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NBS Studies of Mobile Home Foundations

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Washington, DC 20234

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Prepared for:
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

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Abstract

Two papers are presented which discuss the results of tests on soil anchors used to secure mobile homes and of an analytical study of wind and flood loads on soil anchors.

Key Words: Flood loads; mobile home foundations; mobile home standards; soil anchors; soil testing; flood loads

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Preface

This report contains two technical papers which were presented at the Third Mobile Home/Manufactured Housing Engineering Conference in Austin, Texas, January 29-30, 1980. The first paper conveys some of the test results of an NBS field study of the performance of soil anchors used to secure mobile homes against environmental forces. Preliminary conclusions are presented based on the results from tests in silty and sandy soil sites. The second paper conveys some of the results obtained from an analytical study of wind and flood loads on soil anchors. The results of the load calculations are in the form of graphs which present tie forces and pier reactions for several loading cases applied to a 14-ft wide mobile home. The complete set of results from these two studies will be reported in future (early 1981) National Bureau of Standards publications.

PERFORMANCE OF SOIL ANCHORS FOR MOBILE HOMES

by

FELIX Y. YOKEL and RILEY M. CHUNG

Loading requirements for soil anchors used to tie down mobile homes against wind and flood loads are compared with the results of anchor tests in sandy and silty soils. The conclusion is drawn that present anchoring techniques as used in the field do not provide the necessary support, and that anchors could perform adequately if installation techniques were modified to include pre-loading to 1.2σ times the design load.

Key Words: Flood loads; mobile home foundations; mobile home standards; soil anchors; soil testing; wind loads.

PERFORMANCE OF SOIL ANCHORS FOR MOBILE HOMES

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FELIX Y. YOKEL
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NATIONAL BUREAU OF STANDARDS

1. INTRODUCTION

The information conveyed herein was developed in a study which is sponsored by the Department of Housing and Urban Development. In the first part of this study field measurements were made in order to determine the wind forces acting on mobile homes and were published in Reference [1]. Subsequently, an analysis was made of the forces on mobile home foundations resulting from wind and flood loads. The results of that analysis, which were not yet published, are discussed in a separate presentation in this conference. This presentation conveys the results of a study of the performance of soil anchors which is still in progress. In the first stage information was compiled on existing knowledge and test data and was published in Building Science Series Report 107 [2]. In the second stage anchors are tested in three types of soil: silts, sands, and clays. It is hoped that this work will provide the background information needed to assure adequate mobile home foundation performance.

2. LOADS ACTING ON SOIL ANCHORS

Figure 1 shows two typical mobile home tiedown methods. "Near-tie" and "far-tie" connections are defined in the figure. Both types of connections are used in practice. The dimensions shown, which are typical for a 14 ft. wide mobile home, could be different in any particular case. For instance, the clearance above ground could be greater, the distance between the chassis beams could be different, or the diagonal ties could be attached to the chassis beam at a different point. Table 1 shows strap forces caused by various environmental loads which were calculated for a 14 ft. wide mobile home with the strap attachments shown in Figure 1.

TABLE 1: Strap Forces Induced by Environmental Loads

Loading	Strap Forces, lb/ft			
	Near-Tie		Far-Tie	
	Vertical	Diagonal	Vertical	Diagonal
HUD Hurricane	0	220	80	205
NBS Hurricane	120	280	195	220
Buoyancy, 1 ft Head	250	80	300	50
Buoyancy, 1/2 ft Head + 5 ft/sec velocity flow*	95	50	100	40
Buoyancy, 1/2 ft Head + HUD Standard Wind	160	130	200	110

* It is assumed that the water level is 1 ft above the underside of the mobile home.

The "HUD Hurricane" is the hurricane load stipulated in the Federal Standard [3]. The "NBS Hurricane" is the loading recommended in Reference [1]. The buoyancy is calculated for the stipulated differential head, which is the difference between the water levels inside and outside the mobile home. The "HUD Standard Wind" is calculated in accordance with the Federal Standard [3].

Loads are given for a 1 ft length of mobile home and have to be multiplied by the anchor spacing if strap loads are calculated.

Note that all wind loads induce a substantial force in the diagonal straps. The HUD Hurricane induces no vertical strap force when there is a near-tie connection and a very small vertical strap force for far-tie connections. Vertical strap forces are greater for the NBS Hurricane load; however, they are still substantially less than the diagonal forces. Flood loads on the other hand are primarily resisted by vertical-strap forces.

Even though it was conservatively assumed that the piers do not resist any lateral loads, it can be concluded from an examination of Table 1 that, to be effective against wind, anchors must be capable of resisting loads with a substantial component in the horizontal direction.

3. PERFORMANCE OF SOIL ANCHORS

Since the soil anchor tests are still in progress a conclusive discussion of the results cannot be presented at this time. This section therefore concentrates on qualitative aspects of anchor performance.

Tests were conducted on two sites:

Site 1 is located on the grounds of the National Bureau of Standards in Gaithersburg, Maryland. It is a site of residual silty soils. Test borings indicate generally about 2 feet of man-made fill consisting of local material, overlying residual clayey and sandy silts derived from the in-place weathering of the underlying quartz rich schist rock of the Wissahickon formation. No groundwater was observed in any of the borings during drilling and up to 5 hours after drilling. Long term water observations were not made. The standard penetration resistance, or N values (ASTM D-1586), range from 9 to 18 and 7 to 16 blows per foot for the fill and the residual soils, respectively, Laboratory test results indicated that the natural soils had moisture contents ranging from 12.5 to 30.8 percent and consisted of 62 to 83 percent by weight of material passing No. 200 sieve. The liquid limit and plastic limit were at 39 and 27 percent, respectively. The natural soils may be described as clayey silt with some fine sand, or ML according to ASTM D-2487. Strength tests indicate an unconfined compressive strength of about 4000 psf on one specimen, while a direct shear test yielded an angle of shearing resistance (ϕ) of 30° and a cohesive strength (c) of 200 psf. The direct shear test results may have been influenced by the presence of quartz fragments in the tested soil specimen.

Site 2 is in Odenton, Maryland and is sandy. Test borings indicate that part of the site is overlain by a thin but very dense crust of silty sand with gravel fill, which has a depth of 0.5 to 1 foot and a recorded range of standard penetration resistance from 20 to 40 blows per foot. Underlying the crust is a 6 to 9 foot thick fine to medium sand layer which rests on sandy silty clay soils. The standard penetration resistance of this sandy soil was recorded from 10 to 21 blows per foot. There was no water in the test borings to the depth where cave (collapse of the borehole) occured which ranged from 5 to 6.5 feet. More than half of the tests on Site 2 were conducted in a location which was not covered by the dense crust. The natural soil deposits at the Odenton site belong to the Potomac group of Cretaceous Age which is generally characterized by interbedded sand and silty clay materials. The sandy soils in this group are generally in the medium to dense state due to the overconsolidated nature of the Cretaceous-Age deposits. Soil laboratory test results are presently not available.

Figure 2 shows a vertical pullout test on a 6-inch single helix anchor in sand (Site 2) installed vertically to its full 4 foot depth. Vertical displacements of the anchor head in inches are plotted against loads in kip. Two cycles of unloading and re-loading were conducted at 1 kip intervals in order to assess the characteristics of pre-loaded anchors. Note that the initial load-displacement curve is rather steep and there is a break (change in slope) at point A at about 1 kip load. This trend is characteristic for most tests and is frequently more pronounced than in this figure. The re-loading curves are generally much steeper than the initial "virgin" loading curve, indicating substantial strain-hardening effects. The characteristics of the curve are interpreted as follows: Whenever load is applied, the soil is consolidated, and up to this load, its load-displacement characteristics are modified. As soon as the applied load exceeds the pre-load, the load-displacement curve follows the virgin curve which would be obtained in monotonic loading. The initial break in the curve at point "A" can be attributed to pre-consolidation of the soil which is about equivalent to a 1 kip anchor pull.

Figure 3 shows the load-displacement curve for an approximately co-axial pull on an anchor which was installed at an angle of 45^o to the horizontal. Note that this curve is similar to the one shown in Figure 2, except that the load capacity is much lower because of the reduced anchor depth due to the 45^o installation angle. The break in the virgin curve occurs at about 0.5 kip.

Figure 4 shows the load-displacement curve for a vertically installed anchor pulled at an angle of 40^o to the horizontal. The initial stiffness of this anchor is very low (only 1.2 kip capacity at a 4 inch displacement), since the 3/8 inch thick shaft provides very little lateral soil resistance. However, as the shaft is bent in the direction of the pull the soil resistance increases and the ultimate pullout resistance exceeds that for a vertical pull. The initial slope of the re-loading curves is attributable to the elastic displacement of the anchor shaft which occurs before the soil resistance is engaged. Otherwise the re-loading curves show characteristics similar to those in the previously discussed tests.

The re-constructed virgin curves for the tests shown in Figure 2, 3 and 4 are plotted in Figure 5. The figure illustrates the difference in the performance characteristics. Note the large displacement required to develop load resistance in a vertically installed anchor subjected to diagonal load, the most commonly encountered situation associated with present mobile home anchoring technolgoy.

Figure 6 shows the results of cyclic tests on the sandy site (Site 2). The upper curve is for cyclic tests at 0.75 of ultimate pullout capacity on an anchor which was not pre-loaded. Note that up to about 60 cycles there is a gradual decrease in the displacement per cycle. Above 60 cycles the displacement is constant at about 1-inch per 100 cycles. This performance is consistent with the observation of volume changes in loose to medium sands subjected to cyclic shear stresses. Note that the performance can be substantially improved by a single monotonic pre-loading cycle (see the lower curve).

Up to this point the discussion of performance characteristics of anchors was confined to the sandy site (Site 2), where test results were more consistent and repeatable. Figures 7 and 8 illustrate qualitatively the difference between anchor performance characteristics in the sandy and the silty sites.

In Figure 7 virgin loading curves in sand and silt are compared. Note that the vertical pullout tests have similar initial performance characteristics and identical ultimate loads (a test with a similar ultimate load from the silt site was selected to facilitate comparison). However, the anchor on the silt site maintained its load up to an 11-inch displacement (not the entire range is shown) while the anchor in sand failed at a 2-1/4 inch displacement. This can be explained in part by the fact that the shear strength of the silt deposit did not decrease as rapidly with decreasing depth as that of the sand deposit. Probably for the same reason the difference in strength between the vertical and the inclined anchor was greater in the sandy site. Figure 7 does not show the entire range of the tests on the silty site. In all the three tests shown, the anchors in the silty site maintained their strength over a large range of displacements.

Figure 8 shows a comparison between cyclic tests in the sandy and the silty site. Note that in the silty site there was no significant displacement after 80 load cycles (tests were continued for 300 load cycles).

Figure 9 shows a comparison between soil test probe[1/] readings and anchor capacity. Since in the sandy site test probe readings increased rapidly with depth (see Figure 2), the reading at 3 ft depth was selected for the sand as well as the silt data. Note that while there is a definite correlation, there is also considerable scatter of data.

1/ The soil test probe is a commercial in-situ measurement device developed by the anchor industry.

4. CONCLUSIONS

Any conclusion drawn from the previously discussed data is preliminary, since testing is still in progress. However, the data at hand are reasonably consistent and their trends can be clearly recognized. Two important conclusions can be drawn:

(1) Present anchoring techniques as used in the field do not provide the necessary support for the diagonal ties

This conclusion does not necessarily imply that the ultimate pullout load is too low, but rather that the horizontal displacement necessary to develop the needed load capacity is excessive. The situation is further aggravated by the fact that, particularly in the silty site, the virgin loading curves of various tests are not very consistent. Thus some anchors will develop their load resistance sooner than others. Since a mobile home is rather stiff, this situation will cause certain straps to be overloaded and fail, before other straps are loaded to capacity.

(2) Anchors could perform adequately if installation techniques would be modified to include pre-loading to about 1.25 times the design load in the direction of the anticipated reaction force.

Pre-loading would not only decrease displacements by an order of magnitude, it would also insure that adequate load capacity is available.

In addition to the above discussed performance characteristics there is one more observation that should be mentioned. Anchors are supplied with a coat of paint which is supposed to provide protection against corrosion. In the NBS tests, anchors were inserted and extracted. In almost all instances this operation stripped the paint. Unless better corrosion protection techniques are developed, anchors should not be expected to maintain their load capacity for extended periods of time.

5. REFERENCES

[1] Marshall, R. D., (1977), "The Measurement of Wind Loads on a Full-Scale Mobile Home," NBSIR 77-1289, Center for Building Technology, National Bureau of Standards, Washington, D.C., Sept. 1977, 120 pp.

[2] Kovacs, W. D. and Yokel, F. Y., (1979), "Soil and Rock Anchors for Mobile Homes - A State-of-the-Art Report," NBS Building Science Series 107, Center for Building Technology, National Bureau of Standards, Washington, D.C., Oct. 1979, 147 pp.

[3] Mobile Home Construction and Safety Standards. Department of Housing and Urban Development, Federal Reporter - Part II, Dec. 1975.

