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AUTHOR: R. Taylor, NCEL and
P. Valent, Brian Watt & Associates

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PORT HUENEME, CALIFORNIA 93043

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METRIC CONVERSION FACTORS

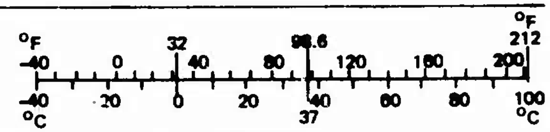
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Anchors, moorings, holding capacity, seafloor soils

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This design guide provides an overview to the selection and sizing of drag embedment anchors and mooring chains and to the diagnosis and solution of typical drag anchor performance problems. The site information required for anchor type selection is outlined. Two options for sizing the drag anchor are offered. The more exacting of these options includes a method for determining the mooring load resistance developed by that length of mooring chain embedded in and sliding on cohesive seafloor soils. Example problems for anchor

continued

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20. Continued

system design on cohesionless and cohesive seafloors are provided. The last section outlines drag anchor performance problems and provides possible solutions. More detailed information can be found in the references.

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1. Anchors 2. Holding capacity I. 42-040

This design guide provides an overview to the selection and sizing of drag embedment anchors and mooring chains and to the diagnosis and solution of typical drag anchor performance problems. The site information required for anchor type selection is outlined. Two options for sizing the drag anchor are offered. The more exacting of these options includes a method for determining the mooring load resistance developed by that length of mooring chain embedded in and sliding on cohesive seafloor soils. Example problems for anchor system design on cohesionless and cohesive seafloors are provided. The last section outlines drag anchor performance problems and provides possible solutions. More detailed information can be found in the references.

PREFACE

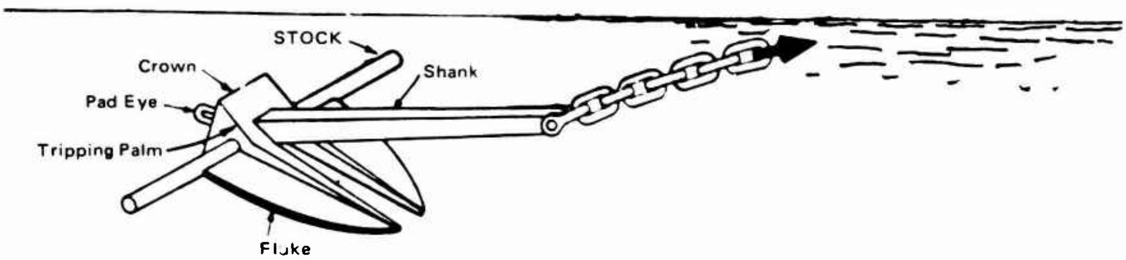
The Naval Civil Engineering Laboratory (NCEL) was tasked to improve the Navy's capability to select and design drag embedment anchors. Beginning in 1979, NCEL has conducted a 3-year anchor test program, sponsored by the Naval Facilities Engineering Command (NAVFAC) and Naval Sea Systems Command (NAVSEA), to accurately describe drag embedment anchor behavior. Data from this test program were used to develop and validate procedures to predict anchor holding capacity as a function of seafloor type and engineering properties.

Preparation of this design guide was sponsored by NAVSEA. The guide is structured to be used by the novice as well as those experienced in ocean operations or mooring design.

This design guide provides an overview to the selection and sizing of drag embedment anchors and mooring chains and to the diagnosis and solution of typical drag anchor performance problems. The site information required for anchor type selection is outlined. Two options for sizing the drag anchor are offered. The more exacting of these options includes a method for determining the mooring load resistance developed by that length of mooring chain embedded in and sliding on cohesive seafloor soils. Tables or charts within this guide can be used independently for routine anchor selection and cost estimating purposes, and they can be used within the structured (flow-charted) format provided to determine detailed anchor system performance. Depending on the design option selected, this includes anchor drag distance, embedment depth, holding capacity, anchor chain capacity, and characteristics of the mooring chain system. Example problems for anchor system design on cohesionless and cohesive seafloors are provided. The last section outlines drag anchor performance problems and provides possible solutions. More detailed information can be found in the references.

CONTENTS

1. ANCHOR SELECTION



DRAG ANCHOR ELEMENTS

Use Tables 1.1 and 1.2 to assess the suitability of the drag embedment anchor for your application.

If the drag anchor is a good choice ...

or

If knowledge of the site is insufficient to make a choice ...

Go to Section 2.

If the drag anchor is a poor choice ...

Select and design an alternative anchor type.

See: Handbook of Marine Geotechnology,
Chapters 1, 4, 5, and 6
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043
(Ref 1)

or

NAVFAC Design Manual DM-26:
Harbor and Coastal Facilities
Naval Facilities Engineering Command
Washington, DC 20390
(Ref 2)

Table 1.1. Generalized Features of Drag Embedment Anchor Systems

Positive Features
1. Broad range of anchor types and sizes available.
2. High capacity (greater than 1,000,000 lb) achievable.
3. Standard off-the-shelf equipment.
4. Broad use experience.
5. Can provide continuous resistance even though maximum capacity has been exceeded.
6. Anchor is recoverable.
Negative Features
7. Anchor functions poorly in rock/coral seafloors.
8. Anchor behavior is erratic in layered seafloors.
9. Low resistance to uplift loads; therefore, large line scopes required to cause near horizontal loading at seafloor.
10. Penetrating/dragging anchor can damage pipelines, cables, etc.
11. Loading, for most anchor types and applications, must be uni-directional.

Table 1.2. Performance of Anchor Types as Function of Seafloor Type and Loading Condition

Parameter	Anchor Type[a]			
	Drag Embedment	Deadweight	Pile	Direct Embedment
Seafloor Material Type				
Soft clay, mud	+	+	-	+
Soft clay layer (0 to 20 ft thick) over hard layer	-	+	+	o
Stiff clay	+	+	+	+
Sand	+	+	+	+
Hard glacial till	-	+	+	+
Boulders	o	+	o	o
Soft rock or coral	o	+	+	+
Hard, monolithic rock	o	+	-	-
Seafloor Topography				
Moderate slopes, <10 deg	+	+	+	+
Steep slopes, >10 deg	o	o	+	+
Loading Direction				
Omni-directional	o	+	+	-
Uni-directional	+	+	+	+
Large uplift component	o	+	+	+
Lateral Load Range				
To 100,000 lb	+	+	-	+
100,000 to 1,000,000 lb	+	-	+	-
Over 1,000,000 lb	o	o	+	o

[a]See Reference 1 for further detail.

KEY: + = functions well
- = normally not a good choice
o = does not function

2. DETERMINATION OF SEAFLOOR CHARACTERISTICS

A. SITE DATA REQUIRED FOR DRAG ANCHORS

Topography

Slope of seafloor

Relief (greater than 1 meter (3 feet))

- sand waves
- slump features

Sediment Layer Thickness

Investigate to 3 to 5 meters in sand and 10 to 15 meters in clay

- thickness of strata
- depth to competent rock

Seafloor Material Type

Classify by:

- university and government contacts and literature (Table 2.1)
- sampling
- visual observations and testing

B. SOIL SAMPLING METHODS

Obtain one sample from each anchor location.

For Sands and Gravel: Use grab samples and dredges (Figure 2.1)

For Clays, Silts and Muds: Use gravity corer (Table 2.2)

C. DETERMINATION OF SEAFLOOR MATERIAL TYPE

SOILS -- Can be deformed by finger pressure.

Differentiate between:

SANDS (cohesionless) -- free draining
CLAYS (cohesive) -- slow draining

SANDS: More than 88% of material is composed of grains visible to the eye (larger than No. 200 sieve, 0.074 mm in diameter).

Soil is nonplastic; segregates readily into individual grains.

Gravity corers are often recovered empty because sample is washed out during retrieval; if empty, check corer cutting edge for evidence of damage from gravel or rock. Use grab sampler to verify sand.

MUDS, CLAYS: Less than 88% of material is composed of grains visible to the eye (larger than No. 200 sieve).

Soil is plastic, cohesive; works like a putty or modeling clay.

<u>CORAL</u> -- Identified by rock dredge sample.

<u>ROCK</u> -- Identified by rock dredge sample.

For most moorings, further delineation of seafloor type is needed. This is accomplished by determination of seafloor engineering properties. Table 2.3 provides a more detailed breakdown and relates soil type to generalized anchor performance.

Table 2.1. Sources of Marine Geological and Geotechnical Data

Universities and Government Organizations

Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964

National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, NOAA, Boulder, CO 80302

Chief of Operations Division, National Ocean Survey, NOAA, 1801 Fairview Avenue, Ease Seattle, WA 98102

Chief of Operations Division, National Ocean Survey, NOAA, 1439 W. York Street, Norfolk, VA 23510

Naval Oceanographic Office, Code 3100, National Space Technology Laboratories, NSTL Station, MI 39522

Scripps Institution of Oceanography, La Jolla, CA 92093

Chief Atlantic Branch of Marine Geology, USGS, Bldg 13, Quissett Campus, Woods Hole, MA

Chief Pacific Arctic Branch of Marine Geology, USGS, 345 Middlefield Road, Menlo Park, CA 94025

Woods Hole Oceanographic Institution, Woods Hole, MA

Journals and Conference Proceedings

Journals of Geotechnical Engineering, ASCE

Marine Geotechnology, Pergamon Press, NY

Canadian Geotechnical Journal, National Research Council of Canada, Ottawa, Canada

Geotechnique, The Institution of Civil Engineers, London

Ocean Engineering, Pergamon Press, NY

Offshore Technology Conference, Houston, TX (yearly)

Civil Engineering in the Oceans (1 through 4)

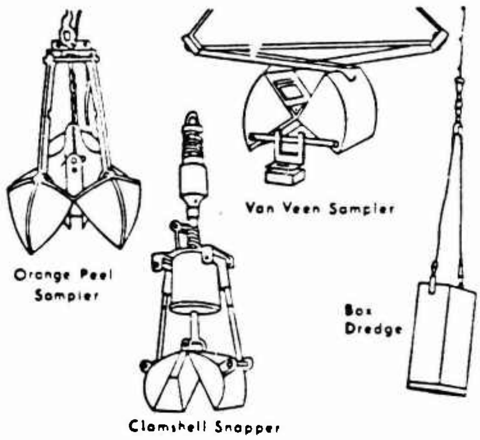


Figure 2.1 Grab samplers and dredges.

Table 2.2. Summary of Short Corer Characteristics

Characteristics	Value
Corer Overall Length	
m	0.98 to 4.57 (usually 1.83)
ft	2.5 to 15 (usually 6)
Weight	
kN	0.18 to 4.45 (usually 0.89)
lb	40 to 1,000 (usually 200)
Sample Length	
m	0.3 to 3 (usually 1.2 to 1.8)
ft	1 to 10 (usually 4 to 6)
Sample Diameter	
mm	38 to 67 (usually 64)
in	1.5 to 2.6 (usually 2.5)
Ship Requirements	Winch, "A" or "U" frame
Wire	Capable of supporting the corer and wire out with an acceptable factor of safety from 3.2 mm to 12.7 mm (1/8 in. to 1/2 in.) depending on the size of the corer
Accessories	Extra liners, spare core catchers, spare core cutters, end caps, release

Table 2.3. Influence of Soil Type on Anchor Performance

Soil Type	Description	Remarks
Sand	Medium to dense sand with bulk wet density (γ_b) of 110 to 140 pcf. Typical of most nearshore deposits. Standard penetration resistance (SPT) range - 25 to 50 blows/ft.	Holding capacity is consistent provided sand fluke angle is used.
Mud	Normally consolidated, very soft to soft, silt to clay size sediment typical of harbors and bays. Soil strength increases linearly with depth at 10 psf/ft ± 3 psf/ft. Approximately equates to SPT of 2 blows/ft at 20-ft depth.	Holding capacity is reasonably consistent provided anchor flukes trip open. Certain anchors (see Table 3.1) require special care during installation to ensure fluke tripping.
Clay	Medium to stiff cohesive soil. Soil shear strength (s_u) considered constant with depth. s_u range -- 3-1/2 to 14 psi. SPT range -- 4 to 16 blows/ft.	Good holding capacity which will range between that provided for sand and mud. Use mud value conservatively or linearly interpolate between sand and mud anchor capacity (stiff clay (14-psi) capacity equals sand capacity). For stiff clay (s_u > 7 psi) use sand fluke angle.
Hard Soil	Very stiff and hard clay (s_u > 14 psi, SPT > 16) and very dense sand (SPT > 50, γ_b > 140 pcf). Seafloor type can occur in high current, glaciated, dredged areas.	Holding capacity is consistent provided anchor penetrates. May have to fix flukes open at sand fluke angle to enhance embedment. Jetting may be required. Use holding capacity equal to 75% sand anchor capacity.
Layered Seafloor	Heterogeneous seafloor of sand, gravel, clay, and/or mud layers or mixtures.	Anchor performance can be erratic. Proof-loading desired to verify safe capacity.

Continued

Table 2.3 Continued

Soil Type	Description	Remarks
Coral/Rock	Can also include areas where coral or rock is overlain by a thin sediment layer that is insufficient to develop anchor capacity.	Unsatisfactory seafloor for permanent moorings. Can be suitable for temporary anchoring if anchor snags on an outcrop or falls into a crevice. Consider propellant-embedded anchors.

3. SELECTION OF DRAG ANCHOR TYPE

Given the soil type, an anchor is selected based on:

(1) performance (see Tables 3.1 and 3.2)

(2) handling (see footnote a, Table 3.1)

(3) availability and cost

Table 3.1. Relative Holding Capacity Performance of Several Anchor Types

Seafloor Consistency	Performance		
	Excellent	Good	Satisfactory
Soft (mud, clay)	Stevmud Stato Boss Hook Stevfix[a] Bruce Twin Shank	Stevdig[a] Stevin[a] Flipper Delta Danforth[a] G.S.[a] LWT[a] Moorfast Offdrill II	Bruce Cast Stockless[a] Two-Fluke Balanced[a]
Hard (sand, hard clay)	Stevdig Stevfix Bruce Twin Shank Stato Boss Bruce Cast	Danforth G.S. LWT Moorfast Offdrill II Hook Two-Fluke Balanced	Stockless

[a]For fixed/fully opened flukes on soft seafloors. Movable flukes may not trip.

Table 3.2. Efficiencies of 15-Kip Drag Anchors in Cohesionless and Soft Cohesive Soils

Anchor Type	Efficiency	
	Cohesionless (Sand)	Soft Cohesive Mud
Stockless		
48-deg fluke angle		
with movable flukes	4	2.2
with fixed flukes	4	4.3
35-deg fluke angle		
with movable flukes	6	-
with fixed flukes	6	-
Two-Fluke Balanced		
with ball guide	7	2.2
Danforth	11	8
G.S.	11	8
LWT	11	8[a]
Stato	23	20
Moorfast	9[b]	8
Offdrill II	9[b]	8
Stevin	-	11[a]
Stevfix	26	17[a]
Flipper Delta	-	9
Stevdig	26	11[a]
Stevmud	-	22
Boss	23	20
Hook	7	17
Bruce Cast	23	3
Bruce Twin Shank	24	14

[a]For fixed fully opened flukes.
[b]For 28 deg fluke angle.

Holding Capacity (T_M) = Efficiency (e) · Anchor Air Weight (W_A)

(NOTE: These are ultimate holding capacities. Do not use for anchor weights over 15 kips.) Values are conservative for anchor weights less than 15 kips.

