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Dynamic analysis of foundation of Bir Hospital Trauma Centre, Kathmandu, Nepal

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ABSTRACT

The rapid incrase in population of Kathmandu metropolitan city in last two decades has demanded the construction of multistoried buildings. As the height of building increases, variation in moments and force along the height of the structure becomes vulnerable and is more pronounced when the structure rests in soft fluvio-lacustrine sediments like in the Kathmandu Valley. Similarly, the amplitude of vibration causes bending of rebars which can damage the foundation and ultimately the building, if proper care is not taken during the design phase. Therefore, this paper aims in calculating the amplitude of vibration at natural frequency, seismic interial force and its change for the height of the Bir Hospital Trauma Centre, Kathmandu. The elastic parameter, modulus of elasticity needed for analysis was estimated from a graphical method. Shear modulus was calculated using empirical ralation. Density of strate was estimated in the laboratory and load of the structure was referred from Indian Standard of design loads. The maximum amplitude of vibration calculated was 12 mm at 19.3 Hz whereas it was 1.5 mm at the natural frequency for all portions avoiding coupling effect. The variation in seismic horizontal force and moment was largest at the height of 9–15 m showing the possibility of failure at such height at the time of earthquake.

INTRODUCTION

The Kathmandu Valley lies in a synclinal basin filled up by fluvio-lacustine sediments of Pleistocene age (Yoshida and Igarashi 1984). Bir Hospital lies in the core of the Kathmandu City (Fig. 1). The surrounding area is incorporated by heavily constructed buildings and those which are being constructed. Most of the buildings of the area belong to public concern parties. The Bir Hospital Trauma Centre is seven storied with raft foundation above 12 mm thick slab over the back filled boulders. The major portion of the structure is founded at the depth of 8 m and the arch shaped portion (Fig. 2) lies at the depth of 4 m. Dynamic characteristics of the foundation was not considered as a compulsory work in construction except for the major buildings due to lack of legal act and awareness among builders. To aware the builders about subsurface soil behavior and suitable foundation design which has less risk from earthquake vulnerability, this paper primarily focuses on vibration of the foundation at natural frequency and at the time of earthquake. Because enough data on the elastic properties of soil of the study area was not available, evaluation of the vibration analysis of foundation was crried out by the graphical method of analysis with the help of empirical relations, and the reference data of HEET Consult (1999).

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SUBSURFACE GEOLOGY

The subsurface strata showed four prominent layers until the depth of 12 m (Fig. 3). The first layer was composed of filling materials of bricks and wooden wheels used previously during the construction till the depth of 3 m. The second layer until the depth of 4 m was sandy silt which was followed below by light grey medium to fine sand

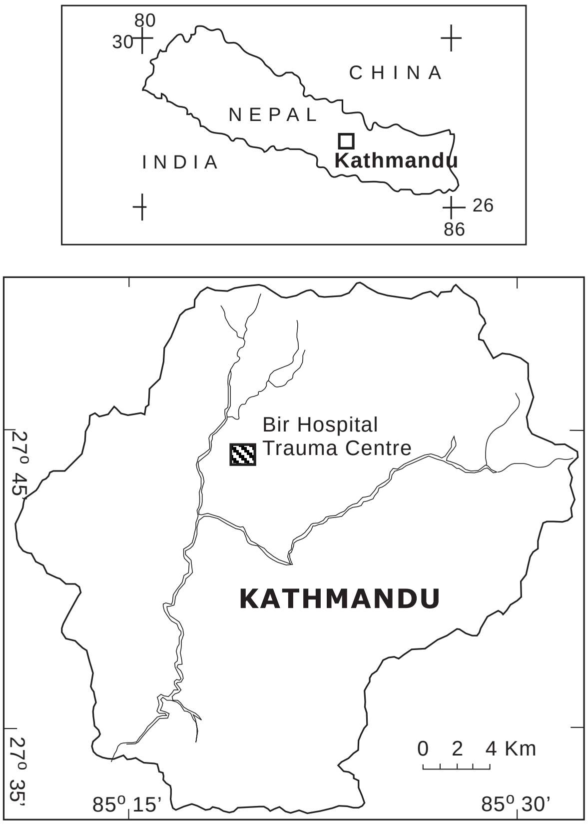

Fig. 1 Location map of study area

upto the depth of 8 m. The water table and arc shaped portion of the foundation lies at the top of this layer. The forth layer was medium to coarse sand upto the depth of 12 m, on top of which the major portion of the foundation was casted.

