ALLEGED DAMAGE TO THE RESIDENCE OF G. McAVON DUE TO TRAFFIC INDUCED VIBRATIONS

MICHIGAN HIGHWAY RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

ALLEGED DAMAGE TO THE RESIDENCE OF G. McAVON DUE TO TRAFFIC INDUCED VIBRATIONS

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Michigan State Highway Commission
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This report covers the results of an investigation concerning alleged vibration damage to the George McAvon residence at 9118 Dixie Highway (M 29) in Fair Haven. Mr. McAvon has notified the Department that his house has been damaged by vibrations resulting from truck traffic over a pavement failure near the front of the house.

Background Information

Mr. McAvon's home reportedly was built over 50 years ago, and was purchased by him within the past five years. He reports that the foundation was in good condition at the time of purchase.

During the summer of 1969, the concrete pavement failed near the front of the house. Complaints from Mr. McAvon and his neighbor evidently resulted in temporary repairs with bituminous materials. However, a bump still existed at the site and further complaints were made. Permanent repairs with poured-in-place concrete were made during September 1971.

Mr. McAvon sent a letter to the Metro District office on September 26, 1971 requesting an inspection of his house. A preliminary inspection was made by the Soils Section, with the engineer's report stating that "... The visible settlement along the front basement floor and wall (100-ft NE of bump) would indicate that there may well be a deeper related soil condition, i.e., a saturated silt or very soft clay. It was noted that the present elevation of Anchor Bay appears to fluctuate above and below the existing basement footing elevation. The lake shore is approximately 150-ft S of the porch front, and the basement drains toward the lake. ... The cracking on the porch deck and the porch foundation walls may be due to frost heaving as evidenced by the shallow soil cover along the footing perimeter (estimated to be 1.0-ft$\pm$). Since both the basement wall and the porch have settled according to the owner, one may have to assume that adverse soil conditions are affecting both situations."

Since the owners complaint involved vibration, it was decided that vibration measurements should be made at the site. A request was sent to the Research Laboratory to schedule the testing, and the owner was advised in a letter of January 5, 1972 that such measurements would be made after the ground had thawed in the spring.

Damage

Damage to the McAvon house consists primarily of differential settlement of the front porch and the foundation for the front wall of the house. The owner reports that the porch roof has pulled away from the house, allowing water to enter the front wall and leak inside the house. The porch wall is cracked in many places, as indicated in Figure 1. The basement wall also is cracked, as shown in Figure 2. Figure 3 shows the front porch steps, and adjacent sidewalk settlements that indicate to some extent the nature of the soil problems that exist. Note that the downspout empties into the area that has subsided.

Vibration Measurements

Vibration measurements were made at the site on June 6, 1972. 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 for some measurements, and clamped to the front porch slab for others. Output from the accelerometers was recorded on a two-channel oscillograph. A general plan of the site, and test locations are shown in Figure 4. Test runs were made with the Research Laboratory's two-axle truck, which has a gross vehicle weight of approximately 30,000 lb and rear axle weight set at the legal load limit of 18,000 lb. Since the pavement defect at the site had been repaired, the bump was simulated by impact boards with ramp height of 2-in. Truck speed over the boards was approximately 25 mph for all runs.

Initial tests were made with the accelerometers attached to the stake at location a, and impact boards at location A (Fig. 4). Impact boards then were moved to B, which is the location of the former pavement bump, and the accelerometers remained at a. Finally, the accelerometers were clamped to the porch slab at b and the impact boards were moved back to A. Results of the tests are shown in Table 1. In addition, the following results were found for comparison with the vehicle-induced vibrations. 1) With the accelerometers mounted on the stake at a; a man walking on the ground 6 ft from the stake caused outputs of 0.003 g, the core sampler being driven at location No. 2 caused 0.002 g, and a 10-lb sledge dropped less than 2 ft at a spot 3 ft away from the stake, caused 0.013 g. 2) With the accelerometers mounted on the porch slab at b; a man walking on the porch caused 0.003 g, a man walking on the ground next to the porch caused 0.002 g, and a man jumping off from the porch, (approximately 3-ft drop), caused 0.011 g.

The response generated by the test vehicle traversing the impact boards was not significantly different at the various locations. The vibration amplitude was slightly lower than measured previously at another site with similar soil conditions. This is to be expected because the McAvon house is set back farther from the roadway than the previous site.

