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DYNAMIC LOADING OF SOILS AND FOUNDATIONS

Shamsher Prakash*

Synopsis

In this paper, the problems of dynamic loading of soils and foundations have been briefly described. These include stress-strain characteristics of soil, stability problems and problems associated with machine foundations and compaction of soils and application of blasting techniques for civil engineering purposes. Areas where fruitful research is needed have also been indicated. A comprehensive bibliography has also been appended.

Introduction

Dynamic loads may be caused due to (a) earthquakes, (b) bomb-blasts, either surface or air, (c) machines, (d) fast moving traffic and (e) construction operations e.g. pile driving. The nature of loads may be repetitive, and such loads pose a variety of problems to a foundation engineer in the design of earth dams, retaining walls and machine foundations. The phenomenon of dynamic loading can be usefully employed for constructive purposes e.g. pile driving for compaction of loose soils and for large scale excavations. In this paper, different facets of these problems have been described in brief along with suggested problems for research. A comprehensive list of bibliography has been appended for further reference of the reader.

Nature of Loads

The loads occuring in nature may be classified into the following categories:—

(a) Slow repetitive

(b) Fast repetitive

(c) Transient

  (i) Single impulse

  (ii) Multiple-impulse

Figures 1 and 2 show schematically the diagrams of dynamic loods versus time. These are very simplified presentation of actual loading conditions. Actual loads in the field may often differ from the simplified loading diagrams presented above in the following respect:—

(a) The loading in nature is not truly periodic. Also, the magnitude of load in subsequent loading cycles is not the same as in the first cycle. This is especially so during an earthquake, Figure 3. Figure 4 shows trace of vertical acceleration of ground due to pile driving operations.

(b) Purely dynamic loads do not occur in nature. It is always a combination of static plus dynamic load. Static loads are caused by the dead weight of the structure and the sub-structure.

* Professor of Soil Dynamics, University of Roorkee, Roorkee, U.P., India.

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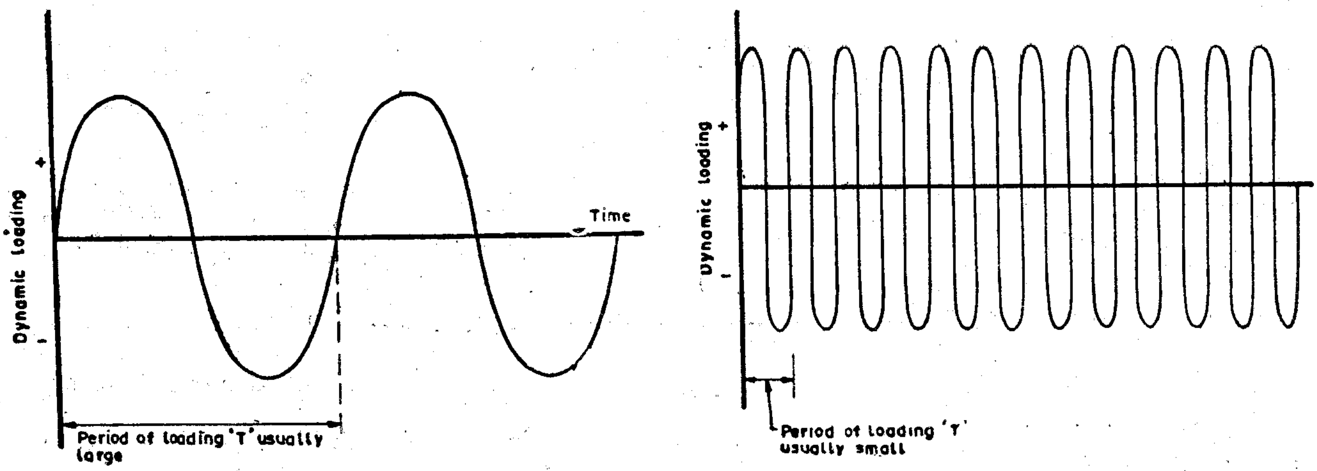
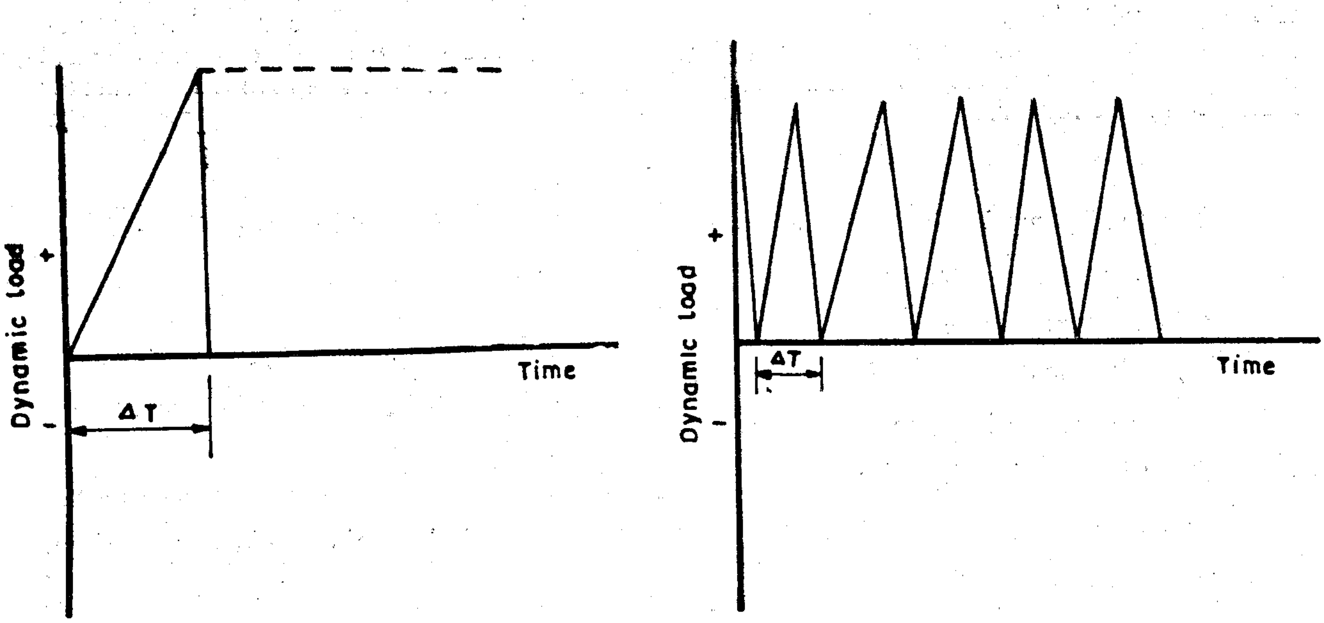