4. SIZING THE ANCHOR

After selecting an anchor type, then size the anchor according to one of the following options:

OPTION 1 -- HOLDING CAPACITY CURVE OPTION (Refer to Section 6)

Advantages: suitable for most Navy mooring applications including permanent fleet moorings

valid for anchor air weights up to 50 kips

Limitations: assumes chain for mooring line with a factor of safety (FS) of 3 on break strength

valid only when anchor can penetrate to full depth

OPTION 2 -- ANALYTIC MODEL - APPLICABLE ONLY TO MUDS AND CLAYS (refer to Section 7). Option 2 is more complex than Option 1 and should only be used when Option 1 is limited.

Advantages: treats anchor and mooring chain independently

can be used where anchor drag is restricted

can be used where soil layer thickness is not sufficient to permit full penetration of the anchor

valid for anchor air weights greater than 50 kips

most accurate method for deeply embedded anchor-chain systems

Limitations: applicable only to muds and clays

5. FACTORS OF SAFETY REQUIRED

The following are the factors of safety required* for the specified mooring types:

Mooring Type	Item	Factor of Safety
For Navy fleet moorings:	Stockless anchors	1.5
	High efficiency[a] anchors	2.0
	Chain in mooring line	3.0
For other than Navy fleet moorings:	All anchors	2.0
	Chain in mooring line	3.0

[a]High efficiency anchors are any of the group of large-fluked anchors similar to the Danforth, Moorfast, Stato, Stevin, Flipper Delta, or Bruce anchors commonly used to moor floating drilling units, as opposed to the Stockless-type anchors usually employed as conventional ship anchors.

*From NAVFAC Design Manual DM-26 (Ref 3).

6. OPTION 1 - HOLDING CAPACITY CURVE OPTION

PROCEDURE

DEFINE LOADS AND SOIL TYPE

1. Determine required ultimate horizontal holding capacity.

   a. Determine maximum design horizontal load, H_D - see NAVFAC DM-26 (Ref 2) or other.

   b. Determine required factor of safety, FS (Section 5).

   c. Calculate required ultimate horizontal holding capacity, H_U,

$$H_U = FS \cdot H_D$$

2. Identify seafloor material type and characteristics (Section 2).

SELECT ANCHOR TYPE AND SIZE

3. Select anchor type (Tables 3.1 and 3.2).

4. Select anchor weight and calculate anchor-chain system ultimate horizontal capacity, T_M:

   a. Select anchor air weight, W_A, for first trial from Figure 6.1 (sand/hard seafloors) or Figure 6.2 (soft). Use $T_M = H_U$ to determine W_A. Note required reductions in holding capacity for anchors used in hard soil (Figure 6.1).

NOTE: POSSIBLE TO SKIP TO STEP 6 FOR MOST ROUTINE*
ANCHOR-CHAIN MOORINGS

b. Determine T_M for the selected anchor from Figure 6.1 (sand/hard seafloors) or Figure 6.2 (soft).

5. Check adequacy of drag distance.

a. Adjustments to T_M:

(1) When drag distance in mud is limited, the anchor may not penetrate deep enough to mobilize its full capacity. Compare allowable drag distance (D) to maximum required to achieve ultimate capacity. If D/L MAX. (Figure 6.3) $\cdot$ L > drag distance allowed, then determine the percentage of T_M mobilized, r, as a function of normalized drag distance from Figure 6.3 for mud. See Figure 6.4 or refer to manufacturer's literature for fluke lengths (L).

(2) In sand, mobilization of ultimate anchor capacity requires 10 fluke lengths drag for movable flukes and 8 fluke lengths for fixed flukes. One or two fluke lengths may be required for tripping in soft soils. Hard soil drag distance is usually not critical. Drag distance (after fluke tripping) is about 2-1/2 fluke lengths to ultimate capacity and 1 fluke length to safe capacity (1/2 ultimate).

---

*Refers to noncritical moorings where anchor dragging is not catastrophic, where seafloor characteristics are generally well known, and where historical anchor data are available.

b. Check adequacy of selection.

(1) If T_M differs significantly from required capacity (H_U or H_D depending on requirement), then repeat step 4 with new anchor size and/or type selection.

(2) Determine safe anchor mudline capacity:

$$T_{MS} = T_M/FS$$

If $T_{MS} < T_M$ at a specified design drag distance, use $T_M = T_{MS}$ and compare to the maximum design horizontal load H_D. If $T_M < H_D$, select a larger anchor.

6. Check adequacy of soil thickness.

a. Obtain anchor fluke tip penetration, d_t, required to develop full capacity (Table 6.1).

b. If soil thickness, t, is less than anchor penetration required, d_t, then:

(1) Select new anchor requiring less penetration, or

(2) Go to Option 3 for mud seafloor.

DETERMINE CHAIN SIZE AND LENGTH

7. Select chain size.

a. Estimate chain required breaking load, T_U:

$$T_U = 1.15 \cdot FS \cdot H_D \quad \text{(FS = 3 recommended for chain)}$$

b. Select chain size, D_c (Table 6.2).

c. Calculate chain maximum design tension at top of catenary, T_D (Figure 6.5).

d. Calculate required chain breaking load, T_U:

$$T_U = FS \cdot T_D \qquad (FS = 3 \text{ for chain})$$

e. Check adequacy of chain size.

(1) If T_U differs significantly from chain breaking load (Table 6.2), then repeat steps b through e with new selection.

(2) Chain breaking load should be at least 1.5 · maximum anchor-chain system capacity, T_M.

8. Determine chain length required.

a. Calculate catenary length, s (Figure 6.5).

b. Calculate total chain length required, L_t:

(1) Sand/hard seafloor:

$$L_t = s$$

(2) Soft seafloor (mud):

$$L_t = s + H_U \quad (\text{and } s \text{ in feet, } H_U \text{ in kips})$$

9. Determine anchor setting distance to design load.

   a. Sand - Assume three fluke lengths drag distance needed to achieve anchor design (safe) capacity for FS = 2

   b. Mud - Calculate anchor setting distance D_p. Select D/L from Figure 6.3 at appropriate FS. FS = 2 recommended:

$$D_p = L(D/L)$$

A flow chart of this Option 1 procedure is provided as Figure 6.6.

Table 6.1. Estimated Maximum Fluke Tip Penetration (d_{tm}) of Some Drag Anchor Types in Sands and Soft Clayey Silts (Mud)

Anchor Type	Normalized Fluke Tip Penetration, (d_{tm}/L) (fluke lengths)	
	Sands/Stiff Clays	Mud (e.g., Soft Silts and Clays)
Stockless[a]	1	3
Moorfast Offdrill II	1	4
Stato Stevfix[a] Flipper Delta Boss Danforth LWT[a] G.S. (type 2)	1	4-1/2
Bruce Twin Shank Stevmud	1	5-1/2
Hook	1	6

[a]In mud, anchor flukes fixed fully open or held open initially.

Fluke tip penetration, $d_t = d_t/L \cdot L$; L from Figure 6.4.

Table 6.2. Stud-Link Chain Proof and Breaking Loads for Range of Chain Diameters

Diameter	Proof load			Breaking load			Approx weight	
	Grade 2	Grade 3	Oil Rig Quality ORQ	Grade 2	Grade 3	Oil Rig Quality ORQ	15 Fathoms	1000 Feet
Inches	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
1 [illegible]	153000	214000	216000	214000	306000	325000	2353	26144
1 [illegible]	166500	229000	232500	229000	327000	352500	2529	28100
1 [illegible]	176000	247000	249000	247000	352000	380000	2720	30222
1 [illegible]	188500	264000	267000	264000	377000	406000	2926	32511
1 [illegible]	201000	281000	285000	281000	402000	432000	3133	34811
1 [illegible]	214000	299000	303500	299000	427000	460000	3336	37066
2	227000	318000	322000	318000	454000	488000	3528	39200
2 [illegible]	241000	337000	342000	337000	482000	518000	3748	41644
2 [illegible]	255000	357000	362000	357000	510000	548000	3971	44122
2 [illegible]	269000	377000	382500	377000	538000	579100	4218	46866
2 [illegible]	284000	396000	403000	396000	570000	610000	4454	49488
2 [illegible]	299000	418000	425000	418000	598000	642500	4749	52766
2 [illegible]	314000	440000	447000	440000	628000	675000	5016	55733
2 [illegible]	330000	462000	469500	462000	660000	709500	5285	58722
2 [illegible]	346000	484000	492000	484000	692000	744000	5580	62000
2 [illegible]	363000	507000	516000	507000	726000	778500	5878	65311
2 [illegible]	379000	530000	540000	530000	758000	813000	6176	68622
2 [illegible]	396000	554000	565000	554000	792000	849000	6471	71900
2 [illegible]	413000	578000	590000	578000	826000	885000	6782	75355
2 [illegible]	431000	603000	615000	603000	861000	925000	7111	79011
2 [illegible]	449000	628000	640000	628000	897000	965000	7435	82611
2 [illegible]	467000	654000	666500	654000	934000	1005000	7777	86411
3	485000	679000	693000	679000	970000	1045000	8116	90177
3 [illegible]	504000	705000	720500	705000	1008000	1086500	8460	94000
3 [illegible]	523000	732000	748000	732000	1046000	1128000	8815	97944
3 [illegible]	542000	759000	776050	759000	1084000	1169000	9188	02088
3 [illegible]	562000	787000	804100	787000	1124000	1210000	9543	06033
3 [illegible]	582000	814000	833150	814000	1163000	1253000	9929	10322
3 [illegible]	602000	843000	862200	8430[illegible]	1204000	1296000	10314	114600
3 [illegible]	622000	871000	892100	871000	1244000	1339550	10700	118888
3 [illegible]	643000	900000	922000	900000	1285000	1383100	11102	123355
3 [illegible]	664000	929000	970000	929000	1327000	1477000	11488	127644
3 [illegible]	685000	958000	1021000	958000	1369000	1566000	11878	131978
3 [illegible]	728000	1019000	1120000	1019000	1455000	1750000	12661	140678
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4	816000	1143000	1298000	1143000	1632000	1996500	14324	159156
4 [illegible]	862000	1207000	1347400	1207000	1724000	2062500	15272	169689
4 [illegible]	908000	1272000	1397000	1272000	1817000	2134000	16405	182277
4 [illegible]	956000	1338000	1569700	1338000	1911000	2398000	17441	193788
4 [illegible]	1004000	1405000	1672000	1405000	2003000	2508000	18477	205300
4 [illegible]	1053000	1474000	1775000	1474000	2105000	2675000	19260	214000
4 [illegible]	1102000	1543000	1870000	1543000	2204000	2805000	20263	225144
4 [illegible]	1153000	1613000	1904000	1613000	2305000	2852000	21642	240465
5	1203000	1685000	1940000	1685000	2407000	2900000	22766	252955
5 [illegible]	1255000	1757000	2000000	1757000	2509000	2995000	23902	[illegible]65577
5 [illegible]			2060000			3090000	25100	[illegible]78888
5 [illegible]	1359000	1903000	2125000	1903000	2718000	3185000	26371	2[illegible]3011
5 [illegible]			2190000			3280000	27500	305[illegible]55
5 [illegible]	1466000	2052000	2250000	2052000	2932000	3349000	28700	318[illegible]89
5 [illegible]	1520000	2128000	2310000	2128000	3039000	3418000	30054	333933
6	1629000	2280000	2444000	2280000	3257000	3568000	32567	361855
6 [illegible]	1684000	2357000		2357000	3367000		33600	373333
6 [illegible]	1795000	2512000		2512000	3589000		36550	406111

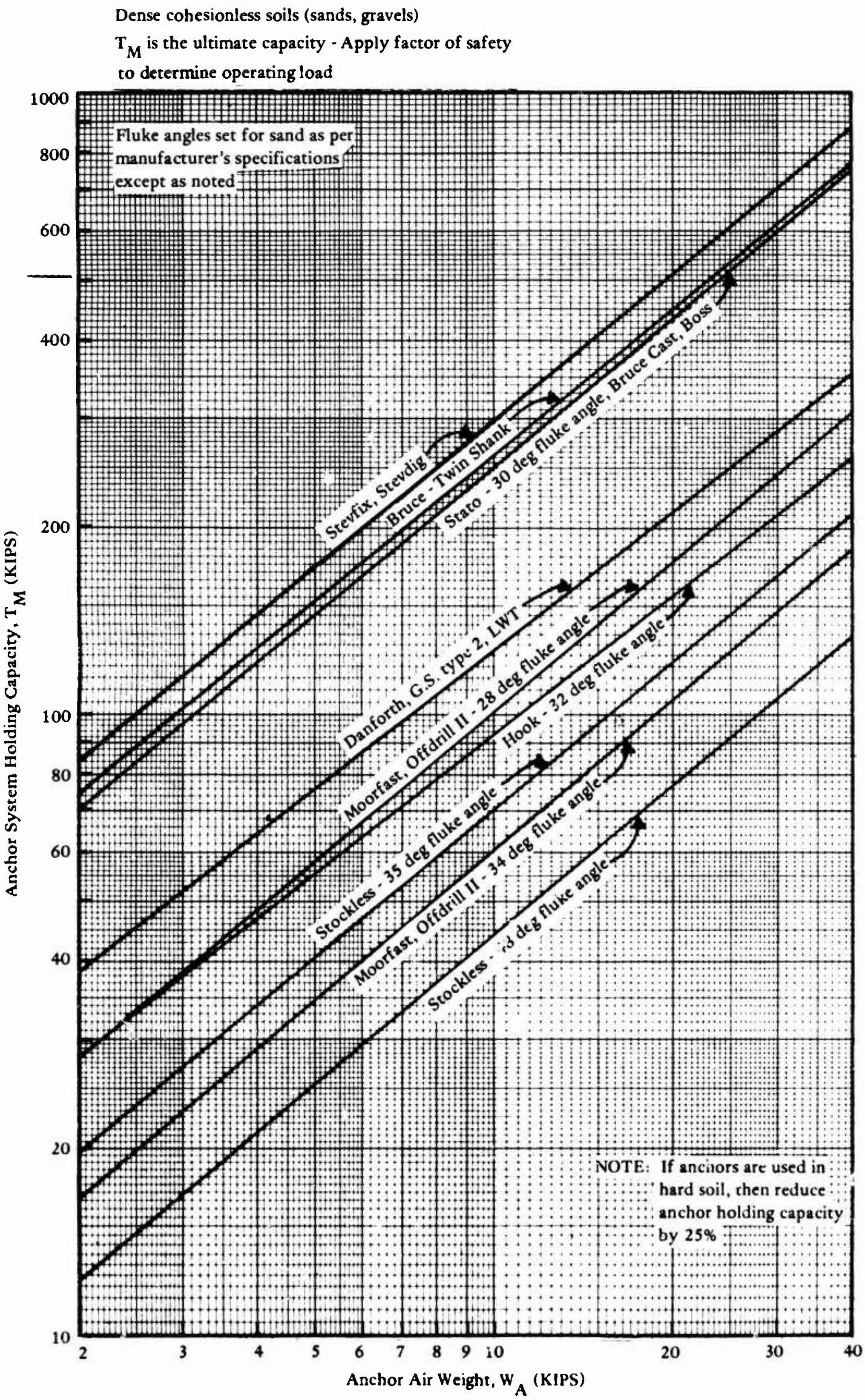


Figure 6.1. Holding capacity at mudline - sand (anchor-chain system).

