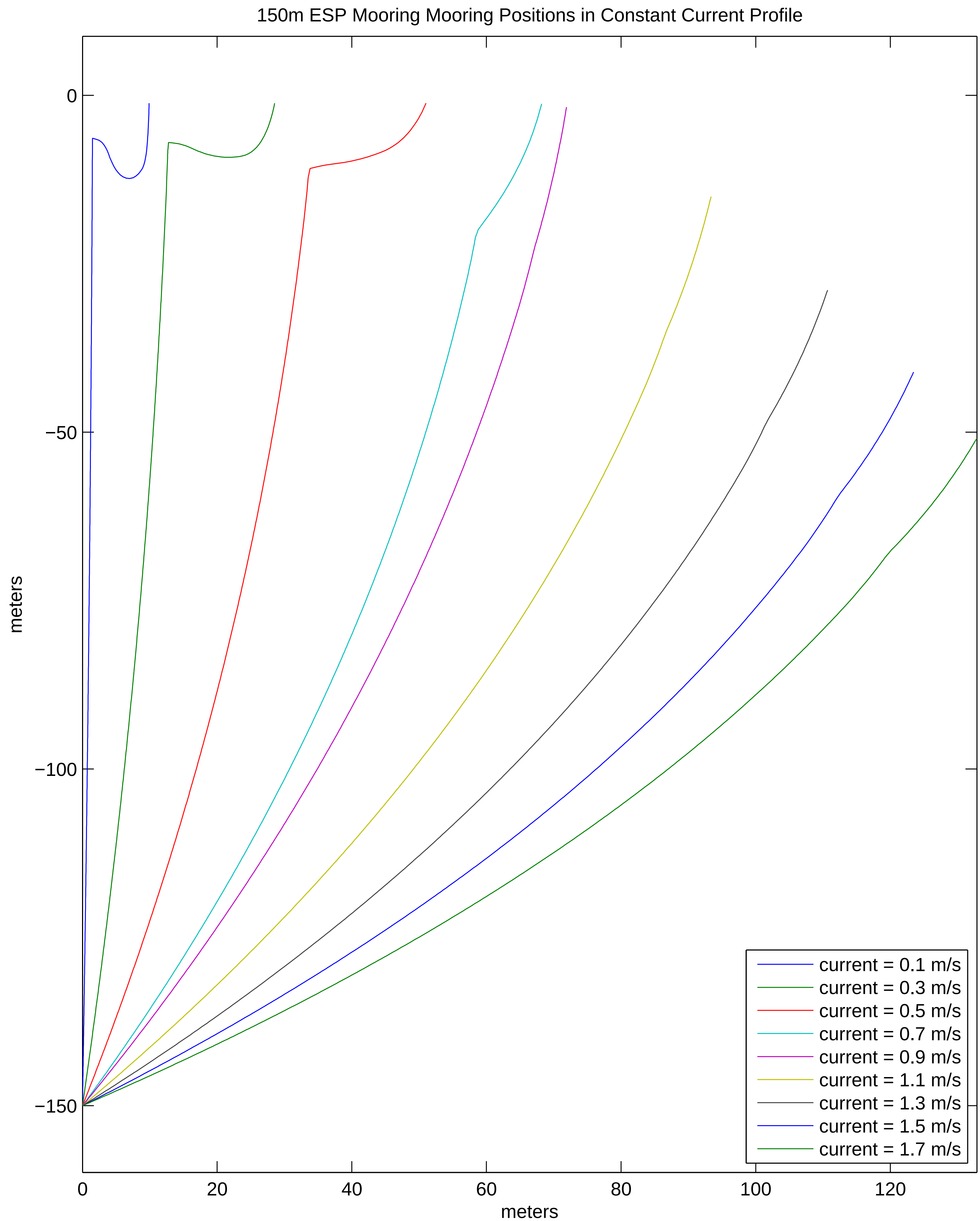


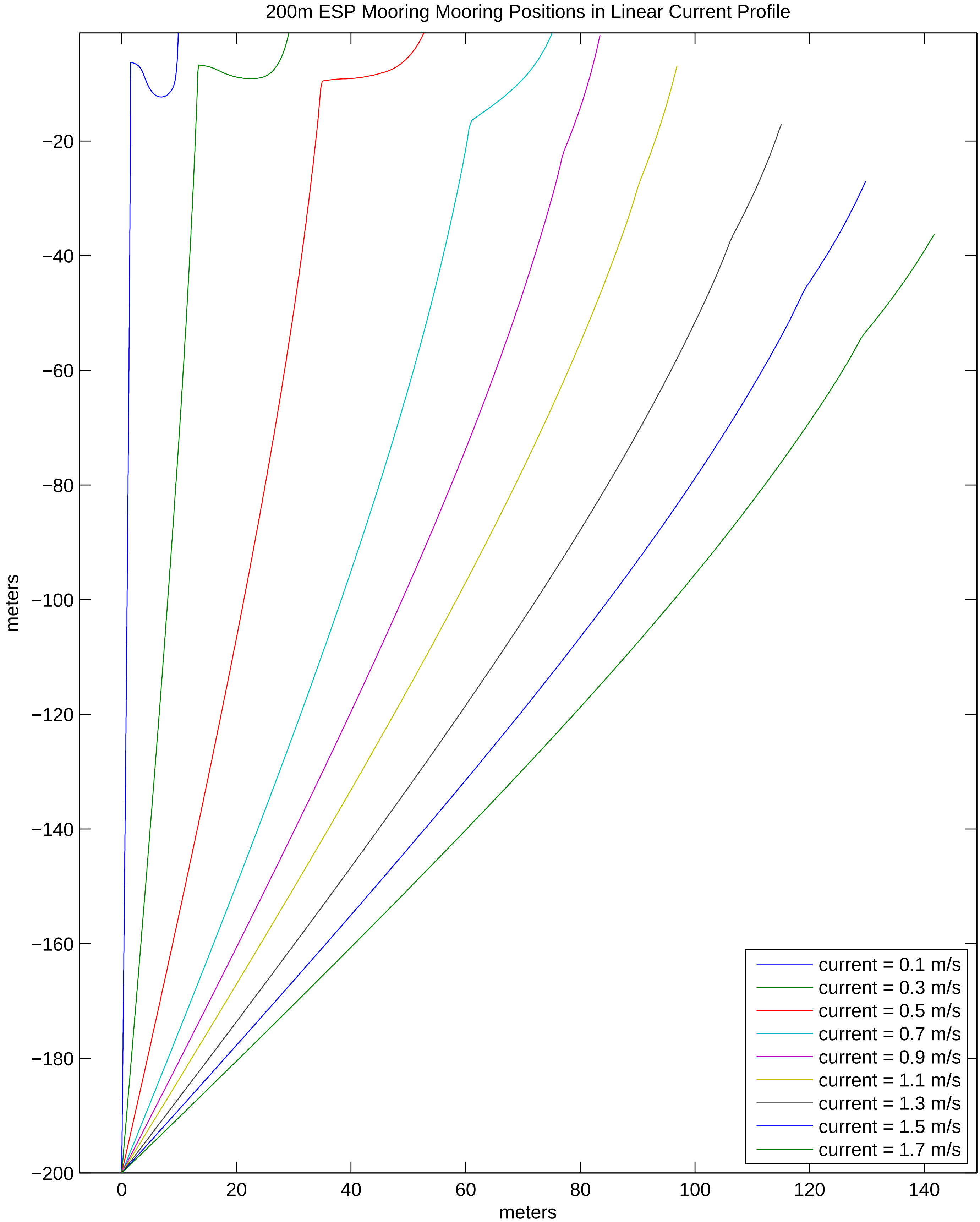
50m ESP Mooring Mooring Positions in Constant Current Profile
meters
meters
0
−10
−20
−30
−40
−50
0
5
10
15
20
25
30
35
40
45
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

