

LIQUEFACTION POTENTIAL ANALYSIS OF KATHMANDU VALLEY

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ABSTRACT

Empirical approach of liquefaction potential analysis based on standard penetration test (SPT) is a popular method for studying liquefaction. Same method of analysis was employed to calculate the liquefaction potential of few locations in Kathmandu Valley namely; Singhadurbar, Maharajgunj, Jamal and Naxal. Using data of 22 boreholes, taking reference of magnitude 8.0 and ground acceleration 0.3 g, factor of safety (FS) was calculated using SPT value (N). The findings were compared with liquefaction hazard map of Kathmandu Valley prepared on the basis of semi-empirical approach. N value was paramount to calculate liquefaction potential and higher N value exhibited higher FS in most of the locations. Percentage of fine contents consistently influenced FS. FS increased with increase in percentage of fine contents. The effect of depth on FS against liquefaction was less significant. Based on FS, possibility of liquefaction was found to be high in most part of the study area as it was in hazard map. However, few locations that were unsafe in hazard map were found to be safe in this study. It not only depicts the relevancy of empirical approach over semi-empirical approach for site specific liquefaction investigations but also for preparing more reliable liquefaction hazard map.

KEYWORDS: liquefaction potential, SPT, empirical approach, Kathmandu Valley

1. INTRODUCTION

1.1 Background

Liquefaction of soil, defined as significant decrease in shear strength and stiffness due to increase of pore water pressure, continues to be a major cause of structural damage and loss of life during earthquakes (Cetin et al. 2002). In the past, world has seen several large scale devastating effects of liquefaction during the earthquakes (e.g. 1964 Niigata earthquake, 1985 Kobe earthquake, 1989 Loma Prieta earthquake and 2001 Bhuj earthquake). The phenomenon of seismic soil liquefaction has been able to draw the interest of researchers. They have studied it via assessment of soil liquefaction potential (Vipin et al. 2010).

There are two general approaches for the assessment of liquefaction. One is the use of laboratory testing of undisturbed samples and other is the use of empirical relationships based on correlation of observed field behaviour with various in-situ tests for identifying the index properties (Cetin et al. 2004). The later approach is the dominant approach and is common in practice. The main reason for the selection of later approach is due to the experimental difficulties and high cost in the former approach. Seed and Idriss (1971) developed a method for liquefaction potential based on both laboratory and field based data. The method was called simplified method. This method

was modified by Seed et al. (1985) with use of the field based SPT data only. Later twenty experts reviewed and developed more convincing empirical approach based on SPT and related development made over the previous decade (Youd et al. 2001). They summarized four in-situ tests methods for the assessment of liquefaction. These are namely; (1) the standard penetration test (SPT) (2) the cone penetration test (3) measurement of in-situ shear wave velocity (V_s) and (4) the Becker penetration test. Among these tests, the oldest and still the most widely used method is SPT, and this paper has also used the same method.

Previous studies have described the details on use of SPT based data for liquefaction resistance evaluation (e.g. Seed et al. 1985, Youd et al. 2001, Cetin et al. 2004 and Jha and Suzuki 2009). Field based SPT values have been used by some other studies to evaluate the liquefaction potential of geographical area like cities and states (Sonmez 2003 and Vipin et al. 2010). Though these studies were based on the SPT value of study area, they did not mention the variation in values of site specific boreholes. However, there are possibilities of variation in site specific SPT values because of variation of soil profile within study area. This increases the importance of consideration of site specific liquefaction potential while doing developmental works. This is very important consideration to make while infrastructure

development works are done in liquefaction prone and unplanned urban environments like Kathmandu Valley.

A study was conducted at some locations of the Kathmandu Valley; Singhadurbar, Maharajgunj, Jamal and Naxal to study the site specific liquefaction behavior. SPT value was calculated from twenty two boreholes in these locations. The detail location map of the study area and sample site is presented in Fig.1.

While using SPT for liquefaction potential in site specific hazard studies, occurrence or non-occurrence of liquefaction can be evaluated on the basis of FS of each borehole sites. FS is the ratio of cyclic resistance ratio of soil (CRR) to the cyclic

stress ratio of the soil (CSR). The ratio greater than unity suggest non-liquefiability of the borehole sites. This process is based on Youd et al. (2001).

