ALLEGED DAMAGE TO THE RESIDENCE OF S. D. FRALICK DUE TO TRAFFIC INDUCED VIBRATIONS

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MICHIGAN HIGHWAY RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

ALLEGED DAMAGE TO THE RESIDENCE OF S. D. FRALICK DUE TO TRAFFIC INDUCED VIBRATIONS

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This report covers the results of an investigation concerning alleged vibration damage to S. D. Fralick's residence at 422 East State Street (US 23) in Cheboygan. On several previous occasions Mr. Fralick has indicated to the Department that he believes the house was damaged as a result of vibrations caused by truck traffic on the highway.

Background Information

Mr. Fralick rebuilt the front portion of his house during the summer of 1961. A local engineering consultant designed the footings, which were placed as specified, along with new basement walls and brick veneer.

In August 1962, there was a pavement disruption in front of the house. Heavy trucking over the faulted pavement reportedly caused considerable vibration of the house. Mr. Fralick reported that at about this time, footings and walls began to crack. The City of Cheboygan made surface repairs in the area which relieved the problem for about two months. However, on December 5, 1962, Mr. Fralick reported to the District Office that the vibrations were very noticeable again, and getting worse. He also reported a settlement of one portion of the house.

A field inspection was conducted by the Soils Section on December 19, 1962, which revealed, "A general geological problem in the immediate area of Mr. Fralick's residence as well as throughout the entire City of Cheboygan. This poor subsoil condition does make it most difficult to design or construct either highway or residential structures. This difficulty is due largely to the presence of a deep lacustrine deposit of plastic calcareous clay. This type of material is poorly drained and is usually wet." The District Construction Engineer recommended repair and resurfacing in the area.

In 1963 the settled portion of the highway in front of Mr. Fralick's house was removed and replaced with concrete base course, and the entire street was resurfaced. The repairs evidently alleviated the problem, and there was no complaint from Mr. Fralick until December 1970. At this time he informed the District Office of the recurrence of vibration in his house. District personnel inspected the pavement and found no obvious settlement or bump that might cause the house to vibrate. The problem was referred to the Assistant Deputy Director, who requested that vibration measurements be made at the site. Mr. Fralick was contacted and advised that a vibration survey would be made at the site, and it was agreed that such measurements should not be made until the spring thaw removed frost from the ground.

Damage

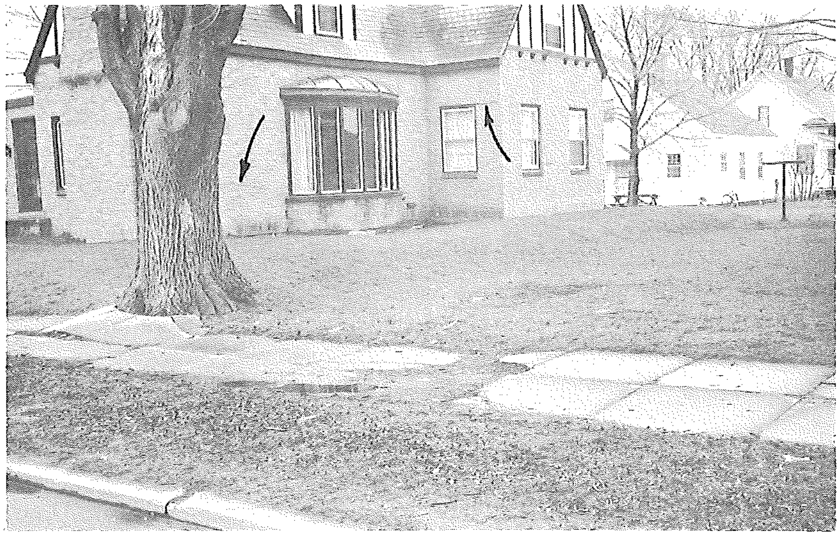
The Fralick house has been severely damaged by differential settlement. In general, the north corner of the house, including the fireplace, has settled and rotated away from the remainder of the building. Figure 1 gives an indication of the condition of the exterior of the house. Interior walls show similar cracking. The basement floor is cracked and faulted (Fig. 2). The soil problem is illustrated to some extent by the condition of the sidewalk immediately north of the house (Fig. 3).

It also was noted that a large brick school situated directly across the street from the Fralick house, and nearly the same distance from the street, shows no signs of serious structural failure and has obviously been there for many years.

Vibration Measurements

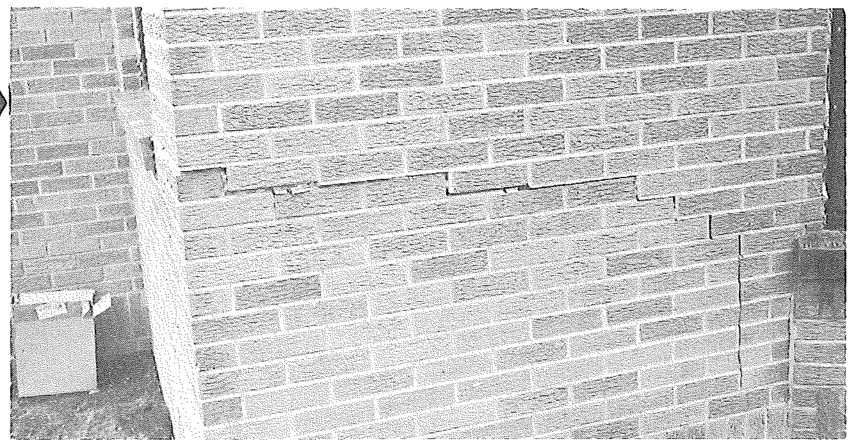
Vibration measurements were made at the site on May 12, 1971. Two 2-1/2 g accelerometers were used to measure vertical and horizontal accelerations simultaneously. The accelerometers were mounted on a steel stake driven into the ground. Output from the accelerometers was recorded on a two-channel oscillograph. A general plan of the site, and test locations, are shown in Figure 2. Test runs were made with the Research Laboratory's two-axle truck, which has a gross vehicle weight of about 30,000 lb. Vibrations caused by a few commercial vehicles were recorded as well. Two-inch impact boards were also traversed by the test vehicle to simulate faulted pavement.