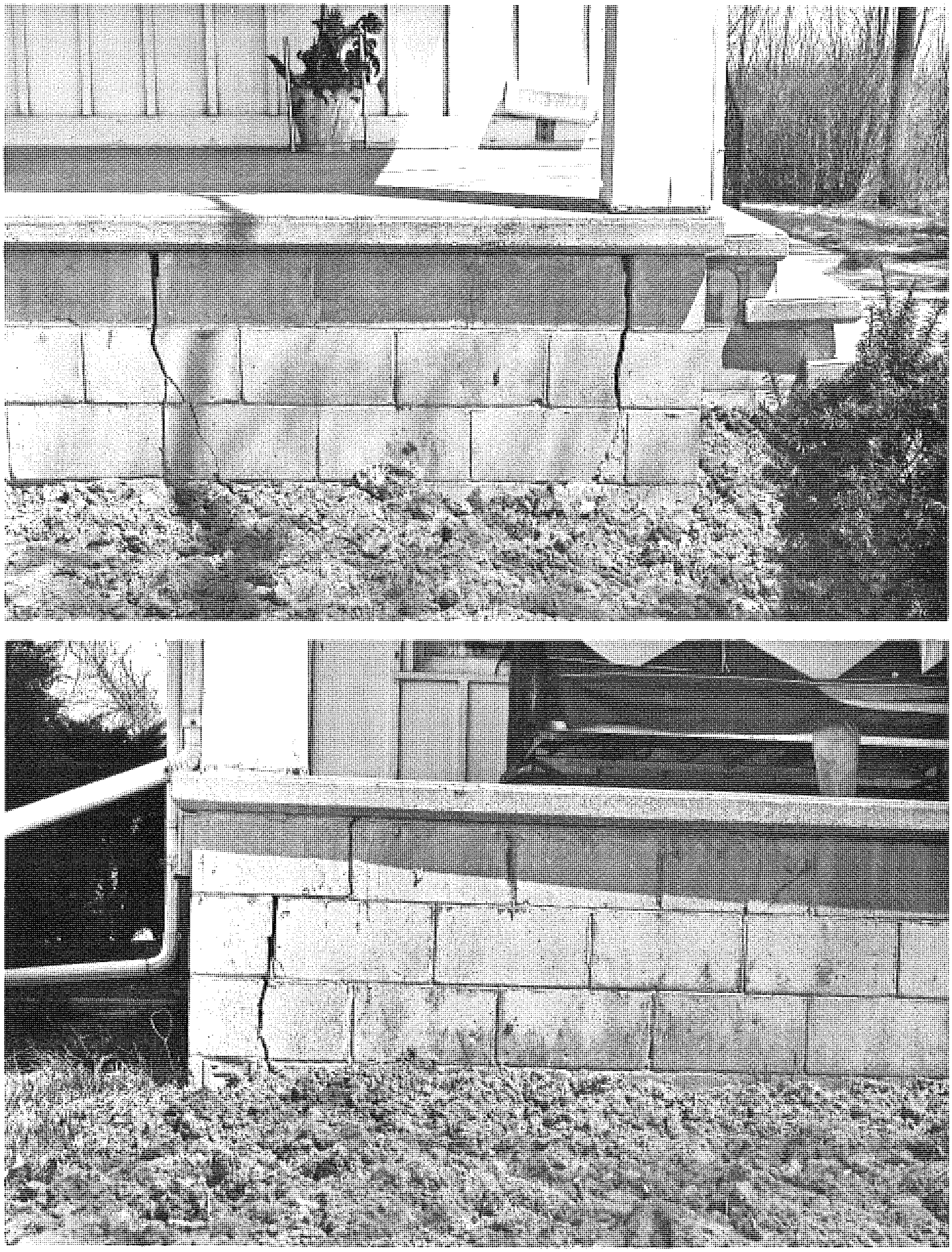
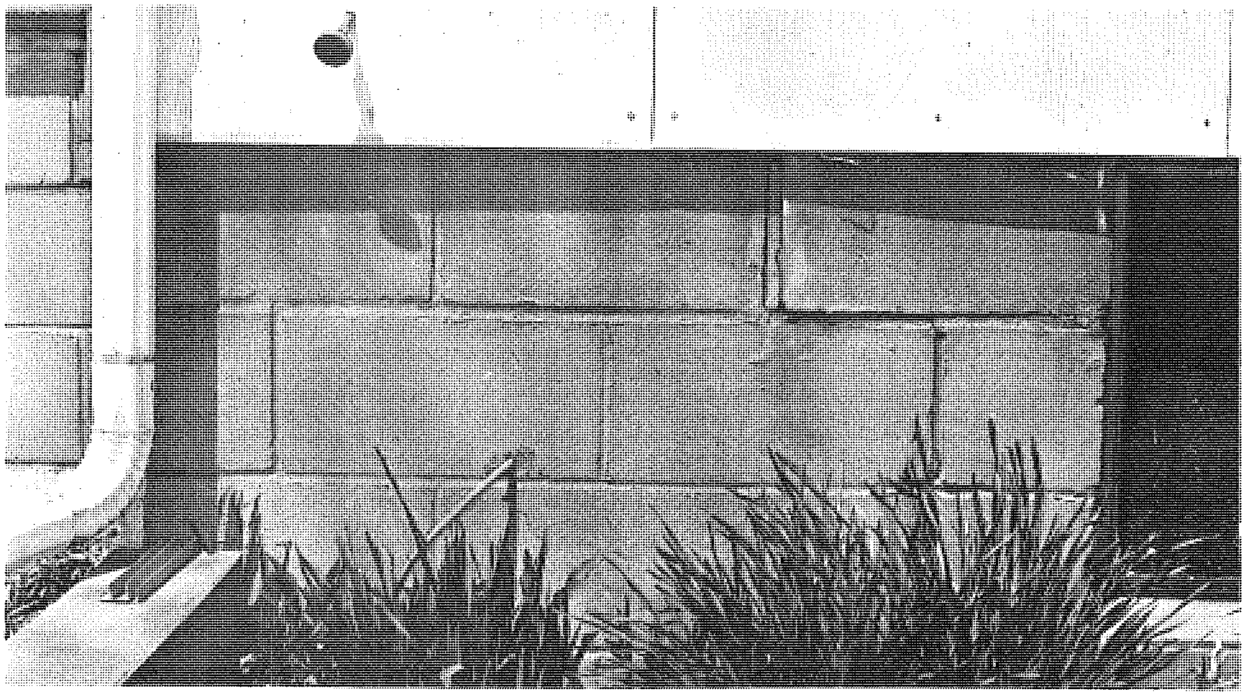
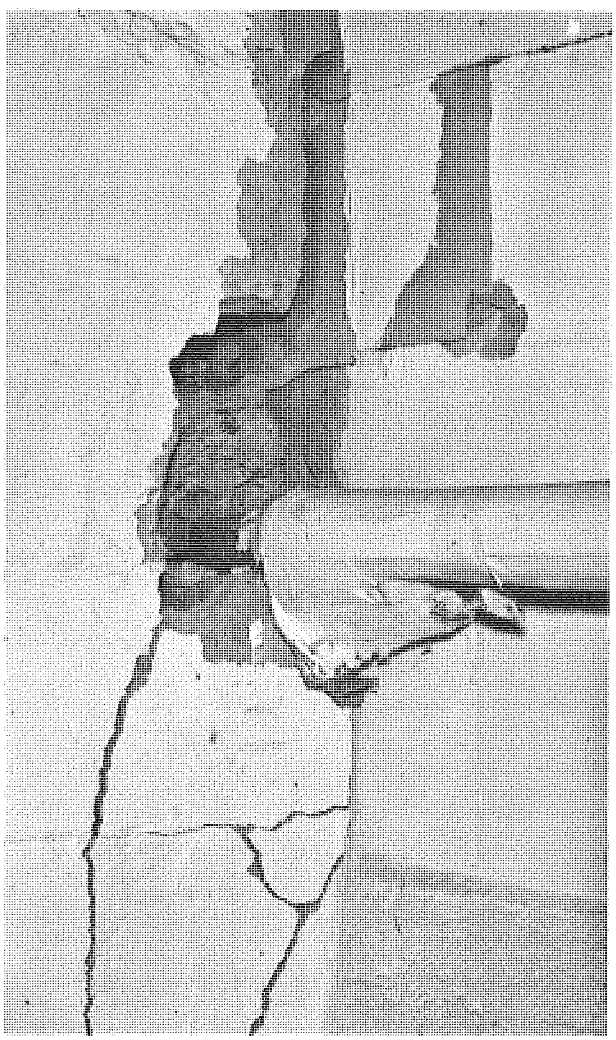


