THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Civil Engineering

Preliminary Report No. 1

WIND FORCES ON MOBILE HOMES
PRELIMINARY ANCHORAGE REQUIREMENTS

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ACKNOWLEDGEMENT

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WIND FORCES ON MOBILE HOMES

Following Hurricane Donna in September of 1960, Mobile Home Owners, Public Officials, Mobile Home Manufacturers, Dealers and Insurers became concerned about the damages suffered by mobile home units subjected to high winds. While this concern has been focused on the problems of Florida and other Southeastern States, the problem of wind damage to these units is of importance to other areas as well.

It has been estimated that if mobile home units can be held upright and in place during a high wind the losses can be reduced by approximately 70% or more. With so much to be gained from anchoring these units the present studies at the University of Michigan have been undertaken with the sponsorship of the Foremost Insurance Company to try to determine the best anchoring procedures consistent with economy and safety.

The mobile home has a shape which is not commonly encountered in other structures. Further, it is lighter than a conventional home, is set on a narrow foundation, and is open beneath. These peculiarities make the mobile home unique in its response to high winds. It seemed necessary therefore to make some wind tunnel tests to determine exactly what the wind forces are on the unit. These studies are now underway at the University of Michigan. The results of these tests will not be known for some time and a final report will not be made until they are complete.

There are, however, some preliminary findings which may be of value to interested parties and these are the subject of this report. Some of these concern the nature of the winds to be encountered, a topic which has long been a matter for study, and use will be made here of the most recent information available. Additional findings deal with various anchoring devices. Public power utilities and telephone companies use many kinds of anchors as do many of the outdoor advertising companies. Some of the most recent thinking as to the strength of these devices will be presented.

THE WIND

Under severe atmospheric conditions some mobile homes are able to resist the wind forces, yet reports have been obtained in this study of units being overturned in winds as low as 65 miles per hour. What then do we mean here by high or strong winds?

The United States Weather Bureau reports that the sources which spawn strong winds are cyclonic storms, frontal regions, tropical cyclones (hurricanes), severe thunderstorms, squalls, tornadoes, and special winds. Under usual conditions cyclonic storms are broad enough and have pressure gradients low enough so that most mobile homes are able to withstand the winds produced.

The frontal region is characterized by strong gusts and steep horizontal pressure gradients. Wind forces in these regions are sometimes of a magnitude sufficient to overturn a mobile home. Brekke[1] states that "tropical cyclones are severe storms accompanied by strong, squally winds ranging from 75 to 150 mph." He also says that "A squall is a wind of considerable intensity cause by atmospheric instability; it is characterized by gusts that rise quickly and fall gradually." Wind forces in squalls and tropical cyclones (hurricanes) frequently overturn mobile homes.

It is doubtful that any structure can be designed to withstand the violence of a tornado and still be economically feasible. The relative narrowness of a tornado's path and its unpredictable nature increase the chance of any given structure's survival to such a degree that it would be unreasonable to attempt such designs.

In brief, it should be possible to anchor a mobile home against the action of winds up to hurricane velocity without excessive cost or difficulty.

Thom[2] has made extensive statistical studies of the fastest-mile-of-wind for U. S. Weather Bureau stations throughout

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[1] Brekke, Guttorm N., "Wind Pressures in Various Areas of the United States," Building Materials and Structures Report 152, United States Department of Commerce, National Bureau of Standards, 1959.

[2] Thom, Herbert C. S., "Distribution of Extreme Winds in the United States," Journal of the Structural Division, Proceedings of ASCE, Vol. 86, No. ST4, April, 1960, p. 11.

the United States. His maps show this velocity for probable periods of recurrence of 50 years and 100 years for velocities at a height of 30 feet above the ground. The southern portion of Florida and the Southeastern seaboard show the greatest velocities which are of the order of 90 to 120 mph for a 50 year recurrence and of 100 to 130 mph for a 100 year recurrence.

Height plays an important part in establishing such velocities, actual recorded velocities at heights above 30 feet being much greater. In addition, the location of the recording instruments with respect to shielding from other structures and the like may introduce deviations from these standardized values. Topography, alone, may cause considerable differences which should be evaluated locally.

For inland areas the usual one-seventh-power law may be taken to adjust local readings to the basic level of 30 feet. This may be expressed thus:

$$V_{30} = V_h\left(\frac{30}{h}\right)^{1/7}$$

where h is any height, V_h is the velocity at that height, and V_{30} is the velocity at the basic 30 foot level.

There is much disagreement as to velocities in regions below the 30 foot level. If the one-seventh-power law is applied to reduce the velocity to a ten foot level one obtains the following:

$$V_{10} = V_{30}\left(\frac{10}{30}\right)^{1/7} = 0.208V_{30}$$

Since this value would seem ridiculously low and since the effect of vegetation, other structures, and the like is an unknown factor, a conservative assumption would be to use the 30 foot values as basic even at the level of the mobile home.

Wind velocities may be reduced to pressures by making use of the basic velocity-pressure relationships for fluids, namely,

$$q = \rho\frac{V^2}{2}$$

where q is the dynamic pressure, V the velocity, and ρ the mass density of the fluid, in this case air. The value of ρ varies with temperature and barometric pressure (altitude). Applying a value of $\rho = 0.00238$ slug/ft^3 at standard sea-level conditions of temperature and barometric pressure one obtains

$$q = \frac{1}{2} \times 0.00238 \times \left(\frac{5280}{3600}\right)^2 V^2 = 0.002558V^2 \qquad (1)$$

V being expressed in miles per hour.

To obtain the local pressure at any point on the surface of an object the dynamic pressure, q, must be multiplied by a pressure coefficient, C_p. If the total force on the object is desired the dynamic pressure must be multiplied by a shape coefficient and the area. It is precisely at this point that this report must be preliminary for no coefficients of pressure or shape are now available which would apply to objects having the shape of a mobile home. These coefficients are dependent upon the geometric shape of the object, its orientation to the wind, and air friction effects, in order of importance as listed. While it is hoped that satisfactory values of the pressure and shape coefficients will be obtained and reported later, it is possible to make some assumptions.