6. S. I. CONVERSION

The following conversion factors should be used to convert dimensions and forces given in this report to S. I. Units:

To Convert	To	Multiply by
in	mm	25.40
ft	m	0.3048
lb	N	4.448
kip	KN	4.448
psf	Pa	47.88

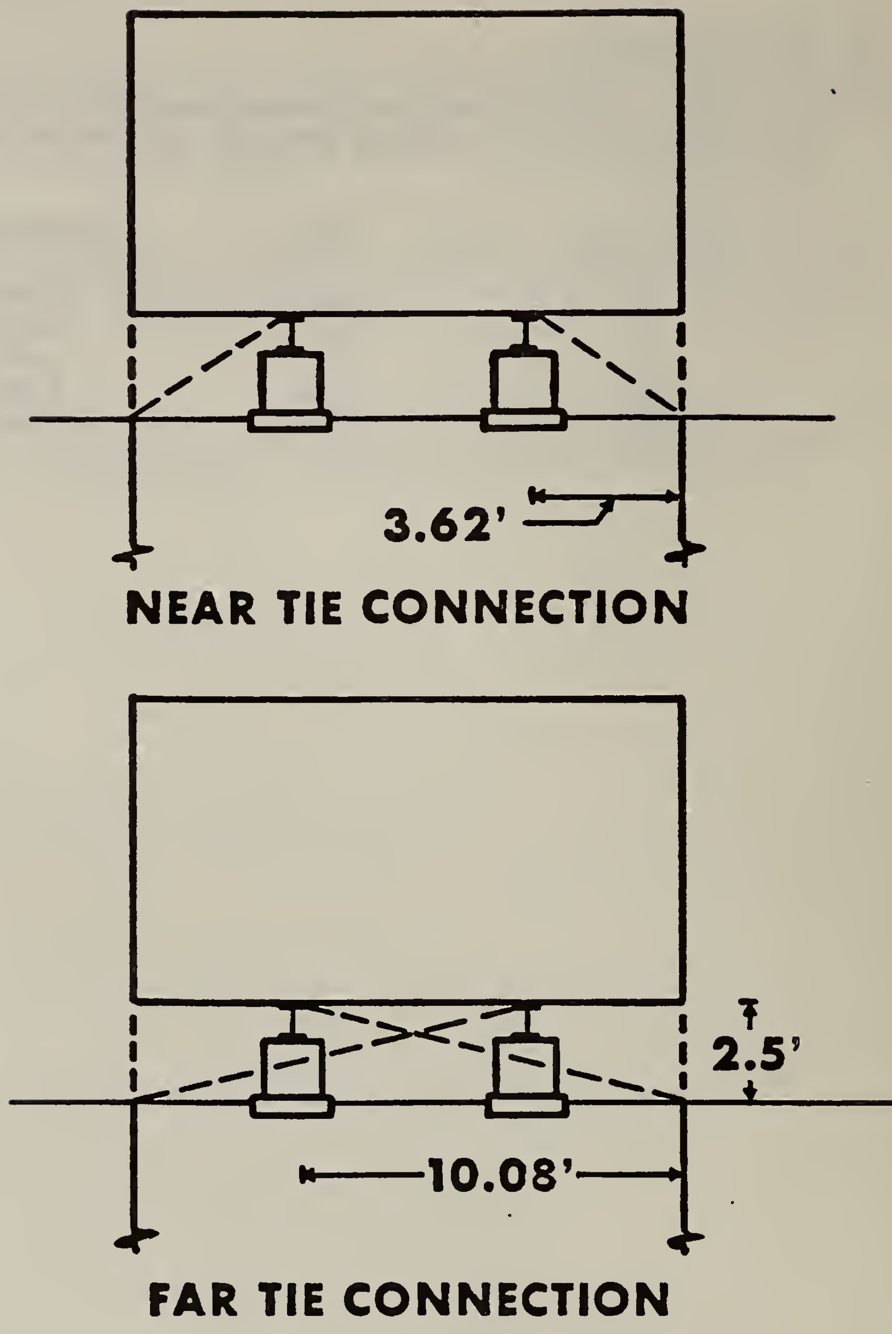

Figure 1. Typical tie down arrangements for a 14-foot wide mobile home.

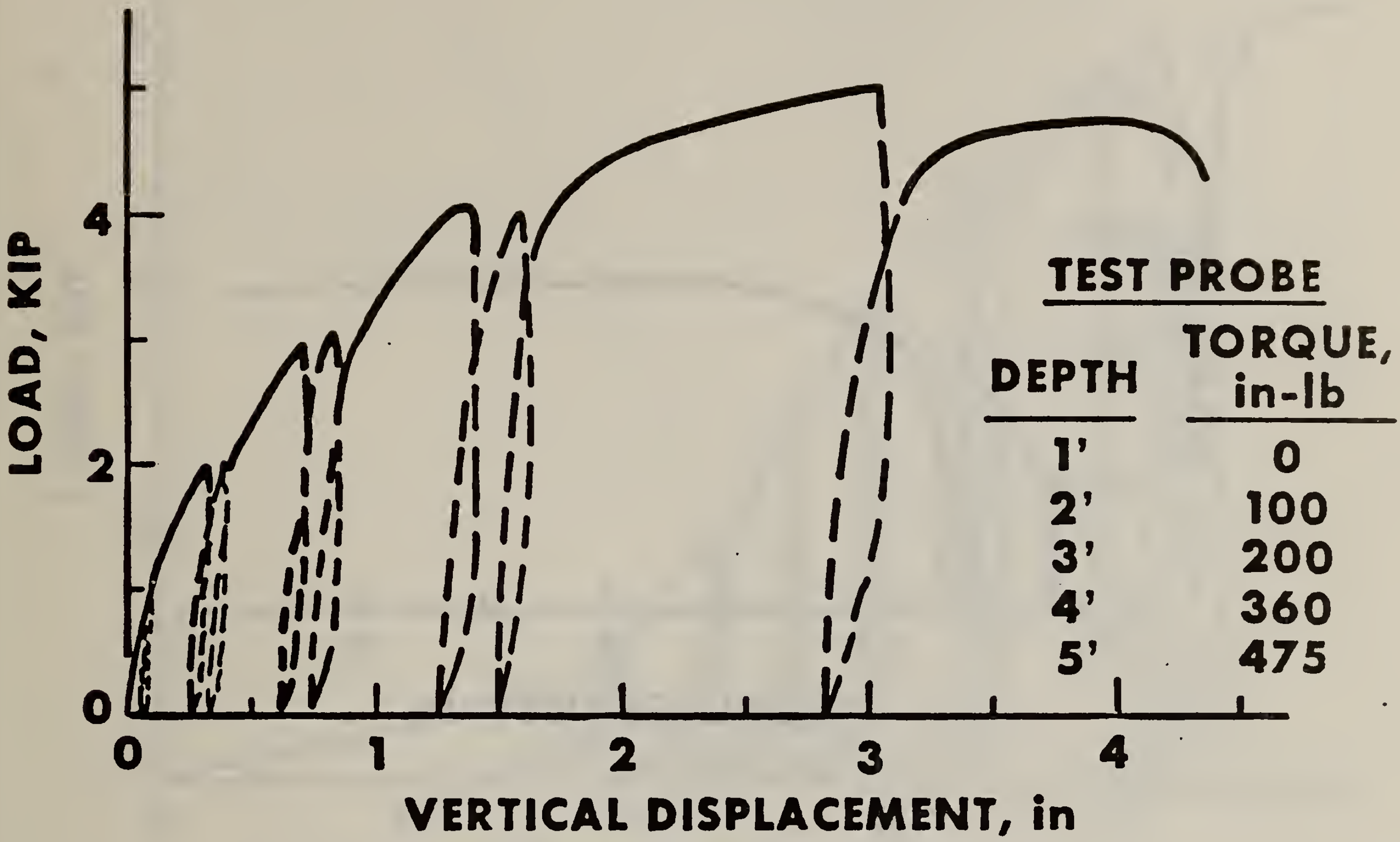

Figure 2. Vertical pullout test on vertically installed 6-inch single helix anchor in sandy soil.

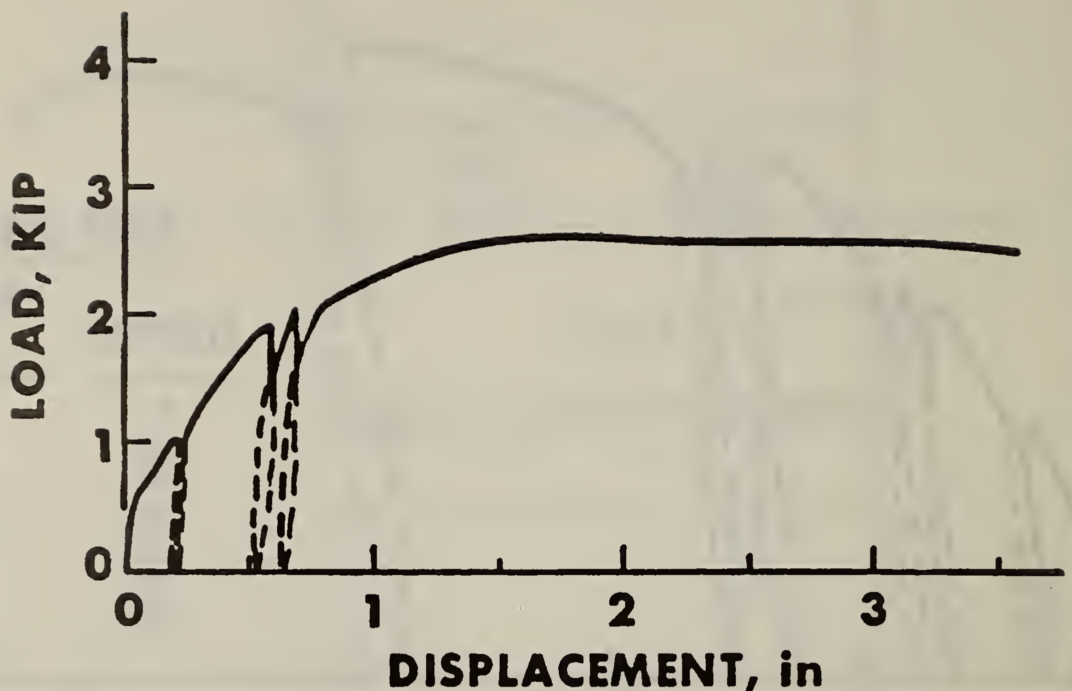

Figure 3. Pullout test load applied at an angle of 40° to the horizontal to a 6-inch single helix anchor installed at 45° to the horizontal in sandy soil.

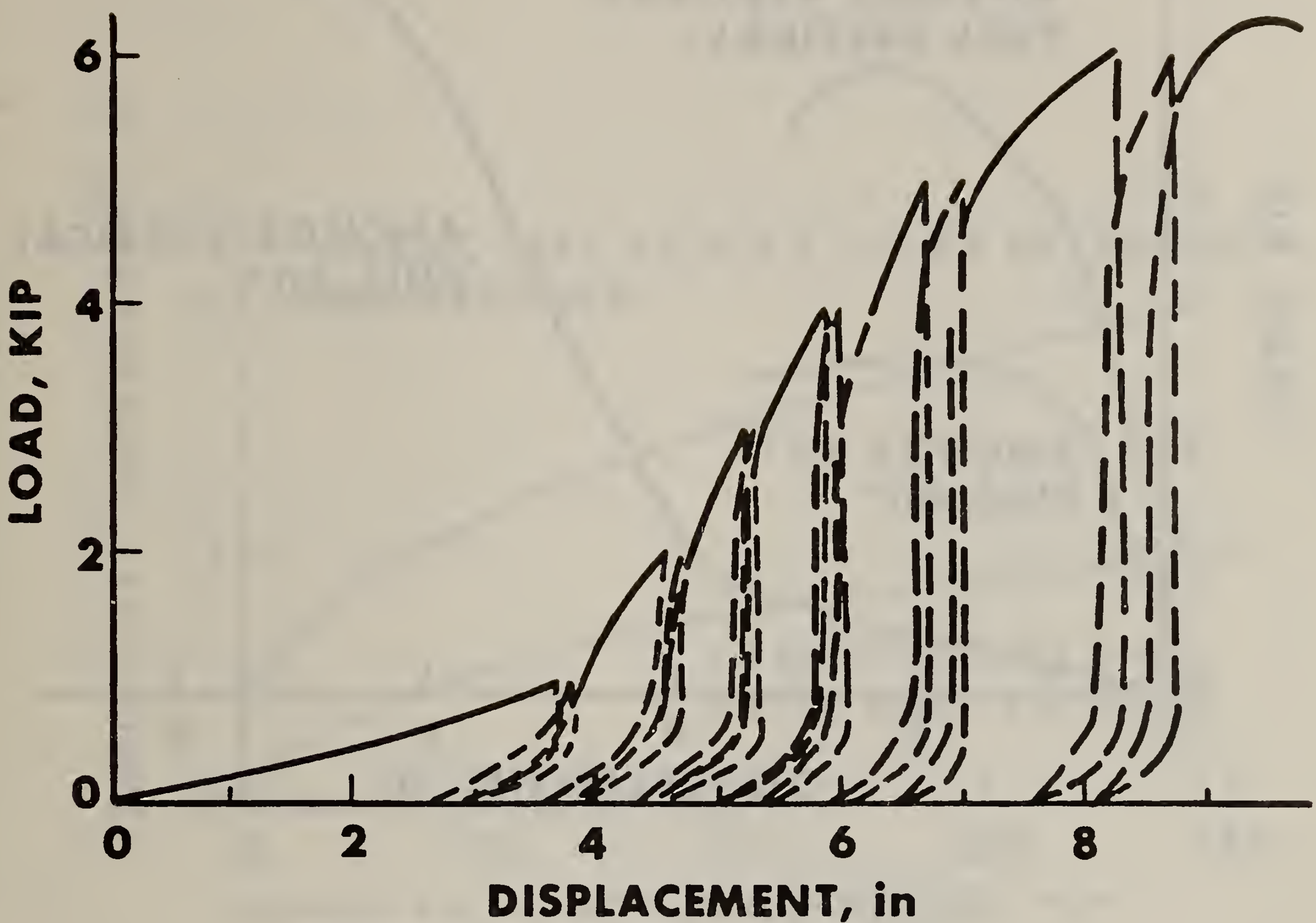

Figure 4. Pullout test load applied at 40° to the horizontal to a vertically installed 6-inch single helix anchor in sandy soil.

