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Vibration isolation of buildings housed with sensitive equipment using open trenches – Case study and numerical simulations

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ABSTRACT

The vibration isolation of buildings housed with sensitive equipment is always a challenging one due to the stringent vibration criteria imposed on them. The paper presents a case study on the vibration isolation scheme adopted for an important building of space research agency. The vibration levels in the building had to follow the vibration criterion which is in the form of a set of one – third octave band velocity spectra, expressed as vibration criterion curves. Various sources that can generate vibrations in the building were identified and assessed. The external sources and the internal sources of vibration were analyzed and the possible limits of vibrations were evaluated. The selection procedure of design frequency, which is the significant step in the design of vibration isolation trench under the passive isolation scheme, is explained. Numerical simulations were developed to evaluate the influence of trench parameters on the amplitude reduction of Rayleigh waves propagating across the trench. Based on the results from numerical simulations, the vibration isolation trench was designed to reduce the amplitudes of vibrations produced from external and internal sources.

1. Introduction

Ground vibrations caused by machines, construction equipment, traffic, blasting, piling and other human activities can create problems to people and buildings with sensitive equipment. Most of the vibrations that are generated due to surface sources are transmitted as Rayleigh waves with particles (ground motion) experiencing elliptical motion. When the frequencies of these generated vibrations match the natural frequency of structures, resonance may follow leading to the disruption of purpose of the structure. Therefore for the design of buildings housed with sensitive equipment, vibration criteria curves were developed and published by Gordon [1]. These vibration criteria are generic in nature, as they are suitable for a wide range of instruments and tools in the fields of microelectronics, medicals and pharmaceuticals. The reduction of ground vibrations is usually achieved by altering the frequency of vibration or by changing the location of source or by varying the characteristics of the surrounding ground [2]. When the possibility of modifying the source and machines does not exist, effective isolation of vibrations is realized with the help of wave barriers. Wave barriers often take the form of open trenches, trenches filled with low stiff materials, sheet piles [3–8] etc.

As most of the vibration energy is transmitted as Rayleigh waves, several studies had been done on the effectiveness of wave barriers, such as open trenches, filled trenches and driving piles on the isolation of vibrations. Beskos et al. [9] studied the effect of structural isolation using open or filled trenches under plane strain condition using boundary element method, while this study was extended to 3D homogenous soil condition by Dasgupta et al. [10] and to 2D non homogenous soil by Leung et al. [11]. Ahmad and Hussaini [12] developed design expressions for evaluating the effectiveness of open and in filled trenches in homogenous soil deposits. Yang and Hung [13] studied the effectiveness of three wave barriers, open trench, in filled trench and elastic foundation, in reducing the train induced vibrations using numerical simulations and found that effectiveness is dependent on the wavelength of the propagating wave and the normalized depth of the trench is the influencing parameter when open trenches are used for isolation. The reduction of train induced vibrations by means of trenches was numerically studied by Andersen and Nielsen [14] and Adam and Von [15] and brought out the influence of trenches in reducing the vibrations. While Adam and Von [15] found that open trenches are more efficient in reducing even the induced low frequency vibrations, Andersen and Nielsen [14] concluded that provision of a softer backfill material in trench improves the isolation effect. Naggar and Chehab [16] established that the effectiveness of barriers increases when the ratio of depth of trench to the wavelength increases and soft barriers are more efficient than stiff barriers.

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Çelebi et al. [17] conducted field experiments on vibration isolation using wave barriers and concluded that trenches backfilled with softer material than soil is more effective for passive isolation. Field experiments to evaluate the efficiency of open and geofoam barriers in reducing the steady state vibrations produced by machine foundations were performed by Alzawi and Naggar [18]. The full scale experimental study conducted by Ulgen and Toygar [19] concluded that geofoam barriers can reduce the air borne vibrations and the screening effectiveness of open trenches and geofoam wave barriers are very close. The vibration amplitudes could be reduced by 67% or more when the normalized depth of 1 or 1.5 was provided. Thompson et al. [20] studied numerically the possibility of using soft material filled and open trenches in reducing the train induced vibrations and found that depth of trench is the influencing parameter in reducing the vibrations.

The vibration isolation using trenches is generally classified into active isolation scheme and passive isolation scheme [21]. The isolation systems that are installed around the source or at a close distance from the source are known as active isolation systems, while those surround the point of interest (object, machinery, building etc.) are known as passive isolation systems. The paper deals with the passive isolation system adopted for a building housed with sensitive equipment which follows stringent vibration criteria. A description of the problem including the sources of vibration along with the analysis of vibrations is given. The numerical simulations used to analyze the influence of trench parameters on the amplitude reduction of vibrations are described in detail. The selection of trench design parameters and the implementation of the isolation trench at field are also elaborated.

