Field Tests to Determine the Behavior of Piles in Loess

Essais sur place pour déterminer le comportement de pieux enfoncés dans du lœss

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Summary

Loess, a soil covering vast areas in several continents, has caused much concern regarding settlements. Particular problems are inherent in the construction of hydraulic structures, which will subsequently have their foundations wetted, because wetting greatly reduces the strength of loess. An extensive study involving the driving of 44 piles and 28 pile load tests was made in Nebraska loess to determine the behavior of piles.

The results showed that placement by driving only in thoroughly prewetted loess was most desirable for displacement piles and produced the maximum load capacity for wetted conditions. Nondisplacement piles could be driven in dry loess. However, displacement piles required preexcavation in dry loess, and these piles had relatively low load capacity after wetting the loess.

End-bearing piles are recommended for low-density loess, but friction piles are possible in medium-dense loess. Dense loess may not require piles for ordinary footings.

Sommaire

Le lœss, un sol recouvrant de vastes régions dans plusieurs continents, a soulevé plus d'un problème de tassement. Des problèmes spéciaux sont inhérents aux ouvrages hydrauliques vu que l'humidification de leurs fondations réduit grandement la résistance du lœss. Pour déterminer le comportement des pieux, les auteurs ont fait dans le lœss du Nebraska une étude extensive comprenant l'enfoncement de 44 pieux ainsi que des essais sur la force portante de 28 pieux.

Les résultats ont montré qu'il était préférable d'utiliser un sol préalablement humidifié pour l'enfoncement de pieux, cette condition donnant aux pieux une force portante maximum. Les pieux de section plus grande, produisant un refoulement, nécessitent un déblayage préalable du lœss sec et ont une force de résistance relativement très faible après humidification du lœss.

Des pieux résistant principalement par la pointe sont recommandés pour le lœss de faible densité, des pieux à résistance latérale peuvent être utilisés dans un lœss de densité moyenne. Un lœss de forte densité ne nécessite pas de pieux pour des fondations ordinaires.

Introduction

When building hydraulic structures on loess, settlement is a most important problem because of the break-down of the soil structure upon wetting and loading. Since construction takes place before hydraulic service begins, the problem becomes that of building in natural material with the aim of making the structure serviceable in wet material. This earth material is frequently of loose structure because of its wind-blown method of final deposition. It is generally made up of relatively uniform silt-size particles which are bonded together with fairly high strength in dry conditions. In the Nebraska and Kansas area petrographic studies showed that this bond generally is the result of thin clay coatings which surround the silt particles. When these clay coatings are wetted, the strength is weakened and consolidation can easily take place. Piles have been considered as a solution to the problem and will undoubtedly be a common construction procedure for rigid irrigation structures such as power plants, pumping plants, gate structures, and other appurtenant canal structures. In attempting to visualize the suitability of piles, these questions were asked:

(1) How must piles be placed since the loess is quite firm and sometimes hard when dry?

(2) What happens to piles when the loess becomes thoroughly wetted?

(3) Can the natural structure of loess support friction piles or must there always be firm bearing?

(4) What kind of piles are desirable?

Testing Program

A research study (BOR, 1951), near Ashton, Nebraska, of full-scale pile tests was conducted to answer these questions. The location was in the northcentral part of the major loess deposits of the midwestern states. The test sites contain loess which is representative of that found at many proposed irrigation projects (*Holtz* and *Gibbs*, 1951). Site 1 contained end-bearing piles resting in firm sand underlying shallow loess and Site 2 contained friction piles in loess greater than 60 feet deep. The loess at both sites was at a medium range of density, 80 to 90 lbs. per cu.ft.

The complete study included driving 44 piles and performing 28 pile load tests. Two general types of piles were studied: (1) nondisplacement piles, and (2) displacement piles.

Each test site contained an area in which piles were placed in natural dry loess and an area which was prewetted by surface ponding to a depth greater than the proposed pile length. (Such ponding required about 6 weeks' time.)