METHODS

Ambient dynamic analysis

The movement of foundation due to steady state of vertical vibration was considered in ambient dynamic analysis of foundation. From the knowledge of basic dynamic it was expected that the amplitude of vibration increased to a maximum value at about the natural frequency of the system and then progressively decreased as the frquency was further increased. The prediction of amplitude of vibration of building foundation due to disturbing force is required for dynamic foundation design of the building. There are various modes of vibration but for the present study only the vertical vibration due to the ambient road traffic was considered. When the multistoried building supported on a geometrically equivalent circular base is subjected to a series of traffic, the building will be subjected to a steady state vibration with a translatory and rocking components. This is termed as a coupled vibration. Relation between the amplitude of vibration with two factors viz. frequency factor and mass ratio are given below:

$$\alpha_o = \omega R (\rho/G_s)^{0.5} \qquad (1)$$

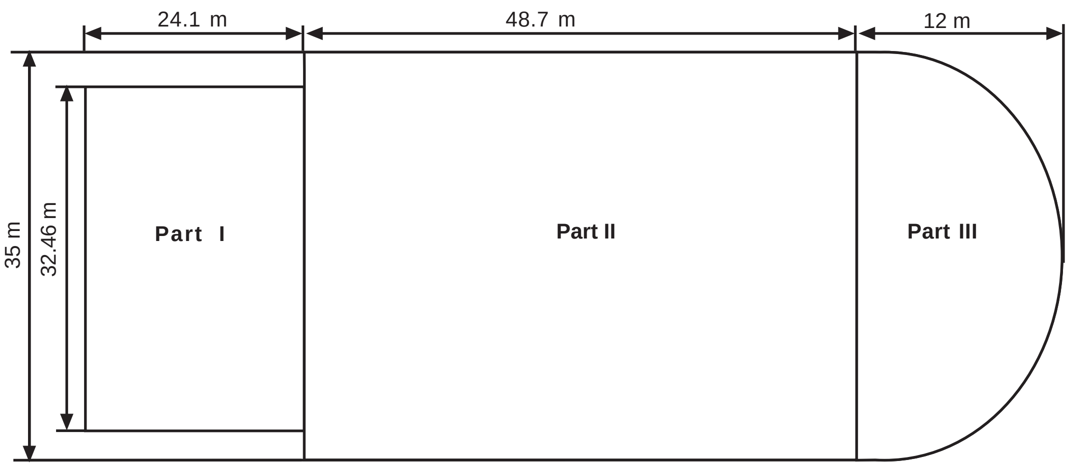

Fig. 2 Partition of the foundation for determination of amplitude at natural frequecy

Depth, m	Lithology	Description of soil	Average SPT value	Elastic modulus, Es (KN/m^2)	Density (kg/m^2)	Shear modulus (KN/m^2)
1 m 2		Silty clay and filling material	–	–	–	–
3 4		Light grey loose and plastic silt	7	0.020	1600	0.0080
5 6 7		Light grey fine to medium sand	9	0.030	2170	0.0120
8 9 10 11 12		Light grey medium dense to coarse sand	18	0.043	2240	0.0171

Fig. 3 Subsurface distribution of strata of the Kalimati Clay; their average SPT value, elastic modulus, density and shear modulus (after HEET 1999)

$$b = (M/\rho R^3) \qquad (2)$$

where, a_o is frequency factor, ω is frequncy of the disturbing force (rads/s), ρ is density of supporting soil (tons/m^3), R is radius of foundation for circular base (m), which can be replaced by root square of the ratio area to π for rectangular or square base, G_s is shear modulus of the supporting soil (kN/m^2), and M is mass of vibrating foundation (ton).

