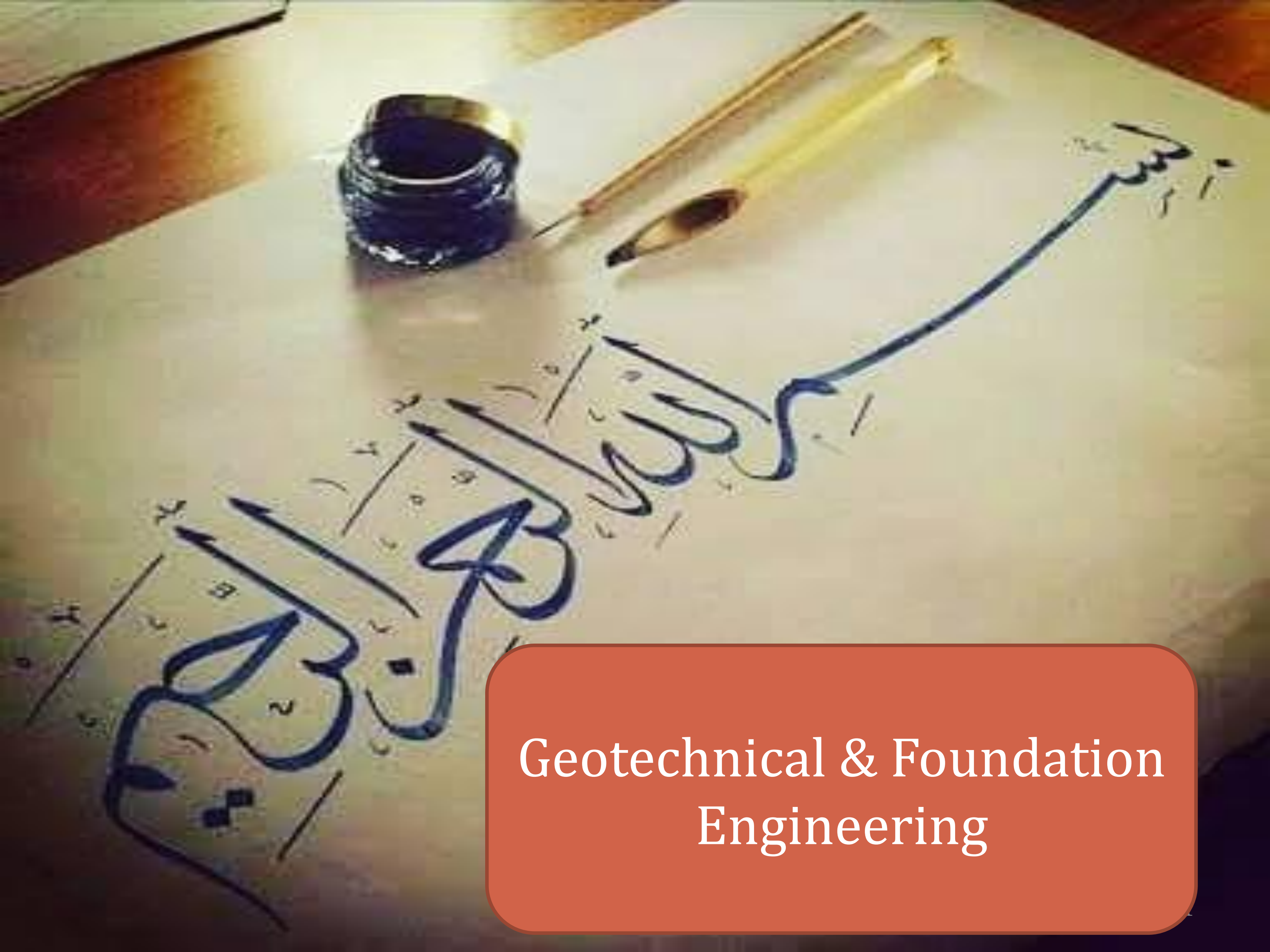

Geotechnical & Foundation Engineering

Soil Dynamics

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SOIL DYNAMICS

Introduction:

SOIL Dynamics deals with the engineering behaviour of soils subjected to time varying loads and loads applied very rapidly.

