MICHIGAN DEPARTMENT OF TRANSPORTATION
M•DOT

ALLEGED DAMAGE TO SUSAN SHILANDER'S HOUSE DUE TO TRAFFIC-INDUCED VIBRATIONS

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Research Laboratory Section
Materials and Technology Division
Research Project 91 TI-1562
Research Report No. R-1317

Lansing, January 1992

The following report covers the results of an investigation of the Susan Shilander residence located at 4562 Hesslund Rd, near Ludington, Michigan. The investigation is regarding alleged structural damage to the house caused by ground vibrations generated by heavy equipment used to construct US 31. The Shilanders also feel that damage to their house was caused by vibrations from highway traffic on US 31, north of their home. US 31 is a four-lane freeway constructed during 1986 through 1989, and opened to traffic in late 1989.

Background

The Shilanders contracted with the consultant firm of Nordlund & Associates Inc. to perform a structural inspection of their house. In their report of March 28, 1991 (Appendix A) they indicated that a vibration study would be necessary to monitor the level of ground vibrations from US 31. The report also recommended that soil borings be taken to determine the type of soil and water table elevation underlying the house.

In April 1991, Susan Shilander sent a letter with a copy of the consultant's report to Alton Rhodes, MDOT Project Engineer at Scottville, in which she expressed concern for the cracking of the interior walls and differential settlement of the house. Mr. Rhodes requested that a study be performed by the Materials and Technology Division.

The Shilander house is a two-story wooden frame house with a basement. According to the consultant's report, the house is estimated to be 75 to 100 years old. The Shilanders have lived in the house since 1989.

The basement walls are constructed mostly of fieldstone and mortar. Portions of the north half of the west wall and two thirds of the north wall have been replaced with concrete blocks. The owners estimate the repairs to the basement wall were done about 15 years ago. The fieldstone walls show signs of crumbling and spalling of mortar from numerous joints.

The house has two chimneys, one located on the outside of the north wall of the house, not in use and in very poor condition, and the other located approximately in the center of the house. The interior chimney has a stone base approximately 3-1/2 ft high with the remainder built of brick, extending from the basement foundation through the two floors and the roof.

Two wooden support beams run across the basement in an east-west direction, spaced 8 ft apart. Figure 1 shows how one of the beams is supported by the chimney located in the approximate center of the basement. The beam is notched into the chimney such that the chimney actually supports some of the load of the upper floors. Two fieldstone walls that protrude inward from the outer basement walls towards the center of the room also carry some of the load. Joists running north-south support the first floor and rest on the support beams and north-south outer basement walls.