Initial tests were made with both accelerometers attached to the stake at location ① , (Fig. 2) and similar tests were conducted at location ② . Then one accelerometer was attached to the porch adjacent to location ② , to check whether the structure and ground were indeed reacting in the same manner. Results indicated that they were. The last eight test runs were made with the accelerometers at location ③ near the corner of the large brick school building across the street from the Fralick house. Results of the tests are shown in Table 1. In addition it was found that a man walking across the yard 8 ft away from the accelerometer caused readings of about 0.02 g. A man walking near the instruments caused readings of 0.06 g, and by jumping lightly on the ground, a man could generate 0.07 to 0.10 g output.

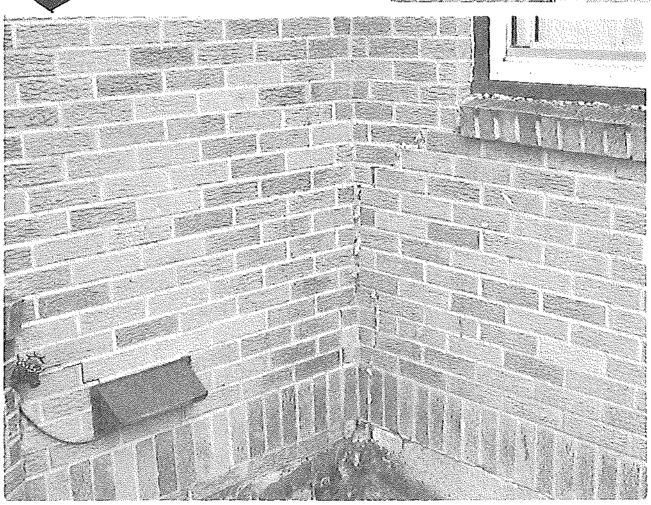


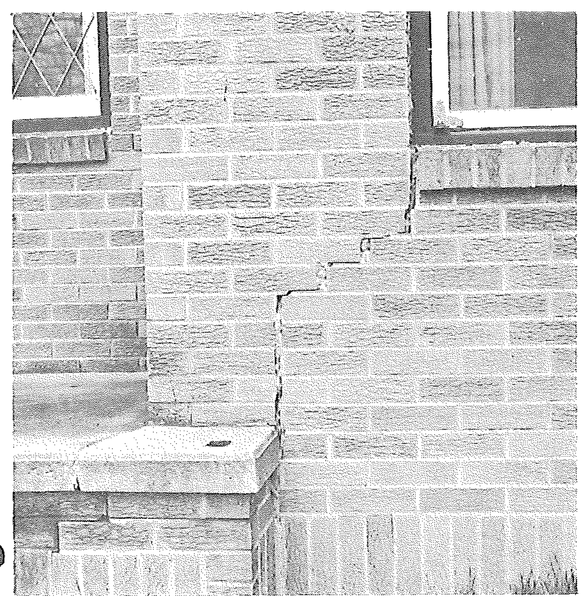
General view showing some major fractures

Fracture of brick veneer, north corner.



Failure of brick veneer, northwest side.





Failure of front wall and porch.

Figure 1. Views of damage exterior of Fralick residence.