The first objective of this study was to find the site specific liquefaction potential and the second objective was to conduct a comparative analysis of liquefaction potential of study sites obtained from empirical approach (this study) with liquefaction hazard map of whole Valley based on semi-empirical approach carried out by United Nation Development Programme (UNDP) in collaboration with Ministry of Housing and Physical Planning (MOHPP) (UNDP/MOHPP 1994).

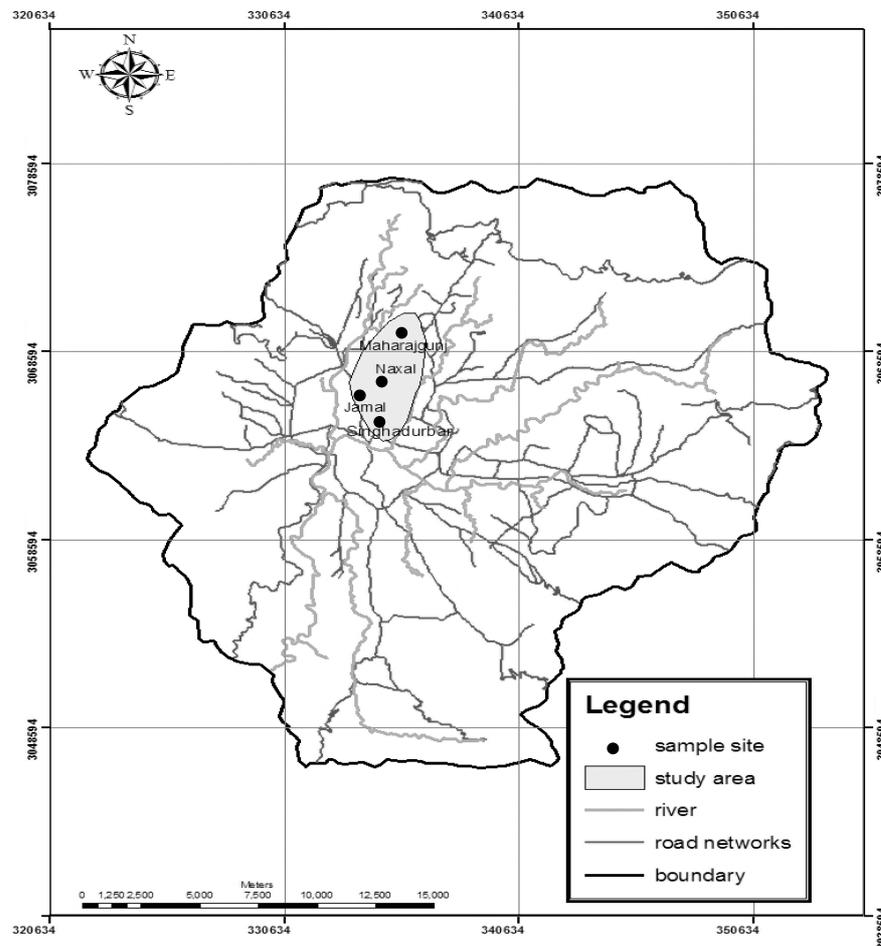


Fig.1. Location of the study area in the map of Kathmandu Valley

1.2 Study Area

Himalayan arc experienced four large earthquakes of magnitude around 8.5 since 1897. One third part of the arc lies in Nepal (Pandey et al. 1999). The central part of the arc that has not been active during past has been considered as a potential zone for large earthquake, which can provoke damage to the Kathmandu Valley and its

surrounding areas that lies in the arc (Pandey et al. 1999). In Nepal and nearby region, earthquake of magnitude greater than 8 have occurred every 80 years on an average (NSET 2008).

The deposition in the Kathmandu Valley is lacustrine and fluvial in origin with thickness up to 500 m (Yoshida and Gautam 1988). The filling sediments are made up of clay, silt, sand and gravel.

Areas with loose sand deposits have a greater chance of liquefaction after the earthquake. The explained evidences after the 1934 earthquake in the book entitled “*Nepal Ko Mahabhukampa*” (The great earthquake of Nepal, 1935) indicates that wide spread liquefaction had occurred at loose sand deposited areas of Valley (Rana 1935). Besides, a study by UNDP and MOHPP in 1994, have stated that there are active faults lie near Kathmandu Valley. Moreover, bowl shaped topography of the Valley increases the possibility of magnifying damage due to ground acceleration.