2. Case study – problem definition

2.1. Background

The Indian Space Research Organization (ISRO) is the highly reputed space agency of government of India. The Space Application Centre (SAC) of ISRO (located in Ahmedabad, Gujarat state) is in charge of the design and development of satellite communication, navigation, remote sensing and space science using state of the art technology. A Payload Fabrication and Test Facility (PFTF), is designed at the Bopal campus, Ahmedabad, to meet the future requirement of increased load. This facility houses many sensitive equipments and requires a very stringent vibration control in the proposed PFTF building. The building also houses several air handling units (AHU's) and they vibrate to some degree. The proposed building has 9 blocks with stringent requirements in terms of vibration control. The vibration criteria is in the form of a set of one – third octave band velocity spectra, expressed as vibration criterion curves, VC-A through VC-E as root mean square velocity (V_{rms}). The generic vibration criteria by Gordon [1] is shown in Fig. 1. Fig. 2 shows the blocks with their vibration limits. The vibration requirements for the blocks are VC-E (125 μin/s between 1 and 80 Hz), VC-C (500 μin/s between 1 and 80 Hz) and VC-B (1000 μin/s between 8 Hz and 80 Hz), as per ISO and Gordon criteria. Based on manufacturer's specifications, above limits shall be achieved in one-third octave band between frequencies of 4–80 Hz.

2.2. Identification of vibration sources

The sources of vibration for the proposed facility can be classified generally as external sources (outside the building; mainly traffic) and internal sources (within the building; human excitation and service machinery including AHUs). A dynamic analysis was carried out by ISRO for quantifying the vibrations due to internal sources, viz, human induced vibration and chamber induced vibrations. For Block-2 with vibration criterion as 125 μin/s, the rms velocity (V_{rms}) at 1/3rd octave band between frequency range of 4–80 Hz obtained at location near to sensitive equipment was 78 μin/s, which is about 62.4% of the limiting value. Similarly, for Blocks-1, 3, 4 and 5 with vibration criterion as 500 μin/s, the obtained V_{rms} at location near to sensitive equipment was 116 μin/s, which is about 23.2% of the limiting value. For Blocks 7 and 8, with vibration criterion as 1000 μin/s, the V_{rms} obtained at a point in isolated floor slab near to sensitive equipment was 736 μin/s, which is about 73.6% of the limiting value.

When external sources of vibration are considered, it is important to analyze the vehicular traffic that can generate immense impact to the site, which depends on the proximity of road, road condition, traffic intensity, vehicle weight and speed. The building site has a railway line at 375 m away and a public road close to the building. It was realized that the train movement as well as the vehicle movement in the road could impart vibrations to the proposed building. The vibration caused in the proposed building by passing trains can be due to both ground-borne vibration and air borne noise. It is to be considered that train induced vibrations are functions of train velocity, type of train and type of soil. For the analysis of external vibrations, the behavior of building when subjected to ground-borne vibration due to passing of trains and traffic movement on the road were considered.

2.3. Determination of shear wave velocity

MASW (Multichannel Analysis of Surface Waves) tests at four sites within the PFTF building location were conducted by a private consulting agency. The shear wave velocity profiles were obtained up to a depth of 50 m. MASW tests showed that shear wave velocity is gradually increasing with depth, the value being about 200–250 m/s at surface, increasing to 480 m/s at 30 m depth. The shear wave velocity increases to about 650 m/s at 50 m depth.

2.4. Field tests and analysis of vibration measurements

For the analysis of vibrations due to external sources, vibration measurements at the proposed site were carried out by Institute of Seismological Research, Gandhinagar, Gujarat state. Vibration measurements were carried out in the presence of nearby vibration sources, viz., train movement, vehicle movement and combination of train and vehicle movement. Based on these different types of vibration sources, three possible conditions were identified by including the worst case scenario with train movement and road roller movement on the nearest road. The three conditions were:

Case 1: Train movement
Case 2: Train Movement + Road Roller Movement
Case 3: Road Roller Movement

As the magnitude of vibrations due to train movement is dependent on various factors such as type of train, weight of coaches, speed etc., vibration measurements were carried out during the passage of traveler trains and goods trains at various timings. The vibration data from the accelerometers were recorded at a sampling speed of 200 samples/s. Accelerometer measurements were taken in three directions, viz., longitudinal, transverse and vertical directions. The eight locations, where measurements were taken, are shown in the Fig. 3. The eight locations were named as SMA, SMB, SMC, SMD, SME, SMF, SMG and SMH. The acceleration- time histories were obtained at these eight locations and in the aforementioned three directions. The base line correction and band pass filtering between the frequency range of 4–80 Hz were done using commercially available software. The frequency domain analysis was done using a MATLAB code.

The velocity – time histories were obtained after filtering out the signals below 4 Hz and above 80 Hz. These velocities were plotted in frequency domain using FFT (Fast Fourier Transform) analysis in MATLAB program and 8 critical cases were identified on the basis of peak velocity in the frequency domain. The identified critical cases are described in Table 1. Maximum velocities at various locations for the critical cases were obtained from the velocity – frequency plots. A