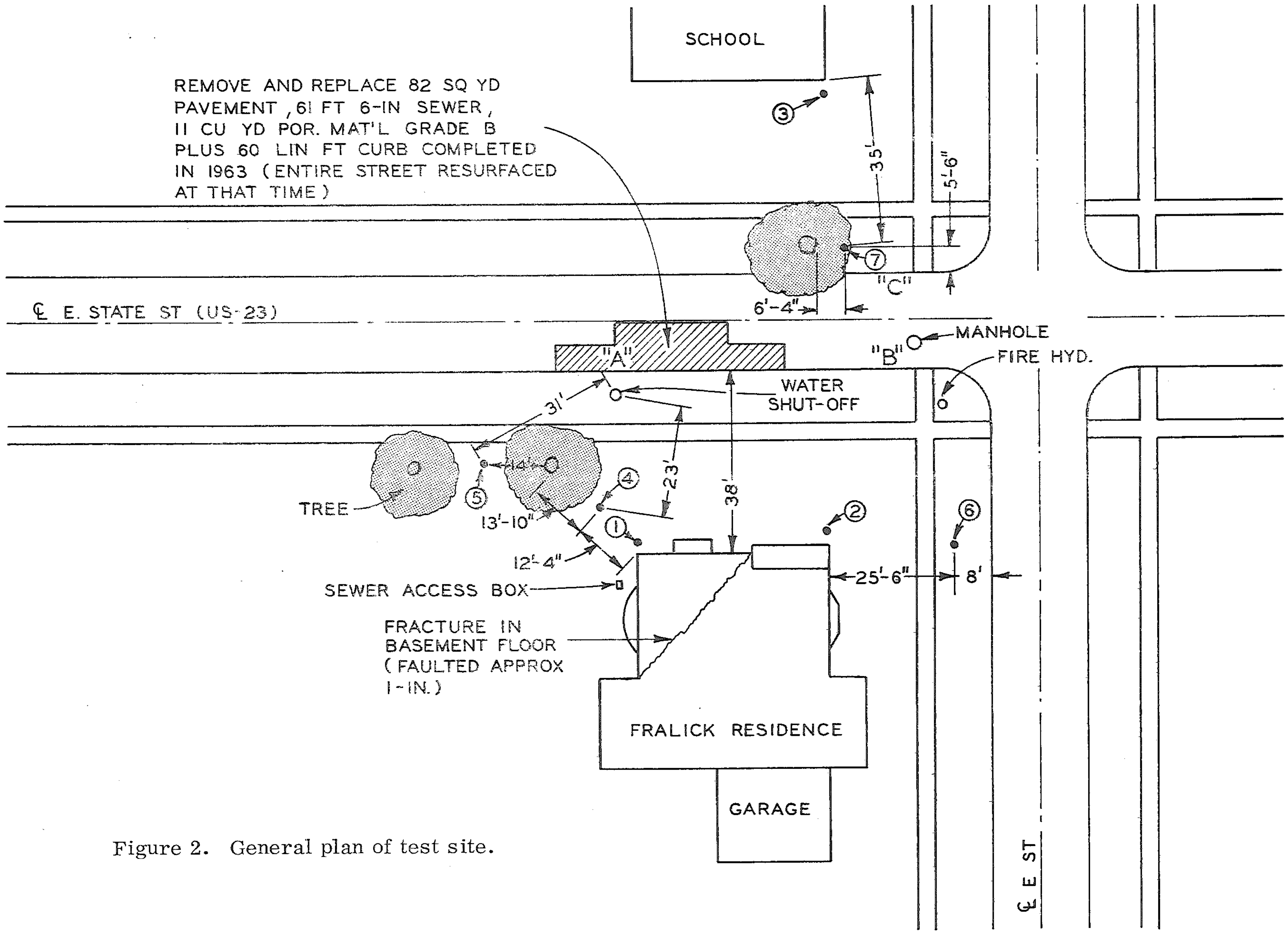


Figure 2. General plan of test site.

TABLE I
Results of Acceleration Measurements at Fralick House

Run	Truck	Direction of Travel	Lane	Approx Speed, mph	Impact Boards (2 - in.)			Acceleration Location	Maximum Recorded Acceleration	
					Yes	No	Location		Horizontal	Vertical
1	MDSH	SE	I	30		X		1	0.04*	0.01
2	MDSH	NW	I	30		X		1	0.01	0.00
3	MDSH	SE	I	30		X		1	0.04*	0.01
4	MDSH	NW	I	30		X		1	0.00	--
5	MDSH	SE	O	30		X		1	0.05*	0.01
6	MDSH	NW	I	30		X		1	0.00	0.00
7	MDSH	SE	O	10	X		A	1	0.01	0.01
8	MDSH	SE	O	10	X		A	1	0.01	0.01
9	MDSH	SE	O	10	X		A	1	0.02	0.01
10	Tanker	SE	I	25		X		1	0.01	0.00
11	MDSH	SE	O	10	X		B	1	0.01	0.01
12	MDSH	SE	O	10	X		B	1	0.01	0.01
13	MDSH	SE	O	10	X		B	1	0.01	0.01
14	MDSH	SE	O	30		X		2	0.01	0.00
15	MDSH	NW	I	30		X		2	0.00	0.00
16	MDSH	SE	O	30		X		2	0.01	0.00
17	MDSH	SE	I	30		X		2	0.00	0.00
18	MDSH	SE	O	10	X		B	2	0.01	0.01
19	MDSH	SE	O	10	X		B	2	0.01	0.01
20	MDSH	SE	O	10	X		B	2	0.01	0.01
21	Tanker	SE	I	20		X		2	0.00	0.00
22	MDSH	SE	O	10	X		B	2	0.01	0.01
23	MDSH	SE	O	10	X		B	2	0.01	0.01
24	MDSH	SE	O	10	X		B	2	0.01	0.01
25	Tanker	SE	I	40		X		2	0.01	0.00
26	MDSH	NW	I	30		X		3	0.00	0.00
27	MDSH	SE	I	30		X		3	0.01	0.00
28	MDSH	NW	I	30		X		3	0.01	0.00
29	MDSH	SE	I	30		X		3	0.01	0.00
30	MDSH	NW	O	10	X		C	3	0.01	0.01
31	MDSH	NW	O	10	X		C	3	0.01	0.01
32	MDSH	NW	O	10	X		C	3	0.01	0.01
33	MDSH	NW	O	20	X		C	3	0.01	0.01

* Maximum value occurred when truck had passed by the accelerometer location, and approached the vicinity of the manhole near the intersection of E St.

Since the sewer and water inlets to the house apparently are not far from accelerometer location (1) , the higher values recorded in runs 1, 3, and 5 suggest the possibility of vibration transmission to the property by these connections, or by the action of the manhole structure on a given layer of soil. Mr. Fralick had reported previously that vibration was most noticeable when trucks passed a position that is near the manhole.

The response generated by the test truck traversing the impact boards was not significantly different at any of the locations, nor were the values unusually high when compared to results of previous tests at other test sites.

To interpret the results of the vibrations testing, reference is made to chapter 50 of Harris and Creede (1). "Early tests indicated that for typical small dwelling units, a peak acceleration of 0.1 g corresponded to a caution limit which might mark the beginning of minor plaster cracking, etc., and that 1 g was a limit above which significant structural damage could be expected."

Langefors in Sweden, Edwards in Canada, and Bumines in this country have made experiments correlating peak particle velocity in the earth with damage to structures. Their results agree very closely with one another, and are in general agreement with the acceleration criteria of Harris and Creede.

Comparison of the tabulated acceleration values with the limiting values from Harris and Creede, shows that the vibrations present at the site are far below the amount required to directly cause the severe structural damage evident at the site. This is as expected, since it is obvious that the problem is one of differential settlement.

Soils Investigation

Inspection of the Fralick property, consideration of the vibration data, and the localized pavement failure, seemed to indicate that there was considerable variability in the soil conditions in the immediate vicinity of the house.