Local pressure coefficients on buildings[3] having length to width ratios up to 4 show values up to about +1.0 as a maximum on the windward side, the dominant value being +0.9. On the leeward side this local pressure coefficient varies from -0.61 to -0.69. These values are somewhat higher than the values of +0.8 for the windward side and -0.5 for the leeward side of an average building as given by the American Society of Civil Engineers.[4] It can be shown that if the object is not resting on the ground the coefficients tend to increase. Since a mobile home is commonly set so that the winds can move beneath, the higher values are appropriate and, for the purposes of this preliminary report, may be taken as +0.9 and -0.6 for average maximum pressures.

The shape coefficient, frequently referred to as the drag coefficient, is derived from the integration of the pressure coefficients as they are distributed across the faces of the object. Using the data from the Iowa studies[3] the coefficient for a flat roofed building having a length to width ratio of 4 is 1.33

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[3] Chien, N., Feng, Y., Wang, H. J., Siao, T. T., Wind-Tunnel Studies of Pressure Distribution on Elementary Building Forms, Iowa Institute of Hydraulic Research, State University of Iowa, 1951.

[4] "Wind Bracing in Steel Buildings," Final Report, ASCE Sub-Committee No. 31, Transactions of ASCE, Vol. 105, 1940, p. 1713.

Woodruff and Kozak[5] present data indicating that the drag coefficient for a plate with an aspect ratio of 6 (length to height) is about 1.3 and for a parallelopiped with a width to height ratio of 1 and an infinite length the coefficient is 2.03. In all probability the drag coefficient for a mobile home lies somewhere between 1.3 and 2.0. For the purpose of this report it will be taken as 1.5.

Not only are the values of the pressures and forces acting on a mobile home significant but also the location of the centers of the pressure plays an important part. The Iowa tests[3] show that for winds acting normal to the wall the pressure centers are each near the geometric center of the exposed face. However, when the wind force is at a 60° angle from normal the center of windward pressure is 0.15 the height below the center and for the leeward pressure is 0.10 the height above the center. Thus the spread in these values is 0.25 times the height. A more accurate determination of this factor for mobile homes will need to await the test results.

Another element of wind and its effects on mobile homes is the variability of the wind itself. The data available from wind tunnel testing is all based on the use of steady wind velocities. In nature this is not the case, hence some allowance must

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[5] Woodruff, Glenn B. and Kozak, John J., "Wind Forces on Structures: Fundamental Considerations," Journal of the Structural Division, Proceedings of ASCE, Vol. 84, No. ST4, July, 1958.

be made for gusts. Sherlock[6] shows that the gust factor may be taken as 1.3 and that it is independent of height. Gentry[7] confirms that the factor is from 1.3 to 1.4 even during hurricane winds. In this report the value of 1.3 will be used. The following paragraph summarizes the above statements concerning the effects of the wind.

Referring to Equation (1), the value of the maximum local pesssure will be:

Windward Side

$$p = C_p q = +0.9 \times 0.002558V^2 = +0.00230V^2$$

Leeward Side

$$p = C_p q = -0.6 \times 0.002558V^2 = 0.00154V^2$$

Applying the assumed gust factor these values become:

Windward Side

$$p = +1.3 \times 0.00230V^2 = +0.00299V^2 \qquad (2)$$

Leeward Side

$$p = -1.3 \times 0.00154V^2 = -0.00199V^2 \qquad (3)$$

For the total force tending to move the mobile home downwind the value becomes:

$$\begin{aligned} F &= 1.5 \times 1.3 \times 0.002558V^2A \\ &= 0.00498V^2A \qquad (4) \end{aligned}$$

where A is the area of the side of the mobile home.

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[6] Sherlock, R. H., "Variation of Wind Velocity and Gusts with Height," <u>Transactions of ASCE</u>, Vol. 118, 1953, p. 463.

[7] Gentry, Robert C., "Wind Velocities During Hurricanes," <u>Transactions of ASCE</u>, Vol. 120, 1955, p. 169.

THE MOBILE HOME

While the forces caused by the wind are the major consideration in anchoring a mobile home against strong winds, there are some aspects of the mobile home itself which contribute to the problem. Most of these concern the weight of the unit and the foundation.

Weights naturally vary with the manufacturer, model, and the user. A fifty foot ten wide as delivered will have weights ranging from 10,000 pounds to 12,500 pounds depending on model and maker. An average value of 11,100 pounds was found from weights given by 11 manufacturers. The users contribution can be very substantial by the time he adds dishes, cooking equipment, clothing, bedding, TV sets, and other specialized equipment. It is estimated that this can easily reach another 1,000 to 1,500 pounds. The total weight of the unit in place will run from 10,000 to 14,000 pounds for a fifty foot ten wide.

Many of the modern mobile homes have side aisles and fixed equipment along the left wall. This produces a decided shift in the center of gravity of the coach. One fifty foot ten wide was weighed and the center of gravity was found to be 1.485 feet to the left of center and 1.269 feet above the bottom of the frame. The addition of the users equipment in this coach would tend to shift the center of gravity upwards slightly and further to the left.

In setting a mobile home the usual practice is to block it under the main longitudinal members of the frame. The spacing of these members on the mobile home is therefore of importance since the farther apart the members are the more effective will be the blocking in resisting the overturning action of the wind. With different manufacturers the spacing of the longitudinal member varies from 55 inches to 75 inches with some manufacturers using a perimeter frame. It would appear that the most critical spacing for this study would be the 55 inch one.

ANCHORAGE REQUIREMENT

After considering the wind and its action and the condition of the mobile home, the logical question is "How much anchorage is required?".

Assuming a wind velocity of 125 miles per hour with gusts 30% greater and a fifty foot mobile home weighing 12,000 pounds, the anchorage required is 282 pounds per lineal foot (See Appendix, page 27, for computations).

It is assumed for preliminary purposes that this figure is 280 pounds per foot. (See Figure 1) Only the testing program can verify or deny the accuracy of this assumption. Attention must then be focused on the simplest, cheapest, and most widely applicable method for achieving this anchoring force.