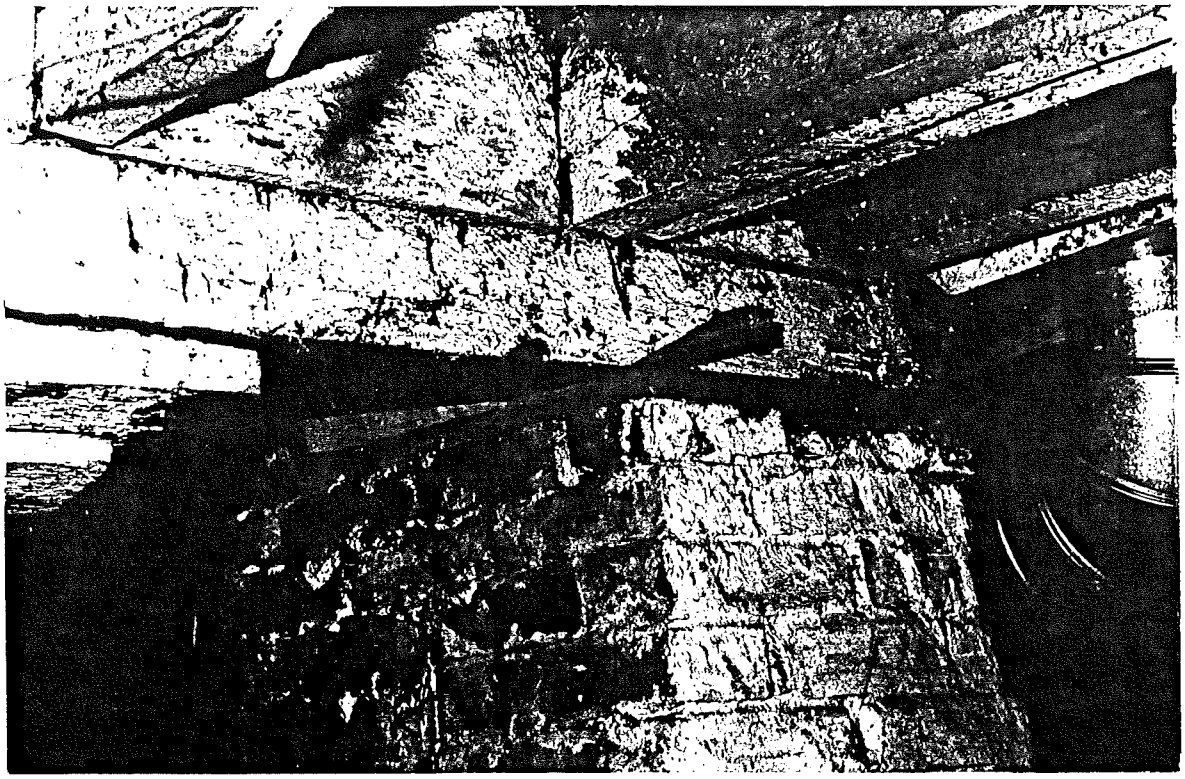

Figure 1. Wooden beam supported by chimney. Note the wooden shims installed to fill gap of missing mortar.

House Damage

The Shilanders stated that they felt most of the damage occurred during the construction of US 31. The contractor loaded and unloaded heavy construction equipment on some property approximately 200 ft west of their house (Fig. 2).

The house is approximately 400 ft from the US 31 freeway. In the consultant's report the Shilanders state that since the opening of the freeway they have noticed an increase in the number of plaster cracks, and that objects in the china cabinet will vibrate and occasionally fall over. The Shilanders further allege that the cracks in the plastered walls and ceilings, and the settlement of the house, have resulted from these freeway traffic and construction equipment induced vibrations.

A visual inspection of the house was initially conducted by D. Smiley, P. O'Rourke, A. Rhodes, and R. Pena on May 29, 1991, and a follow-up inspection was done by E. Quiroga and V. Barnhart on November 5, 1991. It is evident that differential settlement of the house has occurred as indicated by cracks in the plastered walls and ceilings, although they are not excessive for a house as old as this one. The Shilanders stated that much of the cracking that has occurred has been covered over by paneling. It is possible that many of the cracks that are covered occurred more than two years ago, since the Shilanders have occupied the house for only two years.

The non-functioning chimney located on the outside of the north wall of the house has mortar cracks and is pulling away from the house due to its partial collapse (Fig. 3). The chimney located in the central portion of the house is also experiencing settlement as indicated by the gaps where the chimney passes through the first and second floors. There is a section of the concrete floor of the basement near the southwest corner of the chimney approximately 10 to 15 sq ft in size that has collapsed and broken (Fig. 4). The concrete has been removed thereby exposing the sand base which is supporting the floor. It appears that the sand has either been removed or has settled over time.

Another sign of differential settlement is indicated by the open porch located on the south face of the house (Fig. 5). The porch consists of a concrete slab floor that rests on a concrete block foundation of unknown depth with the roof supported by wooden columns that rest on the slab. It was constructed at approximately the same time the basement walls were repaired. The foundation has settled approximately 1-1/2 in. causing the porch roof to pull away from the house.

Vibration Study

Prior to the May 29 inspection a ground vibration study had been conducted by the Structural Research Unit on May 20, 1991 at the Shilander residence (Appendix B). Vibrations were monitored between the hours of 11:25 AM and 1:30 PM. Locations of the seismometers are shown in Figure 2.