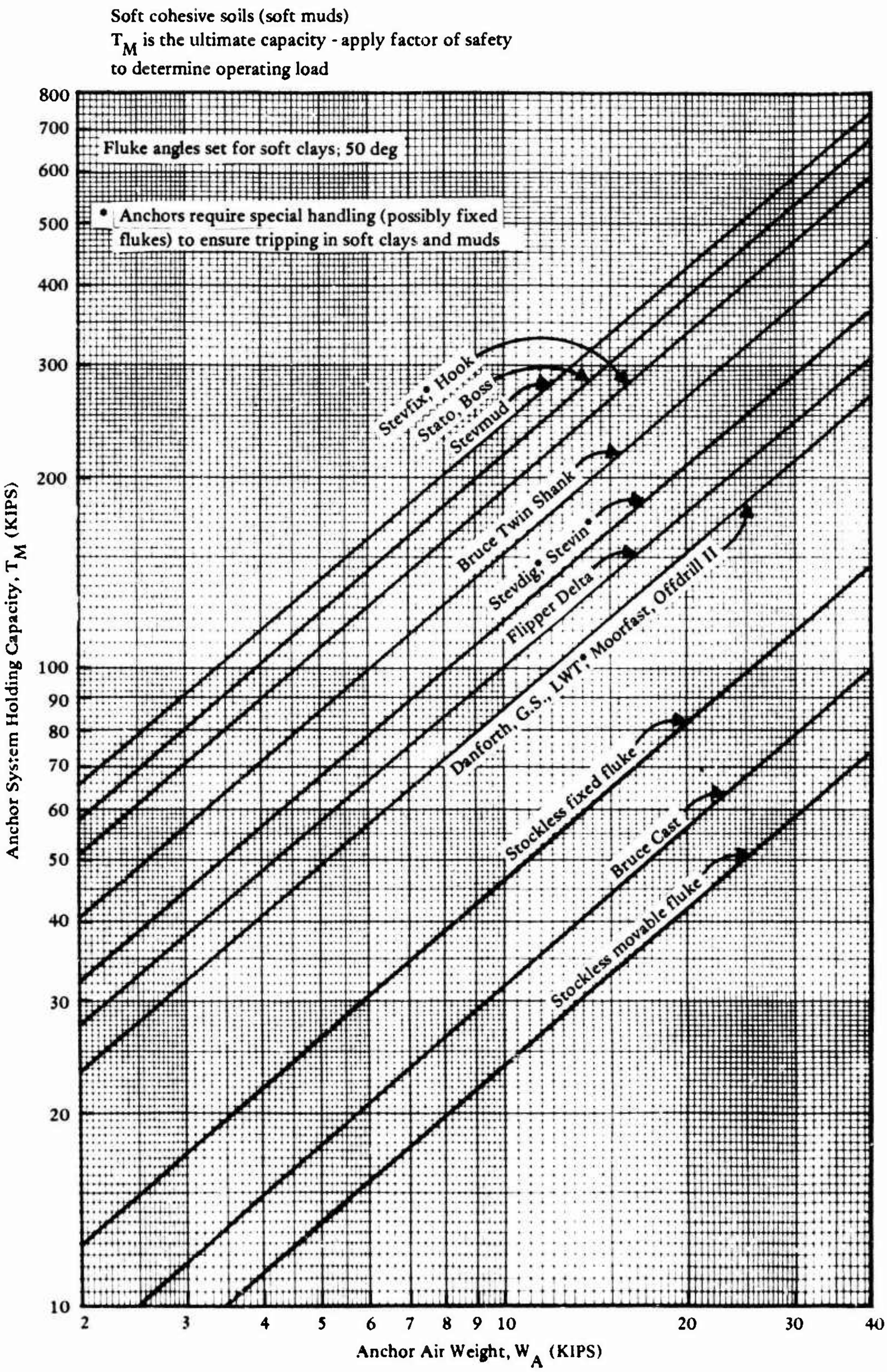
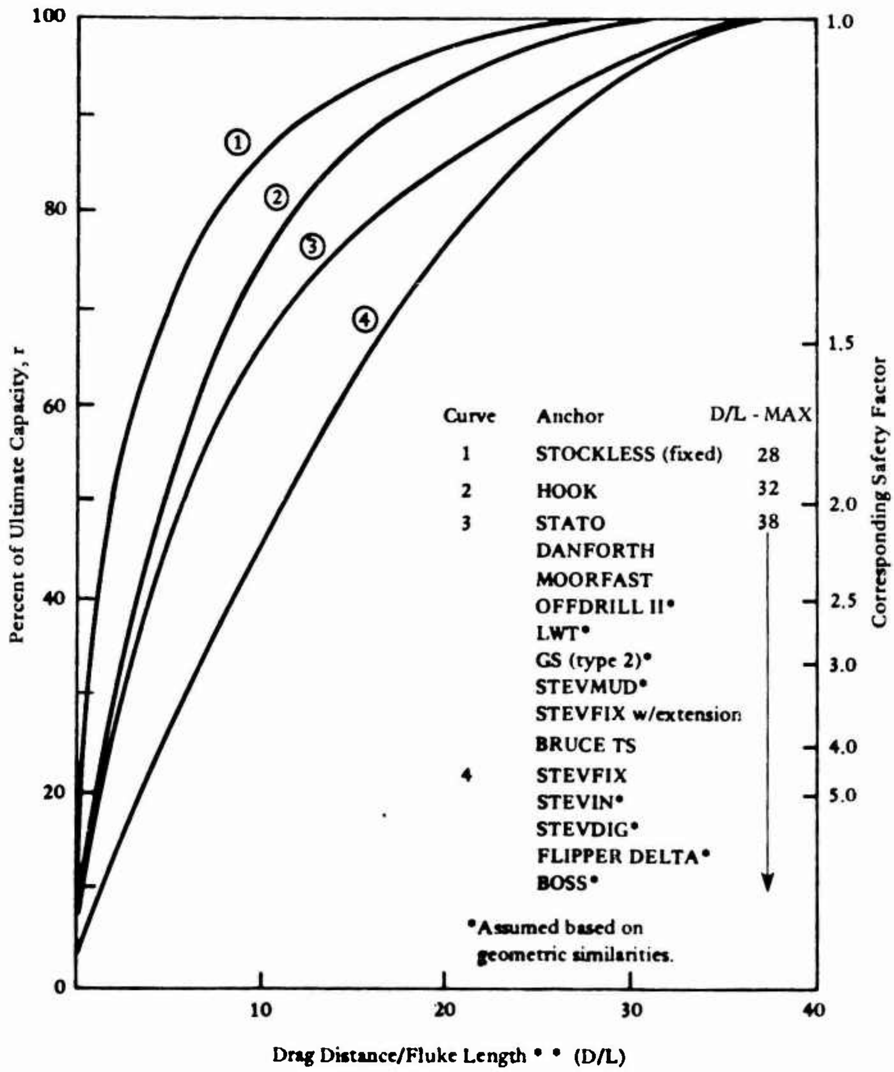


Figure 6.2. Holding capacity at mudline - mud (anchor-chain system).



** ANCHOR FLUKE LENGTH AS DEFINED HERE WAS TAKEN FROM MANUFACTURERS' LITERATURE; MANUFACTURERS OFTEN INCLUDE THE CROWN AND TRIPPING PALM IN THEIR DEFINITION OF FLUKE LENGTH.

Figure 6.3 Percent of ultimate holding capacity mobilized versus normalized drag distance in mud.

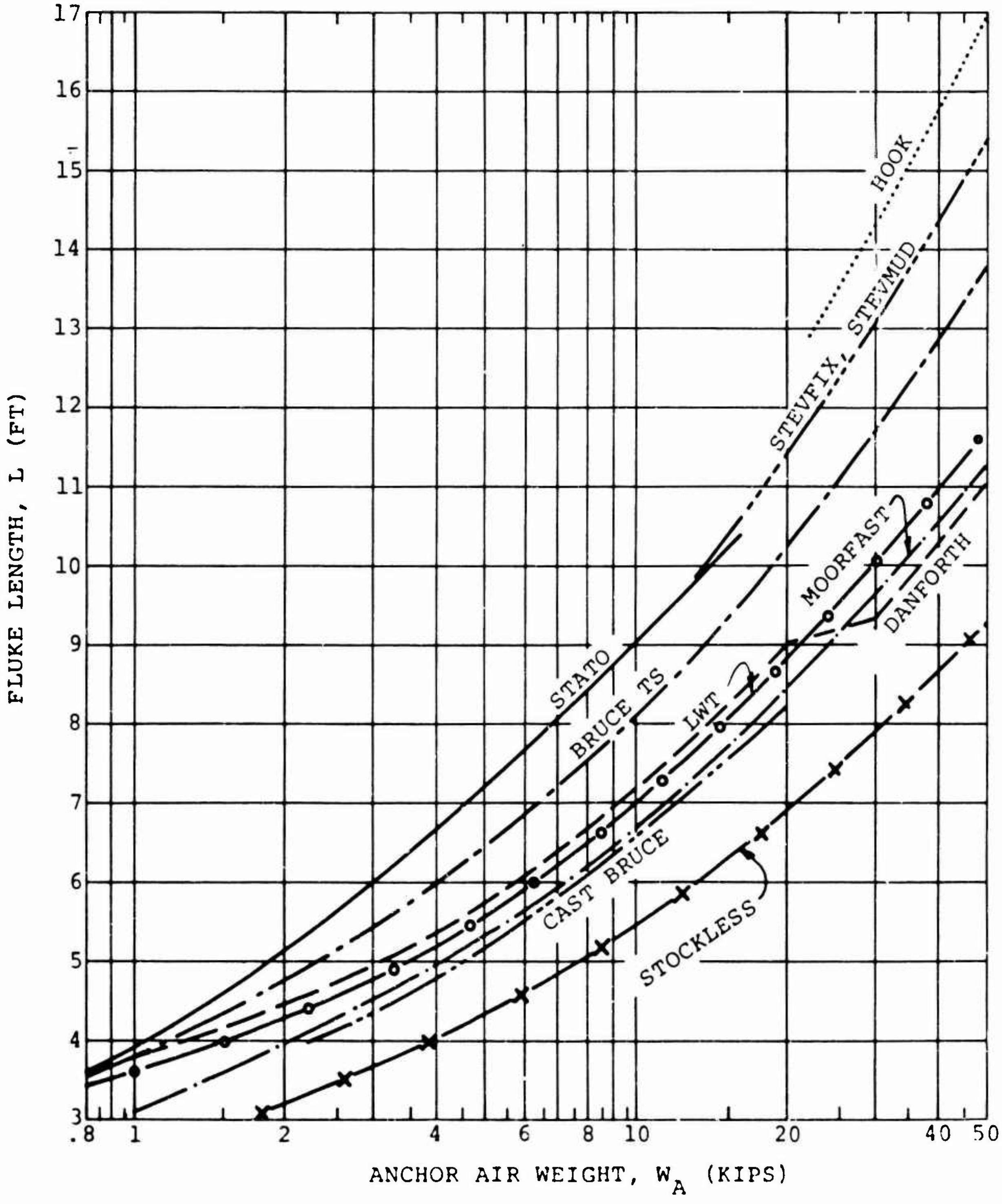
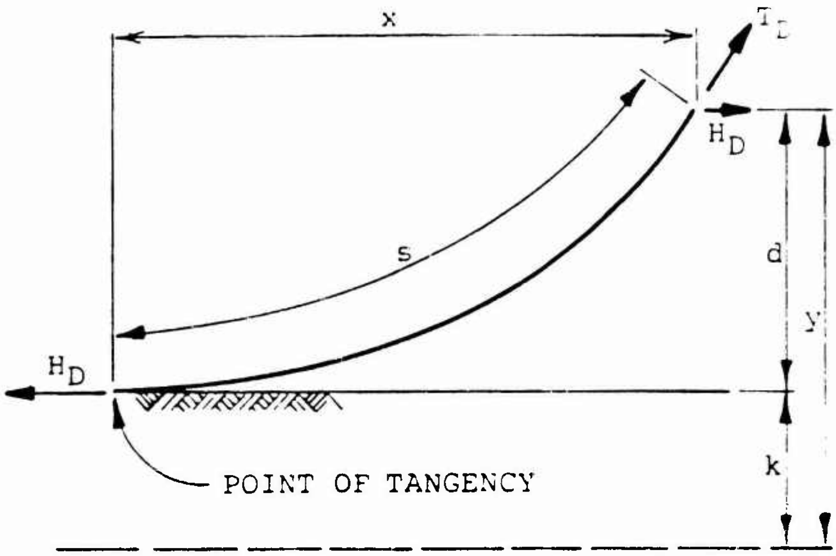


Figure 6.4 Fluke length versus anchor air weight for several drag anchor types.



TO DETERMINE TENSION AT VESSEL:

$$T_D = w(k + d)$$

where: w = mooring line weight per length
k = H_D/w
d = water depth

TO DETERMINE CATENARY LENGTH:

$$s = [d(2k + d)]^{0.5}$$

Refer to NAVFAC DM-26 (Ref 2) for added details.

Figure 6.5. Catenary characteristics.

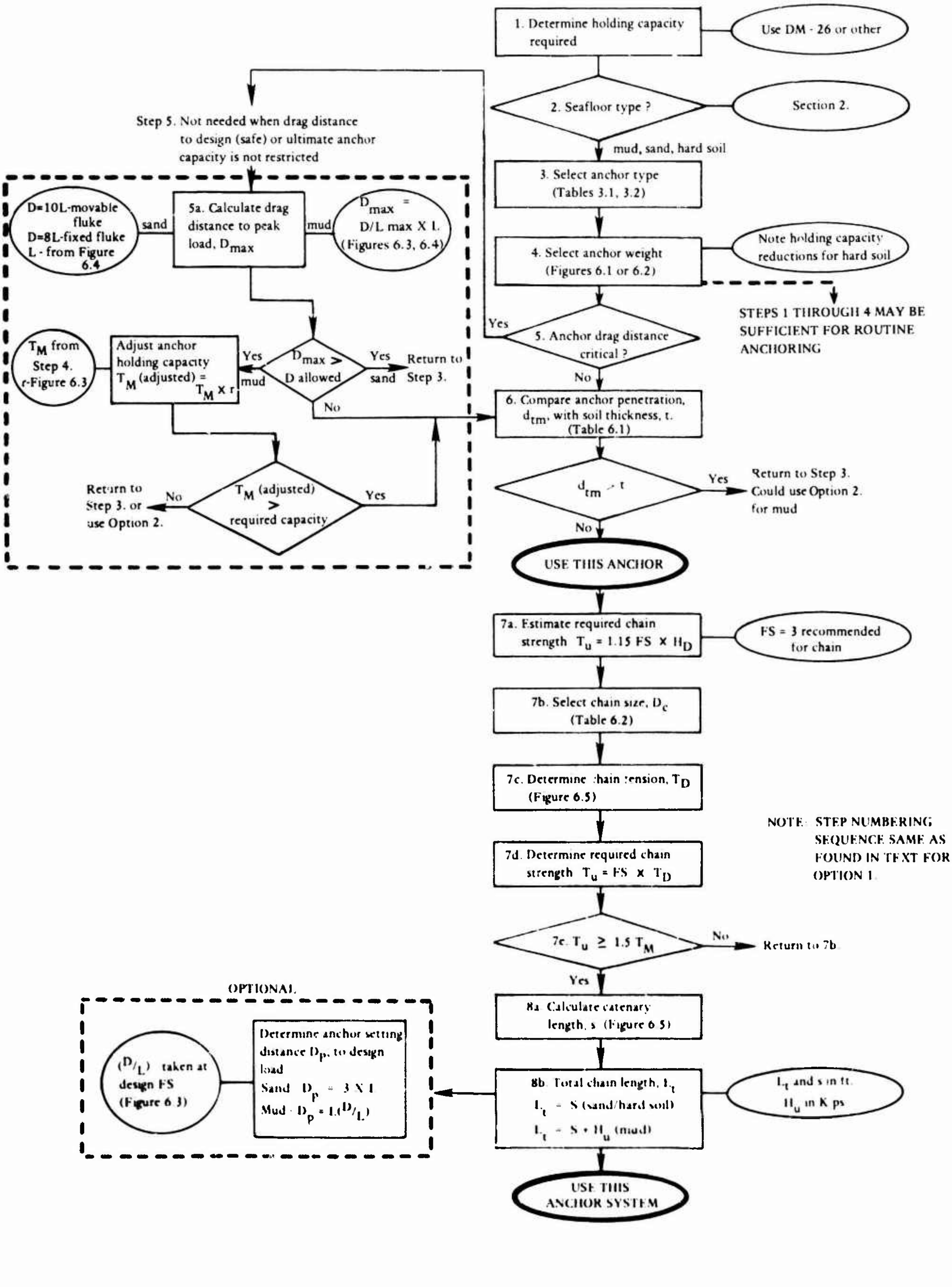
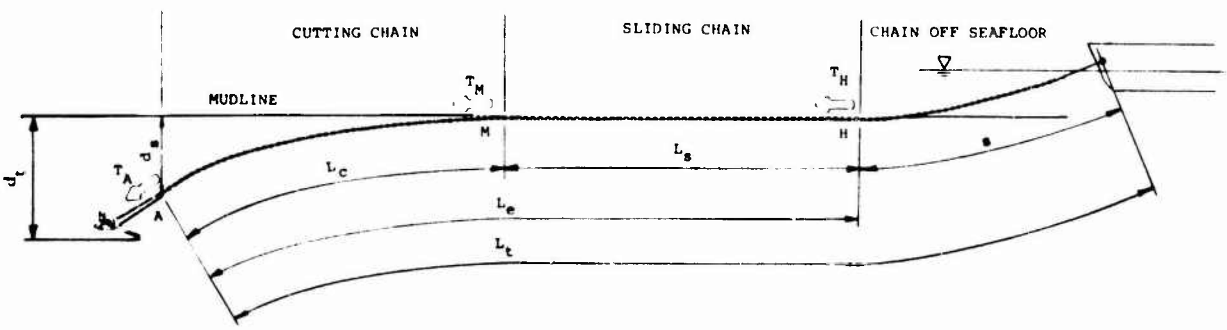


Figure 6.6. Flow chart of Option 1 - Holding capacity curve design method.