Kathmandu Valley is the capital city of Nepal; the largest urban conglomerate holds an estimated to hold a population of one million in 2011 within the metropolitan area alone. Population density according to 2001 census was 13,225 per square Kilometers (Kathmandu Metropolitan City 2011). From the few literatures that are available, Kathmandu Valley is vulnerable to great earthquake and there could be huge damage associated with it.

1.3 Previous study on liquefaction in Kathmandu Valley

In the past, some work has been done for liquefaction potential analysis in the Kathmandu Valley. A liquefaction hazard map of Kathmandu Valley (UNDP/MOHPP 1994) was prepared using semi-empirical approach proposed by Juang and Elton (1991) with 123 boreholes. Juang and Elton mentioned twelve factors for the preparation of liquefaction susceptibility map.

This study took in consideration only six of those factors namely; depth of water table, grain size, depth of burial, capping layer, age of deposits and liquefiable layer thickness. On the basis of these factors, a general criterion was developed for rating the liquefaction susceptibility as high, moderate, low and very low. However, this study did not focus on the site specific liquefaction potential. Further; the calculation did not consider major geotechnical parameters like N value, earthquake magnitude and acceleration which are very important to study liquefaction behavior of soil. In general, most part of the Valley seems to be in high liquefaction potential zone as shown in liquefaction hazard map.

Another study on earthquake disaster mitigation in Kathmandu Valley was carried out by JICA and Government of Nepal in (2002). The study reported that the greatest probable earthquake in the Valley could have magnitude around 8.0 and peak ground acceleration 0.3 g.

Some studies have shown that Kathmandu bears non homogenous soil strata even within small area (e.g. IOE 2001) which suggest that liquefaction potential of small area may differ.

Past studies have limited information on site specific liquefaction potential. It is paramount to

document the site specific liquefaction potential of even small area of the Valley in order to prevent and minimize the probable damage that might occur during large earthquake in the valley.

2. METHOD

This paper mainly focuses on the liquefaction potential analysis on specific locations in the Valley using earthquake magnitude 8.0 and acceleration 0.3g. An empirical method was used for liquefaction potential analysis. In this method, CSR and CRR were calculated and FS was determined. FS was calculated for SPT value at different depth for each borehole locations.

The SPT was conducted by driving a split spoon sampler into the soil for a distance of 30 cm by a standard hammer of 65 kg weight falling through a height of 75 cm. The spoon attached to a drill rod was lowered into the bottom of the hole. The standard hammer usually known as monkey hammer was allowed to fall on the top of the drill rod until the sampler gets penetrated into the soil through a distance of 150 mm. This depth of penetration was the seating drive and was not accounted for.

After the seating drive, the actual test started and blows required for next two successive penetrations of 150 mm were recorded and added. This value was called as N value or SPT value. The test was conducted for each 1.5 m interval of depths.

2.1 Estimation of CSR

CSR was calculated using formula by Seed and Idriss (1971)

$$CSR = (\tau_{av}/\sigma'_{vo}) = 0.65(a_{max}/g)(\sigma'_{vo}/\sigma'_{vo})\gamma_d \quad (1)$$

Where a_{max} = peak horizontal acceleration at the ground surface, g = acceleration due to gravity, σ_{vo} and σ'_{vo} are total stress and effective stress respectively, γ_d = stress reduction coefficient.

a_{max} depends on the earthquake magnitude and epicentral distance from the rupture zone. The earthquake magnitude of 8.0 and acceleration of 0.3 g as reported in JICA (2002) was used for the analysis.

In Eq.(1), γ_d describes the flexibility of soil profile. To estimate γ_d , Seed and Idriss (1971) developed world wide used curve of γ_d verses depth. Lio and Whiteman (1986) developed a new relationship and Youd et al. (2001) reported Eq.(2) which was used for the determination of γ_d .

$$\gamma_d = \frac{(1.000 - 0.4113z^{0.5} + 0.04052z + 0.0017532z^{1.5})}{(1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2)} \quad (2)$$

Where, z is depth below ground surface in meters.

2.2 Estimation of CRR

N value obtained from the field test was used for the estimation of CRR. The measured N value was corrected by using the following relation

$$(N_1)_{60} = N_m C_N C_E C_B C_R C_S \quad (3)$$

Where $(N_1)_{60}$ is the SPT blow count normalized to an overburden pressure of approximately 100 kPa and a hammer energy ratio or hammer efficiency of 60%.