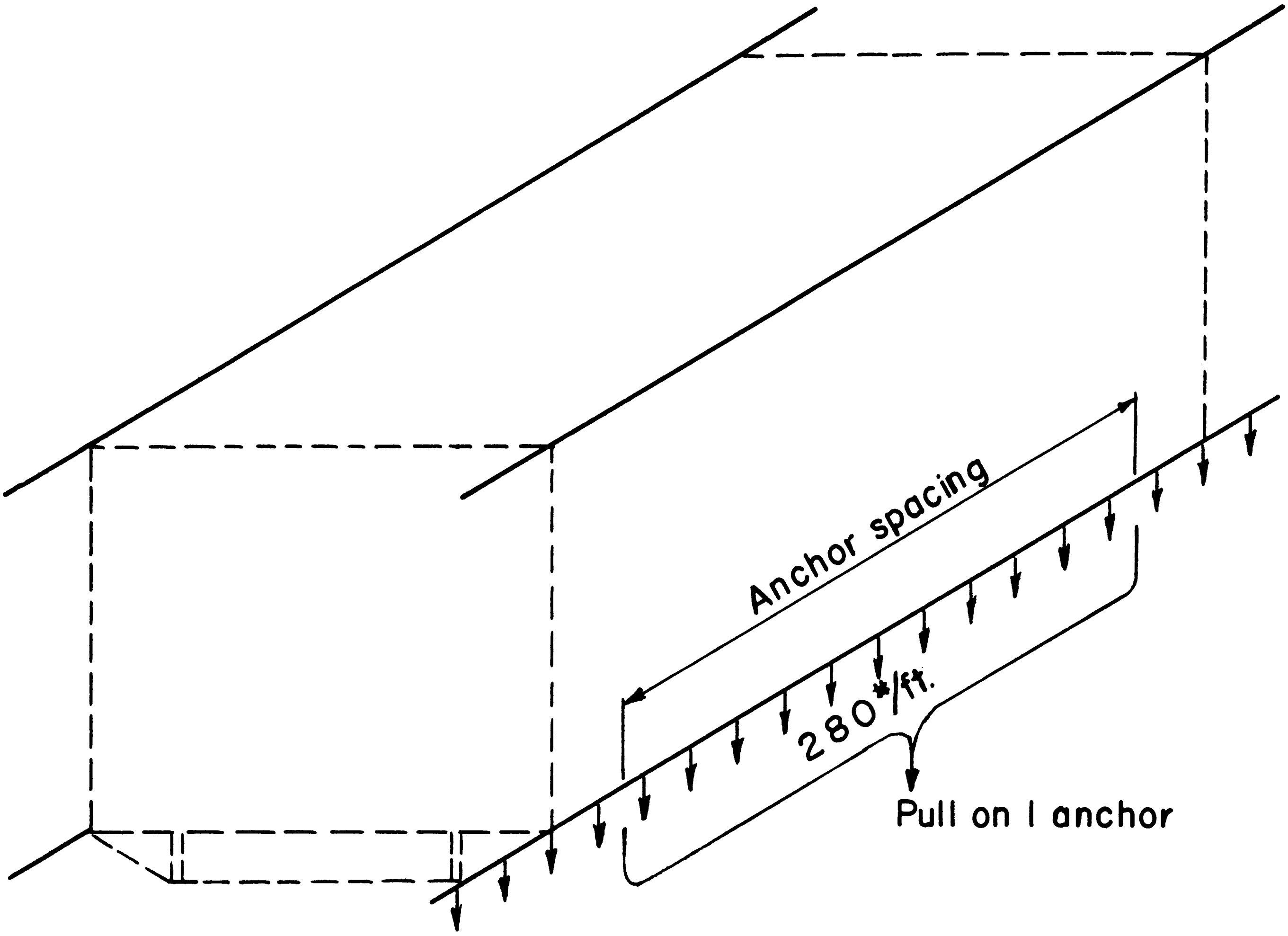


Figure 1

Segment of a Mobile Home Showing
Preliminary Estimate of Anchor Requirement

ANCHORAGE SYSTEM

The most widely used and simplest anchor system is the so-called "dead man". Typically this may consist of a concrete block either cast in place or positioned below the ground surface, to which is fastened the anchor rod or cable. Usually, but not always, a portion of the reaction is due to the weight alone of the anchor block, this augmented by the weight of the overlying soil.

A pair of examples of the dead man method, which were observed in Florida mobile home parks, will serve for illustration. One device consisted of a 3/4 inch rod with a welded angle end-piece, threaded through a hollow concrete building block. The block was set into the ground, with about 3 1/2 feet of back filled cover. Another method consisted of a fence post, 5 feet long, embedded in 23 inches of concrete at the bottom of a pre-bored hole of perhaps 6 inches to 1 foot in diameter at the bottom.

There are, of course, many possible variations of this method, depending upon the inclinations of the builder and available materials. However, they are all essentially similar, that is, they all require a pre-excavated hole into which are placed the structural elements of the anchor.

Besides simple methods using on-hand material such as described above, various manufacturers sell prefabricated dead man anchors. Several fabricate expanding and fixed-cone anchors of various sizes and nominal holding power. Details of their construction and installation may be found in their sales literature. These are currently widely used as pole ties by utility companies and for fence end-post supports. The listed sizes generally require 6 or 8 inch pre-bored holes of from 4 to 7 feet depth, and entail back filling and tamping after installation of the anchor.

Another popular soil anchor, and one which seems particularly suited to sandy beach areas in Florida, is the screw auger. This consists of a circular helically deformed plate fastened to the bottom of a sturdy rod, which is turned into the soil to the required depth. Although this device is limited to

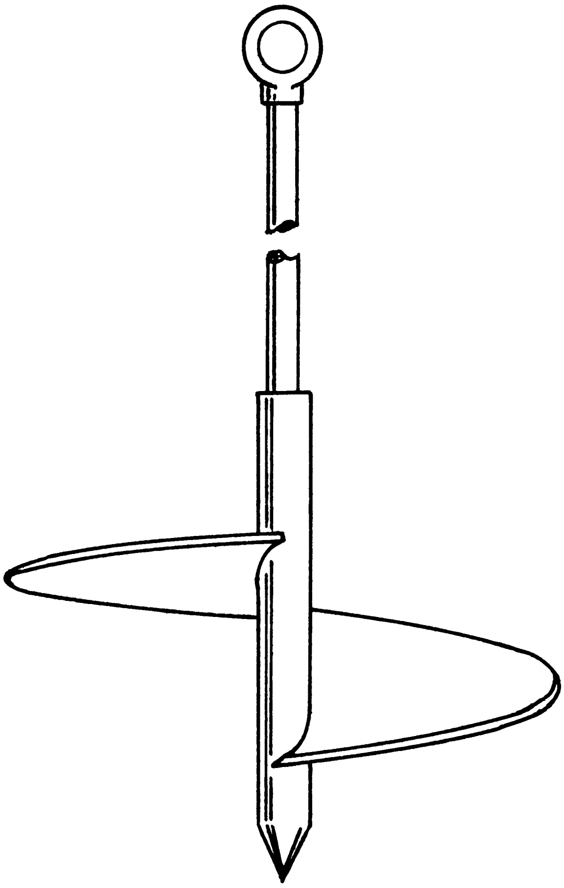


Figure 2
Screw Auger

looser or softer soils, it is particularly these soils in which it is difficult to achieve a secure anchorage by dead man devices. Also it does not require auxiliary equipment for installation and is relatively foolproof given the proper soil conditions.

