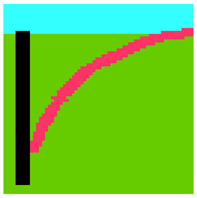
STA CHAIN

BURIED ANCHOR CHAIN PROGRAM

Version 3, February, 2009

USER MANUAL

STA chain is a computer program for the analysis of anchor chain (or wire) cutting through soil. The program was originally developed for work with the US Navy and plate anchors in 1988. The program does not consider how the end of the chain may have been embedded. However, the analysis considers a lateral load applied to a chain and calculates its equilibrium cut profile through the sea bed.



STA CHAIN permits the user to specify up to two different soil layers, each of which may have varying strength properties. The layers must be cohesive soils. Primary results from the program provide the tension vector the chain (or cable) applies at the buried padeye, given the load and angle specified by the user at the top end.

Users of the program are cautioned to exercise experienced and careful engineering judgment when interpreting the results from STA CHAIN. This is especially important with this program, since results can be obtained in seconds on a modern PC. This rapid speed and ease of use does not alter the care and attention needed from the user associated with selecting the appropriate geotechnical and loading conditions

No part of this document should be taken in isolation or out of context and interpreted in a manner inconsistent with the overall framework and intent of this document.

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INTRODUCTION

When anchors are deeply embedded in the sea bed the anchor chain, or cable forerunner, may contribute significantly to the total passive resistance of the anchor system. The computer software described in this document has been developed specifically for the study of buried anchor chains. In recent years it has been widely applied to pile anchors where the chain (or wire) is attached to a padeye on the side of the pile that is deeply embedded below the sea bed.

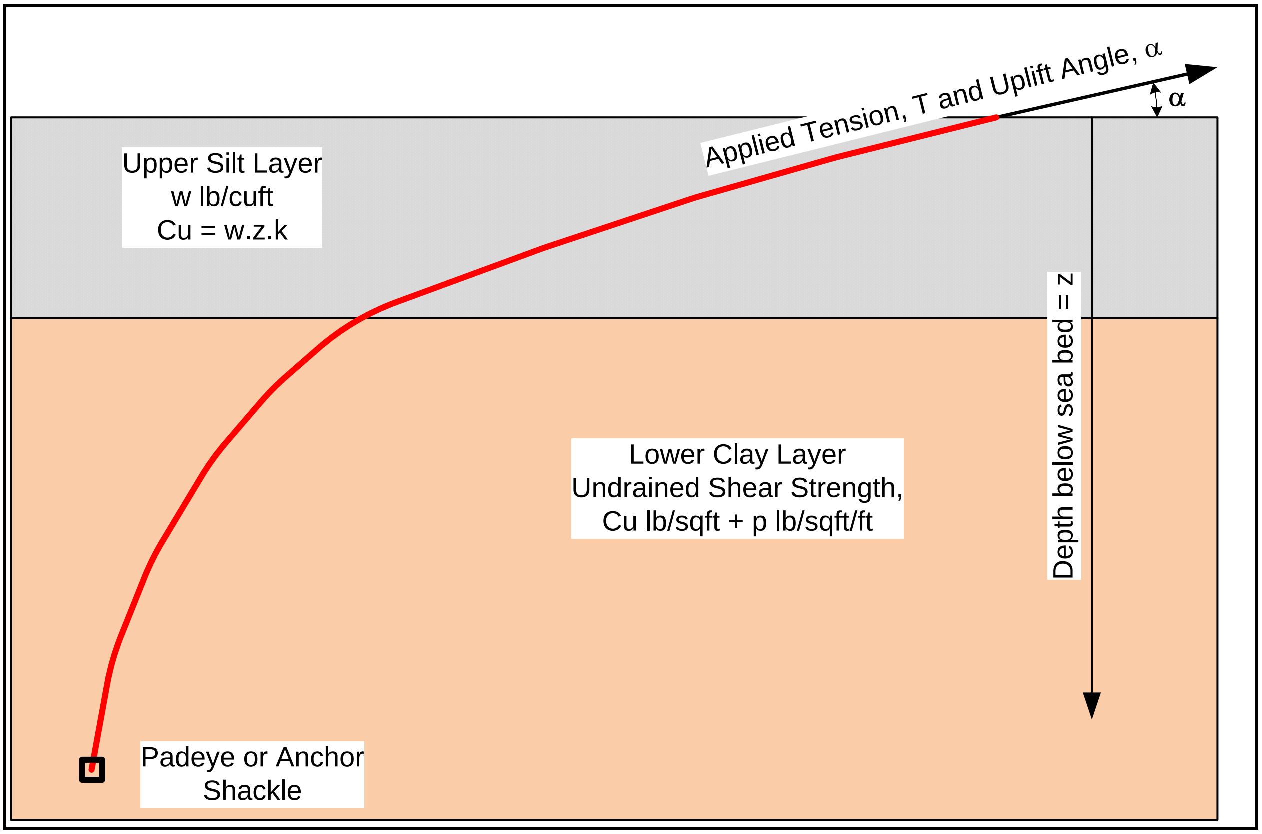


FIGURE 1 – Buried Mooring Line

STA CHAIN may be used to find the geometry and forces in an anchor chain (or cable) attached to an embedded anchor in cohesive soils. The program will calculate the profile of the anchor chain through the sea bed soils, from the anchor to the surface of the sea bed, and will find the tension in each elemental length. User defined boundary conditions include top tension and angle of applied load, as well as soil strength and line size parameters.