How soil responds to earthquakes comes in the domain of Soil Dynamics. 20 to 30 m of soil below ground surface significantly influences the damage patterns of structures during an earthquake. The nature of soils in this zone has a crucial influence on some important parameters of ground shaking that finally travels up to ground surface. This phenomenon is popularly known as *soil amplification*.

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Comparison: Soil Mechanics & Soil Dynamics

(i) In Soil Mechanics static loads are considered, that do not change with time. For example, the stress and strain induced at a depth below the ground surface due to construction of a dam are constant. ***Equilibrium equations*** are used to determine them. In Soil Dynamics applied loads vary with time. This implies that the stress and strain induced in the soil are also functions of time. The governing equations are thus those of ***wave propagation***.

(ii) Because of the difference in the nature of applied loads we need to consider soil parameters that are relevant for cyclic loading. These include inelastic hysteretic behaviour of soils and at times the increase in pore water pressure due to load repetitions.

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Comparison: Soil Mechanics & Soil Dynamics

iii) In problems of Soil Mechanics, the magnitudes of loads being applied *a priori*, i.e. loads are known and then analyze and design is carried out. In Soil Dynamics, sometimes loads may not be known as *a priori*. For example, the inertia forces generated during earthquakes are dependent on the earthquake itself and their magnitude becomes apparent only during the loading process.

(iv) In Soil Mechanics the basic interest is that vertical stresses imposed do not exceed soil capacity and vertical displacements, i.e. settlements are within permissible limits. In Soil Dynamics, particularly during earthquakes, focus is on lateral movements and attempt is to keep them within limits.

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Similarities: Soil Mechanics & Soil Dynamics

i) Engineering behaviour of soils under static as well as dynamic loading is a function of density, water content, confining stress, stress history, drainage conditions, levels of strains etc. In case of engineering behaviour of soils under dynamic loading, special attention needs to be paid to the rate of loading and whether, during shear, the soil dilates or suffers volume reduction. For example, if the rate of loading is increased while conducting an Unconfined Compression Strength test, typically the strength of the soil increases which can be attributed to viscous effects. Similarly, the pore water pressure developed during undrained tests can be negative or positive depending on the density of soil.

ii) There are similarities also in designing. For example, a footing is designed for a prescribed maximum settlement. A machine foundation can be designed on similar lines for a prescribed maximum amplitude of vibration.

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For the Consulting Geotechnical Engineer to be able to competently handle problems in Soil Dynamics requires that he/she be able to understand the requirements of Mechanical Engineers and be able to provide needed inputs to Structural Engineers. This calls for a good knowledge of vibration theory and principles of wave propagation as well as that of modem numerical/analytical techniques.

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APPLICATIONS:

1. Machine Foundations :

There are several types of machines such as reciprocating machines, rotary machines, punch presses, shredders, forge hammers, rollers, laser beam recorders, etc. that transmit time varying (dynamic) loading to the underlying soil. Machines such as reciprocating pumps and rotary machines transmit sinusoidal loading where as machines such as punch presses, shredders and forge hammers transmit impact type of loading to the underlying soil. Dynamic forces from these machines induce vibrations in the foundations and make it uncomfortable for the people working around them. If the vibrations are excessive, they can cause damage to the connecting piping or even the machine itself. Consulting Geotechnical Engineer should make sure that the vibrations of the designed foundation are within the prescribed limits as stipulated by the manufacturer of the machine and also that they do not cause distress to the surrounding structures. Also, appropriate remedial measures for an existing foundation transmitting excessive vibrations should be suggested.