7. OPTION 2 - ANALYTIC MODEL

[Applicable only to muds and clays.]

Option 2 requires calculation of total holding capacity by anchor system element. Calculation starts with anchor, then cutting chain, followed by sliding chain. A flow chart of this procedure is provided as Figure 7.1.



DEFINITION OF SYMBOLS FOR ANCHOR-MOORING LINE SYSTEM

A. RANGE OF VALIDITY OF OPTION 2

Soil Strength Profile

The analytic method of Option 2 should be applied only to normally consolidated cohesive soil profiles with a range of strength gain rates (with depth) of 0.010 ksf/ft ± 0.003 ksf/ft.

This limitation does not apply to the method when the penetration depth is known. The procedure for calculating the anchor holding capacity, when the penetration depth and soil strength at the anchor are known, will be valid for a broad range of soil strengths, through the soft clay range to the mid-medium strength clay range (i.e., up to an undrained soil shear strength of 0.7 ksf).

Mooring Line Type

The analytic method (in particular the anchor penetration prediction) is believed applicable only when the chain size is such that the chain breaking load is 50% greater than the ultimate capacity of the anchor. This situation exists when a factor of safety of 2 is used for design of the anchor and 3 is used for the mooring chain. When the mooring line to the anchor is wire rope or oversized chain, then the developed penetration relationships are not valid; however, modifications to the developed procedure to account for these untested conditions are suggested in Section 7C.

B. PROCEDURE

Loads and Soil Description

1. Obtain loads as described for Option 1 (Section 6, step 1).

2. Identify seafloor material type (Section 2). In addition, obtain undrained soil shear strength, s_u, via in-situ tests or laboratory tests on core samples (Ref 1).

Anchor Type and Size

3. Select anchor type (Tables 3.1 and 3.2).

4. Select anchor weight and calculate anchor ultimate holding capacity, T_{AU}.

   a. Select anchor initial air weight, W_A:

$$W_A = (0.75)\ H_U/e$$

where: H_U = required ultimate horizontal capacity

e = anchor efficiency (Table 3.2)

Or use Figure 6.2 at $T_M = 0.75\ H_U$ to determine W_A.

b. Obtain anchor fluke length, L (Figure 6.4).

c. Estimate fluke tip penetration, d_t, as lesser of:

(1) Maximum penetration, d_{tm}, at unlimited drag distance, D (Figure 7.2 at D/L = 50).

(2) Penetration, d_t, at specified maximum allowable drag distance, D.

(3) Thickness of soil layer, t.

d. Obtain undrained soil shear strength, s_u, from step 2, at depth d_t.

e. Obtain holding capacity factor, $N_c fBL$, from Figure 7.3.

f. Calculate anchor ultimate capacity, T_{AU}.

$$T_{AU} = s_u(N_c\ f\ BL)$$

where: N_c = holding capacity factor sensitive to plate shape and depth (dimensionless)

f = factor converting the rectangular fluke area $B \cdot L$ to true fluke area (dimensionless)

B = anchor fluke width

g. Check adequacy of anchor selection with respect to ultimate capacity. If $T_{Au} \neq (0.75 \text{ to } 0.85) \cdot H_U$, then select new anchor air weight and repeat steps 4c through 4g.

5. If maximum allowable design drag distance is specified, then calculate anchor design holding capacity, T_{AD}. A 50-ft allowable drag distance to design or safe working anchor capacity is typical for Navy fleet moorings. Initiate calculation with anchor selection from step 4g.

   a. W_A, L, $N_c fBL$, and soil layer thickness available from step 4.

   b. Estimate fluke penetration depth, d_t, as lesser of:

      (1) Fluke penetration, d_t, at design drag distance, D (from Figure 7.2).

      (2) Thickness of soil layer, t.

   c. Obtain undrained soil shear strength, s_u, at depth d_t.

   d. Calculate anchor design capacity, T_{AD}:

$$T_{AD} = s_u(N_c \, f \, BL)$$

   e. Check adequacy of anchor selection with respect to design capacity. If $T_{AD} < (0.75 \text{ to } 0.85) \cdot H_D$, then return to step 4a and select larger anchor air weight. Repeat steps 4 and 5.

Chain Size

6. Select chain size.

   a. Estimate chain breaking load, T_U:

   $$T_U = 1.15 \cdot FS \cdot H_D \quad (FS = 3 \text{ for chain})$$

   b. Select chain size, D_c (Table 6.2).

   c. Calculate chain maximum tension, T_D (Figure 6.5).

   d. Calculate chain required breaking load, T_U:

   $$T_U = FS \cdot T_D \quad (FS = 3 \text{ for chain})$$

   e. Check adequacy of chain size.

      (1) If T_U differs significantly from chain breaking load (Table 6.2), then repeat steps 6b through 6e with new selection.

      (2) Chain breaking load should be at least 1.5 · maximum anchor-chain system capacity, T_M.

Anchor-Embedded Chain System Holding Capacity

7. Determine anchor system capacity, T_M, at maximum penetration.

   a. Obtain depth of anchor end of chain, d_s, the lesser of:

      (1) Maximum penetration, d_{sm}, at unlimited drag distance, D, (from Figure 7.4 at D/L = 50).

(2) Maximum penetration at specified maximum allowable drag distance, D.

(3) Thickness of layer, t, minus one fluke length, L.

b. Obtain anchor-embedded chain capacity, T_M, from Figure 7.5. Interpolate for intermediate chain sizes. NOTE: Figure 7.5 can be used to determine T_M at any anchor drag distance.

c. Check adequacy of anchor selection with respect to anchor-chain system ultimate capacity. If $T_M < H_U$, then select next larger anchor air weight and repeat steps 4b through 4f and steps 7a through 7c.

d. Check adequacy of anchor selection with respect to anchor-chain system design capacity if capacity is limited by drag distance. Determine $T_{MS} = T_M/FS$. If $T_{MS} > T_M$* at a specified drag distance, use $T_M = T_{MS}$ and compare to H_D. If $T_M < H_D$, select a larger anchor.

Total Chain Length

8. Determine total chain length from anchor to vessel fairlead.

a. Determine length of chain cutting into the seafloor, L_c. Given T_M and d_s from step 6, obtain L_c from Figure 7.6.

b. Determine length of chain in catenary, s (Figure 6.3). For economy, use s at design, not ultimate load.

c. For optimum design, length sliding on seafloor, L_s, is zero. See Section 8 to include sliding segment, L_s.

---

*T_M = T_{AD} (from 5d) + buried chain resistance.

d. Total length of chain required, L_t, is:

$$L_t = L_c + L_s + s$$

9. Calculate anchor setting distance to design load.

a. Select D/L from Figure 6.3 at appropriate FS. FS = 2 is recommended and values are provided.

$$D_p = L(D/L)$$

C. MODIFICATIONS FOR WIRE ROPE AND OVERSIZED CHAIN

The developed method for anchor penetration prediction is believed to apply only for those chain-anchor combinations where the chain breaking strength is about 50% greater than the anchor ultimate capacity. When the mooring line to the anchor is wire rope or oversized chain, then the following modifications are suggested to the holding capacity prediction procedure.

Wire Rope

A wire rope mooring line will not develop significant holding capacity, and its contribution can be ignored. However, the anchor in this system will penetrate deeper, reaching stronger soils. It is suggested that the holding capacity of the wire rope-anchor system be assumed equal to that of the appropriate chain-anchor system.

To estimate the depth of anchor penetration for the wire rope system, the entire system holding capacity, T_M, is assumed to be developed at the anchor. Then the equation

$$s_u = T_A/(N_c \ f \ BL)$$

is used to determine the undrained soil strength, s_u, necessary to develop that T_A, and the soil strength profile is examined to find the soil depth at which that strength is found.

Oversized Chain

Oversized chain used in an anchor system will develop an increased resistance to mooring line penetration because of its larger bearing and frictional areas. Thus, penetration of the attached drag anchor will be inhibited, and the holding capacity developed by the anchor itself will be smaller (than with the normal-sized chain) because the anchor will be in shallower, weaker soil. It is suggested, to be on the safe side, that the holding capacity, T_M, of the oversized chain-anchor system be assumed equal to that of the appropriate chain-anchor system. Then the probable penetration of the oversized chain-anchor system is projected through an iterative process.

For the first iteration the anchor penetration depth is reduced by 10% from that predicted from Figure 7.2. The anchor contribution at this depth is computed from step 4f, and the contribution of the oversized chain is added using Figure 7.5. The system holding capacity from the first iteration, T_{M1}, is then compared to the assumed holding capacity, T_M, and the assumed depth of anchor penetration is adjusted. The iterations are repeated until the desired fit is achieved between T_M and T_{Mn}.

It is emphasized here that neither this suggested method for treating anchor systems with oversized chain nor the method for wire rope mooring lines has been validated in the field or laboratory.

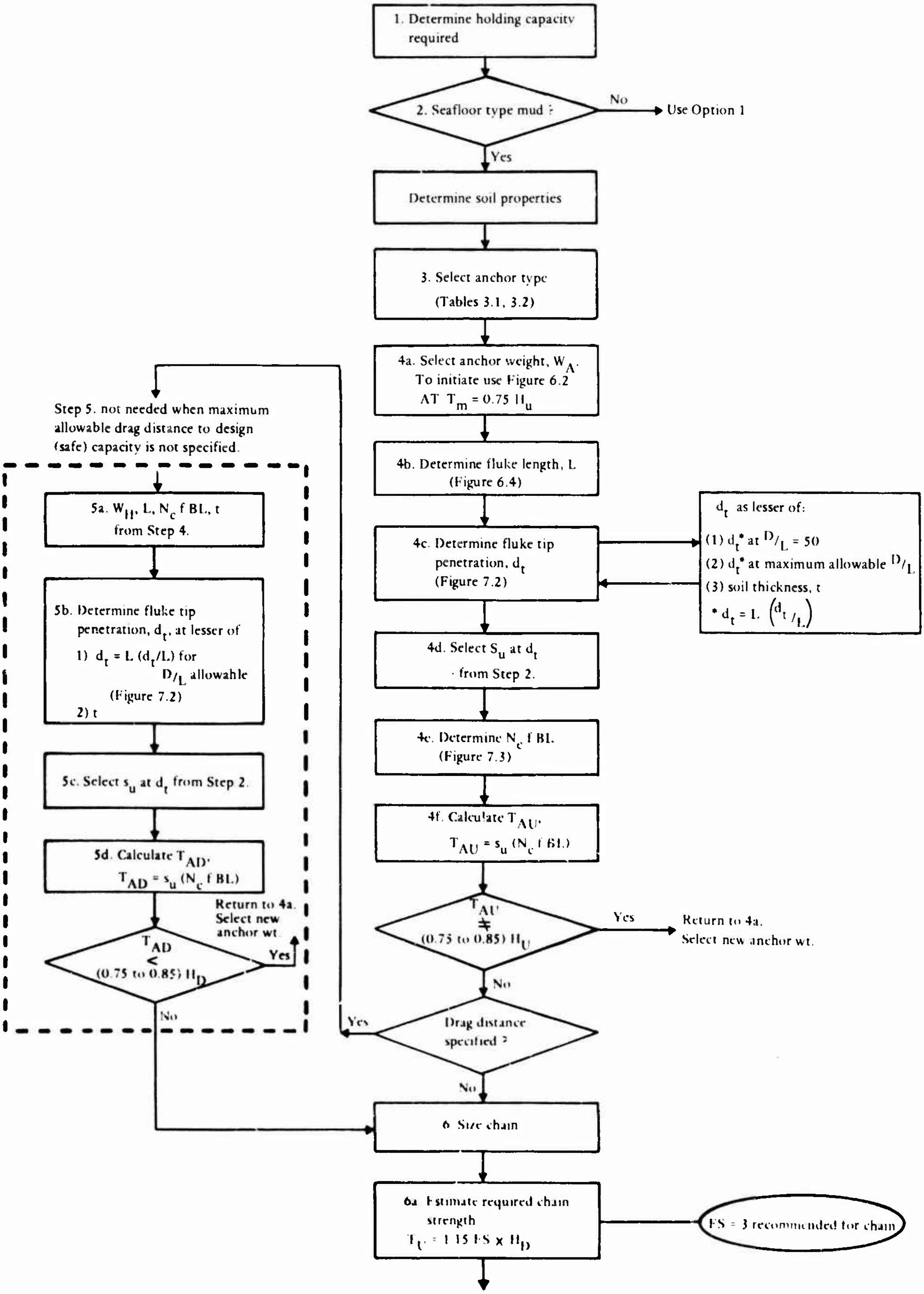


Figure 7.1. Flow chart of Option 2 - Analytic Model.

