Guidelines for safe multi-stump and deadman anchors


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Contents

1. *Introduction*

This guide was conceived with the purpose of revising and reinforcing the safety measures that are to be taken when utilizing stumps and deadman anchors for cable logging systems. There are guides from the 70's (Studier and Binkley 1976, Prellwitz and Lee, 1977) that have the necessary concepts in physics and soil mechanics that lead to safe anchoring. However, when these guides were written, the forests of the Pacific Northwest were quite different from what they currently are. Large stumps and trees are no longer available, at least not in industrial forests, making the availability of safe anchors a struggle. Shorter rotations leading to small diameter timber, the lack of space for landings and the processor cut (short stumps) are all elements contributing to a different scenario compared to the 70's and 80's. Unfortunately, inadequate anchor design not only leads to severe accidents including fatalities, but it can also imply economic losses and lost productive time.

This guide is structured with two general topics that are common to stump and deadman anchors, which is cable yarding as a logging system, and soil properties. Then two separate sections describe each anchoring system and their particularities. In addition, this publication includes deadman anchor design charts with examples for eight different soil types, in order to determine the soil type, the designer needs to characterize the soil strength on site as indicated in section 4.2. These design charts are only to provide guidance and are no substitute for through field assessment and designer experience.

It needs to be emphasized that anchoring a yarder should not be taken lightly, and needs to be performed by experienced workers. Working with natural elements such as trees and soil is not an exact science, especially since in the field, conditions are generally not ideal (ie. Stumps are not where we need them, soil is shallow, etc.) and experienced judgement is needed.

2. *Cable yarding*

The majority of cable yarding systems need anchoring to be able to support themselves and the load they carry during the yarding cycle. Some rigging configurations require more anchors than others. For example, a single span standing skyline requires anchors for the tower and tail tree, and a multi-span system requires additional anchors for the intermediate support.

The yarder manufacturer guide provides the guidelines indicating the minimum number of anchors needed and their location with respect to the yarding direction (in the horizontal and vertical planes). The guidelines will generally include an angle range (in degrees) in which the anchors must be located to safely operate the equipment. Not having anchors within the correct angle range can result in catastrophic failure. This happens because on a different configuration anchors are not sharing the load and a few or even only one guyline can eventually take too much or all of the load.

All guylines on a yarder should equally share the load

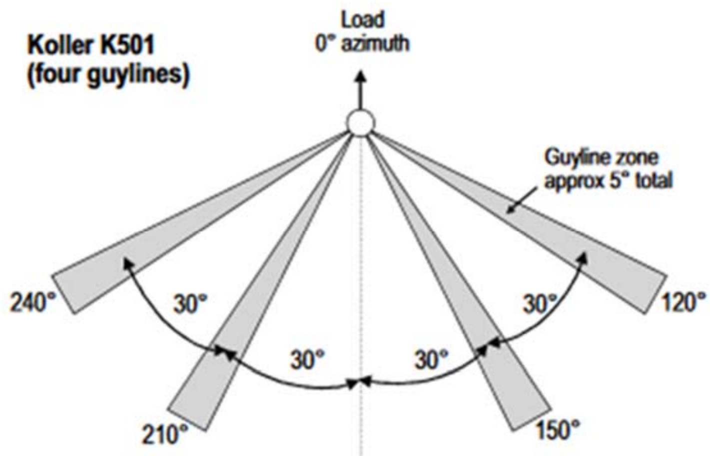


Figure 1. Example of anchoring guidelines for a Koller K501 yarder, from Cornell and Kellogg (2004).

Anchors are tied to the tower with guylines, the general requirement for guylines used to anchor towers must be at least of the size, strength and number recommended by the equipment manufacturer (Oregon Occupational Safety and Health Standards, Division 7 (437-007-0650 (2))). In addition to the requirements for anchor location in the horizontal direction (Figure 1), it is also very important to consider the vertical component of the anchor location. That is governed by the distance between the tower and the anchors. The closer the anchors are to the tower, the steeper the angle between the tower and the anchors. The steeper this angle is, the more tension will be transferred to the anchor and greater compression force will be exerted on the tower, which can lead to catastrophic consequences (Figure 2).

Figure 2. Tower lateral “buckling” due to excessive compressive forces. Source: Augusto Kahler. Operacion con cables en torres de madereo.

There is a wide variety of anchors, the most common and economical option has been usually tree stumps. However, stumps have to be in the right location and have certain characteristics to be usable for this purpose. Another forms of anchor are “deadman” (buried log), machine or mobile anchors, rock bolts and tipping plates. This guide will cover deadman and stump anchors in detail. A different guide is available that fully covers mobile anchors: *Mobile Anchors for Cable Yarding Systems* by Leshchinsky and Russell (2016).

In engineering design, a system is built to greater standards to account for unintentional exceeded loads, high variability in the property of components, effects of weathering and decay during service within others. In general, a method to quantify the allowable load for safely designing these systems is called factor of safety (FS) which is the ratio between the failure load and allowable load (Hibbeler, 2003). The same holds true for logging applications as well. Although not an official standard or standard by code, in the western United States based on static loading of new wire rope a safety factor of 3 to 1 has been generally used with logging and rigging applications. Cable utilizes the 3 to 1 factor whereas most hardware (shackles, blocks, etc.) will use a 5 to 1 factor. This is to say that if a cable has a safe working load (SWL) or operating load of 10,000 lbs then the ultimate breaking strength of new wire rope is approximately 30,000 lbs. This safety factor must be used with caution as age, wear, tear and damage can quickly lower the ultimate breaking strength of any given material.

3. Soil properties

When we are using anchors that depend on soil strength, it is critical to understand how soil affects their holding capacity.

The holding capacity of soil for all types of anchors fundamentally depends on many characteristics, with three predominant features tending to dictate its behavior as an anchor:

3.1 Soil texture

One way of classifying soils is by its texture. The major soil textural classes are conformed by different proportions of three main particle size groups: gravel, clay, silt and sand. The smallest particle size is clay, followed by silt, sand, and then gravel, which is the largest of these textures. For a reference, think of a clay particle being smaller than the width of the tiniest human hair, and sand being between the diameter of a human hair and the eraser of a pencil. Texture can tell us about the chemical and physical properties of soil and for that reason, it is important to assess the soil texture to understand how it would affect its capacity to hold an anchor.

Soils with high clay and silt content tend to be cohesive when loaded quickly, which in simple terms is the bond or "glue" between to keep soil particles together; this depends in part on the shape of the soil particles and moisture. Clay particles are plate-shaped giving them a large area of contact for chemical and physical bonds. For example, if you hold a clod of clay soil, it will stay together, but if you go to the beach and grab dry sand, it will probably slip through your fingers. So if you are pulling on a stump, a deadman or a mobile anchor placed on a less cohesive soil (sand), then you will likely to have lower holding capacity on your anchors.

Soils with high sand or gravel content tend to be more frictional, meaning that their strength derives less from the bonds associated with cohesion, and more on the actual friction between grains of soil. The larger the weight of overlying soil on a deadman anchor, the larger the friction that may be mobilized to resist anchor forces, and the more stable an anchor will be.

3.2 Soil moisture

Think of soil as a collection of particles, the voids between the particles contain water, air or a mix of them. Water can have a very different effect on soil depending on its texture. A clayey soil saturated with water will reduce its shear strength because water trapped in its very small voids cannot escape under loading, resulting in less bonding and contact between grains. This lowers strength, as the contact friction between particles is not sufficiently mobilized. Sands and gravels have large voids, meaning that even when saturated, water may escape under loading and thus, full friction may be mobilized.

The ability of these particles holding together and overcome forces and stresses in different directions determines the soil strength, which ultimately controls in a large proportion, the holding capacity of any type of anchor we decide to put in place to hold yarding equipment.

3.3 Soil density

When we look at soil density, we need to think at a larger scale. A denser soil (with less voids) will deliver more resistance to pull, especially when we think of stumps and deadman anchors. The more grains present in a given volume results in a higher density, and consequently, more contact points and possible bounds between grains – this implicitly means a soil is in a stronger state. This is largely the reason that compaction is used as a means of improving the strength of native soil for roads, foundations, etc. For stumps specifically, a denser and deeper soil means more resistance to pull since the root system is able to go deeper in the soil horizon and the soil structure can hold them in place strongly. Have you tried to pull weeds on compacted clay? Most of the time, the weeds will break before the root system can get out of the soil, the same applies for a tree root system. Testing performed in radiata pine showed that 92% of trees failed by uprooting on non-cohesive soils (for example sandy soils) compared with 11% failing by this mode on clay soils (Moore, 2000).

On the other hand, a similar mechanism works for a deadman, after a trench is built, it has to be covered back with soil and compacted as much as possible. Having a denser soil in the front wall of the trench will also make it harder for the log to pull out.

4. Deadman anchors

When there are no adequate stumps, or they are not located at the right angle to use as anchors, and there is no room for equipment anchors, a deadman can be a suitable solution. Deadman anchors consist of a buried log or a bundle of logs wrapped with a strap which is then attached to a yarder guyline. The effectiveness of this type of anchoring system depends on several aspects, including soil texture, compaction, burial depth and log dimensions among others. In order to understand how these features affect anchor effectiveness, we need to start by understanding how they work.

4.1 Theory

A deadman works by providing support through soil resistance, both from the structure and weight of the soil on top and in front of it. This resistance counteracts tension forces in the guylines, providing support. Guylines should be set in a way they share the load, but sometimes, lateral excursion (when skyline is pulled to the side during lateral yarding) and other factors during the operation can possibly transfer the majority of the load if not all, to only one guyline. For that reason, deadmen should be designed to support the design load of the guyline with the appropriate safety factor. As simple as it sounds, the amount of tension the deadman is able to resist before failure depends on several factors, including those related to the strength of the deadman itself. As suggested by Prellwitz and Lee (1977), a deadman can fail in three different ways:

a. Bending stress: depending on the log dimensions and its wood properties, the tension on the guyline can make the log bend at the point of cable attachment. In order to avoid this issue the log needs to have the correct dimensions in terms of diameter and length for safe holding capacity. A long log with small diameter is more likely to bend and break. In order to aid design guidelines, Prellwitz and Lee (1977) proposed a factor of safety that is a result of the ratio between the bending stress on a log pulled in the middle and the maximum allowable bending stress for wood of a defined species. This maximum value is the maximum stress on the wood before it fails.

b. Shear stress: another form of failure is shear at the log point of attachment. In this case, the log fibers start breaking as the wire rope bites into the wood. Larger log diameter and utilizing bearing plates between the wire rope and log is crucial to maximize the shear strength of the log (Prellwitz and Lee, 1977). The plate works by distributing the load across a larger section compared with the rope by itself.

c. Pullout: of these three modes of failure, pullout depends on the soil in which the deadman is buried. How much the soil weighs its compaction and moisture. When the log is buried, the resisting force on the trench is called the passive earth pressure, which is mobilized with the increasing compressive contact of the deadman with is adjacent soil. This is the lateral pressure exerted by the soil, which depends on soil structural properties and interaction with the log.

4.2 Design

Safe anchoring design for deadman anchors depends on many factors; log dimensions, soil characteristics, slope, angle of pull and depth of the trench. Since the series of combinations between all these factors is so large, there is not a one easy answer as to how to design the deadman safely. In this guide, we provide nomographs in which the user can find the maximum anchor capacity (in lbs), in other words, the maximum pulling force on deadman of a determined diameter and length under different circumstances. These results are presented for idealized soil properties. Note that every soil is different and even a given soil may have strength changes with changing moisture or density. It is important to characterize the strength of your soil on site for analysis, for example, using an inexpensive vane shear device, the test standards are described by ASTM D2573/D2573M-18. If specific soil characteristics are unknown, inappropriate design may take place, thus it is important to either be extremely conservative in design or determine soil properties quantitatively. This should always be performed on a site-by-site basis. In order for the reader to understand the derivation of these anchor capacities, the calculation procedure is explained as follows:

Soil Capacity

The first and more complex part of the process is to calculate the soil resistance against pullout and uplift. Uplift occurs when the angle of pull is steep and the log only has its own weight and the weight of the soil above it as a resisting force, in the case of pullout, with a lower angle of pull, the log has a wall of undisturbed soil as a resisting force. For pullout calculations, we need to model the soil rupture pattern, which was modeled as a logarithmic spiral (Jumikis, 1987). Then, we need to calculate the resistance of all the soil that would eventually be displaced by the log (Figure 3). This is highly dependent on the type of soil (i.e. the shear strength of the soil) in which the deadman is being placed, as well as the depth of burial and amount of soil in front of the trench (especially if close to a bank). The lowest resistance between uplift and pullout, represents the deadman's ultimate capacity from soil resistance, this capacity is also calculated including a safety factor of three to be consistent with Prellwitz and Lee (1977) and the fact that soil properties are extremely variable.

