Vibration measurements on a steel joist floor: Montreal

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40001201
Technical Note (National Research Council of Canada. Division of Building Research), 1973

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

No. 573

TECHNICAL NOTE

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DATE 6 March 1973

PREPARED FOR Record purposes.

SUBJECT VIBRATION MEASUREMENTS ON A STEEL JOIST FLOOR - MONTREAL

The office staff in an industrial building, recently built in the St. Laurent district of Montreal, complained of disturbing vibrations due to persons walking along the floor. The floor had been designed according to Part 4 of the National Building Code and a recalculation showed that all existing requirements of strength and deflection had been satisfied. The following measurements were undertaken in order to assess the complaint and to determine the floor characteristics. This information should assist in arriving at improved design criteria to avoid future complaints. A trial remedial procedure, consisting of stiffening posts, was also evaluated by measurements.

DESCRIPTION OF FLOOR

The floor under investigation is the second floor of a two-storey office wing of a large industrial warehouse. The floor structure consists of 20-in.-deep open-web steel joists, approximately 5 ft c-c, with a 4-in.-deep concrete slab on ribbed steel decking, spot welded to the joists at intervals of approximately 2 to 3 ft. The floor joists are supported on steel beams and columns. The framing diagram is shown in Figure 1, as are the 2nd floor partitions. First floor partitions are similar except that those near points 3 and 5 are absent. A densely knotted rubber-backed industrial carpet was glued to the concrete floor.

EXPERIMENTAL PROCEDURE

The first measurements were conducted on 13 February 1973. A Larsen servodrive accelerometer was mounted on a brass base that was fitted with three spikes in order to penetrate the carpet to the concrete. This was necessary to prevent a modification of the vibrations due to the cushioning effect of the carpet. The signals were filtered at 9 Hz in a Kron-Hite filter and recorded on a Century GP 420 galvanometer.

The locations of the observation points are shown in Figure 1 by letters A to F. Points 1 to 4 refer to measurements during a trial remedial solution, which will be discussed later. Point A was generally used as the reference signal, the other points were monitored in turn by the second accelerometer. Floor excitation consisted of walking, heel impact (up on toes, down on heels by a man weighing 220 lb. (100 kg)) and man-made steady state excitation of the floor at its resonance frequency.

RESULTS

(a) Experimental

The results of the measurements are shown in Figures 2 to 8. From the record of decay of vibrations, the resonance frequency was determined to be between 5.8 and 6.1 Hz. The damping was found to be from 8 to 11 per cent of critical, determined from the record of decay of vibrations caused by impact or by steady state excitation.

Figure 2 shows that the floor vibrations resulting from a normal brisk walk resemble a steady state vibration of the order of 0.005 g peak acceleration. According to Reference 1, this places it within the perceptible region of continuous vibration.

The heel impact tests shown in Figures 3, 4, 5, 7, and 8 provide an indication of the transmission of vibrations normal to the joists. Figure 3 shows that points A and B vibrate essentially in phase when excited at A and the acceleration amplitudes transmitted to B are approximately 2/3 of those at A. As shown in Figure 4, at point C the vibrations induced at A are slightly out of phase and the acceleration amplitudes are reduced by about 1/2. Figure 5 shows that at point D, three joists away from A, the vibrations are essentially 180° out of phase with vibration amplitudes comparable to those transmitted to C. In all these records the time history is seen to be more complex than that of a simple single-degree-of-freedom decaying system. This is typical for such floors, which are actually two-way systems supported on flexible beams, containing partitions and other objects that give the floor system irregular properties.

Figure 6 shows the decay of steady state vibrations at the fundamental frequency induced by a person. The rapidly decaying envelope indicates substantial damping in the floor system.

The transmission of vibrations from A to E and E to A is indicated in Figures 7 and 8, respectively. At point E the amplitudes are approximately 1/3 of those produced at A by a heel impact. A comparison between Figures 7 and 8 shows that a heel impact produced by the same person at point E results in acceleration amplitudes which are about 1/2 of those produced at A. Figure 8 indicates a transmission of approximately 1/2 the amplitudes from point E to A.

The results from Figures 7 and 8 can be related to the presence of partitions near point E and demonstrate a reduced level of impact response. The partitions also reduce the vibration amplitudes transmitted from other slab locations that do not contain partitions. Since there are no significant changes in the resonant frequencies of the joist with nearby partitions at E, the reduced response can be ascribed primarily to increased amounts of damping provided by the partitions rather than an increase in stiffness.

(b) Psychological

By sitting at a work desk during different walking activities, some attempt was made to determine what kinds of disturbance created annoyance. It appeared that the continuous vibration created by a person walking down the floor was more disturbing than a transient vibration due to heel impact, even though the acceleration levels were considerably less in the former case. This indicates that continuous vibration due to walking may be a more significant criterion for floor systems with low frequency than the frequently used criterion of transient vibration from heel impact given in Reference 2.

