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# A SPT Based Evaluation of Liquefaction Potential of Rapti Main Canal in District Balrampur


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**ABSTRACT**

*Rapti main canal is leading distributary under the project Saryu Nahar Pariyojna. Rapti main canal having a stretch of 125 km and a capacity of 95 cumeec travels through districts Balrampur, Behraich and Shravasti. Seismic soil liquefaction is evaluated along this stretch in terms of factor of safety (FS) against liquefaction along the varying depths of soil profile for earthquakes of different moment magnitudes using Indian standard penetration test (SPT) based on simplified procedure suggested by Seed & Idriss. As the majority of sites along the stretch of Rapti main canal are water-logged and having inorganic silt and poorly-graded sand, the susceptibility of liquefaction is observed to be very high at many places.*


**KEYWORDS : Factor of Safety, Standard Penetration Test (SPT), Seed & Idriss, Rapti Main Canal, Liquefaction.**

## 1 Introduction

It is broadly accepted that Earthquakes are most severe natural disaster that destroys the building and harms the human lives. Earthquake shaking may cause a loss of strength and stiffness of soil which may be classified as liquefaction and defined as a phenomenon of loose/soft cohesionless soil which is submerged below the water table loses its strength and stiffness due to the increase in pore water pressure under intense ground shaking. During liquefaction soil behaviour changes from solid state to closely liquid state. Strong earthquake motions, intense ground shakes are responsible for soil liquefaction. Reduction in the shearing resistance of soil is also depends upon the duration of ground shaking and intensity of ground shaking. If the deformation of shear resistance is high enough to cause damages to buildings, roads and other structures are called ground failure. Liquefaction occurs when the loose, saturated cohesionless soil breaks down due to an intense applied load. As the soil structure fails, the loose soil particles trying to move into a denser configuration. In a condition of ground shaking, however, there is not enough time for the water in the pores of the soil to drain. Instead the water is trapped and prevents the soil particles from coming into contact with each another. This is accompanied by an increase in soil water pressure, which reduces the contact forces between the individual soil particles.

If the soil water pressure is low enough, the soil stays in equilibrium. However, once the water pressure exceeds a certain limit, it causes the soil particles to move, thus causing the decrease in strength of the soil and results in failure of the soil mass. During intense ground shake when the shear wave travels through saturated soil structures, it causes the granular soil structure to deform and the weak part of the soil begins to collapse. The collapsed soil fills the lower layer and forces the pore water pressure in this layer to increase. If increased water pressure cannot be released, it will continue to build up and after a certain limit effective stress of the soil becomes zero. If this situation occurs then the soil layer losses its shear strength and it cannot certain the total weight of the soil layer above, thus the upper layer soils are ready to move down and behave as a viscous liquid.

Soil liquefaction phenomenon mainly depends on the factors like as magnitude, intensity of earthquake, duration of an earthquake, peak ground acceleration, type of soil and thickness of strata, fines content, relative density, degree of saturation, permeability of soil, variation in ground water level, normal and effective stress, grain size distribution and shear modulus degradation (Youd and Perkins, 1978; Youd et al. 2001).

The susceptibility of a soil layer to liquefy is expressed as factor of safety against liquefaction and is evaluated by simplified procedure suggested by Seed & Idriss (1971). In this simplified procedure factor of safety against liquefaction is evaluated by taking the ratios of cyclic resistance ratio (CRR) to cyclic stress ratio (CSR). Cyclic resistance ratio shows the capacity of soil to resist the liquefaction and cyclic stress ratio defines the seismic loading on soil.

Factor of safety (FS) of a soil layer at given site is obtained with the help of various in-situ tests like standard penetration test (SPT), cone penetration test (CPT), shear wave velocity test ($V_s$) and Becker penetration test (BPT). (Youd et al., 2001). In above mentioned methods, SPT test is most widely used in fields due to its simplicity and easiness. Factor of safety by using simplified procedure is mainly dependent upon vertical stress, effective vertical stress, peak ground acceleration, earthquake magnitude, SPT N-value, fines content and consistency limits of soils (Seed & Idriss, 1971; Seed et al., 1985; Youd et al.,2001).