N_m = measured SPT value, C_N = correction for over burden stress, C_E = correction for hammer energy ratio (ER), C_B = correction factor for borehole diameter, C_R = correction factor for rod length, and C_S = correction for samplers with or without liners. Corrections to SPT modified by Skempton (1986) as listed by Robertson and Wride (1998) and cited by Youd et al. (2001) are used for calculation of $(N_1)_{60}$.

$$C_N = (P_a / \sigma'_{v0})^{0.5} \quad (4)$$

Where P_a is atmospheric pressure equals to approximately 100 kPa (1 atm) and the value of C_N is limited to 1.7.

Values of other correction factors such as $C_E = 1$ for safety hammer, $C_B = 1.05$ for borehole diameter 115 mm, $C_R = 0.85$ for rod length 4 m to 6 m and $C_S = 1$ for sampler without liners listed in (Robertson and Wride 1998) were used in this analysis. The corrections factors are standardized for local context in different countries (Seed et al. 1985). Since there are no local standards, above mentioned correction factors have been used in this study.

CRR depends on the fine content of the soil. For fine contents equal to or more than 5%, 15% and 35%; SPT clean sand based curve with relationship between CSR and $(N_1)_{60}$ suggested by Youd et al. (2001) was used. But, for fine contents less than 5%, CRR is calculated using following equation.

$$CRR_{7.5} = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{[10 \cdot (N_1)_{60} + 45]^2} - \frac{1}{200} \quad (5)$$

2.3 Estimation of FS

For estimating Factor of Safety, following equation based on Youd et al. (2001) was used.

$$FS = \frac{CRR_{7.5}}{CSR} \cdot MSF \cdot K_\sigma \cdot K_\alpha \quad (6)$$

Where, MSF is the magnitude scaling factor. For earthquake magnitude others than 7.5, we need to modify FS by multiplying it by MSF. The value of MSF for lower bound ($M < 7.5$) and upper bound

($M > 7.5$) as introduced in Youd et al. (2001) was used given in Eqs (7) and (8) respectively.

$$MSF = 10^{2.24} / M_w^{2.56} \quad (7)$$

$$MSF = (M_w / 7.5)^{-2.56} \quad (8)$$

K_σ is the correction factor for effective overburden and K_α is the correction factor for sloping ground. The consideration of factors K_σ and K_α is beyond routine practice and hence is not considered in this study.

A soil profile and details of procedure used for calculation of FS at a borehole location is given in Fig.2 and Table 1 respectively. The soil profile revealed the type of soil at different depths and ground water table position. The soil was classified on the basis of Unified Soil Classification System (USCS).

Where, GWT = Ground water table, FC = Fine content, a_{max} = Peak horizontal ground acceleration

Since value of FS is below one except for depth 4.5 m, the location S1 was unsafe.

3. RESULTS AND DISCUSSIONS

In total, seven boreholes from Singhadurbar, four boreholes from Maharajgunj, four boreholes from Jamal and seven boreholes from Naxal were considered for analysis. The FS verses depths were calculated and its relation with N values was analyzed. FS values below the ground water table were considered for analysis. In the legend of Figures plotted for FS verses depth, the numbers within the brackets denote the depth of ground water table for that particular borehole. Moreover, the symbol of the legend denotes the location name and borehole number. For example, S1 represents the Singhadurbar area of borehole number one.

This study used empirical approach to calculate the liquefaction potential. In this approach, the relationship of FS verses depth and FS verses N values is paramount. No constant pattern was observed when FS was plotted against depth as shown in Figs (3, 5, 7 and 9). The studies by Hwang et al. (2004), Sonmez (2003) and Jha and Suzuki (2009) also reported inconsistent relationship between FS and depth.

Factor of safety was found to increase with increase in N value in all the borehole locations (Figs 3 to 10) except three boreholes in Singdurbar area at particular depths (S1, 7.5 m; S4, 7.5 m and S5, 6.0 m). In these locations, FS were inconsistent with other depths in the same boreholes due to the proportion of fine contents. The increase in proportion of fine contents increased the FS even for the same value of N . Increase in N value and fine contents corresponded to the increase of FS in

Table 1. FS calculation at S1 borehole of Singhadurbar

Average Density = 17 kN/m ³ , GWT = 3.6 m, a _{max} = 0.3 g, Earthquake Magnitude = 8.0											
Depth (m)	SPT (N)	FC(%)	Soil type	σ_{vo}	σ'_{vo}	C_N	$(N_1)_{60}$	CRR	γ_d	CSR	FS
4.5	27	4	SP	76.5	67.5	1.2	33	0.35	0.97	0.21	1.4
6	15	9	SP-SM	102	78	1.1	17	0.18	0.96	0.24	0.6
7.5	17	14	SM	128	88.5	1.1	18	0.19	0.94	0.26	0.6
9	15	9	SP-SM	153	99	1.0	15	0.16	0.92	0.28	0.5
10.5	18	3	SP	179	109.5	1.0	17	0.18	0.89	0.28	0.5
12	25	13	SM	204	120	0.9	23	0.26	0.86	0.28	0.8

previous studies as well (e.g. Sonmez 2003 and Hwang et al. 2004).