Structural capacity

The second part consists of determining the structural capacity of the log, including bending stress and shear stress. Bending stress was calculated by treating the log as a beam in which a force is being applied in the middle, this measure depends on length and center diameter. Shear stress is calculated under the same assumption of a beam; in this case, shear is calculated for a circular section and only depends on the mid-length log diameter and species. Once both stresses are calculated, they are compared against maximum allowable shear and bending stresses for Douglas-fir, found as reference design values (NDS, 2005) and calculated for a safety factor of three (3). Once these two numbers are calculated, we pick the lowest between the two, because that will be the limiting factor for the structural capacity of the log against failure.

Figure 3. Logarithmic spiral soil rupture pattern before and after pullout.

This method allows the calculation of a deadman anchor capacity by determining the soil and log structural capacities and which of the two is limiting depending on the amount of load. The lowest of those capacities is the one utilized to find a log size.

Factors such as steep angles of pull, weak soils, not enough burial depth, steep terrain as well as inadequate log dimensions contribute to reduce anchor capacities. When large logs are not available, the best options to increase deadman anchor capacity is deeper burial and a lower angle of pull. Another option is to use several logs in the trench, however, the capacity of those multiple-log deadman anchors are outside of the scope if this publication.

This document provides guidelines to aid in the design of single log deadman anchors, these guidelines include a design chart specific for Douglas-fir as well as eight example soil types for a deadman at four different burial depths. These can be found on Appendix II.

Design needs to be performed by an experienced person. Deadman movement needs to be inspected daily (this can be done painting the strap as it exits the ground) as well as wire rope and other components subject to wear. Additionally, we recommend working with a tension meter to monitor actual loads during the operation.

5. Stump anchors

With decreasing rotation age, stumps are getting smaller. If we assume a structurally sound root system, research and experience has shown that the smaller the stump diameter the lower the holding capacity of that stump as an anchor. One common way of addressing this issue is to rig several stumps to act as a single anchor, however, many aspects of the stumps and proper rigging should be carefully considered to ensure proper holding capacity.

5.1 Theory

Stumps work as anchors by simply providing their natural root support system. Trees grow roots for several reasons, including anchorage and support of their aerial system as well as to withstand strong winds and snow weight depending on their habitat. The tree develops root growth and subdivisions to provide a platform of few heavy and thick roots at the base to maximize ground-anchoring capacity (Coutts, 1987). The need for growing roots varies widely by species and their individual growing conditions including soil depth, water table, slope, soil temperature and many other factors. Many of these factors are crucial in selecting a stump that will provide sufficient anchoring capacity. When used as anchors, stumps can commonly fail in two ways:

a. Overturning: this can occur for several reasons. A shallow root system, will not have enough holding capacity to act as a reliable anchor, if roots are not deep enough, pulling the stump at an angle will usually end with the stump tipping over. Another reason can be too small diameter trees, or suppressed trees (small crown), these trees might either be too young and are still developing their root systems or are suppressed by other trees and do not have enough resources to develop a large crown and root system.

b. Shear: this can occur when the stump and/or roots are not structurally firm. Hollow, partially burned stumps or snags are at a high risk of shearing at their point of cable attachment. Root rot can cause weakening of the root structure, which can break apart as the stump is pulled.

5.2 Choosing a stump

a. Species: Douglas-fir is known for developing deep roots with a growth habit of large, frequently branched roots deep below the soil surface (McMinn, 1962; Kalela 1949 and Horton 1958) making it the best option for an anchor stump in the Pacific Northwest. Other species such as pine, cedar and spruce are acceptable. Research work performed by Pyles *et. al* (1991) shows Western hemlock has a lower ultimate load capacity compared to Douglas-fir at the same DBH (diameter at breast height).

b. Size: diameter at breast height (DBH) is related to tree age, site class, and silviculture. Younger trees usually have smaller diameter and with that, stumps with lower holding capacity. It has been shown that DBH is highly correlated with holding capacity. A commonly used relationship states that the holding capacity of a stump increases with the square of the stump diameter (Pyles *et al.*, 1991; Stoupa, 1984; Studier and Binkley 1974). The rationale behind this relationship is the fact that the root system needs to grow in balance with the aerial part of the tree. However, this relationship does not include other factors affecting root development such as soil, water table and disease. A study performed in Douglas-fir trees shows that the average length of the root system is related to the size of the tree crown, so in general, dominant trees with a large crown will develop larger root systems (Figure 4). Then, tree crown size is a good additional indicator of root development.

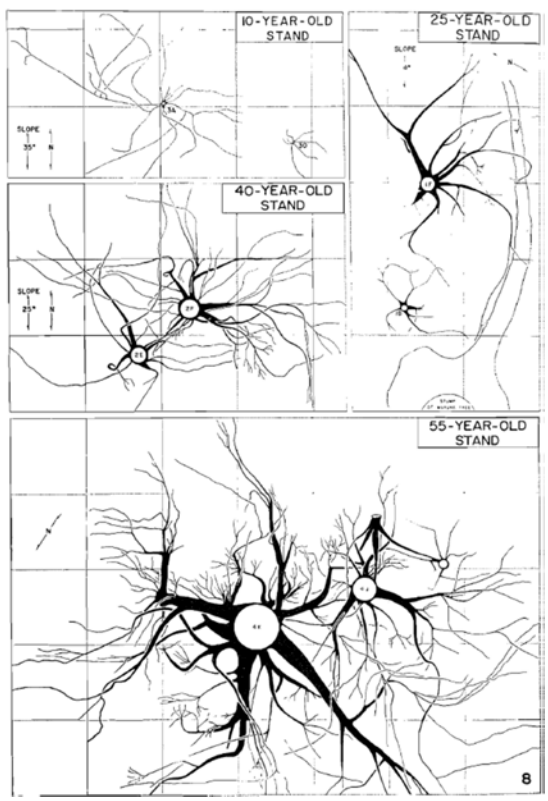


Figure 4. Douglas-fir root systems at different ages, from McMinn (1963)

c. Soil: Douglas-fir does not have the ability to grow roots under shallow water tables compared with other species (Minore and Smith, 1971; Hermann, 1977; Sutton, 1991).

Then, holding capacity will usually be better in deep soil. If the soil has been disturbed and the root system compromised, or there is evidence of the tree growing on sheer rock surface or loose rock, that is an indication of poor root anchoring and greater risk of pullout. The same applies for trees growing in shallow water table or swamps. Those should not be chosen as anchoring points.

d. Disease: butt and root diseases can severely affect the anchorage of infected trees (Filip *et al.*, 2014). There are two types of root disease that most commonly affects the root structural integrity of Douglas-fir in the Pacific Northwest. The most important is laminated root rot. This disease causes decay of the major roots causing them to break off the root collar (Thies and Sturrock, 1995). When choosing a tree, watch for:

   - Nearby uprooted and dying trees, laminated root rot infects trees in pockets.
   - Rounded tops, bushy branch ends, thinning foliage and distress cone crops. These are signs of an unhealthy tree.
   - When a tree is felled, watch for spots or crescent shaped reddish/chocolate brown stain on the stump while is fresh (Figure 5). Stain fades within days. This could be an indication of laminated root rot.
   - Bark beetle attack, these beetles can colonize the tree after it has been weakened by a root disease.

   The second most important disease is Schweinitzii root and butt rot. This disease is more common in older trees and the most reliable sign is its fruiting bodies located near the lower area of the stem or the ground (Goheen and Willhite, 2006). These are mushroom like conks, which can emerge from wounds, cracks and fire scars indicating advanced decay. Butt swell is also an indication of an infected tree.

Figure 5. Crescent shape stain on Douglas-fir with laminated root rot. Photo credit: Steve Wilent, Society of American Foresters.

5.3 Design

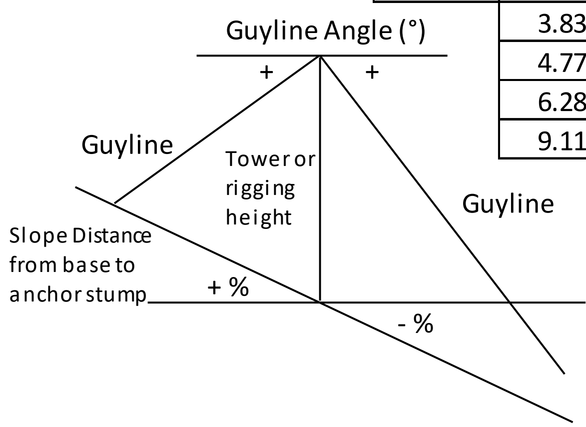
5.3.1 Single stump

a. Location:

Angle of pull is extremely important and needs to be considered on the vertical and horizontal directions. When we look at a single stump on the vertical plane it is recommended to keep this angle to a maximum of 50° ((Oregon Occupational Safety and Health Standards, Division 7 (437-007-0650 (3)))), this means the stump needs to be at a minimum horizontal distance from the tower (Table 1). The greater the angle of pull, the lower the stump capacity (Peters and Biller, 1985). The table below (Table 1) provides a guide for estimating the slope distance from the tower or tail tree to anchors for various ground slopes and desired guyline angles per foot of tower or tail tree height. To adjust for landing excavation, use the adjusted tower height, i.e. the tower height minus the landing excavation.

For example: For a 100 ft tower on a 60% side slope you would need to go downslope a minimum of 1.97 x 100 = 197 feet to find a stump to stay within a 50 degree guyline angle. On the uphill side you would need to go upslope a minimum of 100 x 0.65 = 65 feet to stay within a 50 degree guyline angle.

Ground slope (%)	Guyline Angle (Degrees)							
	-25	-15	0	15	25	35	45	50
90	3.10	2.13	1.49	1.15	0.98	0.84	0.71	0.64
85	3.42	2.25	1.54	1.17	1.00	0.85	0.71	0.64
80	3.84	2.41	1.60	1.20	1.01	0.85	0.71	0.64
75	4.41	2.59	1.67	1.23	1.03	0.86	0.71	0.64
70	5.22	2.83	1.74	1.26	1.05	0.87	0.72	0.65
65	6.49	3.12	1.83	1.30	1.07	0.88	0.72	0.65
60	8.72	3.51	1.94	1.34	1.09	0.90	0.73	0.65
55	13.64	4.05	2.08	1.40	1.12	0.91	0.74	0.66
50		4.82	2.24	1.46	1.16	0.93	0.75	0.66
45		6.02	2.69	1.53	1.20	0.95	0.76	0.67
40		8.16	3.03	1.61	1.24	0.98	0.77	0.68
35		12.91	3.48	1.71	1.30	1.01	0.78	0.69
30			4.12	1.84	1.36	1.04	0.80	0.70
25			5.10	1.99	1.44	1.08	0.82	0.71
20			6.74	2.18	1.53	1.13	0.85	0.73
15			10.05	2.42	1.64	1.19	0.88	0.75
10				2.73	1.77	1.26	0.91	0.78
5				3.15	1.94	1.33	0.95	0.81
0				3.73	2.14	1.43	1.00	0.84
-5				4.59	2.41	1.54	1.05	0.88
-10				5.98	2.74	1.67	1.12	0.92
-15				8.57	3.20	1.84	1.19	0.97
-20					3.83	2.04	1.27	1.03
-25					4.77	2.29	1.37	1.09
-30					6.28	2.61	1.49	1.17
-35					9.11	3.03	1.63	1.26
-40						3.59	1.80	1.36
-45						4.38	1.99	1.48
-50						5.58	2.24	1.62
-55						7.60	2.54	1.78
-60							2.92	1.97
-65							3.41	2.20
-70							4.07	2.48
-75							5.00	2.83
-80							6.40	3.27
-85							8.75	3.84
-90								4.61



Note: Guyline angle measured from horizontal. Positive angles are below horizontal.