a–Slow repetitive loading b–Fast repetitive loading

Fig. 1—Steady state dynamic loading



a–Single impulse transient load b–Multi impulse transient load

Fig. 2—Transient loading

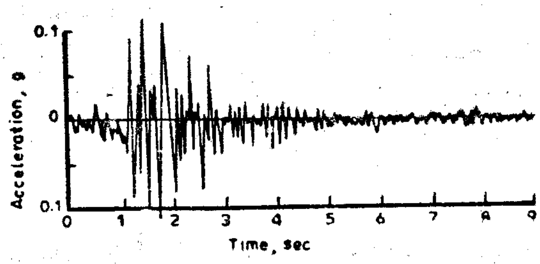


Fig. 3—Typical earthquake record Elcentro, May 18, 1940 N-S component

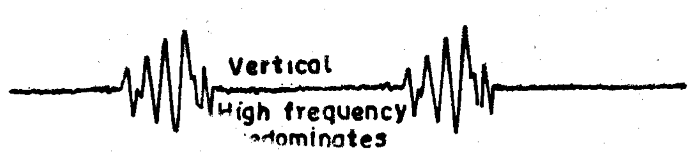


Fig. 4—Trace of vertical acceleration of ground due to pile dreving

If the frequency with which the load is applied is close to the natural frequency of the system, the effect of both dynamic nature and resonance is felt. However, if the frequency of loading is far removed from the natural frequency of the system, the effect of only rate of loading is perceptible.

It is not quite easy to determine precisely the natural frequency of systems involving structures made up of soils e.g. embankments, fills and foundations. Therefore, many a time an arbitrary criterion is employed.

Problems of Dynamic Loading of Soils

In the following sections different aspects of the various problems of dynamic loading of soils are briefely discussed.

1. Stress Deformation and Strength Characteristics of Soils.

Soils differ from other engineering materials like concrete and steel in many respects. One of the factors of great importance is that the soils are formed by processes of nature over which no human agency has any control. As a result of this, the soils are heterogeneous in nature and determination of soil properties is a necessary job in connection with any foundation project. The dynamic loading introduces an additional variable. In any case, an effort has to be made to simulate the loading conditions of the field in the laboratory.

All the soil tests reported in the published literature may be classified into the following categories :—

(a) Transient loading tests.

(i) Single impulse transient load (Casagrande and Shannon 1948).

(ii) Transient pulses repeated at regular short intervals a number of times (Seed 1960, Seed and Chan 1966).