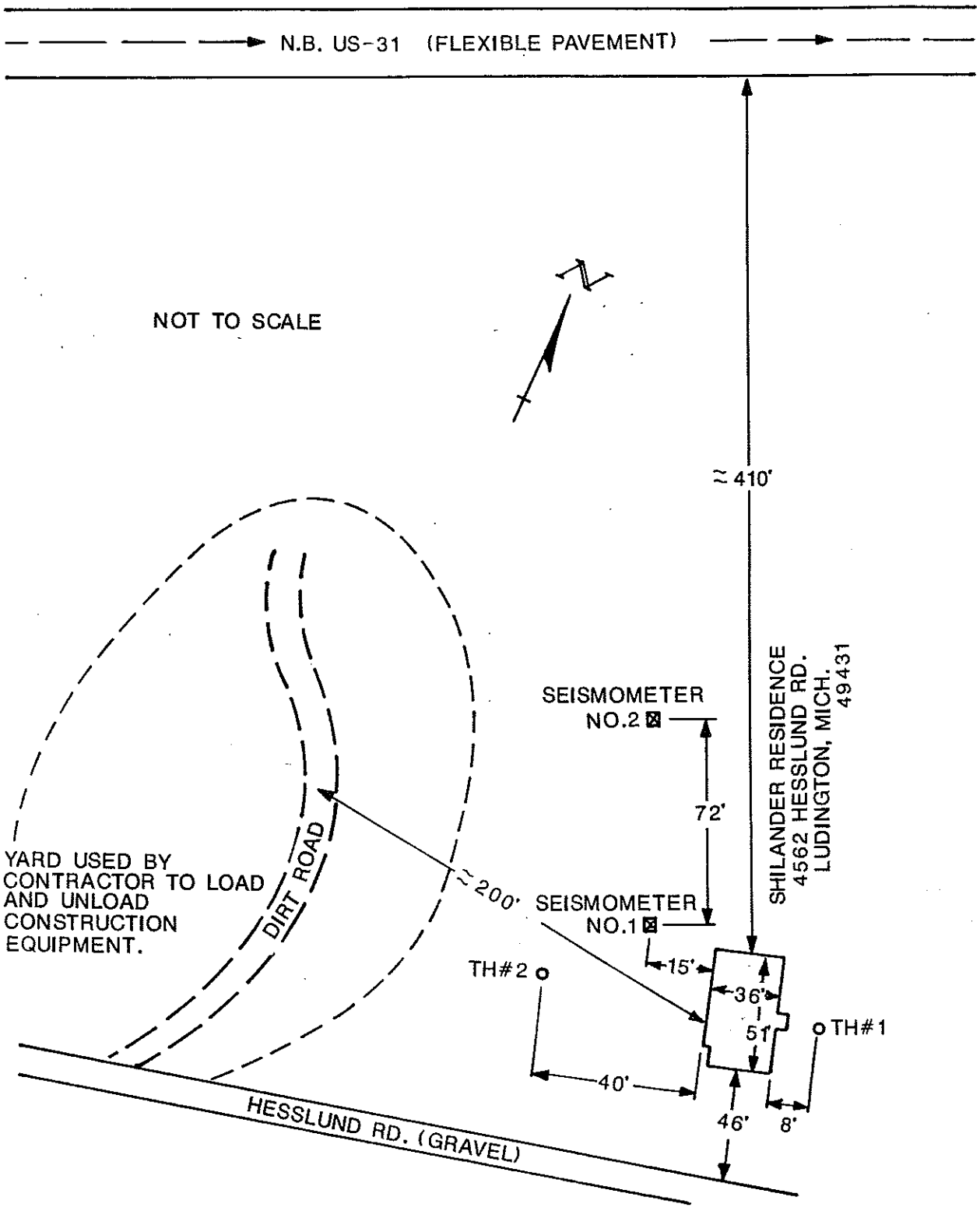

Figure 2. Location of Shilander House with respect to northbound US 31. Location of soil borings and seismometers also shown.

Figure 3. Chimney shows signs of distress as indicated by cracking and pulling away from house.