Table 1. Slope Distance from Tower to Anchor for Various Slopes and Desired Guyline Angles (for 1-foot tower height) adapted from Pyles *et al.* 1991.

On the horizontal plane, guylines need to be placed carefully so the angles in between them are similar so the load is equally shared. During the yarding cycle, tension is not only applied straight towards the corridor, it varies with lateral excursion, thus transferring the load to an opposite guyline. When load is not well distributed, the entire load can be transferred to a single stump (Figure 6) potentially causing catastrophic failure. Refer to the yarder manufacturer guidelines to find the correct angles between guylines.

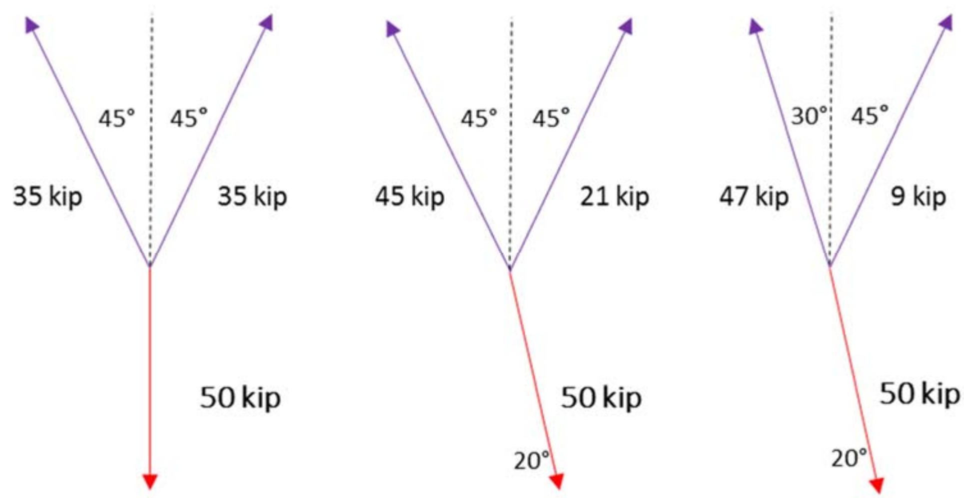


Figure 6. Example of tension changes due to changing angles using fixed ropes (not using blocks to distribute the load)

b. Stump rigging:

There are some common practices when rigging stumps, whether the plan is to rig one or multiple stumps, the same precautions need to be taken (Studier and Binkley, 1974 and Oregon OSHA, 2010):

- Notch depth and height: each stump needs to be notched in a way that is not too deep to compromise the holding power of the stump or too shallow that the wire rope could easily slip off the stump. The recommended notch depth is 1 ½ to 2 times the diameter of the guyline (Brian Tuor, pers. comm.). For the same reason, the notch cannot be placed too close to the top of the stump, a minimum of 12 inches of stump above the notch; it should be placed as low as possible but avoiding cutting the roots. When a tree is chosen to be used as a stump, stump height needs to be considered in advance before felling the tree.

- Notch direction: the notch needs to be in lead towards the angle of pull (Figure 7) and when choosing the stump consider that the stump is strongest:

pulled by the side rather than upwards
pulled uphill rather than downhill when on a slope
upwards rather than downwards when on the back side of a ridge.

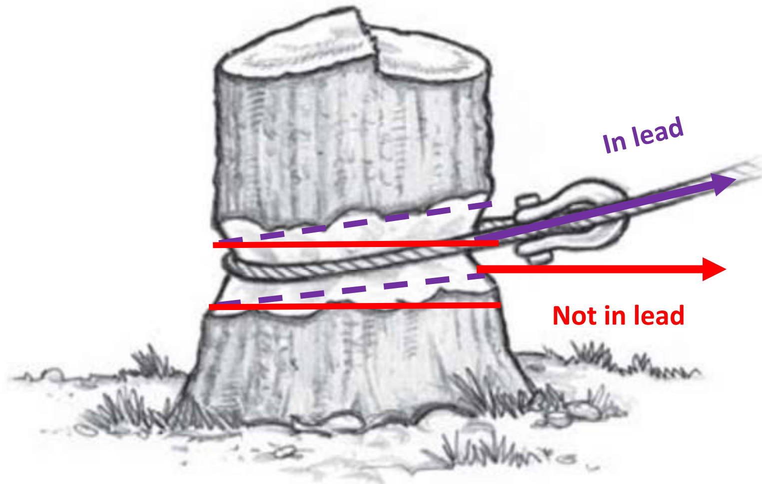


Figure 7. Example of notch in lead (as pictured, following dotted line) and not in lead (solid lines) towards the angle of pull. Adapted from Oregon OSHA (2010).

Generally, single stump yarder guylines are secured to the stump by either a safety shackle or screwy bell. Safety shackles need to be secured with a pin and a molly, in the eye, and be sized according to the wire rope breaking strength. Lift and tail tree guylines can be secured by cable clips. With cable clips, it is advised to wrap the stump several times before securing the line, since by wrapping the stump; it helps to take out extra strain that may be placed into the cable clips. Additionally, when placing the cable clips it is important that the U portion of the clip be on the dead side of the line and that the saddle portion goes on the live side (Never saddle a dead horse).

In tightening guylines it is important to get them taut. It may be necessary with long guylines to utilize a mechanical means (yarder, come-along) to get them tight. It is also important to not over-tighten the guylines which would induce a buckling force into the tree before the load is applied. If during the yarding process the tree stays within its diameter at the point of attachment, then the guylines are sufficiently tight. By keeping the tree within its diameter this will help to ensure a buckling force is not placed in the tree. If the tree continues to move outside of its diameter it may be necessary to install additional guylines.

5.3.2. Multi-stump

When a single stump is not adequate to safely support the guylines, a system of multiple stumps can be used. This setting is highly effective as long as it is well designed, by making sure that all stumps are sharing the load equally.

a. Stump Selection:

   The location of the multi-stump anchors have the same considerations as single stumps when it relates to the horizontal and vertical directions with respect to the tower. Within the multi-stump system, it is important to consider the stump alignment is spread as evenly as possible and in lead towards the direction of pull. The even spread allows the load to be shared evenly as well, the same way it works for the guylines with respect to the tower. Remember, angles have a very significant effect on stump loading.

b. Rigging types:

   There are several methods to combine stumps to increase the holding capacity of an anchor. Selection of each stump needs to be made carefully, taking into consideration species, size, soil, stump health and location. The most common methods are the following:

   - Twister tie back: this method consists of tying the anchor stump back to one or more stumps to increase the holding power of the front stump. It is important to consider the lead on the tie back stumps and ensure that a side or up force is not created on the main anchor stump.

   Generally, the twister line is commonly a section of haywire. One end of the haywire is secured to either stump. The line is then wrapped around both stumps as seen in Figure 8. The tail end of the line is then tied off to one of the stumps usually by way of a timber hitch. It is important that each of the legs of line have approximately the same tension.

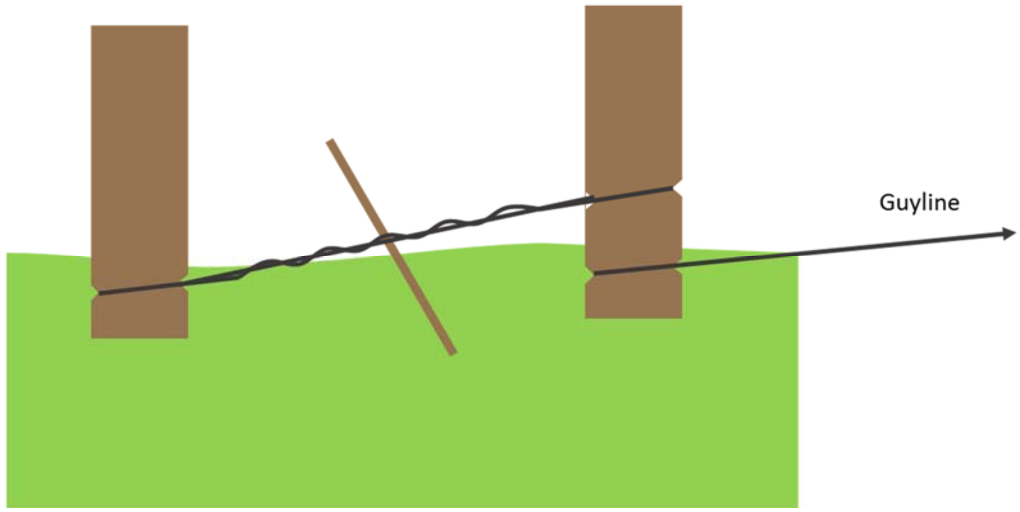


Figure 8. Twister tie back.

Insert a sturdy stick between the two legs and begin twisting the line over itself until taut. Then, wedge the stick in the ground to hold the wrap perpendicular to the line, keep it firm but not tight. When performing this task or releasing the twister, be cautious and hold it firmly, since unexpected release can cause serious harm. Never use a power saw to simply cut the stick, this could result in a catastrophic release of the line tension.

- Wrap and go back: Two stumps in alignment with the line to be anchored is needed. This method consists of anchoring to the back stump and then wrapping the line around the front stump. In this setting, the back stump will generally hold 1/3 of the load and the front stump 2/3 of the load. But the load distribution will also depend on the strength of both stumps and guyline tension. The notch in the front stump has a large impact on how much tension is transferred to the back stump. A deep tight notch will create more friction on the line and will reduce the amount of line tension to the back stump. A third stump in this type of configuration generally provides a negligible improvement in overall anchor capacity due to the friction in the first two stumps, however, it works as an insurance if the first one were to fail.

- Bridle block or Crow's foot: in this setting, two stumps have a line tied between them with a block floating on the line, acting as an equalizer and distributing the load evenly between both stumps (Figure 9). Both stumps need to be properly notched and the angle between both stumps (interior angle) and the block cannot exceed 120°. The larger this angle or further apart the stumps are, the more load the stumps and strap are going to receive (Table 2). It is important to use an equalizer line that is long enough to create a small interior angle. It is important to note that a haulback block is probably not rated with enough capacity for this configuration. Larger breakdown blocks are generally needed for a bridle block setup.

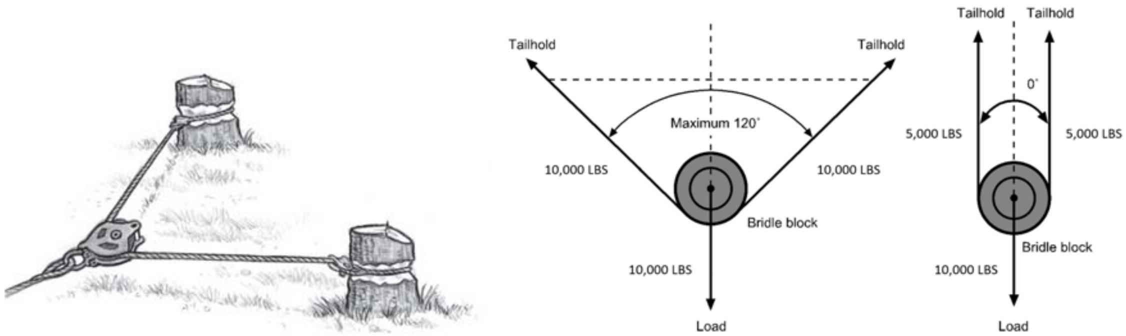


Figure 9. Bridle block from Oregon OSHA (2010)

Interior angle (°)	Tension on each stump
20	51%
30	52%
40	53%
50	55%
60	58%
70	61%
80	65%
90	71%
100	78%
110	87%
120	100%

Table 2. Proportion of the original load on each stump when using a bridle block

- Jill-poke: This system generally works by placing a larger log between two stumps that allows the stumps to work together. One example of such a system is where the line is anchored to the back stump and then the log is placed between the back stump and the front stump. As the anchor line is tightened, the anchor will start to be pulled forward and thus pushing on the log against the front stump.