Without going into all of the economic and personal preferences which will enter into the final choice of anchorage method, the following suggestions might be considered as a guide:

(a) In loose, sandy soil and softer clays, also where high water tables are encountered, the screw auger is preferred.

(b) For dense or rocky sands and stiffer clays a cast in place or expanding dead man is preferred.

(c) Where a prefabricated or precast dead man is used it is especially important that the soil be thoroughly tamped around and above the anchor.

In general, the cast in place or soil auger is preferred over the prefabricated anchor. In any event, the safe holding power of a particular anchor may be determined by the methods discussed in the next section.

DESIGN TIE-DOWN CAPACITY

The computations on pages 28 to 31 in the Appendix present examples of a method for evaluating the safe design capacity of both dead man and screw auger systems. Some example computations are included and typical soil resistance values are given as a guide for various conditions. It should be pointed out that some judgement must be exercised in using these methods and particularly the soil conditions should be carefully studied to assure that the appropriate soil resistance values are employed. It should also be pointed out that moisture content of the soil plays an important part in choosing resistance values. Lower values should always be applied if during the seasons a particular soil can become saturated.

Page 28 presents a general procedure for evaluating dead man tie-down capacity. Equations A and B indicate the tie-down reaction as controlled by either side shear and surcharge, or by the weight of soil within the projected cone of influence. Suggested side shear values for use in Equation A are shown. Note that these values are available only where concrete is poured against the natural soil or where an expanding anchor is used. These resistances should not be used when considering distrubed soil, as in a back filled precast block dead man.

The example computation on page 29 is for a cast in place concrete plug, 1 foot in diameter, 2 feet deep, with 3 feet of surcharge acting. The indicated safe design capacity in loose sand would be about 1,500 pounds.

Pages 30 and 31 present an evaluation of a typical screw auger anchor. For the nominal 6 inch by 48 inch anchor, the safe

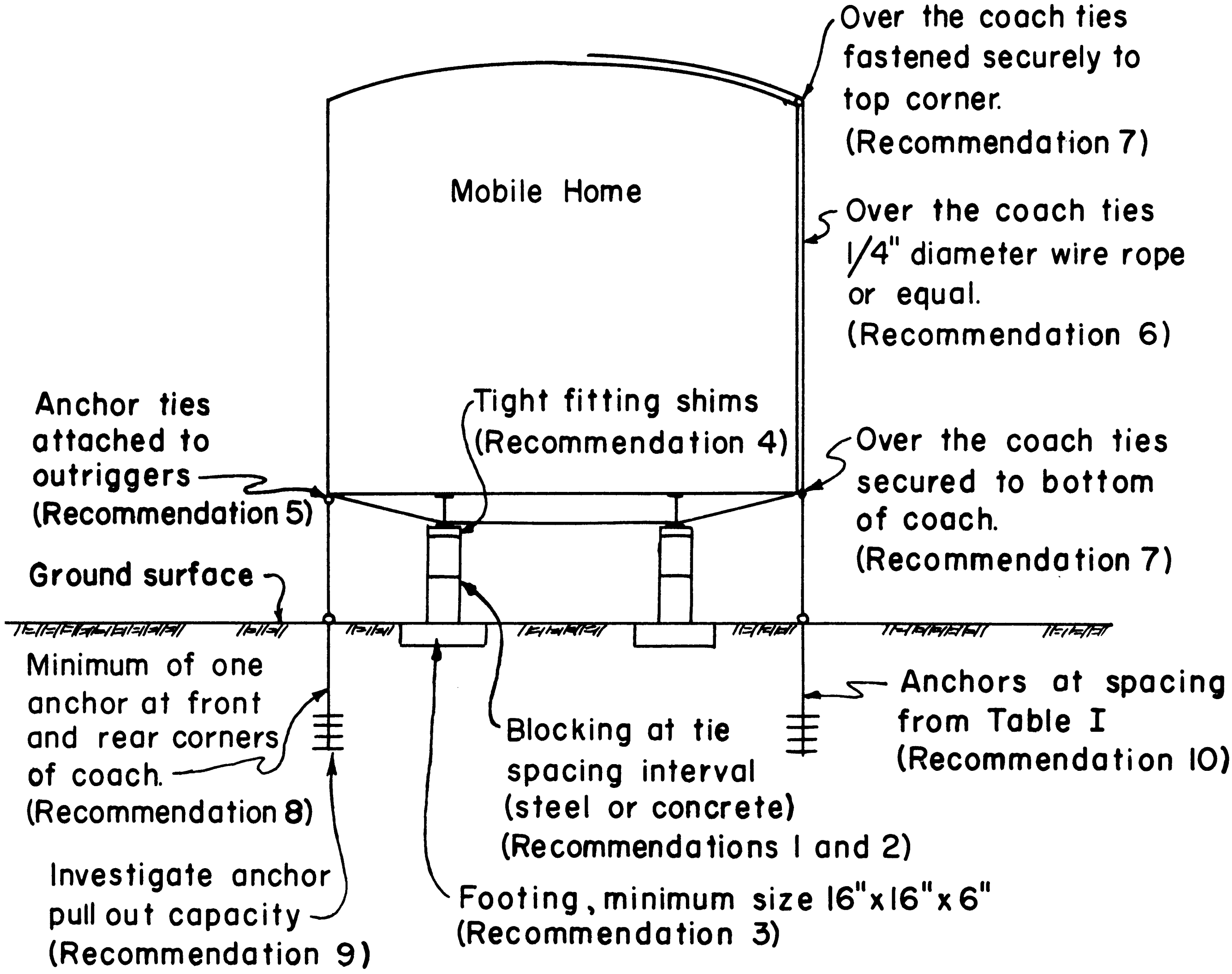


Figure 3
Summary of Preliminary Recommendations

indicated design capacity for a medium sand is 2,200 pounds pull. This is somewhat less than the 2,500 pounds recommended by the manufacturers.