Field SPT value (Fig. 3) was used to get the value of Young's modulus (E_s). As the Poisson ratio of loose earth material is 0.24–027, the common value of 0.25 was chosen. Then the shear modulus was calculated as:

$$G_s = E_s/(2 + 2\nu) \qquad (3)$$

where, ν is Poisson ratio. Due to changes in structural design, the foundation was divided into three portins as they differed in dimensions and load of 1.7 ton/m^2 per floor was used for the calculation and load at different portions was calculated using unit pressure and area of the portion. After getting the value of frequency factor (a_o) and mass ratio (b) the value of constant k was obtained from Fig. 4. The amplitude was calculated using the ralation:

$$\text{Amplitude} = k\,(Q/G_s\,R) \qquad (4)$$

where, Q = load due to building (ton) and other symbols are as defined before.

Dynamic analysis at earthquake

Himalayas are in the dynamic state and therefore, earthquakes are frequent in the whole region including Nepal. The seismic records of the Kathmandu region suggest a return period of about 25 yerars indicating that a devastating earthquake is enevitable in the long run and likely in the near future (Basnet et al. 1988). Similarly, minor earthquakes are quite frequent and due consideration is required to build up earthquake resistant design of structures. The seismic velocity information obtained from the micro tremor survey shows that the granular fluvial section of the valley is attributed to a P-wave velocity of 1850–1990 m/s. Similarly, the S-wave velocity of the fluvial granular section shows 1000 m/s and clayey sediments show 300 m/s. The velocity of bedrock was assumed to be 3000 m/s by Pandey et al. 1992). According to the national building code of India (IS 1987a), the Kathmandu Valley lies in zone V (extremely hazardous) and recommended value of basic seismic coefficient is 0.08 g (m/s^2) for earthquake intensity

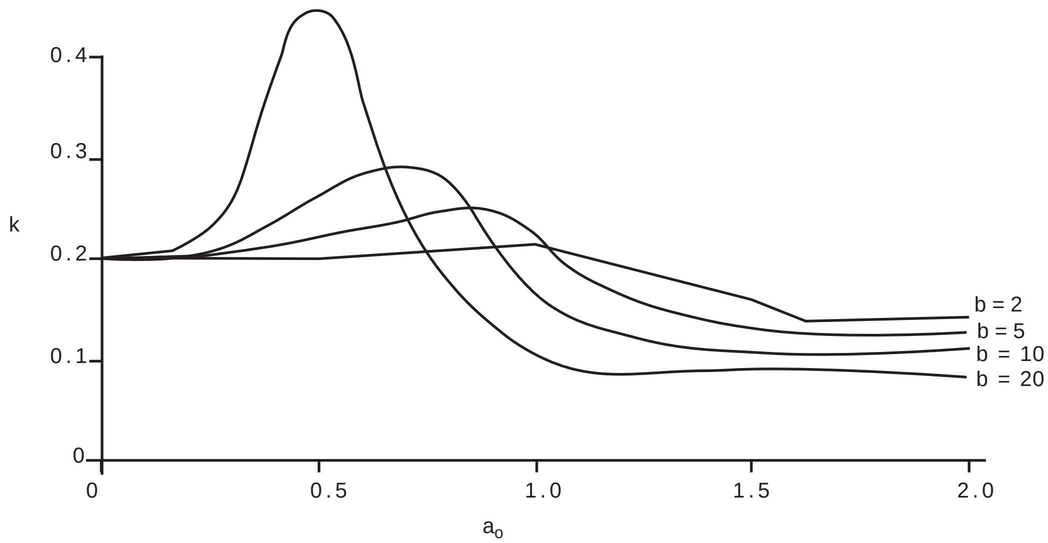

Fig. 4 Frequency factor for different mass ratio (Richard et al. 1970)

of 8.5. The coefficient of horizontal acceleration should be increased by upto 50% for important public building. The P-wave and S-wave produced during the earthquake set the ground into a state of horizontal and vertical vibrations. It is the horizontal vibration that causes the great damage to the structure.

The structure has to resist inertial forces caused by movement of ground. If the ground under a structure moves, the structure must also moves with it to avoid rupture. Therefore inertial force must be considered in the design. The magnitude of earthquake forces depends upon a number of factors, such as severity of earthquake and the mass of the structure. The seismic inertial force was calculated as:

$$S_f = \alpha_c M \quad (5)$$

where, S_f is seismic inertial force, M is mass of the structure (ton), and α_c is a horizontal acceleration of the ground (m/s^2) that was obtained as:

$$\alpha_c = \alpha_o \beta I g \quad (6)$$

where, α is a horizontal seismic coefficient, β is soil foundation system factor (=1) for medium soil (IS 1987a), I is importance of structure (=1.5) for hospitals (NBC 1994), and g is acceleration due to gravity (9.8 m/s^2).