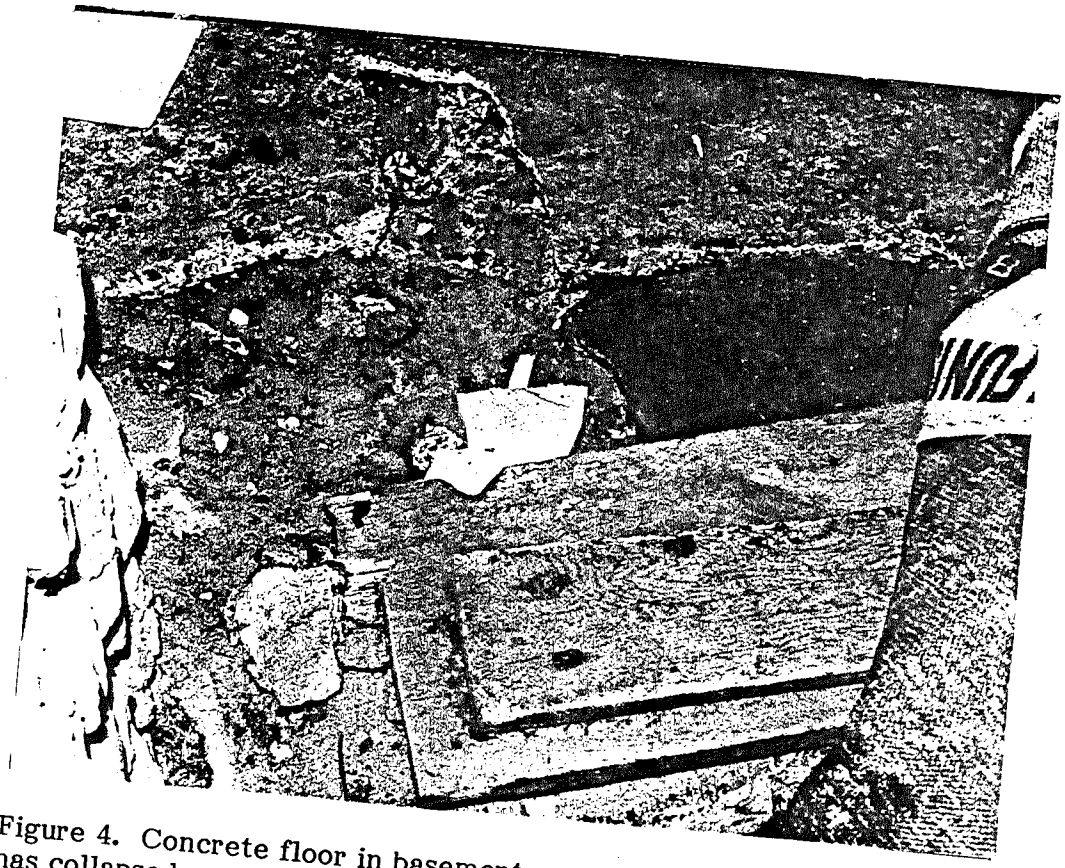

Figure 4. Concrete floor in basement next to the chimney, where floor has collapsed.