(c) Calculated Frequency

The floor is primarily a one-way system and the fundamental frequency δ, in Hz, corresponds closely to that of a simply-supported one-way beam:

$$\delta = \frac{\pi}{2L^2} \sqrt{\frac{EI}{w/g}} \qquad (1)$$

where

E is the modulus of elasticity;
I the moment of inertia;
w/g the mass per unit length; and
L the span.

The calculated properties of this floor are:

$L = 420$ in. (35 ft);
$w = 20.8$ lb/in. (50 psf);
$g = 386.4$ in. /sec^2;
$E = 29 \times 10^6$ psi;
$I = 335$ in.^{4} (joists only); 852 in.^{4} (joists and slab acting compositely).

These values give fundamental frequencies of 3.8 cps assuming no composite action and 6.0 cps assuming full composite action. The measured value, 5.8 - 6.1 cps, compares closely with the calculated value assuming full composite action.

The floor joists are supported on a 16 WF 36 exterior beam spanning 24 ft between columns (Figure 1). Assuming the beam is simply-supported and supports half the floor span, Eq. (1) results in a fundamental frequency of 5.0 cps for the WF support beam; this should result in a fundamental frequency of the floor system considerably less than 6 cps. Thus measured frequencies indicate a much higher beam stiffness, which could be due to beam interaction with the wall, beam continuity, etc.

REMEDIAL MEASURES

After discussions of various possible remedial actions, such as stiffening trusses, cross bracing, partitions, and dampers, it was decided to try a system that appeared to provide a high probability of success, was reasonably economical, and was acceptable to the owners. This consisted of placing pipe columns at distances of approximately 15 to 20 ft near the midspan of joist, from the underside of the second floor to the reinforced concrete main floor slab. In order to assess such a scheme measurements were taken on 23 February 1973 with temporary adjustable pipe columns placed in positions 1 and 3 and vibrations recorded at points 1, 2 and 4, as shown in Figure 1. The temporary columns were placed on the rug below and jacked by hand against the underside of a joist.

Figure 9 shows the vibration records at points 1 and 2, as a result of a person walking down the floor (perpendicular to joists) between points 1 and A with a temporary pipe column under point 1. The peak accelerations over the support are seen to be approximately 0.0015 g, whereas at point 2 they reach 0.005 g. Figure 10 shows vibration records at points 1 and 4 due to similar walking disturbance. The peak amplitudes at point 4 reach approximately 0.005 g. From both the traces in Figure 10 the frequency of vibration of the joist with the support at point 1 can be seen to be approximately 8 - 9 Hz, whereas from Figure 9 the frequency of the unsupported joist under point 2 is seen to be near 6 - 7 Hz.

DISCUSSION OF REMEDIAL PROCEDURE

The results of the temporary remedial posts show that the amplitudes of acceleration due to walking are decreased considerably near the point of support, but not elsewhere. If, however, temporary posts were placed near mid-span and on a more solid support, the amplitudes of motion all along the supported joist would be decreased considerably. Furthermore, since the frequency of vibration of the supported joist has been raised, the disturbance has been moved from the range of highest human sensitivity located in the 3 to 6 Hz range. (Reference 1, Figs. 44-8, 9, and 10.) Finally, the uniform vibration pattern of the floor system has been broken up into components having higher resonance frequencies. In terms of human perception this may have a beneficial effect.

If the insertion of the posts at every third joist from the second floor to the main floor slab is not entirely satisfactory, the floor between the stiffened joists could then be further stiffened by insertion of cross bracing along the line joining the posts. This may become necessary if the slab cracks longitudinally over the supported joists.

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2. Lenzen, K. H. Vibration of Steel Joist-Concrete Slab Floors. A. I. S. C. Engineering Journal, July 1966.

ACKNOWLEDGEMENT

This investigation was undertaken as a result of an inquiry to the Division of Building Research by Louis P. Derome, Consulting Engineers, Valleyfield, Quebec. The cooperation of the members of the staff of Louis P. Derome, Goodyear Tire and Rubber Co. of Canada Ltd., the owners of the building, and of members of the staff of Dominion Bridge Ltd., Montreal, is gratefully acknowledged.