THEORY

The basis of the method is to assume a planar chain configuration, with chain 'tension forces and chain self weight, balanced at each elemental location by soil forces. These soil forces are considered both normal to, and tangential to each chain elemental section. Figure 2 shows the forces acting on an element of the chain.

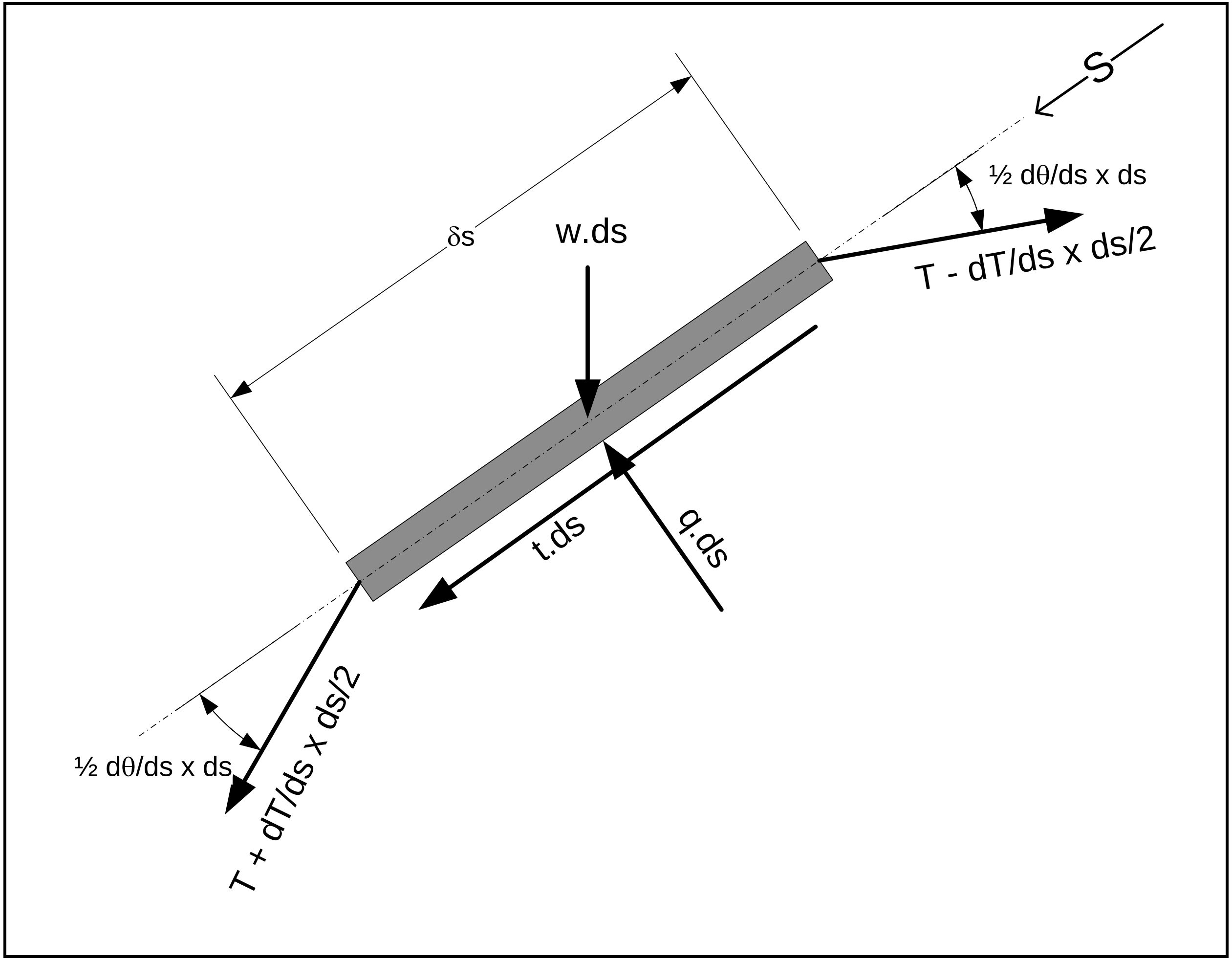


FIGURE 2 – Element Static Force Balance

Defining D, as the chain nominal diameter, the area bearing against the soil, per unit length, **Ab,** is approximately found from:

Ab = 2.6 x D

This is a somewhat empirical relationship. A link width to bar diameter ratio of 3.6 to 3.9 is common, but the bearing area of the chain on the soil is obviously less than this, since some links are on edge. The user is advised to observe the effect on the solution of varying D.

If the user selects wire instead of chain, the wire diameter is used with no multiplier to find Ab.

The chain surface area per unit length, **As**, that must be dragged through the soil is defined as:

$$\mathbf{As} = 11.3 \times D$$

If wire is selected the wire diameter is multiplied by π to find As.

The normal soil resistance per unit length of chain, q, and the tangential soil resistance per unit length, t, are found from:

$$q = Nc \times Cu \times \mathbf{Ab}$$

Where Nc is a bearing capacity factor and Cu is the undrained shear strength of the soil.

$$t = \alpha 1 \times Cu \times \mathbf{As}$$

Where α1 is an adhesion factor (suggested values 0.2 – 0.4 for wire and 0.4 – 0.6 for chain). In part, the adhesion factor accounts for soil separation.