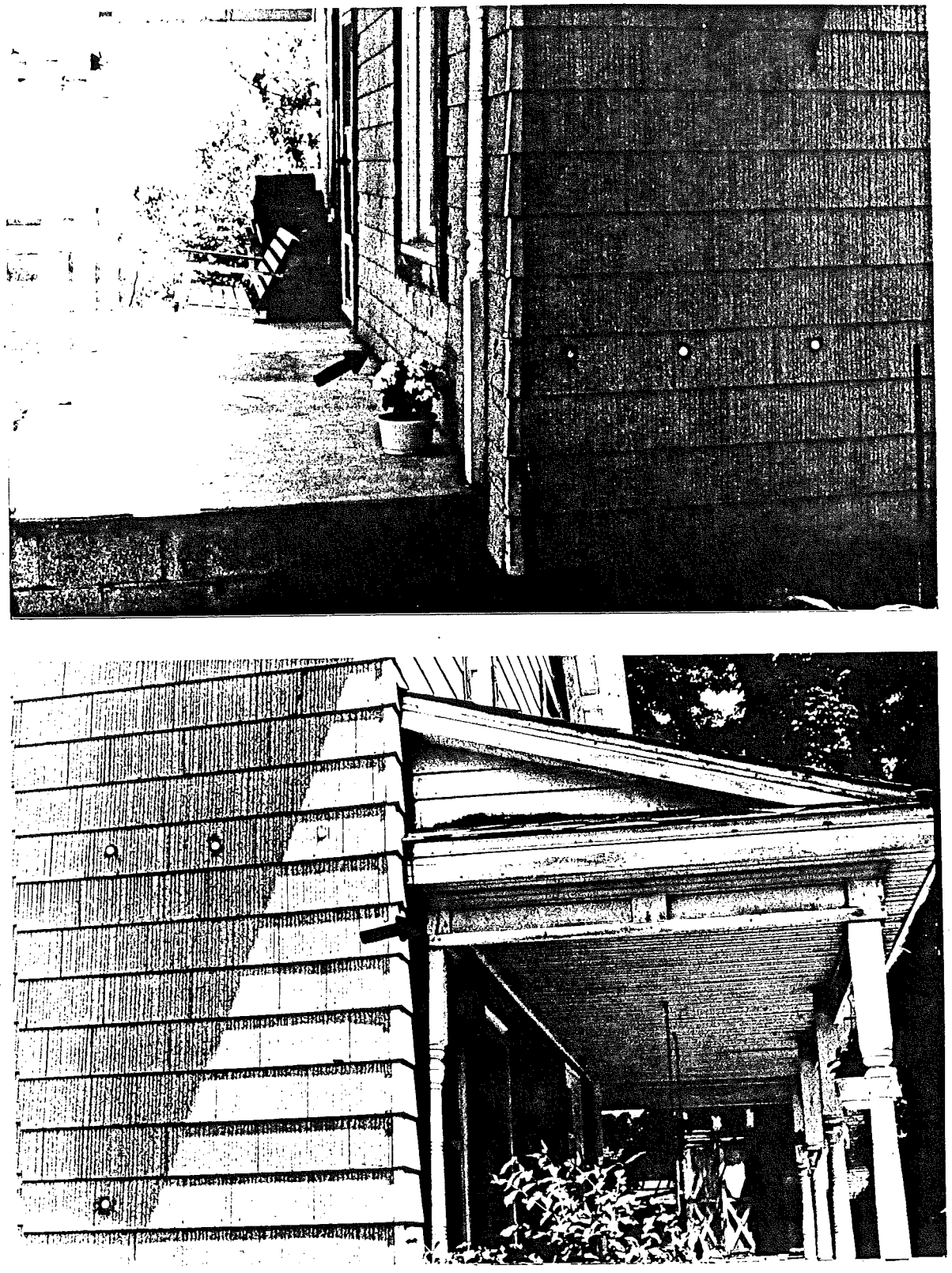

Figure 5. Porch pulling away from house approximately 1-1/2 inches due to settlement of its foundation.

The highest values recorded during the monitoring period at the Shilander residence were 0.0042 in./sec of ground particle velocity for seismometer No. 1 and 0.0052 in./sec of ground particle velocity for seismometer No. 2.

The threshold for human perception of ground vibrations is at approximately 0.03 in./sec of ground particle velocity. Activity that creates vibrations in excess of 0.05 to 0.06 in./sec of ground particle velocity can be expected to generate complaints from occupants of nearby dwellings. However, no physical damage to a building can occur at these levels of ground particle velocity. Harris and Crede (1) conducted tests to measure peak ground velocities of typical brick and frame houses subjected to shock and vibrations over a wide range of frequencies. They, too, support the study conducted as they found that "...when the ground velocity was as great as 4 to 5 in./sec, damage was likely to occur. In independent investigations, a damage index is given equivalent to a ground velocity of 4.7 in./sec." The current guidelines as set forth by the American Association of State Highway and Transportation Officials (AASHTO) is to limit vibration levels to 0.5 in./sec of ground particle velocity in residential areas with dwellings constructed with plastered and/or gypsum board walls.

Based on these guidelines and referenced studies, the readings obtained for the Shilander house are much lower than both the threshold for human perception and the current AASHTO guidelines. Our readings of the vibrations generated by the vehicle traffic on US 31 are too low to have caused the structural damage alleged by the Shilanders.

The Shilanders also allege that damage to their house was caused by ground vibrations generated during construction activities for US 31. The contractor loaded and unloaded heavy construction equipment on property located approximately 200 ft west of the Shilander's house.

Although monitoring the ground vibrations generated by the heavy construction equipment was not possible for this investigation, vibration studies involving steel track dozers and heavy rubber-tired vehicles have been done at other construction sites. These studies have found that steel track dozers operating within 26 ft of a building generated ground vibration levels of 0.25 in./sec of ground particle velocity. Although this level is high enough to generate complaints from the occupants of a building, it is not sufficient to cause structural damage. Note that this value is also within the AASHTO guidelines for vibration levels for residential buildings. The construction equipment used to construct US 31 was operating at a distance of 150 to 200 ft from the Shilander house. At this distance the ground vibration levels for the steel track dozers would be approximately 0.03 in./sec, which is at the threshold of human perception.

Soil Investigation

Appendix C contains the soil borings and standard penetration tests that were conducted by the Geotechnical Unit on June 20, 1991 at the Shilander residence. The borings indicate the underlying soil to be mostly sand with occasional clay lenses. The standard penetration test indicates that the sand is loose to moderately compact. The soil profile is typical of the Ludington area.

Discussion

There is no question that the Shilander house is experiencing settlement. The question is whether the vibrations generated by either construction equipment or highway traffic from US 31 could have caused or contributed to the settlement as alleged by the Shilanders.

The house is approximately 75 to 100 years old. It is alleged that the house has endured these years undamaged, only to experience the damage in question during the last two years. Since damage to the house has not been progressively monitored, and we have merely seen the present condition of the house, we can only rely on the Shilander's statements. It is imperative to understand that if the Shilanders feel ground vibrations, and then witness settlement or damage of their house, it is natural for them to assume that the vibrations were the cause. The ground vibration levels recorded, however, are not consequential from a structural point of view. Our soils investigation indicated that a loose to moderately compact sand deposit underlies the house foundation. This sand has likely consolidated, causing settlement over time.

The object of this investigation was not to ascertain the exact cause of the alleged damage. The tests conducted fall short of providing such detailed conclusions, as this would not appear to be the Department's responsibility.