PRELIMINARY RECOMMENDATIONS

The following recommendations must be considered preliminary only and are subject to changes after wind tunnel tests are complete, however they represent the most recent available data applying to mobile homes and similar structures.

1. Blocking should be installed beneath the main longitudinal frame of the mobile home at the same interval of spacing as the tie-down anchors and should be in line with them.
2. Blocking should be of steel or concrete. If concrete building blocks are used, cores should be placed vertical with a solid 4 inch concrete cap block on the top beneath the frame. Class "A" block should be used which meets American Society for Testing and Materials Specifications for manufacture.
3. Footings beneath blocking must be firm, in good condition, and not less than 16 x 16 inches in plan dimension. Footing thickness should be a minimum of 6 inches.

4. Shimming between the blocking pier and the steel frame must be of treated wood of first quality or other firm material. Shims must be fitted tightly to prevent rocking of the unit under the action of wind gusts.

5. In the absence of test information to the contrary, anchor ties either attached to the ends of the outriggers of the frame or passing over the coach may be accepted. The anchor ties to the frame outriggers appear to be sufficient at this time.

6. Ties passing over the coach should be at least 1/4 inch diameter wire rope, 1/2 inch diameter manila rope, 3/8 inch diameter nylon rope, webbed straps, or equal. Over the coach ties should be able to sustain a minimum load of 2,800 pounds before breaking for an anchor spacing of 10 feet. Ties should be doubled or of increased capacity for greater anchor spacings.

7. Ties passing over the coach should be snug and fastened securely to the coach body at both top corners. In addition ties passing over the coach and perpendicular to the ground should also be secured to the coach body as close to the bottom as practical.

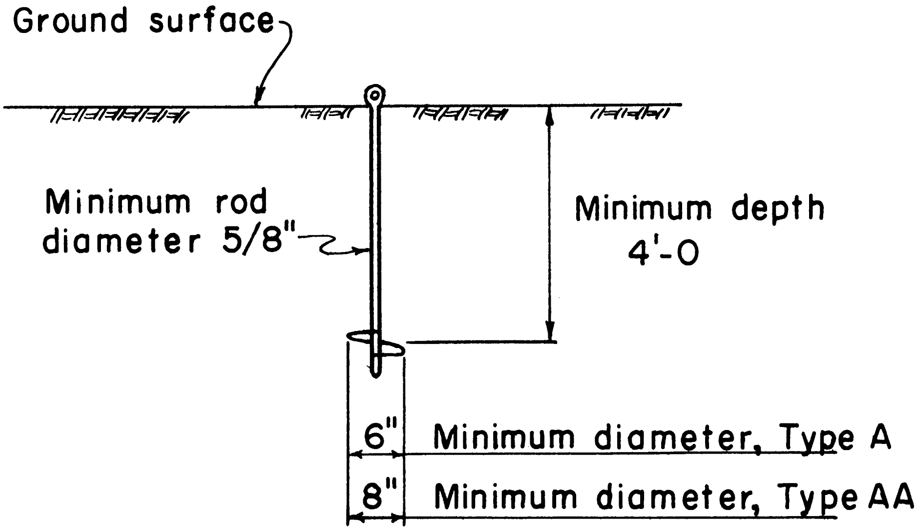
<u>8.</u> At least one anchor should be placed near each front and rear corner of the coach.

<u>9.</u> If a quantity of a particular type of anchor is to be installed in a given area, or if any installation is to be made in an area of uncertain soil conditions, a special investigation of pull out capacity on the anchor should be conducted in the field. A safety factor of 1.3 to 2.0 may then be applied to the force required to pull out the anchor and the spacing of anchors along the coach established to give an average tie-down force of 280 pounds per lineal foot on each side. For example, if a pull out force for a particular anchor is found to be 5,000 pounds and a safety factor of 1.5 is applied, then the spacing required would be $\frac{5{,}000}{1.5 \times 280} = 11.9$ feet. A spacing of 10 or 11 feet would probably be used.

<u>10.</u> Recommended spacings along each side of the mobile home are given in the Table I, page 23, for various soil conditions and the following anchor types.

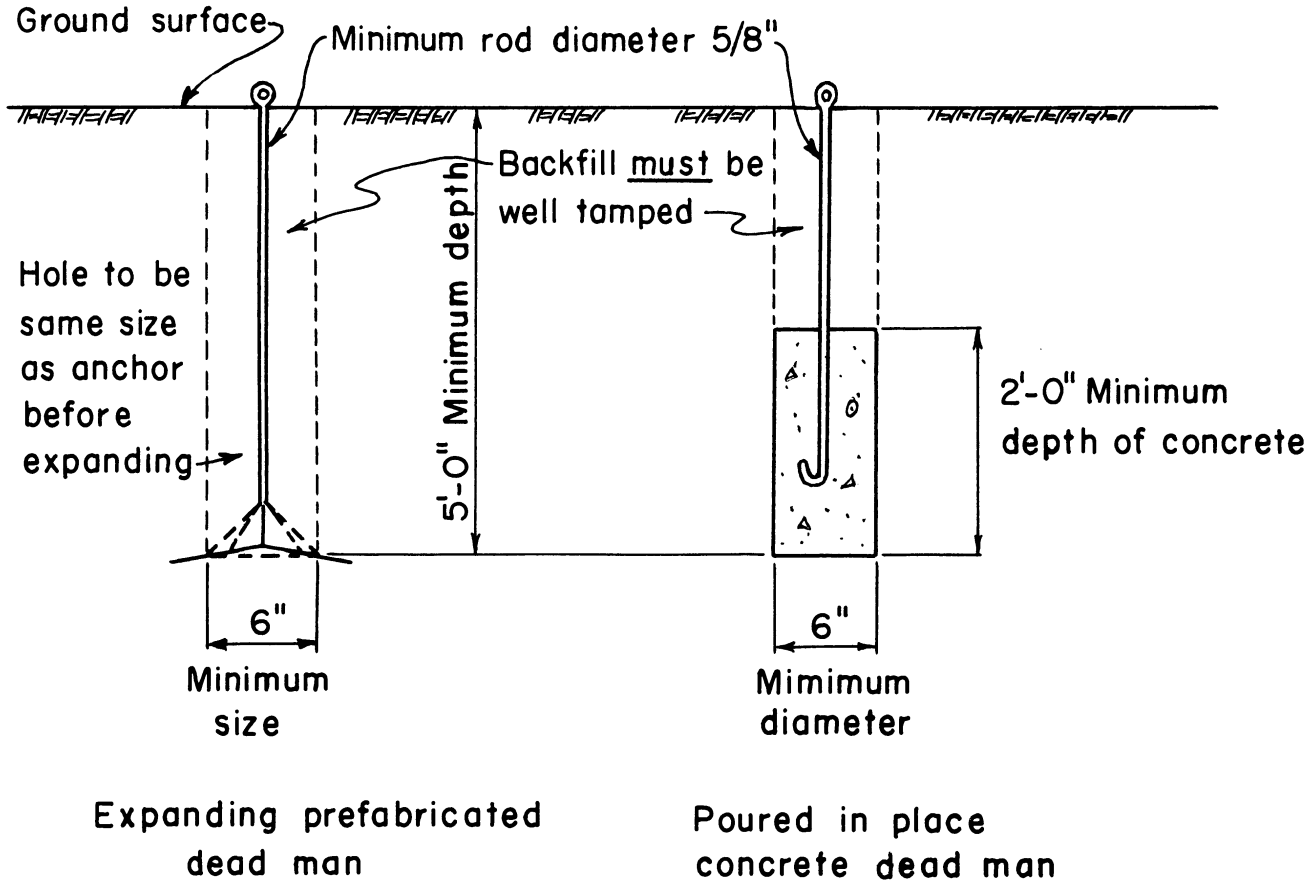
Type A - A screw auger of minimum auger diameter of 6 inches with a minimum 5/8 inch diameter rod installed with a minimum depth of 4 feet.