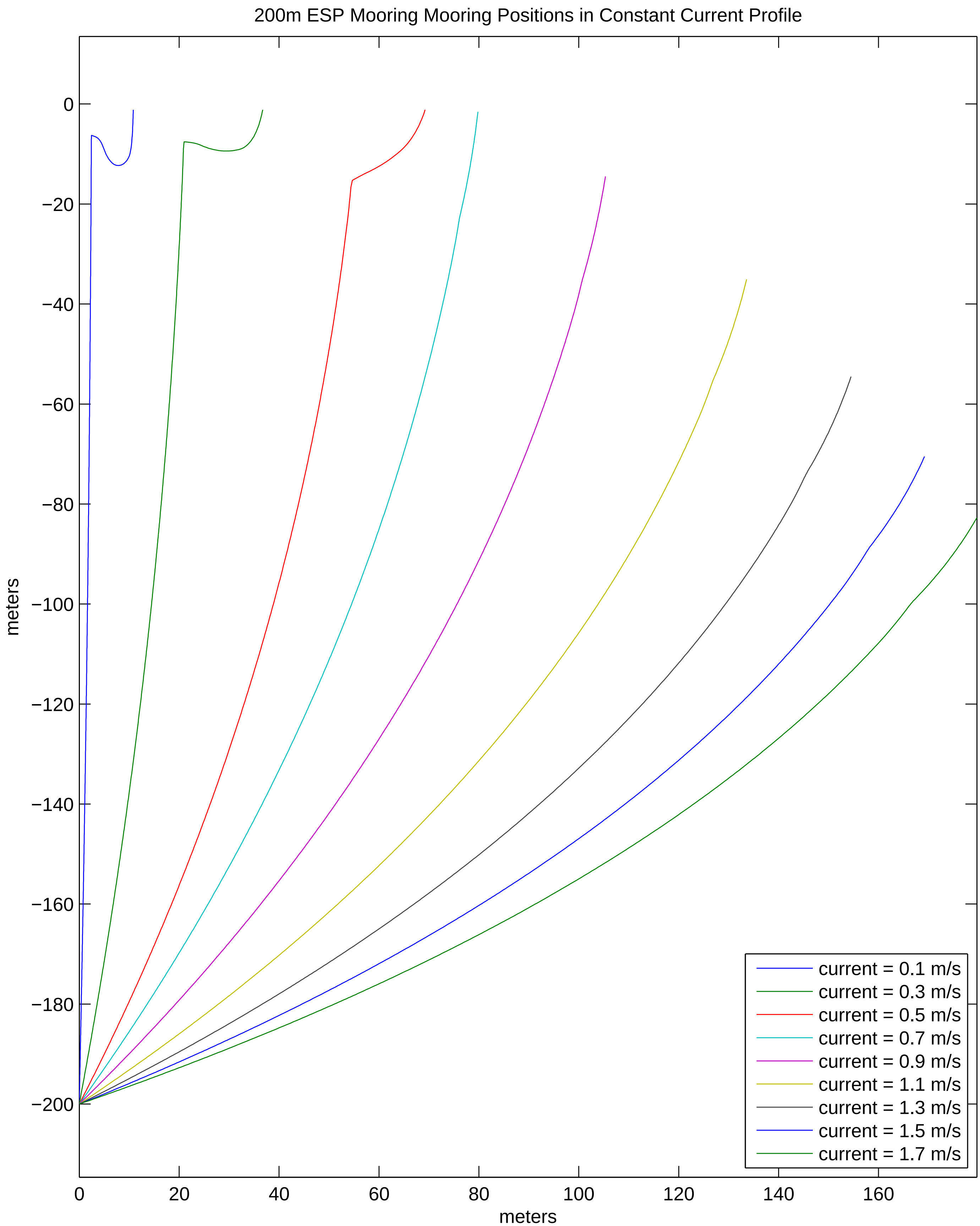

100m ESP Mooring Mooring Positions in Linear Current Profile
meters
meters
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
0
10
20
30
40
50
60
70
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