There are several possible causes of the damage in question. One theory might be that, based upon inspection of the fieldstone and reconstructed basement walls, some of the damage that has occurred may be the result of the procedure used to replace the northwest corner walls of the house. The fieldstone wall shows signs of distress as indicated by the spalling and crumbling of the joints in numerous places. The cracks and spalls in the wall allow settlement of the supported structure. The replacement operation likely distributed the weight of the upper structure unevenly and concentrated much of the weight on the remaining portion of the house foundation. This shifting in weight distribution creates uneven stresses throughout the structure. Though the frame of the house is sturdy enough to resist this shift in loading, cracks in the plastered walls and ceilings can occur.

Another possible cause for the cracking of the plastered walls and ceilings is indicated by the chimney located in the central portion of the house. As one can see from Figure 1, the mortar and brick from the chimney has deteriorated to the point where wooden shims were installed to fill the gap between the support beam and the chimney, possibly to re-level the first floor and keep it from bowing. The chimney is in fact supporting much of the overall weight of the house. This type of support has afforded movement of the upper structure over time. There is also a hole in one fieldstone support wall which has badly deteriorated over time. This deterioration may also have brought about some movement of the supported structure. It appears that brick was installed in an effort to provide support for the beam. The broken area in the basement floor at the base of the chimney may be an indication that the chimney is overloaded as it supports much of the weight of the upper floors. The operation used to replace the stone wall may have transferred much of the load of the house to the supporting beam and therefore also to the chimney.

Naturally, many other possibilities exist.

CONCLUSIONS

From this study it is clear that the Shilander house has settled, but there is no indication that freeway traffic has induced ground vibrations great enough to cause any settlement that would result in structural damage to the house. The procedure used during the replacement of the basement wall is one theoretical or probable cause for most of the visible cracking in the house.

REFERENCES

1. Harris and Crede, Shock and Vibrations Handbook, Volume 3, McGraw-Hill, New York, 1961, § 50-37.

APPENDIX A

CONSULTANT'S REPORT FOR VISUAL INSPECTION OF SHILANDER HOUSE

Member

NORDLUND & ASSOCIATES INC.

CONSULTING ENGINEERS AND SURVEYORS

Member

James T. Nordlund, Sr., P.E., R.L.S.
Richard L. Hays, R.L.S.
James T. Nordlund, Jr., P.E.
Charles J. Christy
Nicholas Matlash

813 E. Ludington Avenue
Ludington, Michigan 49431
Telephone (616) 843-3485

345 First Street
Manistee, Michigan 49660
Telephone (616) 723-6460

March 28, 1991

Re: Building Inspection
File: 435-1

Miss Susan Shilander
4562 Hesslund Road
Ludington, Michigan 49431

Dear Miss Shilander:

On Tuesday, March 19, 1991, a visual inspection of the house at 4562 Hesslund Road was conducted.

The house is a two'story with a basement and is estimated to be 75 to 100 years old.

The current residents have lived in the structure for two years.

In the basement the north wall and the north half of the west wall are constructed of concrete block. The remaining walls are constructed with field stone. It is estimated that the concrete block portion of the walls were built within the last fifteen years to replace the original field stone walls. In these areas no visible cracks were found. The field stone areas show evident signs of distress with mortar crumbling and falling from joints in numerous places.

The house contains two chimneys, one on the north side that is not currently in use and the second which is located approximately in the center of the house. The north chimney, which is constructed of brick, has been badly damaged due to settlement as indicated by cracks in mortar joints and by pulling away from the building. The other chimney, with dimensions of approximately two feet square, has a stone base four feet high with brick used for the remainder. This is experiencing settlement also as indicated by cracks located near the chimney where it passes through ceilings on the first and second floor caused by its movement with respect to the house.

The concrete floor west and south of the chimney is badly broken. Two holes each approximately six inches in diameter southwest of the chimney show a medium to fine orange sand base. Tapping on the concrete in these areas indicate that it is hollow below the floor.

The upstairs portion of the house shows all the typical signs of settlement, including numerous cracks in the plaster, uneven floors and several places where the ceilings have bowed.

The most obvious case of differential settlement involves the open porch located on the south side of the house. The porch is constructed of a concrete slab supported by concrete block walls with columns resting on the slab to support the roof. The base has settled approximately 1-1/2 inches causing the porch roof to pull away from the house.

The house is estimated to be located 300 feet from the northbound lands of the U. S. 31 Expressway. During the inspection you indicated that since the opening of the section of expressway you have noticed an increase in the number of plaster cracks and other problems related to settlement. It was also noted that each week several items in your china cabinets will move or fall over. It is believed this is caused by vibration created by vehicle traffic on the expressway. Under certain conditions vibration in soil will cause consolidation creating settlement.

We recommend three steps to better determine the rate of settlement and the possible causes for the increase in settlement.

First, the installation of calibrated crack monitors to enable us to verify movement and approximate a rate of movement (see enclosed sheet for more information).