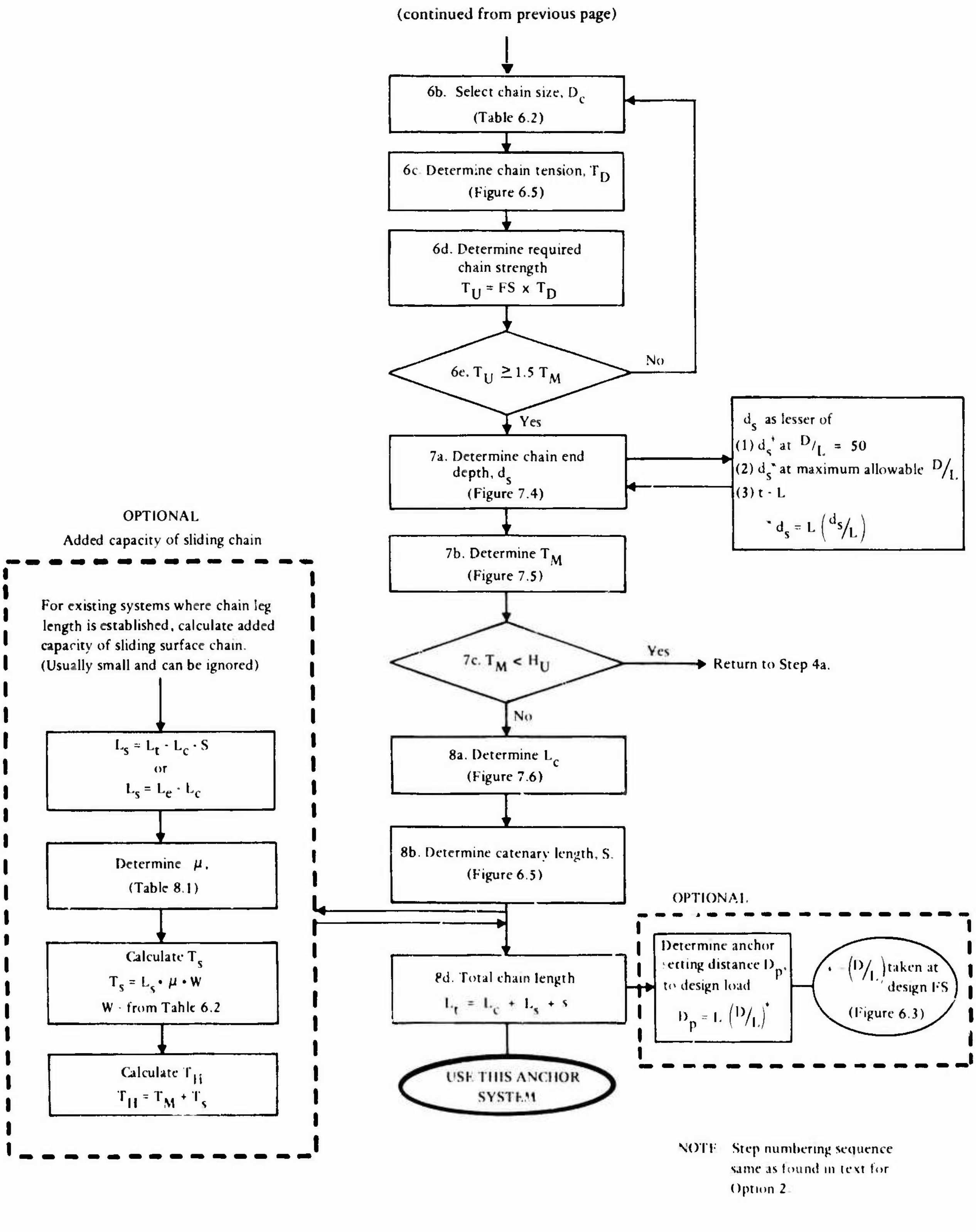


Figure 7.1. Continued

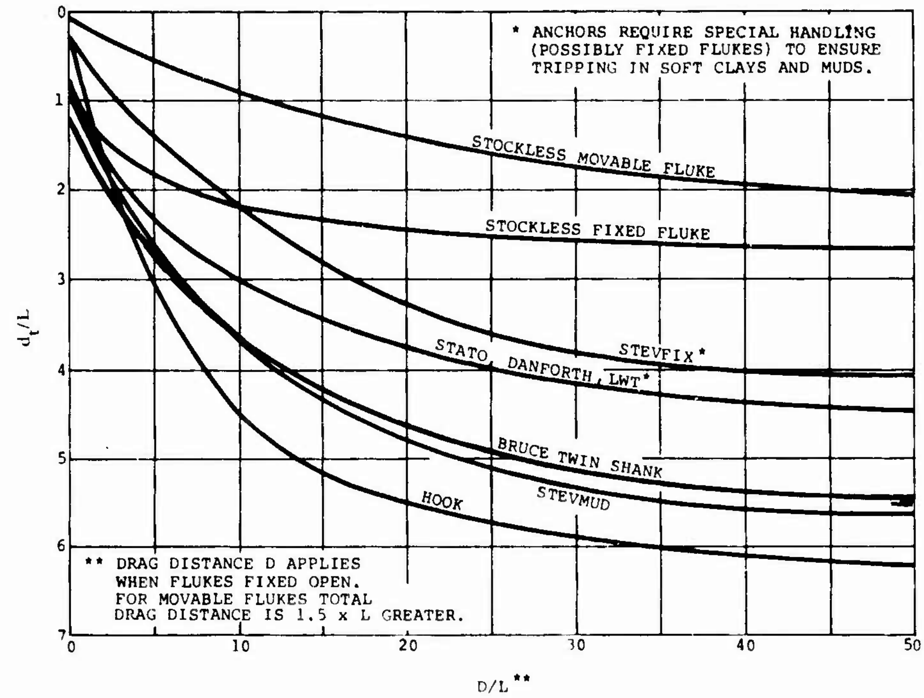


Figure 7.2 Predicted normalized fluke tip penetration versus normalized drag distance.

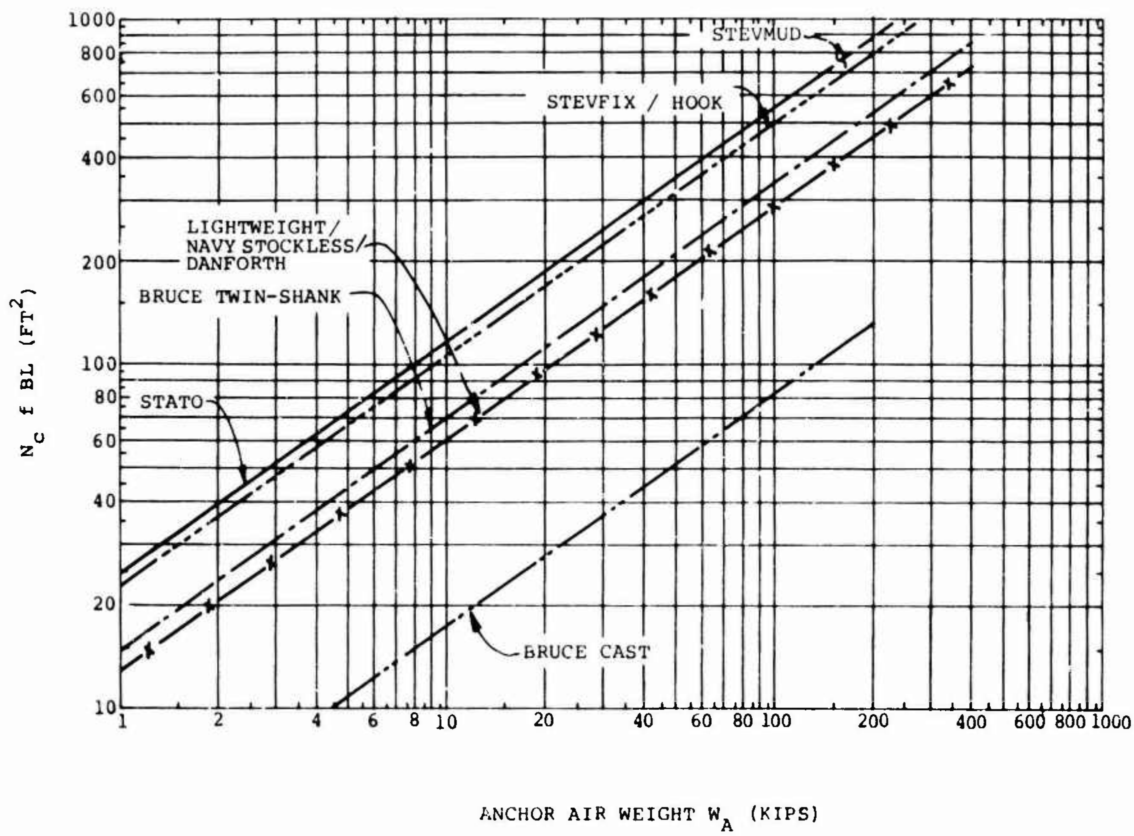
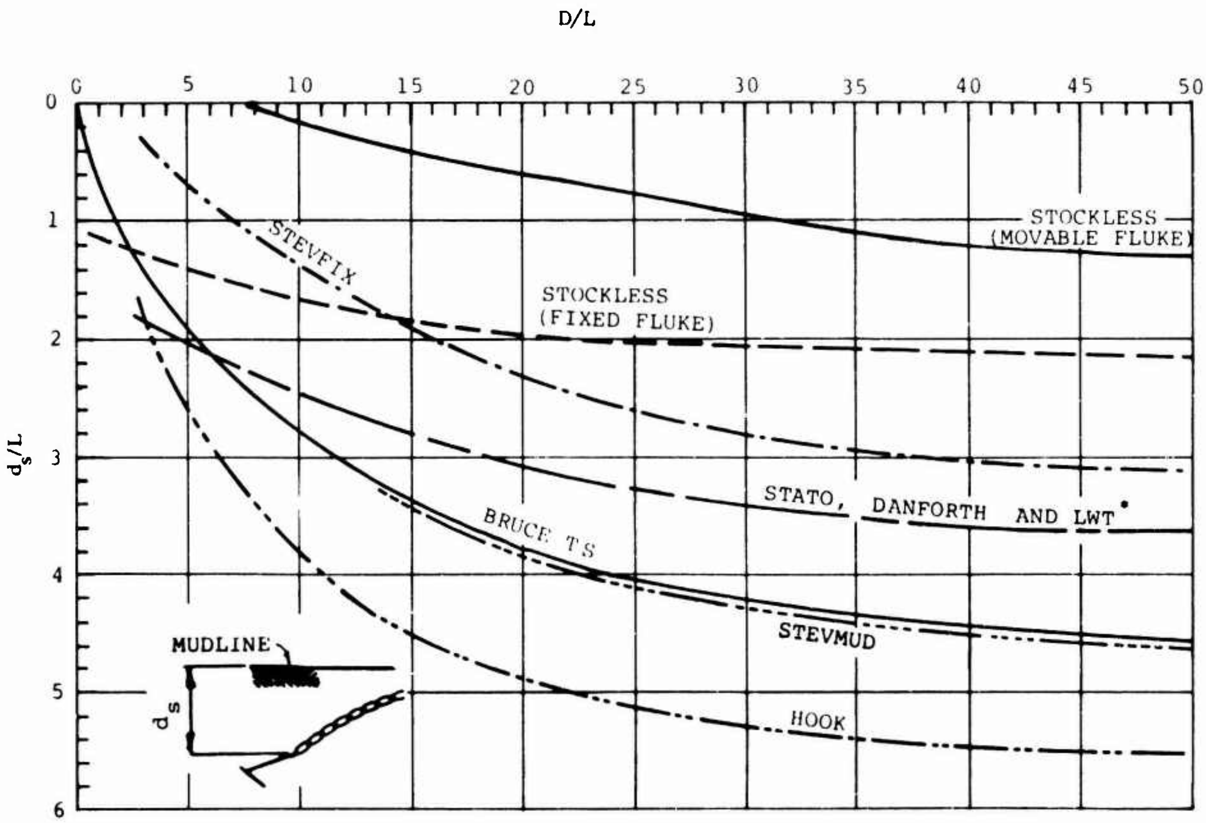


Figure 7.3 Anchor holding capacity factor, $N_c fBL$, versus anchor air weight, W_A, based on anchor designs available in June 1982.



*For pre-set or fixed open flukes

Figure 7.4 Normalized shank tip penetration versus normalized drag distance for eight anchor types.

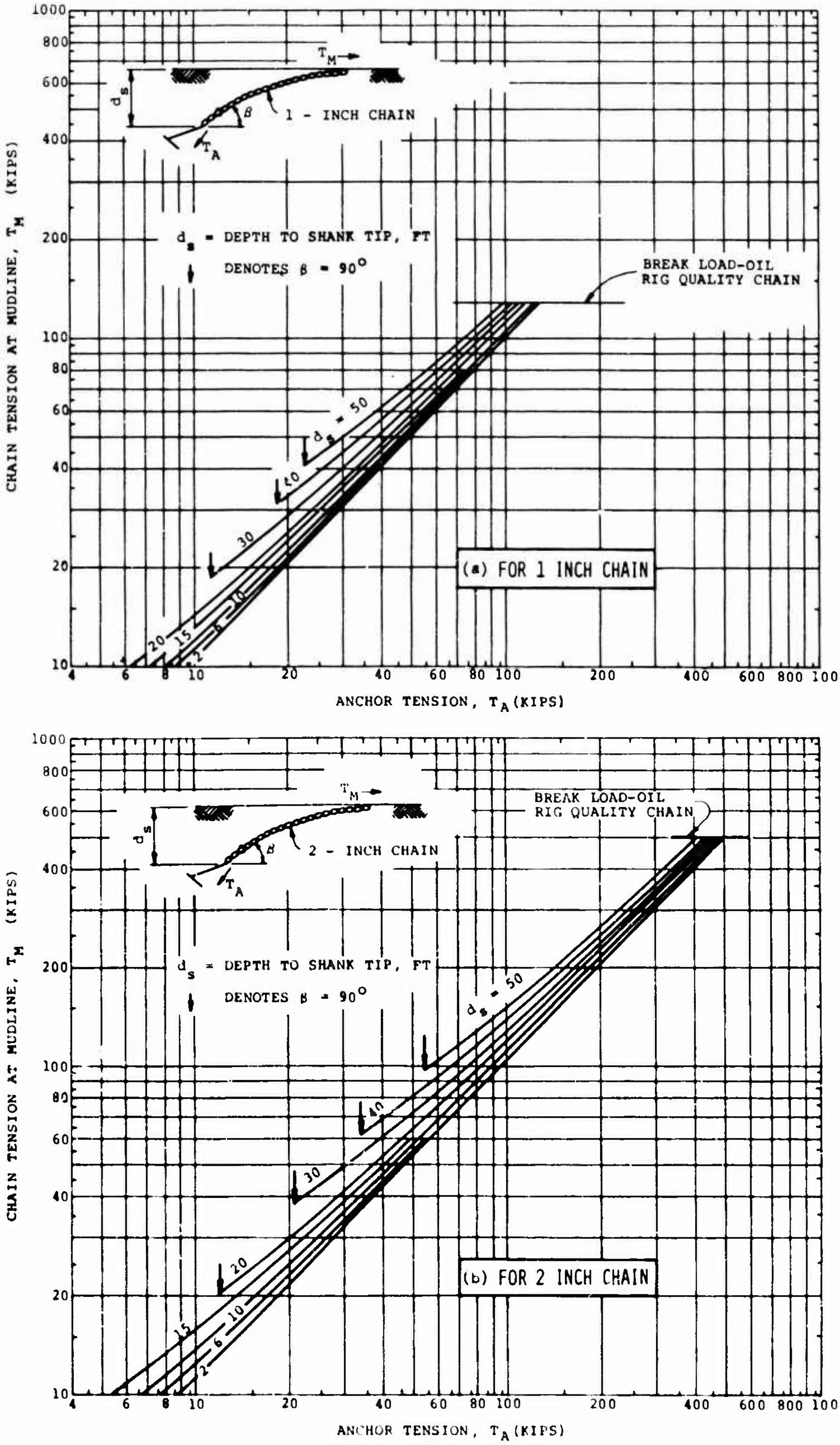
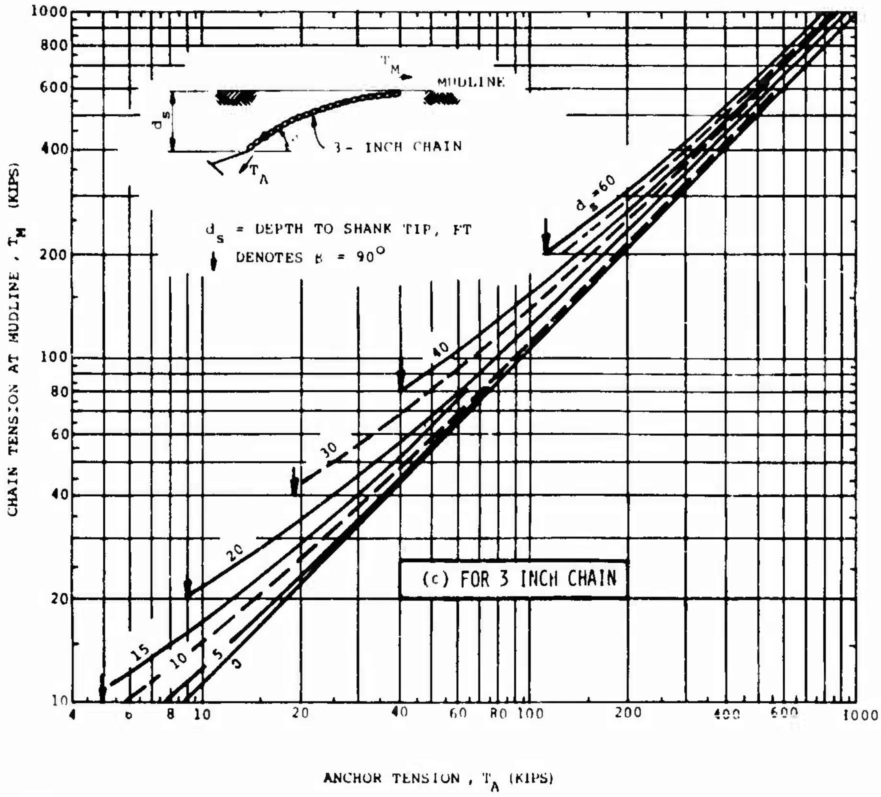


Figure 7.5 Tension at mudline versus tension at anchor.