METHOD OF SOLUTION

The above equations are solved from the user defined conditions of chain tension and angle at the sea bed, proceeding back down the chain (or wire). Solutions are found for dT and d(theta) in angular increments decided by the program and based upon the initial element length set by the user. The length of chain between each angular step is calculated by the program. In each line of the spreadsheet calculation the program computes the equilibrium conditions for a single element. These conditions include tangential friction and normal reaction forces between the element and the sea bed soil, and element weight. Additionally the change in chain tension and chain angle are computer over the element length.

The angular change between elements acts as a control on the element length. The consequence of this scheme is to limit the maximum element size to that specified by the user, and to reduce it where necessary to maintain an accurate chain profile, for example where large changes in soil strength occur.

If the user specifies an initial element length which is too small, the desired chain length and depth may not be modeled before all elements have been calculated. Although a very detailed model of the upper part of the chain will be found, the lower part will not be modeled. Alternatively, if the user specifies an initial element length which is too large, a coarse description of the upper part of the chain will result, some inaccuracies in the area of large soil stiffness changes, and small chain bend radius may occur. An unnecessary extension of the chain length vertically down beneath the anchor may also be modeled. Some experimentation with initial element length is therefore necessary. The ideal element size is one which carries the chain just further than necessary. This will give the most accurate results as the largest number of elements possible (105) will be used in the section of chain of interest.

“SOLVE UPPER ELEMENT LENGTH” BUTTON

In Version 3 of STA CHAIN a button has been added, “Solve Upper Element Length”. Clicking this button invokes the Excel Solver Add-In via a simple VBA macro code. The Solver must be available in the version of Excel you are using. A separate note on this is available from STA. One click on this button will generally find an upper element length that will result is a maximum depth in the analysis within 0.1% of the Padeye depth specified by the user.

SOIL MODEL

The upper soil layer is modeled as a weak silt with a user specified submerged weight and a user specified depth. The undrained shear strength of the silt, Cu(silt), is taken as a linear function of the overburden pressure:

$$Cu(silt) = z.gb.k$$

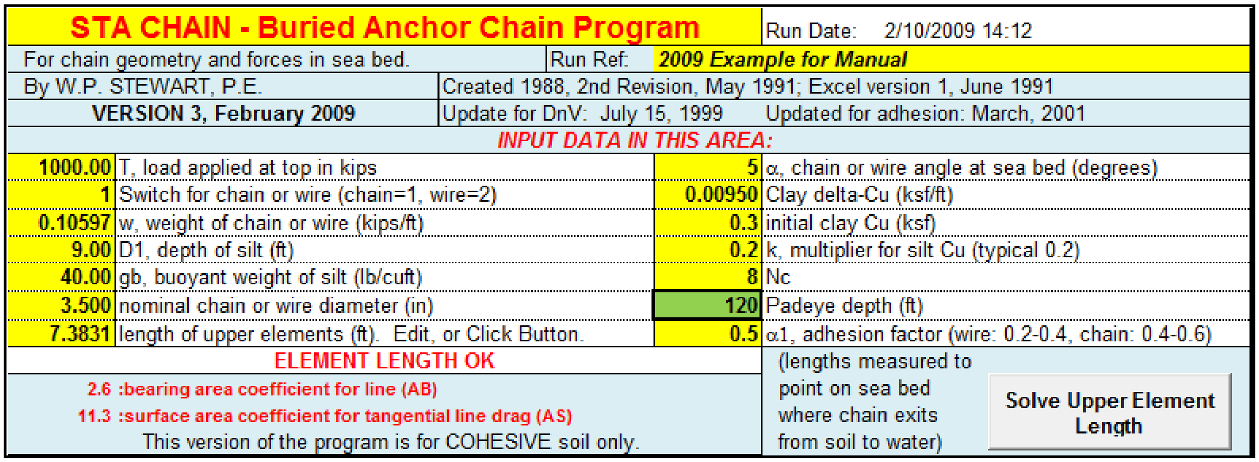
Where z is measured downwards from the sea bed, gb is the buoyant weight of the silt and k is a multiplier. The program will adjust the silt strength for the first element beneath the sea bed to prevent a numeric instability if the line weight exceeds the bearing capacity of the silt. As the depth and silt strength increases, the user-defined silt strength will be restored. The actual silt strength used will be shown in the detailed results and in the graphs. The value for the undrained shear strength of the second soil layer is calculated from:

$$Cu(clay) = Cu(initial) + z.Cu(delta)$$

Where z is measured downwards from the surface of the clay layer. As for soft silt, very soft clay surface shear strengths will be adjusted by the program to give sufficient support to prevent heavy lines sinking into the sea bed. This will be reflected in the graphical results for the sea bed undrained shear strength and in the detailed tabular results.

In many cases just the clay layer may be modeled and the depth of the silt will be specified as zero. Alternatively the silt can represent a softer or stiffer layer of clay over the clay below.

INPUT DATA



STA CHAIN - Buried Anchor Chain Program

Run Date: 2/10/2009 14:12

For chain geometry and forces in sea bed.

Run Ref: *2009 Example for Manual*

By W.P. STEWART, P.E.