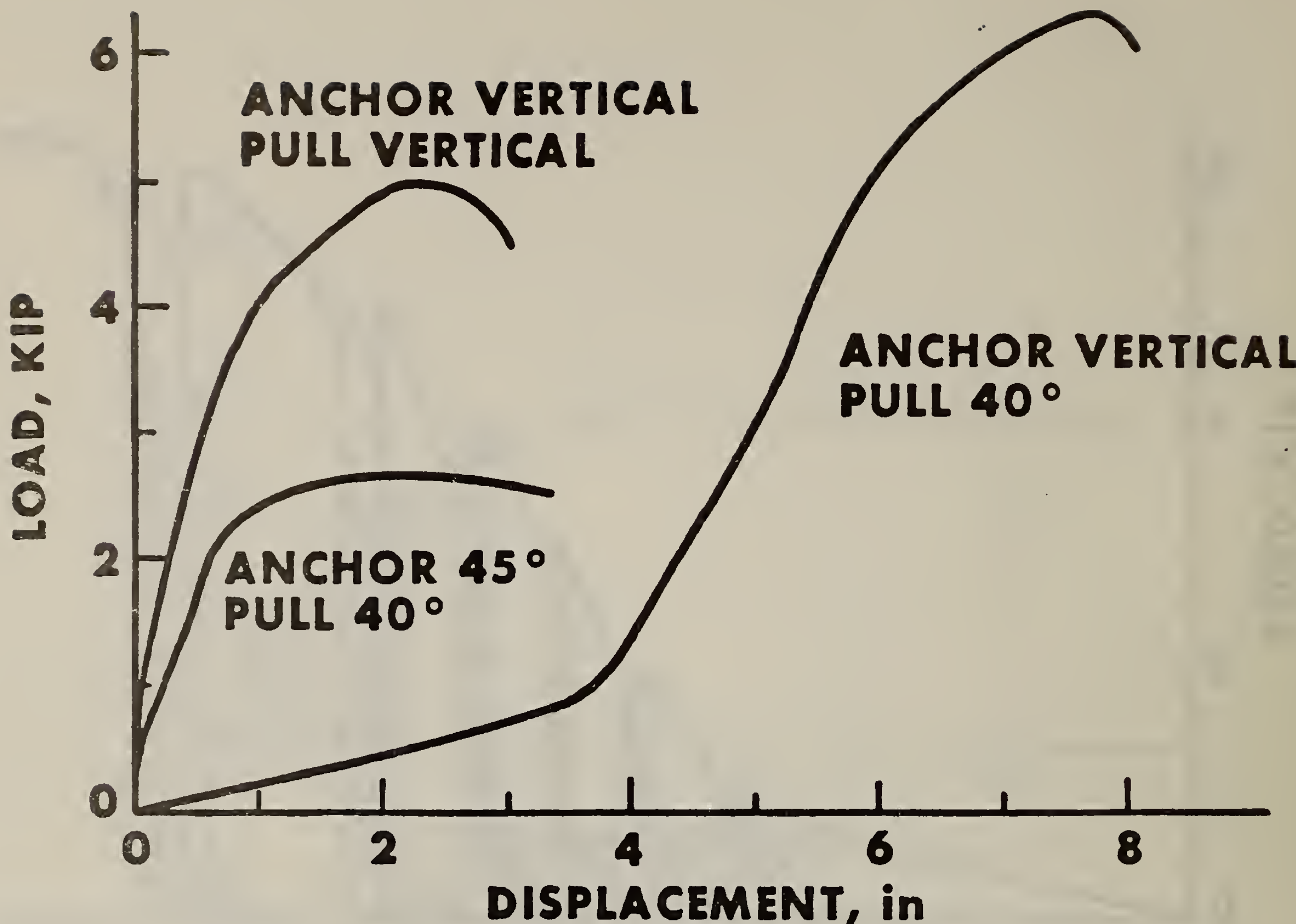

Figure 5. Comparison of the performance of 6-inch single helix anchors in sandy soil under various loading conditions.

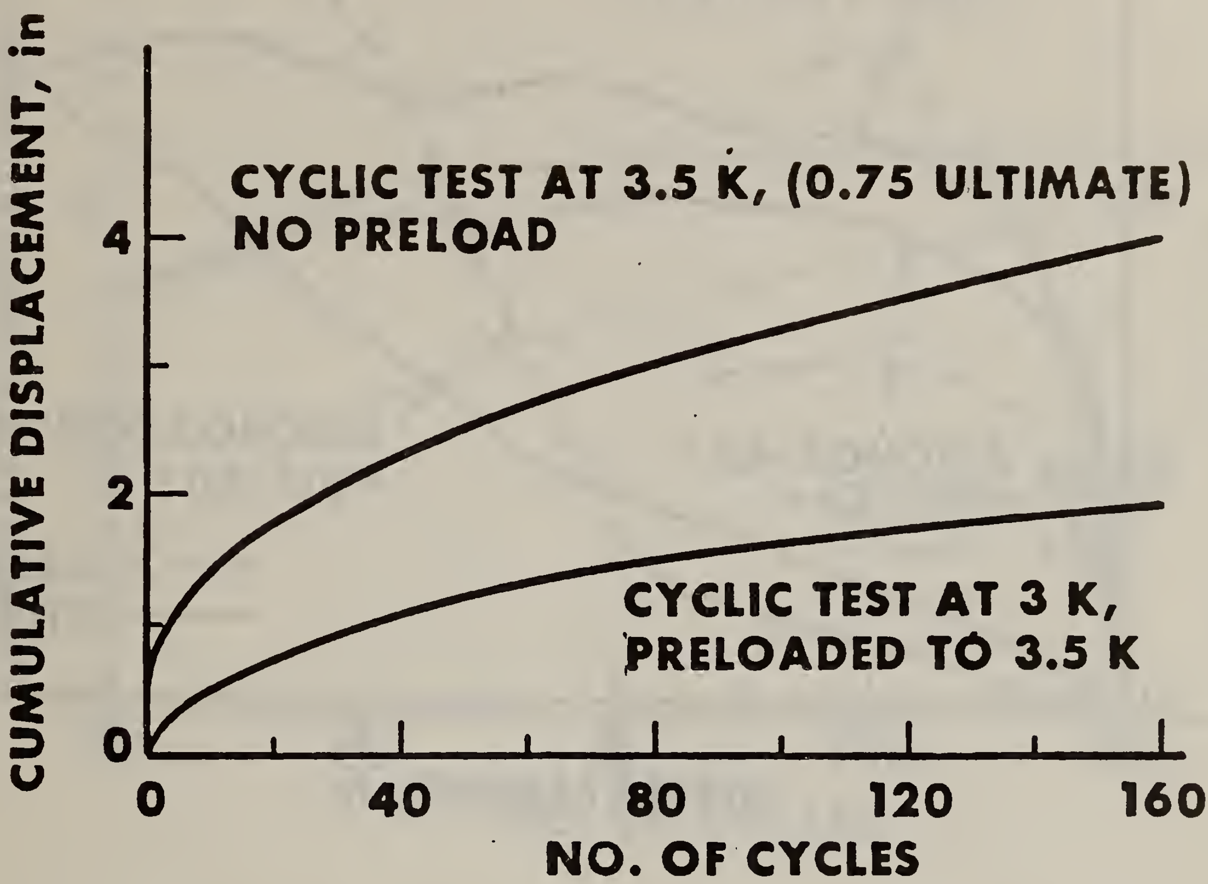

Figure 6. Results of cyclic tests on vertically installed 6-inch single helix anchors in sands subjected to vertical load.

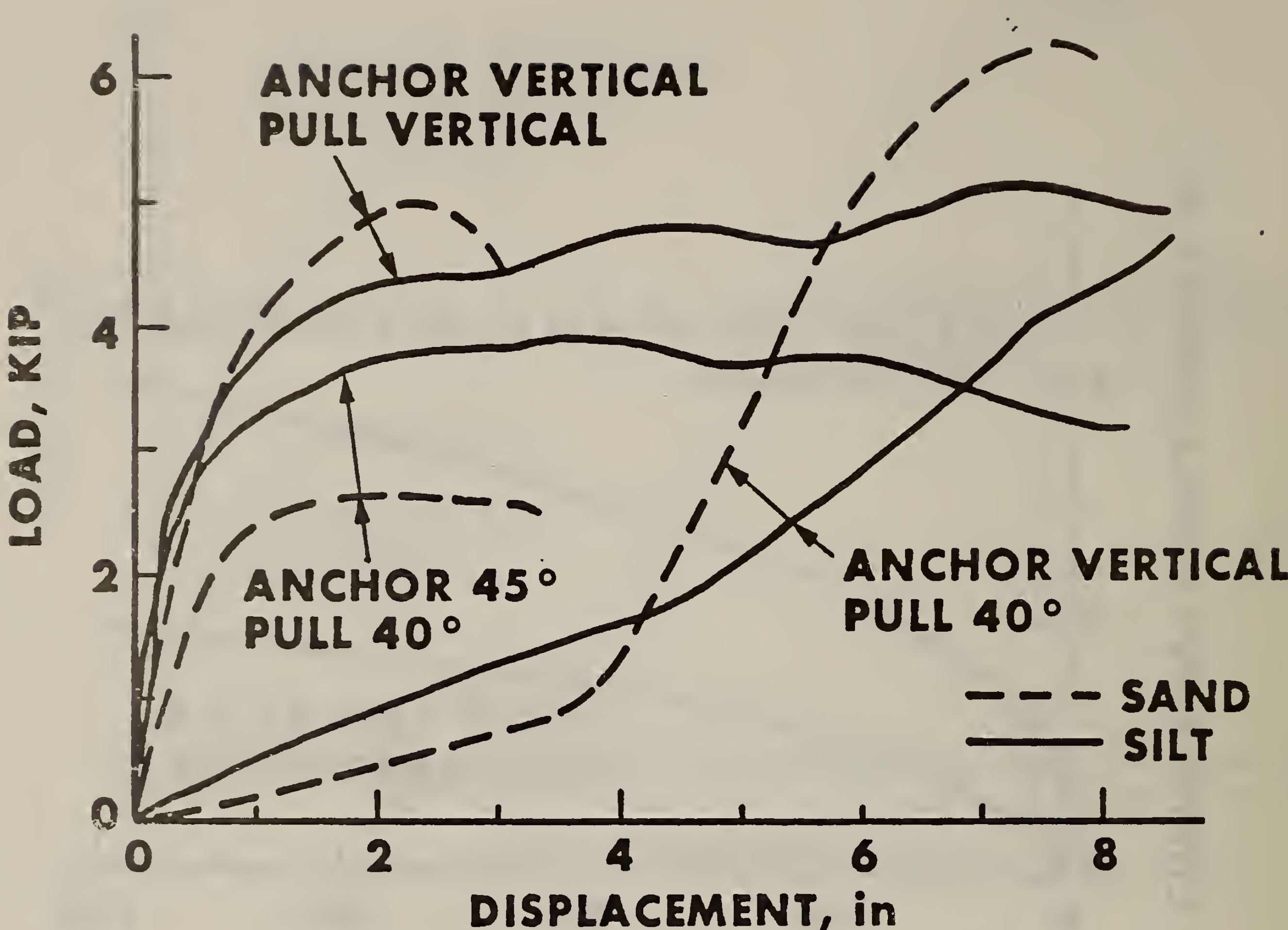

Figure 7. Comparison of monotonic (virgin) loading curves for 6-inch single helix anchors in sand and silt.

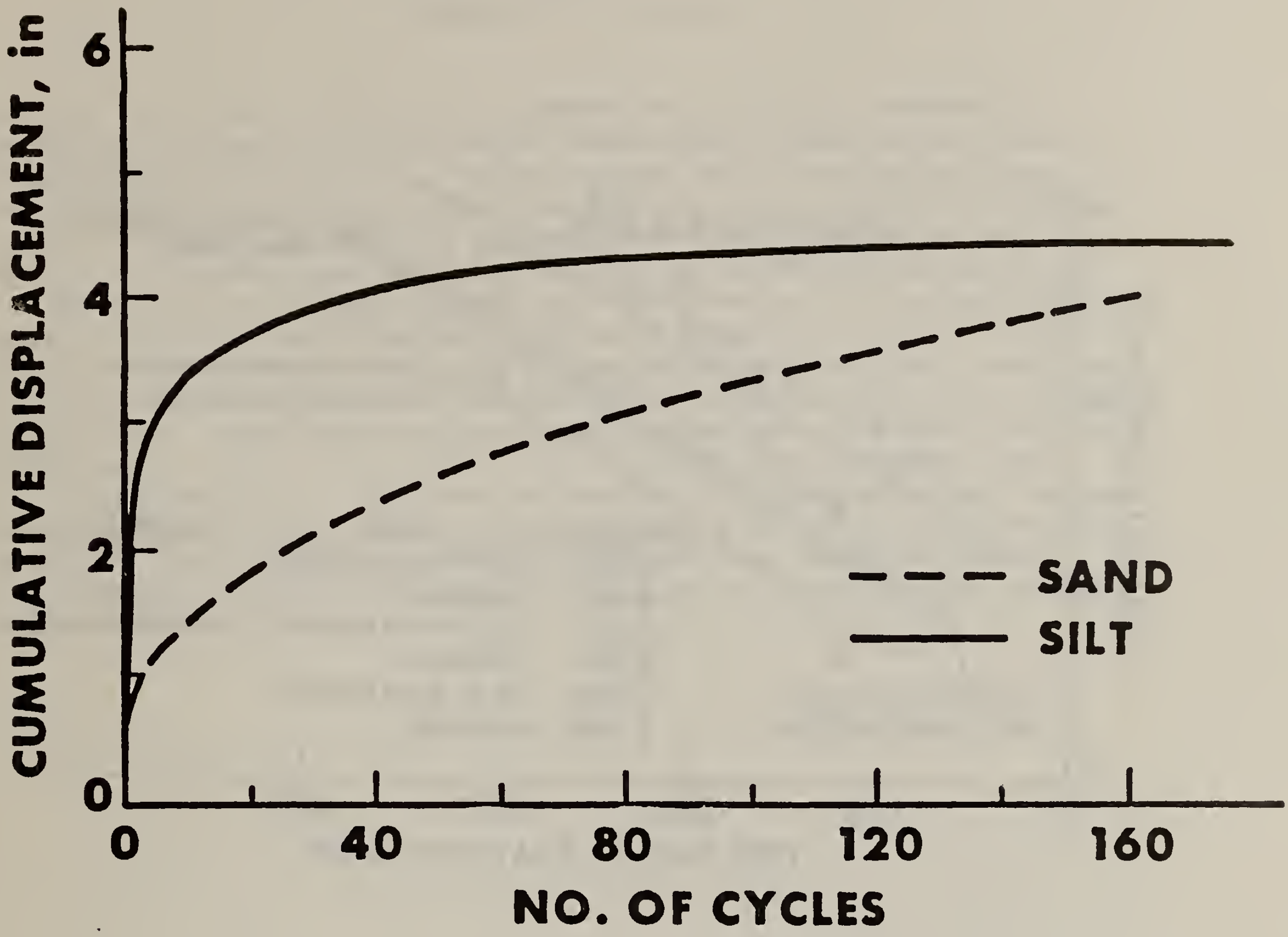

Figure 8. Comparison of cyclic tests on 6-inch single helix anchors installed vertically in sand and silt and subjected to vertical load cycles of 75 percent of ultimate pullout load.