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APPLICATIONS:

2. Geotechnical Earthquake Engineering:

Earthquakes can damage or destroy buildings, bridges, towers, retaining walls, dams, water front structures, in fact, all man made structures as well as naturally existing formations such as slopes. The frequency of earthquake loading may

(i) match the natural frequency of existing structures and give rise to *resonance* which manifests in inducing high displacement amplitudes leading to damage,

(ii) induce large inertia forces in a structure leading to excessive lateral forces, or

(iii) trigger *liquefaction* to take place in a saturated soil below the foundation and lead to structural damage or collapse.

Consulting Geotechnical Engineers have an important role to play in providing valuable input for seismic hazard mitigation such as:

(i) the natural period of the underlying soil,

(ii) the design ground motion for structures,

(iii) dynamic soil properties for soil-structure interaction studies, etc

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APPLICATIONS:

3. Construction Vibrations:

- Several processes employed during Civil Engineering construction such as dynamic compaction, vibratory compaction, blast densification of sand, pile driving, mechanical trenching, explosive demolition, etc. set off vibrations in the ground and these vibrations propagate through the surrounding soil to adjacent structures and may cause either damage or cosmetic cracking. Guidelines are now being developed using knowledge of the dynamic behaviour of soils along with response spectra of ground motions recorded during the above said activities. These guidelines are for such diverse activities as

(i) determining safe distances from the source of vibration,

(ii) organizing proper sequencing of blasts,

(iii) estimating the thickness of the lift and number of passes of the roller for compaction etc

Slope Stability

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SOIL DYNAMICS

APPLICATIONS:

4. Nondestructive Characterization of subsurface:

Nondestructive methods like seismic reflection, seismic refraction and spectral analysis of surface waves are increasingly being used to characterize subsurface geology and some times even the pavement systems. These methods use seismic waves and their propagation characteristics through underlying materials to establish the shear wave velocity, thickness and Poission's Ratio of the subsurface layers. These methods also give an indication of the depth to the bed rock and the ground water table. These methods are not substitutes for drilling, sampling and testing. Properly planned and executed, they can optimize exploration programmes by maximizing the rate of ground coverage and minimizing the drilling requirements. Many principles of wave propagation through soils are applicable to seismic methods and a sound knowledge of attenuation of seismic energy along ray paths, reflection and transmission of seismic wave along boundaries in a layered medium, etc. are required for proper interpretation of results.

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APPLICATIONS:

5. Offshore structures:

- Offshore structures are subjected to alternating lateral forces and time varying vertical forces due to passage of waves. The period and height of waves also vary. These varying loads are transmitted to the foundations in the seabed and then to the soil below the seabed. The cyclic loading may induce high pore water pressures leading to stability problems and excessive settlements. Many floating offshore platforms have connecting pipes and the stability of these pipes also becomes an issue. These problems are typically dealt within the framework of not just soil-structure interaction but soil-structure-fluid interaction and is one of the most challenging design problems encountered in professional practice

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APPLICATIONS:

6. Traffic and rail induced vibrations:

- With the increase in speed of trains and vehicles, traffic induced vibrations have to be taken account of in designing tracks and pavements. The vibrations are also becoming not only an environmental concern but also a concern for the Consulting Geotechnical Engineer from another viewpoint. The micro-vibrations induced by the transit of trains or vehicles may not result in the collapse of nearby buildings, they, however, can cause the malfunctioning of sensitive/ delicate instruments located in these buildings and cause disturbance to the people living along the track lines. Here also, the subsoil acts as a medium of wave transmission from the source to the neighboring structures. A good understanding of cyclic behaviour of subsoil is required in addition to several other parameters such as speed of the train, type of the train, building foundation, distance to the building from the track etc. for a proper design so as to reduce the vibrations reaching the building and to mitigate their effect.

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APPLICATIONS:

7. Other problems:

There are several other problems that require a knowledge of Soil Dynamics for their solution. Few problems are as follows:

(i) *vibration isolation and screening* so as to reduce or minimize the vibrations transmitted to foundation/building,

(ii) *force transmission* so as to reduce the force transmitted to the subsoil,

(iii) seismic protection of buildings, and

(iv) control and reduction of structural vibrations

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Nature and Type of Dynamic Loading on Soils:

Dynamic loads vary in their magnitude, direction, or position with time. The type of dynamic loading in soil or the foundation of a structure depends on the nature of the source producing it.