One of the major important factors that govern the variation of liquefaction potential is the ground water table position. Lower depth of ground water table position indicates the higher probability of liquefaction. The ground water table in the small area may vary due to the ground elevation and soil stratification. The position of water table may vary even at the same level due to the permeability of soil. The ground water table position at Singhadurbar, Maharajgunj, Jamal and Naxal were found to be in the range of 0.4 m to 3.6 m (Fig.3), 7.4 m to 12 m (Fig.5), 3.0 m to 3.2 m (Fig.7) and 1 m to 7 m (Fig.9) respectively. The difference in the value of factor of safety that was observed in these study sites may also be due to the difference in the level of ground water table.

The study done by MOHPP/UNDP (UNDP and MOHPP 1994), reported Naxal area to be in moderately liquefiable zone while Singhadurbar, Maharajgunj and Jamal area were in high potential liquefiable zone. The findings of this study revealed that the borehole location S2 in Singhadurbar area, M4 in Maharajgunj area, N2 and N6 in Naxal area were in safe zone while rest eighteen locations were found to be unsafe. This result was found to be quite different with previous result and which justifies the necessity of consideration of site specific liquefaction study.

On the basis of the findings of this study and past literatures it is evident that some parts of Kathmandu Valley pose a risk of liquefaction. According to Rana (1935), ground oscillation and fountain as high as of 3 to 4 m height was observed during 1934 earthquake. With magnitude of earthquake 8.0, JICA's study on the disaster assessment estimated, 1.3 % of population would die and another 3.8 % would be seriously injured (JICA 2002) and much of the damage in lifeline services in the Valley lifelines (such as waterworks, sewerage, and electric lines) etc would create great impact on urban population. To prevent and mitigate the probable disaster in future, its of prime importance that detail studies are carried about the effect of liquefaction in the Valley and empirical method of studying liquefaction behaviour of the

sand deposit in the Valley is an appropriate tool for the identification of safe and unsafe zone against liquefaction for particular area. Knowledge of safe

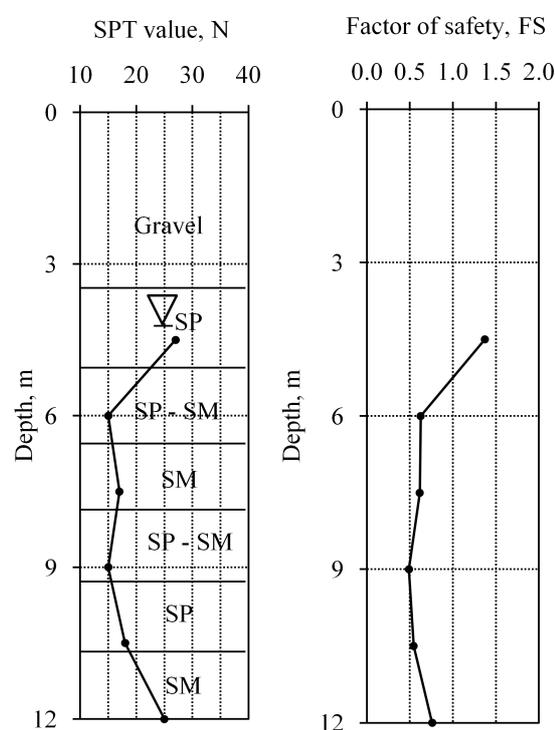
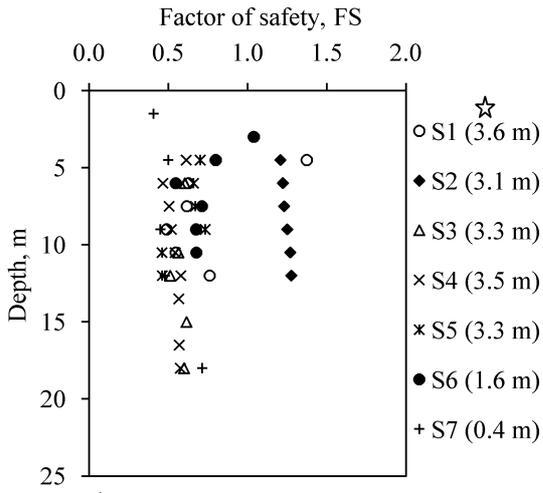


Fig.2 Soil profile and Factor of safety of S1 borehole

and unsafe zone are important for applying countermeasures to safeguard the developmental works in the Valley.