The soil layer may be liquefy if FS<1 and non-liquefy if FS>1 (Seed & Idriss, 1971). Later Seed & Idriss (1982) proposed that a value between 1.25 and 1.5 taken as non- liquefiable. By obtaining factor of safety (FS) we access liquefaction potential of soil at a certain depth in soil layer. Soil susceptible to liquefaction at different moment magnitudes are determined by simplified procedure to obtain the remedial measures before or during construction to avoid failure against liquefaction. So it is better to provide liquefaction prone map at different moment magnitudes of a given site for providing guidelines to seismic design and soil stabilization. In this article, an attempt has been made to determine factor of safety (FS) against liquefaction at different moment magnitude along the depth at each representative bore hole along the stretch of Rapti Canal (at district Balrampur, Behraich and Shravasti) based on method proposed by Seed & Idriss (1971).

## 2 The Study Area

Rapti main canal having length 125 km and capacity about 95 cumecs in a stretch along districts Balrampur, and Shravasti. Rapti main canal is an essential part of Saryu Nahar Pariyojna which will provide irrigation to 12.0 lacs h.a. area (C.C.A) of Behraich, Shravasti, Gonda, Balrampur, Basti, Siddharthnagar, Sant Kabir nagar and Gorakhpur through 8240 km long distribution system.

The study area consist a rapti barrage on river Rapti near village Lachmanpur in Bhinga tehsil of district Behraich.

Along the stretch of Rapti main canal (125 km) nine village are chosen to obtain a number of borehole locations and related data such as SPT N- value, normal vertical stress, effective vertical stress, fines content, liquid limit, plastic limit, plasticity index, bulk density, dry density, moisture content, various shear characteristic, and soil classifications.

### 2.1 Geologic Conditions and seismicity

Balrampur is located at 27.43°N latitude and 82.18°E longitude. It has an average elevation of 106 meters. The town is situated on the bank of the river Rapti. The Balrampur (U.P.) district is surrounded on the north and the northeast by Nepal and Shivalic range of Himalaya (also called tarai region), on the east by Siddharth Nagar (U.P.) district, on the southeast by Basti (U.P.) district, on the south and the southwest by Gonda (U.P.) district and on the west by Shrawasti (U.P.) district.

The total wetland area in the district is computed as 21348 ha. Natural wetlands dominated the district. The major wetland categories of the district are Rivers/Streams, Ponds/Lakes, Waterlogged (natural), and Ox-bow lakes/ Cut-off meanders. Most of the natural wetlands are closely distributed in the southern part of this district. Reservoirs/barrage is the major manmade wetlands. There are almost 13 such sites, found mostly in the northern part of the district. In addition there are 1811 small wetlands (<2.25 ha) distributed throughout the district. The Geological Survey of India (G. S. I.) first published the seismic zoning map of the country in the year 1935. With various modifications made subsequently, this map was primarily based on the extent of damage suffered by the different regions of India due to earthquakes. This map shows the four different seismic zones of India. The different seismic zones of the nation, which are importantly shown in the map are given below:

Zone - II: This is said to be the least active seismic zone.
Zone - III: It is included in the moderate seismic zone.
Zone - IV: This is considered to be the high seismic zone.
Zone - V: It is the highest seismic zone.

As per IS 1893 - part 1 (2002) Balrampur district lies in zone IV (having zone factor = 2.4) which is liable to moderate damage by earthquakes and intense ground shaking according to earthquake zonal map of India. Even though no major earthquake happened close to it, the territory being not far away from the Great Himalayan Boundary fault, experiences the effects of moderate to great earthquake occurring there.

### 2.2 Geotechnical site characteristics

Most of the parameters namely SPT N-values, dry density, wet density, specific gravity, ground water depth, fines content and consistency index, required for the assessment of factor of safety against liquefaction (FS) of the soil profile at different soil sites along the stretch of Rapti main canal, are obtained from the borehole data of different sources. Since the boreholes are closely bunched along the stretch of Rapti main canal, a specific site is chosen from the cluster of SPT boreholes. Thirty borehole locations along the stretch of Rapti main canal are used to evaluate liquefaction potential. The SPT boreholes depths are varies from the range of 1.0-30 m. SPT blow counts ranges from 5 to 30.