- Equalizer Line: In this system, three or more stump anchors are tied together utilizing a continuous equalizer line (Figure 10). Depending on how it is configured the tension to each stump is approximately equal. The length of the bridle strap is important in keeping the bridle line tension to desirable limits. This system utilizes a series of blocks and cable (rope) to tie all of the stumps to a common anchor. It is important in designing a multi-stump anchor that all components are sized correctly. If any component is undersized, it could become the weak link that could cause a catastrophic failure.

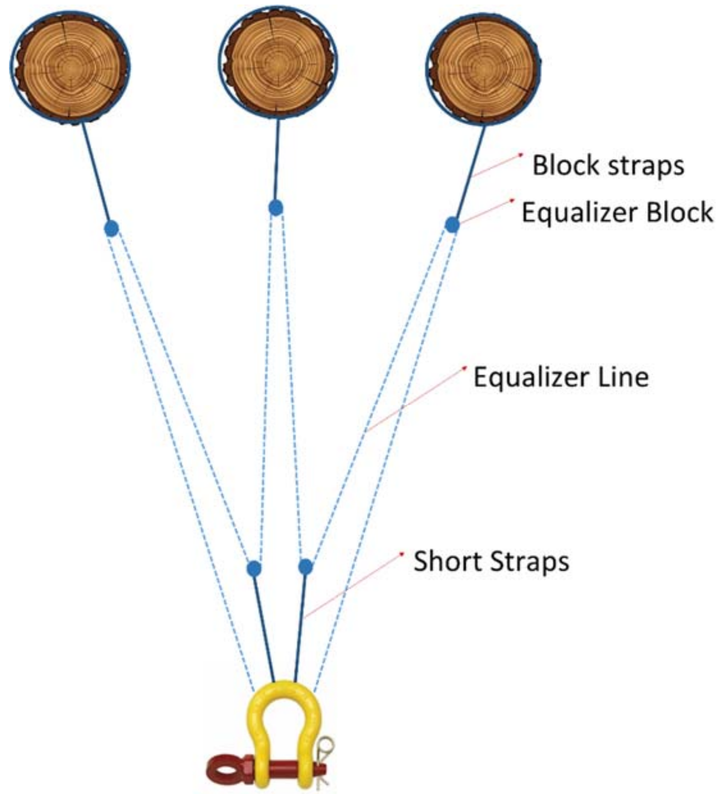


Figure 10. Example of an equalizer line

In designing this system, it is important to take into account the ultimate breaking strength of the line you are attempting to anchor. Once that has been determined the other components can be sized correctly.

It is also imperative to note that too much spread on the anchor stumps or too short of an equalizer line can create a situation where the system will become overloaded. According to Figure 11, it is important to watch the interior angle between the two outer parts of the system. As the interior angle grows, so does the tension created in the system. It is vital to keep the angle as low as possible. The best way to decrease this angle is to add more length to the equalizer line.

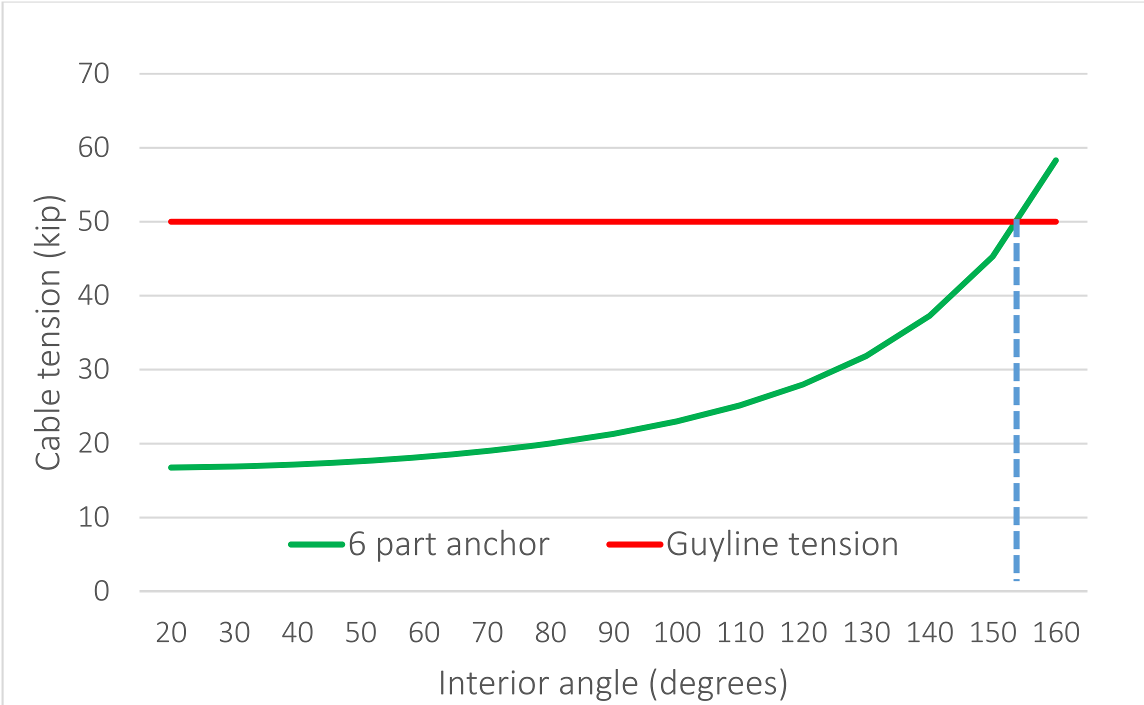


Figure 11. Maximum stump load in a 6-part equalizer system similar to the one shown in Figure 10, loaded with 50 kip on the guyline

Steps to set up an equalizer line:

- Stumps: In order to calculate the load to each component first determine the number of stumps needed to offset the ultimate load of the line being anchored. See guidance on stump selection 4.3.1.

- Equalizer Line: The equalizer line is the continuous line that ties all of the components together. The example given in Figure 10 shows a 6-part equalizer line setup to tie the three stumps together. To determine the tension of this line with the assumption that the angle between the two legs going through the bridle block is zero degrees, is to simply divide the ultimate strength of the line to be anchored by 6. The calculated number may not exactly match a cable or ropes ultimate breaking strength. In this case chose a line that has a breaking strength just above the calculated number.

- Block Straps and Short Straps: In this example each of these straps offsets two parts of the equalizer line. In this case, the ultimate breaking strength of these straps would be equal to twice the calculated breaking strength of the equalizer line.

- Equalizer Blocks: To correctly size our blocks, they would be equal to the breaking strength of the block straps or short straps.

- Equalizer line length: The equalizer line length can be calculated. In Table 3 are given calculated line lengths for a 6-part (3 stump) equalizer system were “stump spread” is the distance between the two outer stumps. It is important to note that as the spread of the stumps increases, more line is need to keep the interior angle low.

Total rope (ft)				
	Stump spread (ft)			
Interior angle (degrees)	10	20	30	50
10	344	688	1,031	1,719
20	172	344	516	859
30	115	229	344	573
40	86	172	258	430
50	69	138	206	344
60	57	115	172	287

Table 3. Total rope length (ft) needed to achieve desired interior angle

An example of how to set up an equalizer line is given in Appendix I.

5.4 Synthetic rope applications

Synthetic rope applications in logging have demonstrated advantages in worker ergonomics due to its higher breaking strength to weight ratio when compared with commonly used steel wire rope. This ratio can be as higher as 9 to 10 times when the two are compared (Leonard *et al.*, 2003). By having much lighter rope, it is much easier for a worker to carry the rope and other hardware in steep terrain. Lately, loggers have been using this type of rope for multi-stump rigging. In terms of design, guylines made of synthetic materials, including the end connectors, must have the equivalent strength capacities of wire rope, as indicated by OR OSHA Division 7 (Oregon Occupational Safety and Health Standards, Division 7 (437-007-0650 (8))). Because synthetic rope has a different wear and damage compared with wire rope, inspection is critical to determine strength reduction. Pilkerton and Garland (2004) provide useful guidance on the use synthetic rope in logging applications, including insight on fatigue and damage.

5.5 Cost considerations

When compared to a deadman, stump anchors are definitely the most economic option. When stumps are available and in the right position, it only takes to rig them correctly without the need of an additional piece of equipment. For the most part, the rigging hardware is not overly expensive and can have multiple other uses. Deadman anchors require more time and resources, digging the trenches can take anywhere from 1 to 3 hours depending on the size of the excavator and soil. A rocky soil will take longer to dig, and if the soil is too shallow such as the minimum depth cannot be achieved, another option such as equipment anchors or large log bundles might be a better option.

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7. Appendices

Appendix I- Example design of an equalizer line

Example

1. Determine ultimate breaking strength of guyline or skyline: most rigging shops can help with finding out this value. It is important to get the breaking strength for your line as this can vary from manufacturer to manufacturer. In this example, we will look at a guyline with a breaking strength of 36 tons (72,000 lb).

2. Determine how many anchors will be used in multi-stump: in this case we will be using 3 stumps for our anchor.

3. Determine number of line parts: since we are using 3 stumps we will be using 6 parts of our equalizer line (see diagram below).

4. Determine the equalizer line length from chart: it is important to keep the interior angle of the two outside legs below 50 degrees. A lower interior angle will put less strain into the system. If the angle goes beyond 50 degrees this will induce greater strain on the system. Once you know the spread of the two outside anchors, you can go to Table 3 to find the length of your equalizer line. As an example: If our stump spread is 30 feet and you wish to keep the interior angle below 40 degrees, then you would need 258 feet of line.

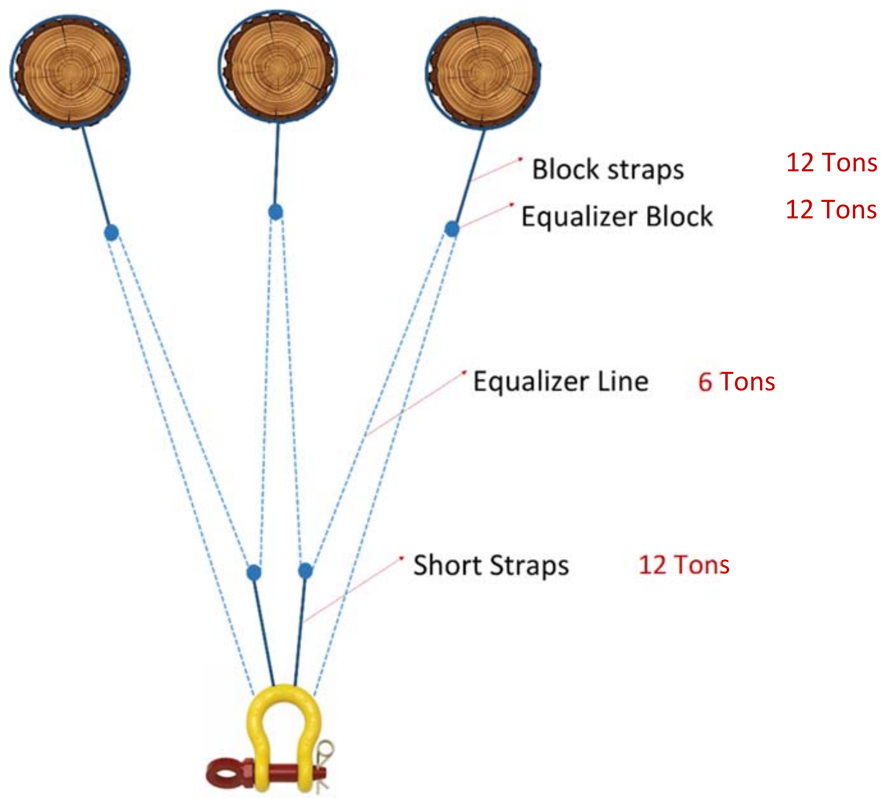
5. Determine the tension of the equalizer line: divide the ultimate breaking strength of the guyline or skyline you plan to anchor by number of equalizer line parts. This is assuming that the angle between each of two legs going through a bridle block is zero degrees. In our case 36 tons / 6 parts = 6 tons (12,000 lb) of breaking strength is what would be needed for the equalizer line. **If the stumps are not in a perfect fan shape horizontally or are on an extremely different vertical plane, then it may be necessary to up the size of all of your equalizer components.** Here again your rigging shop can help with this value.