Figure 1. Condition of porch foundation showing cracking at the southeast (upper) and southwest (lower) corners.





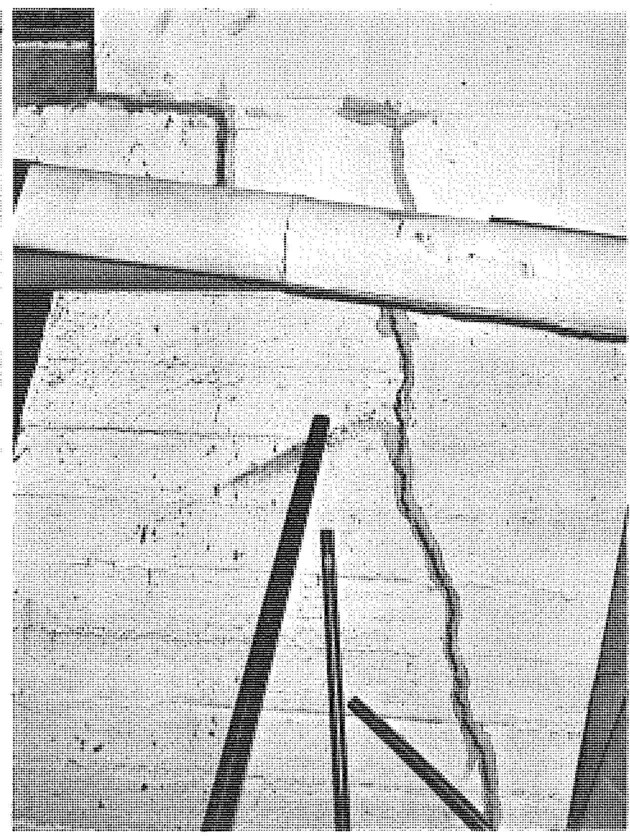


Figure 2. Condition of basement walls showing cracking at the southeast corner (upper, exterior). The center-front (left), and on the west side wall, near the southwest corner (above).

