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VIBRATIONS CAUSED BY PILE DRIVING

by

R. H. Ferahian

This annotated bibliography gives information concerning the magnitude of vibrations and/or settlement in the soil or buildings caused by pile driving. It has been prepared in answer to an enquiry received by the Division of Building Research. The references contained in this list are those held in the Library of the Division of Building Research.

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1965

Crockett, J. H. A. Some Practical Aspects of Vibration in Civil Engineering, p. 253, Symposium on Vibration in Civil Engineering, Imperial College, April 1965, G.B.

This paper ranges widely over vibration control in civil engineering, describing a number of failures, and their solutions. A variety of recent schemes carried out or projected is described and some research on very long-term vibration effects is discussed. There is a brief reference to the present state of the law in Great Britain regarding vibrations. The section on vibration control in piling virtually reproduces the relevant sections of the paper by Crockett, 1959.

Lambe, T. W. and H. M. Horn. The Influence on an Adjacent Building of Pile Driving, for the M.I.T. Materials Centre, Sixth International Conference, Montreal, Canada, September 1965, International Society of Soil Mechanics and Foundation Engineering.

This paper presents the results of field measurements of heave and settlement of Building 10, the central structure of the MIT Campus, and pore water pressures developed under it as a result of pile driving at the adjacent site of the Materials Centre (Building 13). Maximum heaves between 0.02 and 0.03 ft. were measured during pile driving and maximum net settlements between 0.02 and 0.03 ft. were recorded after completion of pile driving. The heave preceded the settlement. Values of excess pore pressure head greater than 40 ft. of water were measured. The pore pressures built up and dissipated at very rapid rate, and the building movements were much smaller than would be expected from the large excess pore pressures which were developed. A theoretical analysis based on the "stress path method" correctly predicts a small net settlement, but considerably overestimates the actual value.

Building 10 is founded on timber piles (design load 10 to 12 tons per pile) which terminate in the upper portion of the soft clay. The Materials Centre (which is behind Building 10) is supported on 537 cast-in-place piles driven into the till and/or rock. Each pile has a design load of 70 tons and consists of concrete-filled steel shell having 12 3/4 in. outside diameter and 1/4 in. wall thickness. Because of its settelement record, central location, aesthetic importance, and close proximity to the site of construction (as close as 10 ft.) there was considerable concern for the safety of Building 10 during construction. To reduce chances of disturbing the building, the piles of Building 13 were pre-augered.

<u>1963</u>

Alpan, I. and T. Meidav. The Effect of Pile Driving on Adjacent Buildings - A Case History, RILEM Budapest 1963, Vol. 2, pp. 171-81.

During the building operations of a new housing project adjacent to two-storey buildings, harmful vibrations were observed in connection with pile driving. It is established that the detrimental effects of the vibrations can be substantially diminished by the use of pre-augered piles. The author reports that the examination of the energy transmitted by the vibrations enabled a better assessment of the degree of damage than the comparison of the acceleration criteria.

Ihara, R. et al. Investigation of Vibration and Noise due to Pile Driving, Rly. Res. Inst. Tokyo Qtly. Rept. 1963, 4(3), 38-9.

1961

Sior, G. The Damaging Effects of Vibrations due to Pile Driving Operations, Bautech., 1961, 38(6), 181-5.

This paper examines the possibility of damage due to pile driving operations and suggests suitable limits of vibration. The following are some of the conclusions:

(1) A general relation between the magnitude of impact and the amplitudes of the vibrations could not be established.

(2) Damage may occur due to elastic and/or plastic soil deformations.

(3) Waterclogged soils show higher amplitudes of vibration.

(4) The process of pile driving compacts the soil, thus raising its natural frequency. This compaction does not, however, cause an increase in the amplitudes of vibration.

(5) The greater the penetration of the pile, the smaller is the vibration.

(6) For soft soils, there is virtually no attenuation of the vibrations within a radius equal to the depth of the pile. The three components of the vibrations have virtually the same magnitude.

(7) Protective ditches around the structure can lower its vibration levels.

(8) A steam hammer (energy 5 ton metres/blow) driving steel sheet piles in a cohesive soil caused vibrations, at a point 4 metres away, of vertical amplitude 662μ at 18 Hz. μ is a micron (1×10^{-6} of a metre) and Hz. stands for hertz (cycles/second). The amplitude of vertical vibrations due to pile driving (Franki type) at the same distance was 535μ at 14 Hz. The driving energy was 12 ton metres/blow.