Figure 1 shows that the surface of the ground along the northwest side of the house has subsided. It also shows that the house has no eaves trough, so that water from the roof would be dropped into the depression adjacent to the house. Although the backfill reportedly was granular, and the footings drained, it would seem that excess water in soil of the type at the site could be a constant source of trouble. Figures 1 and 3 show the area of sidewalk

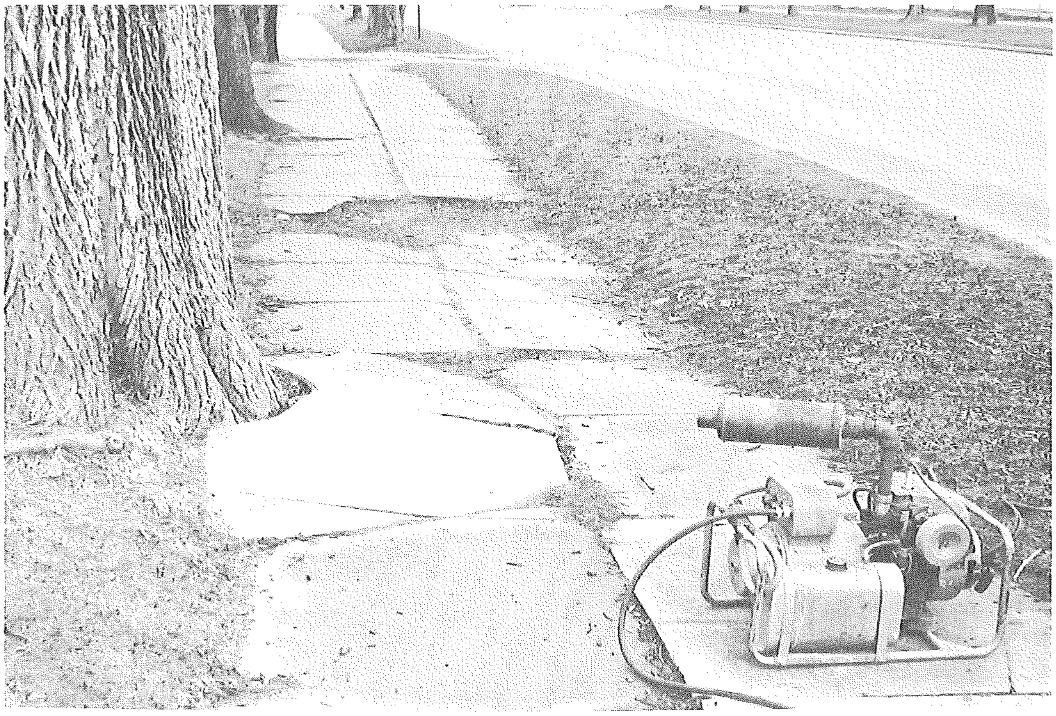


Figure 3. Sidewalk settlement immediately north of house.

that has subsided, immediately north of the house. For these reasons, a request was made to the Laboratory's Soils Unit for a limited sampling of the soil around the house, and also near the school across the street.

Soil borings were made at locations marked ④ through ⑦ in Figure 2. A penetration record was kept for all test borings to a depth lower than the foundation level. Continuous samples were recovered from borings at locations ④ , ⑤ , and ⑥ on the Fralick's property. A Sprague-Henwood type sampler was used to conduct the penetration test and to recover 1-in. diameter, relatively undisturbed samples. A penetration record in terms of number of blows per foot[1], soil profile, and moisture content for the borings at locations ④ , ⑤ , and ⑥ are shown in Figures 4, 5, and 6, respectively. A penetration record and soil profile for boring ⑦ are shown in Figure 7. In general, the blow counts do not indicate a stronger soil condition at the school. The soil profile in the vicinity of the house consists of 2 ft of sandy top soil and 5 ft of soft red silty clay over red plastic clay. The penetration record indicates non-homogenous subsoil with varied strength in different locations of the site. The ground water table was estimated to be located at a depth of 4 to 5 ft.

(1) 40 lb weight and 24-in. drop.