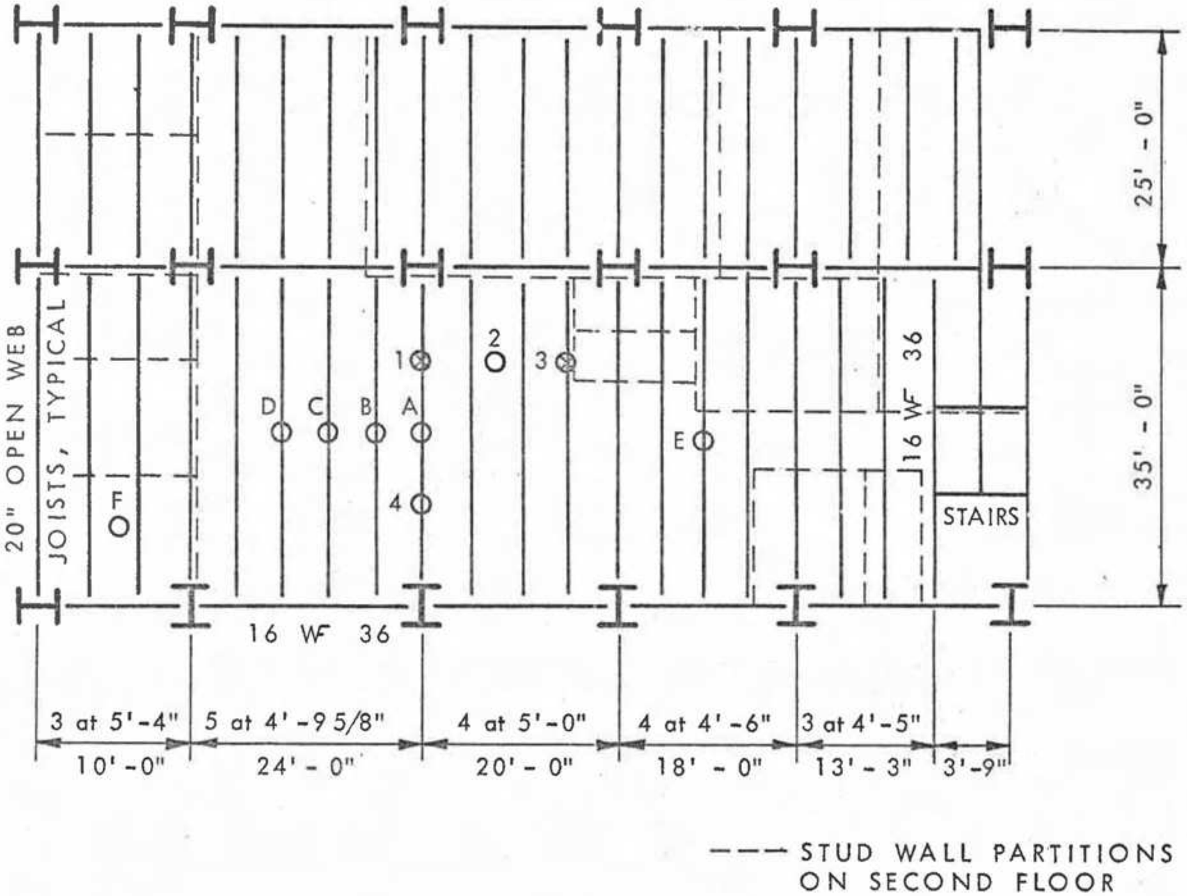

FIGURE 1

SECOND FLOOR FRAMING PLAN AND TRANSDUCER LOCATIONS (A TO F, 1, 2 AND 4)

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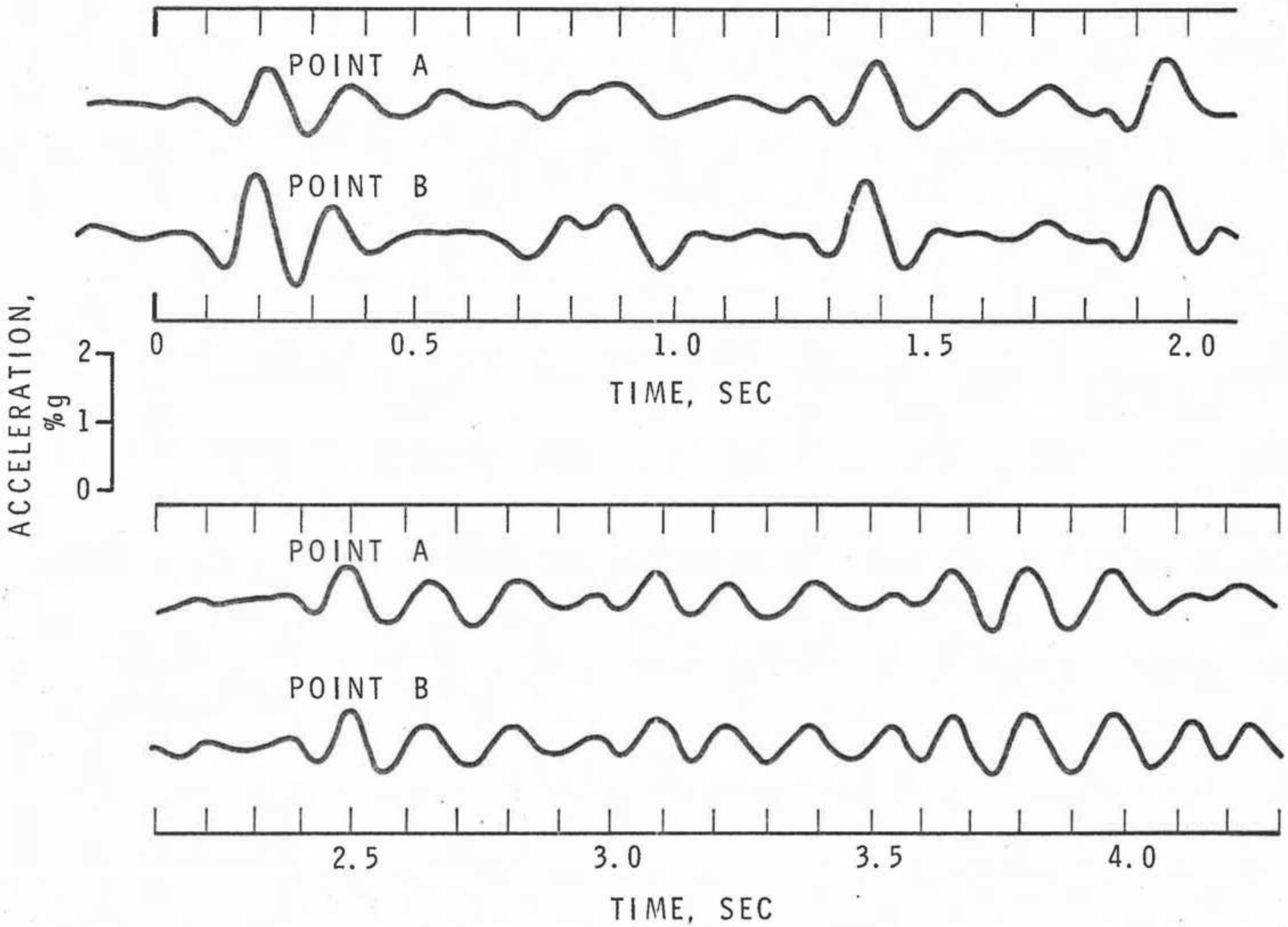