Created 1988, 2nd Revision, May 1991; Excel version 1, June 1991

VERSION 3, February 2009

Update for DnV: July 15, 1999 Updated for adhesion: March, 2001

INPUT DATA IN THIS AREA:

1000.00	T, load applied at top in kips	5	α, chain or wire angle at sea bed (degrees)
1	Switch for chain or wire (chain=1, wire=2)	0.00950	Clay delta-Cu (ksf/ft)
0.10597	w, weight of chain or wire (kips/ft)	0.3	initial clay Cu (ksf)
9.00	D1, depth of silt (ft)	0.2	k, multiplier for silt Cu (typical 0.2)
40.00	gb, buoyant weight of silt (lb/cuft)	8	Nc
3.500	nominal chain or wire diameter (in)	120	Padeye depth (ft)
7.3831	length of upper elements (ft). Edit, or Click Button.	0.5	α1, adhesion factor (wire: 0.2-0.4, chain: 0.4-0.6)

ELEMENT LENGTH OK

2.6 :bearing area coefficient for line (AB)

11.3 :surface area coefficient for tangential line drag (AS)

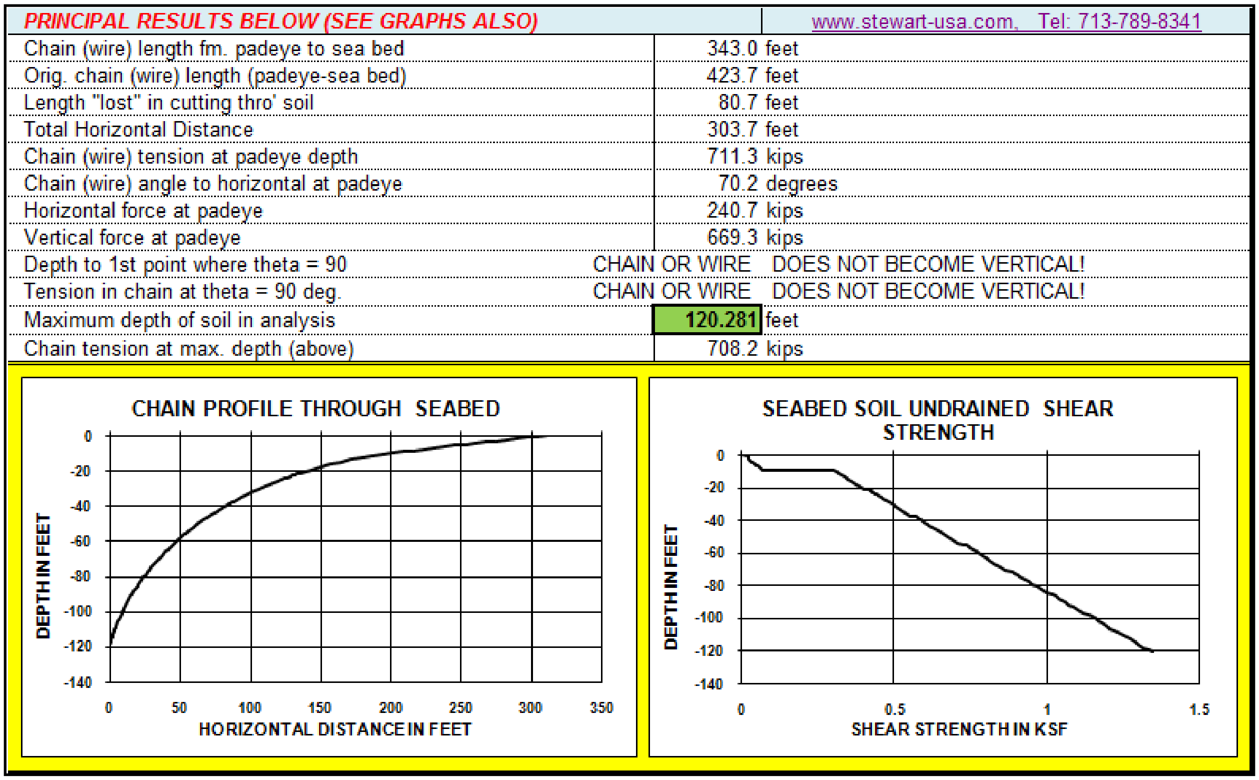
This version of the program is for COHESIVE soil only.

(lengths measured to point on sea bed where chain exits from soil to water)

FIGURE 3 – Input Data

1. *Run Date* is automatically added to the output (see upper left of screen). If your computer has the wrong date, or if you wish to edit the date for any other reason, you can do so.
2. A user-specified *Run Reference* can be added.
3. T, the load applied to the line at the sea bed, in kips.
4. A, the line uplift angle at the sea bed (see Figure 1) in degrees.
5. Switch for wire or chain.
6. w, weight in air of the line in lbs/ft.
7. D1, depth of top layer, termed silt but modeled as clay, in feet.
8. Diameter of wire or the bar diameter of the chain in inches.
9. Length of upper line elements in feet (see sections above for further information).
10. Clay delta-Cu in ksf/ft (typically 8 to 10 for normally consolidated soft clay).
11. K, multiplier for silt buoyant weight to get equivalent Cu value.
12. Nc, bearing capacity factor, used throughout depth of analysis (typical value 9.0).
13. Padeye Depth, or depth of anchor shackle, in feet from sea bed. The chain tension, chain angle, and component of chain tension in the horizontal and vertical directions at the depth specified will be found and printed. Note that the chain profile will normally be continued past the padeye, depending upon the upper element length specified by the user (see below).
14. α1, adhesion factor (typically 0.2 to 0.4 for wire and 0.4 to 0.6 for chain, see Theory Section, above).