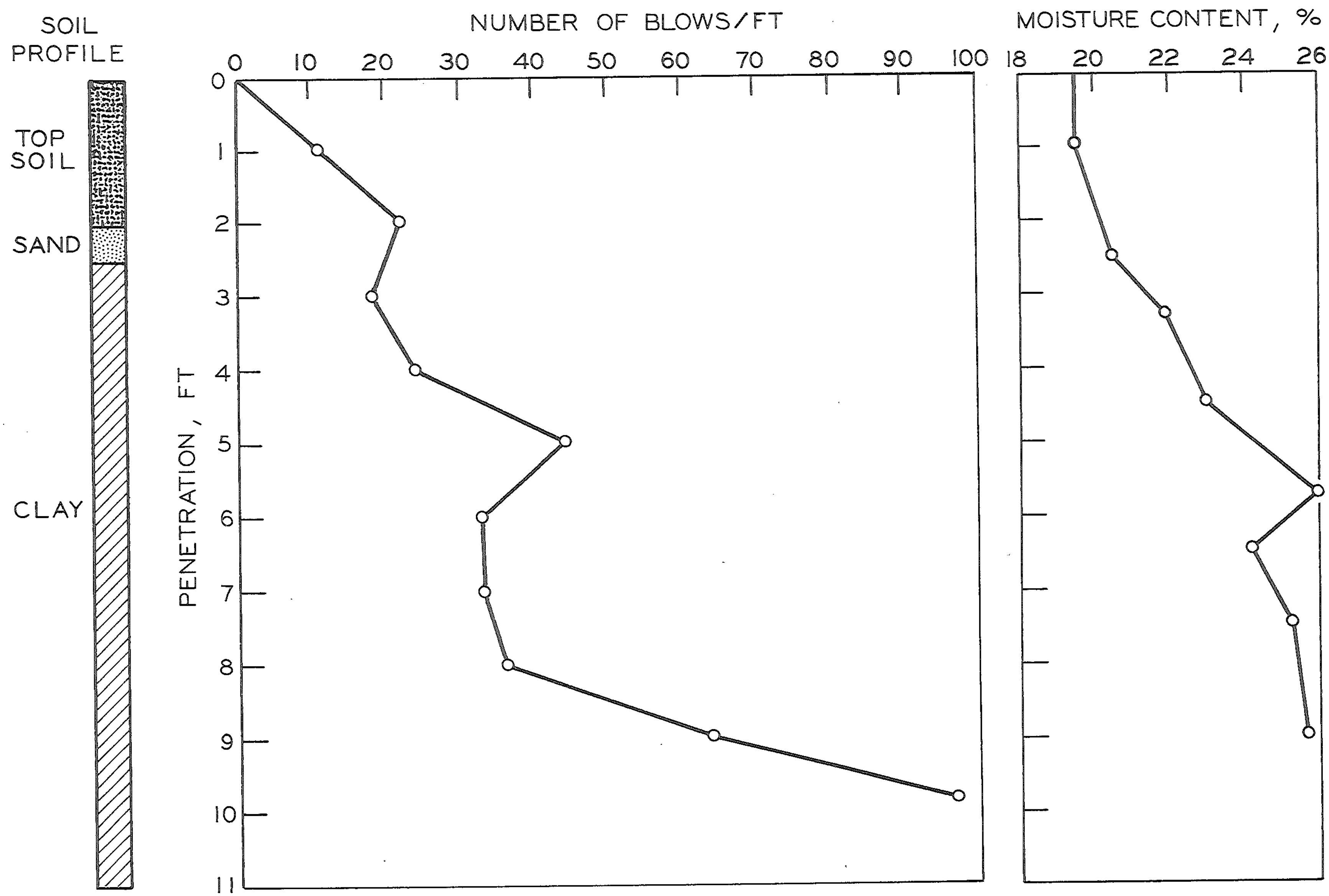


Figure 4. Penetration of point (4).

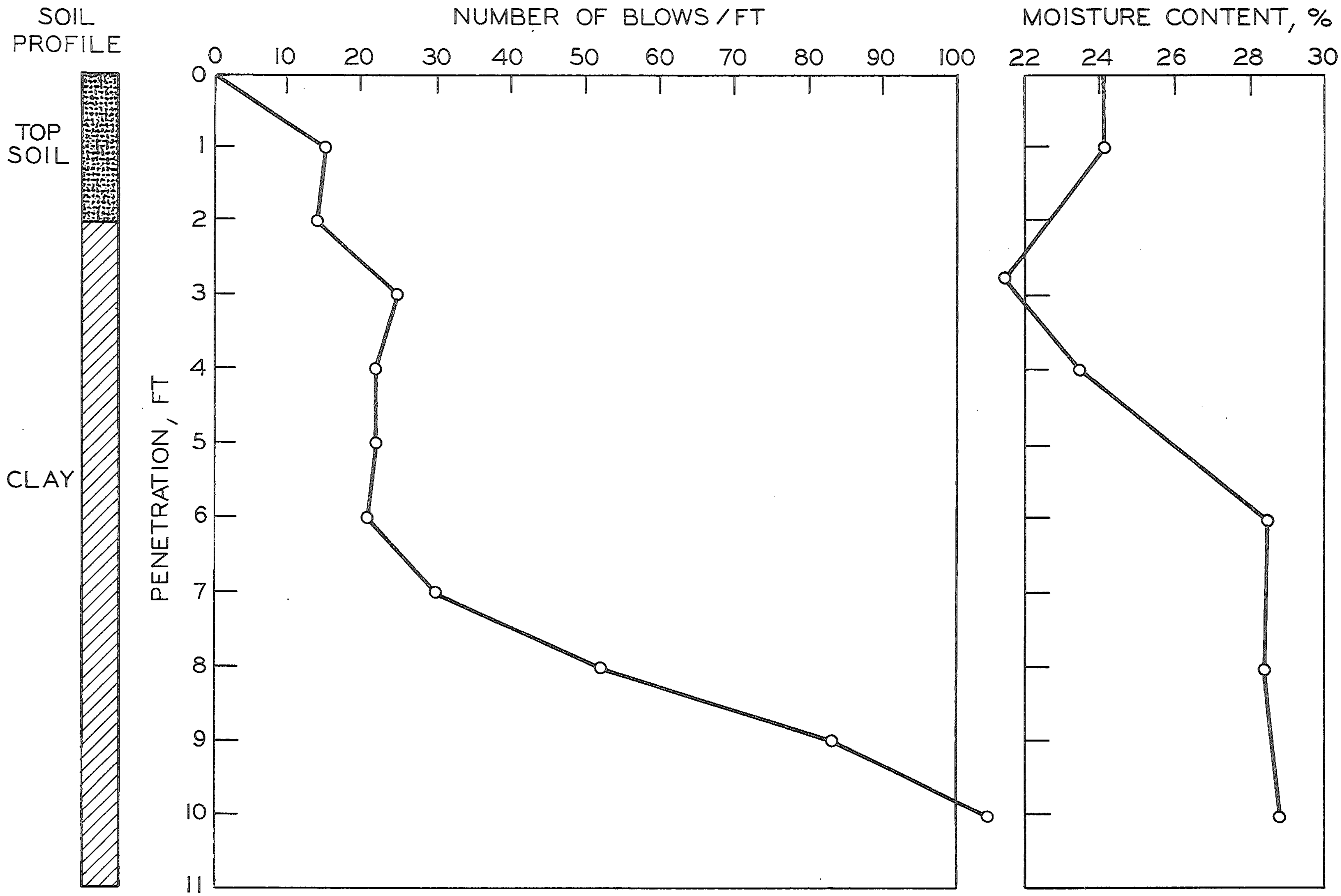


Figure 5. Penetration of point (5) .