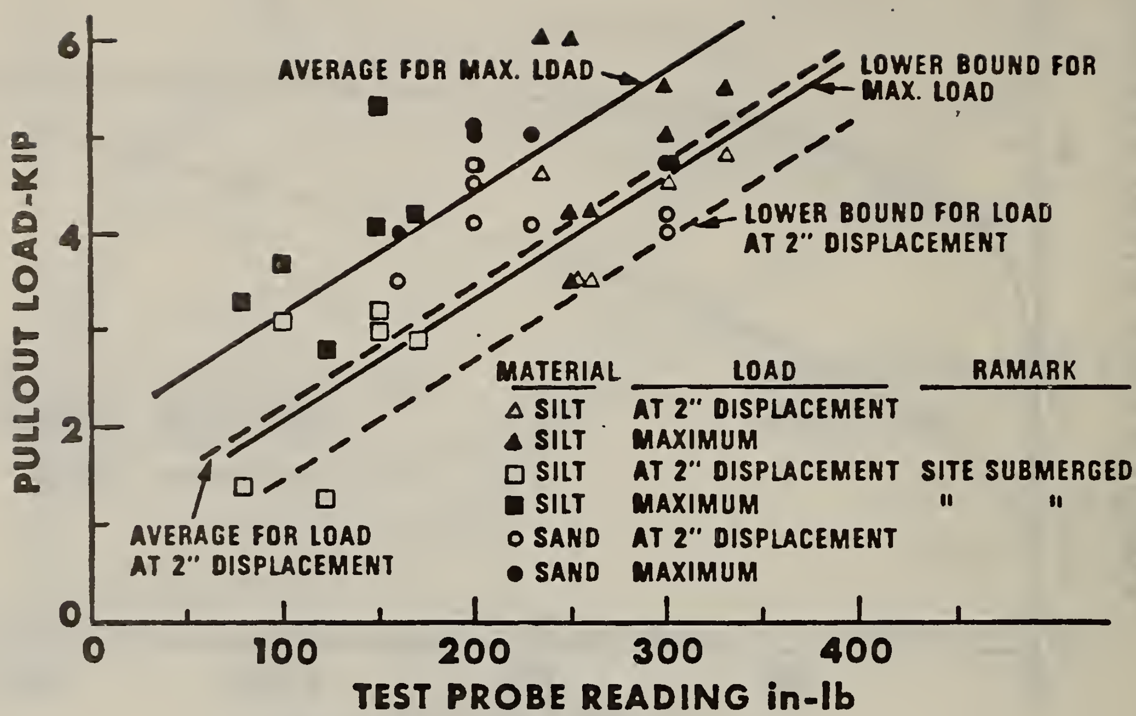

Figure 9. Correlation between test probe readings and 6-inch single helix anchor capacity.

WIND AND FLOOD LOADS ON SOIL ANCHORS

by

CHARLES W. C. YANCEY

Analyses were made of the forces transmitted to typical foundation systems as the result of wind and/or flood loads acting on 12-ft and 14-ft single-wide mobile homes. The objectives of the analytical study were to derive unit force information from which the required number of vertical and diagonal ties and pier supports can be determined and to compare the tie-down requirements dictated by hurricane wind pressures with those necessitated by flood loads. The results of the load calculations have been summarized as a series of computer-generated graphs. The graphs present the vertical and diagonal tie forces, pier reactions and total resultant anchor forces caused by hurricane wind pressures and flood forces. This paper discusses the results from 8 of the total 32 conditions included in the study. It was found that hurricane loads will induce relatively high tensile forces in the diagonal ties, thereby suggesting that anchor systems must be designed to resist a substantial horizontal load component. It was also found that relatively small differential water levels may cause potentially critical forces in the vertical ties.

WIND AND FLOOD LOADS ON SOIL ANCHORS

by
CHARLES W. C. YANCEY
NATIONAL BUREAU OF STANDARDS

1. INTRODUCTION

The information conveyed in this presentation was developed in one stage of a project which is being sponsored by the U.S. Department of Housing and Urban Development. The principal objectives of the project are: to determine the distribution and magnitude of wind forces on mobile homes, to determine the performance characteristics of soil anchors, to quantify the forces transmitted to mobile home foundation systems and to derive a standardized performance test method for soil anchors. In the initial stage of the study, existing information and test data were compiled and were published in NBS Building Science Series 107 [1]. A concurrent activity involved making field measurements of actual wind pressures to determine the wind forces acting on a typical mobile home, the results of which were published in Reference [2]. Then, an analysis was made of the forces transmitted to typical foundation systems as the result of wind and/or flood loads acting on 12-ft and 14-ft single-wide mobile homes. This presentation conveys some of the results obtained from the analytical study of foundation loads. The complete set of results will be reported in a future National Bureau of Standards publication. In another stage of the study, commercially-available soil anchors are being tested for their pull-out characteristics in three types of soil: silts, sands and clays. The results obtained from these anchor tests are discussed in a separate presentation at this conference.

The physical characteristics of typical foundation systems were used to generate input data for the loads analysis. Figure 1 shows two common foundation systems, consisting of pairs of piers located beneath the two chassis beams and soil anchors to which vertical and diagonal metal "ties" are attached. In order to insure the adequacy of these mobile home foundations, it is necessary to determine the forces that would be transmitted to their components (i.e. ties, piers and anchors) as a result of extreme winds and floods.

2. WIND AND FLOOD LOADS

Wind Loads

Three different cases of wind load application were used: wind pressures specified in the HUD Mobile Home Construction and Safety Standards [3] for (1) the "Standard Wind Zone" and (2) the "Hurricane Zone" and (3) hurricane wind pressures recommended by the National Bureau of Standards [2]. Table 1 shows the pressure magnitudes applied to the walls and roof for the three cases. The results from the two hurricane pressure cases will be discussed in this presentation. Figures 2 and 3 show the resultant drag and uplift forces derived from the HUD and NBS Hurricanes (assuming 90 mph wind speeds) respectively.

It should be noted that the drag and uplift forces for the NBS Hurricane were derived from idealized uniform pressures. Furthermore, only the portion of the pressure acting on the sidewall was considered in the calculations based on the assumption that the horizontal force on the skirt would not be transmitted to the mobile home. As shown in figure 3, the uplift force for the NBS Hurricane is acting at a distance of 0.4B from the windward wall, where B is the width of the mobile home and the drag force is applied at 0.6H above the ground, where H is the height from the ground to the top of the mobile home. In the case of the sidewalls, the uniform pressure shown in figure 3 resulted from averaging from top to bottom and from end to end.

Table 1 - Design Wind Pressures (psf)

Wind Case	Horizontal Pressure on Walls	Uplift Pressure on Roof
HUD STANDARD ZONE (I)	15	9
HUD HURRICANE ZONE (II)	25	15
NBS HURRICANE	26.5*	28*

*Average Values

Flood Loads

Mobile homes located in flood plains may be subjected to the effects of buoyancy and/or velocity flow depending upon the nature of the flooding and the air tightness of the home. Thus two types of flood forces were considered in the calculations: buoyancy forces and drag forces.

Buoyancy forces result when there is a difference between the level of the floodwater outside the mobile home and that on the inside. The magnitude of the buoyancy force is dependent on the rate of entry of the water into a closed mobile home relative to the rate of rise of the floodwater. Buoyancy forces were calculated for differential water levels of 0.5 - 2.0 ft in increments of 6 in. These values were selected on the basis of some limited field observations made by NBS. It was assumed that these uplift forces were uniformly distributed across the underside of the mobile home floor area.

A drag force would be applied to the sidewall of a mobile home if the floodwater has horizontal velocity. The drag forces were calculated by the following equation.

$$F_D = \frac{C_D A \rho V^2}{2}$$

where

F_D = Drag force

C_D = Drag coefficient

A = Projected vertical submerged area

ρ = Mass density of water

V = Average flow velocity

A flow velocity of 5 ft/sec was used in computing the forces. This velocity was selected on the basis of the assumption that it would be undesirable to locate a mobile home in a zone where larger flow velocities are expected. The drag coefficient was assumed to be of the order of that used for a typical barge, which was determined to be approximately 1 according to reference [4]. Thus, C_D was assumed equal to 1. The projected vertical submerged area was determined for a 1-ft wide strip of the mobile home by varying the submerged depth, h_s. Values of 0, 1.0 and 2.0 ft were used for h_s. The bottom of the mobile home floor was taken as the datum for values of h_s and the depth of the chassis beam (10 in) was then added to h_s. Hence h_s equal to zero (0) corresponds to the case where only the chassis beams are submerged.

The resultant drag and buoyant forces are shown schematically in figure 4. The drag force, F_D, was assumed to act at a distance of 1/2 the submerged depth (based on a uniform velocity profile) above the bottom of the chassis beams. As in the case of wind forces, it was assumed that the drag force on the skirt would have a negligible effect on the mobile home. The buoyant force was also combined with the HUD Standard Wind (Zone I) but the results of that case study will not be discussed herein.

3. VARIABLES CONSIDERED IN THE ANALYSES

3.1 Physical Characteristics of Mobile Homes

Realizing that there is a wide range of features of mobile homes as they are positioned on their supports that would affect the forces transmitted to the foundation systems, it was necessary to identify the most important features and to set limits on their magnitudes. The characteristics considered as variables in the calculations are: (1) width of mobile home, (2) weight of mobile home, (3) horizontal eccentricity of the center of gravity with respect to the vertical geometric center, (4) center to center spacing of chassis beams, (5) height of the mobile home above the ground (y_t in figure 1), (6) the horizontal distance from the edge of the mobile home to the diagonal tie attachment point (x_t in figure 1), and (7) tie-down arrangement.

Two widths of mobile homes were used in the analysis, 12 ft and 14 ft. Double-wide units were not specifically considered. The height of the mobile home was assumed to be 8 ft in all cases. Several sources were consulted in establishing a range of weights for the above-mentioned widths of single-wide units. It was found that the unit weight (i.e. per lineal foot) varies from 180 to 300 lb for 12-ft wide models and from 240 to 560 lb for 14-ft wide mobile homes. Typical weights were selected on the basis of information obtained from several producers and industry sources. The weight values used in the calculations are shown in table 2.

Because of the layout of the furnishings and major appliances in mobile homes, their weights generally do not act through the geometric center. Rather, there is an inherent eccentricity in the transverse direction. To determine reasonable values of the eccentricity for 12-ft wide and 14-ft wide units, a study was made of several spatial layouts and weights of the contents of mobile homes as shipped from the manufacturer. The eccentricities (e) that were selected for the analyses are shown in table 2. When considering overturning about the leeward pier, it was assumed that the weight was eccentric on the downwind side of the centerline. Thus, a lower bound resisting moment (contributed by the weight of the mobile home) was used in the calculations.

The spacing between the main chassis beams can vary from about 5 ft to 8 ft. Measurements were made on several 1960- and 1970-vintage mobile homes located on the NBS grounds and 6.46 ft was found to be a typical spacing. This, center-to-center spacing was used for the calculations.

The height of a mobile home above the ground is dependent on the height of the piers or other load-bearing support system and could vary over a considerable range. For example, the bottom of the chassis beams may rest virtually on the ground. On the other hand, a mobile home in a flood plain locale may have to be elevated 5 feet or more above the ground to satisfy code requirements. A typical value for y_t is 2.5 ft, which can be derived by assuming a 10-in chassis beam, a 2-in thick cap, two 8-in high concrete blocks and a 4-in thick footing and that the bottom of the footing is 2 in below ground level. The range of y_t values used was from 1 - 8 ft (table 2).

Dimension x_t is dependent on the chassis beam spacing. It was assumed that the frame ties are wrapped around the chassis beams, resulting in the tiedown configurations shown in figure 1. The physical characteristics used in the analyses are summarized in table 2.

Table 2 - Physical Characteristics Used in the Loads Analyses*

B, ft	W, lb/ft	e, ft	x_t (Near Tie), ft	x_t (Far Tie), ft	y_t, ft
12	230	0.55	2.62	9.08	1 - 8
14	250	0.75	3.62	10.08	1 - 8

B = Nominal width of mobile home
W = Unite weight of mobile home
e = Horizontal eccentricity of the center of gravity with respect to the vertical centroidal axis of a cross-section
x_t = Horizontal distance from the point beneath an exterior wall at which the vertical and diagonal ties intersect to the point where the diagonal tie attaches to the underframe of the mobile home
y_t = Vertical distance from the point of intersection of the ties with the anchor head to the underside of the floor of the mobile home.