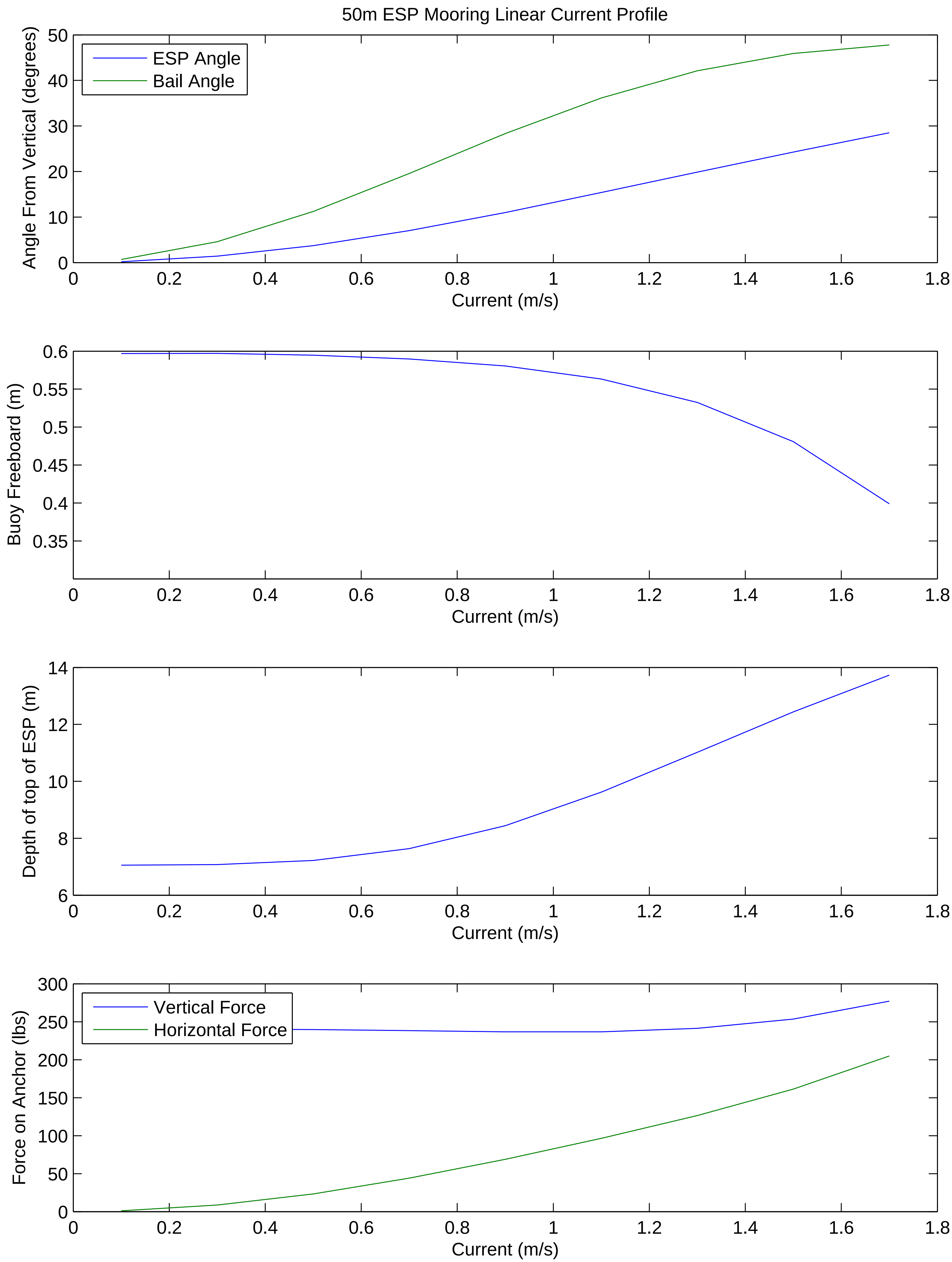

100m ESP Mooring Mooring Positions in Constant Current Profile
meters
meters
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100
0
10
20
30
40
50
60
70
80
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s


150m ESP Mooring Mooring Positions in Linear Current Profile
meters
meters
−20
−40
−60
−80
−100
−120
−140
0
20
40
60
80
100
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

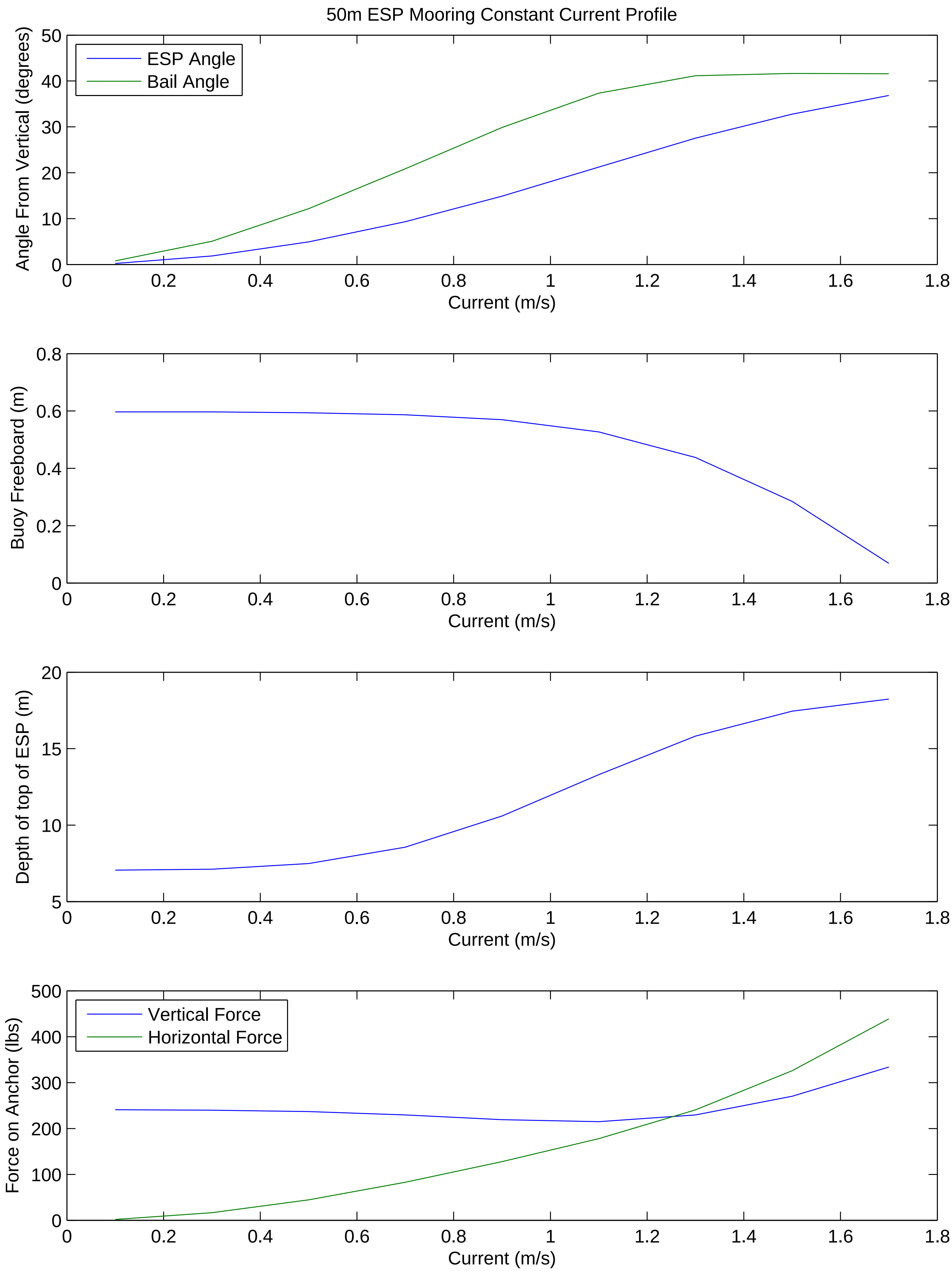

150m ESP Mooring Mooring Positions in Constant Current Profile
meters
meters
0
−50
−100
−150
0
20
40
60
80
100
120
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