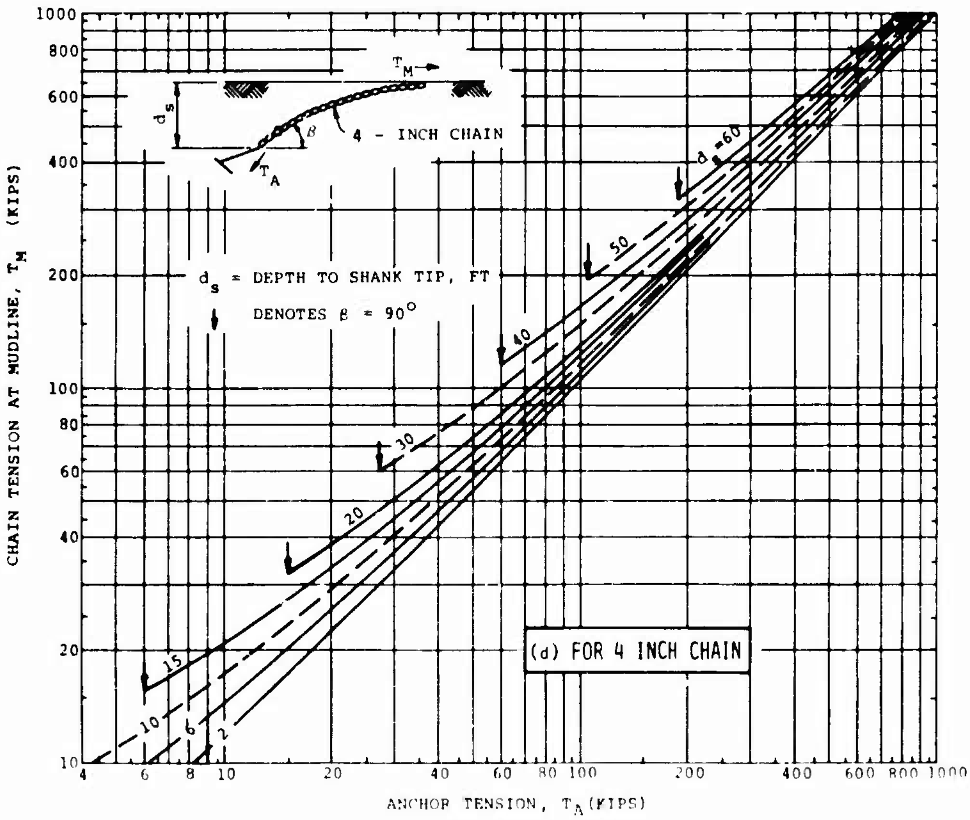
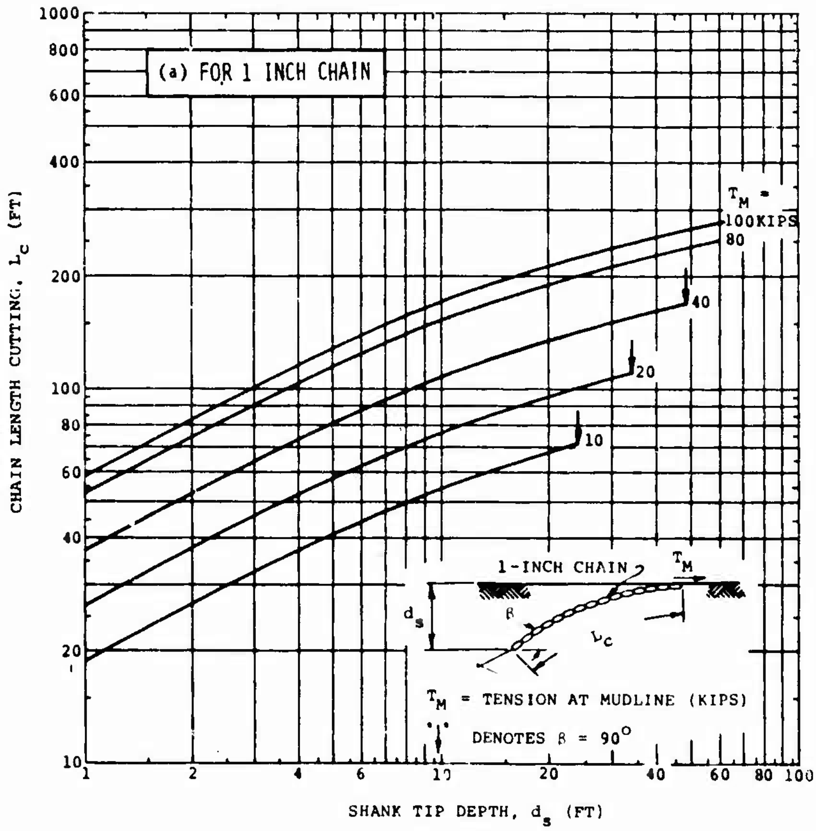


Figure 7.5 Continued.



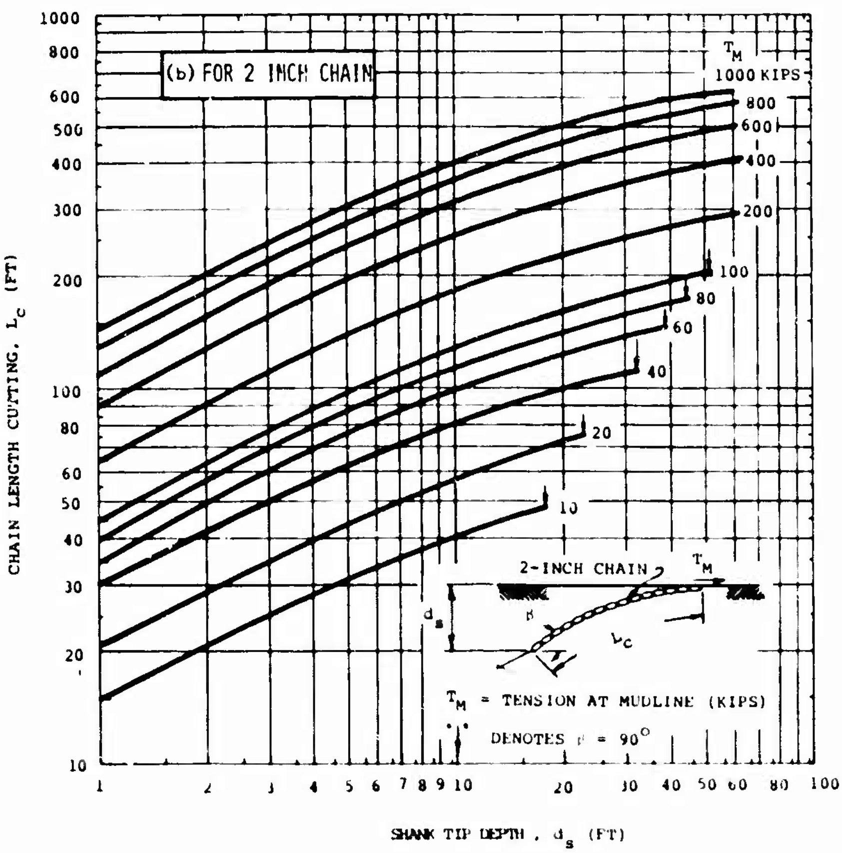
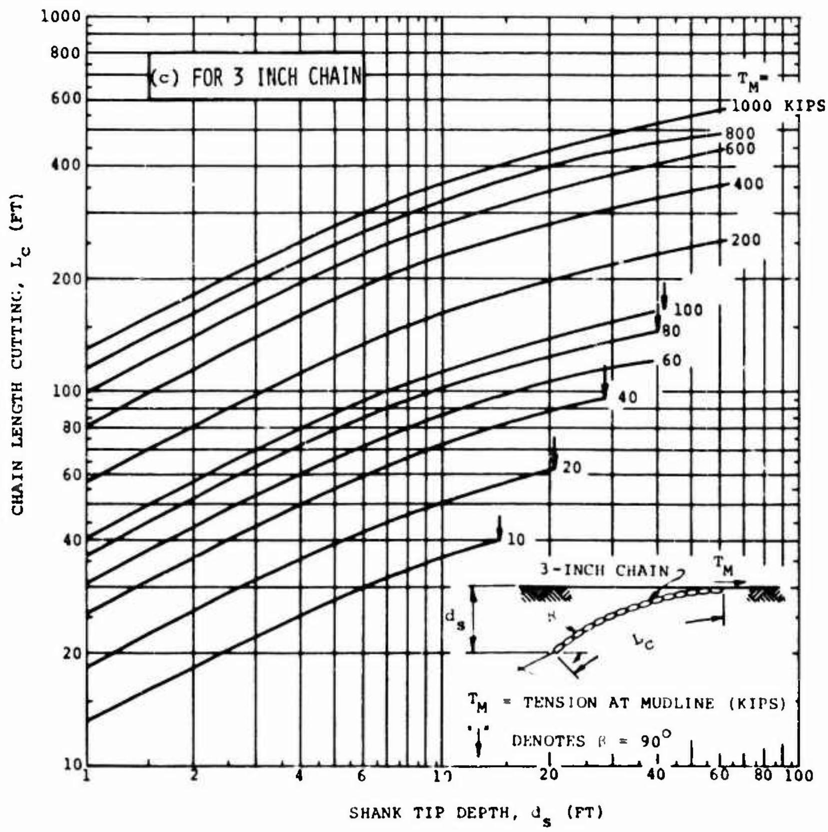


Figure 7.6 Length of chain cutting into soft clay seafloor versus depth of anchor shank tip. Chain assumed tangent to seafloor at mudline.



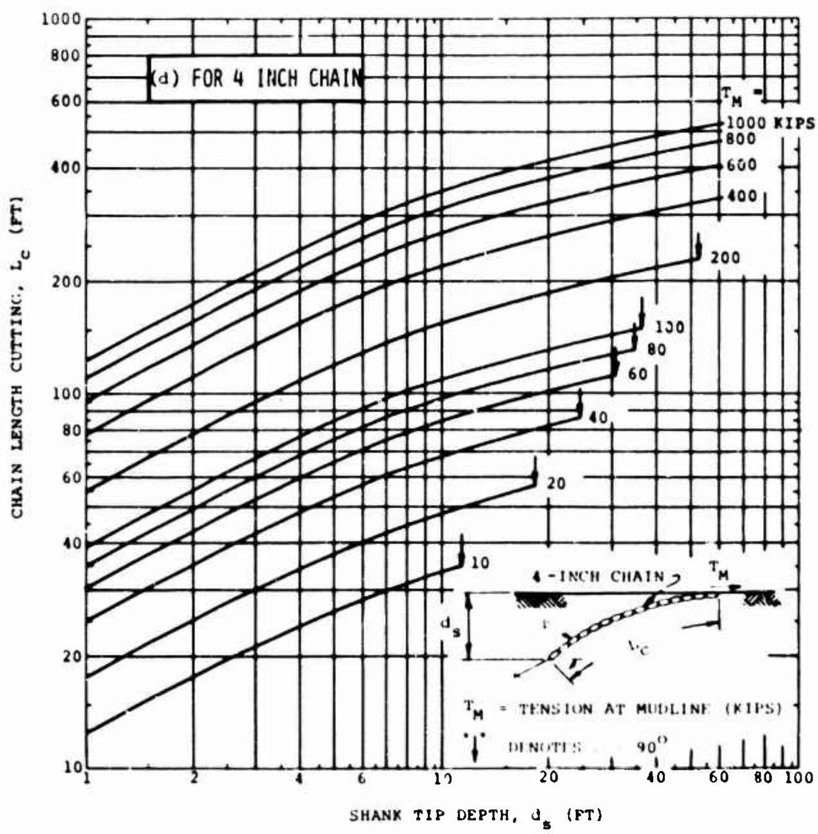


Figure 7.6 Continued.

8. ADDED HOLDING CAPACITY FROM SLIDING CHAIN

A. APPLICATION

An optimum design uses the anchor and embedded or cutting chain to develop the necessary holding capacity. The use of additional chain, to lie on the seafloor and provide added "frictional" resistance, is generally not a cost-effective way to develop added necessary system holding capacity. Generally, anchor system capacity is best increased by increasing anchor size rather than chain length. However, for those situations where nonoptimum choices must be made, the following guidance is given for the prediction of the sliding resistance of mooring line lying on the seafloor, L_s. Refer to Section 7, page 29 for definitions.

B. PROCEDURE

1. Calculate length of sliding mooring line, L_s.

   a. Options 1 and 2:

      (1) On sand seafloors,

$$L_s = L_t - s$$

      (2) On mud seafloors,

$$L_s = L_t - (s + H_U)$$

where: H_U = ultimate horizontal holding capacity in kips

b. Option 3:

$$L_s = L_t - (s + L_c)$$

2. Calculate friction force, T_S, developed by sliding section of mooring line.

$$T_S = L_s w\mu$$

where: w = weight of mooring line per unit length from Table 6.2

μ = friction coefficients from Table 8.1.