1. Periodic dynamic load: It varies in magnitude with time and repeats itself at regular intervals, for example, operation of a reciprocating or a rotary machine.
2. Nonperiodic dynamic loads: These do not show any periodicity, for example, wind loading on a building.
3. Deterministic loads: These are those loads that can be specified as definite functions of time, irrespective of whether the time variation is regular or irregular, for example, the harmonic load imposed by unbalanced rotating machinery.
4. Nondeterministic loads: These are those loads that can not be described as definite functions of time because of their inherent uncertainty in their magnitude and form of variation with time, for example, earthquake loads
5. Cyclic loads: These are those loads which exhibit a degree of regularity both in its magnitude and frequency

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Nature and Type of Dynamic Loading on Soils:

The operation of a reciprocating or a rotary machine typically produces a dynamic load pattern. This dynamic load is more or less sinusoidal in nature and may be idealized.

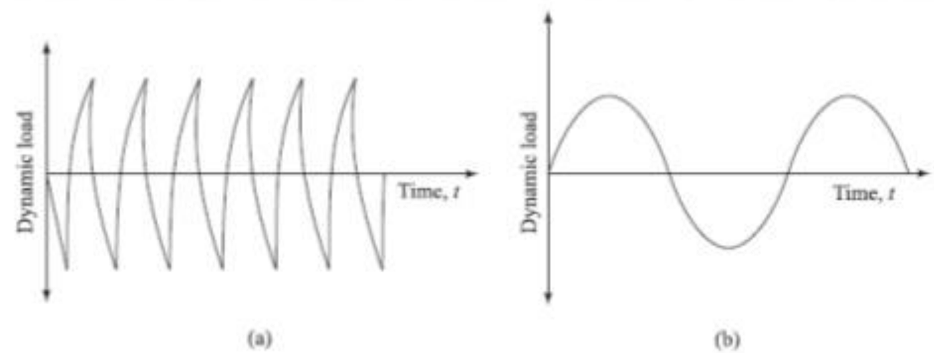

Figure 1.1 (a) Typical load versus record for a low-speed rotary machine; (b) Sinusoidal idealization for (a)

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Nature and Type of Dynamic Loading on Soils:

The impact of a hammer on a foundation produces a transient loading condition in soil, as shown in Figure (a). The load typically increases with time up to a maximum value at time $t = t_1$ and drops to zero after that. A typical loading pattern (vertical acceleration) due to a pile-driving operation is shown in (b).

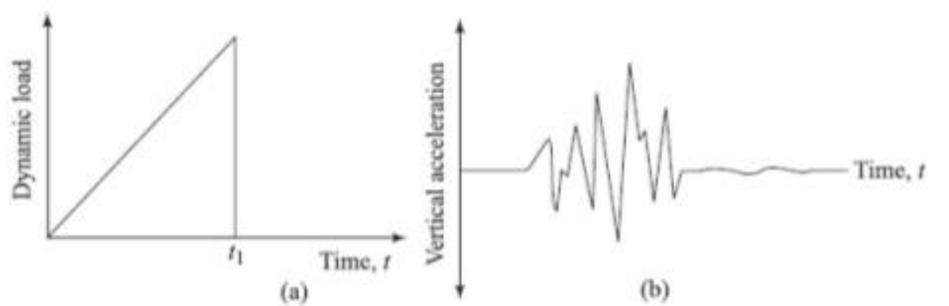

Figure 1.2 Typical loading diagrams: (a) transient loading due to single impact of a hammer; (b) vertical component of ground acceleration due to pile driving

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Nature and Type of Dynamic Loading on Soils:

Pure dynamic loads do not occur in nature and are always a combination of static and dynamic loads.