*Refer to figure 1 for a pictorial description of these symbols.

3.2 Resistance of Pier Supports to Lateral Load

As mobile home chassis beams are generally not positively connected to the vertical support members (i.e. piers), the amount of lateral load resistance provided by the pier supports is dependent on the magnitude of the resulting friction force. The appropriate coefficient of friction to be used in assessing the lateral load resistance would be a function of many variables even when the specific materials are defined. It was observed by the author that the current ANSI/NFPA Standard 501A [5] has no explicit requirement that piers be built to resist lateral loads. In the light of the absence of an explicit code or standard requirement, it was conservatively assumed that the soil anchors must resist the entire horizontal load. In addition, the effect on the anchor loads of assuming lateral friction factors between 0 and 40% (i.e. percent of the piers' vertical reaction), was considered in a parametric study.

3.3 Load Transfer by Over-the-Roof Ties

An over-the-roof tie is a continuous strap or cable which is attached in varying degrees to a mobile home. The amount of tensile force transferred from one side of the mobile home to the other depends on the magnitude of friction between the tie and the unit. The two extreme cases are when (1) no load is transferred from one side to another and (2) all the load is transferred (i.e. a frictionless attachment of the tie to the mobile home). The first condition was assigned a load transfer coefficient, $\alpha = 0$, while $\alpha = 1$ represents the second condition. Intermediate load transfer cases were considered in a parametric study.

4. RESULTS FROM LOAD CALCULATIONS

The results of the load calculations have been summarized as a series of computer-generated graphs. The graphs present the resulting tie forces, pier reactions and total resultant anchor forces for the loading cases described in section 2. A total of 32 conditions have been summarized in graphical form and will be presented in a future NBS publication. The results of several of the cases will be discussed in the following paragraphs of this section. Primarily the tie and pier force results will be discussed in this presentation.

4.1 Wind Loads

Figure 5 shows the free-body diagrams for the mobile home when subjected to the idealized wind drag and uplift forces. The resulting forces for both near tie and far tie underframe connections are shown. Figures 6A and 6B compare the tie and pier forces as a function of the slope of the diagonal ties for the HUD Hurricane and NBS Hurricane respectively. The two graphs are the results of analyzing a 14-ft wide mobile home with a near tie configuration. To the left of the vertical dashed line overturning is impending and the windward vertical ties are loaded (T_1 in fig. 5A), while to the right of the line sliding is impending and the upwind vertical piers are loaded (P_L in fig. 5A). The boundary line represents the point at which overturning is just balanced by the diagonal frame tie without any resistance provided by either the windward vertical tie or the windward pier. The symbol α on the graphs indicates the load transfer coefficient as discussed in section 3.3. It is of interest to compare the two graphs for the typical case of $y_t = 2.5$ ft and $x_t = 3.62$ ft, which results in a diagonal slope of 0.69. From figure 6 it is seen that for $y_t/x_t = 0.7$ the windward vertical tie is not loaded as a result of the HUD Hurricane pressures. On the other hand, a force as high as 130 lb/ft could be induced in the windward vertical tie by the NBS Hurricane pressures (refer to figure 7, $\alpha = 1$), due to the higher overturning moment. It is also noted that the windward pier force is significantly higher for the HUD Hurricane, because sliding of the mobile home would be the response mode over a wider range of values of the diagonal tie slope.

Figures 7A and 7B compare the tie and pier forces, resulting from the HUD and NBS Hurricanes respectively, for the far tie arrangement. The slopes shown along the abscissa reflect a range of y_t values from 1 to 8 ft. It is noted that on these two graphs there is no vertical boundary line because overturning is the mode of failure over the entire range of underframe tie slopes. As a corrollary to this condition, the windward vertical tie and the leeward pier are always loaded.

Since graphs such as the ones discussed above show the tie and pier forces for a unit length of the mobile home, they can be used to determine the numbers of vertical and diagonal ties and pier supports that are required for a given total length.

Thus, using specified minimum tie and pier support capacities, one can compute the minimum number of these support elements required per side of single-wide mobile home. For example, given a 70-ft long mobile home and using the minimum working load of 3150 lb as specified in ANSI/NFPA 501 A [5] the number of diagonal ties required is derived as follows. Refering to figure 6A (HUD Hurricane) for a diagonal tie slope of 0.7, a windward diagonal tie force of 240 lb/ft is scaled.

Total Force = 240 x 70 = 16800 lb

$$\text{No. of Diagonal Ties Required} = \frac{16800}{3150} = 5.4, \text{ say } 6$$

Table 4.2.2.1 (a) of ANSI/NFPA 501A also indicates that 6 diagonal ties are required for a 70-ft long mobile home located in a hurricane zone. It was found that the numbers of ties required according to figures 6A and 7A were in reasonably good agreement with those specified in the ANSI/NFPA 501A table, in the range of diagonal tie slopes permitted by Standard 501A. For slopes steeper than those permitted by the ANSI/NFPA Standard, the numbers of diagonal ties required for the near tie arrangement (according to figure 6A) exceed the 501A requirements. It should be noted the above-mentioned comparisons of numbers of ties required are based on the assumption that all ties are loaded to 3150 lb. As is suggested by the vertical tie force ordinates in figure 7B, the NBS Hurricane would dictate the use of more vertical ties than are required according to ANSI/NFPA 501A.

4.2 Flood Loads

4.2.1 Buoyancy Forces

Figures 8A and 8B show the diagonal and vertical tie forces resulting from buoyancy pressure acting on the underside of a 14-ft wide mobile home, without flow velocity. Figure 8A shows the tie forces for the near tie connection, while figure 8B shows the forces for the far tie connection. Differential heads (Δh) of 0.5, 1.0, 1.5 and 2.0 ft were used in the calculations. It was assumed that the line of action of the weight of the mobile home was concurrent with uplift force vector. The effects of this assumption were considered to be negligible in view of the relatively small eccentricity (0.75 ft) used and the fact that imminent tilting would tend to align these forces. To derive the diagonal and vertical tie forces, it was assumed that their magnitudes would be proportional to their relative strains resulting from a unit extension of the vertical tie. Thus, the force in the diagonal tie was found to be equal to the product of the force in the vertical tie and the sine squared of the angle of the diagonal tie with respect to the horizontal. This approach implies that the stiffnesses of soil anchors in both the horizontal and vertical directions are equal. While inclined pull test results indicate that the orthogonal stiffnesses are not equivalent, it is not felt that the tie force results are significantly affected by the assumption. Since the relative contribution of the diagonal ties is generally small, the direction of the resultant anchor force is going to virtually be vertical. Note that although the vertical tie forces are significantly greater than the diagonal tie forces over most of the range of diagonal tie slopes, there is a trend of convergence as the slopes increase. As would be expected from the resulting flatter slopes the differences between the vertical tie force and diagonal tie force ordinates are even greater for the far tie connections.

By comparing the ordinates in figures 6B and 8A, it is seen that the magnitudes of vertical tie forces caused by a 1-ft differential head are greater than those caused by the NBS Hurricane loading condition. Since the same anchors have to resist wind as well as flood loads, it is important to determine the buoyancy force resistance of anchors originally installed for resisting wind loads. For example, it could be assumed that mobile home anchors have been installed to resist the NBS Hurricane forces shown in figure 9. The resultant forces for both the windward and leeward anchors and the angle of inclination of the resultant with the horizontal are shown for the near tie arrangement. Likewise, figure 10 shows the resultant anchor forces and their angles of inclination as caused by floodwater buoyancy forces. Thus, anchors installed to resist NBS Hurricane forces in figure 9 could be evaluated for the forces shown in figure 10 for various assumed differential floodwater levels. Note that graphs such as figure 10 may not be directly applicable to some actual installations since the resultant forces were calculated for cases in which there is a diagonal and vertical tie at each anchor location. This arrangement is not typical of many field installations. Anchor forces can always be calculated by combining the vertical and diagonal tie forces vectorially to obtain the magnitude and direction of the resultant force that must be resisted by a double-headed anchor (i.e. an anchor head to which two ties are attached).

4.2.2 Drag Forces

Vertical and diagonal tie forces caused by a floodwater flow velocity of 5 ft/sec acting normal to the long side of a 14-ft wide mobile home are shown in figures 11 and 12 respectively. The drag forces are proportional to the depth to which the mobile home is submerged, h_s. The graphs were developed for submerged depths of 0.5 to 2.0 ft. For convenience, h_s is measured from the underside of the mobile home floor and then 10 inches were added to the assigned value of h_s to account for the exposed surface of the chassis beam. Calculations were performed for three levels of differential head (Δh), 0, 0.5 and 1 ft. Figures 11 and 12 were derived for the case $\Delta h = 0.5$ ft.

In general, the effect of the flood drag forces is less than that of a horizontal wind force of equal magnitude, since the former does not exert an overturning moment. Thus, the extent to which vertical tie forces are induced is primarily dependent on the level of differential head and not on the magnitude of the drag force.

It should be noted that the drag forces were calculated assuming that the exposed area would be limited to the submerged portion of the mobile home wall and chassis beam. It is acknowledged that the lateral forces could be significantly greater should large pieces of floating debris get lodged against the mobile home or caught by the anchoring ties.

5. SUMMARY

As a result of the wind and flood load calculations discussed above, the following observations have been made.

1. Hurricane loads, be they caused by the HUD Hurricane or the NBS Hurricane pressures, will induce relatively high tensile forces in the underframe diagonal ties. This relatively large diagonal tie force suggests that anchor systems must be designed to resist a substantial horizontal load component. Furthermore, the vertical tie forces resulting from the HUD Hurricane are of less magnitude, particularly for the near tie connection.

2. In light of the magnitudes of the diagonal tie forces caused by the hurricane loads, conventional anchor installations - characterized by installing anchors nearly vertical - may not be capable of resisting the horizontal force components without excessive displacements.

3. It was found that relatively small differential heads may cause potentially critical forces in the vertical ties. For example, buoyancy forces accompanying differential heads of 0.5 ft and greater will cause vertical tie forces approximately equal to or greater than those caused by the HUD Hurricane over the entire range of diagonal tie slopes used in the calculations. In the same vein, buoyancy forces accompanying differential heads of 1.0 ft and greater will cause vertical tie forces approximately equal to or greater than those caused by the NBS Hurricane.

4. In view of observation 3 above, it is suggested that in cases where mobile homes may be subjected to hurricane winds and flooding, the number of vertical ties be determined by the flood load requirements and the number of diagonal ties be determined by the wind load requirements.

6. REFERENCES

[1] Kovacs, W.D. and Yokel, F.Y., (1974) "Soil and Rock Anchors for Mobile Homes - A-State-of-the-Art Report," NBS Building Science Series 107, National Bureau of Standards, Washington, D.C., October 1979, 147 pp.

[2] Marshall, R.D., (1977), "The Measurement of Wind Loads on a Full-Scale Mobile Home," NBSIR 77-1289, National Bureau of Standards, Washington, D.C., September 1977, 120 pp.

[3] Mobile Home Construction and Safety Standards, U.S. Department of Housing and Urban Development, Federal Register, Vol. 40, Part II, December 1975.

[4] Hoerner, Sighard F., "Fluid Dynamic Drag: Practical Information on Aerodynamic Drag and Hydrodynamic Resistance." 2nd Edition, Midland Park, N.J., 1958.

[5] Standard for the Installation of Mobile Homes, ANSI/NFPA 501 A, (1977) Manufactured Housing Institute, Chantilly, VA, and National Fire Protection Association, Boston, MA.

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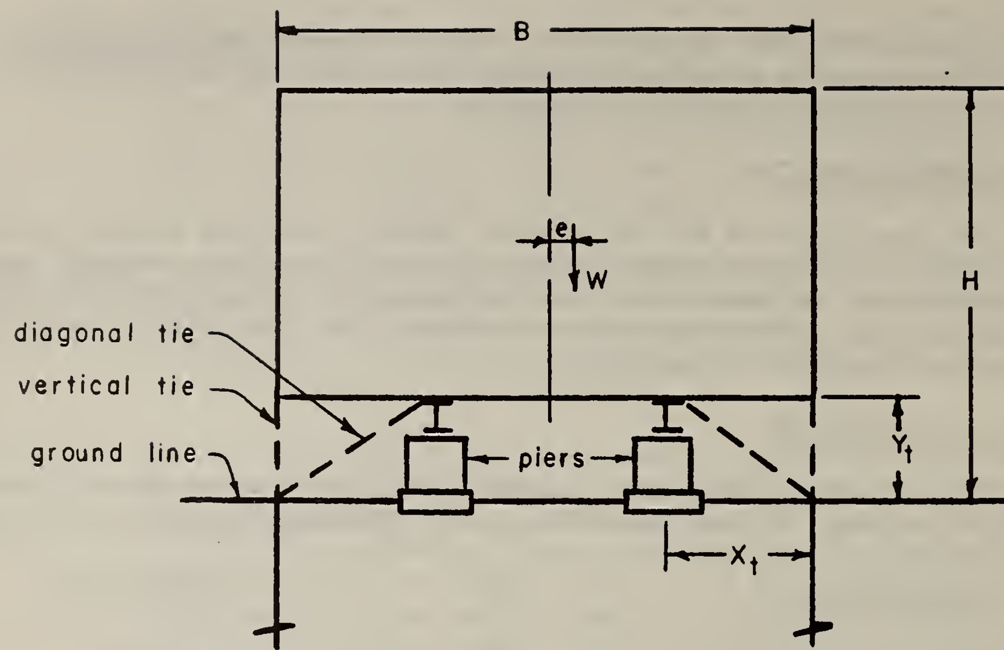
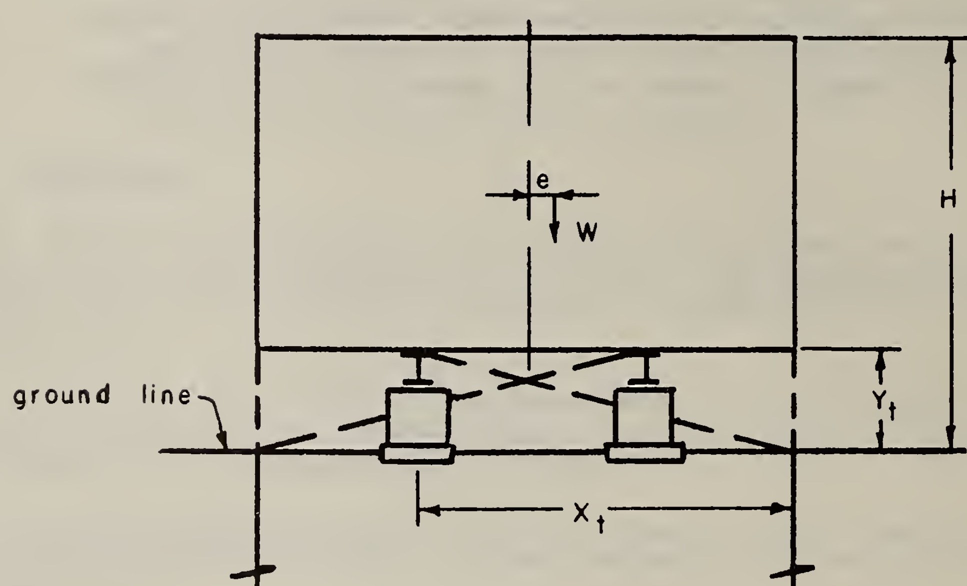
8. S.I. CONVERSION