PRINCIPAL RESULTS



PRINCIPAL RESULTS BELOW (SEE GRAPHS ALSO)	www.stewart-usa.com, Tel: 713-789-8341
Chain (wire) length fm. padeye to sea bed	343.0 feet
Orig. chain (wire) length (padeye-sea bed)	423.7 feet
Length "lost" in cutting thro' soil	80.7 feet
Total Horizontal Distance	303.7 feet
Chain (wire) tension at padeye depth	711.3 kips
Chain (wire) angle to horizontal at padeye	70.2 degrees
Horizontal force at padeye	240.7 kips
Vertical force at padeye	669.3 kips
Depth to 1st point where theta = 90	CHAIN OR WIRE DOES NOT BECOME VERTICAL!
Tension in chain at theta = 90 deg.	CHAIN OR WIRE DOES NOT BECOME VERTICAL!
Maximum depth of soil in analysis	120.281 feet
Chain tension at max. depth (above)	708.2 kips

FIGURE 4 – Principal Results

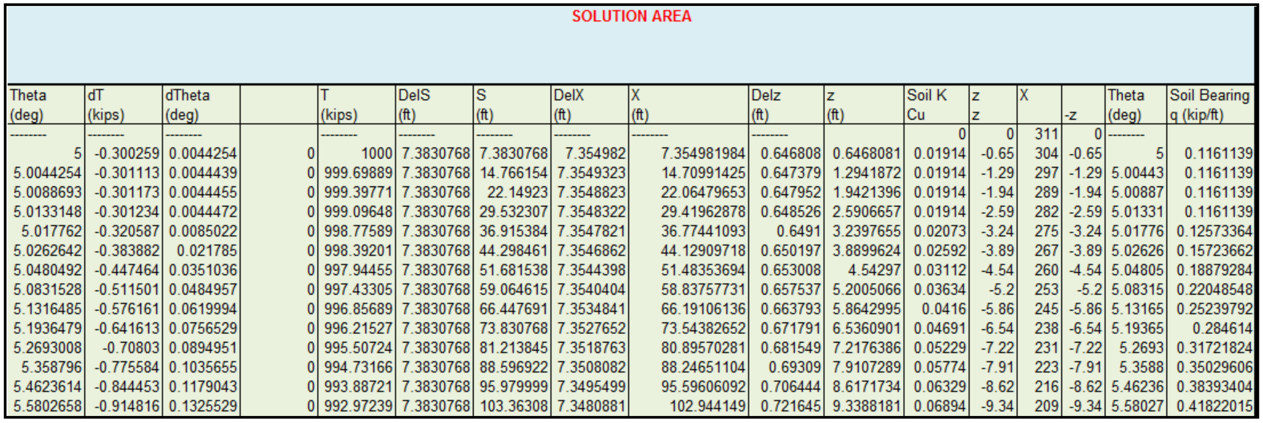
1. *Chain length from padeye to sea bed* is the length measured along the chain from the padeye to the point where the chain leaves the sea bed. The equilibrium and geometry of chain elements may be calculated beyond the padeye, but this does not affect padeye forces.
2. *Original chain length* is the length measured vertically upwards from the padeye to the sea bed and then horizontally along the sea bed to the point where the chain actually exits.
3. *Length "lost" in cutting through the soil* is the difference between the above two terms.
4. *Chain tension at padeye depth* is the tension in the chain at the depth of the padeye specified by the user. Chain tensions below this will be calculated if the initial element length is large enough. If the initial element length is too small (the chain profile will show if this is the case) the program will print a warning *CHAIN TOO SHORT; INC.EL.LENGTH!.*
5. *Chain angle to horizontal at padeye* is angle of the chain at the depth of the padeye specified by the user. A warning is printed if the chain is too short.
6. *Horizontal force at the padeye* is the horizontal component of the tension in the chain calculated at the depth of the padeye specified by the user. A warning is printed if the chain is too short.
7. *Vertical force at the padeye* is the vertical component of the tension in the chain calculated at the depth of the padeye specified by the user. A warning is printed if the chain is too short.
8. *Depth to first point where theta = 90* is the depth to the point where the chain angle becomes vertical. If the upper element size is small and the soil is soft the chain modeled may not be long enough to reach a vertical attitude. If this is the case a warning is printed, *CHAIN DOES NOT BECOME VERTICAL!* This may be what the user wants and does not imply any error condition.

9. *Tension in chain at theta = 90* is the tension calculated at the point where the chain angle becomes vertical. (See 4.8, above).
10. *Maximum depth of soil in analysis* is the depth of the last chain element. This depth is increased or decreased by adjusting the upper element length. Generally simply click on the "Solve Upper Element Length" button.
11. *Chain tension at maximum depth* is the tension calculated in the last chain element modeled. Note that this may be anywhere in the range from zero to the applied top tension, depending on soil and chain parameters selected by the user.

Charts of the chain profile and sea bed undrained soil strength are produced below the principal results.