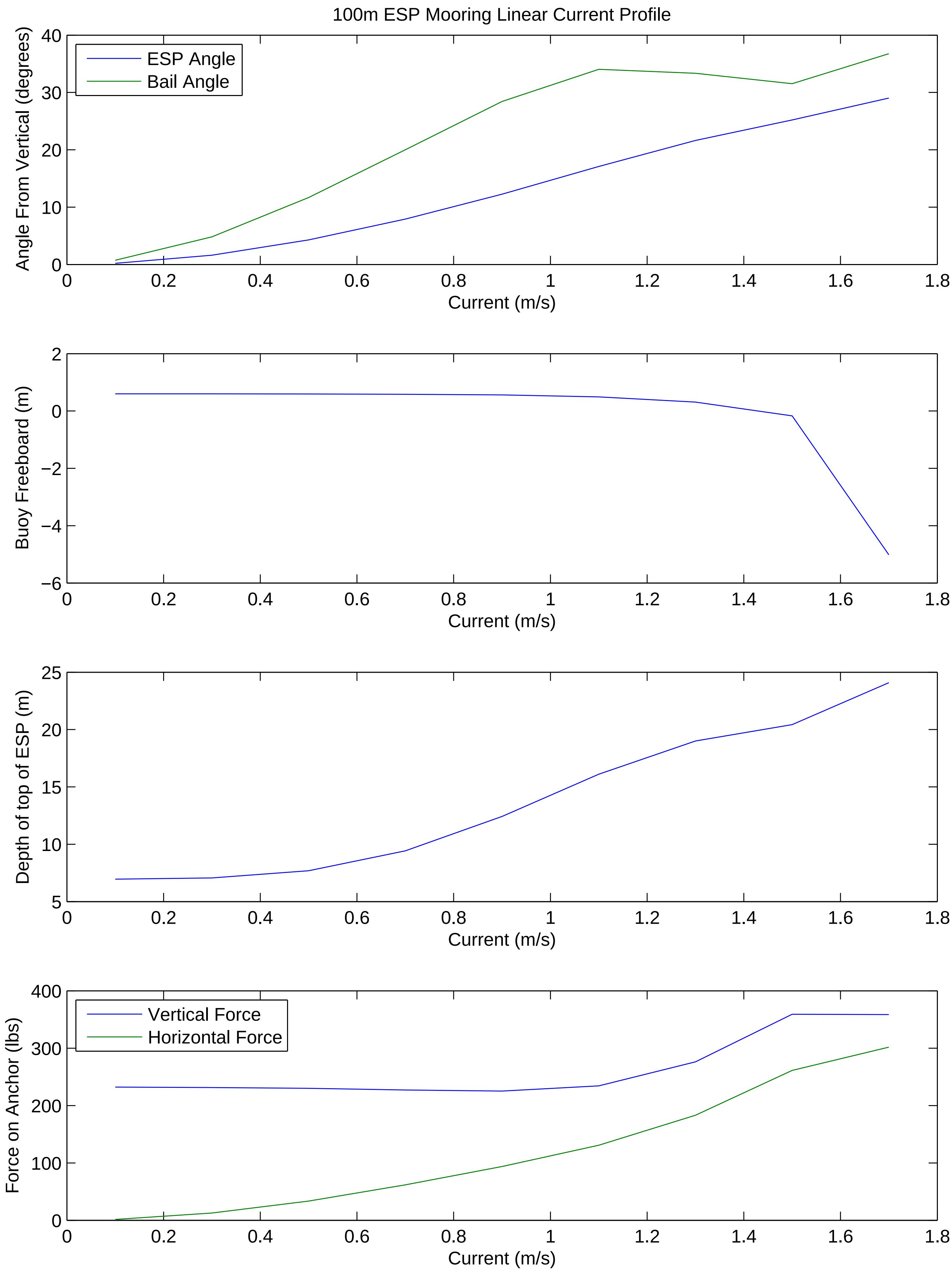

200m ESP Mooring Mooring Positions in Linear Current Profile
meters
meters
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
0
20
40
60
80
100
120
140
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s


200m ESP Mooring Mooring Positions in Constant Current Profile
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
meters
0
20
40
60
80
100
120
140
160
meters
current = 0.1 m/s
current = 0.3 m/s
current = 0.5 m/s
current = 0.7 m/s
current = 0.9 m/s
current = 1.1 m/s
current = 1.3 m/s
current = 1.5 m/s
current = 1.7 m/s

