Foundation Vibration Isolation Methods

ASHWANI JAIN, D. K. SONI
Deptt. of Civil Engineering
National Institute Technology
Kurukshetra-136119
INDIA

Abstract: - All machine foundations except very small ones should be regarded as engineering problem to be dealt with cautiously. The larger ones give rise to enormous dynamic loads, causing vibrations, which the designer must take into account. Care must be taken to ensure smooth running of machine by avoiding harmful vibrations in the base or in the sub-soil or if the foundation does not rest on the ground, in the floor which supports it and may transmit vibrations to the surroundings. Foundation vibrations may result in differential settlement of foundation, deformation and cracks which may greatly disturb the operation of the machine. Potential uneven wear may result in running hot or even in shaft failure with subsequent standstillness of the machine and perhaps the shutdown of works involving serious loss in production. Vibrations may be particularly harmful where the gas pipelines are connected to the foundations, because the vibrations may impair the tightness of the pipe joints, with possible gas leakage and explosion causing considerable damage. Workers health too requires avoidance of vibrations. Care must be taken that laboratories using precision instruments are sited sufficiently far away to avoid soil vibrations. The presence of heavy road and rail traffic in close vicinity of industrial as well as office and residential areas has amplified the vibration problem. Particularly dangerous oscillations may arise if tower like industrial structures such as silos and chimneystacks are subjected to periodic forces. Prior attention must be given to eliminate the harmful oscillations or reducing them to acceptable limits. In the present paper, an overview of various vibration isolation techniques has been carried out. Most of the available methods for active isolation, i.e. isolation at the source and passive isolation, i.e. isolation at the receiver have been discussed. These methods include inner balancing in machines, isolation by location, stabilization of soils, use of structural measures and seismic mountings. Screening of disturbances using different type of wave barriers has been reviewed.

Key-Words: - active isolation, passive isolation, wave barrier, counter-balancing, seismic mounting, barriers

1 Introduction

Dynamic loads on foundations and soil structures may act due to earthquakes, bomb blasts, operation of reciprocating machine and hammers, construction operation such as pile driving, quarrying, fast moving traffic including landing of aircrafts, wind or loading due to wave action of water [1]. Vibration isolation is the action or treatment that eliminates the unwanted vibration or reduces it to an acceptable level [2]. Active isolation or action at the source relates to the minimization of vibration transmitted through the machine foundation to the surrounding area. Active isolation can be achieved by proper location of source, modification of operating conditions, inner balancing of machines and by providing seismic mountings for machines producing unhealthy vibrations. Passive isolation or action at the receiver relates to the minimization of vibration reaching an item of sensitive equipment from the surrounding area through its foundation. It can be achieved by proper siting, and by providing seismic mountings for sensitive equipments. Vibration energy travels from source to receiver through whatever intervenes - the soil, sand, clay, rock or other material that makes up the ground, or reinforced concrete, steel masonry or other material of a building. Various methods can be devised to modify the transmission path to reduce severity of vibration being transmitted from source to receiver [3]. These include the use of underground barriers between vibration source and structure. The barrier would absorb or reflect the vibration waves. Theoretically, an open trench is the most effective isolation technique. But for practical reasons, however, it is often difficult or impossible to install and maintain an open trench to sufficient depth. In-filled (with concrete or bentonite) trenches, vibration isolation screen, concrete core wall, sheet pile wall, rows of piles are effective wave barriers.

2 Vibration Criteria

For the design of foundation in which vibrations are taken into account, it is necessary to establish criteria to provide means of assessing whether the design is satisfactory. The following conditions should be satisfied.

1 No vibration damage is done to the structure in which the machine is housed and also to the adjacent structures.
2 No damage is done to the machine itself.
3 The performance of machine or the adjacent machines is not impaired.
4 Excessive maintenance cost for the machines and structures is not generated.
5 The health of workers in the vicinity is not impaired.
6 The health and comfort of the people in the surrounding area is not adversely affected.
7 Resonance should not take place, i.e. operating frequency of the machine should not match with the natural frequency of the foundation. The zone of resonance should be avoided; otherwise induced amplitudes may be very high.