3. Calculate total horizontal holding capacity, T_H:

$$T_H = T_M + T_S$$

Table 8.1. Recommended Friction Factors for Mooring Line

Mooring Line	Ocean Bottom	Friction Factors, μ	
		Starting	Sliding
Chain	Sand[a]	0.98	0.74
	Mud With Sand[a]	0.92	0.69
	Mud/Clay	0.90	0.56
Wire Rope	Sand[a]	0.98	0.25
	Mud With Sand[a]	0.69	0.23
	Mud/Clay	0.45	0.18

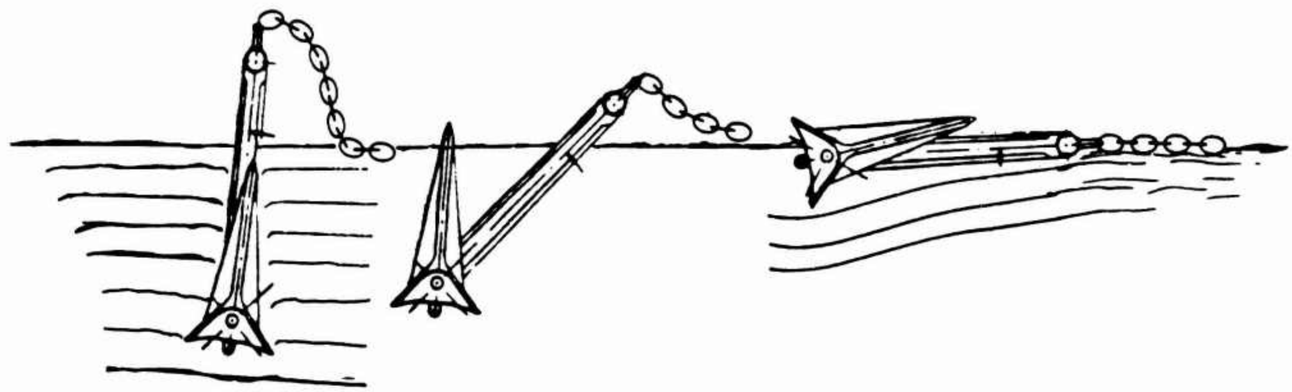
[a](from Ref 3)

9. IMPROVING ANCHOR PERFORMANCE

Anchors do not always behave as predicted. Table 9.1 provides guidance that was derived from analysis of field anchoring problems to enable field corrections to poor anchor behavior. Figures 9.1 through 9.4 illustrate some of the problems described in Table 9.1.

Table 9.1. Ways to Improve Anchor Performance

Problem	Symptom	Possible Reason	Possible Solution
Poor mud performance	• Near constant line tension 1/2 to 2 times weight of anchor and mooring line on seabed (see Figure 9.1)	• Flukes not tripping	• Increase size of tripping palms; add stabilizer • Weld or hold flukes in open position and place anchor right-side-up
	• Drop in tension during proof-loading with continued drag	• Anchor unstable	• Add stabilizers • Increase stabilizer length • Use different or larger anchor
		• Soil more competent than anticipated	• Reduce fluke angle to sand setting or if possible by a smaller amount (5 to 10-deg reduction)
	• Proof-load tension less than needed	• Seafloor softer than expected • Less sediment than needed over harder substrata	• Use larger anchor • Use different anchor • Add chain • Use backup anchor
Poor sand/ hard soil performance	• Near constant tension 1 to 3 times weight of anchor and mooring line on seabed (Figure 9.2)	• Flukes not tripping	• Sharpen fluke tips; add fluke tip barbs to break up soil • Weld or block flukes in open position • Extend anchor crown by lightweight pipe or plate construction • Water jet anchor flukes into seabed
	• Variable tension 3 to 10 times weight of anchor and mooring line on seabed (Figure 9.3)	• Flukes not penetrating	• Reduce fluke angle; reduction to as little as 25 deg may be needed for very dense or hard soils • Sharpen flukes • Extend or add stabilizers • Use larger or different anchor
	• Rapid drop in tension during proof-loading with continued drag (Figure 9.4)	• Anchor unstable	• Extend or add stabilizers • Use larger or different anchor
	• Proof-load tension less than needed	• Less sediment than needed • Very hard seafloor	• Use larger or different anchor • Add chain • Use backup anchor • Use pile anchor



Anchor failing to trip and sliding on soft bottom.

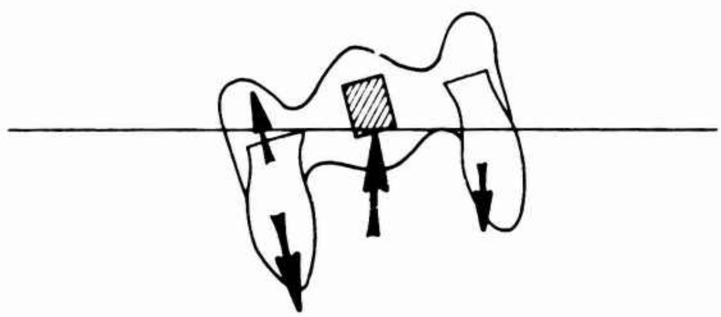
Figure 9.1 Potential anchor problem on soft mud seafloors when anchor is not properly set.

Anchor dragging on hard seafloor with fluke tips unable to bite in.

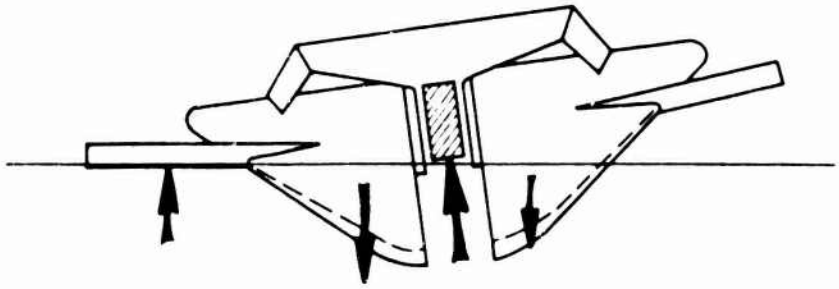
Figure 9.2 Potential anchor problem on hard seafloors.

Anchor standing up but tipping to side and dragging.

Figure 9.3 Potential anchor problem in hard seafloors when fluke angle is too large (after Ref 4).



(a) Unstabilized Stockless anchor rolling in sand (after Ref 4).



(b) Properly stabilized anchor in sand (after Ref 4).

Figure 9.4 Function of stabilizers in sand.

10. EXAMPLE PROBLEMS

A. EXAMPLE DESIGN FOR SAND

A drag embedment anchor system is required to resist a survival horizontal line load of 60 kips. Water depth is 60 ft. Maximum drag distance allowed is 50 ft. The owner has Danforth and LWT anchors in storage.

Option 1 - Holding Capacity Curve Option (refer to Section 6)*

1. Calculate H_U:

   a. H_D = 60 kips

   b. FS = 2.0 (Section 5)

   c. H_U = 2.0 · 60 kips = 120 kips

2. Identify seafloor material type: Medium dense sand of minimum 12-ft thickness.

3. Select anchor types: Danforth and LWT anchors are both good types for this application (Tables 3.1 and 3.2). In sand, e = 11.

*Numbering sequence is the same as found in the procedure.

4. Select W_A and calculate T_M:

a. Select W_A:

At $T_M = H_U = 120$ kips, $W_A = 9.0$ kips (Figure 6.1)

Select 9-kip LWT

NOTE: POSSIBLE TO SKIP TO STEP 6 FOR MOST ROUTINE MOORINGS.

b. Determine T_M for selected anchor.

$T_M = 120$ kips; the 9-kip size is coincidentally the exact choice for $H_U = 120$ kips.

5. Check adequacy of drag distance.

a. Adjustments to T_M:

$$L = 6.8 \text{ ft (Figure 6.4)}$$

For fixed flukes,

$$D = (D/L) \cdot L = 8 \cdot 6.8 \text{ ft} = 54 \text{ ft} \cong 50 \text{ ft allowed}$$

Assume this selection of a 9-kip LWT is satisfactory.

b. Check of selection adequacy:

T_M (200 kips) $\geq H_U$ (200 kips), satisfactory.

NOTE: This step was unnecessary since no adjustments were made to T_M and anchor selection.

6. Check adequacy of soil thickness.

   a. $d_t = L = 7.4$ ft (Table 6.1).

   b. In sands, full penetration is assumed necessary.

   c. $d_t < t$? ($t = 12$ ft, step 2). Satisfactory.

7. Select chain size:

   a. $T_U = 1.15 \cdot FS \cdot H_D = 1.15 \cdot 3.0 \cdot 60$ kips $= 207$ kips

   b. D_c selected is 1-3/4 in. (Grade 2); breaking load = 247 kips (Table 6.2). Assumes the 1-3/4 in. size is more readily available than smaller, but also adequate, sizes.

   c. $T_D = w\,(k + d)$ (Figure 6.5)

      $w = 0.0302$ kip/ft

      $k = 60$ kips/0.0302 kip/ft $= 1{,}987$ ft

      $d = 60$ ft

      $T_D = 0.0302$ kip/ft $(1{,}987 + 60) = 61.8$ kips

   d. $T_U = FS \cdot T_D = 3.0 \cdot 61.8$ kips $= 185.4$ kips

   e. Chain adequacy:

      (1) T_U << chain breaking load. If available, lighter chain may be appropriate.

      (2) Chain breaking load (247 kips) >> 1.5 T_M (180 kips): satisfactory.

8. Determine chain length:

a. $s = [d(2k + d)]^{0.5} = [60 \text{ ft } (2 \cdot 1{,}987 + 60)]^{0.5} = 492 \text{ ft}$

b. $L_t = 492$ ft. Calculate number of shots:

$$n = 492 \text{ ft}/90 \text{ ft} = 5.5$$

Therefore, 5-1/2 shots per leg.

9. Determine anchor setting distance:

$$D_p = 3L = 3 \cdot 7.4 \text{ ft} = 22.2 \text{ ft}$$

Summary - Example Design for Sand

Anchor size selected	12-kip Stato
Chain size selected	1-3/4 in.
Predicted capacity: ultimate	132 kips
Chain length required/leg	492 ft

B. EXAMPLE DESIGN FOR SOFT CLAY

A drag embedment anchor system is required for a class C mooring (design capacity of 100 kips per leg) on a soft clay bottom. The soft clay is known to be normally consolidated and 60 ft thick. Maximum allowable drag distance for anchors to design capacity is 50 ft. Anchors will be blocked open to eliminate tripping distance. Water depth is 120 ft.

OPTION 1 - Holding Capacity Curve Option (refer to Section 6)

1. Calculate H_U:

   a. H_D = 100 kips (design horizontal load)

   b. FS = 2.0 (Section 5)

   c. H_U = 2.0 · 100 kips = 200 kips

   NOTE: The design capacity of 100 kips must be attained within the allowed 50 ft of drag. However, anchor drag distance greater than 50 feet is acceptable to develop the required 200-kip ultimate capacity.

2. Identify seafloor material type: Soft clayey silt (mud) of minimum 60-ft thickness (sediment thickness derived from acoustic reflection data).

3. Select anchor type:

   a. The better performing anchors in soft clays and clayey silts (muds) are Stato, Stevfix, Stevmud, Boss, and Hook (Table 3.1). The Stato is selected because it is available in stock.

   b. In mud, e = 20 (Table 3.2)

4. Select and calculate T_M:

   a. Select anchor air weight:

      For T_M = H_U = 200 kips, W_A = 9.0 kips (Figure 6.2)

      Use 9-kip Stato for first trial

NOTE: POSSIBLE TO SKIP TO STEP 6 FOR MOST ROUTINE MOORINGS

b. $T_M \cong 200$ kips for the 9-kip Stato (Figure 6.2). The 9-kip Stato is the exact choice for $H_U = 200$ kips.

5. Check adequacy of drag distance.

a. Adjustments to T_M: Limitation of drag distance of 50 ft requires check of design capacity.

$$L(\text{9-kip Stato}) = 8.3 \text{ ft (Figure 6.4)}$$

$$D/L = 50/8.3 = 6.0$$

$$r = 51\% \text{ (Figure 6.3)}$$

$$T_{M(50\text{ ft})} = 0.51 \cdot 200 \text{ kips} = 102 \text{ kips}$$

b. Check adequacy of anchor selection:

(1) T_M (200 kips) $\geq H_U$ (200 kips); Yes, Satisfactory

(2) $T_{MS} = T_M/2 = 100 < T_{M(50\text{ ft})} = 102$ kips

Use $T_M = T_{MS} = 100$ kips

$T_M \geq H_D$ (100 kips); Satisfactory

6. Check adequacy of soil thickness:

a. $d_t/L = 4.5$ (Table 6.1)

b. $d_t = 4.5 \cdot 9.4 \text{ ft} = 42 \text{ ft} < 60$ ft; Satisfactory

7. Select chain size:

a. $T_U = 1.15 \cdot 3 \cdot 100 \text{ kips} = 345 \text{ kips}$

b. D_c = 2-1/4 inches, Grade 2 chain with breaking load of 396 kips (Table 6.2)

c. T_D (catenary) = $w(k + d)$ (Figure 6.5)

$$w = 0.0495 \text{ kip/ft (Table 6.2)}$$

$$k = 100 \text{ kips}/0.0495 = 2{,}020 \text{ ft}$$

$$d = 120 \text{ ft}$$

$$T_D = 0.0495(2{,}020 + 120) = 105.9 \text{ kips}$$

d. $T_U = 3.0 \cdot 105.9 \text{ kips} = 317.7 \text{ kips}$

e. Chain adequacy:

(1) T_U (317.7 kips) << breaking load (396 kips), 2-1/4-in. chain satisfactory. Note, 2-in. chain (breaking load = 318 kips) may also be suitable. Could repeat steps 7c and 7d for 2-in. chain.

(2) Check: Chain breaking load (396 kips) >> 1.5 T_M 300 kips), satisfactory.

8. Obtain required chain length:

a. $s = [d(2k + d)]^{0.5} = [120(2 \cdot 2020 + 120)]^{0.5}$

$= 707 \text{ ft}$ (Figure 6.5)

b. L_t (soft seafloor) = $s + H_U$ = 707 + 200 = 907 ft.
Calculate number of shots:

$$n = 907 \text{ ft}/90 \text{ ft} = 10$$

Therefore, use 10 shots per leg.

9. Determine anchor setting distance:

$$D_p = (D/L)*L \qquad \text{(Figure 6.3)}$$

$$(D/L) = 6 \qquad \text{(for Stato at FS = 2)}$$

$$D_p = 6 \cdot 8.3 \text{ ft} = 49.8 \cong 50 \text{ ft}$$

Option 2 - Analytic Model (refer to Section 7)

1. Calculate H_U: Same as Option 1 example.

$$H_U = 200 \text{ kips}$$

2. Obtain soil strength profile (presented in Figure 10.1): from laboratory vane shear tests on high quality gravity corer samples.

3. Select anchor type: Same as Option 1 example.

   Use Stato.

4. Calculate anchor ultimate capacity, T_{AU}:

a. $W_A = 0.75\ H_U/e = 0.75 \cdot 200$ kips/20 (e from Table 3.2)

$= 7.5$ kips

Next largest Stato manufactured is 9.0 kips.

Use 9-kip Stato.

b. $L = 8.3$ ft (Figure 6.4)

c. Fluke embedment, d_t:

d_{tm}/L at full penetration $= 4.5$ (Figure 7.2)

$d_{tm} = 4.5 \cdot 8.3\ \text{ft} = 37\ \text{ft}$

t of soil $= 60$ ft $\quad d_{tm} = 37$ ft

$d_t = 37$ ft

d. $s_u = 0.37$ ksf at d_t (Figure 10.1)

e. $N_c\ f\ BL = 510\ \text{ft}^2$ (Figure 7.3)

f. $T_{AU} = s_u\ N_c\ f\ BL = (0.37\ \text{ksf})(510\ \text{ft}^2) = 189$ kips

g. $T_{AU} = 189$ kips is greater than $(0.75$ to $0.85)\ H_U = 150$ to 170 kips. The next smallest Stato is 6 kips. It was not adequate.