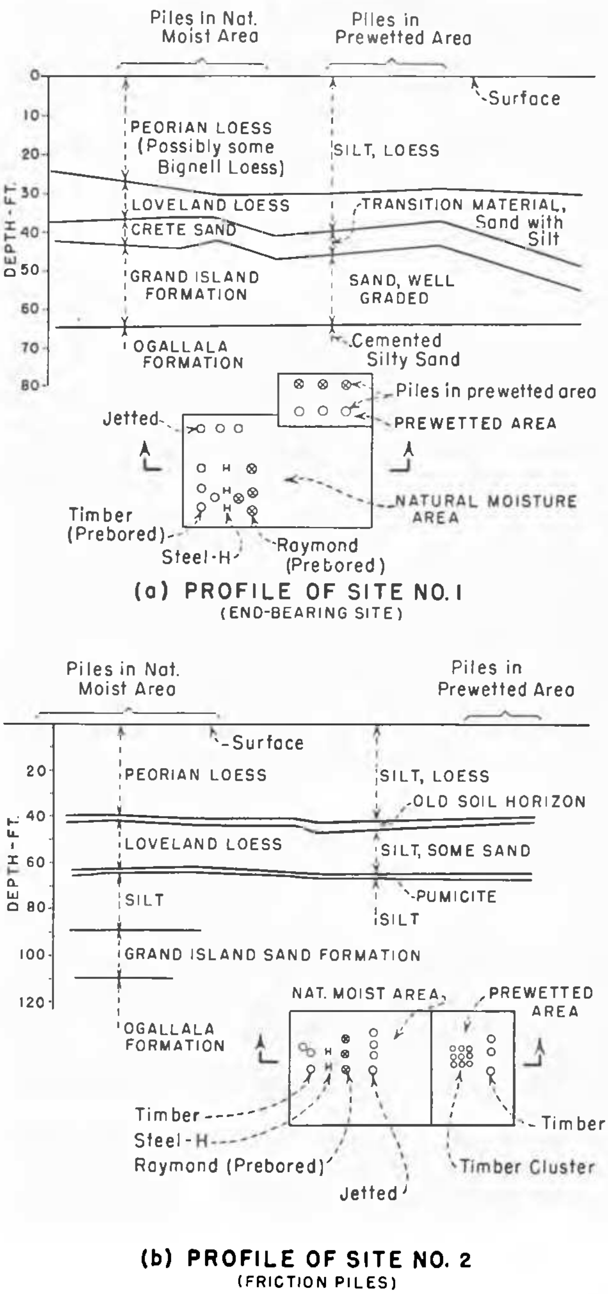


Fig 1 Profiles and Plans of Test Sites
Coupes et plans de l'emplacement d'essai
(*a*) Profile of Site No. 1
Coupe de l'emplacement 1
(*b*) Profile of Site No. 2
Coupe de l'emplacement 2

The natural moisture area of each site contained the following types of piles and placement methods:

Group (1) 3 timber piles placed by driving only or preboring if necessary;

Group (2) 3 steel-H piles placed by driving only;

Group (3) 3 steel shell, cast-in-place concrete piles placed by driving only or preboring if necessary (Raymond shells were selected by the contractor);

Group (4) 3 timber piles placed in jetted holes.

The prewetted area of each site contained only displacement piles placed by driving only. At the friction pile site, in addition to single separated piles, a cluster of nine piles were driven to determine the consolidation effect of pile driving.

Representative piles of each type and placement method were load tested. Piles which were placed in the natural moisture areas were load tested before and after wetting the areas.

One of the purposes for testing end-bearing piles was to study downward drag on the pile resulting from the upper loess settling when wetted. However, this study did not materialize since the loess at this site did not settle as a result of wetting alone.

Soil Conditions

Soil profiles and plans of the two test sites are shown in Fig. 1. In Site 1 (profile shown in Fig. 1*a*) the loess was from 35 to 40 feet deep. The Grand Island sand formation which was considered the bearing material was at about 45-foot depth. Between the loess and the Grand Island sand was sand with silt. The loess varied in density from 84 lbs. per cu.ft. near the surface to about 90 lbs. per cu. ft. at lower depths. The Grand Island sand was quite dense at about 112 lbs. per cu. ft.

In Site 2 (profile shown in Fig. 1*b*) the loess was of considerably greater depth than the proposed pile length of 55 feet. The loess from 0 to 40 feet was of relatively low density, 80 to 85 lbs. per cu.ft. This was underlain by a somewhat clayey old soil horizon, 1 to 2 feet in thickness. Below this old soil horizon to 62-foot depth was another loess slightly more sandy and denser, being at 85 to 95 lbs. per cu. ft.