Type AA- Same as Type A except minimum auger diameter is 8 inches.



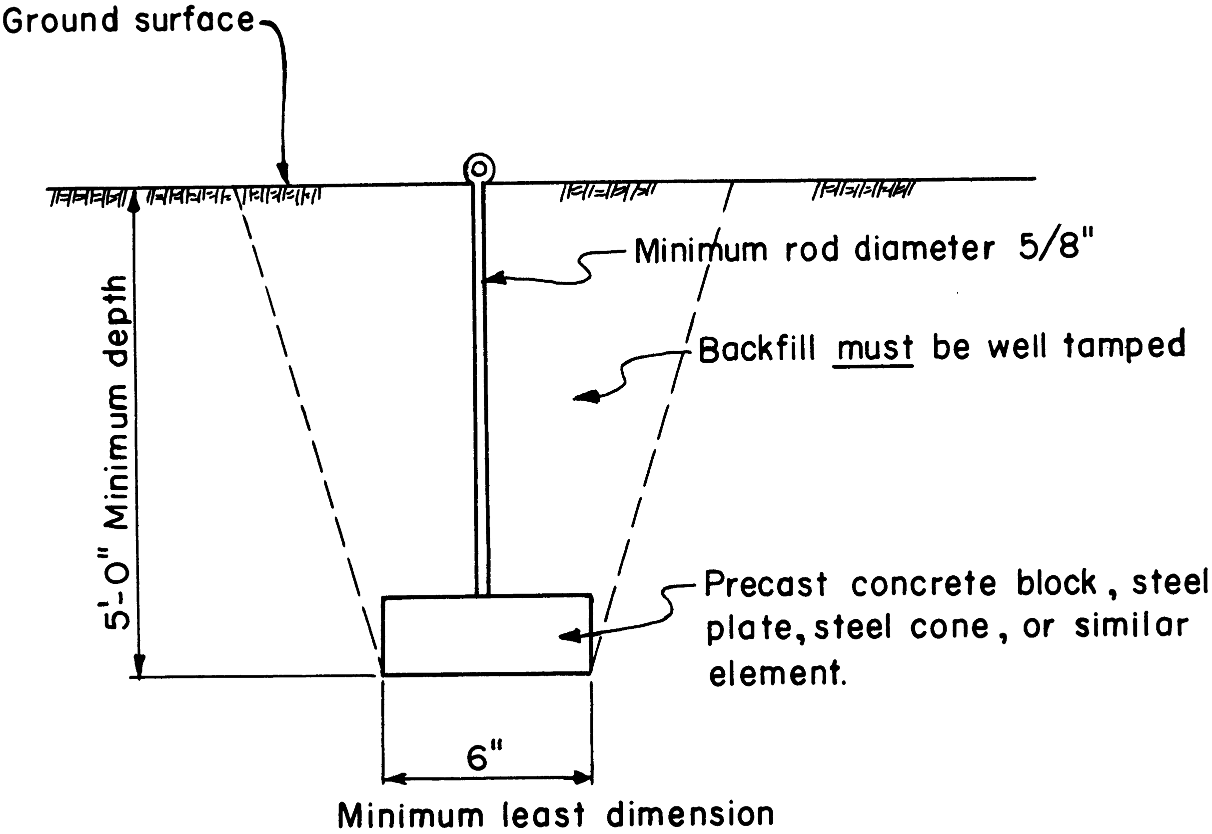
TYPE A & AA ANCHOR

Type B - An expanding prefabricated dead man of 6 inch minimum size or a minimum 6 inch diameter poured in place concrete dead man at least 2 feet in length. The bottom of each hole to be a minimum of 5 feet beneath the ground surface. Back fill must be well tamped. Minimum rod diameter to be 5/8 inch.



TYPE B ANCHOR

Type C - A precast concrete block, a steel or cast iron cone or plate, of minimum least dimension perpendicular to the anchor rod of 6 inches. The bottom of each hole to be a minimum of 5 feet beneath the ground surface. Back fill must be well tamped. Minimum rod diameter to be 5/8 inch.