FIGURE 2

FLOOR VIBRATION RESULTING FROM A PERSON WALKING NORMAL TO JOIST SPANS

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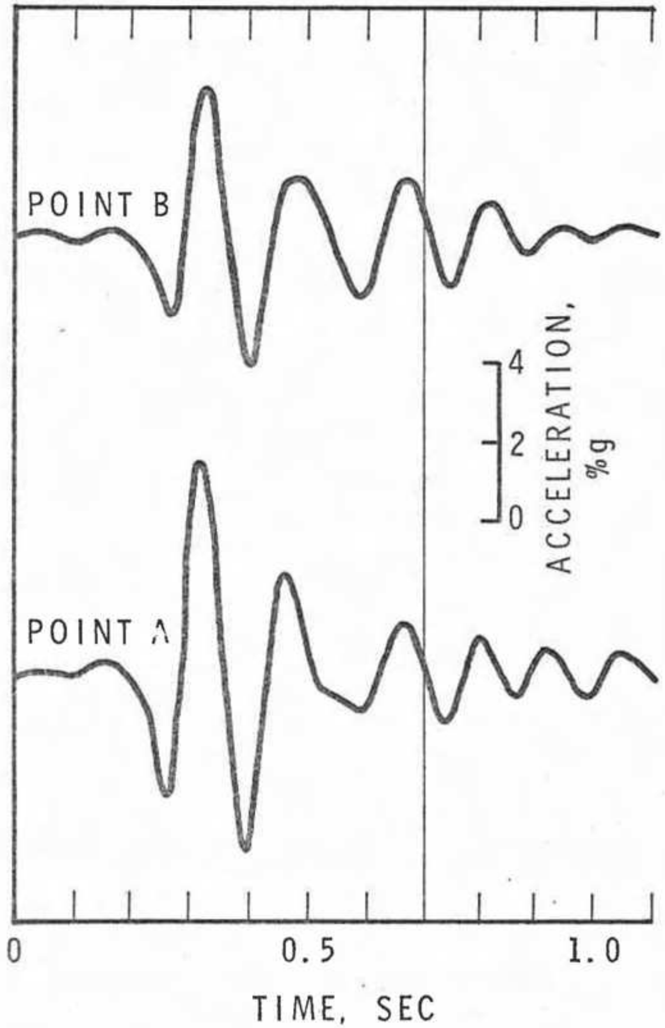