DETAILED RESULTS

The detailed numerical results at each elemental length can be viewed beginning around Row 47 on the main worksheet. A truncated example is shown in Figure 5, below.



SOLUTION AREA

Theta (deg)	dT (kips)	dTheta (deg)		T (kips)	DelS (ft)	S (ft)	DelX (ft)	X (ft)	Delz (ft)	z (ft)	Soil K Cu	z z	X	-z	Theta (deg)	Soil Bearing q (kip/ft)
--------	--------	--------		--------	--------	--------	--------	--------	--------		0	0	311	0	--------	
5	-0.300259	0.0044254	0	1000	7.3830768	7.3830768	7.354982	7.354981984	0.646808	0.6468081	0.01914	-0.65	304	-0.65	5	0.1161139
5.0044254	-0.301113	0.0044439	0	999.69889	7.3830768	14.766154	7.3549323	14.70991425	0.647379	1.2941872	0.01914	-1.29	297	-1.29	5.00443	0.1161139
5.0088693	-0.301173	0.0044455	0	999.39771	7.3830768	22.14923	7.3548823	22.06479653	0.647952	1.9421396	0.01914	-1.94	289	-1.94	5.00887	0.1161139
5.0133148	-0.301234	0.0044472	0	999.09648	7.3830768	29.532307	7.3548322	29.41962878	0.648526	2.5906657	0.01914	-2.59	282	-2.59	5.01331	0.1161139
5.017762	-0.320587	0.0085022	0	998.77589	7.3830768	36.915384	7.3547821	36.77441093	0.6491	3.2397655	0.02073	-3.24	275	-3.24	5.01776	0.12573364
5.0262642	-0.383882	0.021785	0	998.39201	7.3830768	44.298461	7.3546862	44.12909718	0.650197	3.8899624	0.02592	-3.89	267	-3.89	5.02626	0.15723662
5.0480492	-0.447464	0.0351036	0	997.94455	7.3830768	51.681538	7.3544398	51.48353694	0.653008	4.54297	0.03112	-4.54	260	-4.54	5.04805	0.18879284
5.0831528	-0.511501	0.0484957	0	997.43305	7.3830768	59.064615	7.3540404	58.83757731	0.657537	5.2005066	0.03634	-5.2	253	-5.2	5.08315	0.22048548
5.1316485	-0.576161	0.0619994	0	996.85689	7.3830768	66.447691	7.3534841	66.19106136	0.663793	5.8642995	0.0416	-5.86	245	-5.86	5.13165	0.25239792
5.1936479	-0.641613	0.0756529	0	996.21527	7.3830768	73.830768	7.3527652	73.54382652	0.671791	6.5360901	0.04691	-6.54	238	-6.54	5.19365	0.284614
5.2693008	-0.70803	0.0894951	0	995.50724	7.3830768	81.213845	7.3518763	80.89570281	0.681549	7.2176386	0.05229	-7.22	231	-7.22	5.2693	0.31721824
5.358796	-0.775584	0.1035655	0	994.73166	7.3830768	88.596922	7.3508082	88.24651104	0.69309	7.9107289	0.05774	-7.91	223	-7.91	5.3588	0.35029606
5.4623614	-0.844453	0.1179043	0	993.88721	7.3830768	95.979999	7.3495499	95.59606092	0.706444	8.6171734	0.06329	-8.62	216	-8.62	5.46236	0.38393404
5.5802658	-0.914816	0.1325529	0	992.97239	7.3830768	103.36308	7.3480881	102.944149	0.721645	9.3388181	0.06894	-9.34	209	-9.34	5.58027	0.41822015

FIGURE 5 – Detailed Results.

ADDITIONAL GRAPHS

As well as the small graphs on the main STACHAIN worksheet, three additional graphs may be viewed and printed, copied into reports, etc. Each of these graphs also shows a table with the main parameters of the analysis, as well as the user's run reference.