6. Stump Straps sizing: each stump strap would be equal to 2 part of the equalizer line. If the equalizer line comes out to 6 tons (12,000 lb) then the strap breaking strength would need to be 12 tons (24,000 lb).

7. Short Strap tension: calculated the same way as our stump strap tension. In our example, they would equal 12 tons (24,000 lb) as well.

8. Determine the size of your equalizer blocks: since blocks utilize a different factor of safety than cable (5 to vs 3 to 1) it is then necessary to look at the Safe Working Load (SWL) for

each to come up with proper block sizing. In our example of a cable with 36 tons (72,000 lb) of breaking strength we would divide by 3 (the designed safety factor) to determine our cable SWL. Then the SWL of our cable comes out to 12 tons (24,000 lb). Each of our blocks that we utilize in the system would need a SWL of 12 tons. Here again your rigging shop can help in determining the correct block size.



Equalizer line example for a 6 part-3 stump multi-stump anchor for a 36-Ton ultimate breaking strength, assuming that the angle between each of two legs going through a bridle block is zero degrees.

Appendix II- Deadman anchor design

Before using these charts, take into consideration that these are built with example soils and are meant to provide guidance for deadman anchor design, careful assessment of soil and site specific characteristics play an important role on the safe design on these anchoring systems. Deadman anchors should be inspected for movement on a daily basis, and the use of tension monitoring devices are highly recommended.

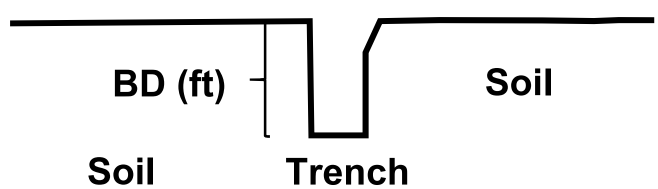
There are two important concepts that need to be well understood to be able to use these design charts:

Soil capacity: this is the maximum capacity of the soil to support the load of the deadman being pulled before failure, this failure can be by uplift or pullout, whichever is first.

Cable demand: this is the amount of load the anchor is being designed for.

How to use the deadman anchoring charts:

1. There are basic assumptions that need to be taken into account to use the charts:
   a. There is no clearance in front of the trench.
   b. The burial depth (BD) is measured to the bottom of the trench NOT the top of the log.
   c. The trench has to be notched in the front face of the deadman.



2. Characterize the strength of the soil on site for analysis, for example, using an inexpensive vane shear device, and find the chart that best characterizes the soil on site. On the chart you can find the soil capacity depending on:

   a. Slope (%)
   b. Guyline angle of pull (degrees)

Summary and characteristics of example soil capacity charts

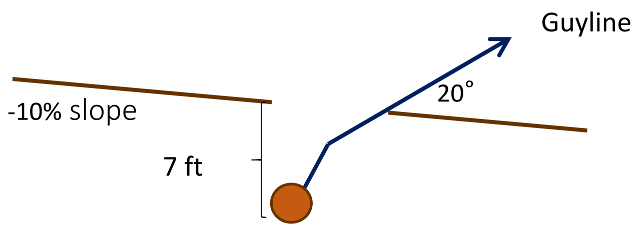
Density	Cohesion (psi)	Unit weight (lb/ft^3)	Friction angle (deg)
Granular soil			
Loose	0	96	25
Firm or slightly compact	0	109	30
Very firm or compact	0	128	35
Clayey			
Very soft	1.74	84	0
Soft	3.48	84	0
Firm	6.96	84	0
Stiff	10.44	84	0
Very stiff	13.92	84	0

3. Once the soil capacity has been found, use the safe working load of the skyline and divide by an arbitrary log length to find your cable system demand. If the soil capacity found in part (2) is greater than the cable demand, use the log-sizing chart to find the log diameter using the calculated ***cable demand*** and the respective length. If the soil capacity is smaller than the calculated cable system demand, use the ***soil capacity*** to find an adequate log size.

4. The log sizing chart is a nomograph with log length on the x axis and anchor capacity per foot of log (lb/ft) on the y axis. Each line represents a ratio between log mid-length diameter under bark and length. By using either the cable system demand or soil capacity and a log length, the log mid-length diameter under bark can be found.

<u>Example 1</u>

1. The landing is located on firm granular soil, the deadman will be located on -10% slope and there is enough distance to achieve 20 degrees angle of pull on the guyline. The available equipment allows for 7 ft burial depth. The chart indicates that the ***soil capacity*** is approximately 1,550 lb/ft (Figure a).
2. The safe working load for the skyline is 50,000 lb. By choosing a log length of 20 ft, the ***cable demand*** is 2,500 lb/ft. Since the soil capacity is <u>lower</u> than the cable demand, the soil capacity needs to be used to find the log size.
3. To determine the log size, a minimum log length needs to be calculated. That can be obtained by dividing the safe working load by the soil capacity as follows: 50,000 lb/1,550 lb/ft = 32 ft. According to the log sizing chart, a 32 ft log at 1,550 lb/ft load yields a diameter/length of approximately 0.088 (Figure b). Then 32ft x 0.088 = 2.82 ft (or 34 in) diameter log in the center.



Sketch of Example 1

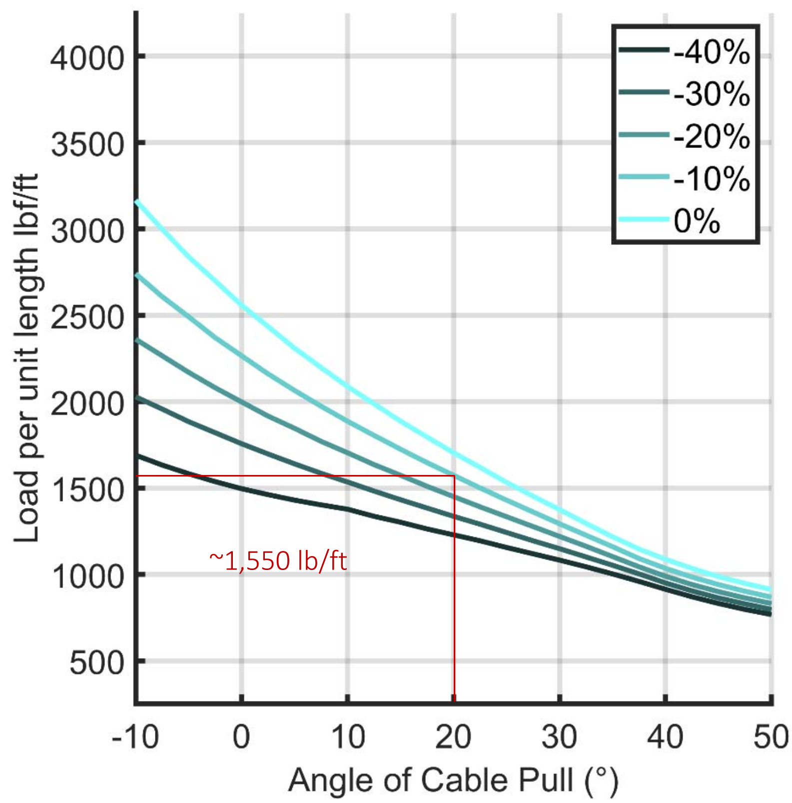


Figure a. Soil capacity for firm granular soil at 7 ft burial depth.

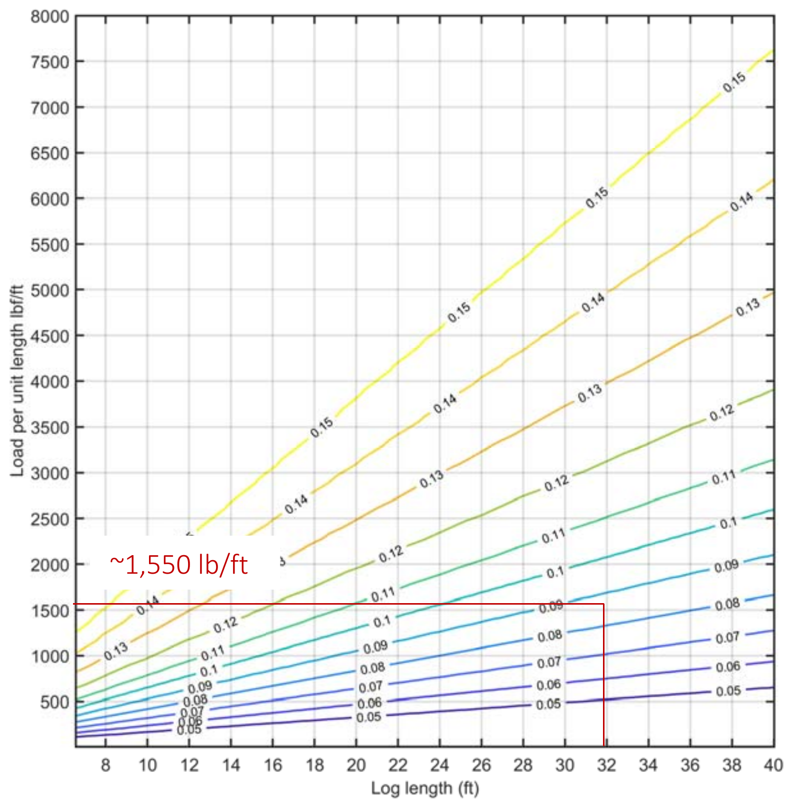


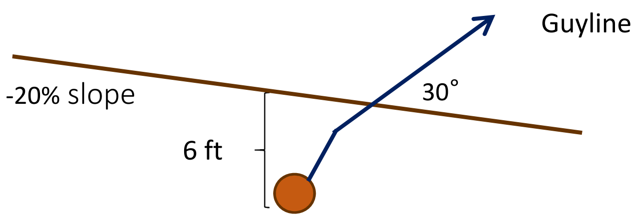
Figure b. Log sizing chart, lines are log center Diameter/Length

Example 2

1. The landing is located on a stiff clay soil, the deadman will be located on -20% slope and there is enough distance to achieve 30 degrees angle of pull on the guyline. The available equipment allows for 6 ft burial depth. The chart indicates that the ***soil capacity*** is approximately 3,550 lb/ft (Figure c).

2. The safe working load for the skyline is 50,000 lb. By choosing a log length of 16 ft, the ***cable demand*** is 3,050 lb/ft. Since the soil capacity is greater than the cable demand, the cable demand can be used to find the log size.

3. According to the log sizing chart, a 16 ft log at 3,050 lb/ft load yields a mid-length diameter/length ratio of approximately 0.15 (Figure d). Then 16ft x 0.15 = 2.4 ft (or 29 in) diameter log at mid-length under bark.