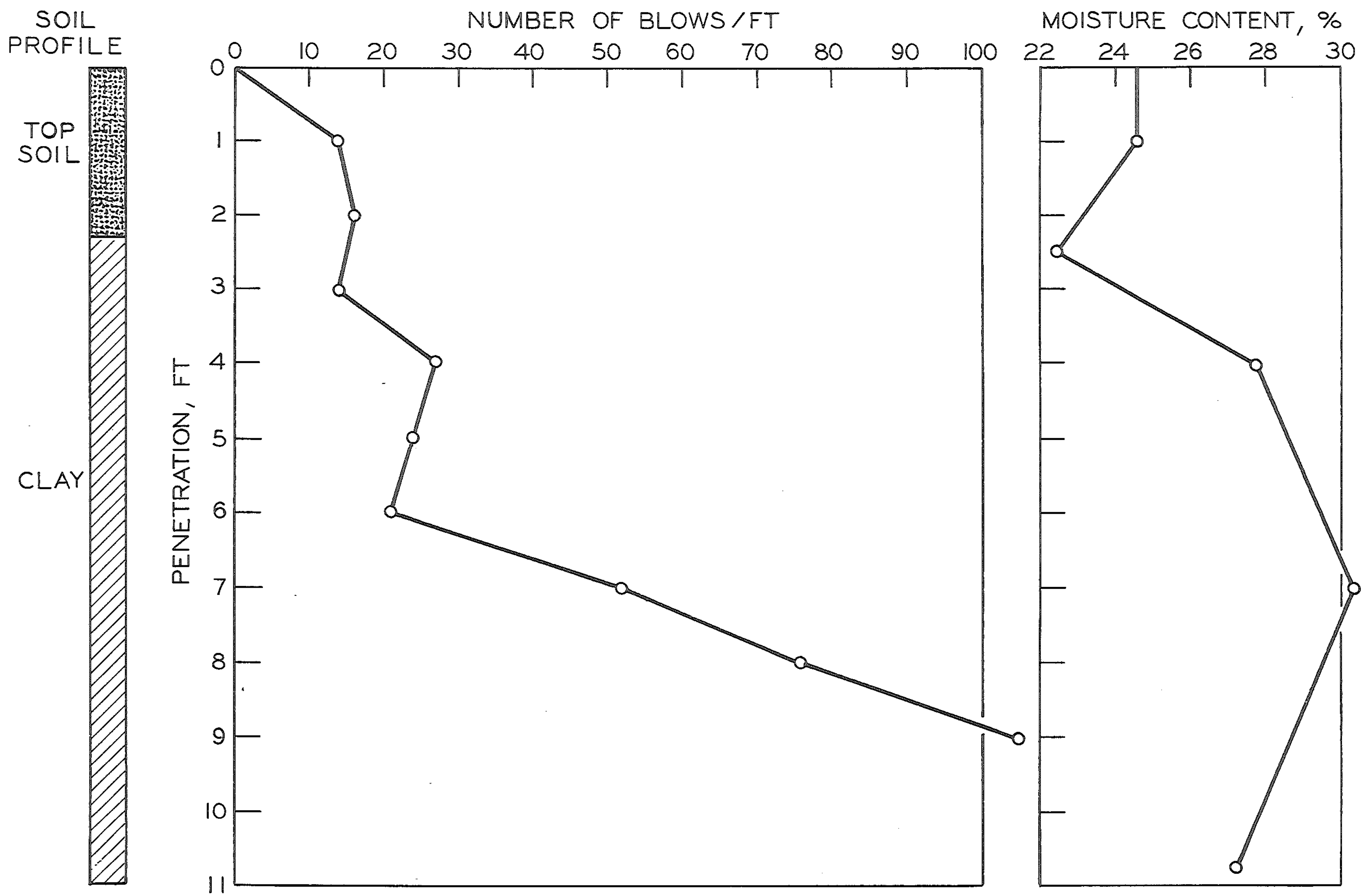


Figure 6. Penetration of point (6).