TYPE C ANCHOR

TABLE I

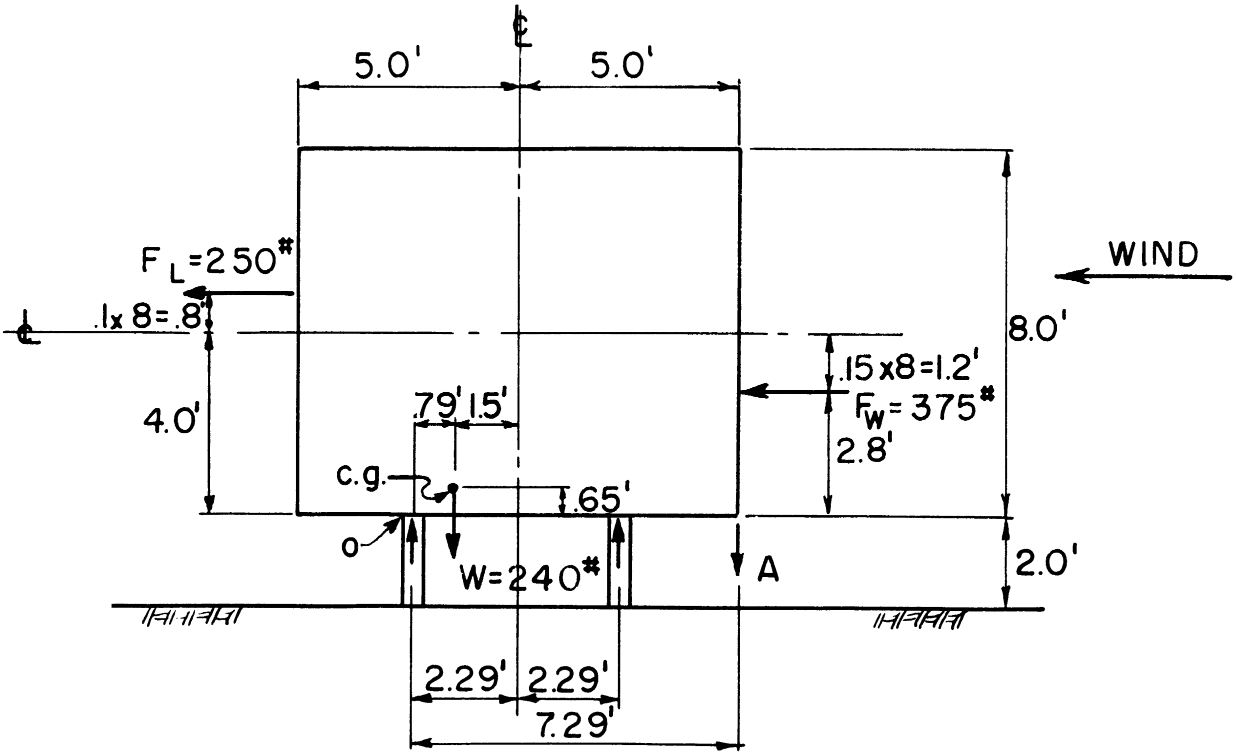
Recommendation 10

Soil Condition	Anchor Type*		Max. Spacing Along Coach
Hardpan A hard, dry strata resembling soft rock	A	Not Recommended	---
	B	Preferred	20'
	C	Acceptable	20'
Stiff Clay or Dense, Rocky Sands Crumbly and slightly damp	A	Not Recommended	---
	B	Preferred	18'
	C	Acceptable	14'
Compact Clayey Sand Firm Clay Usually moist. Most soils in well drained areas	A	Acceptable	10'
	B	Acceptable	14'
	C	Least Acceptable	10'
Soft Clay Wet, plastic soils	A	Preferred	7'
	B	Acceptable	11'
	C	Not Recommended	---
Loose Sand Little clay, dry or wet, also very soft clay	A	Acceptable	4'
	AA	Preferred	10'
	B	Acceptable	6'
	C	Not Recommended	---
Very Loose Sand Peaty Sand Swampy and marshy areas	Anchoring Uncertain See Recommendation 9		---

* See page 20 for description of anchor types for use with Table I.

APPENDIX

ANCHORING FORCE REQUIRED



Assumptions:

Length equal 1 foot

Wind Velocity equal 125 m.p.h.

Weight of Trailer $= 12{,}000/50 = 240\ ^{\#}/'$

Windward pressure, Equation 2: $p = 0.00299\,(125)^2 = 46.8\ ^{\#}/_{\square'}$

Leeward pressure, Equation 3: $p = 0.00199\,(125) = 31.2\ ^{\#}/_{\square'}$

Windward Force: $F_W = 46.8 \times 8 = 375^{\#}$

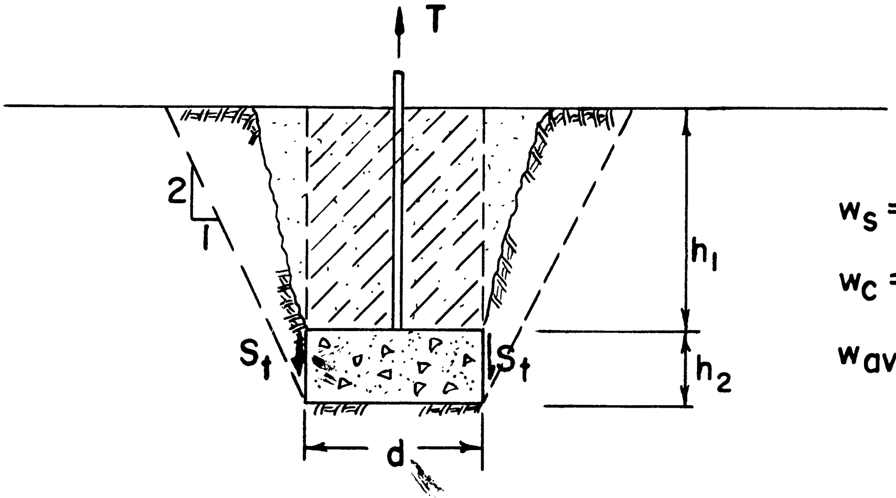
Leeward Force: $F_L = 31.2 \times 8 = 250^{\#}$

$$
\begin{array}{lrcl}
\Sigma M_O; & 250 \times 4.8 & = & 1200\ '^{\#} \\
& 375 \times 2.8 & = & \underline{1050} \\
& & & 2250 \\
& -240 \times .79 & = & -\underline{198} \\
& & & 2052\ '^{\#} \circlearrowright
\end{array}
$$

Force A required per foot: $A = 2052/7.29 = 282^{\#}$

SOIL ANCHOR EVALUATION

DEAD-MAN ANCHOR



w_s = 110 p.c.f., soil

w_c = 150 p.c.f., concrete

$w_{ave.} \approx$ 110 p.c.f.

Equation Ⓐ:

$$T_{(design)} = \underbrace{\frac{\pi d^2}{4}\left[h_2 \times w_c + h_1 \times w_s\right]}_{\text{static weight}} + \underbrace{\pi\, d \times h_2\, S_t}_{\text{side shear}}$$

Equation Ⓑ:

$$T_{(design)} \leq \left[\frac{\pi(d+h_1+h_2)^3}{4 \times 3} - \frac{\pi d^3}{4 \times 3}\right] \times w_{ave.}$$

Suggested values for S_t (Side Shear) at approximate 4 foot depth (Including safety factor).

