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Deformation analysis of foundation: a case study of Bir Hospital Trauma Centre, Kathmandu, Nepal

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ABSTRACT

The rapidly increasing population in the Kathmandu valley has demanded for the construction of multi-storeyed buildings. Such structures can be vulnerable to failures as they are constructed on soft fluvio-lacustrine sediments without detailed deformation analysis of their foundation. Hence, the Bir Hospital Trauma Centre is taken here as a case study for the deformation analysis. The settlement calculated by conventional test methods (e.g., oedometer test, compressibility index, etc) are purely one dimensional and do not represent the actual value where lateral influences are possible. For example, the settlement reckoned from conventional methods was 41.6 mm for the stratification below 4 m depth and 24 mm for the stratification below 8 m depth. On the other hand, using a finite element method, it was 42.5 mm for the stratification below 8 m depth.

Keywords: Building foundation, deformation analysis, Kathmandu, finite element method

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INTRODUCTION

The Kathmandu valley constitutes a synclinal basin filled up with fluvio-lacustrine sediments of Pleistocene age. A rapid increase in the population of the Kathmandu valley in last two decades has demanded for the construction of multi-storeyed buildings. A recent survey shows that the deformation analysis of building foundations is rarely carried out in the Kathmandu valley during their design phase and hence the structures could be vulnerable to failures. Excessive settlement leads to the failure of foundation and ultimately the collapse of building. The failure process is more pronounced when the foundation is placed on such soft fluvio-lacustrine sediments as those of the Kathmandu valley. Hence, this paper primarily deals with the deformation analysis of foundation and geotechnical properties of soil below the foundation. For this purpose, the Bir Hospital Trauma Centre is taken as a case study.

Bir Hospital lies in the core of the Kathmandu city (Fig. 1) and is surrounded by large public buildings. Bir Hospital, Military Hospital, Nepal Airlines Corporation Building, Karmachari Sanchaya Kosh Building, and Post Office are the major structures of the area. The Bir Hospital Trauma Centre is planned to be a seven-storeyed edifice with a raft foundation above 12 mm thick PCC, below which boulders will be compactly placed. A major portion of the foundation is planned at a depth of 8 m whereas the arch-shaped portion (Fig. 2) will be placed at a depth of 4 m.

SUBSURFACE STRATIFICATION

The subsurface stratification at the Bir Hospital Trauma Centre shows four prominent layers (Fig. 3). The first 3 m thick uppermost layer contains fill material (i.e., rubble composed primarily of brick fragments and wooden wheels used during earlier constructions). The second layer consisting of sandy silt is found up to a depth of 4.5 m and it is followed by medium to fine, light grey sand till a depth of 8 m. The fourth and last layer of medium to coarse sand continues to a drilled depth of 12 m.

Stress distribution around the foundation

Stress distribution around the foundation was calculated considering the building's dead and live loads. The results were then compared against the safe bearing capacity of the soil at the borehole depth. In this process, corrected standard penetration test (SPT) values were used to estimate the safe bearing capacity with a factor of safety of 3. The calculation of dead load of the superstructure was carried out considering the dimensions of walls, floors, and columns of