Foundation design data

For design of foundation, the seismic horizontal inertial forces were calculated (Table 2) which act opposite to the direction of movement of wave during the earthquake. The foundation was divided into two parts (Fig. 5) as it lied in two depths which exerted uniform pressure of 1.7 ton/m^2 per floor.

Seismic horizontal force and moment

The earthquake magnitude of 8.5 was considered because this magnitude is generally considered in designing structures in Himalayan regions. The seismic inertial forces at different heights were calculated (Table 3) on the basis of dead load of building which is 1.7 ton/m^2 per floor and height of the building 21.34 m. The width of the building was 72 m. For this purpose it was assumed that the horizontal coefficient at the top of the structure was three times the basic seismic horizontal coefficient which decreased linearly. Then force at any portion of the structure was:

$$F = 1.5 \alpha B w H_1 (1-H_1/2H) \quad (7)$$

Similarly, moment at a point was calculated by:

$$M = 1.5 \alpha B w (H_1^2/2)(1-H_1/3H) \quad (8)$$

where, α is a basic seismic coefficient, B is width

Table 1: Amplitudes for range of natural frequencies

		Frequency			
		0.0193	0.193	1.93	19.3
R_1 = 18.28 m	α_o	0.025	0.25	2.5	25
	b		1.07		
	k	0.195	0.22	0.025	-
	Amplitude, mm	7.92	8.34	1.67	-
R_2 = 22.12 m	α_o	0.03	0.3	3	30
	b		0.89		
	k	0.195	0.215	0.03	-
	Amplitude, mm	11.91	12.82	1.83	-
R_3 = 12 m	α_o	0.0191	0.191	1.91	19.1
	b		1.73		
	k	0.188	0.21	0.045	-
	Amplitude, mm	4.75	5.313	1.123	-

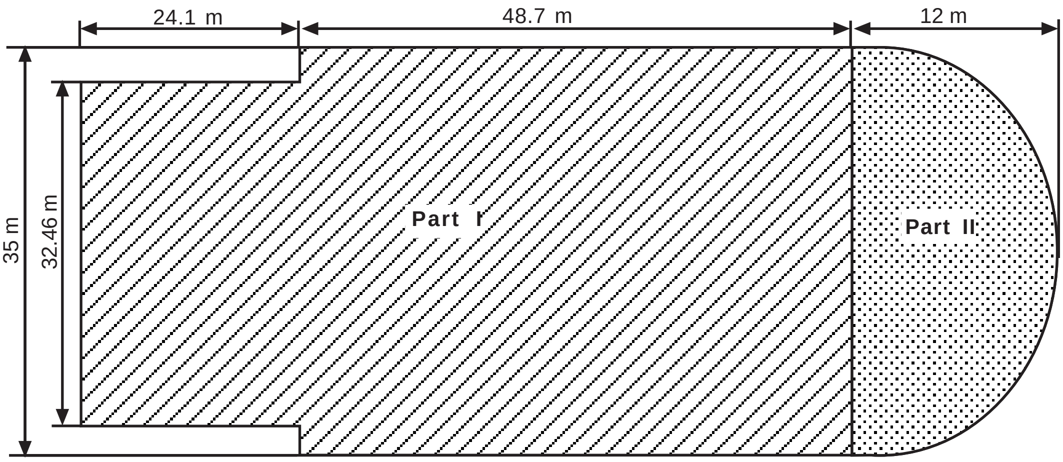

Fig. 5 Foundation partitioning for calculation of seismic inertial force

Table 2: Seismic inertial force

		Earthquake intensity (M)		
		7	8	8.5
Basic seismic coefficient α_o		0.025	0.05	0.08
Importance factor I		1.5	1.5	1.5
Foundation factor β		1	1	1
α_c (m/s^2)		0.3675	0.735	1.176
Horizontal seismic inertial force (KN)	Part I	12637.65	25275.28	35299.61
	Part II	997.01	1994.025	3190.44

of structure, H_1 is height of structure from top to the point of measurement, w is weight of the structure and H is height of the structure.