V. Loose sand	S_t = 80 p.s.f.
Peaty sand	
Loose sand	S_t = 150 p.s.f.
Soft clay	
Compact clayey sand	S_t = 250 p.s.f.
Stiff clay	S_t = 600 p.s.f.

SOIL ANCHOR EVALUATION

DEAD MAN ANCHOR (CONTINUED)

Example computation

Let $h_1 = 3'$

$h_2 = 2'$ Loose sand , $S_t = 150$ p.s.f.

$d = 1'$

$$\text{Equation Ⓐ}: T_{(design)} = \frac{3.1416 \times 1}{4}\left[2 \times 150 + 3 \times 110\right] + 3.1416 \times 1 \times 2 \times 150$$

$$= .785\left[300 + 330\right] + 944$$

$$= 495 + 944 = \underline{\underline{1439 \text{ lbs.}}}$$

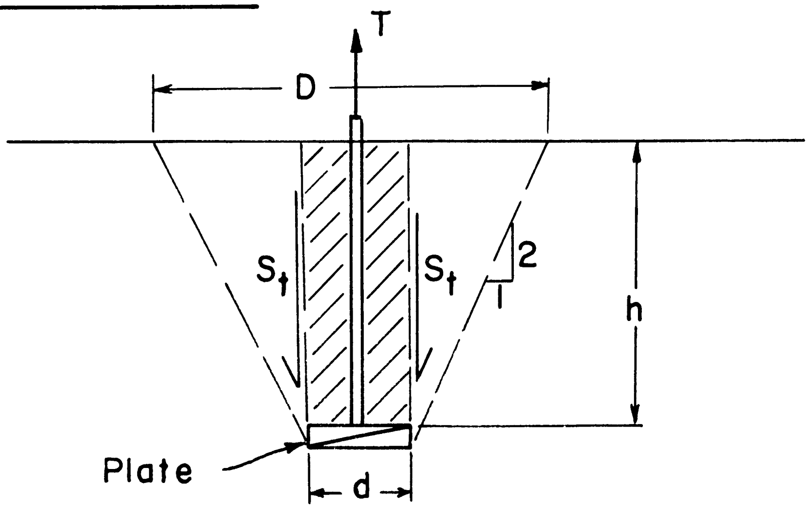
Check:

$$\text{Equation Ⓑ}: T_{(design)} \leqq \left[\frac{3.1416 \times 6^3}{12} - \frac{3.1416 \times 1^3}{12}\right] 110$$

$$\leqq \left[56.5 - .26\right] 110 = 6{,}180 \text{ lbs.} > 1439 \text{ lbs. } \underline{\text{o.k.}}$$

SOIL ANCHOR EVALUATION

SCREW AUGER ANCHOR

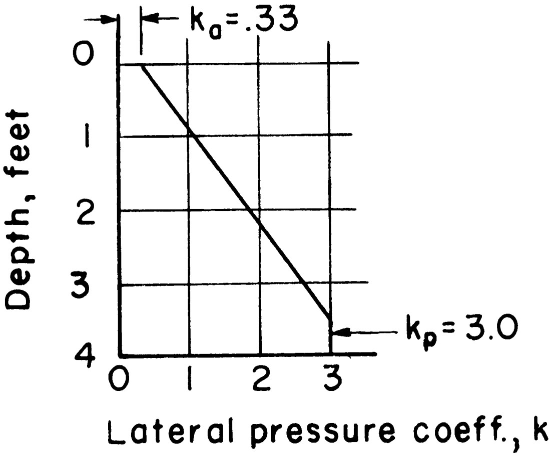


Analysis of typical screw anchor in medium sand

d = 6"   h = 48"   Manufacturer's suggested design T = 2500 lbs.

Ⓒ: Side shear on projected plate area

$$S_{(ave.)} = T/\pi d h = 2500/3.1416 \times \frac{6}{12} \times \frac{48}{12}$$
$$= 400 \text{ p.s.f.}$$



Consider that k_p (passive pressure) controls lateral pressure on shear surface for a distance "d" above plate, then decreases to k_a (active pressure) at ground surface.

SOIL ANCHOR EVALUATION

SCREW AUGER (CONTINUED)

Side shear in sand

$S_t = w\,h\,k \tan\phi$

$T = S_t \times \pi d h = (w\,h\,k \tan\phi)\pi d h$

from 3.5' to 4' depth, $\tan\phi = 1$ (sand on sand)

$\Delta T = (110 \times 3.75 \times 3.0 \times 1.0) \times 3.1416 \times 6/12 \times 6/12$

$= 1240 \times .785 = 975^{\#}$

from 0' to 3.5' depth

$k = 0.33 + (3 - 0.33) \times h'/3.5 = 0.33 + 0.76h'$

$\Delta T = \int_0^{3.5} 110 \times (0.33 + 0.76h')h' \times 3.1416 \times 6/12 \times dh'$

$$= 110 \times 1.570 \times \int_0^{3.5} (0.33 + 0.76h')h'\,dh' = 110 \times 1.570 \left[\frac{0.33h^2}{2} + \frac{0.76h^3}{3}\right]$$

$= 110 \times 1570 \ [2.02 + 10.9] = 2230$ lbs.

$\Sigma T = 975 + 2230 = 3205$ lbs. (side shear limit)

Ⓓ: Static weight limit of projected cone

$D = d + h = 6'' + 48'' = 4.5'$; $H = 48'' + 6'' = 4.5'$

$$V = \frac{\pi D^2 H}{4 \times 3} - \frac{\pi d^2 (H-h)}{4 \times 3} = \frac{3.1416 \times 4.5^2 \times 4.5}{12} - \frac{3.1416 \times .5^3}{12}$$

$= 23.9 - .0328 = 23.87 \approx 24$ cu. ft.

Wt. $= 110 \times 24 = 2540$ lbs. ≈ 2500 design

Recommend safety factor equal 1.5 for temporary load

$T_{(design)} = 3205 \div 1.5 = \underline{\underline{2130 \text{ lbs.}}}$ (in medium sand)

Check: Wt. $= 2540 > T_{(design)} = 2130$ (o.k.)