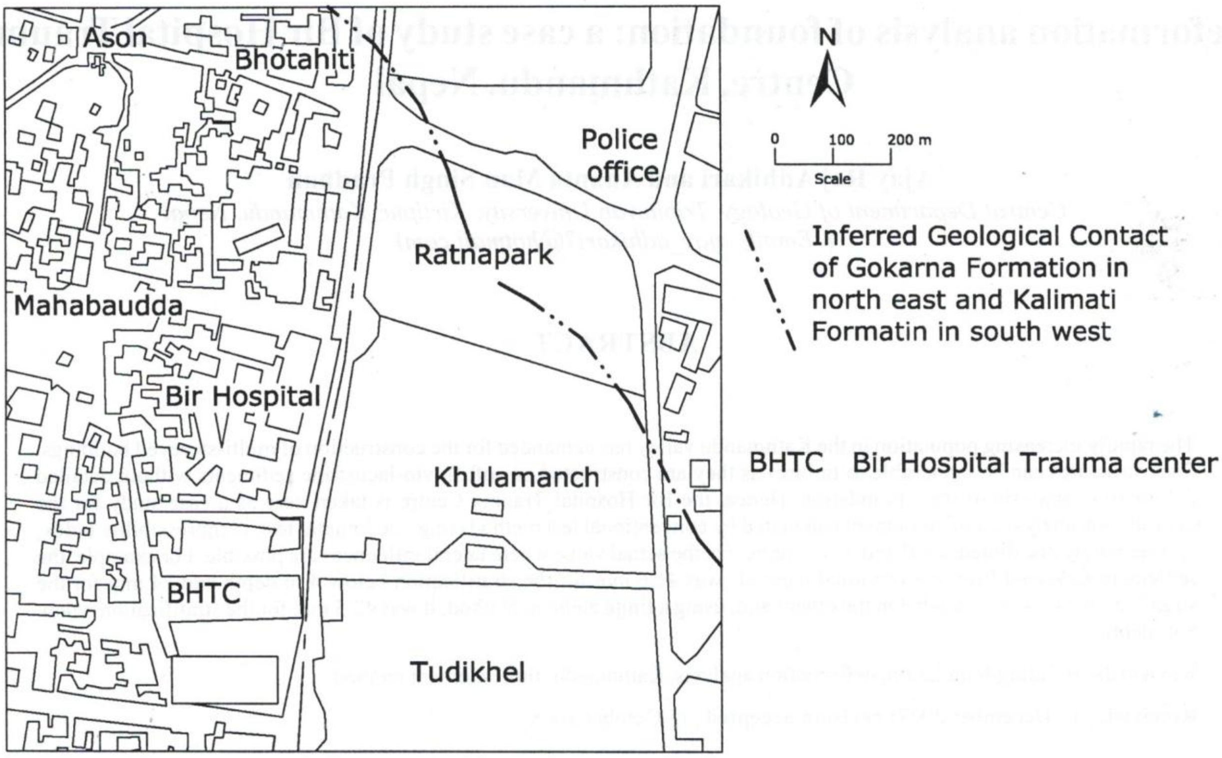

Fig. 1: Location map of the site (Modified after KVMP 2002)

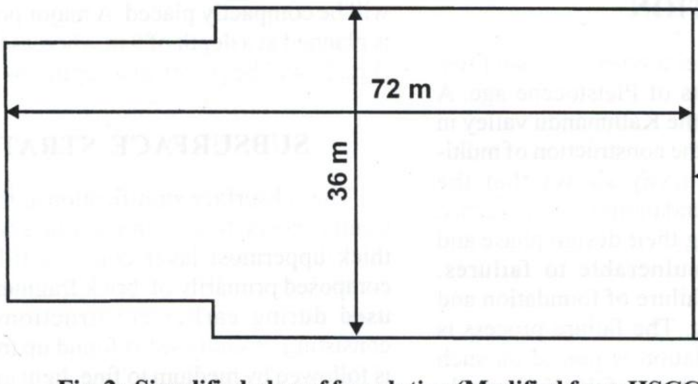

Fig. 2: Simplified plan of foundation (Modified from HSCC 2007)

the proposed building as well as the unit weights of their constituent materials.

Assuming a uniform distribution of load throughout the structure, the following parameters were obtained.

The estimated dead load of the building = 120 kN/m^2

The live load or imposed load of the building = 17 kN/m^2

Hence, the total service load of the building > 140 kN/m^2

The stress distribution below the foundation was calculated (Table 1) considering the most realistic conditions for a raft placed on sand and experiencing a uniform pressure under a rectangular area (Newmark 1935). Newmark has derived an expression for the vertical stress at a point below the corner of a rectangular area of width *B* and length *L* loaded uniformly as shown in Fig. 4.

The following is the popular form of Newmark's equation for σ_z

Soil description	Depth(m)	Column	SPT N-value	Corrected N-value	Safe bearing capacity (kN/m²)
Silty clay and fill	1				
	2				
Low-plastic, loose, light grey sandy silt	3		2	2.0	10
	4		17	16.0	110
Medium to fine, light grey sand	5		6	6.0	40
	6		6	6.0	40
	7		11	11.0	70
Medium dense, coarse, light grey sand	8		7	7.0	40
	9		18	16.5	110
	10		24	19.5	130
	11		18	16.5	110
End of borehole	12		24	19.5	130