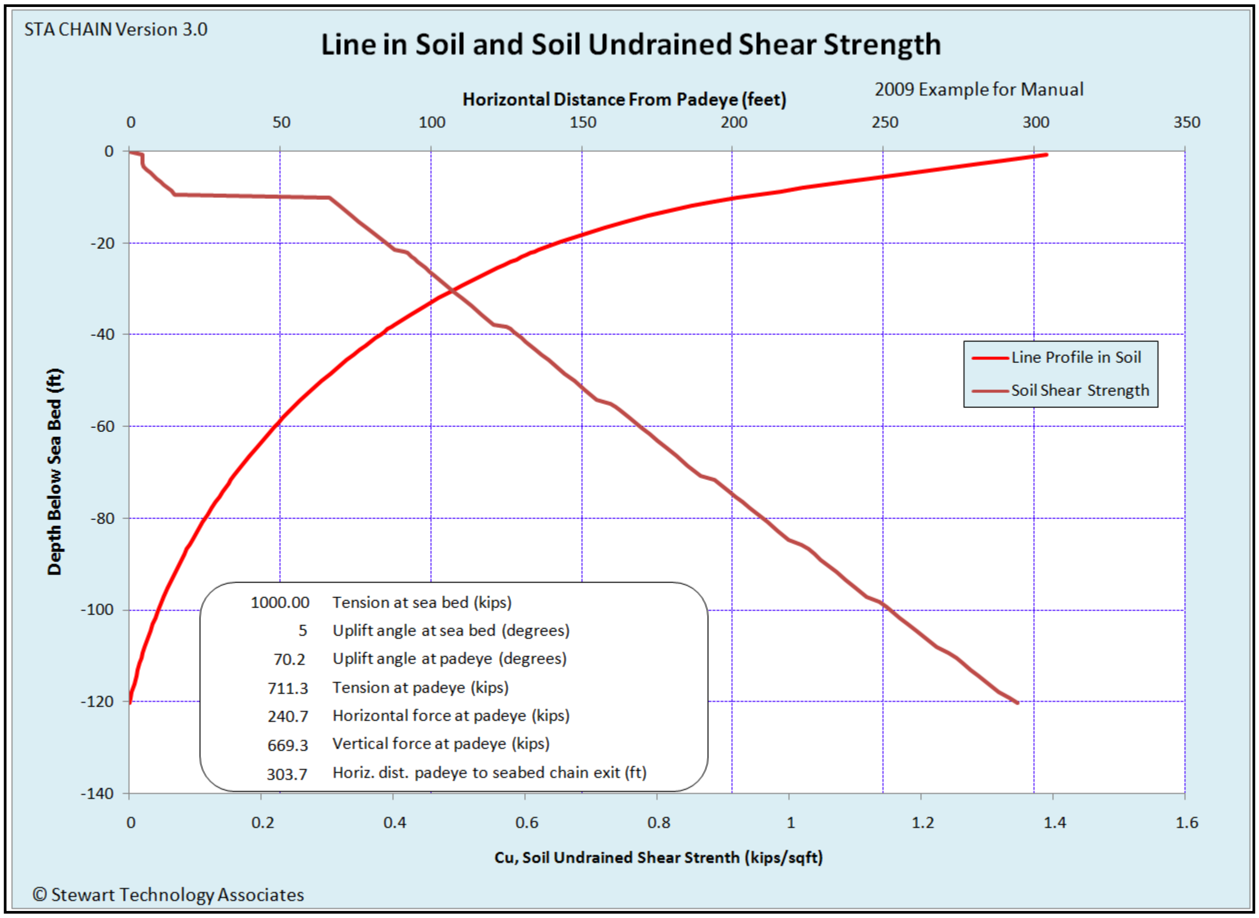


FIGURE 6 – Line Profile in Soil and Soil Undrained Shear Strength.
Note the two horizontal axis scales.