**Table 2 shows summary of mechanical grading and consistency limit of typical site.**

### 3 Assessment of Liquefaction Potential

Liquefaction potential shows the severity of a soil mass to sink or fail. Liquefaction potential is assessed by evaluating factor of safety (FS) against liquefaction which is a ratio of cyclic resistance ratio (CRR) to cyclic stress ratio (CSR). This factor of safety is computed along the entire depth of soil column below ground level at a specified borehole location. Cyclic stress ratio shows seismic demand whereas cyclic resistance ratio gives capacity of liquefaction resistance of soil.

### 3.1 Determination of CSR

Cyclic stress ratio (CSR) considered as seismic demand by a given earthquake and it can be determined by using simplified procedure of Seed & Idriss (1971). This seismic demand is depends on ground surface acceleration, acceleration due to gravity, total vertical stress, effective stress.

$$CSR = \frac{\tau_{avg}}{\sigma'_v} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma'_v}\right)r_d$$

$r_d$ is stress reduction factor based on stability of soil profile.

For routine practice and noncritical projects, the following equations may be used to estimate average values of *rd* (Liao and Whitman 1986).

$r_d$ = 1.0 -0.00765$z$ for $z \le 9.15$ m
$r_d$= 1.174 -0.0267$z$ for 9.15 m <$z \le 23$ m

Where $z$ = depth below ground surface in meters. Some researchers have recommended additional equations for estimating $r_d$ at greater depths (Robertson and Wride 1998), but estimation of liquefaction at these greater depths is beyond the depths where the simplified procedure is verified and where routine applications should be applied. For simplicity of computation, Blake (1996) suggested following equation

$$\frac{\left(1.000 - 0.4113z^{0.5} + 0.04052z^{1.5}\right)}{1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2}}$$

Where $z$ = depth below ground surface in meters.

### 3.2 Determination of CRR

Rauch (1998), approached the clean-sand base curve by the following equation:

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

This equation is only valid for $(N1)_{60} < 30$. For $(N1)_{60} \ge 30$, clean granular soils are too condensed to liquefy and are classed as non-liquefiable. Seed et al. (1985) noted an apparent increase of CRR with increased value of fines content. Based on the empirical data available, Seed et al. developed CRR curves. The equations were developed by Seed and Idriss (1971) for correction of $(N1)_{60}$ to an equivalent clean sand value, $(N1)_{60cs}$ are given below:

$(N1)60cs = \alpha + \beta\,(N1)60$

Where α and β are coefficients determined from the following relationships:

α= 0 for FC ≤5%
α= exp [1.762 (190/FC)] for 5% < FC <35%
α= 5.0 for FC ≥35%
β= 1.0 for FC ≤5%
1.5 β= [0.991 (FC /1,000)] for 5% < FC < 35%
β= 1.2 for FC ≥35%

Numerous factors in addition to fines content and grain characteristics effect SPT results

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

*Nm* = measured standard penetration resistance; *CN* = factor to normalize *Nm* to a common reference effective overburden stress; *CE* = correction for hammer energy ratio (ER); *CB* = correction factor for borehole diameter; *CR* = correction factor for rod length; and *CS* = correction for samplers with or without liners.

For the reason that SPT *N*-values increase with increasing effective overburden stress, an overburden stress correction factor is applied (Seed and Idriss 1982). This factor is commonly calculated from the following equation (Liao and Whitman 1986a):

$CN = (P/\sigma'_{vo})$

*CN* normalizes *Nm* to an effective overburden pressure of $\sigma'_{vo}$ approximately 100 kPa (1 atm), and *CN* should not exceed a value of 1.7