(9) The vertical vibrations in a building due to pile driving 6 metres from it were virtually the same as that caused by a diesel tractor with two loaded trailers passing by at a distance 8 metres away. The amplitudes measured were approximately 20 μ and 50 μ at 7 Hz. on the basement and third floors respectively. The points of measurements were near the walls of the building.

(10) On a cohesive soil the vertical amplitudes of the vibration due to driving a pile 3.2 metres long and with an energy of 12 ton metres/blow was 19 μ at 22 Hz. measured at a point 15 metres away. This was virtually the same as the vibration caused by a fast train passing 7.5 metres away from the point of measurement.

Sonics Drive a Pile 71 ft. while Steam Drives Another 3 in., Engineering News-Record, V 167, November 9, 1961, pp 24-26.

This paper discusses the merits of the vibratory pile driver with special emphasis on the Bodine Sonic Pile Driver. It emphasizes that the Bodine machine works within the sonic range up to and over 100 cycles/second as opposed to frequencies ranging from 15-22 cycles/second for the earlier machines. The suitability of these pile drivers for the different soil conditions is discussed.

<u>1960</u>

Mathieson, E. Some Notes on Vibration Measurements on the Bridge of Don, Civil Engineering and Public Works Review, 1960, <u>55</u> (645), 503-4.

This article presents the results of vibration measurements taken in the course of the construction connected with the widening of the existing Bridge of Don in Aberdeen, Scotland. Vibrations due to pile driving and traffic were recorded. Driving of the piles was by McKiernan-Terry No. 7 steam hammer. The records quoted are for a pile driven 3 ft. from the existing pier. The following conclusions were arrived at:

(1) The maximum vibration recorded on the bridge caused by traffic was of an amplitude of 0.00014 in. at 10 cycles/second.

(2) The maximum vibration recorded on the bridge caused by pile driving was of an amplitude of 0.00016 in. at 100 cycles/second.

(3) All the vibrations recorded were very small and not likely to cause any damage.

(4) The maximum movement caused by pile driving was similar to that caused by traffic. The frequency of the former was greater, but was attenuated very quickly after two cycles of movement, whereas the traffic vibration persisted while the vehicles passed along the spans at either side of the pier.

<u>1959</u>

Crockett, J. H. A. Vibration Control in Piling and Blasting, The Reinforced Concrete Review, Vol. V, No. 2, June 1959.

The author recognizes two main types of vibration control from piling:

(1) the immediate effects of high-acceleration shock, local to the pile;

(2) the oscillatory problems induced by ensuing train of large and fairly constant frequency waves.

The following actual cases are discussed:

(i) Test piling 3 to 4 ft. away from an existing flour mill in Victoria Docks, London, England. The building, typical of the nineteenth century heavy brick-walled construction, had been founded on timber piles. The site consists of an old swamp. The natural frequency of the partly drained soil was 3 1/2 cycles/second. In the early stages of penetration the pile, being in a very unstable condition, vibrates as an inverted pendulum and so transmits a great deal of its excess energy into horizontal vibration waves in the ground. The surface waves, though very large at first, caused quite harmless accelerations because of their low frequencies. The vibrations became steadier as the penetration increased. Down to about 7/8 of the final penetration of the pile, the vibration records at the ground floor level, adjacent to the test pile, show initial sudden movement with acceleration little more than 1/10 g. Thus, the point was approached when sliding of horizontal joints in the brickwork might have been expected. As the test pile was driven further home, however, the soil vibrated less and less. The worst factor of safety was about 1.6 for the horizontal shear. It was decided by the architect in charge that the risk was too great and another form of piling was adopted which induced much less vibration.

(ii) Two buildings on opposite sides of a road in Hull, England, were being constructed simultaneously; one in reinforced concrete frame was finished up to about the second floor level, while that on the opposite site was in the stage of precast pile driving. The green reinforced concrete frame was vibrated so much that its designer wished to stop the piling and the legal powers available were strong for such action. An extensive survey was taken around the piling area and across the road on and around the new reinforced concrete frame. The soil was exceptionally soft silt or clay, with water, causing considerable ground vibrations. The contractor and other people on the structure felt a great deal of vibration, while the light and springy shuttering was actually rattling. The results of the vibration measurements showed that the soil vibrations due to pile driving, with their small amounts of energy compared with that of the usual 1/4 h.p. vibrator, had a negligible effect on compaction, the centring and the shuttering.