Sketch of Example 2

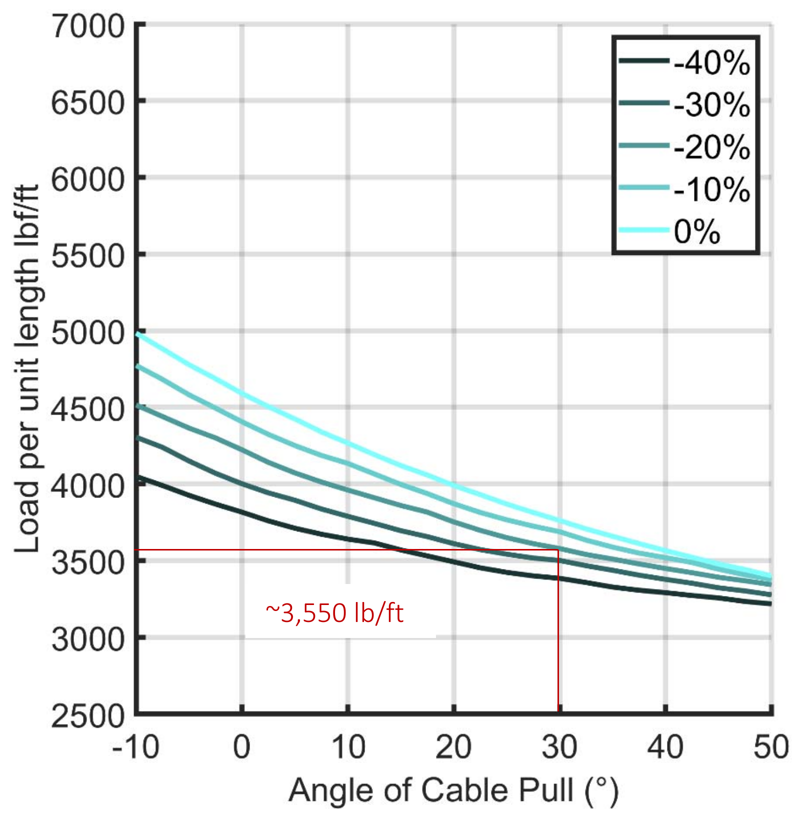


Figure c. Soil capacity for stiff clay soil at 6 ft burial depth.

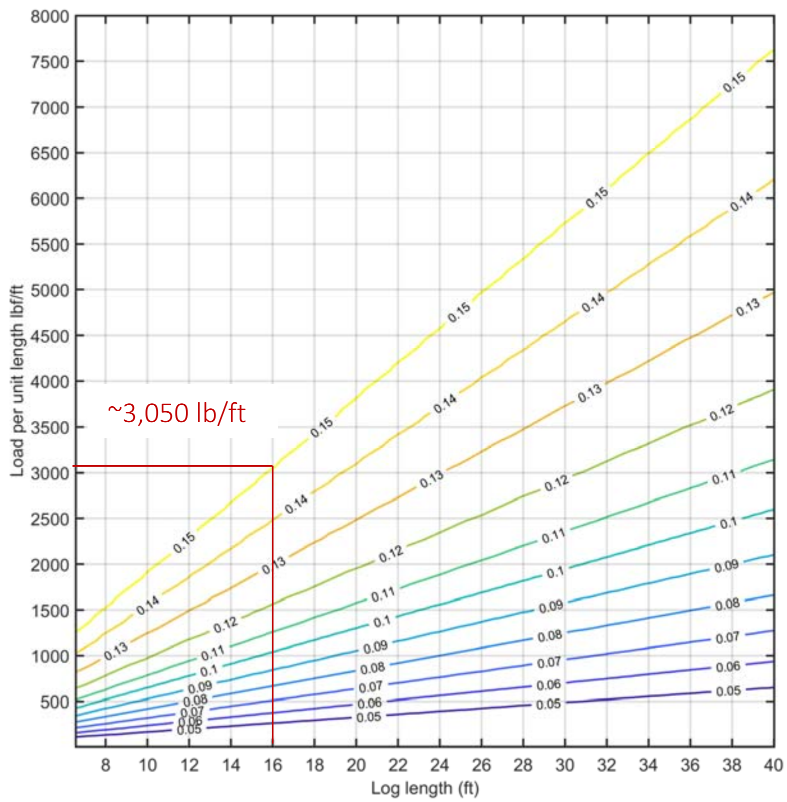
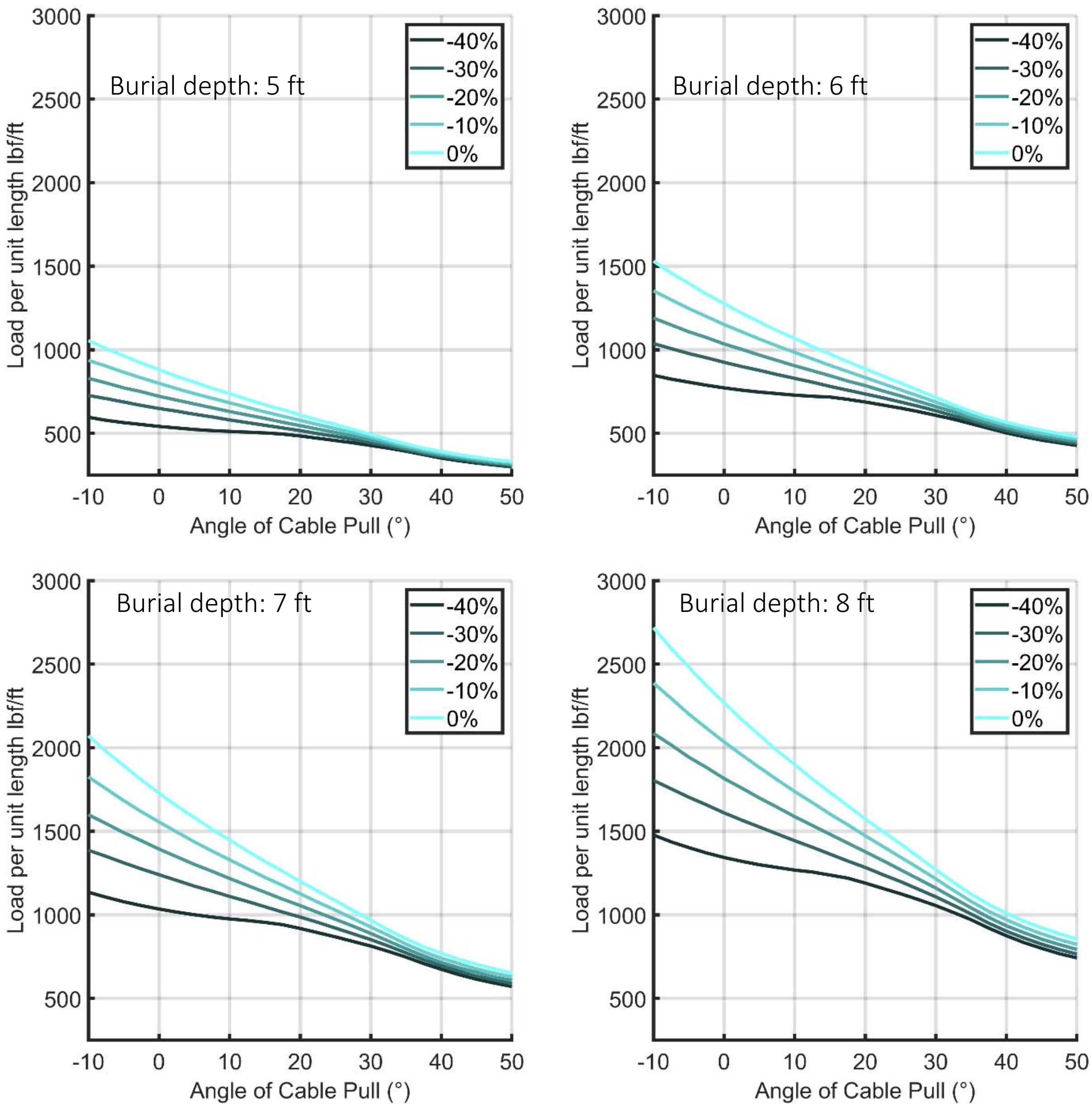


Figure d. Log sizing chart, lines are log center Diameter/Length

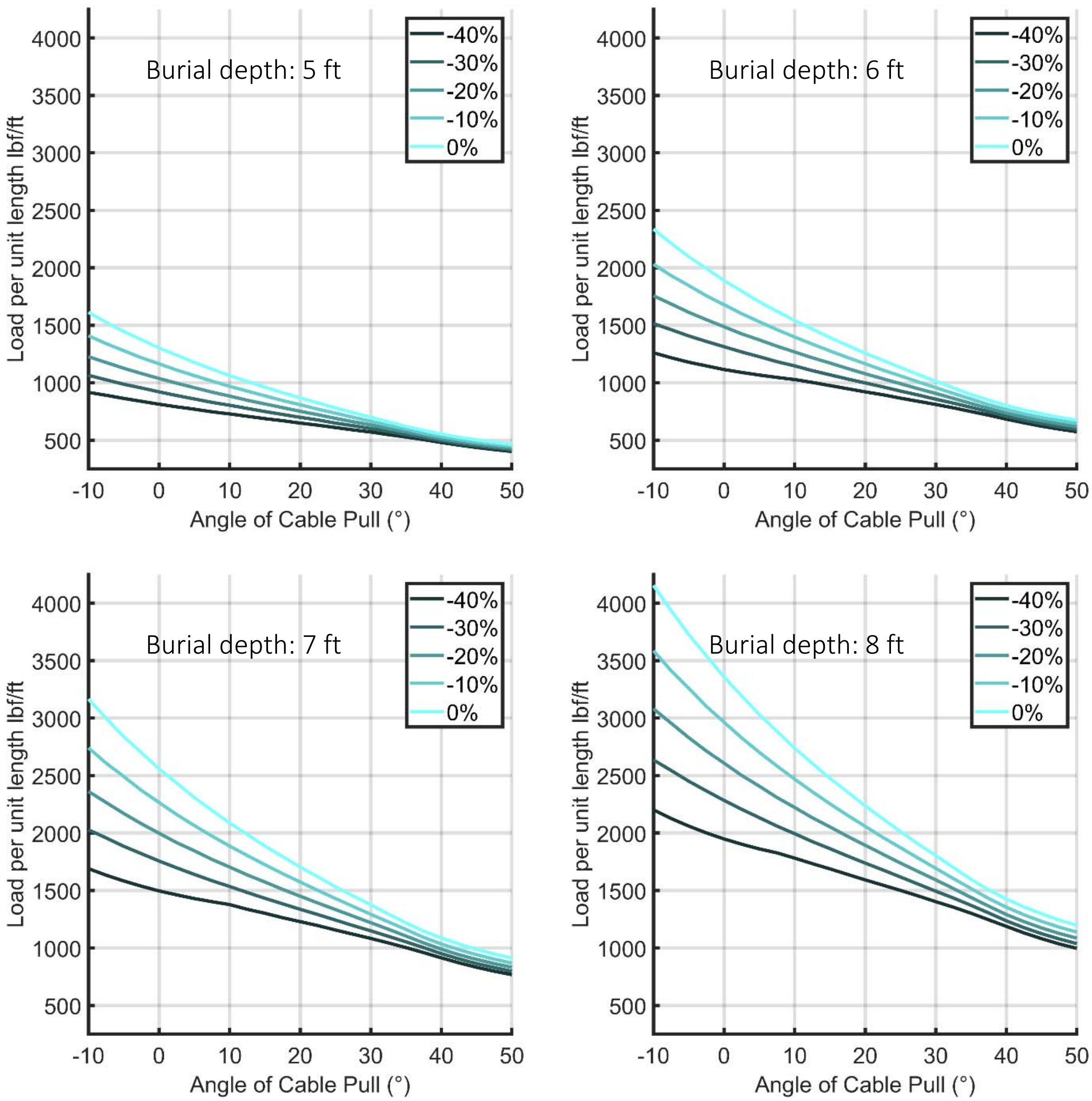
A. Soil Capacity Charts

Note: some weaker soils might not have all different slope lines, this is because those soils are too unstable and therefore unsuitable for deadman anchors.