The second would involve setting up an instrument to monitor ground vibration and attempt to locate its source.

The third would involve digging a hole, by hand with a posthole digger, in the basement in an area where concrete is already broken to attempt to determine where the water table is located and the type of soil below the house.

It you would like to follow up on the recommendations or have any questions, please do not hesitate to call.

Very truly yours,

NORDLUND & ASSOCIATES, INC.

John Kiefer

JK/ne
Encl.

APPENDIX B

VIBRATION STUDY

OFFICE MEMORANDUM

DATE: May 30, 1991

TO: David L. Smiley
Supervising Engineer
Soils, Bituminous & Pavement Performance Unit

FROM: Larry J. Pearson, Supervisor
Structural Investigations Group
Structural Research Unit

SUBJECT: Vibration Monitoring at Shilander Residence (US-31) near Ludington
Research Project 91 TI-1562

A vibration study was conducted on May 20, 1991, at the Shilander residence located on Hesslund Road adjacent to the new US-31 freeway. Vibrations were monitored between the hours of 11:25 AM and 1:30 PM.

As is normal in traffic induced vibrations, large commercial vehicles generated the largest vibration levels. The threshold of human perception of vibrations is at about 0.03 in./sec. of ground particle velocity. Any activity that creates vibrations in excess of 0.05 to 0.06 in./sec. of ground particle velocity can be expected to produce complaints from the occupants of nearby buildings even though no physical damage to the building will results. The current recommended guideline by the American Association of State Highway and Transportation Officials (AASHTO) is to limit the vibration levels to 0.5 in./sec. ground particle velocity in residential buildings with plastered walls and/or gypsum board walls.

The highest values recorded during monitoring at the Shilander residence were 0.0042 inches per second ground particle velocity for seismometer #1 and 0.0052 inches per second ground particle velocity for seismometer #2. These values are very low and could not cause the structural damage outlined in the letter dated March 28, 1991, from the consulting firm.

The homeowner stated that he felt the damage was caused during construction activities. Apparently during construction the contractor loaded and unloaded heavy equipment on the property adjacent to the Shilander home (approximately 200 ft.). Although it is not possible, at this time, to determine the exact level of vibrations generated during the construction, vibration studies involving dozers and rubber-tired vehicles have been done

at other construction locations. These studies have found that a steel track dozer operating within 26 feet of a building generated a vibration level of 0.25 in./sec. ground particle velocity. Although this level is high enough to generate complaints from the homeowners, it is not sufficient to cause damage to the building. The construction equipment used to construct US-31 would have been operating at a distance of 150 feet or greater from the house. At that distance, the previous studies have found that the vibration levels for the steel track dozer were 0.03 in./sec., which is the threshold for complaints due to vibrations.

If you have further questions concerning this project, please contact me at 2-5727.

MATERIALS AND TECHNOLOGY DIVISION

Larry Pearson

Structural Research Unit

LJP:cgc

cc: J. W. Reincke
G. J. Bukoski
B. R. Lower

APPENDIX C

SOIL BORING LOG AND STANDARD PENETRATION TEST DATA

Michigan Department of Transportation
514A (3/84)

SOIL BORING LOG

☐ HYDRAULIC
☒ AUGER

Date	Control Section ID.	Job No.
6-20-91	53034	18890

Location	Permit No.	County
House on Hesslaund Rd.	821-832-153	Mason

	Town	Range	Section
Ludington	18N	17W	31

Test Hole No.	Station	Offset	Ground Elev.
TH#1			106.32

DEPTH (ft.) From	DEPTH (ft.) To	DESCRIPTION	SAMPLER NO.	DEPTH (ft.)	BLOWS OR RECOVERY (in.) 1st. 6"	2nd. 6"	3rd. 6"
0	1	Loose brn. loamy topsoil.					
1	3	Mod. comp. yellow-brn. sand, fine.					
3	11	Loose brn. sand, fine.		5	2	3	6
11	13	Loose brn. sand, med.		10	1	2	3
13	20	Mod. comp. brn. sand, fine.		15	3	8	13
20	24.5	Loose brn. mott. sand, fine, and med., silty sand		20	1	2	3
		lenses.					
24.5	26.5	Loose brn. sand, med., (saturated) at 25'		25	2	4	5
		26.5 E.O.B.					

Free water first noted _____ ft. below surface. Water level below ground after completion.

Casing ☒ In ☐ Out comp hr., 25 ft.
Casing ☐ In ☒ Out comp hr., 25 ft.
Casing ☐ In ☐ Out _____ hr., _____ ft.