3 Counter Balancing

A pre-requisite for smooth running of machine is to minimize eccentricities. With substantial eccentricities, the resulting centrifugal forces may cause harmful vibrations in the machines and their foundations. The aim of balancing is to minimize the eccentricity of the center of gravity of rotating parts.

3.1 Rotary Balancing

Unsatisfactory rotary balance may occur when axis of rotation does not coincide with its main axis of inertia. This results in generation of unbalanced centrifugal forces and deviation moments.

3.1.1 Single-plane (Static) Balancing

Balancing achieved by means of counter-force is called static balancing. If the axial dimension of the rotating part is considerably smaller than its diameter, a satisfactory result can be achieved, even with high operating speed, by static balancing alone. Static imbalance can be corrected by removing mass at the angular position of the heavy spot or by adding mass opposite to its position.

3.1.2 Two-plane (Dynamic) Balancing

Balancing achieved by means of counter-moment is referred to as dynamic balancing. When axial dimension of a rotor is not small in comparison to its diameter, the rotor could be considered to be made up of large number of discs side by side each having its own static imbalance. In this, imbalance can be corrected by adding masses in two planes, details of which can be found out by principles of mechanics.

3.2 Reciprocating Balancing

Here, unbalanced inertial forces can be resolved into two components, one in direction of piston motion and the other perpendicular to the piston motion. There are two methods of inner balancing in reciprocating machines.

1 It is possible to counter-balance completely a component in the direction perpendicular to the piston motion and partly a component in the direction of piston motion.
2 The dimensions of counter weights and their distances form axis of rotation may be selected to counter-balance completely the first harmonic of the component exciting forces in the direction of piston motion. Then the component in the perpendicular direction will increase.

Usually, the first method is employed for the counter-balancing of the engines, because the stress in the engine itself is smaller than those occurring when the other method is used. Another advantage of the first method is that it requires smaller counter-weights.

4 Isolation by Location

By proper location of vibration causing machinery, effective isolation can be obtained. Following are various method of isolation by location.

4.1 Remote Location

If the specific area is to be protected from vibration and if vibration source is known, then consideration could be given to reducing vibration level in the area to be protected, by positioning the two locations sufficiently apart. This technique relies upon the natural decay or attenuation of vibration amplitude with distance [4]. The amplitude of particular interest is that of surface Rayleigh wave which contains the major part of wave energy.

4.2 Geologic Formation

It is possible to select a site for sensitive structure or instruments by taking advantage of basic geological formations. Foundations on sound, deep-seated bedrock will experience smaller vibration amplitudes than foundations on weathered materials or soils subjected to same excitation [5]. Isolation can be achieved by locating a foundation in a protective natural geological structure like a syncline or a deep valley. A mountain range may act as a barrier to long period surface waves, if it is situated between the source of excitation and a site to be isolated.

4.3 Layout of Machine and Equipment

This involves consideration of relative locations of the sources and receivers of the vibrations in the building as a whole. Favourable location for the vibration sources, particularly large machines, is at the basement or the ground level, because the structural response increases with the height of vibration source above the ground. A major consideration is the need to avoid magnification of amplitudes by resonance. The need to locate the vibration sources where they will cause minimal structural response must be considered in conjunction with the desire to have them remote from vibration sensitive areas. This of course demands a compromise not only insofar as the vibration factor clashes with the various other factors that determine layout, but also because a floor that is a desirable site for a machine because the floor would have small response to excitation applied directly by the machine, may also be a desirable site for a sensitive equipment because the floor would have small response also to indirect excitation from machinery elsewhere in the building [6].