5. Check adequacy of anchor selection at 50-ft design drag distance.

a. W_A, L, $N_c fBL$, and t available from step 4.

b. Fluke penetration depth, d_t:

(1) D/L = 50 ft/8.3 ft = 6.0

d_t/L = 2.5 (Figure 7.2)

d_t = 2.5 · 8.3 ft = 21 ft

(2) Soil layer thickness, t = 60 ft >> d_t

Thus, d_t = 21 ft

c. s_u = 0.21 ksf at d_t (Figure 10.1)

d. $T_{AD} = s_u N_c f BL$ = (0.21 ksf)(510 ft²) = 107 kips

e. T_{AD} = 107 kips is greater than (0.75 to 0.85) H_D = 75 to 80 kips. As stated in 4g, the next smallest Stato (6 kips) was not adequate. Therefore, a 9-kip Stato is satisfactory.

6. Size chain: Same as step 7 in Option 1 example.

2-1/4-in. chain selected.

7. Determine anchor-chain system ultimate capacity, T_M:

a. Chain embedment depth, d_s, as lesser of:

(1) d_{sm}/L at maximum penetration = 3.6 (Figure 7.4)

d_{sm} = 3.6 · 8.3 ft = 30 ft

(2) Not required

(3) Maximum possible shank penetration:

$$t - L = 60 \text{ ft} - 8.3 \text{ ft} = 52 \text{ ft}$$

Thus, $d_s = 30$ ft

b. For $T_{AU} = T_A = 189$ kips; use Figure 7.5 to find T_M:

2-in. chain, $T_M = 230$ kips

3-in. chain, $T_M = 235$ kips

c. For 2-1/4-in. chain, $T_M = 231$ kips > 200 kips; satisfactory.

d. Check T_M at 50-ft design drag (refer to steps 7a and 7b).

$T_{AD} = 107$ kips (from step 5d) > H_D (100 kips)

T_M* > T_{AD}; therefore T_M > 100 kips; satisfactory.

The calculations are done for example:

Chain end embedment, d_s, at 50 ft:

$$D/L = 50 \text{ ft}/8.3 \text{ ft} = 6.0$$

$$d_s/L = 2.1 \text{ (Figure 7.4)}$$

$$d_s = 2.1 \cdot 8.3 \text{ ft} = 17.4 \text{ ft}$$

*$T_M = T_{AD}$ + resistance provided by buried chain.

Maximum possible shank penetration (from step 7a(2)) = 52 ft.

Thus, d_s = 17.4 ft

For T_{AD} = T_A = 107 kips, use Figure 7.5 to find T_M:

2-in. chain, T_M = 125 kips

3-in. chain, T_M = 130 kips

For 2-1/4-in. chain, $T_{M(50\ ft)}$ = 126 kips > 100 kips; satisfactory.

T_{MS} = T_M(ultimate)/2 = 231 kips (from step 7c)/2 = 115 kips

T_{MS} (115 kips) < $T_{M(50\ ft)}$ (126 kips)

Use T_M = T_{MS} = 115 kips

$T_M \geq H_D$ (100 kips); satisfactory.

8. Chain length required.

a. Length of chain cutting into the seafloor at ultimate load of T_M = 200 kips.

At d_s = 30 ft (step 7c), use Figure 7.6 to find L_c:

2-in. chain, L_c = 250 ft

3-in. chain, L_c = 220 ft

2-1/4-in. chain, L_c = 242 ft

b. Catenary length, s = 707 ft (from Option 1, step 8).

c. Design for L_s = 0

d. $L_t = L_c + L_s + s = 242 + 0 + 707 = 949$ ft

n = 949 ft/90 ft = 10.5, use 10-1/2 shots per leg

9. Determine anchor setting distance:

$D_p = 6 \cdot 8.3 \cong 50$ ft (Figure 6.3)

SUMMARY - EXAMPLE DESIGN FOR SOFT CLAY

	1	2
Anchor size selected	9 kips	9 kips
Chain size selected	2-1/4 in.	2-1/4 in.
Predicted capacities:		
at 50-ft drag	102 kips	126 kips
ultimate	200 kips	231 kips
Chain length required/leg	907 ft	949 ft

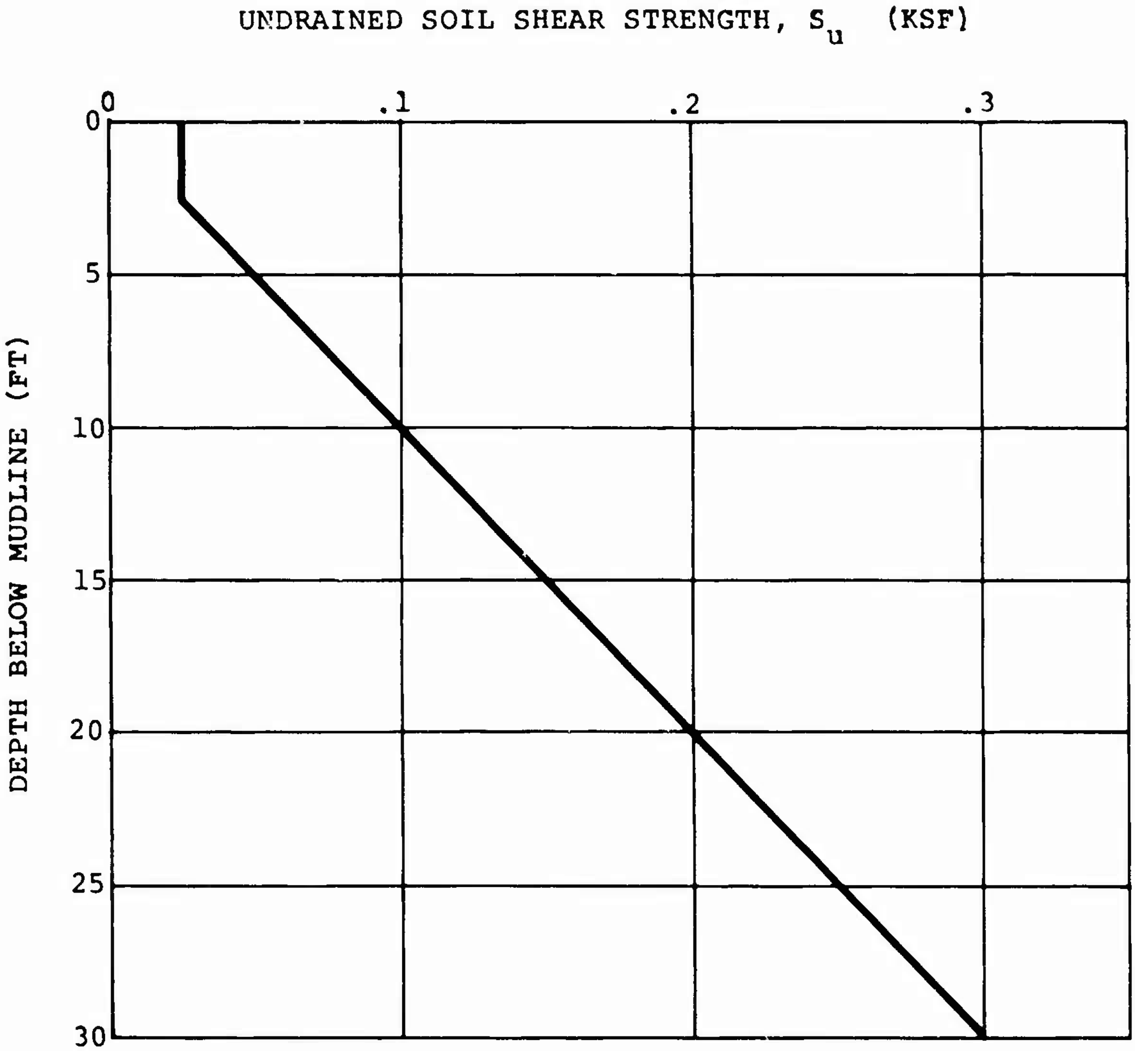


Figure 10.1 Assumed shear strength profile for Option 2 soft clay example problem.

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12. LIST OF SYMBOLS

B	Anchor fluke width (from manufacturer's literature)
D	Anchor drag distance
d	Water depth
D_c	Chain size
D_{MAX}	Drag distance to peak load
D_p	Anchor setting distance
d_s	Anchor shank tip penetration
d_{sm}	Maximum shank tip penetration
d_t	Anchor fluke tip penetration
d_{tm}	Maximum fluke tip penetration
e	Anchor efficiency
f	Factor converting the rectangular fluke area $B \cdot L$ to true fluke area (dimensionless)
FS	Factor of safety
H_D	Maximum design horizontal load
H_U	Ultimate horizontal holding capacity
k	Coefficient equal to H_D/W for catenary equation
L	Fluke length
L_c	Length of chain cutting into seafloor
L_e	Total chain length in contact with seafloor
L_s	Length of chain lying on seafloor surface
L_t	Total chain length required
n	Number of shots of chain
N_c	A holding capacity factor sensitive to plate shape and depth (dimensionless)
r	Percentage of T_M mobilized

s	Catenary length
SPT	Standard penetration resistance
s_u	Undrained shear strength
t	Soil thickness
T_A	Anchor capacity
T_{AD}	Anchor design capacity
T_{AU}	Anchor ultimate capacity
T_D	Chain maximum design tension at top of catenary
T_H	Total horizontal holding capacity (anchor + buried and surface chain)
T_M	Anchor-chain system mudline capacity
T_{MS}	Safe anchor-chain system mudline capacity
T_S	Chain friction force due to surface chain
T_U	Chain required breaking load
w	Mooring line weight per unit length
W_A	Anchor air weight
β	Chain angle relative to horizontal
γ_b	Bulk wet density of soil
μ	Coefficient of friction between chain and seafloor (dimensionless)

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4 Utilities (including power conditioning)
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11 Soil/rock mechanics
13 BEQ
14 Airfields and pavements
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16 Base facilities (including shelters, power generation, water supplies)
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18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
20 POL storage, transfer and distribution
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24 Same as Advanced Base and Amphibious Facilities, except limited to cold-region environments
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29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
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35 Solid waste management
36 Hazardous/toxic materials management
37 Wastewater management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution
40 Noise abatement
44 **OCEAN ENGINEERING**
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
53 Hyperbaric chambers
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
82 NCEL Guide & Updates
☐ **None – remove my name**
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91 Physical Security

SUPPLEMENTARY

INFORMATION

AD-B080279

DEPARTMENT OF THE NAVY
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CA 93043

IN REPLY REFER TO
L08/PDT/jw
42-040
Serial 450
19 Mar 84

From: Commanding Officer
To: Distribution

Subj: Errata Sheet for Technical Note TN-1688, "Design Guide for Drag Embedment Anchors," by R. Taylor.

1. Please replace page 39 with attached page 39.

P D Triem
P. D. TRIEM
By direction

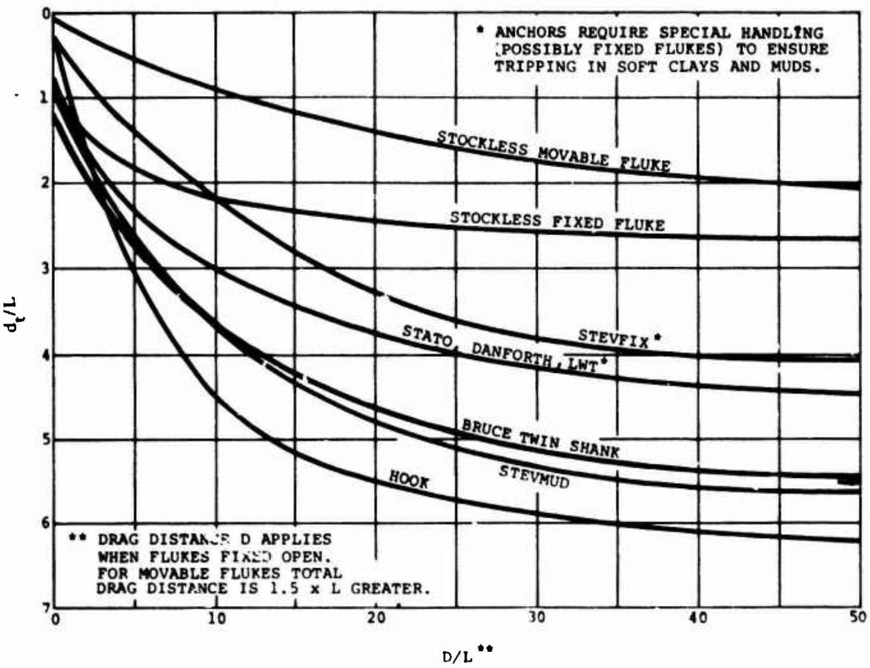

Figure 7.2 Predicted normalized fluke tip penetration versus normalized drag distance.

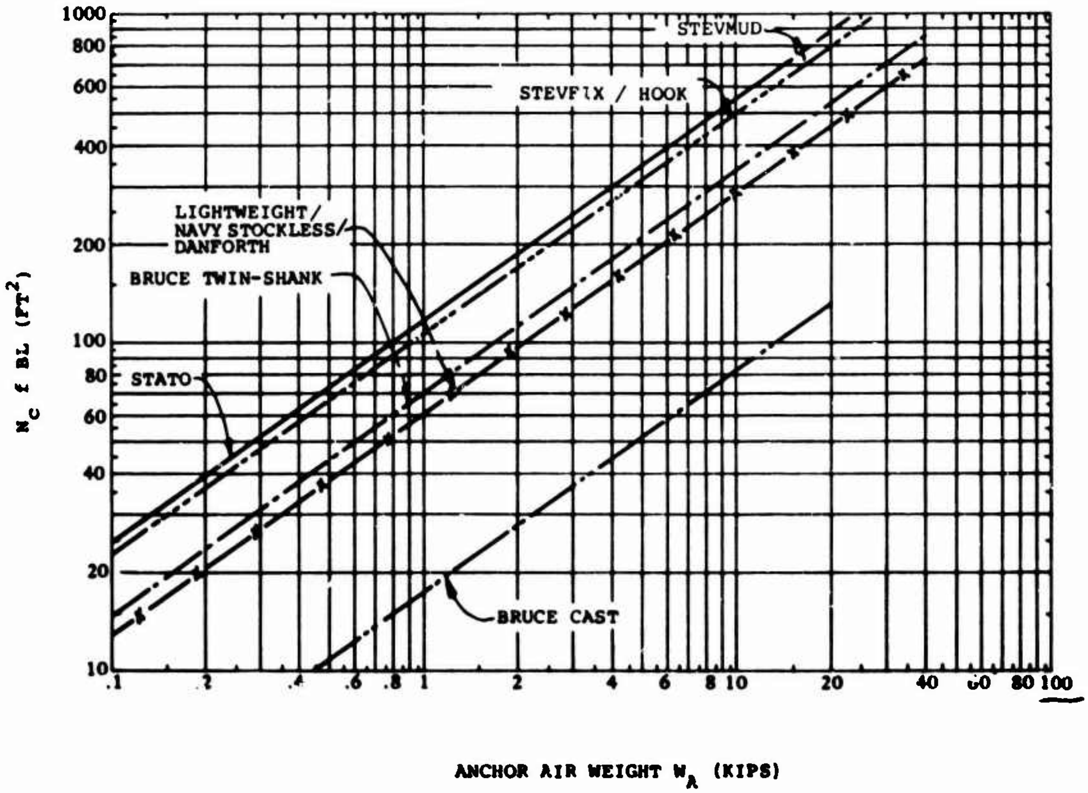

Figure 7.3 Anchor holding capacity factor, N_cfBL, versus anchor air weight, W_A, based on anchor designs available in June 1982.