Figure 3. East end of front porch showing settlement of sidewalk and steps.

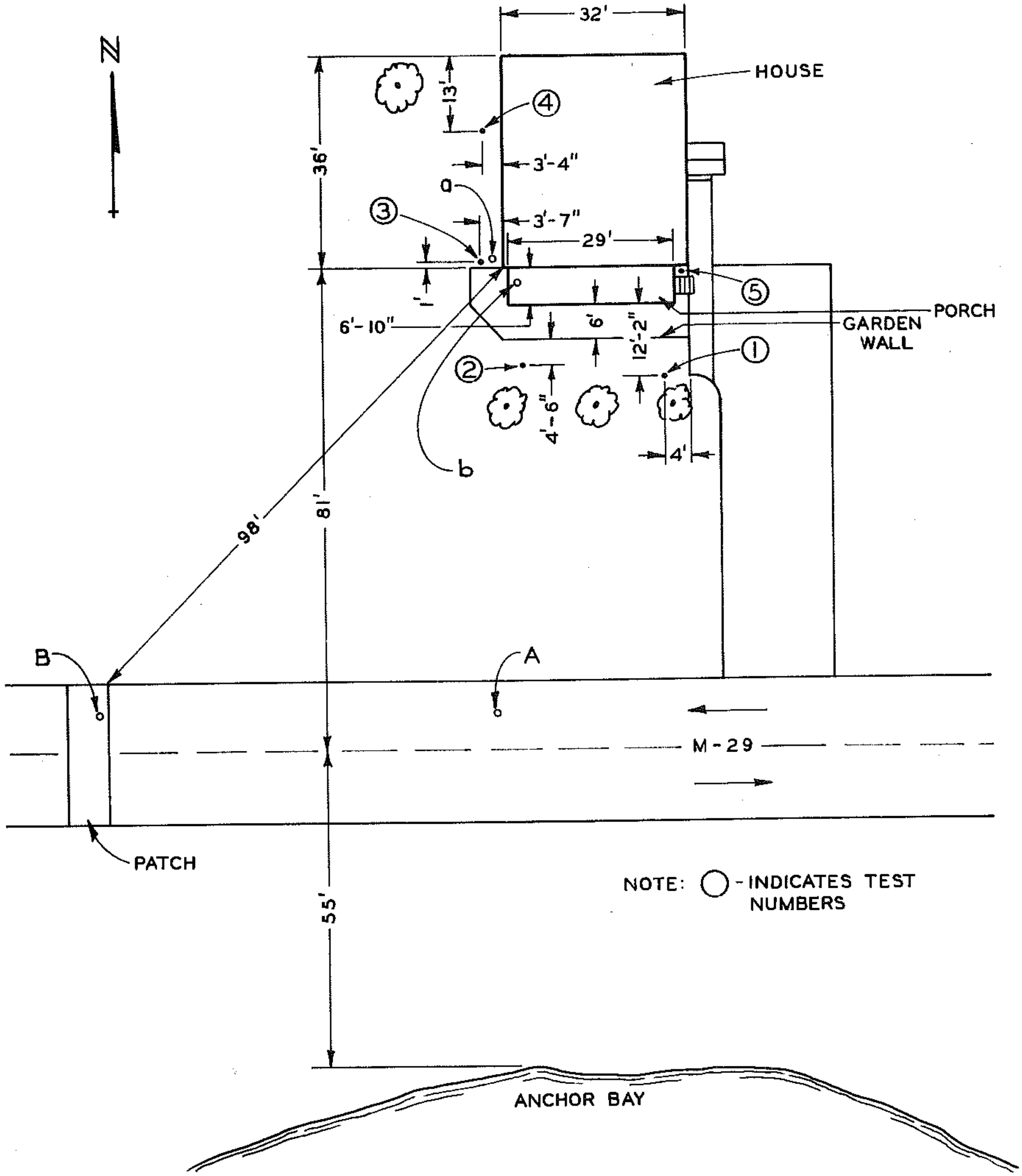


Figure 4. General plan of test site.

TABLE 1
RESULTS OF ACCELERATION MEASUREMENTS
AT MC AVON HOUSE

Run No.	Location of 2-in. "Bump"	Location of Accelerometers	Maximum Recorded Acceleration, g	
			Horizontal	Vertical
1	A	a	0.005	0.009
2	A	a	0.005	0.009
3	A	a	0.004	0.007
4	B	a	0.004	0.007
5	B	a	0.004	0.007
6	B	a	0.004	0.007
7	A	b	0.008	0.007
8	A	b	0.008	0.005
9	A	b	0.009	0.007
	No bump	a or b	0.001	0.001

Reference is made to Chapter 50 of Harris and Crede (1) to provide a basis of comparison for interpreting the results of the tests. "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 & Crede.