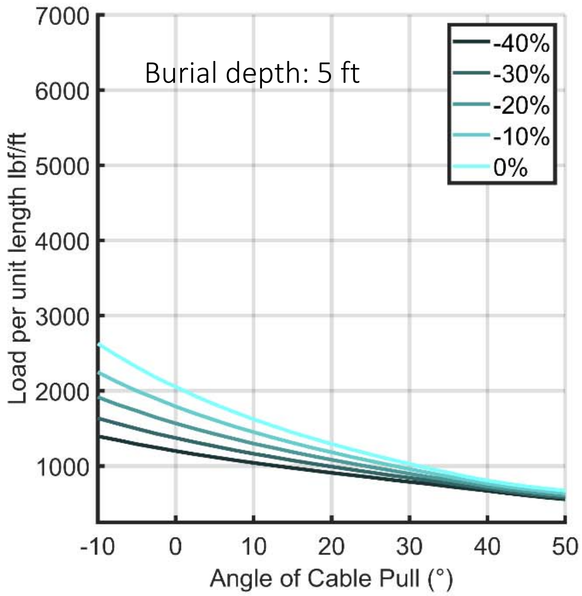
Granular Loose Soil

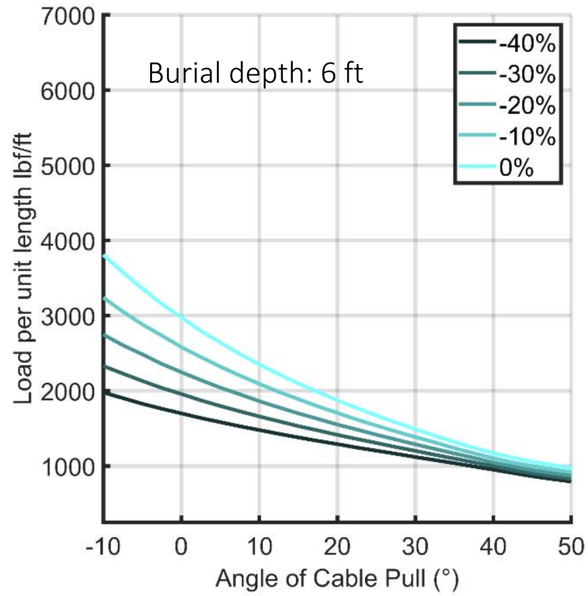


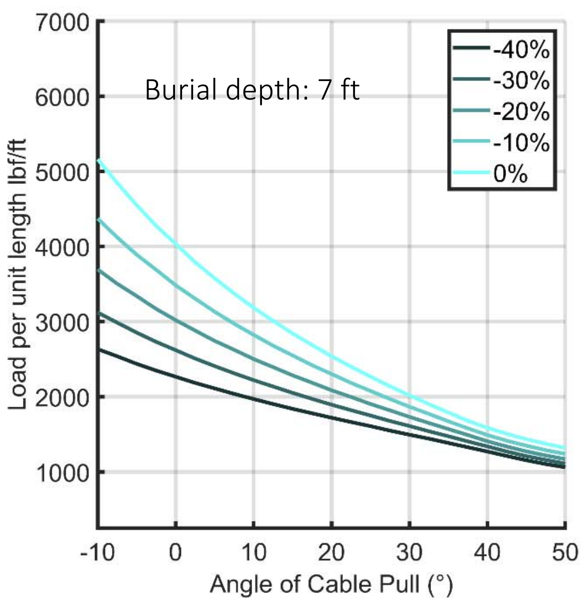
Granular Firm Soil

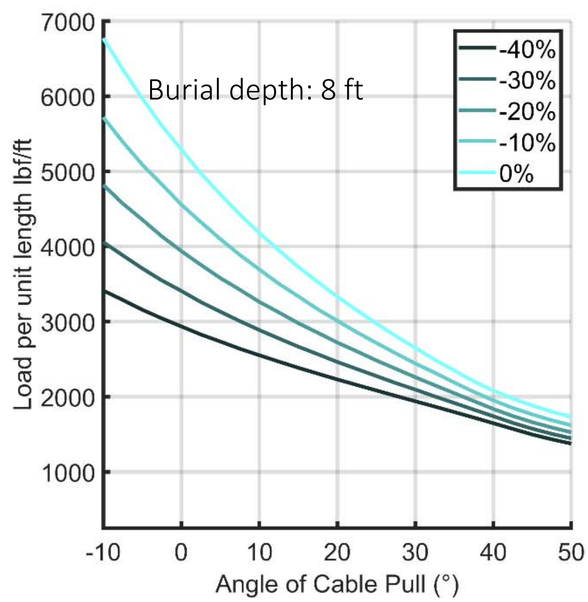


Granular Very Firm Soil

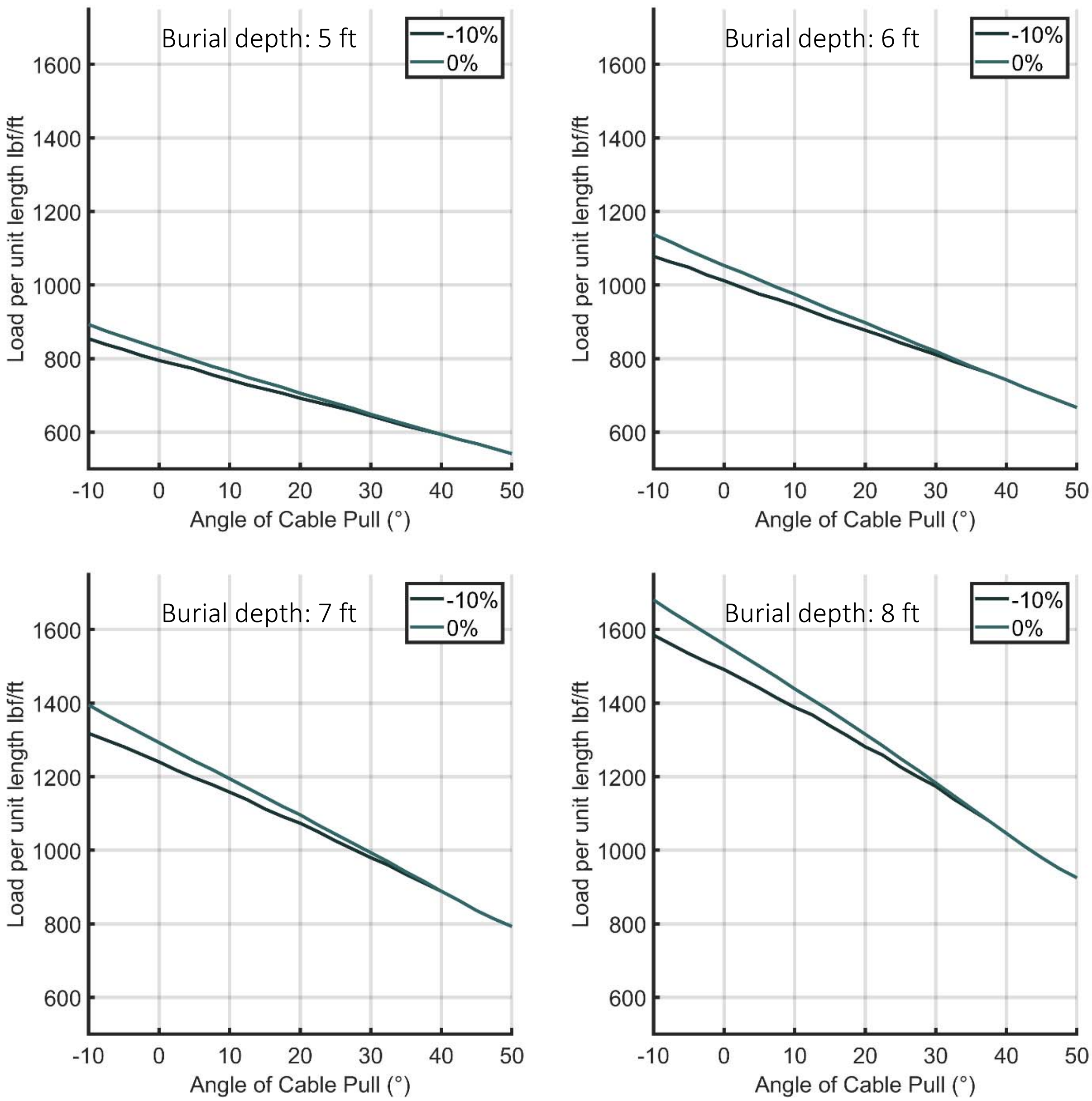