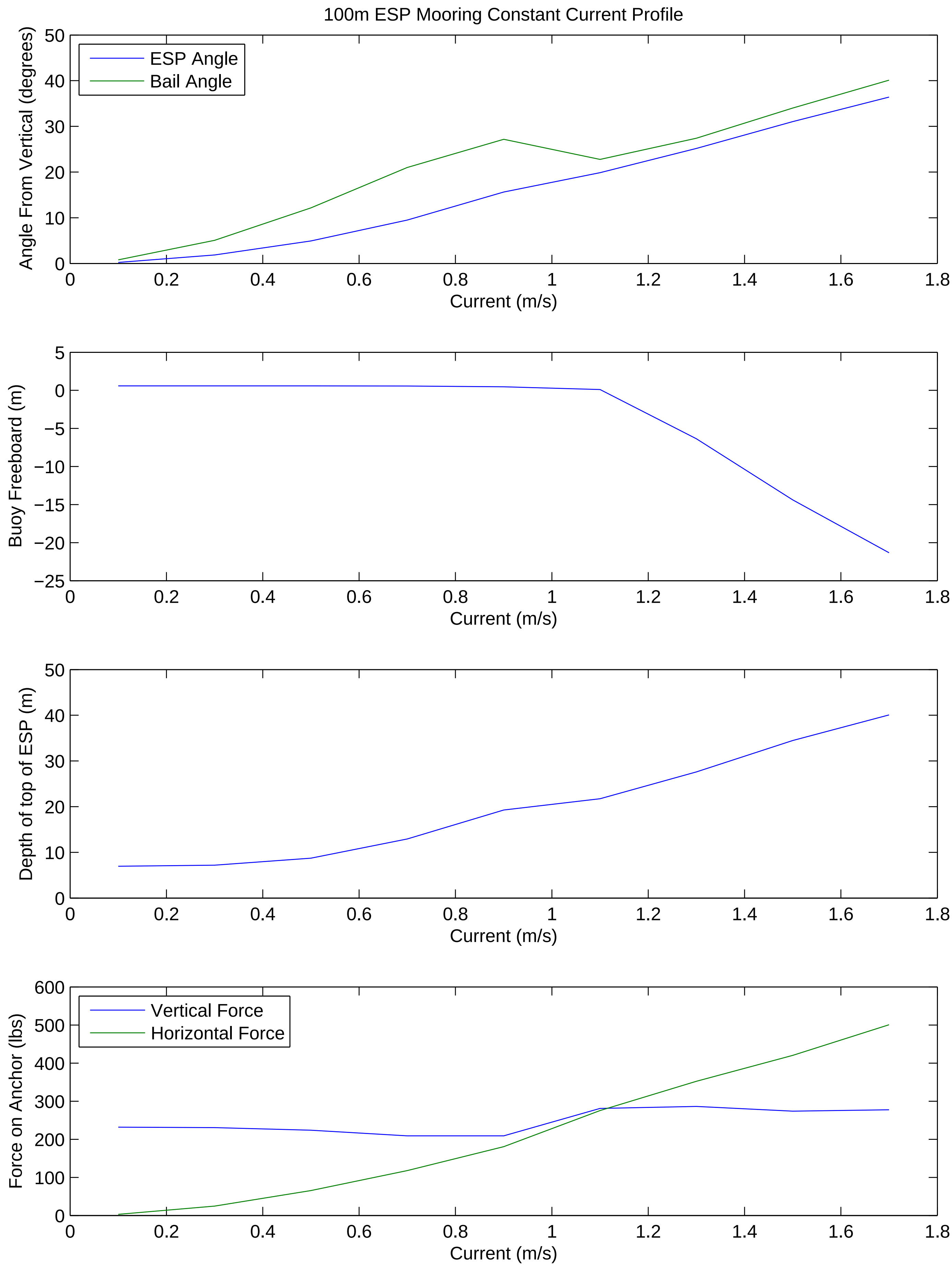


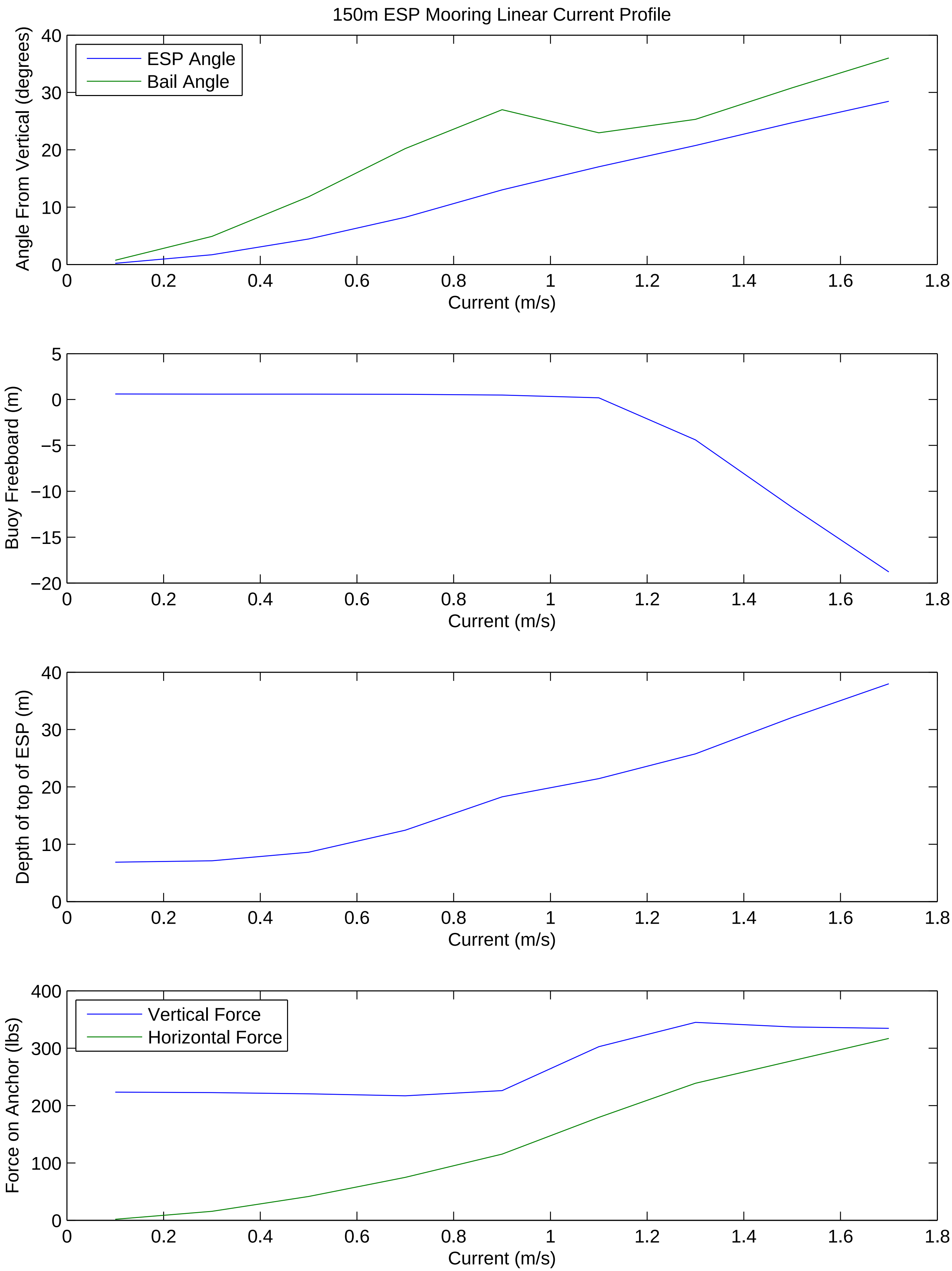
50m ESP Mooring Linear Current Profile
ESP Angle
Bail Angle
Angle From Vertical (degrees)
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Vertical Force
Horizontal Force
Force on Anchor (lbs)
Current (m/s)