**Table1. Correcion to SPT (Modified from Skempton 1986) as Listed by Robertson and Wride (1998)**

| *Factor* | *Equipment variable* | *Term* | *Correction* |
|---|---|---|---|
| *Overburden pressure* | --- | $C_N$ | $(P_a/\sigma'_{vo})^{9.5}$ |
| *Overburden pressure* | --- | $C_N$ | $C_N \leq 1.7$ |
| *Energy Ratio* | Donut Hammer | $C_E$ | 0.5-1.0 |
| *Energy Ratio* | Safety Hammer | $C_E$ | 0.7-1.2 |
| *Energy Ratio* | Automatic-Trip Donut type hammer | $C_E$ | 0.8-1.3 |
| *Bore Hole Diameter* | 65-115 mm | $C_B$ | 1.0 |
| *Bore Hole Diameter* | 150 mm | $C_B$ | 1.05 |
| *Bore Hole Diameter* | 200 mm | $C_B$ | 1.15 |
| *Rod Length* | < 3 m | $C_R$ | 0.75 |
| *Rod Length* | 3-4 m | $C_R$ | 0.8 |
| *Rod Length* | 4-6 m | $C_R$ | 0.85 |
| *Rod Length* | 6-10 m | $C_R$ | 0.95 |
| *Rod Length* | 10-30 m | $C_R$ | 1.0 |
| *Sampling Method* | Standard Sampler | $C_S$ | 1.0 |
| *Sampling method* | Sampler without liners | $C_S$ | 1.1-1.3 |

### 3.3 Determination of Factor of Safety (FS)

The factor of safety (FS) against liquefaction is normally used to evaluate liquefaction potential.

**FS = $(CRR_{7.5}/CSR)$ MSF**

**MSF stands for magnitude scaling factor.**

As CSR and CRR both changes their value with change in depth of borehole so liquefaction potential is evaluated at corresponding depth within soil strata.

### 3.4 Computation of Liquefaction Potential at a typical site

A typical site has been chosen near Rapti barrage on river Rapti near village Lachmanpur in Bhinga tehsil of district Behraich. This typical site consists of three bore holes. The details of corrected SPT N-values are plotted in Figure 2 and depth Vs factor of safety are plotted in Figure 1 of typical one borehole. The soil deposits at this location consists medium compress silt, inorganic silt, poorly graded sand, medium compress silt and silty sand. The Factor of Safety (FS) against liquefaction is computed for earthquakes of different magnitudes at this chosen borehole using above given equations. Factor of Safety (FS) at different depths in selected borehole are computed for earthquakes of magnitude $M_W = 7.0$, $M_W = 7.5$, $M_W = 8.0$ with value of peak ground acceleration of 0.24g.

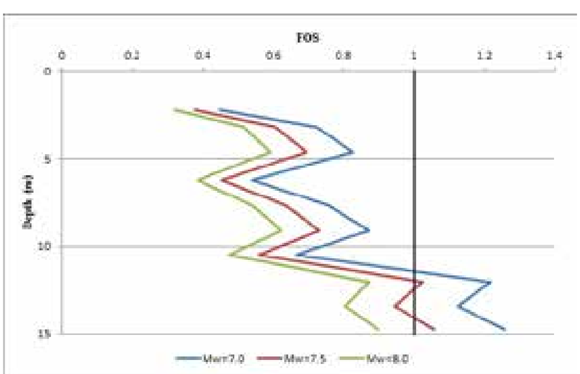


**Fig. 1 Depth Vs Factor of Safety for different moment magnitude**

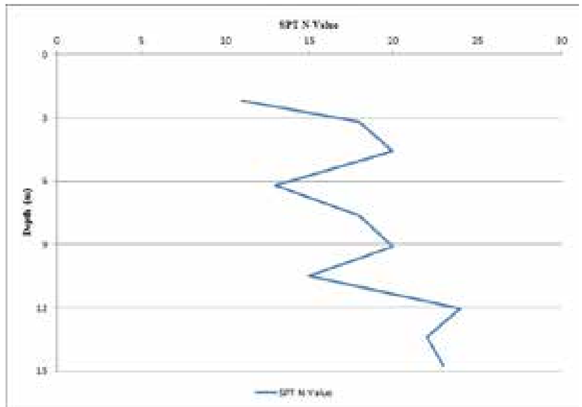


**Fig. 2 Depth Vs corrected SPT N-value**

### 4 Results and Discussion

Seeing the importance of Balrampur city, this study attempts to evaluate the Factor of Safety (FS) for different moment magnitudes having peak ground acceleration 0.24g, using SPT based simplified procedure.

Liquefaction potential is computed at nine villages in Balrampur district namely Lalpur, Ramwapur, Lachmanpur, Gauramafi, Tedhipras, Behdinwa, Bhaluhian, Gulwariya, and Sigraura.