RESULTS AND DISCUSSIONS

The calculate value of amplitude at natural frequency is shown in Table 1. The maximum amplitude of vibration is 12.82 mm ant frequency of 0.193 Hz (Fig. 6) which is ten times smaller than natural frequency. At this frequency the amplitude of vibration has variation upto 50% and shows the probability of failure of the structure which should be balanced by size and loading intensity. But at measured natural frequency, the amplitudes of vibration nearly cope with the size of foundation and loading showing little variations in amplitude of vibration without the coupling effect.

The calculation of seismic horizontal force is as shown in Table 2. The small value of force of seecond portion and the mass behaves as a single unit showing about less than 10% of the force of first portion. Higher the intensity and load of the building, higher the seismic inertial force it will have. The seismic horizontal force and moments vary with heights. The variation is largest in the third floor and the fifth floor showing possibility of failure at these heights. This also agrees with the considerations that the earthquake forces hamper the structure at two-third heights.

CONCLUSIONS

The maximum amplitude at the ambient frequency of vibration was 12.82 mm at frequency of 0.193 Hz. The amplitude at measured natural frequency for all portion of the foundation was nearly same, i. e.

Table 3: Force and moment at heights of structure

S. No.	Height from base (m)	Force (KN)	Moment (KN/m)	Remarks
1	21	0	0	
2	18	7360.25	755.38	
3	15	13596.89	2719.39	Variation is
4	12	18695.72	4079.06	largest in third
5	9	22661.48	10273.2	and fifth floor
6	6	25494.17	15107.65	
7	3	27193.78	16996.11	
8	0	35299.61	18506.88	

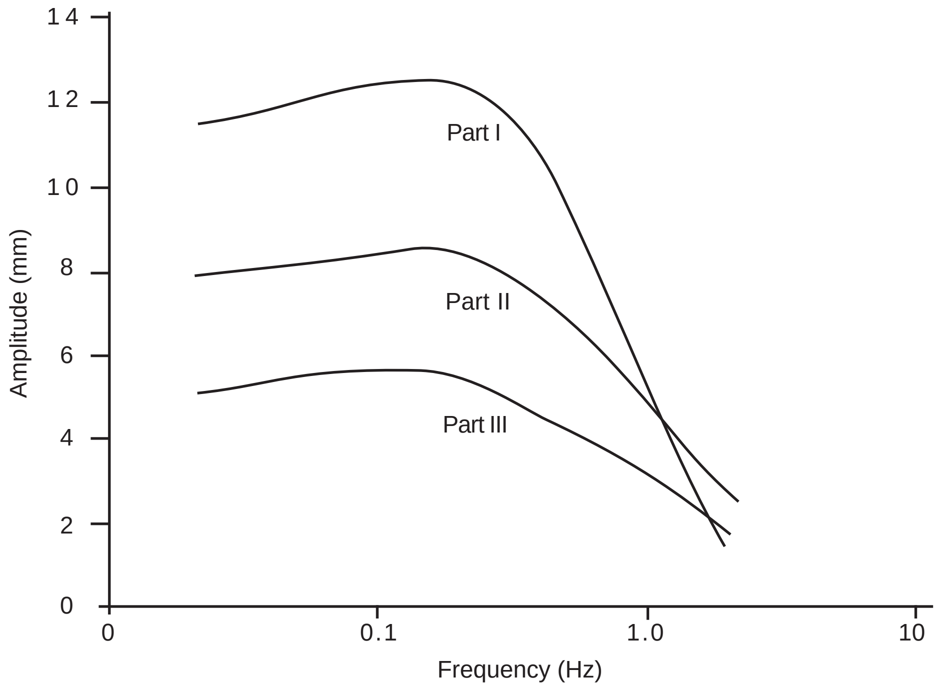

Fig. 6 Plot of natural frequency versus amplitude

1.12–1.91 mm which avoided the coupling effect.

The maximum value of horizontal acceleration was 1.47 m/s^2 at earthquake magnitude of 8.5 and horizontal seismic inertial force was 26301.40 KN.

The moment distribution indicates possibility of failure at height of 9–15 m because of the maximum variation in seismic inertial forces at this height.

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