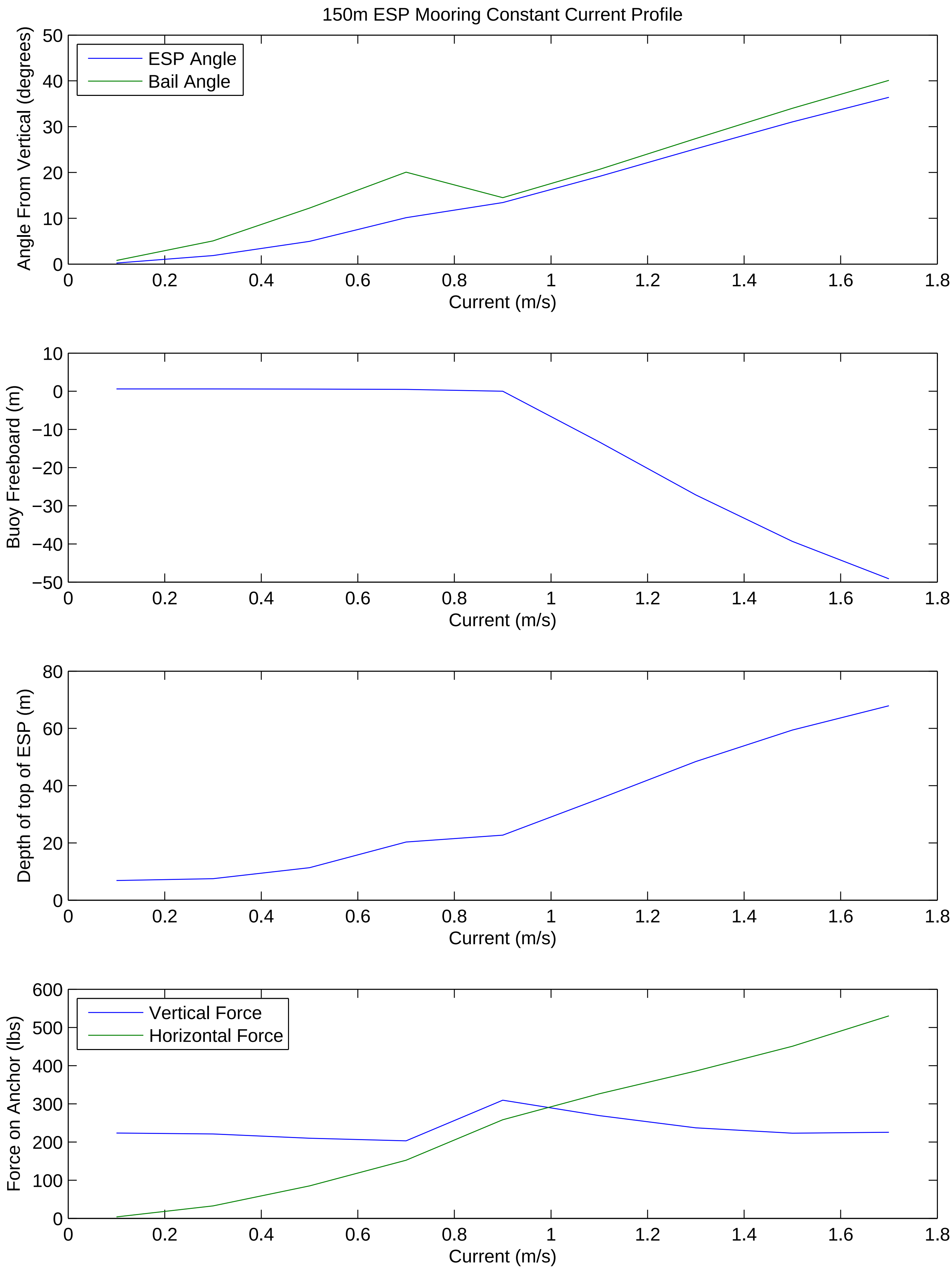

50m ESP Mooring Constant Current Profile
ESP Angle
Bail Angle
Angle From Vertical (degrees)
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Vertical Force
Horizontal Force
Force on Anchor (lbs)
Current (m/s)

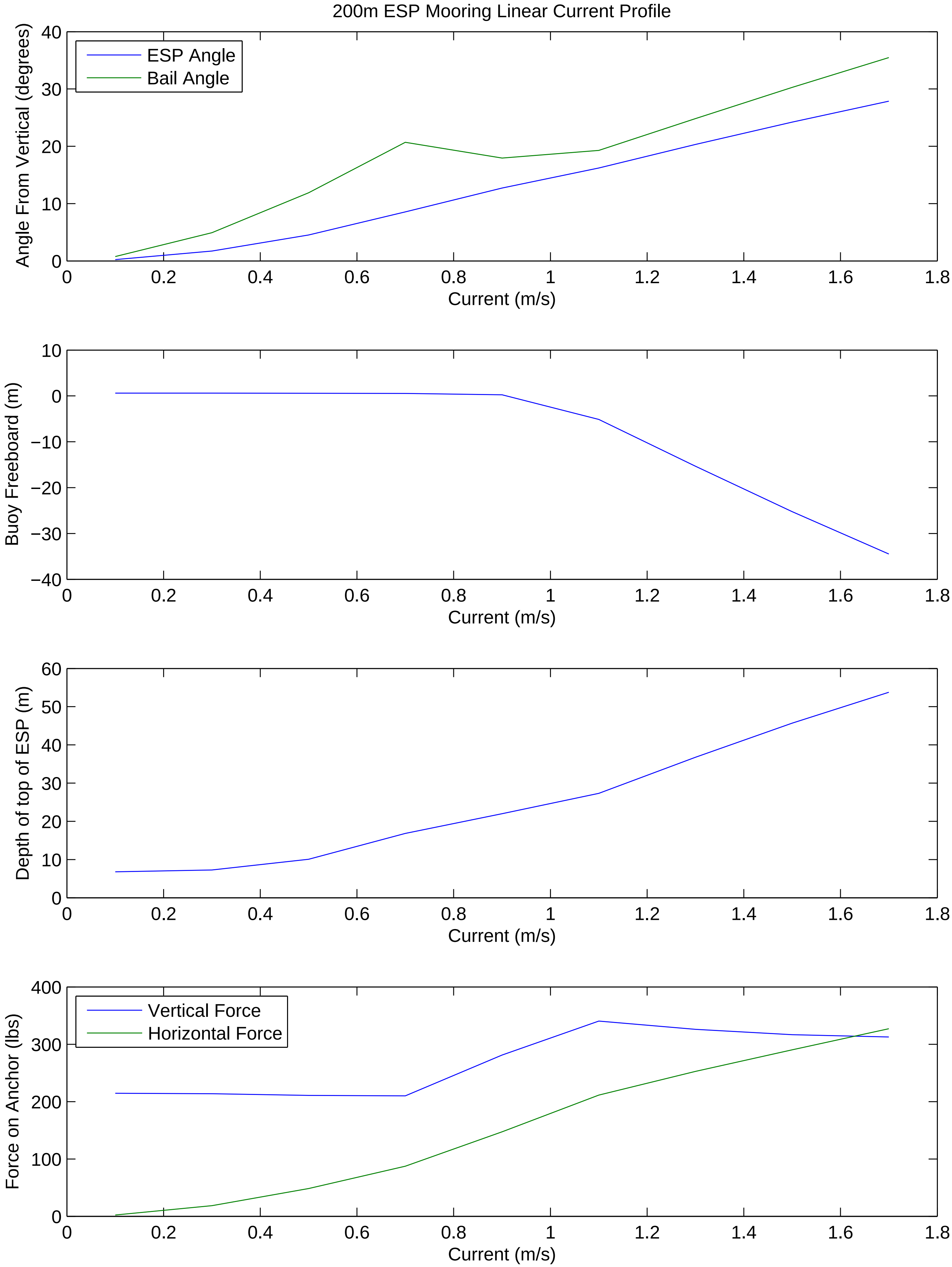


100m ESP Mooring Linear Current Profile
Angle From Vertical (degrees)
ESP Angle
Bail Angle
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Force on Anchor (lbs)
Vertical Force
Horizontal Force
Current (m/s)