A combination of static and dynamic loads simulates the field conditions to a better degree.

(b) Vibratory loading tests.

(i) Samples subjected to vibratory loading of known characteristics i. e. stress level, frequency and amplitude of vibrations and then sheared as in routine tests.

(ii) Soils samples being under vibratory load during tests. This loading condition simulates field loading conditions to a better degree.

Various aspects of this problems are as follows :—

(a) Special equipment needs be designed to simulate field loading conditions. The recording of load and deformation and pore pressures is done on automatic recording devices.

(b) Effect of increased rate of loading on shear parameters c and ϕ, and shear modulus and strain at failure.

(c) Effect of pore pressure on strength in saturted soils.

2. Stability Problems

These include stability of earthen embankments, retaining walls and other retaining structures and stability of foundations. In earth retaining structures, the problem is to compute active and passive earth pressure. Mononobe-Okabe (1929) modified Coulomb's theory and determind an expression for dynamic earth pressures behined retaining walls. Kapila (1966) suggested modified Culumann's construction. The main difficulty is in ascertaining the point of application of the dynamic earth pressures. Experimental investigations carried out in Japan do indicate that the dynamic earth pressure acts at an elevation higher than one-third above the base of the retaining wall assumed in Mononobe-Okabe theory. Analytical and experimental investigations on flexible model retaining walls performed at Roorkee also indicate that point of application of the dynamic increment lies at a higher elevation than one third height from the base. Indian Standard Code (1893–1966)* arbitrarily recommends that dynamic increment of earth pressure be applied at two thirds the height of the retaining wall instead of that at one-third height.

Also, no information is at all available on the change of static "earth pressure at rest" if the basements are subjected to an excitation by an earthquake. These are fruitful areas for future research.

In the stability of earthen embankments, several problems are there. A design engineer is interested in determining the response of the dam to anticipated ground motion (Krishna 1962). He also wants to have tools to perform stability analysis, accounting for changes in properties of the soils due to dynamic nature of loading. (Seed 1960 Prakash, 1966). Information on field behaviour is extremely scanty. Therefore many a time, investigators resort to model tests. (Clough and Pirtz (1958), Seed and Clough 1963, Krishna and Prakash (1965, 1966) Krishna, Prakash and Thakker (1969). However there are uncertainties involved in extrapolating the model test results to prototypes. Perfecting of model testing technique is very fruitful area for future research. Analytical research on stress distribution and deformation pattern within the body of dam and in foundation has been attempted by various investigators by finite element analysis. Fundamental assumption of all such analysis reported to-date (1969) is that the soil is a linearly elastic material. Clough and Chopra (1966), Chopra (1967), Lian Finn and Khanna (1966), Saini and Sekaran (1968 a, b).

Stability of dam foundations is equally important. If the foundation material happens to be medium or loose sand, it may be subjected to complete or partial liquefaction during an earthquake. The problem of liquefaction has been studied in detail by Maslov (1957), Florin and Ivanor (1961), Prakash and Mathur (1965), Krishna, Prakash, Mathur and Gupta (1967) and Prakash and Gupta (1967, 1968), Seed (1968). The investigations fall under two categories : one, tests on soil models on the vibration table and the other, tests on triaxial specimens. In both the cases there are uncertainties in infering the laboratory results to field. Blast test were carried out both at Obra dam site in Uttar Pradesh and Tenughat dam site in Bihar in order to ascertain the possibility of the respective sands to liquefy during an earthquake. Laboratory tests on both the sands were also performed. Correlations of field and laboratory data are promising. (Krishna and Prakash 1967, Prakash and Gupta 1968 b).

Stability of footings during and earthquake and bomb blasts is a problem which has not been paid adequate attention. A footing may be subjected to excessive differential settlement and thus cause damage to the superstructure. In Niigata earthquake of 1964,

* Revised.

the buildings sometimes tilted as much as by 60° with the vertical (Prakash, Gupta and Chandersakaran 1968). This resulted from excessive differential settlements. No precise methods are available to compute total settelements of footings under dynamic loads. Differential settlements on account of even known total settlements is any body's guess. The problem does not appear to be prone to mathematical treatment without over simplifying assumptions because of heterogeneous nature of soils. However, carefully conducted model studies for a specific field problem may offer an alternative and workable solution. The scale of the model is likely to play an important role.

Bearing capacity failure of the soil is not likely to occur primarily because the initial factor of safety in well designed footing is quite high.