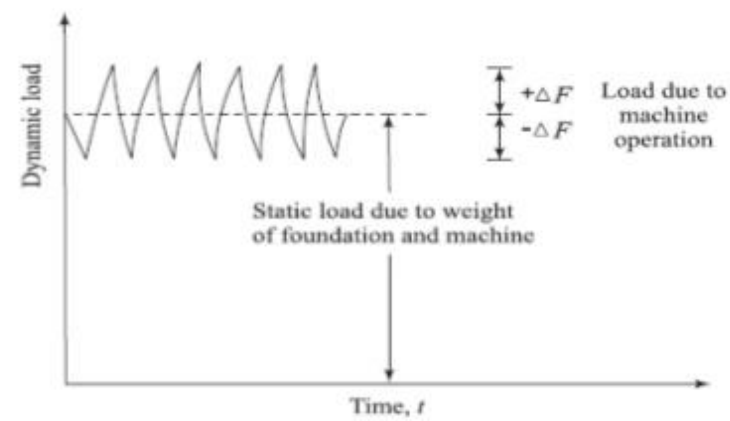

Figure 1.4 Schematic diagram showing loading on the soil below the foundation during machine operation

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Nature and Type of Dynamic Loading on Soils:

Dynamic loading associated with an earthquake is random in nature. A load that varies in a highly irregular fashion with time is sometimes referred to as a random load. Figure shows the accelerogram of the E1 Centro, California, earthquake of May 18, 1940

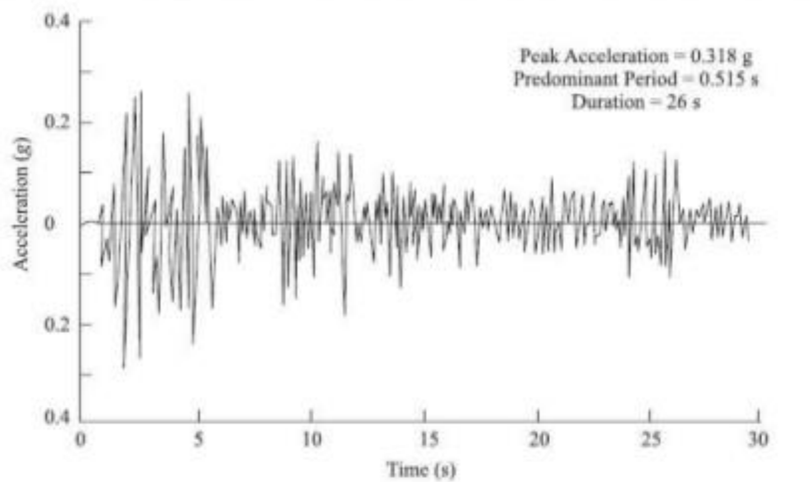

Figure 1.3 Accelerogram of E1 Centro, California, earthquake of May 18, 1940 (N-S component)

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Nature and Type of Dynamic Loading on Soils:

For consideration of land-based structures, earthquakes are the important source of dynamic loading on soils. This is due to the damage-causing potential of strong motion earthquakes and the fact that they represent an unpredictable and uncontrolled phenomenon in nature. The ground motion due to an earthquake may lead to permanent settlement and tilting of footings and, thus, the structures supported by them. Soils may liquefy, leading to buildings sinking and lighter structures such as septic tanks floating up . The damage caused by an earthquake depends on the energy released at its source.

For offshore structures, the dynamic load due to storm waves generally represents the significant load. However, in some situations the most severe loading conditions may occur due to the combined action of storm waves and earthquakes loading. In some cases the offshore structure must be analyzed for the waves and earthquake load acting independently of each other

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Type of Problems related toDynamic Loading on Soils:

In general, the problems involving dynamic loading of soils can be divided in to two categories:

1. Problems involving small strain amplitude response e.g. foundations of machines, which usually have low strain amplitude of the order of 0.0001 to 0.001 %
2. Problems involving large strain amplitude response e.g. strong motion earthquakes, blasts and nuclear explosions , which can develop large strian amplitude of the order of 0.01 to 0.1 %

Thank you