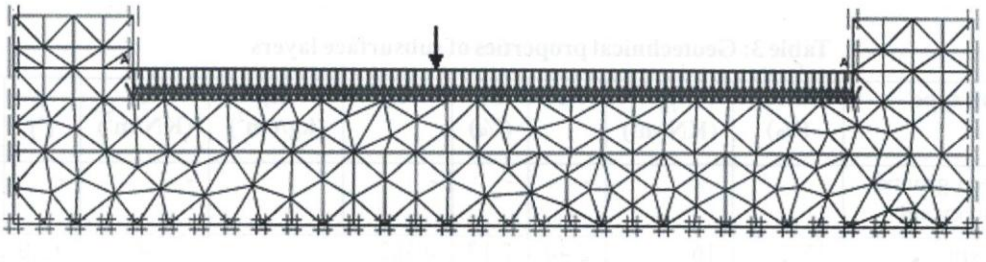

Fig. 4: Generation of mesh

$$\sigma_z = \frac{q}{4\pi}\left[\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+1+m^2n^2}\right)\left(\frac{m^2+n^2+2}{m^2+n^2+1}\right)+\sin^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+1+m^2n^2}\right)\right] \quad (1)$$

where σ_z is the pressure below depth z, q is the total amount of pressure, $m = B/z$, and $n = L/z$.

DEPTH OF FOUNDATION

The depth of foundation for a given contact pressure and subsoil conditions was given by Rankine (1857) and the depth was obtained from the following equation (Venkatramalah 2003):

$$D_f = \frac{q_{ult}}{\gamma\left(\frac{1+\sin\phi}{1-\sin\phi}\right)} \quad (2)$$

where D_f is the depth of foundation, q_{ult} is the ultimate bearing capacity, γ is the unit weight of soil, and ϕ is the friction angle.

The obtained foundation depth was derived as follows:

$$D_f = \frac{140\ kN/m^2}{1.24\ kN/m^3 \times 3.4} = 3.34\ m$$

Table 1. Safe bearing capacity and loading due to the structure

Depth below footing (m)	Pressure due to building (kN/m^2)	Safe bearing capacity from N-value (kN/m^2)
0.5	40.00	80
1.5	39.87	130
3.0	39.88	160
4.5	39.90	120
6.0	39.87	150

Table 2: Settlements at loading of the structure. C_b is a grain size correction factor.

Depth (m)	Parameters	Equation	Settlement (mm)
4	$q_n = 120\ kN/m^2$; $N = 9$; $C_b = 1$	$s = \frac{q_n \times 31.2}{C_b \times N}$	41.6
8	$q_n = 140\ kN/m^2$; $N = 15$; $C_b = 1.25$	$s = \frac{q_n \times 31.2}{C_b \times N}$	24.0

Note: q_n is the intensity of loading (i.e., building's dead load); N is the average N-value of layers below the foundation depth; C_b is the grain size correction factor; s is settlement.

Table 3: Geotechnical properties of subsurface layers

Depth (m)	Soil type	NMC (%)	γ_b (KN/m^3)	G	PI (%)	C_c	E_s (kg/cm^2)	C (KN/m^2)	ϕ (^{o})	K (cm/s)
0–3.0	Disturbed ground with clayey silt	-	-	-	-	-		-	-	-
3.0–4.5	Clayey silt	17.21	16	2.40	7.17	0.302		4	15.0	5.75×10^{-7}
4.5–8.0	Fine to medium sand with clayey silt layers	34.99	21.7	2.49		0.280	300	0	19.5	6.46×10^{-5}
8.0–12.0	Dense coarse sand	31.02	22.4	2.56		0.0702	430	0	33.5	8.9×10^{-5}

Note: NMC = Natural moisture content; γ_b = bulk unit weight of saturated soil; G = specific gravity; PI = plasticity index; C_c = compressibility index; E_s = elasticity modulus; C = cohesion; ϕ = angle of internal friction; K = coefficient of permeability

SETTLEMENT

The calculated settlement values at the estimated intensity of loading (q_n) are given in Table 2, where the average N-values were obtained from the borehole data (Fig. 3) for respective depths of foundation.

The obtained settlements were 41.6 mm and 24 mm for the foundation depths of 4 m and 8 m respectively.

FINITE ELEMENT METHOD

The deformation analysis of the foundation was also carried out using a finite element program. For this purposes