The physical properties of loess are quite similar in respect to gradation, plasticity, and mineral contents. Typical gradations in the area are shown in Fig. 2. As a result of these consistent characteristics we have concluded that structural properties are primarily affected by density and moisture (*Holtz*

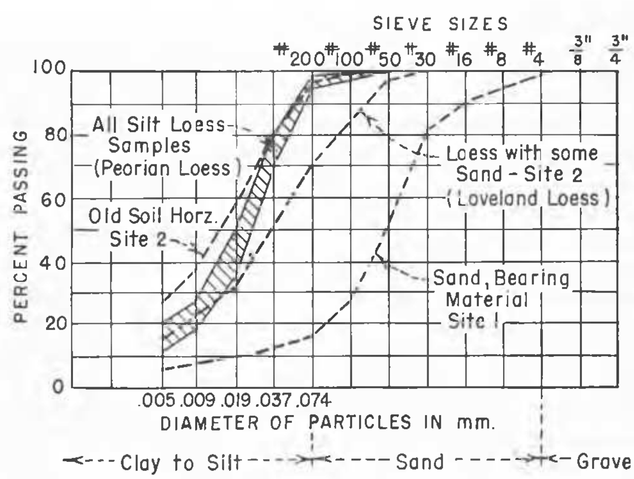


Fig. 2 Gradation Tests
Essais de gradation

and *Gibbs*, 1951). It appears that moisture contents below about 15 percent result in firm loess of high strength, whereas wetted loess having above 20-percent moisture content results in a soft, easily consolidated material of very low shearing resistance. Densities below 80 lbs. per cu. ft. are considered low and most susceptible to large settlements. Loess with densities between 80 and 90 lbs. per cu. ft. is of medium density and may have moderate settlements which may be critical for more delicate structures. Loess with densities from 90 to 100 lbs. per cu.ft. is fairly firm and may support ordinary foundations without serious settlements. Densities above 100 lbs. per cu.ft. will generaly only occur in reworked and recompacted loess and result in somewhat ideal structural properties.

Equipment for Driving and Load Testing

The equipment used for pile driving was a single-acting steam hammer. This equipment was particularly suitable in a research study of this kind because the energy of blows could easily be interpreted and maintained constant for comparing the driving of one pile to another. It had a 5,000-pound hammer dropped 36 inches and operated at 55 to 60 blows per minute.

The preboring of dry holes was done by driving an open-end pipe pile into the ground for about 4 feet, pulling it out, and blowing the soil plug from the pipe with steam. The process was repeated until the desired depth was reached.

The jetted holes were made by ejecting a straight stream of water at 100- to 120-psi pressure into the ground from the end of a long vertical pipe guided by the leads of the pile driver. The jet pipe was worked up and down with short strokes and followed the hole down as it was made. The finished hole was somewhat irregular in shape, varying from 7 to 12 inches in diameter.

Load tests were made by stacking standard railroad rails on a loading frame above the pile to be tested. A hydraulic jack between the loading frame and the pile permitted the application of the load in controlled amounts. The method of testing is shown in Fig. 3.

Result of Driving Studies

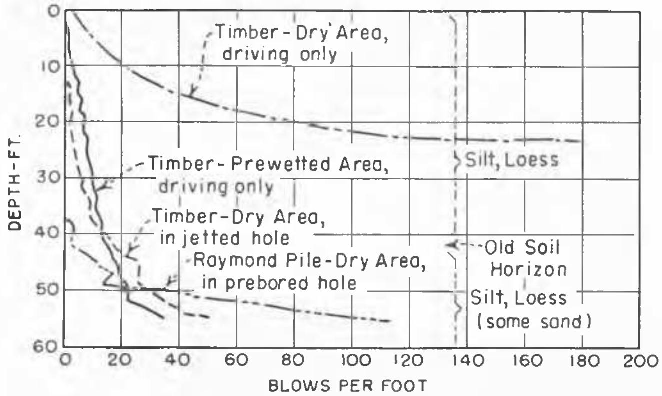
The results of driving studies are presented here by means of three graphs, Figs. 4*a*, *b*, and *c*. These graphs display the record of a representative pile of each of the general conditions.

Fig. 4*a* represents the driving records of the displacement piles placed by various methods in deep loess at Site 2, the friction pile site. The solid line curve is the driving record of a timber pile placed by driving only in thoroughly prewetted loess. Such a pile drove rather easily and gradually picked up resistance of about 36 blows per foot. It was apparent that the denser and more sandy loess below the old soil horizon caused resistance to increase more rapidly. The *Engineering News* formula indicated a safe load of 35 tons for this pile. A similar pile placed in dry loess, shown by dash-dot line, shows a distinct contrast in driving resistance. It was only possible to drive this pile 25 feet before refusal resistance was reached. The safe load of this pile after the soil is wetted should be that indicated by driving a pile in prewetted loess to a similar depth, and, in this case by the *Engineering News* formula, would be about 9 tons. Whereas, a safe load computed from the driving record in the dry loess was 90 tons, which shows that driving in dry loess would give erroneous indications of strength.