Cave in _____ ft., ☐ Wet ☐ Dry

Plugging Method

Suitable Material	☒ 0	ft.
Bentonite Slurry	☐	ft.
Cement Grout	☐	ft.
Plugged Pipe	☐	ft.
Pipe Length	☐	ft.

Sampler ☐ 1-3/4" OD, 1-3/8" ID
☒ 2" OD, 1-1/2" ID

Consistency by inspection of samples and soil resistance to jet rod and casing or auger.

Crew Chief [s] Robert Green

Michigan Department of Transportation
514A (3/84)

SOIL BORING LOG

☐ HYDRAULIC
☒ AUGER

Date	Control Section ID.	Job No.
6-20-91	53034	18890

Location	Permit No.	County
House on Hasslund Rd.	821-832-153	Mason

Town	Range	Section
18N	17W	31

Test Hole No.	Station	Offset	Ground Elev.
TH#2			104.79

DEPTH (ft.) From	DEPTH (ft.) To	DESCRIPTION	SAMPLER NO.	DEPTH (ft.)	BLOWS OR RECOVERY (in.) 1st. 6"	2nd. 6"	3rd. 6"
0	0.50	Topsoil.					
0.50	3	Loose yellow-brn. sand, fine.					
3	5	Loose brn. mott. sand, fine, sandy clay lenses.			N		
5	8	Loose brn.-gr. mott. sand, fine & med., sandy		5	2	1	1
		clay lenses.					
8	13	Loose brn. sand, fine & med.		10	2	4	3
13	16.5	Mod. comp. brn. sand, med.		15	3	6	4
16.5	17	Loose brn. sand, fine.					
17	22	Loose brn. sand, fine & med.		20	2	3	3
22	26.5	Mod. comp. brn. sand, med.		25	3	10	11
		26.5 E.O.B.					

Free water first noted 25 ft. below surface. Water level below ground after completion.

~~Casing~~ ☒ In ☐ Out comp hr., 25 ft.,
Casing ☐ In ☒ Out comp hr., 25 ft.,
Casing ☐ In ☐ Out _____ hr., _____ ft.,

Cave in _____ ft., ☐ Wet ☐ Dry

Plugging Method

Suitable Material	☒ 0	ft.
Bentonite Slurry	☐	ft.
Cement Grout	☐	ft.
Plugged Pipe	☐	ft.
Pipe Length	☐	ft.

Sampler ☐ 1-3/4" OD, 1-3/8" ID
☒ 2" OD, 1-1/2" ID

Consistency by inspection of samples and soil resistance to jet rod and casing or auger.

Crew Chief [s] Robert Green

Michigan Department of Transportation
514A (3/84)

SOIL BORING LOG

☐ HYDRAULIC
☐ AUGER

Date	Control Section ID.	Job No.
6-20-91	53034	18890

Location	Permit No.	County
House on Hesslund Rd.	821-832-153	Mason

Town	Range	Section
18N	17W	31

Test Hole No.	Station	Offset	Ground Elev.

DEPTH (ft.) From	DEPTH (ft.) To	DESCRIPTION	SAMPLER NO.	DEPTH (ft.)	BLOWS OR RECOVERY (in.) 1st. 6"	2nd. 6"	3rd. 6"
		level notes.					
	+5	Hi -5 Elve.					
		100.00 assumed elev.					
	9.75	107.75					
		3.78 105.97 top of ground at house					
		3.43 106.32 *TH #1 8' E of house					
		9.06 100.69 Top of bottom step basement					
		4.96 104.79 *TH#2 40' W of house					
		9.75 100.00 Bm., assum.					
	Bm.	Elev. 100.00 (assumed) Painted x on blacktop					
		at intersection of Hesslund Rd. & Benedict Rd.					
	*	Please note that Test Holes #1 & #2 were taken					
		such that if connected by a straight line would					
		divide the house approximately in half.					

Free water first noted _____ ft. below surface. Water level below ground after completion.

Casing ☐ In ☐ Out _____ hr., _____ ft.
Casing ☐ In ☐ Out _____ hr., _____ ft.
Casing ☐ In ☐ Out _____ hr., _____ ft.

Cave in _____ ft., ☐ Wet ☐ Dry

Plugging Method

Suitable Material	☐ _____	ft.
Bentonite Slurry	☐ _____	ft.
Cement Grout	☐ _____	ft.
Plugged Pipe	☐ _____	ft.
Pipe Length	☐ _____	ft.

Sampler ☐ 1-3/4" OD, 1-3/8" ID
☐ 2" OD, 1-1/2" ID

Consistency by inspection of samples and soil resistance to jet rod and casing or auger.

Crew Chief [s] Robert Green