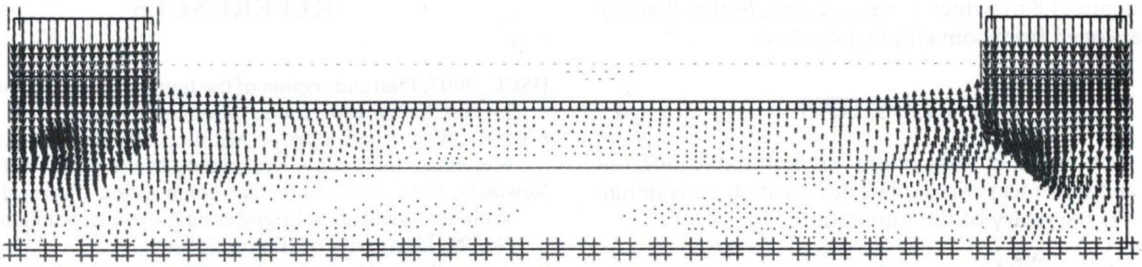

Fig. 5: Total vertical displacement

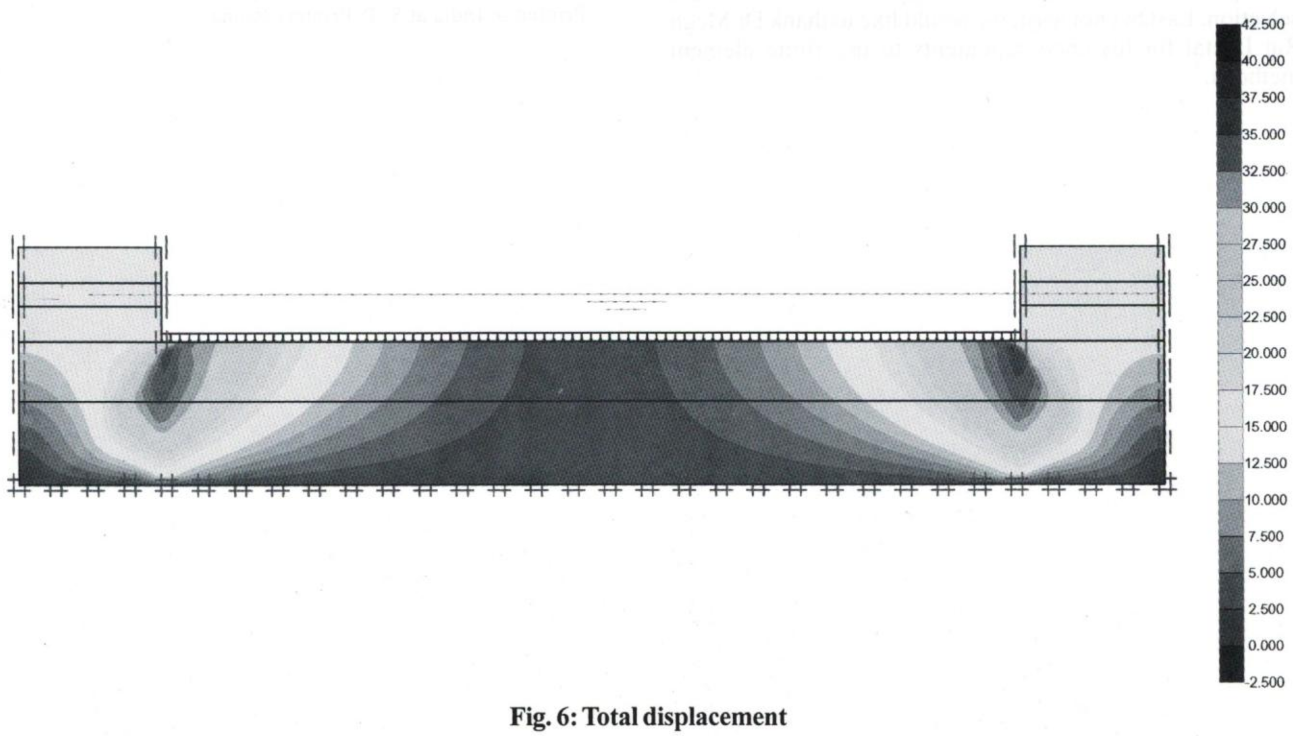

Fig. 6: Total displacement

the subsurface stratification was considered as that of Fig. 3 with the geotechnical properties given in Table 3. For the purpose of finite element analysis, a stratification of 80 m length was modelled and its mid 72 m length was trimmed off to a depth of 8 m for the application of the load (Figs. 5, 6).

Then, the analysis was carried out under the following assumptions.

i. Plastic soil

ii. General Mohr failure criterion

iii. Drained condition

iv. Traction loading system

v. 6-nodded triangular element

vi. Water table at a depth of 4 m

vii. Uniformly distributed load

viii. Planar interface

ix. Total load = 14 t/m^2

The deformation around the foundation obtained from the finite element method is depicted in Figs. 5 and 6. The finite element method gave a maximum displacement of 42.5

mm at a depth of 8 m, which is significantly higher than the values reckoned from conventional methods.

CONCLUSIONS

The foundation is safe under the estimated bearing capacity and settlement criteria. The deformation is maximum at the lower boundary of the foundation.

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