Comparison of the tabulated acceleration values obtained in this investigation, with the limiting values from Harris and Crede, shows that the vibrations present at the site are far below the amount required to directly cause the structural damage evident at the site. This is as expected, since this type of damage is characteristic of the foundation failure associated with differential settlement.

Soils Investigation

Inspection of the McAvon house, consideration of the vibration data, and the type of foundation damage seemed to indicate that there is a soils

TABLE 2
SOIL CLASSIFICATIONS

Boring No.	Depth of Sample, ft	L. L.	P. L.	P. I.	Grain Size Distribution, percent			Soil Classification, Unified System
					Sand	Silt	Clay	
1	0-3	42.10	22.90	19.20				(CL) Inorganic clay of
1	3-6	47.40	24.48	22.92				medium plasticity
1	6-9	51.70	28.13	23.57		10	90	(CH) Inorganic clay of high plasticity
1	9-12	49.10	29.37	19.73				(CL) Inorganic clay of medium plasticity
2	0-3	41.47	25.42	16.05				(CL) Inorganic clay of
2	3-6	43.00	23.44	19.56				medium plasticity
2	6-9	46.82	30.39	16.43	2	19.5	78.5	"
2	9-12	47.65	31.95	15.70				"
2	12-15	44.07	28.85	15.22				"
3	0-3	36.40	24.01	12.39				(CL) Inorganic clay of
3	3-6	42.80	26.28	16.52				medium plasticity
3	6-9	38.80	27.42	11.38	1	21	78	"
3	9-12	43.50	25.00	18.50				"
4	0-3	32.80	23.30	9.50				(CL) Inorganic clay of
4	3-6	38.30	22.75	15.55				medium plasticity
4	6-9	45.20	26.88	18.32		30	70	"
4	9-12	49.40	30.71	18.69				"
5	0-3		No Sample					
5	3-6	41.24	24.12	17.12				(CL) Inorganic clay of
5	6-9	47.59	31.06	16.53		21	79	medium plasticity
5	9-12	49.10	30.25	18.85				

problem. A limited soils investigation was conducted to verify this conclusion.

Soil borings were made at locations marked ① through ⑤ in Figure 4. A penetration record was kept for all test borings to a depth lower than the foundation level. Continuous samples were recovered from all borings. A Sprague-Henwood type sampler was used to conduct the sampling operation and recover 1 in. diameter, relatively undisturbed, samples. A penetration record in terms of number of blows per foot[1] for all borings is shown in Figure 5. The penetration record indicates a non-homogenous subsoil with varied resistance at different locations of the site. The ground water table was estimated to be located very close to the foundation's elevation.

[1] 40 lb weight and 24-in. drop (Not a Standard Penetration Test).