5 Stabilization of Soils

If foundation rests on sandy soil, in order to decrease vibrations, chemical or cement stabilization of soil under the foundation may be used. Such soil stabilization will result in an increase in the rigidity of base and consequently, in an increase in the natural frequency of the foundation. So this method is very much effective when natural frequency of foundation on known stabilized soil is higher than the operational frequency of the engine, which usually is the case. An increase in rigidity will increase still further the difference between frequency of natural vibrations and frequency of the engine; consequently amplitude of foundation vibration will decrease.

When foundation resting on natural soil has natural frequency smaller than the operational frequency of engine, soil stabilization may cause an increase in the amplitude of vibrations. This may be undesirable if the soil is stabilized to such a degree that frequency of natural vibration of foundation merely approaches the operational frequency. But, if a soil is thoroughly stabilized and natural frequency of foundation becomes much higher than the operational frequency of the engine, then such soil stabilization results in considerable decrease in amplitude of vibrations.

The character of vibrations determines the limits of stabilized zones of soil and their shapes. For example, for a foundation subjected mainly to rocking vibrations about an axis passing through the centriod of the base contact area, only a portion of the soil near the edges of foundation needs to be stabilized and it is not necessary to stabilize the soil under the entire foundation.

6 Structural Measures

Structural measures are applied with the purpose of changing natural frequencies of foundation in such a way as to achieve the largest possible difference between them and operational frequency of the engine. Isolation can be achieved by increasing base area or mass of the foundation, by attaching a slab to the foundation, and by using auxiliary spring-mass system [5].

For under-tuned foundation whose natural frequency is lower than the operating frequency, it is better to decrease still more the natural frequency by increasing the foundation mass without enlarging its area of contact. If the operating frequency of the machine is less than the natural frequency of foundation, as in case of reciprocating engine, structural measures are directed towards increasing the natural frequencies of foundation. This can be achieved by increasing foundation contact area and its moment of inertia, as well as by increasing the rigidity of its base by means of piles. A slab resting on soil, attached to foundation can be used to decrease the amplitude of rocking and horizontal vibrations. If a vibrating foundation lies close to another foundation, it may be helpful to connect the two foundations so as to increase the rigidity as a whole. The use of auxiliary spring mass system attached to the main system to dampen its vibrations may be limited due to unhealthy vibrations that may be occurring in the auxiliary system itself. The use of structural measures requires long interruption in operation of engines and considerable expense of funds and material.

8 Seismic Mountings

If the machine is relatively small, this presents a simple and economical solution, but if the machine is large, its re-installation on seismic mountings will involve costly design, construction and loss of output during downtime. Therefore, before deciding to isolate the machine, consideration should be given to the possibility of action at the receiver. Specifically, if vibration is disturbing a particular item of sensitive equipment, isolation of that equipment may be preferable to isolation of the source of vibration. Seismic mountings are in the form of auxiliary spring-mass-dashpot systems [7] and act as vibration absorbers reducing transmissibility either to the foundation of the machinery or to sensitive equipment.

The ratio of force transmitted to the foundation through absorbers to the vibratory force developed by foundation is known as transmissibility ratio (T_r). When frequency ratio (r) varies from 0 to $\sqrt{2}$, greater the amount of damping, lesser is T_r, which is always greater than unity. When frequency ratio (r) varies from $\sqrt{2}$ to infinity, greater the amount of damping, greater is T_r, which is always less than unity. Therefore, damping is favourable in the first range and unfavourable in the second range. In order to have low value of T_r, the operating range is generally kept far away in the second range. Under these circumstances, zero damping is ideally suitable, as this will give extremely low value of T_r. Since, the system has to pass through the resonance zone ($0.5 < r < 2.0$) in reaching the operating point and zero damping will cause high T_r, though for a small moment, therefore, some amount of damping has to be introduced into the system at the cost of higher T_r at the operating point. Hence for effective isolation, natural frequency of isolated system should be as low as possible in relation to the forcing frequency. For systems operating in first range at very low value of frequency ratio, higher damping will give lesser transmissibility, but it is always greater than unity. Therefore, it is not desirable. It is recommended that the frequency ratio should be at least equal to two in all cases of vibration isolation.