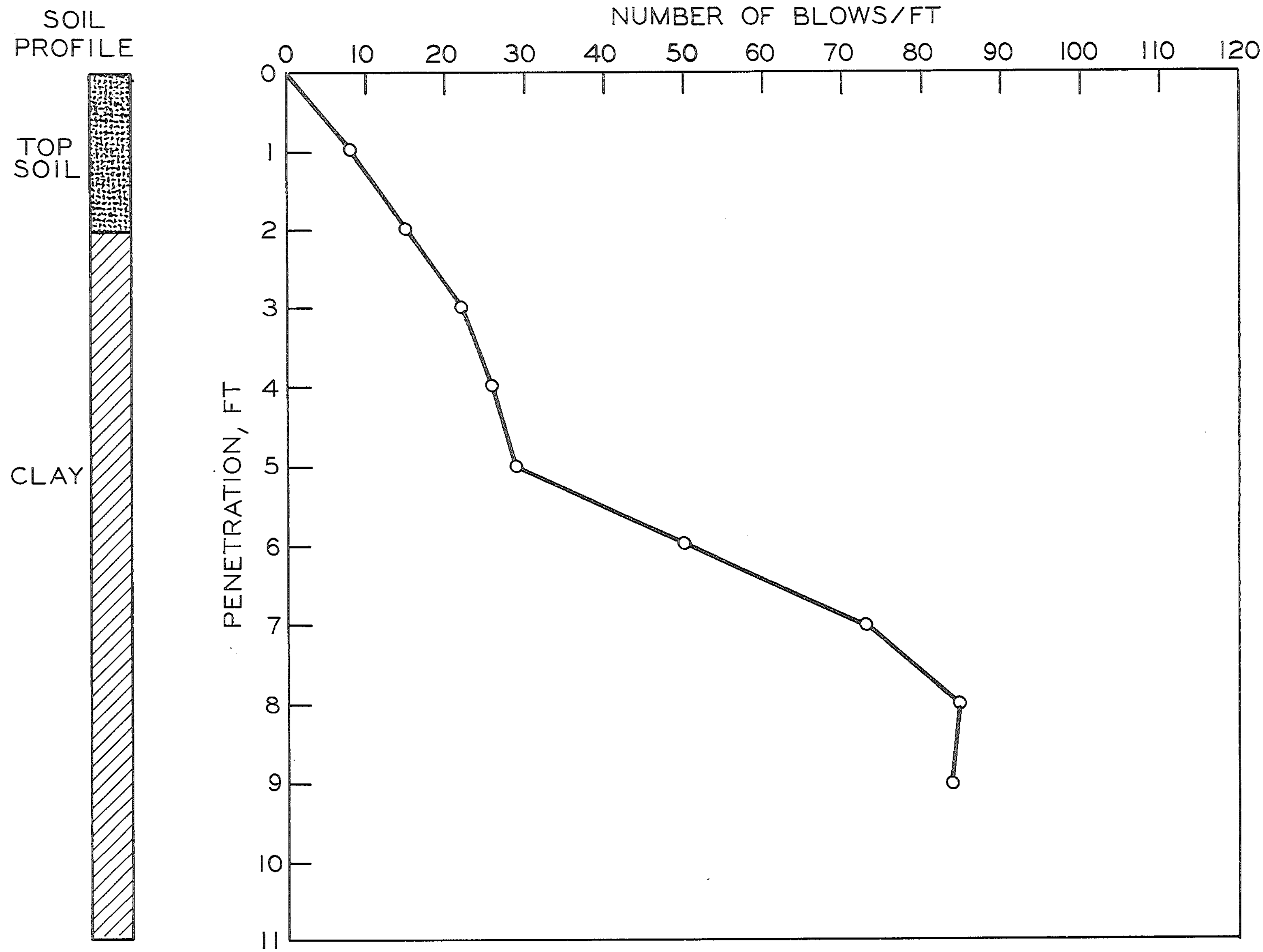


Figure 7. Penetration of point (7).

Atterberg Limits—liquid limit (LL), plastic limit (PL) and plasticity index (PI)—were measured for samples obtained at depths of 5 ft and 10 ft from borings ④ , ⑤ , and ⑥ . These values, along with a moisture content profile, are shown in Figure 8. The reported values of Atterberg limits would classify the soil as an inorganic plastic clay. The water content in the borings ranged between 20 and 30 percent.

Unconfined compression tests were conducted on samples 1-in. in diameter and 2-1/2-in. long, obtained at depths of 5 ft and 10 ft from each boring taken on the Fralick property. Shear strength values measured by these tests are listed in Table 2. Two unconfined compression tests were conducted on remolded samples to determine the sensitivity of the clay. The results of the unconfined compression tests exhibit a considerable difference in shear strength of the clay samples from borings ④ through ⑥ . This difference is an indication of the non-homogeneity of the soil medium. The ratio of the strength of the undisturbed samples to the strength of the remolded samples was above four, thus indicating a very sensitive clay. Sensitive clays lose a large portion of their inherent strength upon remolding.

TABLE 2
SHEAR STRENGTH OF SAMPLES

Sample Number	Depth of Sample, ft	Dry Density, PCF	Water Content, percent	Shear Strength, PSF		Sensitivity
				Original	Remolded	
4-1	5	101.09	23.91	3,649	857	4.3
4-2	10	103.58	24.51	3,945		
5-1	5	101.71	24.85	3,394	703	4.8
5-2	10	102.96	27.42	2,777		
6-1	5	101.71	26.17	1,397		
6-2	10	99.22	28.70	1,381		

In general, the soil investigations conducted in this study are considered elementary. More precise testing techniques were not considered, due to the lack of better soil sampling equipment in the Laboratory. This investigation indicates an undesirable soil condition at this site, which consists of a thick deposit of marine clay with varied degree of softness. Due to the fact that the clay is soft and sensitive, any excavation, remolding, change in stresses (changing of surcharge or lateral support), or variation in drainage pattern could result in significant changes in the strength and deformation characteristics of the soil.