The following conversion factors should be used to convert dimensions and forces given in this report from U.S. Customary Units to S.I. Units:

To Convert From	To	Multiply by
in	mm	25.40
ft	m	0.3048
lb	N	4.448
psf	Pa	47.88
mph	mps	0.447



1A - Near Tie Connection



1B - Far Tie Connection

Figure 1 - Typical Tiedown Configuration for Mobile Homes

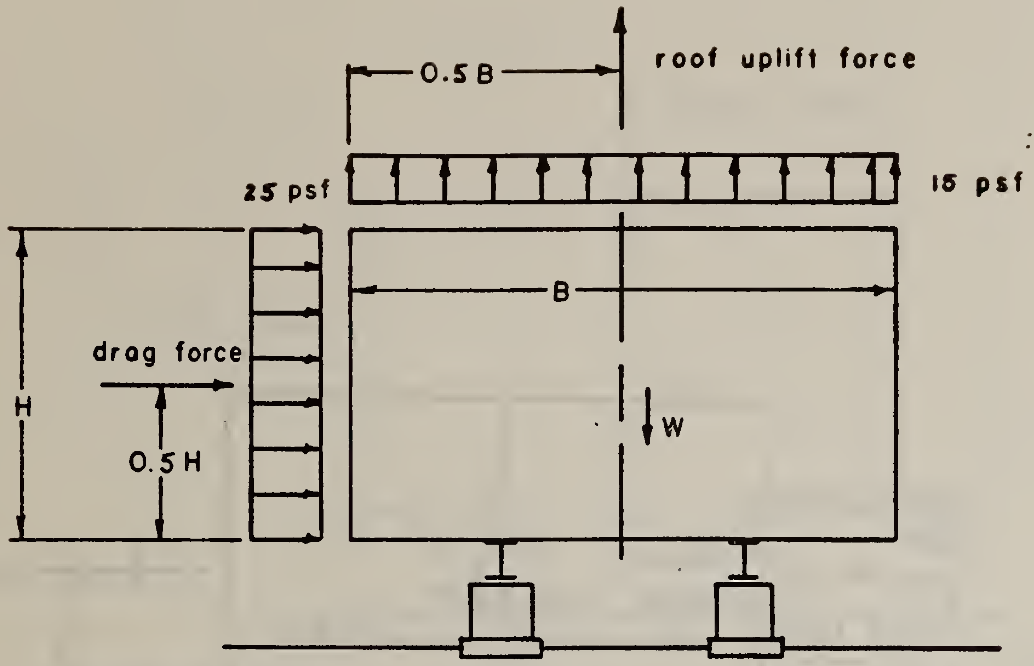


Figure 2 - HUD Hurricane Forces

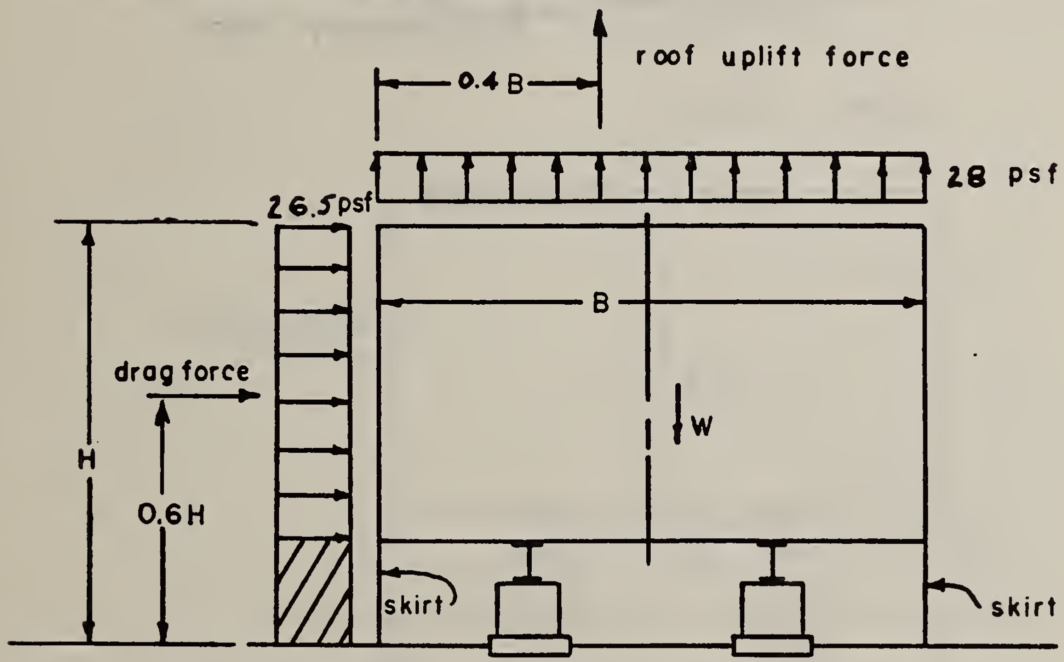


Figure 3 - NBS Hurricane Forces

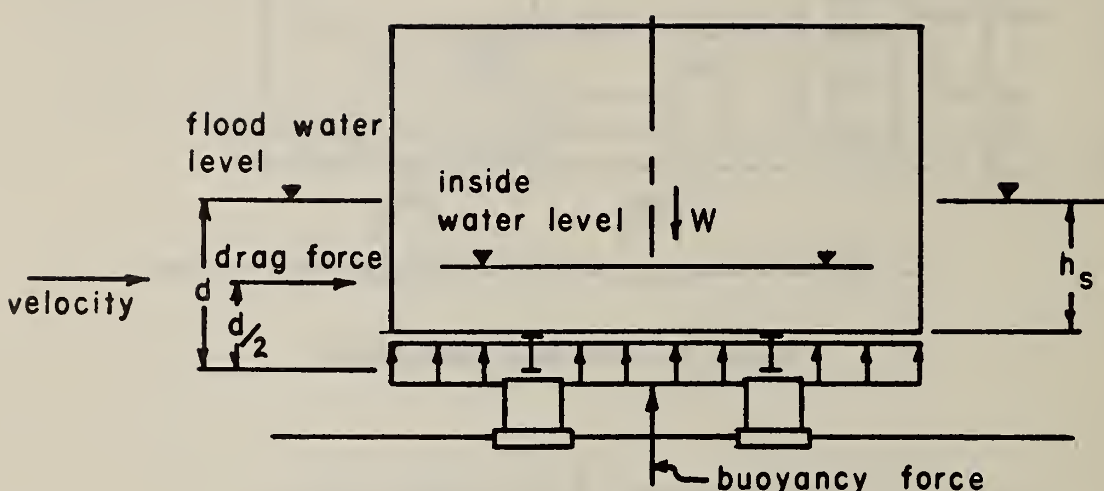
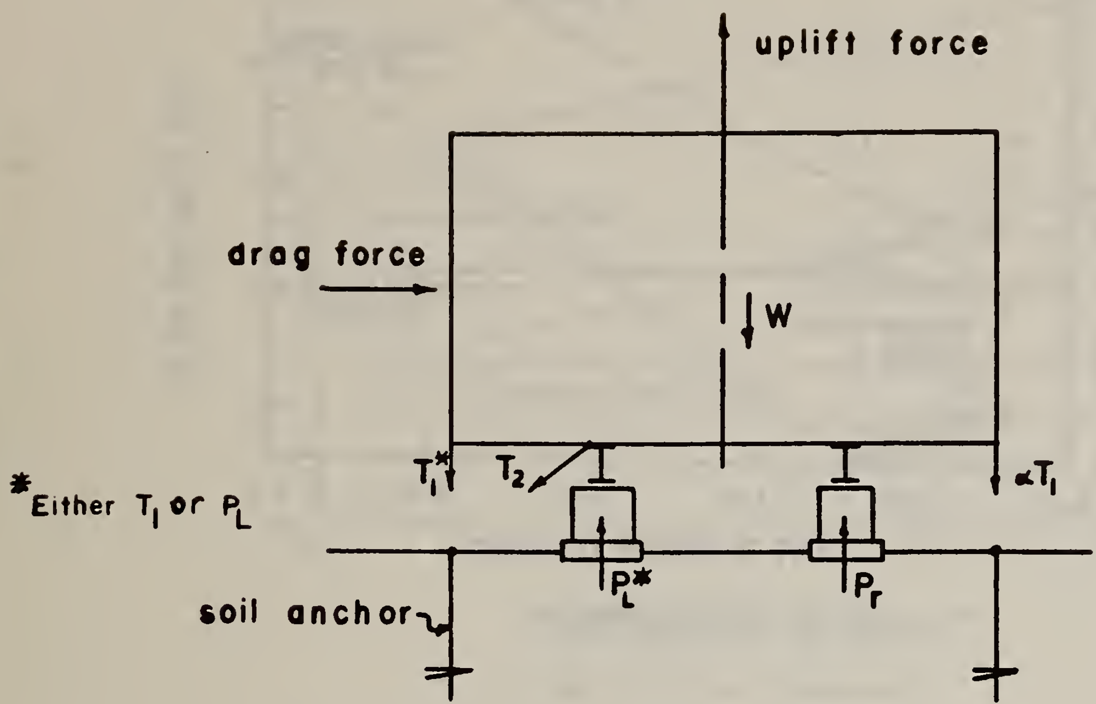
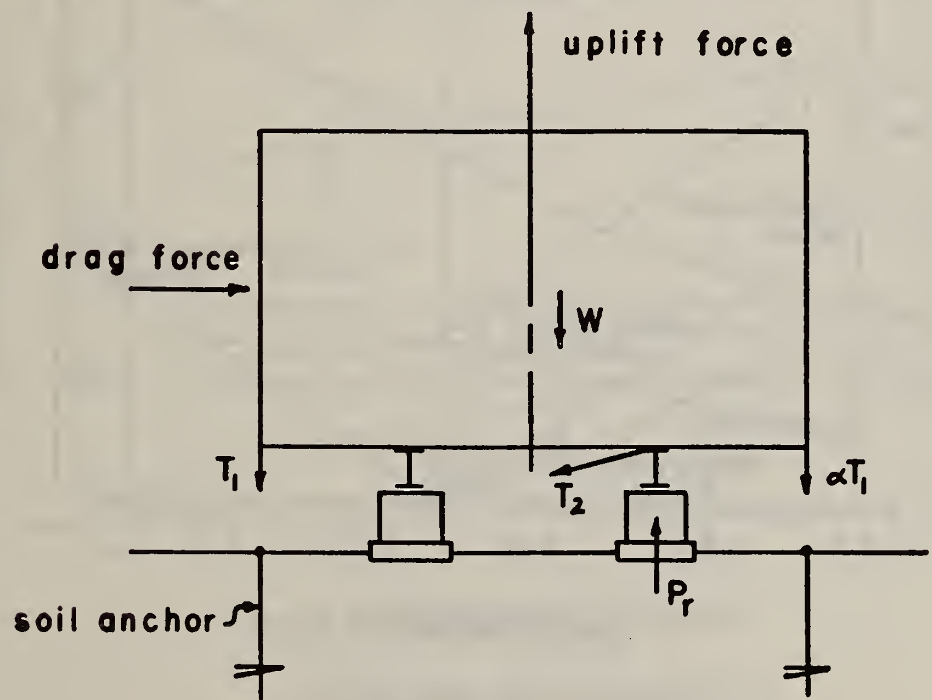