Absorber for machines can be in the form of a single coil spring, which fits into the adjusting slab. For reciprocating engines of medium and high capacities, absorbers containing several springs are used. Rubber absorbers may also be employed for light engines and devices. Depending upon the balance of the engine and its operational requirements, supporting and suspension type springs may be used for vibration isolation of foundations [6].

9 Isolation by Barriers

Waves generated by machine foundation, traffic or blasting may cause distress to adjacent structures and sensitive machinery. Most of the vibratory energy affecting structures is carried by surface (Rayleigh) wave that propagates in the zone close to the ground surface. It is possible to reduce ground vibrations significantly by placing a suitable wave barrier in the ground before the structure. Open trenches, in-filled (concrete or bentonite) trenches, sheet pile walls, concrete core walls or even row of piles can be effective wave barriers.

The concept of isolation by wave barriers is based on reflection, scattering and diffraction of wave energy. Wave barriers may consist in general of solid, fluid or void zone in the ground. At solid to solid interface, both P-waves and S-waves are transmitted, at solid to fluid boundary, only P-waves are transmitted and at solid to void interface, no waves are transmitted [8]. Active isolation is the employment of barriers close to or surrounding the source of vibrations to reduce the amount of wave energy radiated away from the source. Passive isolation is the employment of barriers at the point remote to the source of vibrations, but near a site where the amplitude of vibrations must be reduced. The passive isolation represents the Rayleigh wave isolation.

Rayleigh wave incident on an in-filled or open trench gives rise to reflected R-wave, body (P and S) waves that radiate outward from the trench and the transmitted R-wave.

Body waves may be subdivided into two groups, the reflected body waves that radiate downwards and towards the source, and the transmitted body waves that propagate away from the source. It is the energy contained within transmitted R-wave and transmitted body wave that causes ground vibrations beyond the trench.

The phenomenon of conversion of R-wave energy to other waveforms (P and S) due to presence of scatterer (wave barrier) is known as mode conversion. Beyond the trench, as the distance between trench and transmitted body wave increases, the body waves are partially transformed to Rayleigh wave.

The functional difference between two types of trenches is primarily due to the ability of an in-filled trench to effect passage (transmission) of incident waves into the trench material and then to the zone of screening, which is not possible for open trenches [9]. This results in completely different amounts of wave reflection and mode conversion. Therefore, open trenches are more effective wave barriers because of minimum transmission of wave energy. For practical reasons, however, it is often difficult and impossible to install and maintain open trenches to sufficient depths, which results in the need of providing in-filled (concrete or bentonite) trenches, concrete core wall [10] or piles as wave barriers [11, 12, 13].

The vibration isolation screen 'vibrisol' [14] consists of gas-filled panels (gas cushions), which form stable vertical underground screen. This screen has a vibration isolation effect which is very similar to that of an open trench.

10 Conclusions

1. Inner balancing, i.e. minimizing eccentricities in the rotating parts and thus reducing harmful vibrations, is essential before going in for other methods of isolation.
2. Remote location of vibration source from sensitive equipment may not be very practicable, but layout of machine and equipment in a building should be given due importance.
3. Stabilization of soils as effective isolation technique is more applicable to sandy soils and that too, when natural frequency of foundation on stabilized soil is higher than operating frequency of the machine.
4. For a slab attached to the foundation for horizontal vibration isolation, it should be located as close as possible to the ground level and natural frequency of slab in horizontal mode should be made as large possible.
5. Use of auxiliary spring mass system may be limited due to unhealthy vibrations that may be occurring in the system itself.
6. Seismic mountings are very effective and highly viable in both the active and passive isolation cases and should be universally adopted.
7. More studies are needed for effective use of open and in-filled trenches as vibration isolators, and if used, vibration isolation effectiveness should be checked locally.

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