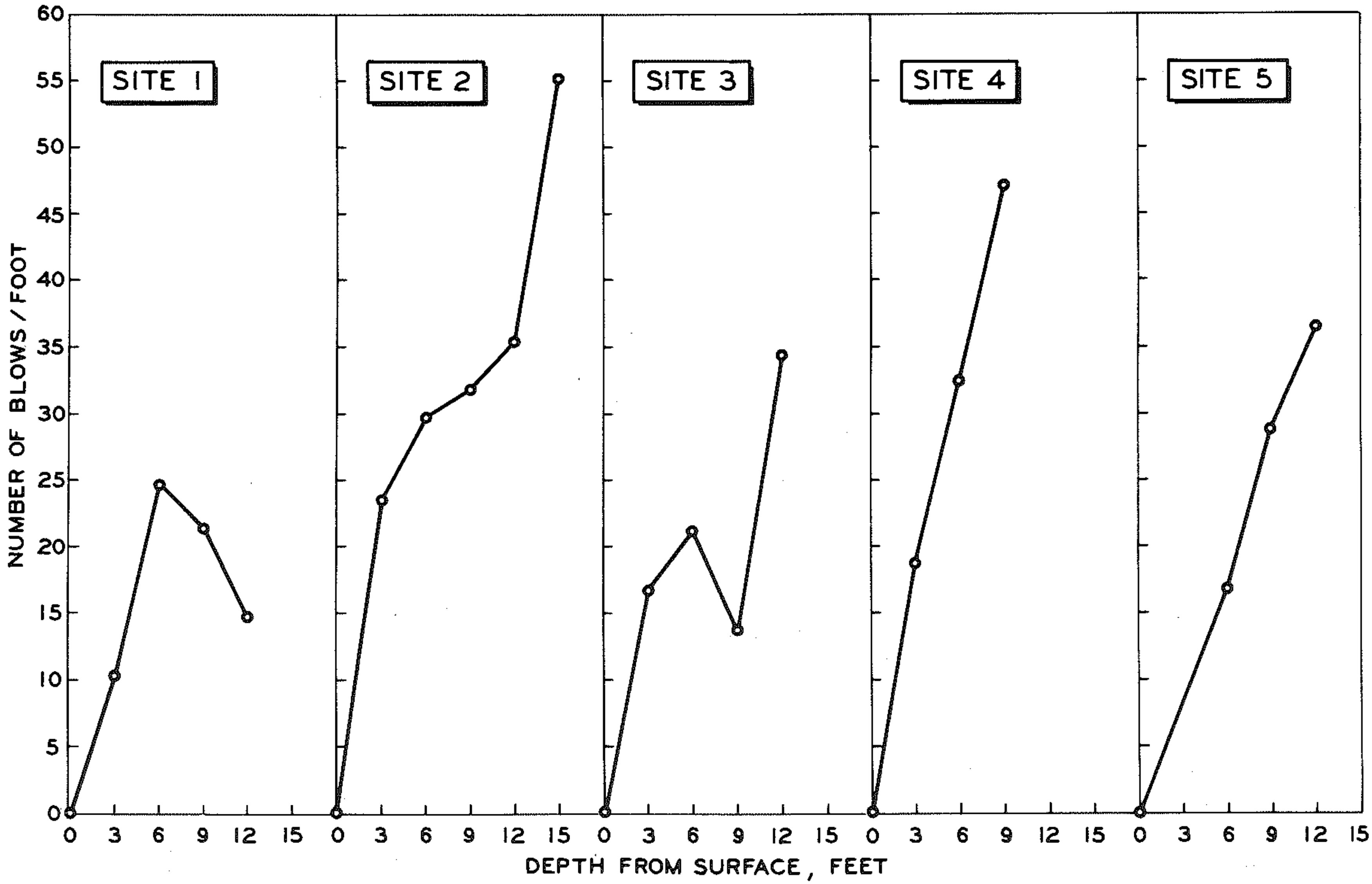


Figure 5. Soil boring penetration records.

TABLE 3
UNCONFINED COMPRESSIVE STRENGTH OF SAMPLES

Boring No.	Depth of Sample, ft	Dry Density, lb/cu ft	Water Content, percent	Unconfined Compressive Strength, Kg/cm^2	Consistency
1	0-3	Sample too soft for test		< 0.25	Very soft
1	3-6	101.15	24.79	2.55	Very stiff
1	6-9	90.91	35.42	1.83	Stiff
1	9-12	Sample too soft for test		< 0.25	Very soft
2	0-3	98.00	23.24	2.13	Very stiff
2	3-6	105.75	21.79	2.91	Very stiff
2	6-9	97.65	28.20	3.52	Very stiff
2	9-12	90.00	37.64	0.55	Medium
2	12-15	97.65	30.48	0.31	Soft
3	0-3	111.11	19.48	3.80	Very stiff
3	3-6	109.57	21.11	3.19	Very stiff
3	6-9	90.63	32.62	1.49	Stiff
3	9-12	98.88	27.76	3.84	Very stiff
4	0-3	Sample too soft for test		< 0.25	Very soft
4	3-6	Sample too soft for test		< 0.25	Very soft
4	6-9	Sample too soft for test		< 0.25	Very soft
4	9-12	90.91	37.09	0.57	Medium
5	0-3	Sample too soft for test		< 0.25	Very soft
5	3-6	105.78	21.66	2.64	Stiff
5	6-9	90.48	33.29	2.66	Stiff
5	9-12	85.57	38.73	0.27	Soft

Liquid Limit, Plastic Limit, and Plasticity Index were measured for samples obtained at 3-ft deep intervals for the five soil borings. Sieve analysis and hydrometer analysis for samples obtained at 6 to 9 ft depth were conducted. Liquid Limit, Plastic Limit and Grain Size Distribution for all soil borings are summarized in Table 2. The measured values of Atterberg Limits and the grain size distribution indicate that the soil in the site of the five borings is an inorganic clay of medium to high plasticity. A soil profile indicating soil classification, Atterberg Limits and moisture content is shown in Figure 6.

Unconfined compression tests were conducted on samples 1-in. in diameter and 2-1/2-in. long, obtained at 3-ft depth intervals, from borings ① through ⑤. Some of the samples had a paste-like consistency and could not be tested. Table 3 summarizes the measured unconfined compressive strength, density, water content, and consistency of all tested samples.