(iii) The control of pile driving operations for several modern apartment blocks situated about 130 ft. from a superb building constructed in 1740 and declared a National Monument, whose ceilings and plaster work were considered to be of great importance, was studied. A 17 in. diameter standard West's Rotinoff test pile was driven 150 ft. away from the house on the approximate site of one of the new apartment blocks. The maximum weight of hammer--3 tons--was used, falling through a height of 3 ft. maximum. No special problems over the site were encountered, and all vibrations within the house structure itself were all less than indicated by the caution curve of Crandel. Since this building was a special one, a new criterion was to be formed. Using the experience of the expert plaster restorers, a relationship was established between the number of cycles of a given amplitude the plaster ceilings are expected to withstand during the normal use of the building in 150 years. The craftsmen estimated the 150 years as the interval before the next restoration of the ceiling is needed. The estimated maximum amplitude due to pile driving around this building was 0.0006 in. with frequencies 10 to 18 Hz. For the estimated number of cycles from the piling operation, the effect on the plaster work was the equivalent of footsteps of people walking about the floors at the domestic rate for 4-5 years. It seemed therefore that there was ample factor of safety against damaging the delicate plaster work.

(iv) A new building in North London was intended near an existing aluminum-framed and clad building, so a test pile was driven to about half penetration to induce maximum ground vibrations. The building was of single-storey, portal frame construction, its maximum height being about 25 ft. at the ridge. Every single part of the building vibrated more strongly than the ground. The cladding of the building vibrated in some places with amplitudes 107 times greater than that in the ground which induced it. Calculations indicated that the total number of the stress variations would be well within the fatigue limit of the aluminum alloys of which the building was constructed.

1955

Steffens, R. J. The Problem of Vibrations in Buildings, Note E 583, February 1955, B. R. S. Garston, G. B. p. 11.

In a survey undertaken in the Huntingdon area (England), piles 20-25 ft. long were driven into clay by a 2-ton single acting hammer. At a distance of 90 ft. from the pile driver, amplitudes of about 0.0006 in. vertical and 0.0002 in. horizontal were recorded, the frequency being generally 10-15 cps. In a house which was 120 ft. from the pile driver, amplitudes of 0.0001 to 0.0002 in. were recorded. Typical records are shown. Measurements taken in the Brentford area, where sheet steel piling 15 ft. long was being driven by a double acting (5000 lb.) hammer at a distance of only about 15 ft. from the outer wall of a house, showed maximum amplitudes of 0.00053 in. vertical and 0.00070 in. horizontal, the frequencies here being usually about 30 cps.

1950

Mallagh, T. J. S. and J. J. Dowling. Vibration from Piling with a Note on Simple Seismograph Equipment used in Pile Vibration Tests, Transaction Vol. 76, Session 1949-50, No. 5, The Institution of Civil Engineers of Ireland.

This paper examines the vibrations due to driving of Franki test piles, in connection with the provision of foundations for a grain silo at Alexandra Quay, Dublin, Ireland. The effect of vibrations might have been serious as the existing rafted buildings had settled unevenly by over a foot. The piles for the proposed foundation had to be driven to within 8 ft. of these buildings through sandy and silty soils of reclaimed land. The vibrations recorded are correlated to the depth of penetration, driving resistance and driving energy. An interesting observation drawn from the results is that the amplitude of the vibrations varied only to a limited extent with variation in the drop of the hammer. Two test piles driven by 9 and 18 ft. drop of the hammer produced practically the same vibrations.

1938

Van Der Haeghen, J. F. L'auscultation des monuments et l'observation de leur stabilité (The Vibration of Monumental Structures), Extrait de la Revue des Questions Scientifiques, mars 1938, Etablissements Fr. Ceuterick, Louvain.

The author describes the effect of traffic, pile driving, ringing of the bells, and wind on "Notre Dame de la Chapelle" Cathedral in Brussels, Belgium. This historical monument, noteworthy in its Roman and Romano Gothic Architecture, is one of the oldest in Brussels. Its great nave and side aisles were erected between 1421 and 1483; the tower dates back to 1504 and the bell tower to 1708. The study of vibration of this historic monument was prompted during the construction of the north-south traffic interchange which required an eight metre tunnel excavation only 15 metres from the tower. It is easy to imagine the delicate situation created by this excavation especially as the entire base of the cathedral is founded on the Bruxelian sand.

The construction of the tunnel called for lowering the water table and trenching under the protection of two curtains of sheet piling 18 metres deep, 34 metres apart and braced by steel framework. The vibrations due to the drop of the 6-ton pile driver in conjunction with the effect of trenching and lowering the water table on the stability of the sandy soils did cause tilting and settlement of the foundations. The rate of these movements were kept within the safety limits by severe restrictions imposed on the pile driving operations. These were effected by limiting the number of pile driving operations per day and also reducing the height of drop of the ram. Vibrations were observed even when the pile driving was as far away as 170 metres. These vibrations were felt not only over the whole extent of the church, but also throughout the entire quarter.