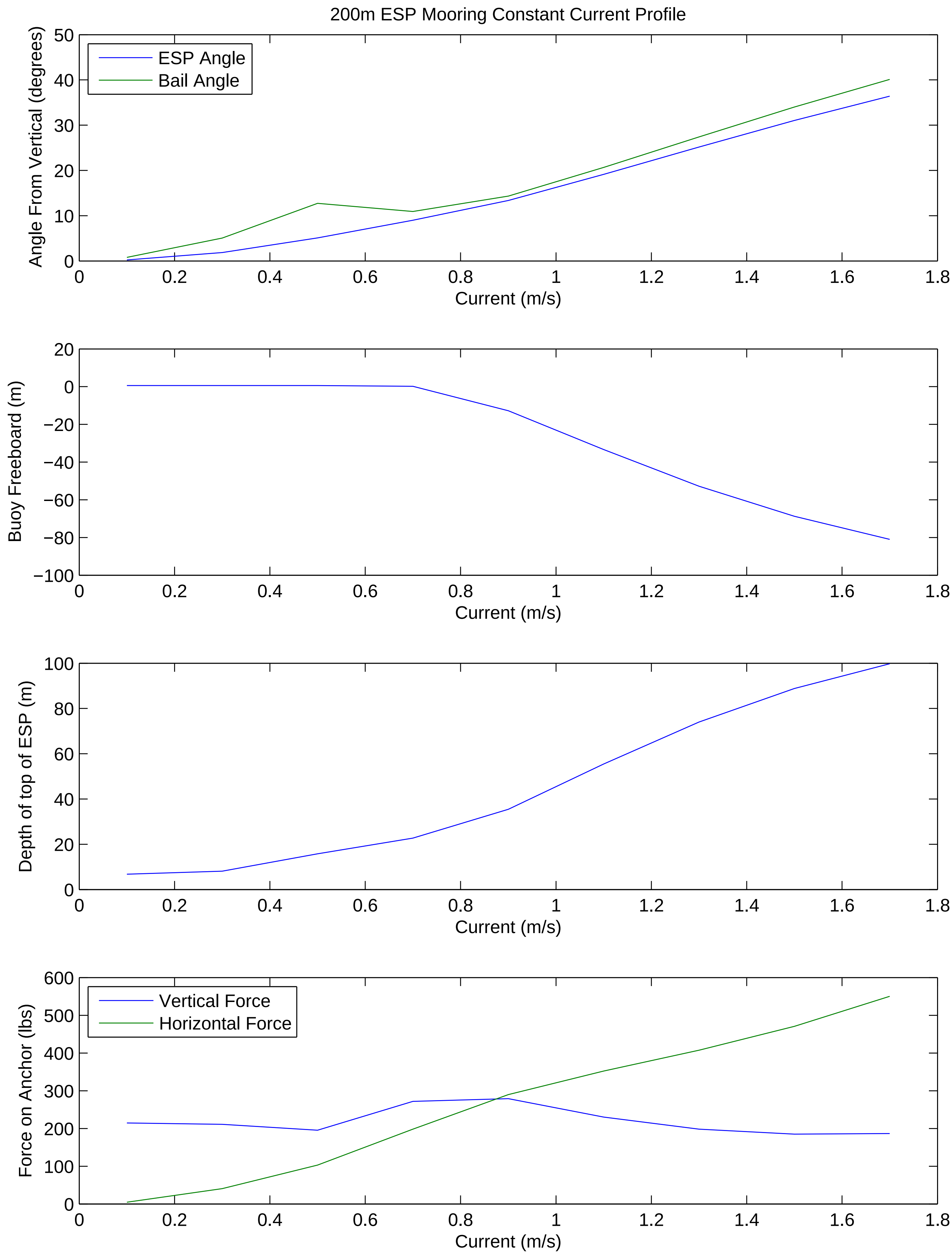

100m ESP Mooring Constant Current Profile
ESP Angle
Bail Angle
Angle From Vertical (degrees)
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Vertical Force
Horizontal Force
Force on Anchor (lbs)
Current (m/s)

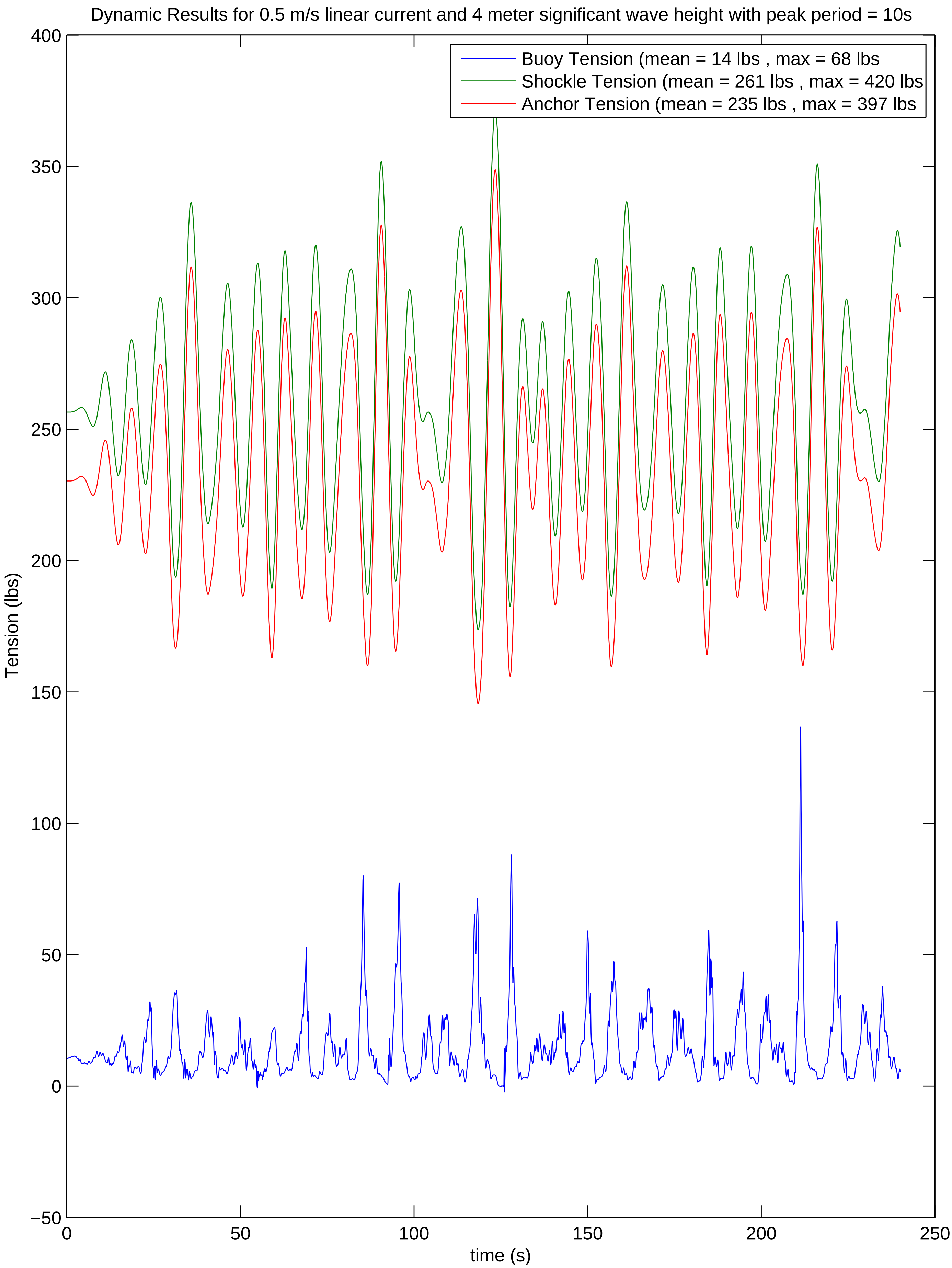

150m ESP Mooring Linear Current Profile
Angle From Vertical (degrees)
ESP Angle
Bail Angle
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Force on Anchor (lbs)
Vertical Force
Horizontal Force
Current (m/s)


150m ESP Mooring Constant Current Profile
ESP Angle
Bail Angle
Angle From Vertical (degrees)
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Vertical Force
Horizontal Force
Force on Anchor (lbs)
Current (m/s)



200m ESP Mooring Linear Current Profile
ESP Angle
Bail Angle
Angle From Vertical (degrees)
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Vertical Force
Horizontal Force
Force on Anchor (lbs)
Current (m/s)


200m ESP Mooring Constant Current Profile
Angle From Vertical (degrees)
ESP Angle
Bail Angle
Current (m/s)
Buoy Freeboard (m)
Current (m/s)
Depth of top of ESP (m)
Current (m/s)
Force on Anchor (lbs)
Vertical Force
Horizontal Force
Current (m/s)