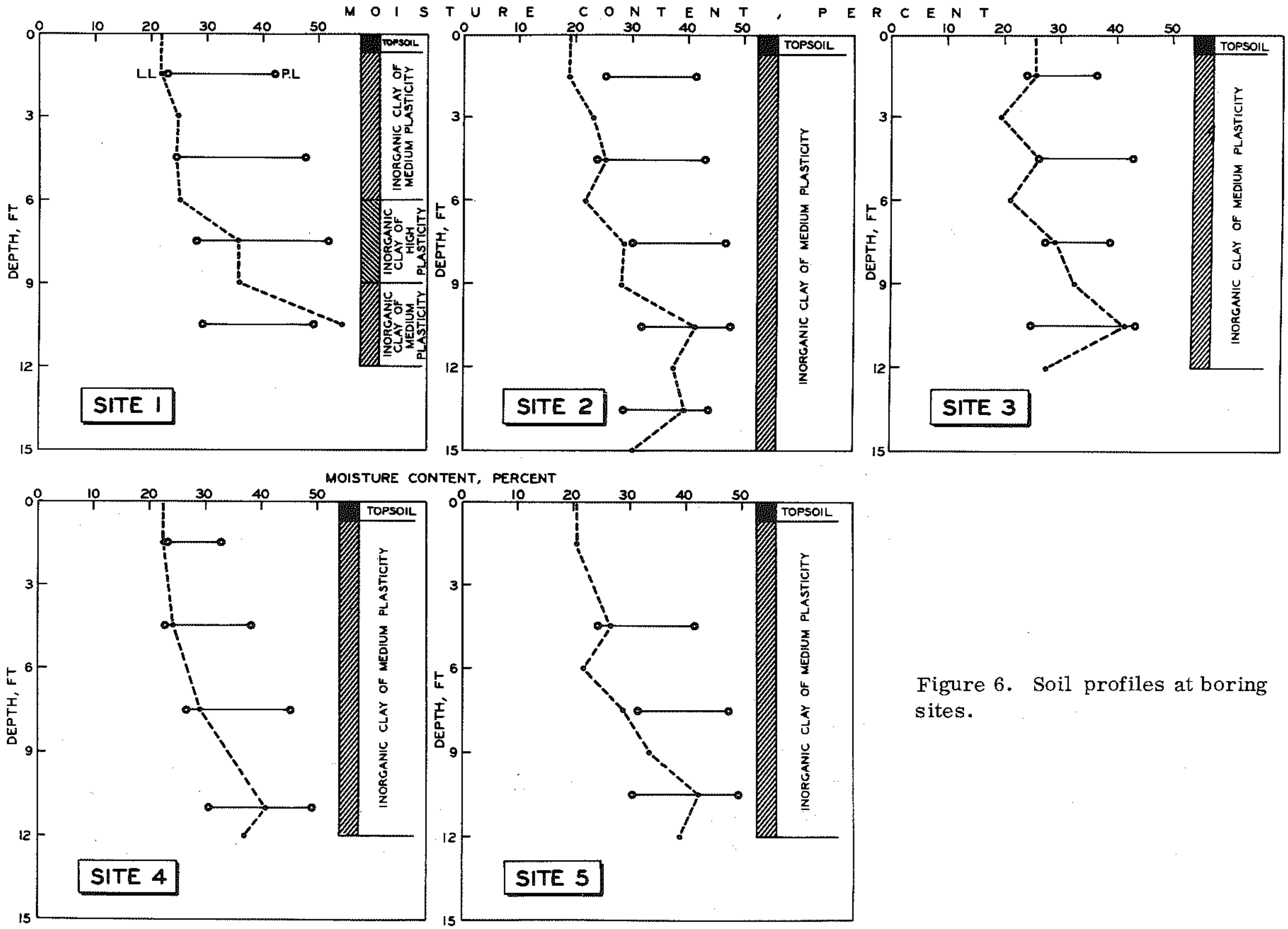


Figure 6. Soil profiles at boring sites.

Table 3 indicates that; 1) the clay in all borings, except boring (4) is stiff to a depth of 9 ft, 2) the clay is soft in all borings, except boring (3), at a depth of 9 to 12 ft (foundation's level), and 3) the consistency of the clay in this site is erratic (non-homogenous).

A review of the monthly water level records of Lake St. Clair for the last 60 years indicates a cyclic fluctuation of elevation in the order of 5 ft. Figure 8 shows the annual average elevation of Lake St. Clair for the years 1912 to the present, along with recorded high levels for recent years. Measurements of current water elevation conducted in this study, indicates that the water level in Anchor Bay is approximately 1 ft below the elevation of the foundation of the McAvon house.

In general, the soil investigations conducted in this study are considered elementary. More precise testing techniques were not used due to immediate unavailability of equipment in the Laboratory, and since the primary objective of this study was to determine whether vibrations have caused the damage to this structure. This investigation indicates the presence of an undesirable soil condition at this site, which consists of a thick deposit of marine clay with varied degrees of consistency, and with water table level very close to the foundation's elevation.

Discussion

Although tests conducted in this study were not extensive and may not provide complete or absolute answers, they do indicate a soils condition at the site that would present serious problems in supporting structures on spread footings designed in the usual manner.

The amount of vibration measured is not significant from a structural point of view. However, in this case it is alleged that the house stood undamaged for 50 years, and suddenly began to settle after the pavement problem occurred. Since we have observed only the final condition of the house, we have no way to accurately establish the progression of the failure except to rely on the owner's statements.