Figure 4 - Flood Forces

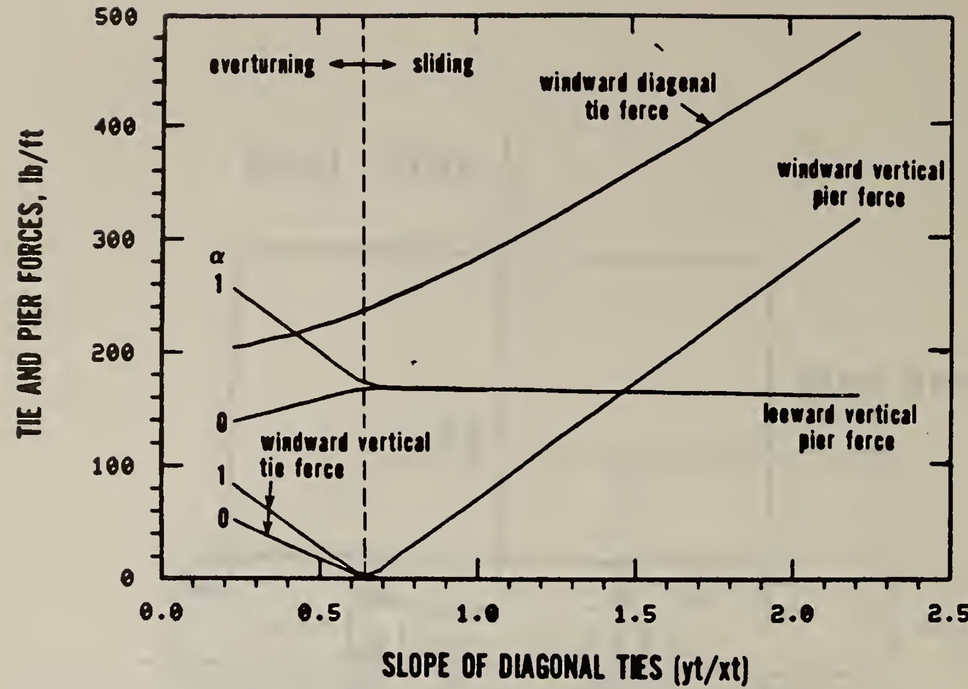


5A - Near Tie Connection

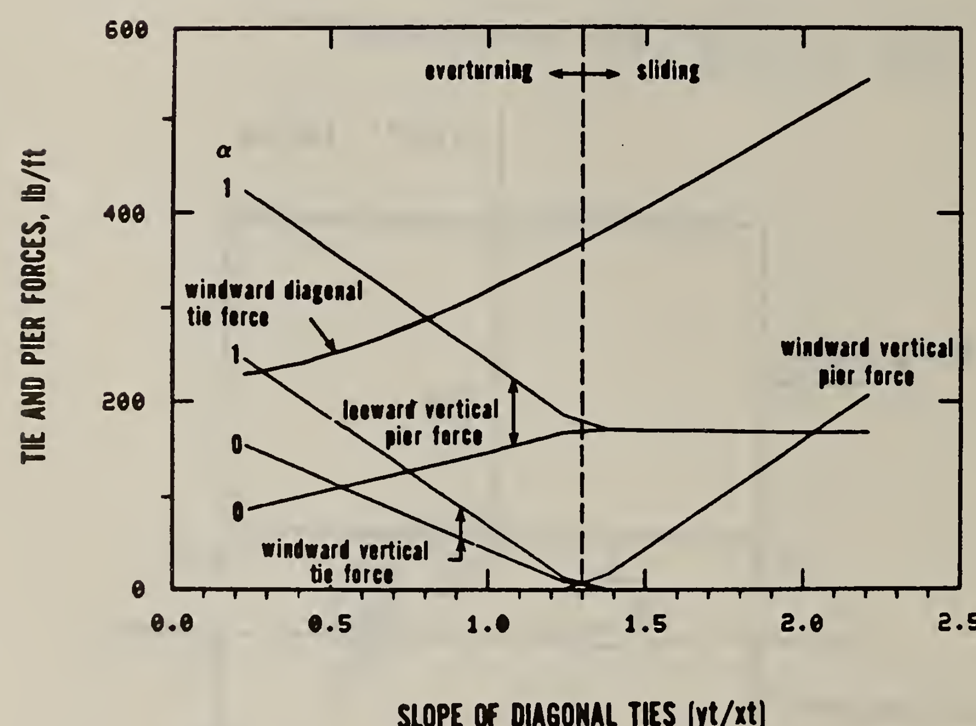


5B - Far Tie Connection

Figure 5 - Free Body Diagrams for Mobile Home Subjected to Wind Forces

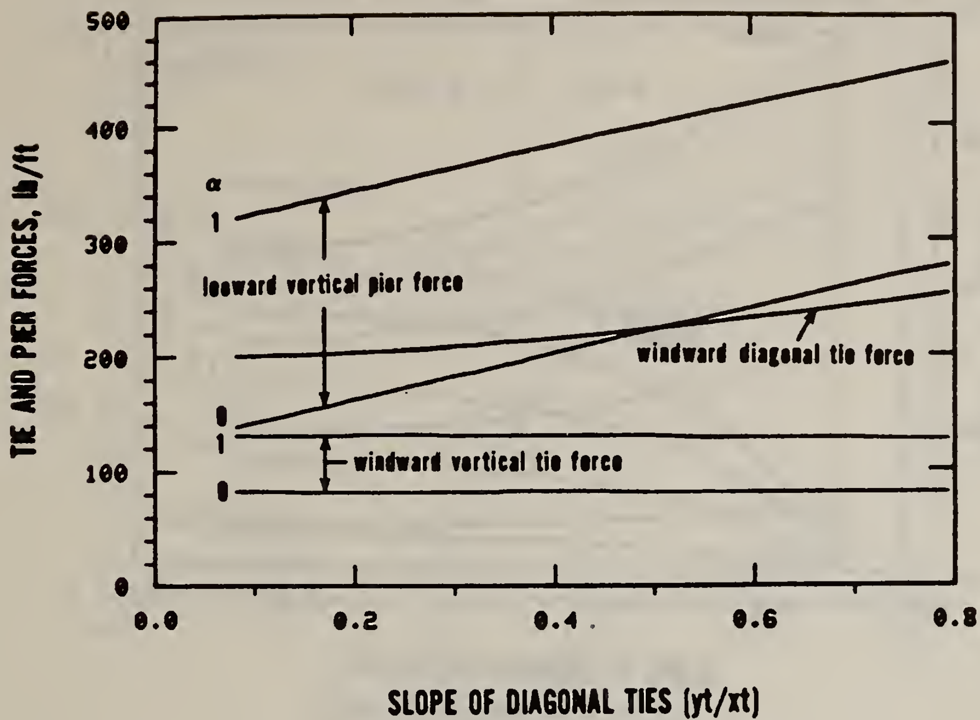


6A - HUD Hurricane Pressures

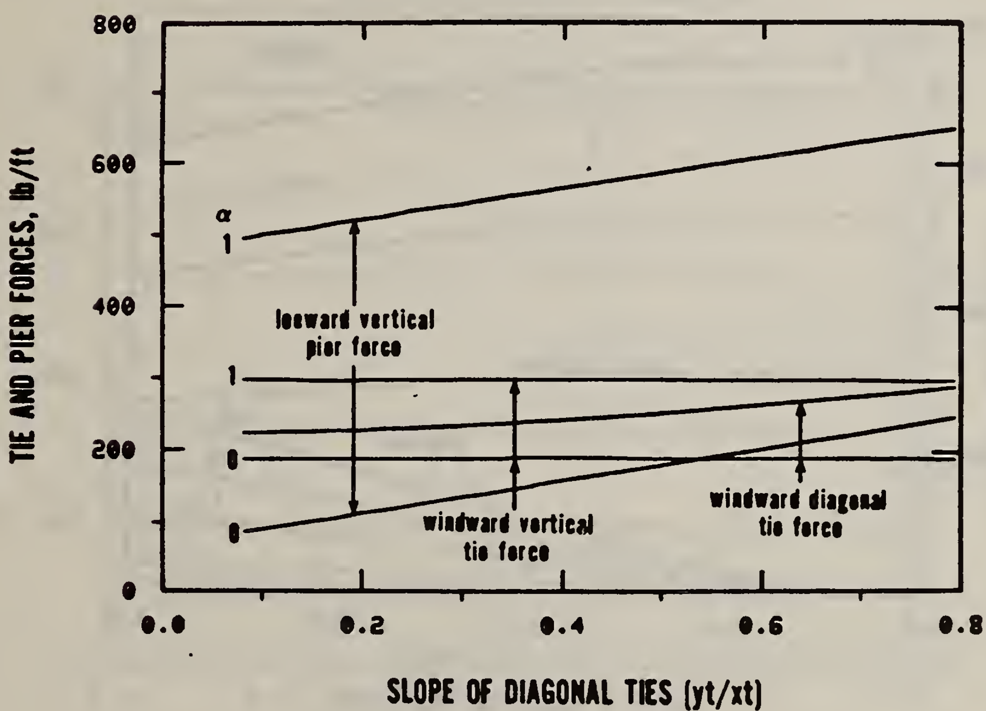


6B - NBS Hurricane Pressures

Figure 6 - Tie and Pier Forces for Hurricane Pressures - Near Tie Connection

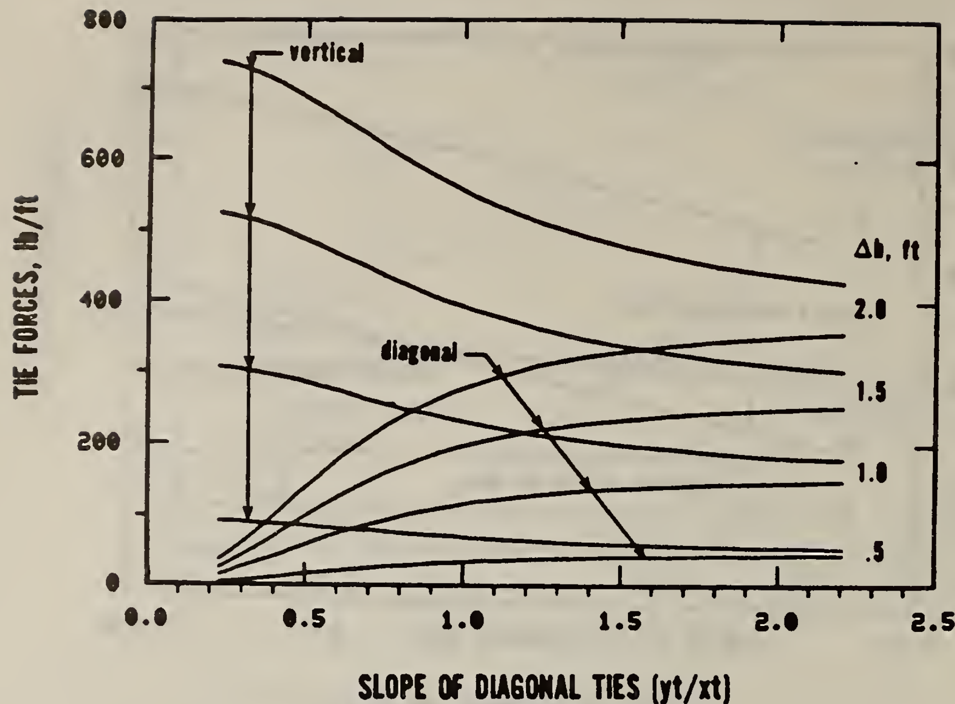


7A - HUD Hurricane Pressures

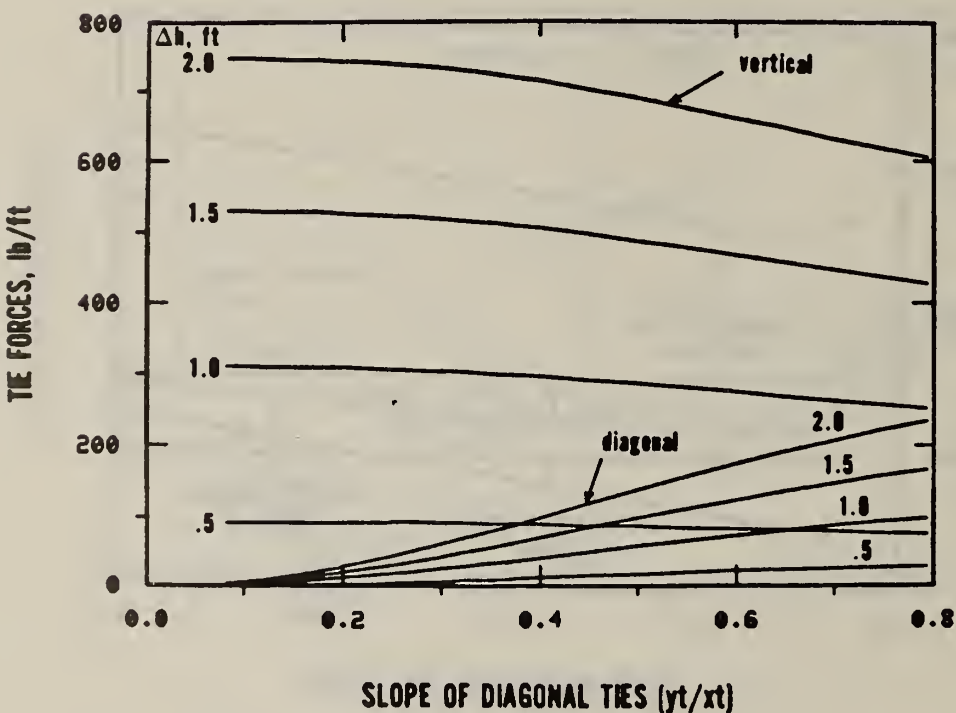


7B - NBS Hurricane Pressures

Figure 7 - Tie and Pier Forces for Hurricane Pressures - Far Tie Connection



8A - Near Tie Connection



8B - Far Tie Connection

Figure 8 - Tie Forces for Flooding Condition without Flow Velocity

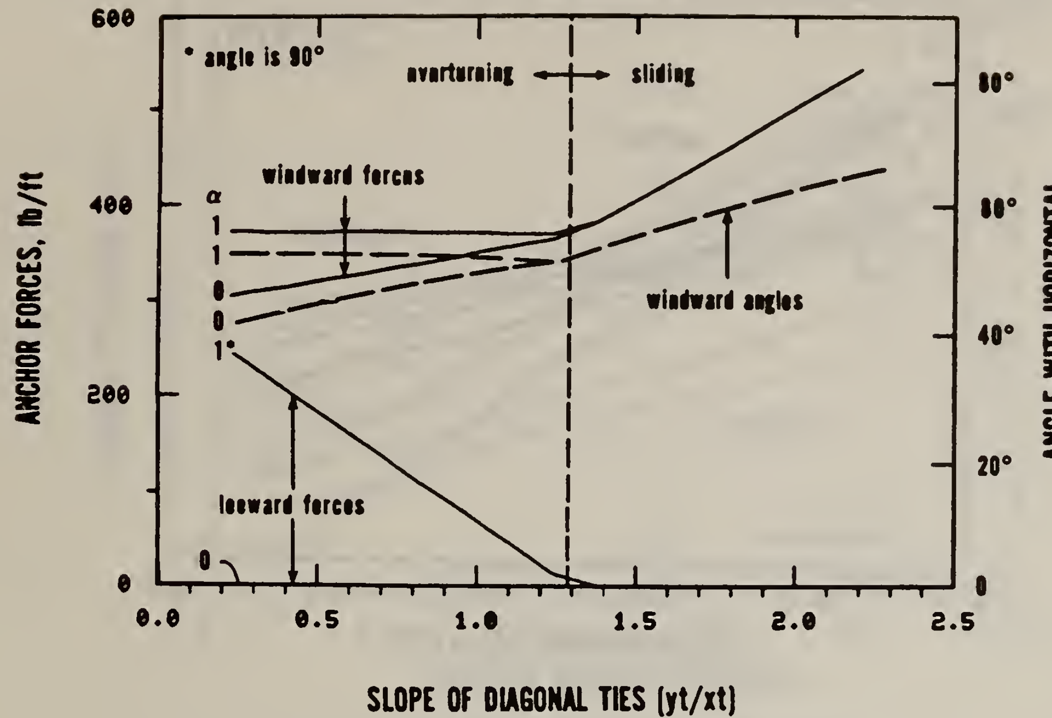


Figure 9 - Resultant Anchor Forces Induced by NBS Hurricane Pressures

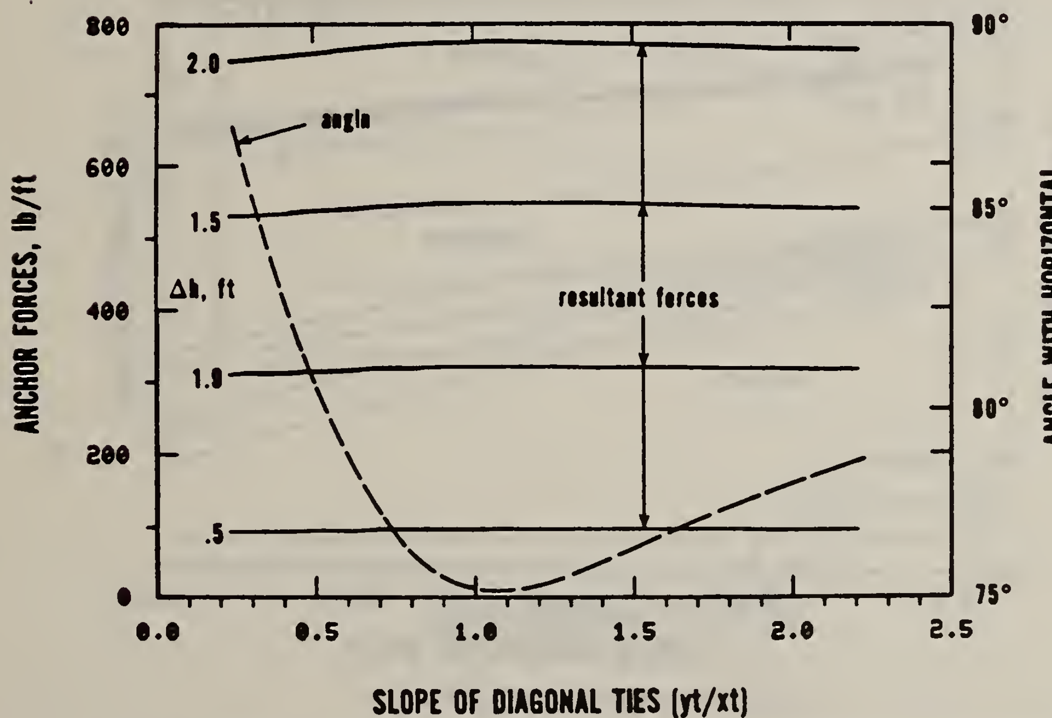
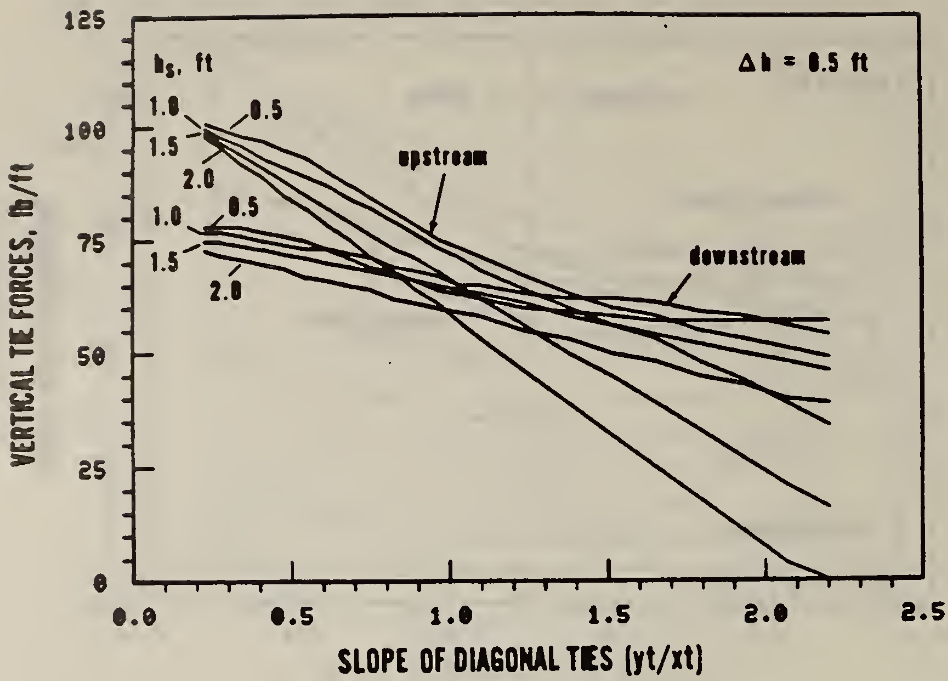