FIGURE 3

VIBRATION OF POINTS A AND B DUE TO HEEL IMPACT AT A

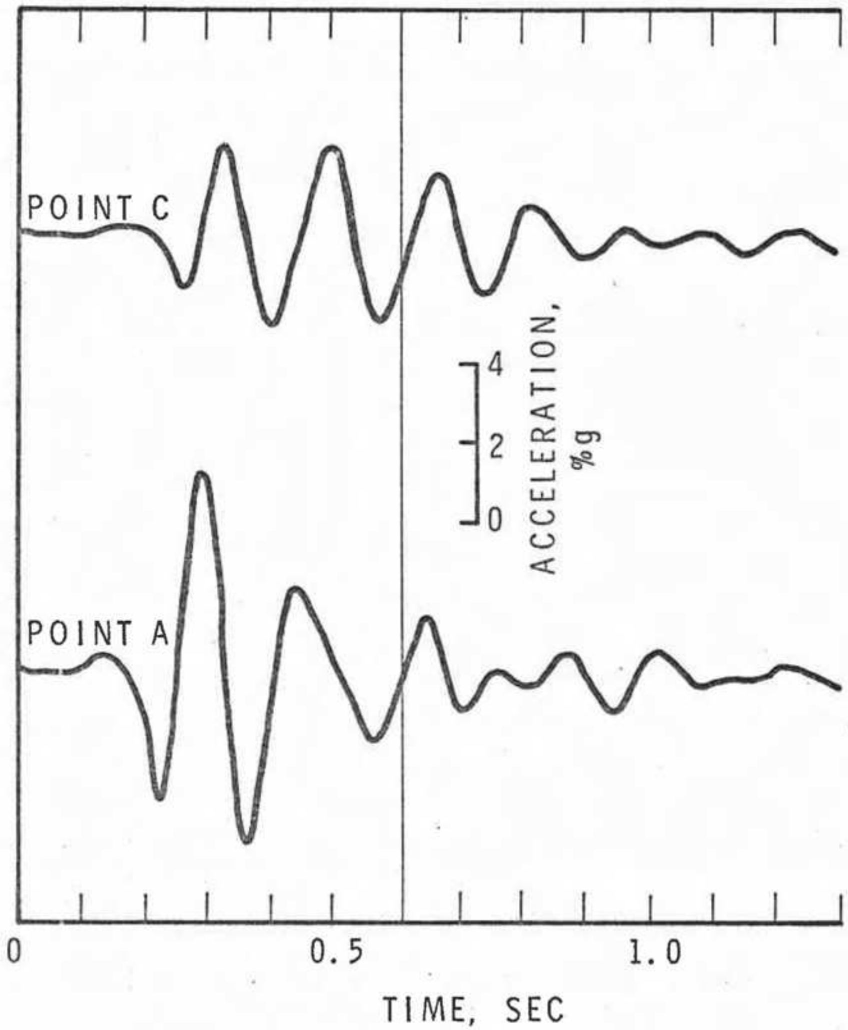

FIGURE 4

VIBRATION OF POINTS A AND C DUE TO HEEL IMPACT AT A

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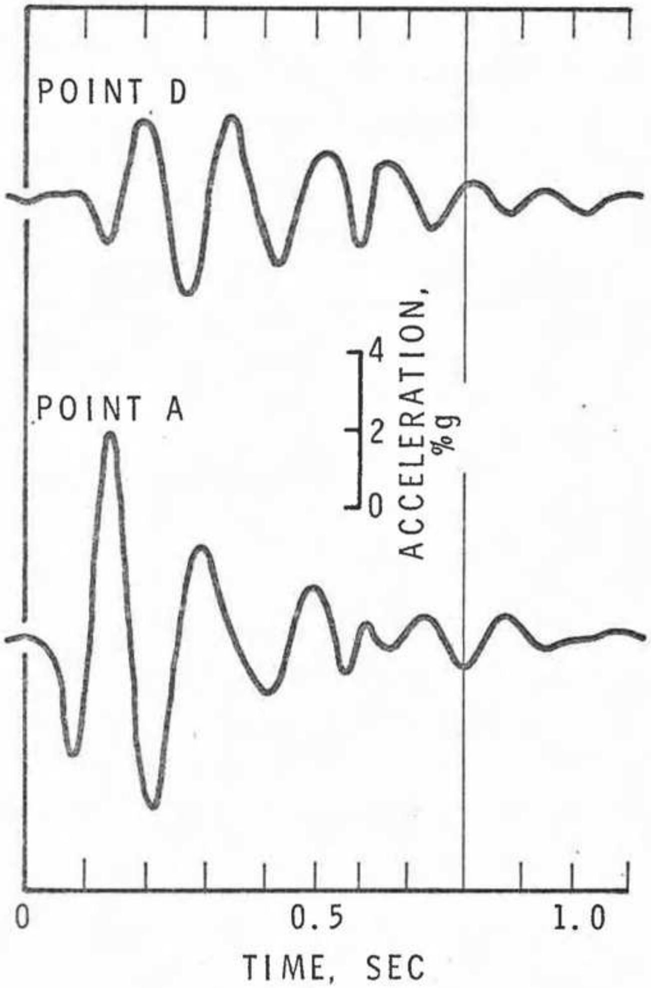