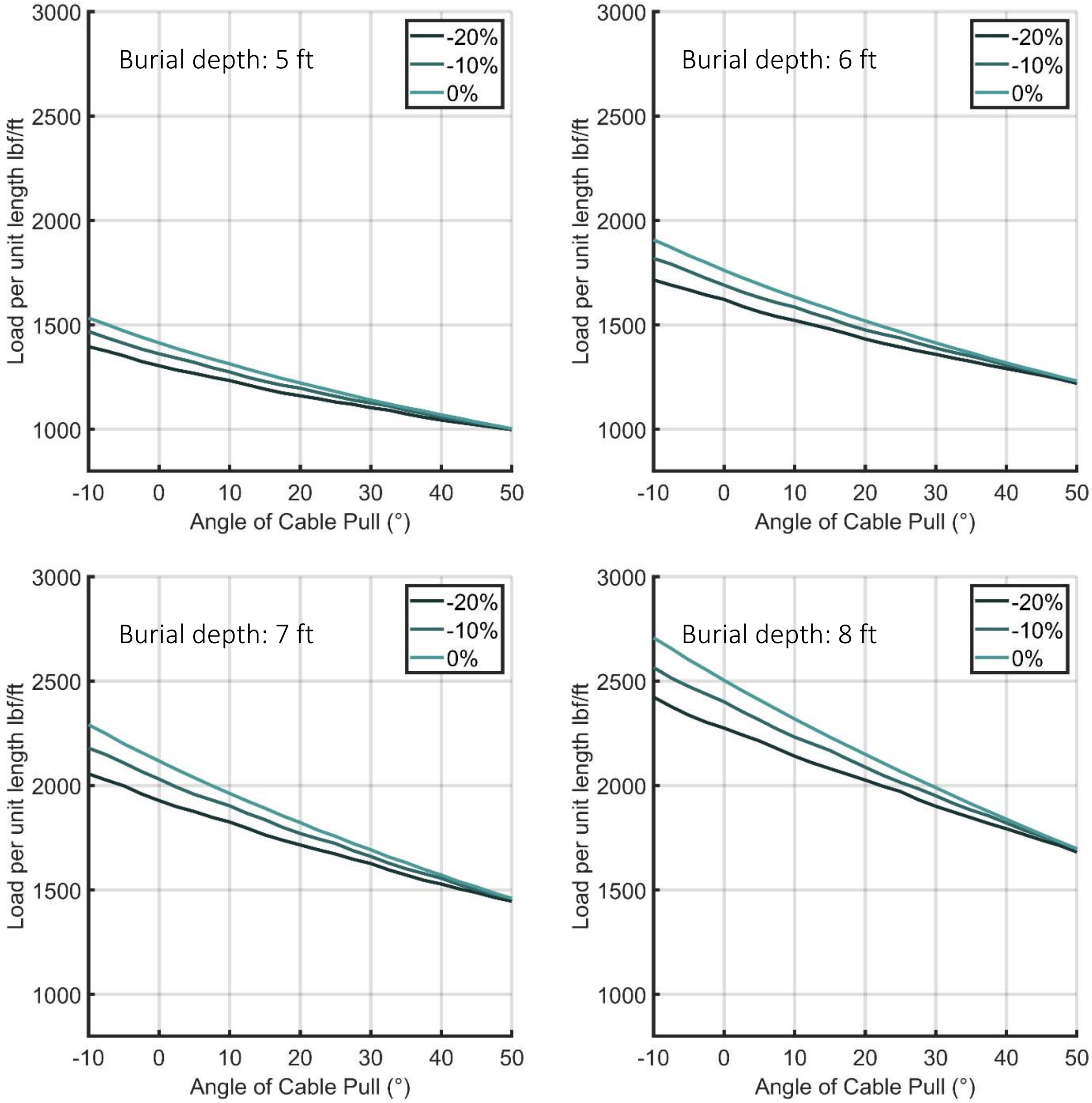




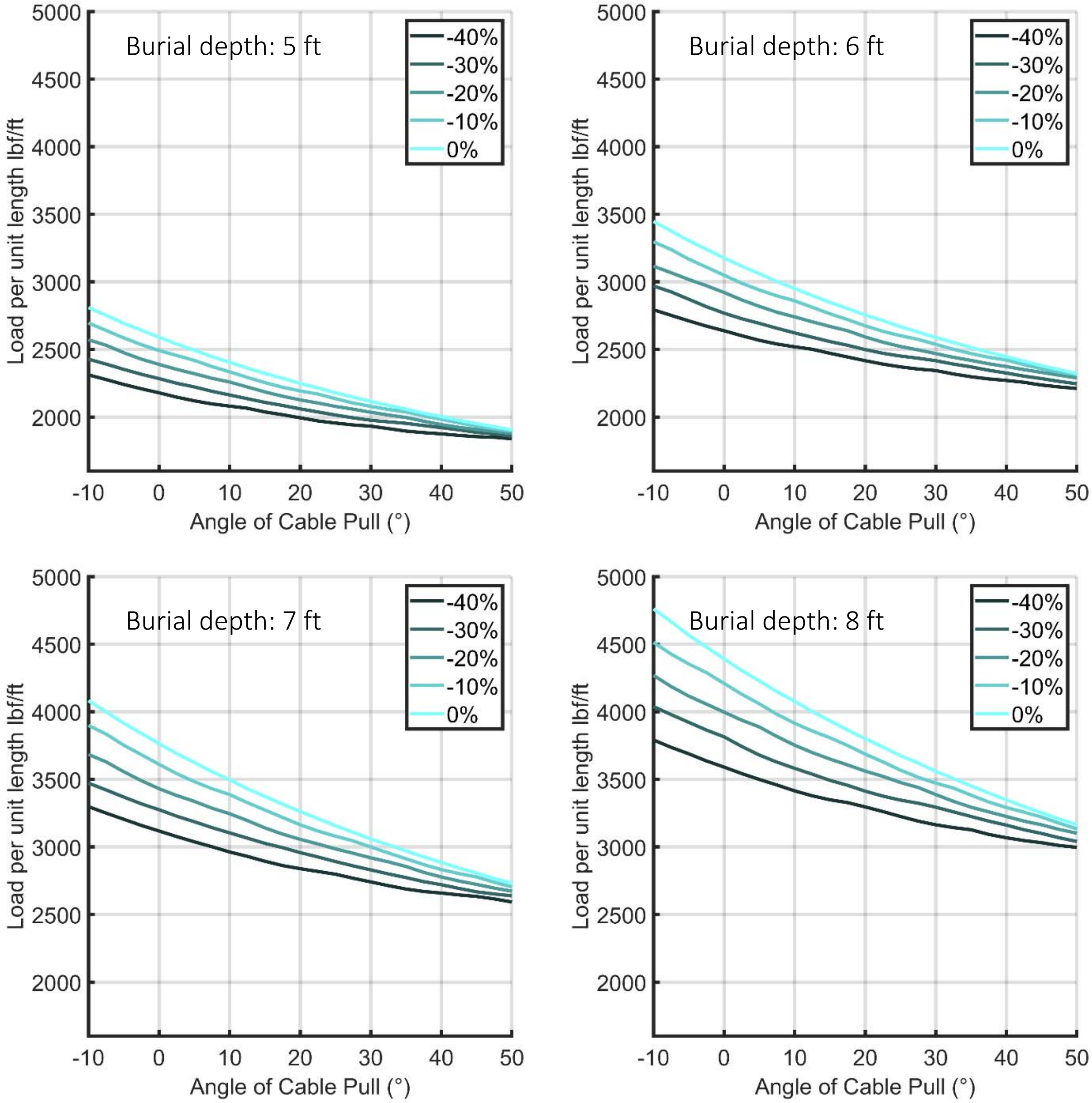
Very Soft Clay Soil



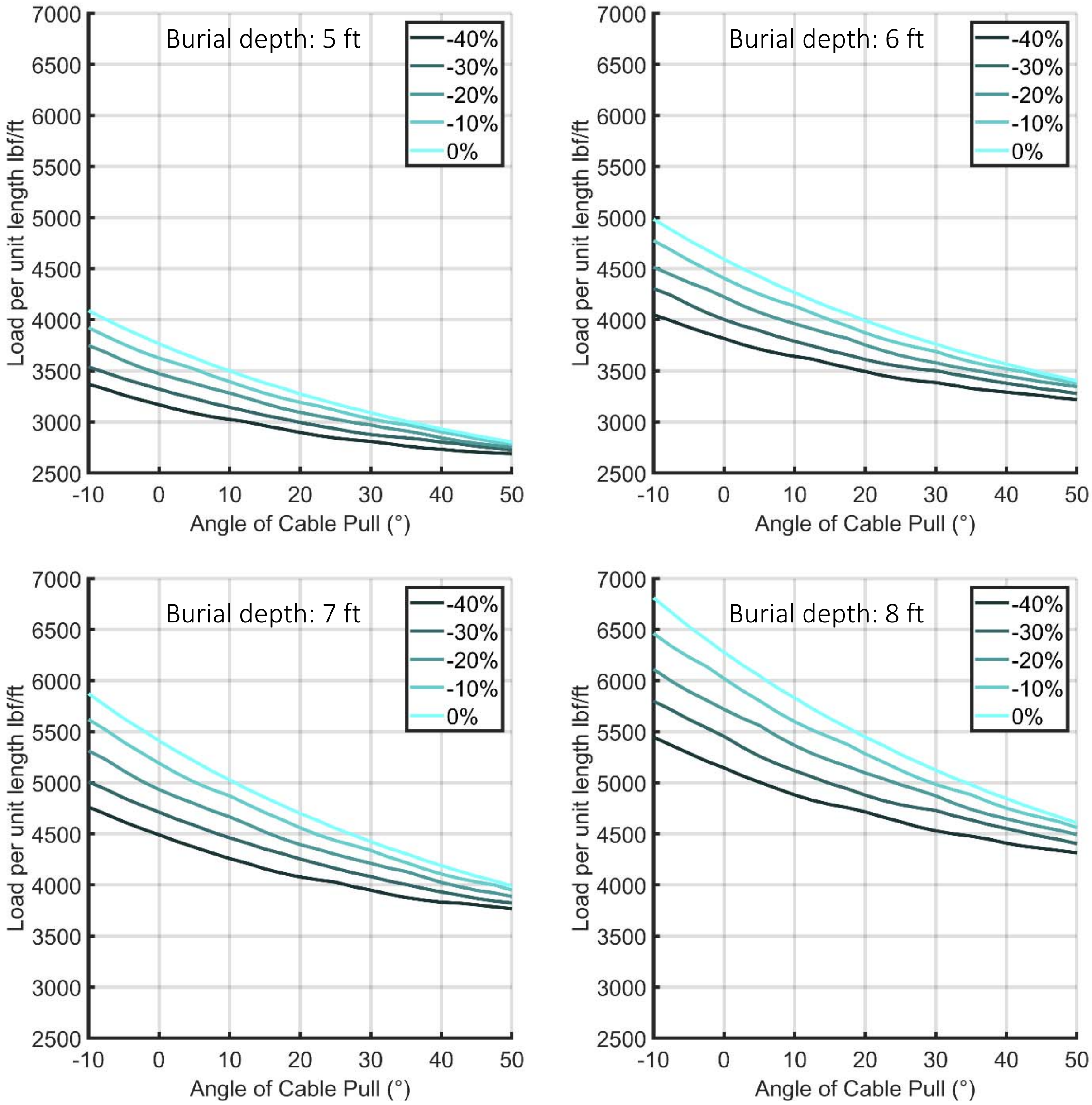
Soft Clay Soil



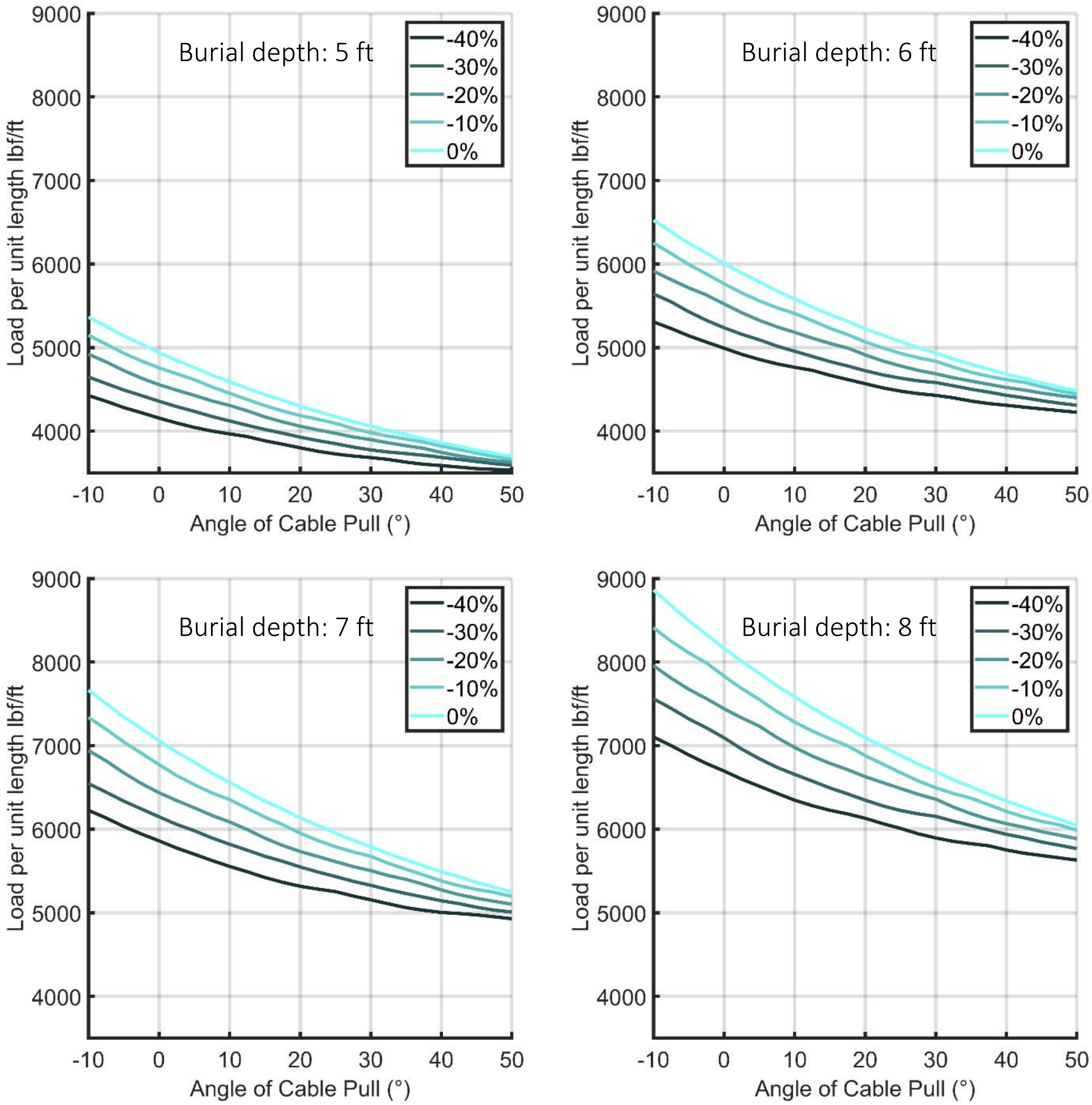
Firm Clay Soil



Stiff Clay Soil



Very Stiff Clay Soil



B. Log sizing chart for Douglas-fir