Dynamic Results for 0.5 m/s linear current and 4 meter significant wave height with peak period = 10s
Buoy Tension (mean = 14 lbs , max = 68 lbs
Shockle Tension (mean = 261 lbs , max = 420 lbs
Anchor Tension (mean = 235 lbs , max = 397 lbs
Tension (lbs)
400
350
300
250
200
150
100
50
0
−50
0
50
100
150
200
250
time (s)

```
#include "ESP.spec"

Problem Description
    title = TITLE
    type = surface

Analysis Parameters
    duration       = TF
    time-step      = DT
    static-relaxation     = 0.1
    static-outer-relaxation   = 0.97
    static-tolerance = 0.000001
    static-outer-tolerance = 0.0001
    dynamic-relaxation    = 1.0
/*    dynamic-lambda = DYNAMICLAMBDA   */
    max-iterations = 3000
    dynamic-tolerance      = 1e-8
    ramp-time     = RAMPTIME
    static-initial-guess =  catenary



Environment
    forcing-method = wave-follower
    input-type     = random

    x-wave         = (XWAVEAMP, XWAVEPERIOD, XWAVEDIR)

    x-current      = XCURRENT

    x-wind         = XWIND
    rho            = 1025
    gravity        = 9.81
    depth          = DEPTH    /* DEPTH is 0.8m shallower than actual depth to account for anchor */

Buoys
    esp_buoy_1  type = axisymmetric
                m = 34  /* Estimated at 75 lbs */
                diameters = (0.0, 0.0762) (.838, 0.0762) (0.8382, .279)
                            (1.067, 0.406) (1.75, .406)
                Cdn = .75   Cdt = 0.25
                Sw = .2    Cdw = 1.0

Anchors
   clump

Connectors
        sphere64      d   = 1.6256     Cdn = 0.5   Cdt = 0.5
                        wet = -11120     m   = 1172.
/*                    length = 1.6256 */


        ESP      d = .762       Cdn = 1.0       Cdt = 1.0
                wet = -890      m = 386
/*              length = 2.0  */

        syn_floats      d = .0762       Cdn = 0.5       Cdt = 0.5
                 wet = -2.17            m = .230

        bail_float      d = .1  Cdn = 0.01      Cdt = 0.01
                 wet = -2000    m = .1


/*              length = .1016 */

        Pivot   d = .1          Cdn = 0.5       Cdt = 0.5
                wet = 0.1               m = 1
```

```
/*              length = .1 */

        ESP_Can   d = .762      Cdn = 0.5       Cdt = 0.5
                wet = -1540     m = 235
/*              length = 0.84 */

        shackle_pair  d = .0762 Cdn = 0.5       Cdt = 0.1
                wet = 8         m = 2
/*              length = 0.1 */



Materials

rochester_cable EA = 3.226e+06  EI = .01        GJ = 1.0
                 m = 0.37                    wet = 2.97
                 d = 0.0096     Cdn = 1.0       Cdt = 0.01
                                Can = 1.0       Cat = 0.0

nilspin_5d16in  EA = 3.434e+06  EI = 24.0        GJ = 1.0
                 m = 0.3124                     wet = 2.0867
                 d = 0.0111     Cdn = 1.5       Cdt = 0.005
                                Can = 1.0       Cat = 0.0

shockle_linear   EA = 1335      EI = .226         GJ = 1e-4
                 m = .909                         wet = 0.1
                 d = 0.052        Cdt = 0.1       Cdn = 1.0
                                  Cat = 0.1        Can = 1.0

shockle_lockout  EA = 1335      EI = .226         GJ = 1e-4
                 m = .909                         wet = 0.1
                 d = 0.052        Cdt = 0.1       Cdn = 1.0
                                  Cat = 0.1        Can = 1.0
                 T = 1335*e+.2*exp(4*e*e)
                 Te = 1335+.16*e*exp(4*e*e)
                 Tee = .16*(.16*e*e+1)*exp(4*e*e)

polyester_7d8in  EA = 1e6      EI = 31         GJ = 1e-4
                 m = .403                           wet = 1.0
                 d = 0.0222        Cdt = 0.01       Cdn = 1.0
                                   Cat = 0.01        Can = 1.0

polyester_5d8in  EA = 560000      EI = 22         GJ = 1e-4
                 m = .2088                           wet = 0.778
                 d = 0.0159        Cdt = 0.01       Cdn = 1.0
                                   Cat = 0.01        Can = 1.0

polyester_1d2in  EA = 346500      EI = 10         GJ = 1e-4
                 m = .1223                           wet = 0.3115
                 d = 0.0127        Cdt = 0.01       Cdn = 1.0
                                   Cat = 0.01        Can = 1.0


trawler_1d2in   EA = 6.0e+07       EI = 1e-4        GJ = 1e-4
                 m = 3.712                          wet = 31.64
                 d = 0.0475        Cdt = 0.05       Cdn = 0.55
                                   Cat = 0.1        Can = 1.0

BatteryCase     EA = 1e+7       EI = 5e5                GJ = 1.0
                m = 181.8                               wet = 980
                d = .91         Cdt = 0.5      Cdn = 0.55
                                Cat = .5       Can = 1.0

Bail            EA = 1e+7       EI = 1.4e4              GJ = 1.0
                m = 22.9                        wet = -200.
                d = .15         Cdt = 0.1     Cdn = 0.1
                                Cat = .5       Can = 1.0
```

```
anchor_swivel   EA = 1e+7       EI = 1.4e4              GJ = 1.0
                m = 9.4                 wet = 37.7
                d = .0762               Cdt = 0.1      Cdn = 0.5
                                        Cat = .5       Can = 1.0

oblong_link     EA = 1e+7       EI = 1.4e4              GJ = 1.0
                m = 10                  wet = 40.0
                d = .0762               Cdt = 0.1      Cdn = 0.5
                                        Cat = .5       Can = 1.0



Layout
   terminal = {
      anchor = clump
   }

segment = {
       length = .53
       material = anchor_swivel
       nodes = (3, 1.0)
   }

connector = shackle_pair

segment = {
       length = POLY_LENGTH
       material = polyester_5d8in
       nodes = POLY_NODES
   }

connector = shackle_pair

segment = {
       length = SHOCKLE_LENGTH
       material = shockle_lockout
     /* material = shockle_linear */
       nodes = SHOCKLE_NODES
   }

connector = shackle_pair

segment = {
       length = 0.3
       material = oblong_link
       nodes = (3, 1.0)
   }

segment = {
       length = 0.66
       material = BatteryCase
       nodes = (10, 1.0)
       attachments = ESP_Can : (9)
   }

connector = Pivot


segment = {
       length = 1.35
       material = Bail
       nodes = (10, 1.0)
       /*attachments = bail_float : (9)*/
   }

connector = shackle_pair
```

```
segment = {
       length = EM_LENGTH
       material  = rochester_cable
       nodes = EM_NODES
       /*attachments = syn_floats : [2,2,28] */ /* floats every meter for bottom 14m of cable */
       attachments = syn_floats : (2,3,4,5,6,7,8,10,12,14,16,18,20,22)
   }
terminal = {
       buoy = esp_buoy_1
   }
End
```