FIGURE 5

VIBRATION OF POINTS A AND D DUE TO HEEL IMPACT AT A

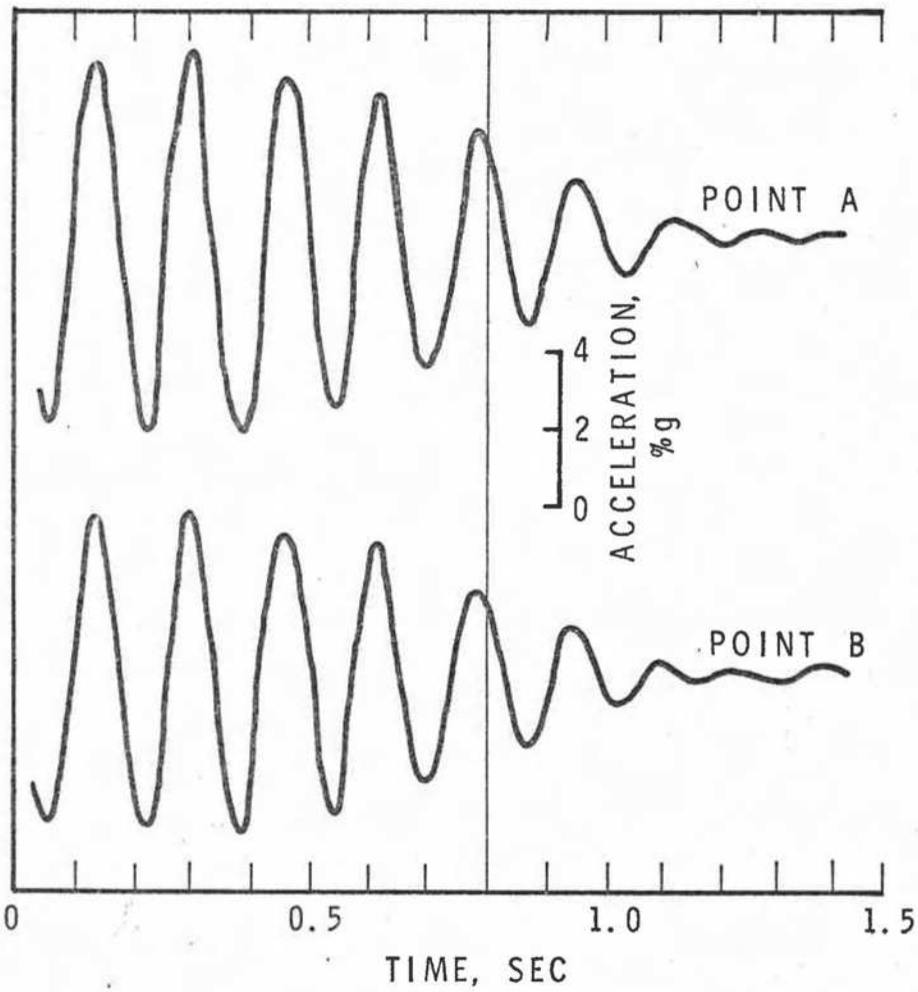

FIGURE 6

VIBRATION DECAY FROM STEADY STATE EXCITATION AT POINT A

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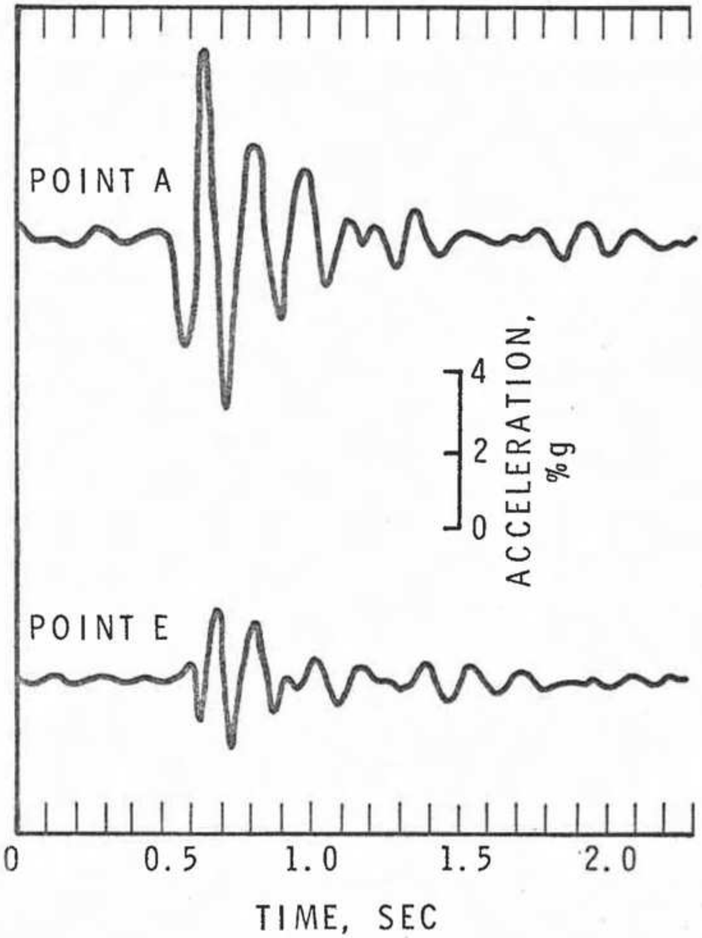