A significant factor in this type of problem is the sensitivity of people to vibrations of the type considered here. This sensitivity is far greater 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 at "intolerable" at certain frequencies. Also, vibratory motion inside a building usually is greater than in the ground due to flexure of floors and walls. These factors usually

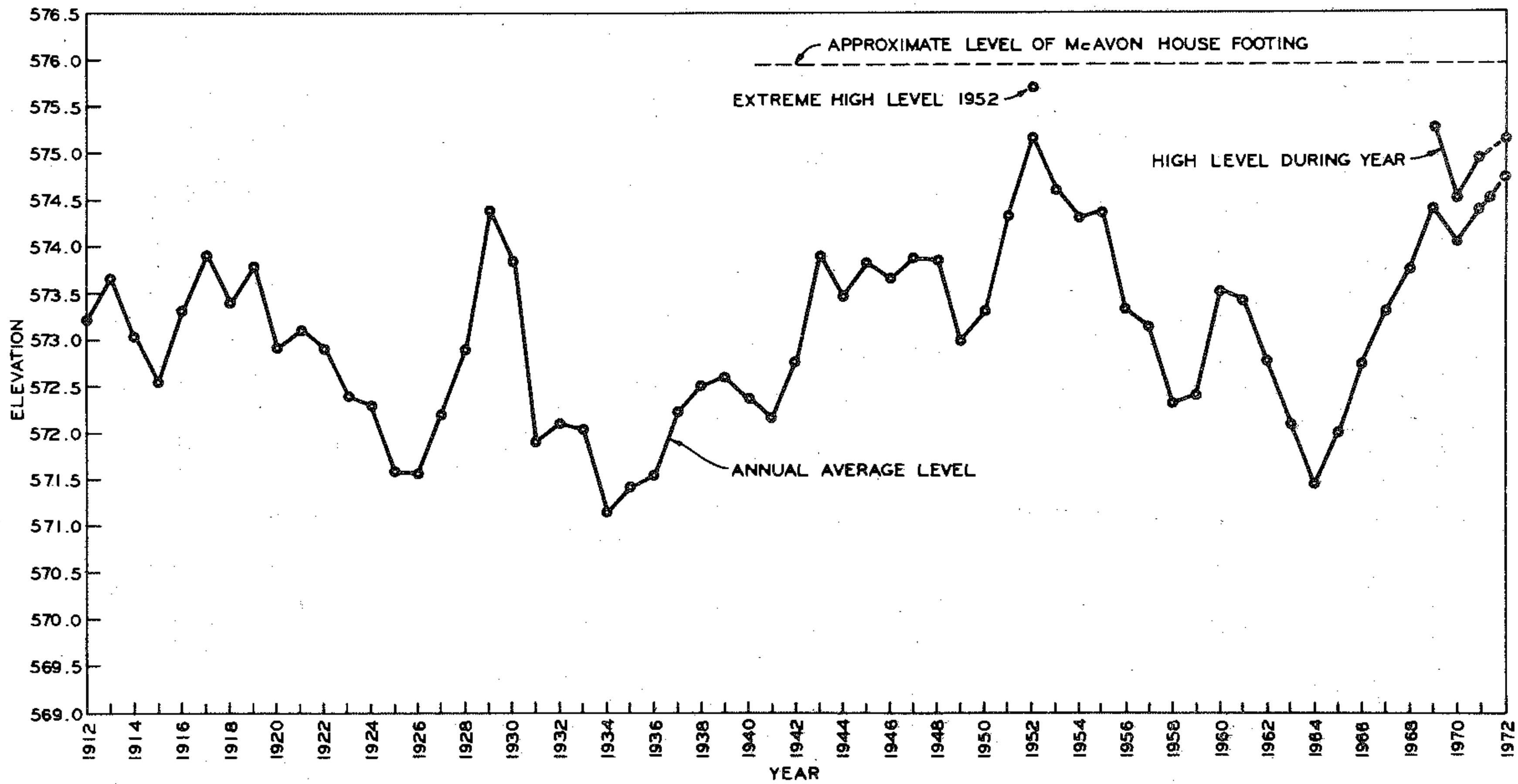


Figure 7. Annual average elevation of Lake St. Clair.

result in expressions of concern from people unwillingly subjected to such vibrations. In the subject tests, ground motion was only slightly noticeable to staff members working in the yard, but it brought immediate expressions of concern from Mr. McAvon's neighbors. If this type of exposure is coincident with building damage, it seems only natural for the people 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 subjected 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 the case at hand, the McAvon house rests on a soft clay deposit.

It is well established that the elevation of the footings of the house is very close to the present level of Anchor Bay. The rise of ground water table to the level of the foundation drastically decreases the bearing capacity of the soil to support the structure. Since the basement drains towards the lake, the rise of water table to the foundation's level must have rendered the existing drainage system useless, thus decreasing the soils support further. Due to non-homogeneity of the clay in this site, the resulting settlement would be expected to be a differential one.

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 caused the structural problems evident at the site. Neither were the methods, equipment or 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.

Conclusions

It is clear from an examination of Mr. McAvon's house, that damage has occurred as a result of differential settlements. This study indicates that traffic induced vibrations were not the direct or immediate cause of the damage. However, we cannot conclude that vibrations have not contributed to the acceleration of the damage. From the soils information available it appears that the final result was likely whether vibrations were present or not. It the foundation were adequate, vibrations of the magnitude indicated should have had no adverse effect on the structure.

REFERENCES

1. Harris and Crede, 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.