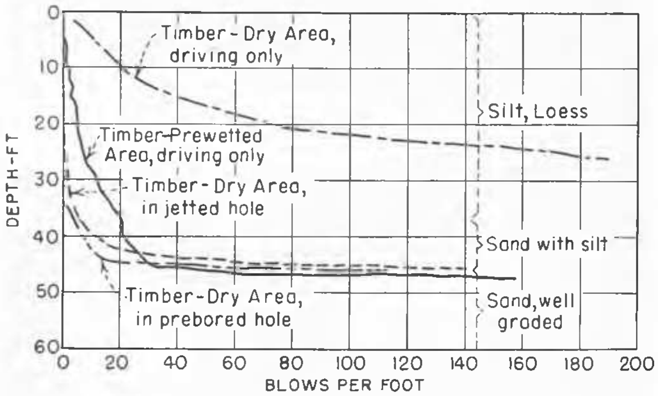
It was evident that, in order to place a displacement pile in dry

Fig. 3 Method of Making Pile Load Test
Méthode d'essai de la charge portante

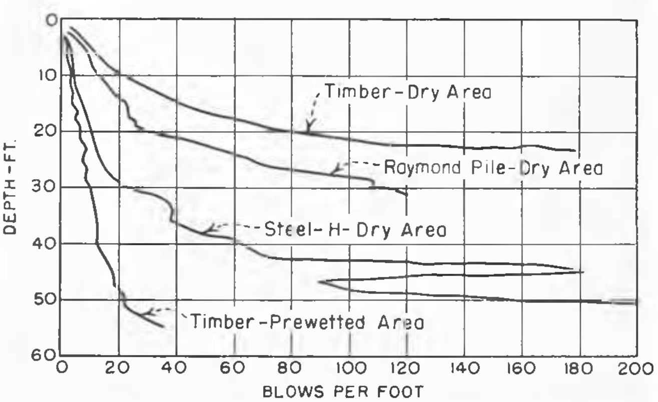
loess to the proposed depth, pre-excavation was necessary. Further, it was found that in order to place a pile in a dry prebored hole, the hole had to be practically as large as the pile. A representative pile placed in a dry prebored hole, shown in Fig. 4*a* by a dash-double dot line, dropped in the hole to 35 feet without resistance and rapidly picked up high resistance from there to the proposed depth of 55 feet. A pile in a jetted hole, shown by the dashed line, had gradually increasing resistance from a depth of 12 feet. Of the three placement methods which permitted the piles to be placed to the proposed depth of 55 feet, the pile placed in the prewetted loess by driving only was considered to give highest strength because maximum con-



(a) Driving records of displacement piles in Site 2, the friction pile site



(b) Driving record of displacement piles in Site 1, the end-bearing site



(c) Comparison of piles of different types placed by driving only in deep loess

Fig. 4 Driving Records
Courbes des enfoncements

(*a*) Driving Records of Displacement Piles in Site 2, the Friction Pile Site
Courbes des enfoncements des pieux occasionnant un refoulement à l'emplacement 1. Emplacement des pieux à frottement latéral

(*b*) Driving Record of Displacement Piles in Site 1, the End-Bearing Site
Courbes des enfoncements des pieux de l'emplacement 1. Emplacement des pointes de résistance

(*c*) Comparison of Piles of Different Types Placed by Driving Only in Deep Loess
Comparaison de pieux de types divers enfoncés dans une couche profonde de loess

solidation of surrounding soil was obtained. Whereas, a pile in a dry prebored hole was considered to give the least strength because practically no consolidation was obtained. Pile tests shown later support these opinions.

In Fig. 4*b*, a similar comparison is made for piles placed in Site 1, the end-bearing site, where the loess was relatively shallow. In general the driving resistance in the loess was similar to that of Fig. 4*a*. The important consideration is that all piles which reached the firm Grand Island sand stratum, increased in resistance almost immediately regardless of whether the pile was in a jetted hole, a prebored hole, or in prewetted material. Therefore, it appears that this sand will adequately support piles placed by any of these methods provided they are snugly held in the upper loess for adequate lateral support.