FIGURE 7

HEEL IMPACT TEST AT POINT A

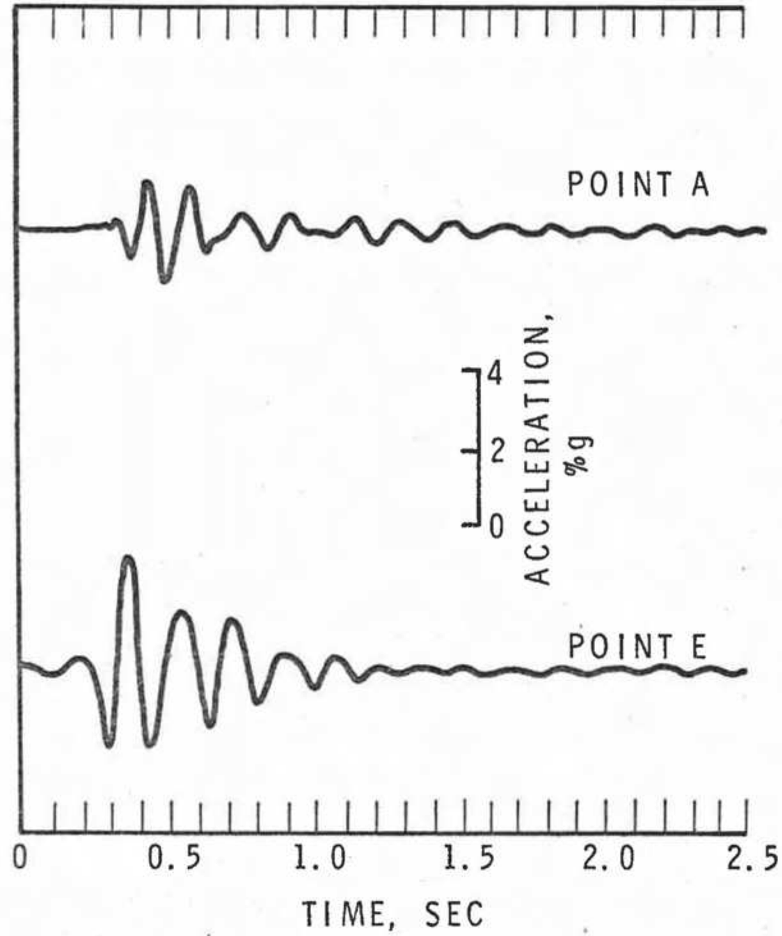

FIGURE 8

HEEL IMPACT TEST AT POINT E

BR 5106-5

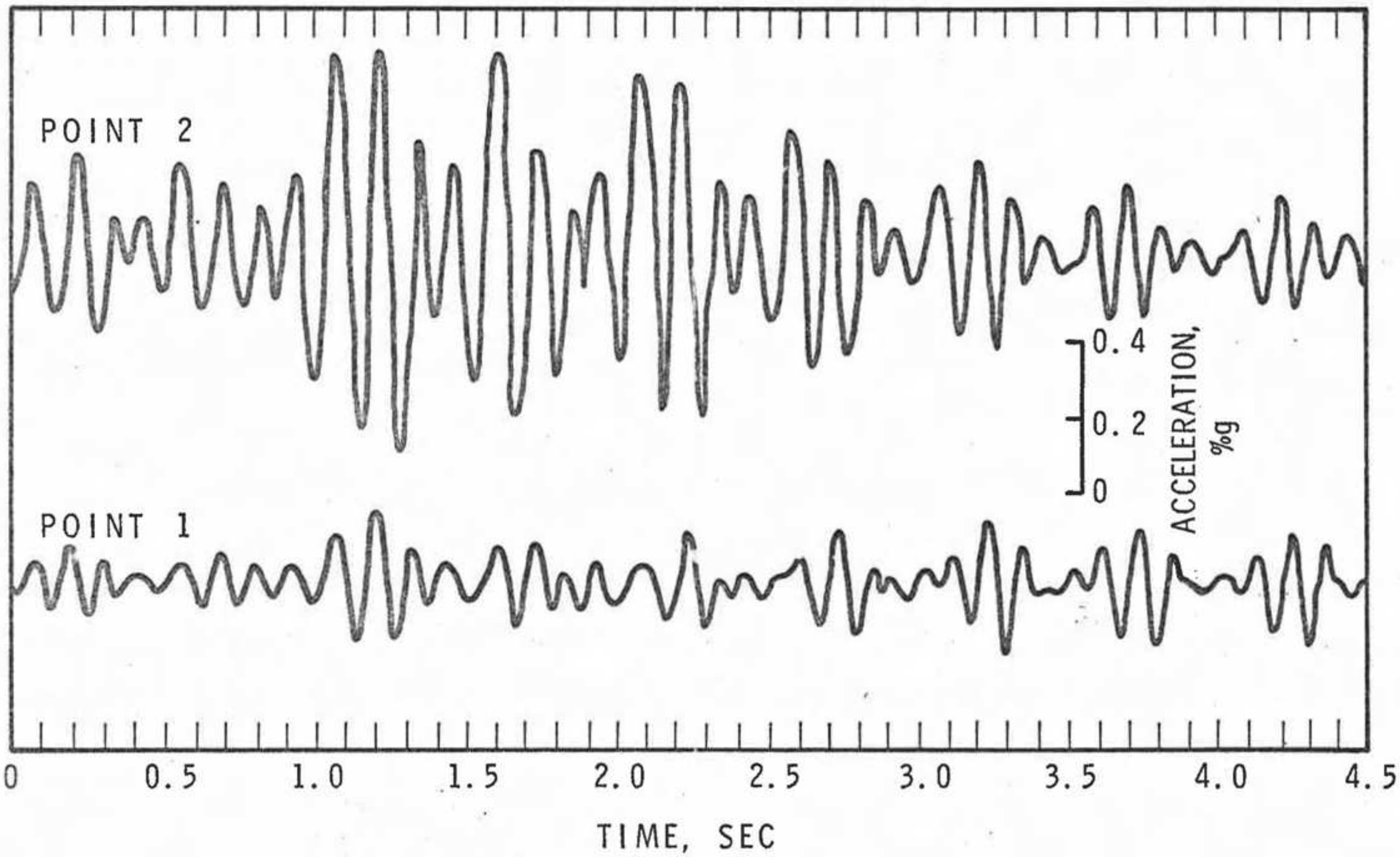

FIGURE 9

VIBRATIONS FROM PERSON WALKING NORMAL TO JOISTS. SUPPORT UNDER POINT 1