The value of Factor of Safety (FS) less than one at certain depth indicate that the soil layer at specific depth probable to liquefy.

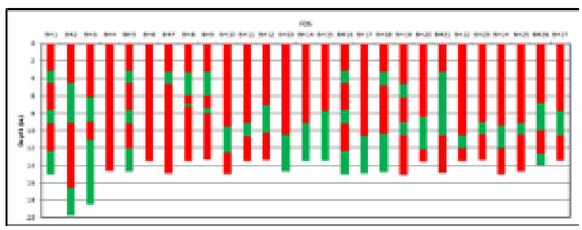

**Fig. 3 Depth wise liquefaction of each bore hole for Mw=7.0**

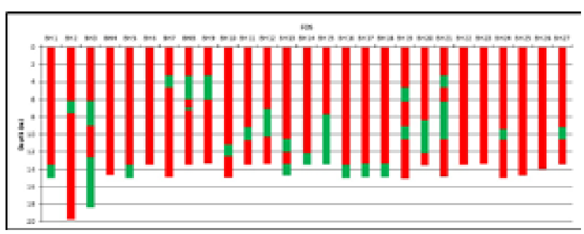

**Fig. 4 Depth wise liquefaction of each bore hole for Mw=7.5**

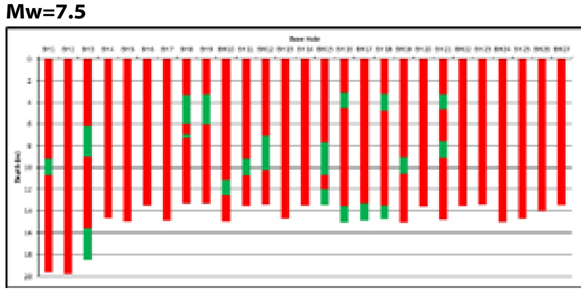

**Fig. 5 Depth wise liquefaction of each bore hole for Mw=8.0**

| S. No. | Depth of Sampling (m) | Particle Size Distribution | | | | | | | Consistency Limit | | | Soil Classification IS:1498-1970 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Gravel | | Sand | | | Silt 0.075-0.002 mm (%) | Clay >0.002 mm (%) | | | | |
| | | Coarse 80-20 mm (%) | Fine 20-4.75 mm (%) | Coarse 4.75-2.0 mm (%) | Medium 2.0- 0.425 mm (%) | Fine 0.425-0.075 mm (%) | | | LL (%) | PL (%) | PI (%) | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| 1. | 2.20-2.50 | 0.0 | 0.4 | 1.2 | 0.8 | 1.2 | 96.4 | 0.0 | 38 | 26 | 12 | MI |
| 2. | 3.20-3.50 | 0.0 | 0.6 | 1.4 | 0.4 | 0.8 | 96.8 | 0.0 | 38 | 26 | 12 | MI |
| 3. | 4.60-4.90 | 0.0 | 0.0 | 1.2 | 1.2 | 1.6 | 96 | 0.0 | 37 | 26 | 11 | MI |
| 4. | 6.20-6.50 | 0.0 | 0.0 | 2.2 | 1.2 | 8.6 | 88 | 0.0 | 28 | 21 | 7 | ML |
| 5. | 7.65-7.95 | 0.0 | 0.0 | 12.6 | 14.4 | 68.6 | 4.4 | 0.0 | - | - | NP | SP |
| 6. | 9.10-9.40 | 0.0 | 0.2 | 0.4 | 1.4 | 27.0 | 71 | 0.0 | 37 | 26 | 11 | MI |
| 7. | 10.50-10.80 | 0.0 | 0.6 | 1.6 | 0.4 | 1 | 96.4 | 0.0 | 38 | 26 | 12 | MI |
| 8. | 12.05-12.35 | 0.0 | 0.0 | 0.0 | 0.0 | 68.5 | 31.5 | 0.0 | - | - | NP | SM |
| 9. | 13.40-13.70 | 0.0 | 0.0 | 10.6 | 18.6 | 55.4 | 15.4 | 0.0 | - | - | NP | SM |
| 10. | 14.75-15.05 | 0.0 | 14.4 | 10.4 | 22.4 | 32.8 | 20.0 | 0.0 | - | - | NP | SM |

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