Fig. 4*c* shows the comparison of driving different types of piles, all of which were placed by driving only. The timber pile in prewetted material drove easiest. In dry material, the non-displacement steel-H pile drove easiest; however, the effect of greater clayeyness in the old soil horizon was particularly noticeable. Displacement piles, both timber and Raymond steel shell piles, drove with much difficulty in dry loess and reached refusal values at relatively shallow depths.

Results of Pile Load Tests

Figs. 5*a*, *b*, *c*, and *d* show the results of load tests on various representative piles in deep loess at Site 2, the friction site. Fig. 5*a* shows a load test for a displacement pile, driven in prewetted loess to a depth of 55 feet. This pile was tested in two series of loadings. The second series was carried to complete failure at 170 tons. However, the curve indicates beginning failure at 120 tons. This curve is used as a measure of comparison for the other piles. Fig. 5*b* shows the test of a displacement pile in a jetted hole. The pile was tested before wetting the area and showed similar strength to that of the pile in the prewetted area. However, after the area was wetted, greater movements may be seen and failure at a somewhat lower load was interpreted. Fig. 5*c* shows the test of a displacement pile in a prebored hole. Although the strength of this pile was fair under dry conditions with an indication of beginning failure at 60 tons, the pile was considerably weaker when the area was wetted. The test indicates great movement under very light loads, particularly when compared to the pile in the prewetted area. Fig. 5*d* shows a test for a pile placed by hard driving to only a shallow depth in dry loess. This pile showed high strength with only slight movement under dry conditions but, after wetting the area, complete failure was obtained under only 60 tons.

Load tests in Site 1, the end-bearing site, were all of high strength, indicating that firm bearing on the sand was entirely satisfactory for all placement methods. Nondisplacement steel-H piles in this area were found to be satisfactory, when embedded 5 feet into the bearing sand. Since it was possible to drive steel-H piles in dry loess and not displacement piles, a nondisplacement pile was considered the only type which was practical to place in dry loess by driving only.

Conclusions

(1) Friction piles in deep loess had considerable difference in load-carrying capacity depending on their placement method.

(*a*) For displacement piles in loess prewetting the soil is recommended since highest strength will be obtained as a result of maximum consolidation of surrounding material.

(*b*) Placing displacement piles in jetted holes may be possible in certain instances since a relatively small hole may be made and some wetting of the hole is obtained from the jet water.

(*c*) Placing displacement piles in dry prebored holes in dry loess is not recommended since practically no consolidation of surrounding material is obtained and considerable weakening of the loess can be expected after wetting the soil.

(*d*) Displacement piles placed by driving alone in dry loess are not recommended since driving is extremely difficult and adequate penetration cannot be obtained.

(2) Nondisplacement steel-H piles can be driven in dry loess, but adequate embedment in permanently firm material is necessary since shearing resistance in loose wetted loess is quite low.

(3) End-bearing piles resting on firm bearing material such as dense sand were found to be quite satisfactory regardless of placement method providing they are snugly held for adequate lateral support.

(4) Both types of displacement piles, timber and Raymond, had similar driving and pile-soil loading characteristics. The strength requirements of the pile itself would mainly govern which pile would be desirable.