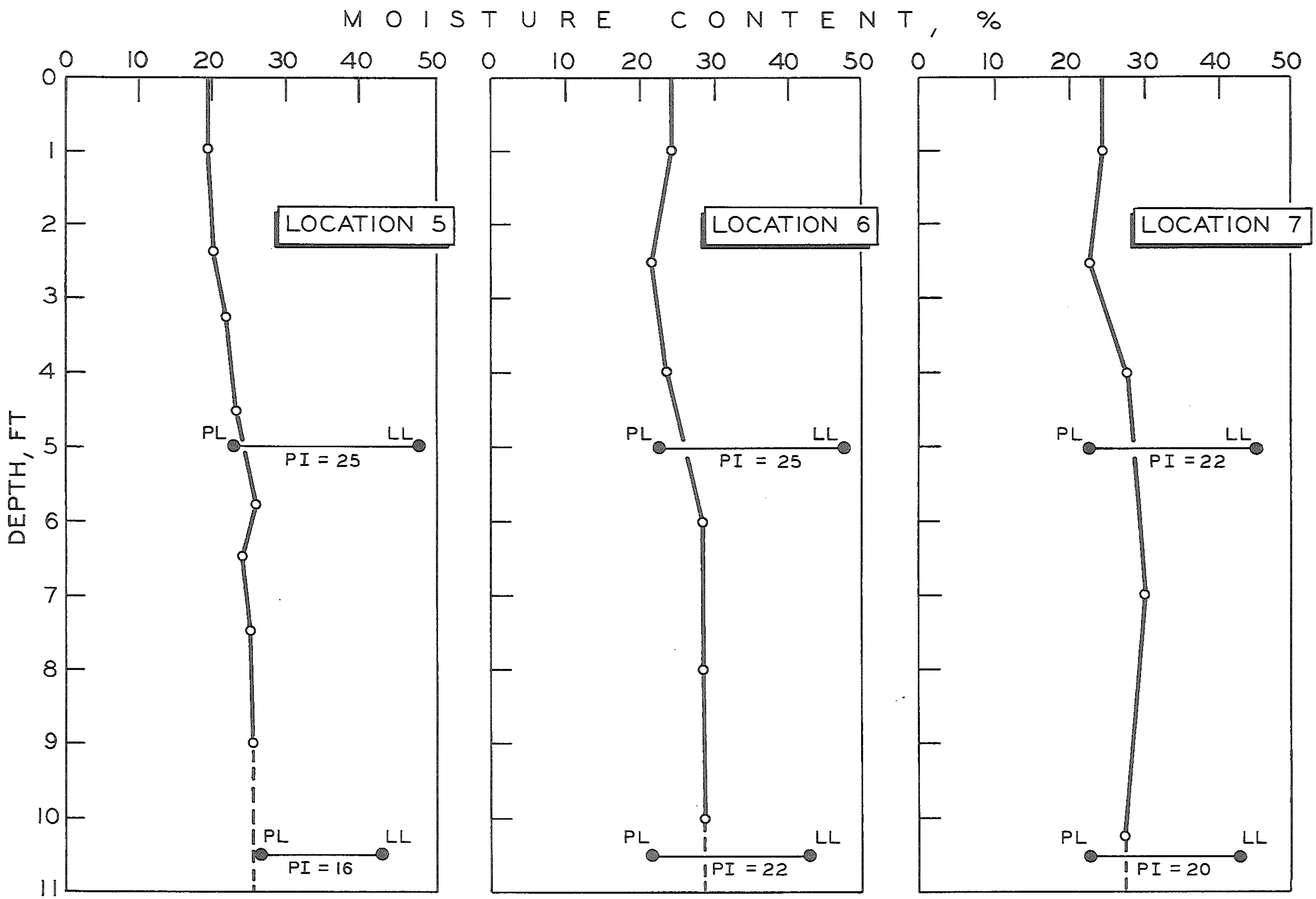


Figure 8. Liquid limit, plastic limit, plasticity index, and moisture profile for borings taken on Fralick property.

Discussion

The vibration tests conducted in this study were not extensive, and do not provide complete answers. They do seem to indicate some connection between the manhole structure in the roadway, and the amount of vibration sensed at the house.

The amount of vibration measured is not deemed significant from a structural point of view. However, people are much more sensitive to vibration than is generally realized. Humans can feel vibrations of 0.0001-in. deflection, and motion of 0.001-in. at 20 cycles per second is annoying. Vibratory accelerations are "noticeable" well below 0.01 g; at 0.04 g they are "unpleasant;" and above 0.25 g are classified as "intolerable" at certain frequencies. These factors usually result in expressions of concern from people unwillingly subjected to such vibrations. If this exposure is coupled with building damage, it is very natural for the person to conclude that the damage is the result of the vibration. Regarding the effect of vibration on settlement, two of the foremost authorities in soil mechanics and foundation engineering, Terzaghi and Peck (2), offered the following statement: "Any structure founded on cohesionless soil is likely to settle excessively if the soil is subject to vibrations from such sources as moving machinery, traffic, pile driving, blasting, or earthquakes. On the other hand, the settlement caused by vibration of a foundation on clay is usually so small that it is unlikely to cause serious damage under any circumstances." In this case the Fralick's house is located on a thick clay deposit.

The soils tests indicate a local condition that is non-homogeneous, and inherently variable by any or all of several different factors. The intent of this investigation was not to determine the exact failure mechanism that took place and that led to the serious structural problems in question. Neither were the methods or the total effort expended in the study necessarily sufficient to that end. This seems reasonable, since it would not seem to be the Department's responsibility to make such a final determination.

Several possibilities exist as causes of the problem. Some that seem most probable are listed below:

1. The sewer connection runs past the sunken corner of the house. It appears to have been dug to an elevation below the footing. In the soil type involved here, such a disturbance could be serious. It also is possible for such pipes, if leaking, to add water to, or remove soil from, the surrounding area.

2. The excavation and backfilling that accompanied the reconstruction of the front portion of the house, and the added weight of the new foundation, might have changed the original load distribution, therefore changing the stress in the soil under one corner of the structure. This could cause additional settlement in one area of the new foundation while other parts of the structure settle at the original rate.

3. The addition of side drains during the construction of the new foundation may have caused a change in the drainage pattern and lowered the water table in the vicinity of the new portion of the footing. This might have caused an additional settlement under the new foundation as a result of the consolidation due to the lowering of the water table. Changes in water content of the soil and the fluctuation in the water table could cause similar effects. Drainage from the roof and water absorption by the large tree north of the house seem to insure that fluctuations will exist.

Naturally many other possibilities exist.

Conclusions

Only one thing is entirely obvious from the study; namely that the footings have failed to support the house. We cannot conclude that traffic-induced vibrations were the cause of this failure. In summary, it appears that the settlement of the Fralick's house is the inevitable consequence of the unstable and non-homogeneous soils situation in the area and possibly the manipulation of those soils due to reconstruction of the house, as well as probable variations in water content of the soil with time.

REFERENCES

1. Harris and Creed, The Shock and Vibrations Handbook, Vol. 3, McGraw-Hill, New York, 1961.

2. Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, 2nd edition, Wiley, New York, 1967.