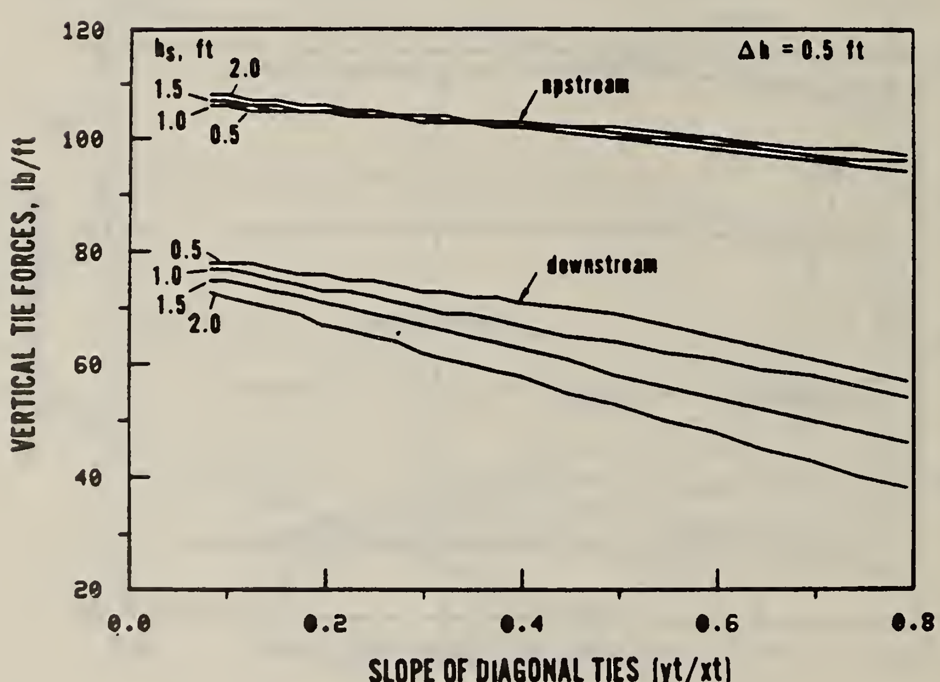


Figure 10 - Resultant Anchor Forces Induced by Floodwater Buoyancy Forces Without Flow Velocity

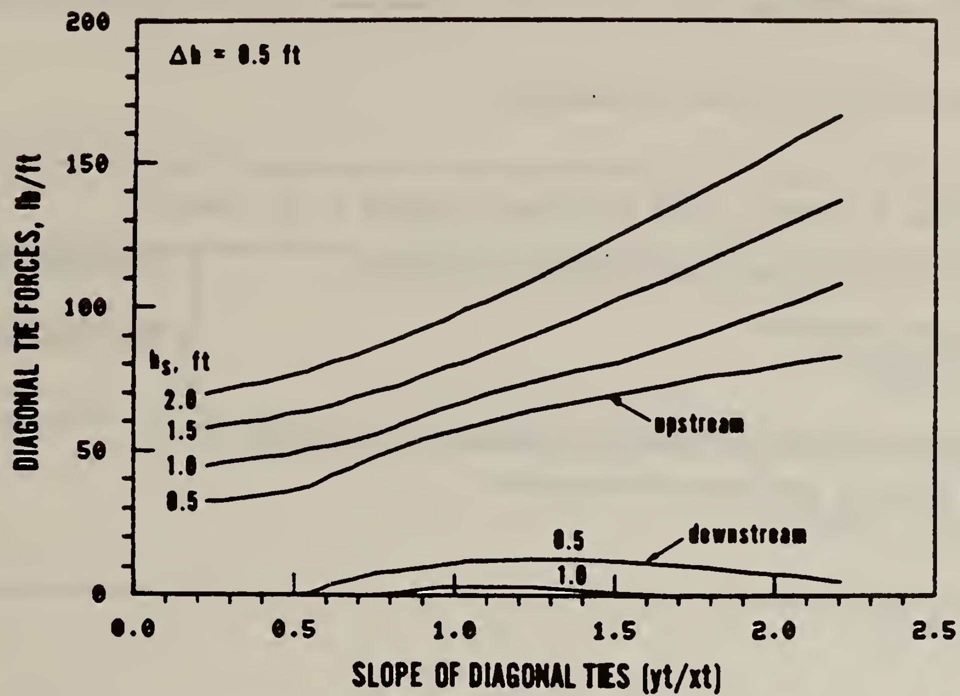


11A - Near Tie Connection

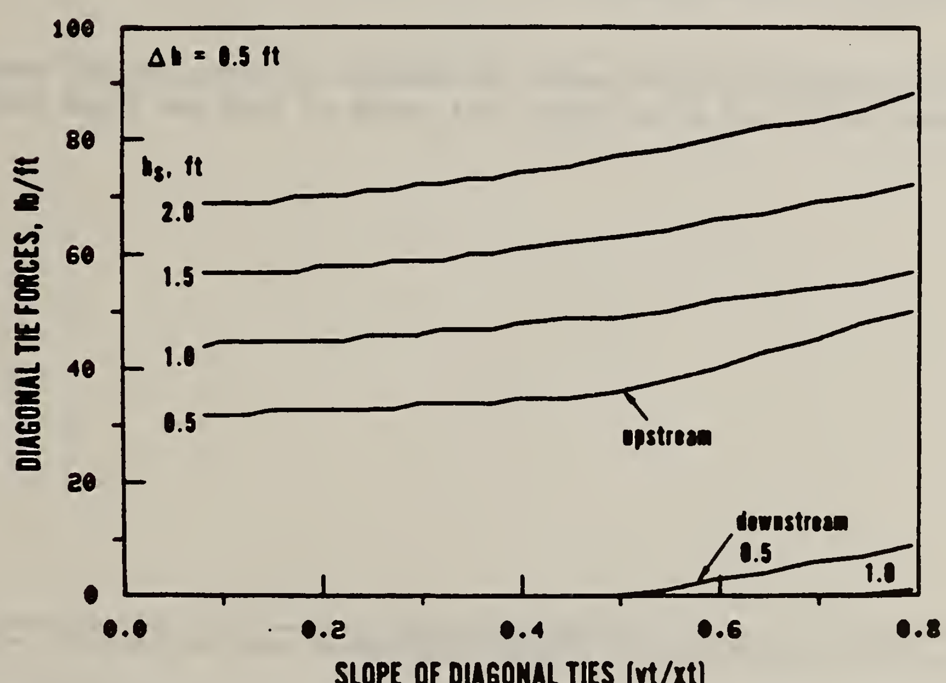


11B - Far Tie Connection

Figure 11 - Vertical Tie Forces Caused by a Flow Velocity of 5 fps and a Differential Head of 0.5 ft



12A - Near Tie Connection



12B - Far Tie Connection

Figure 12 - Diagonal Tie Forces Caused by a Flow Velocity of 5 fps and a Differential Head of 0.5 ft

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Two papers are presented which discuss the results of tests on soil anchors used to secure mobile homes and of an analytical study of wind and flood loads on soil anchors.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

flood loads; mobile home foundations; mobile home standards; soil anchors; soil testing; flood loads

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