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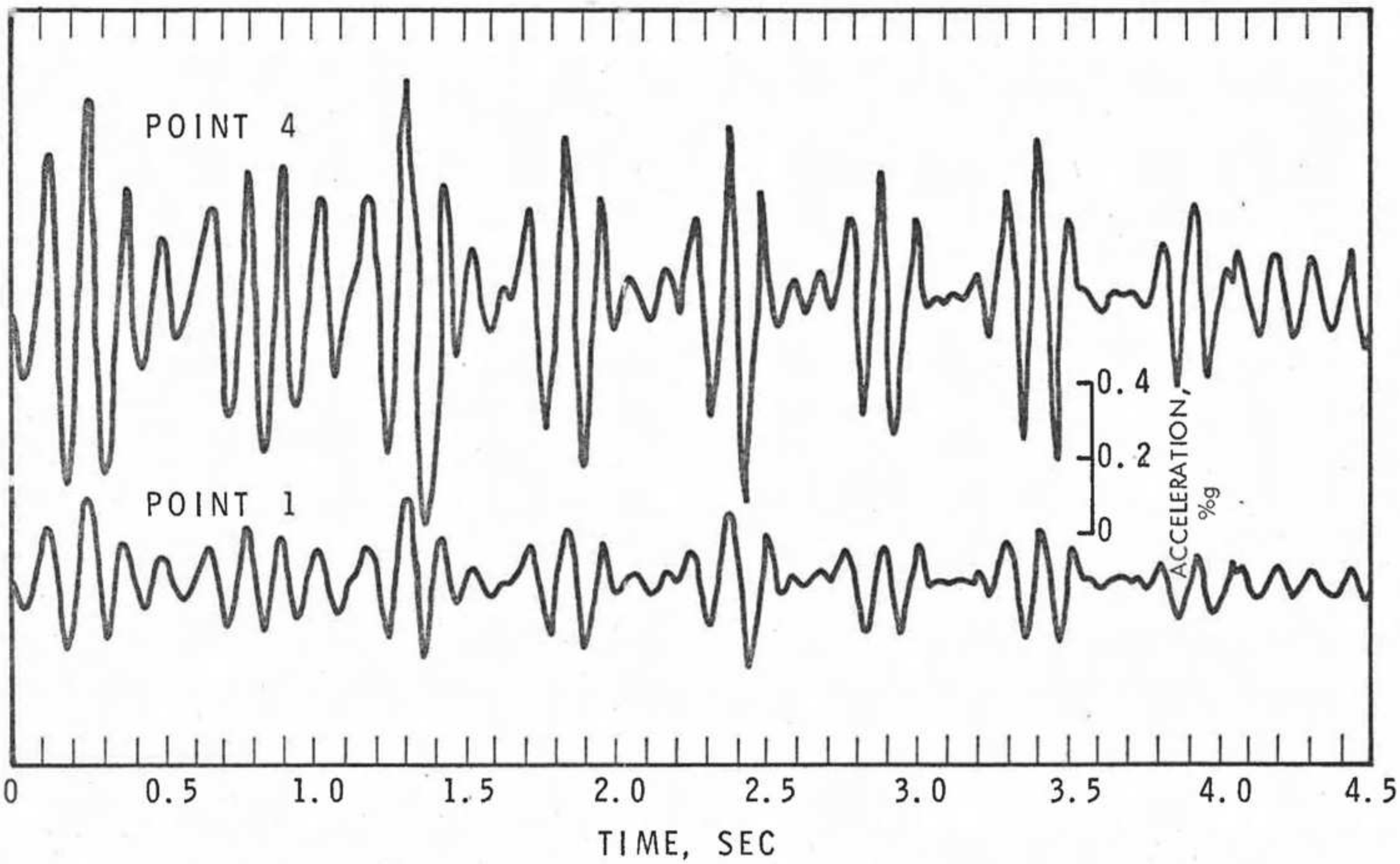

FIGURE 10

VIBRATIONS FROM PERSON WALKING NORMAL TO JOISTS. SUPPORT UNDER POINT 1

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