(d) Machine Foundations

Design of Machine fondation is a very complex job. The design enigeer is first faced with the problem of slecting a method of analysis out of a host of them available, based on theory of elasticity, soil spring concept and several empirical ones. The other problem is to determine suitable soil constants to be used in the design. The soil constants can be evaluated by (i) laboratory tests, (ii) field static tests and (iii) field dynamic tests. Field dynamic test including resonance test on block is recommended since it gives more realistic values. Such a test is usually performed by mounting a mechanical oscillator either on test block or a test plate*. The force of excitation in such a block varies with the frequency. It may therefore be desirable either to incorporate a device in the oscillator so that the force of excitation remains constant with variation in frequency or different oscillators may be used, which would satisfy the above requirement.

In resonance tests, the natural frequency of the soil foundation system depends upon the force of excitation. The ratio of unbalanced force to static weights in an actual machine is usually not more than 10 percent. It is therefore desirable that in a field test this criterion may be adhered to.

In many cases, it may be difficult to excite a block to resonance. Natural frequency in such cases can be determined by studying the free vibrations of the system. The natural frequency so determined is usually higher than the one determined in forced vibration tests. A correlations betweeh the two natural frequencies has been attempted by Puri (1969) based on typical model tests on blocks. Further verification of this correlationship will go a long way in simplifying the interpretation of field tests.

3. Peaceful Uses of Blasts

In earth dam construction, compaction of soils is a must. If the foundations are of loose or medium density and comprise of sands, vibratory technique of compaction may be more effective. Desired densities mey be achieved either by vibroflotation, blasting and pile driving. Vibroflotation is a patented process, while the other two methods can be adapted for use freely. Sufficient quantitative data on planning a field job by blasting technique is available (Prugh 1963, Lyman 1962, Hall 1962), while no such information is available on the amount of compaction achieved by pile driving. Some studies on this aspect of the problem are desirable.

Large excavation jobs can be handled efficiently by mechanical equipment. American engineers are postulating the use of nuclear blasts for excavation of a sea-level Isthmian

* Draf Indian Standard Methods of Test for the Determination of in-situ Dynamic Properties of soils DOC BDC 43 (1476) Jan. 1969.

Canal to connect the Atlantic with the Pacific. (Magnusan 1964, Vortman 1964). This will offer a route parallel to the existing Panama Canal. It is estimated that the technique of nuclear blasting would prove to be cheaper for especially large jobs. It is believed that with cheap manual labour available in India, it may not be necessary to envisage the use of these techniques in the immediate furure.

4. Vibratory Drilling

Piles are driven by conventional methods in this country so far. Considerable effort is spent in the actual operation of driving the pile with the help of pile hammer. Russian engineers have developed vibratory techique of driving piles and caissons. The effort involved in driving a pile by a vibratory hammer is reduced to almost nil. Russians have perfected pile drivers to drive caissons of as much as 5m outer diameter (Levkin 1960). In U.K. and USA also, vibratory drivers are gaining grounds. Once the technique is perfected, several other uses can be made e.g. in soil exploration.

Prakash and Singh (1967) report that for pulling out a 10 cm of casing about 18 m long on the campus of Roorkee University, it took them about a couple days. With a vibratory rig, this could be accomplished in a few minutes. Since large construction activity is ahead for us, development of vibratory hammers will prove to be a very desirable effort.

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DISCUSSION

Discussion on "Soil Investigations and Design of Forging Hammer Foundation" by Shamsher Prakash and D.C. Gupta, Bulletin, Vol. V, No. 1 and 2.

D. Raghu[1], The authors have to be congratulated for the nice work and excellent presentation of paper. However, it is felt that clarification may be made on the following points.

1. The number of strokes of hammer per minute is not mentioned. This is very important, particularly to check whether resonance will occur or not. If the frequency of the hammer strokes and any one of the natural frequencies of the system coincide, resonance will result.

2. It is mentioned in the article that the dynamic tests were made at a depth of 2.44 metres from ground level. It may kindly be mentioned whether the above tests were performed at the level corresponding to the bottom of the foundation.

3. The field data obtained by dynamic tests may be compared with those obtained in design calculations.

4. It is not known whether in the design of the foundations, the synchronism between the two hammers was taken into account or not. If during operation, the frequencies of these two machines synchronise, resonance will occur.

Reply by Authors, The authors are grateful to Sri Raghu for his interest in our paper.

(i) The frequency of operation of the hammer was 120 strokes per minute.

(ii) The dynamic tests had been performed at the depth of foundation proposed by the manufacturer.

(iii) We are planning a study of the performance of the hammer. The results will be reported when they become available.

(iv) The new hammer has been installed in a new shop and not in the existing forge shop. Hence the question of synchronism of the machines does not arise.

1. Department of Civil Engineering, B.I.T.S., Pilani (Rajasthan).