The deposition of soil in the Valley is heterogenous. So, a detail geological investigation is required to understand soil deposition. On the basis of which, minimum distance between two borehole can be recommended. Thus, the selection of boreholes on the basis of soil deposition and preparation of liquefaction hazard map with the results of empirical method is recommended for future study.



☆ Depth of ground water table
Fig.3. Factor of safety verses depth (Singhadurbar)

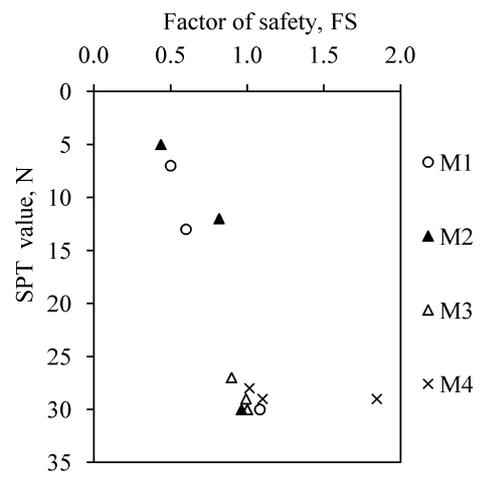


Fig.6. FS verses N value (Maharajgunj)

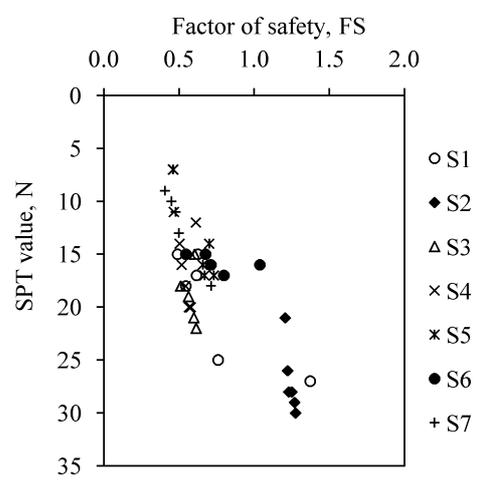
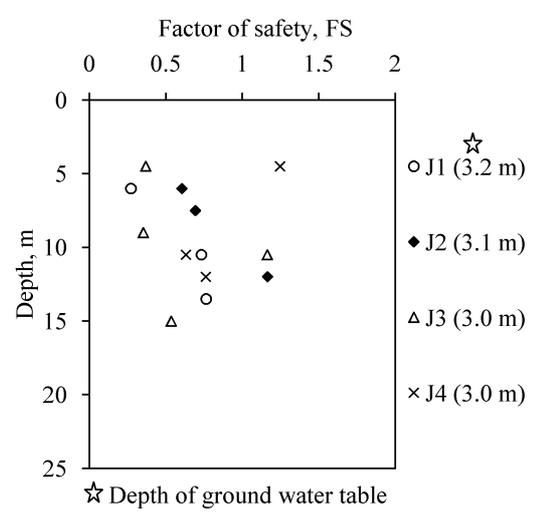
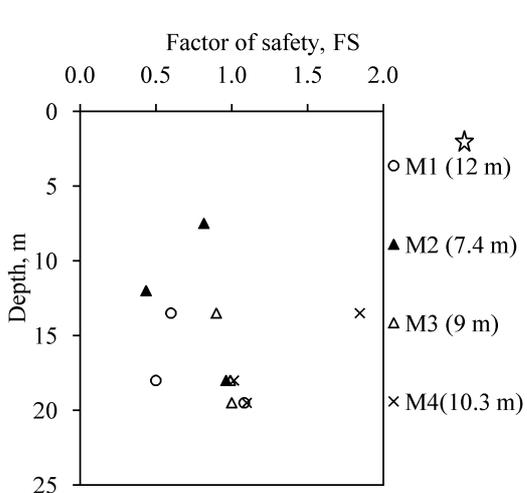