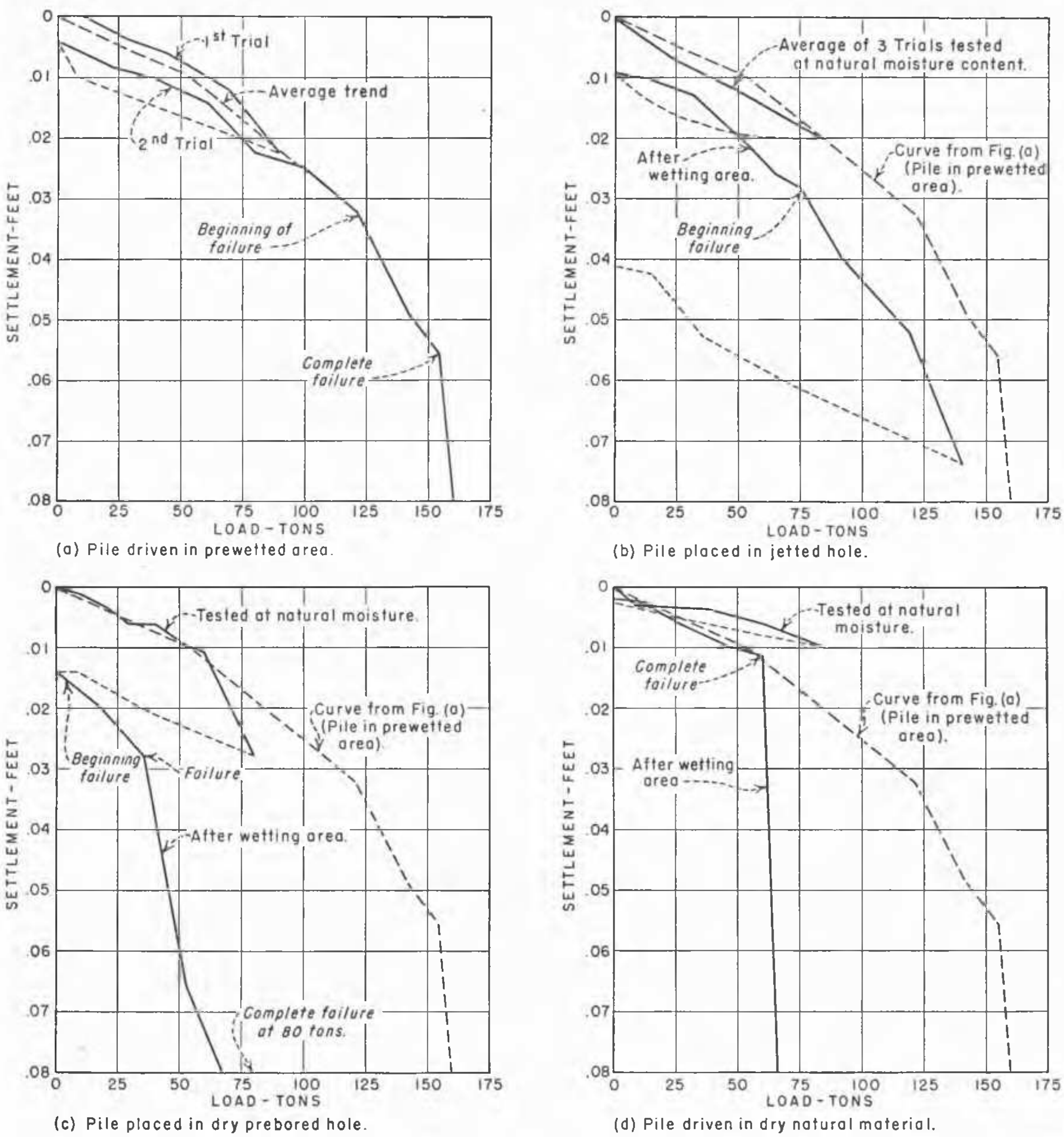


Fig. 5 Comparison of Pile Loads Tests for Friction Piles in Loess
Comparaison d'essais de charge portante pour pieux à résistance latérale enfoncés dans du loess

(*a*) Pile Driven in Prewetted Area
Pieu enfoncé dans un sol humide

(*b*) Pile Placed in Jetted Hole
Pieu placé dans un trou fait par injection d'eau

(*c*) Pile Placed in Dry Prebored Hole
Pieu placé dans un trou foré à sec au préalable

(*d*) Pile Driven in Dry Natural Material
Pieu enfoncé dans un sol sec

(5) For piles placed in loess and assuming material underlying a pile foundation is competent, the following rules are recommended:

(*a*) When loess is at densities below 80 lbs. per cu.ft., piles must have firm end-bearing or a substantial amount of embedment of the ends in dense material of permanently high shearing resistance.

(*b*) When loess is at densities from 80 to 90 lbs. per cu. ft., friction piles will generally be satisfactorily supported purely by adequate embedment in the loess, based on wetted conditions.

(*c*) When loess is at densities greater than 90 lbs. per cu.ft., ordinary structures may be supported without piles, and, if piles are found necessary for critical structures, relatively short lengths may be used.

Acknowledgments

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References

BOR (1951): Report of Loess Research Studies for the Ashton Pile Testing Program, Nebraska. Earth Laboratory Report No. EM-278, Bureau of Reclamation, Engineering Laboratories Branch, Denver, Colorado. December.

Holtz, W. G. and *Gibbs, H. J.* (1951): Consolidation and Related Properties of Loessial Soils. Symposium on Consolidation Testing of Soils, American Society for Testing Materials.