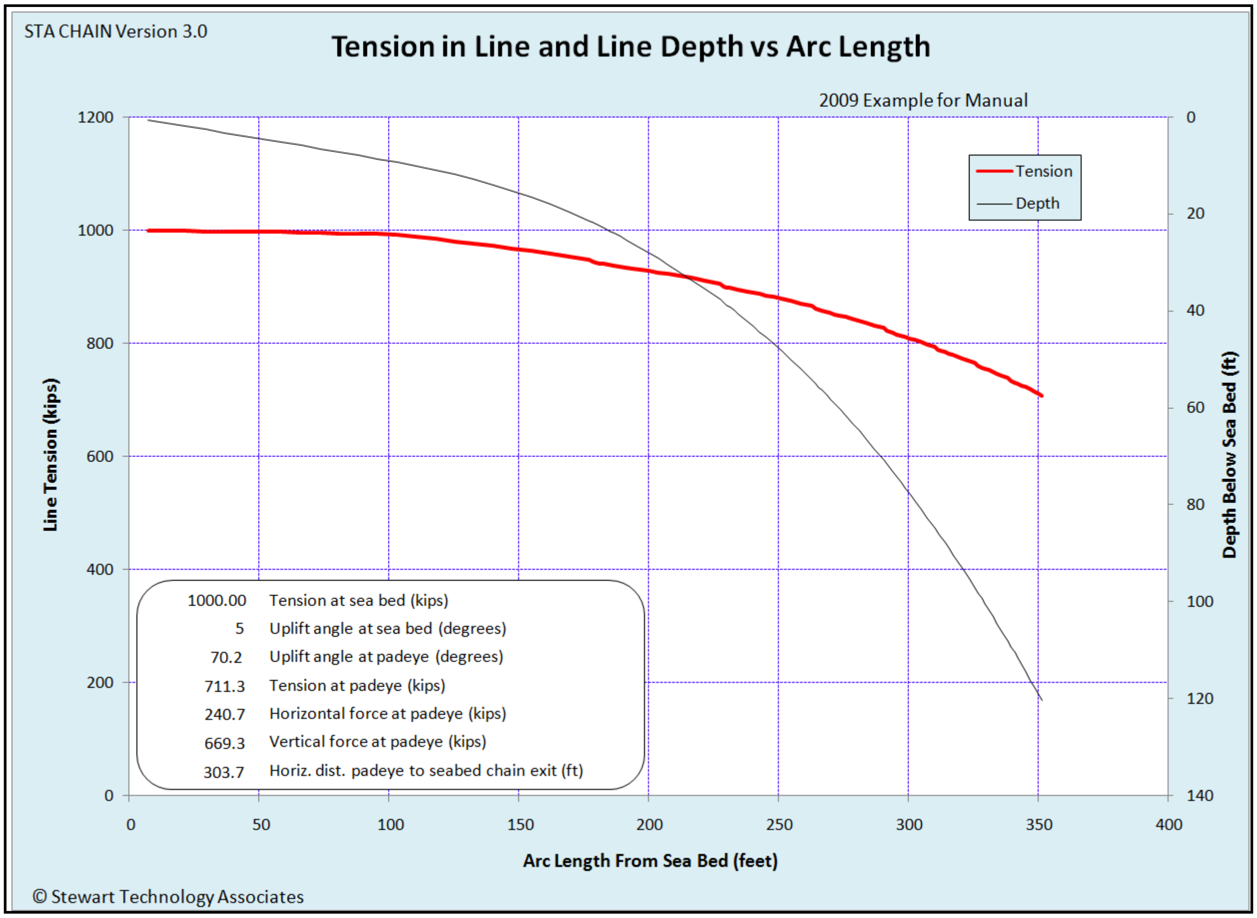


FIGURE 7 – Plot of Line Tension (Left y-axis) and Line Depth Below Sea Bed (Right y-axis) vs. Line Arc Length Measured from the Sea Bed.

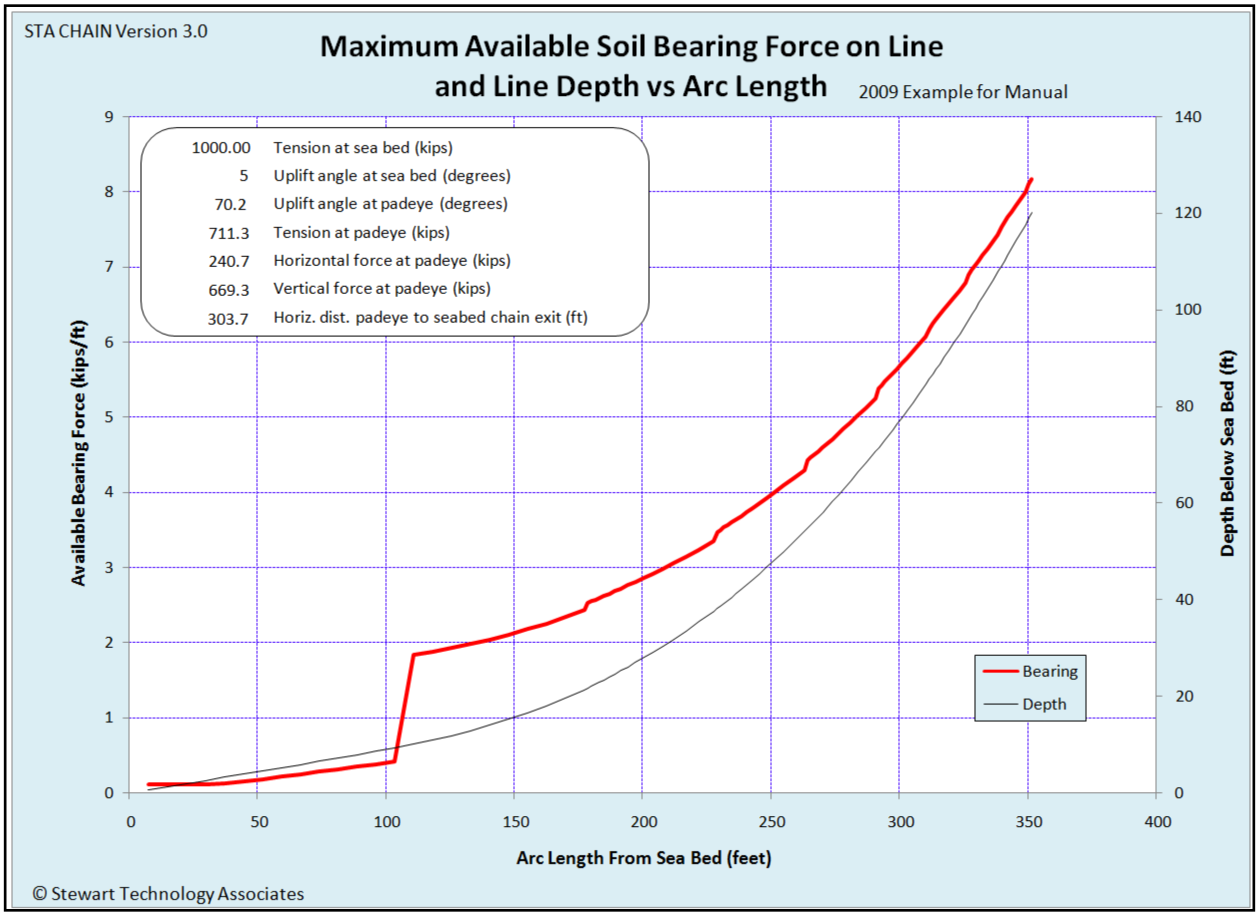


FIGURE 8 – Maximum Available Bearing Force (per unit length) on the Line vs. Arc Length from the Sea Bed.
In cases where the line becomes vertical, the bearing force reported is, as indicated, available, but not used. The bearing force is used wherever the line has been pulled through/into the soil.
Figure 8 also indicates the line depth in the soil (right hand axis).

REFERENCES

1. "Handbook For Marine Geotechnical Engineering", Technical Editor, Rocker, K. March 1985, available from Naval Civil Engineering Laboratory Port Hueneme, California 93043.