Fig.4. FS verses N value (Singhadurbar)



☆ Depth of ground water table
Fig.7. Factor of safety verses depth (Jamal)



☆ Depth of ground water table
Fig.5. Factor of safety verses depth (Maharajgunj)

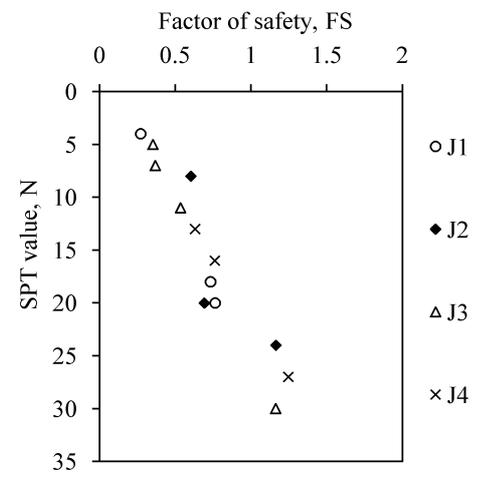


Fig.8. FS verses N value (Jamal)

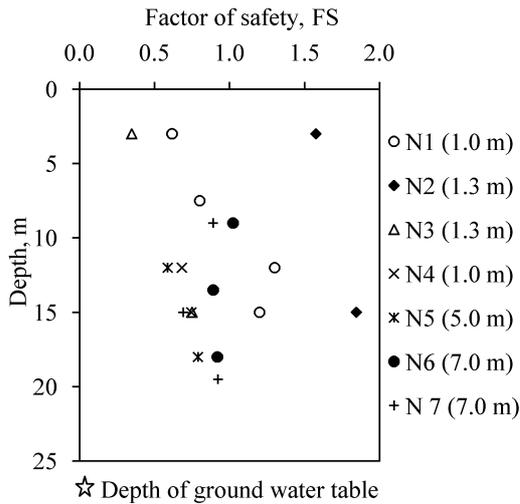


Fig.9. Factor of safety versus Depth (Naxal)

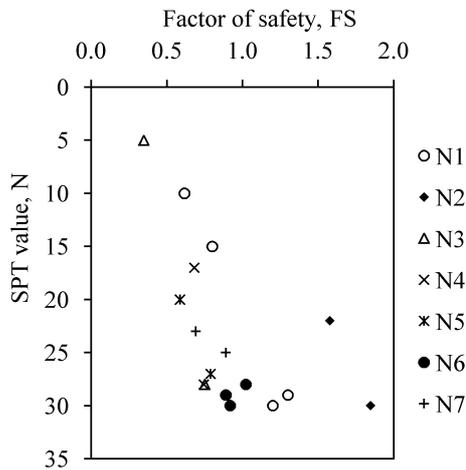


Fig.10. FS versus N value (Naxal)

4. CONCLUSIONS

Liquefaction potential analysis based on empirical approach with N value was carried out at some areas (Singhadurbar, Maharjung, Naxal and Jamal) of Kathmandu Valley. The following conclusions were drawn from the analysis.

- i) The site specific liquefaction potential by using empirical method showed four borehole locations to be in safe zone while rest eighteen locations were found to be in unsafe zone.
- ii) FS increased with increase of fine contents. Similar pattern was observed between FS and N value at most of the cases. However, at borehole depths (e.g. 7.5 m of S1, 7.5 m of S4 and 6.0 m of S5) of Singhadurbar, different pattern was observed due to percentage of fine contents.

iii) Borehole locations in the areas considered to be unsafe in the hazard map prepared by UNDP/MOHPP were found to be safe in the study. For example, Singhadurbar area was depicted to be unsafe zone by using semi-empirical approach while one of the boreholes in the same location (S2) was found completely safe based on empirical approach. Empirical approach might be more relevant than semi-empirical approach while studying small geographic location. Thus, the results of empirical studies are useful for public and government for planning in the small area. Same method can be employed for the identification of liquefaction potential while planning infrastructure developmental works.

iv) Because of heterogeneous nature of deposition was observed in the study locations, a detail geological investigation is desirable for finding out the soil profile of the valley bed which would help to identify the minimum distance required between two boreholes. This could be used to prepare a more reliable liquefaction hazard map of Valley.

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