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A SPT BASED COMPARATIVE ANALYSIS OF LIQUEFACTION POTENTIAL OF RAPTI MAIN CANAL IN DISTRICT BALRAMPUR

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ABSTRACT

Rapti main canal is a sub-project undertaken by Uttar Pradesh irrigation engineering department under the main project namely Saryu Nahar Pariyojna. This main project will provide irrigation to 12.0 lacs h.a. area (C.C.A) of districts Baharaich, Shravasti, Gonda, Balrampur, Basti, Siddharthnagar, Sant Kabir Nagar & Gorakhpur through 8240 km long distribution system. Whereas Rapti Main Canal is 125 km long and a capacity about 95 cumecs.

Liquefaction potential at this site is evaluated and compared by calculating factor of safety against liquefaction (FS) along different depths of soil profile using SPT based different approaches as suggested by Seed & Idriss (1971), Idriss & Boulanger (2006), and Tokimatsu & Yoshimi (1983). Seeing the hazardous effects of recently occurred Nepal earthquake (M_w=7.9), this study is taken out by considering a moment magnitude of M_w=8.0. Since the study area consists of inorganic silt, silty sand, poorly graded sand and comparatively high water table which is susceptible to liquefaction.

KEYWORDS: Comparative Analysis & Liquefaction Potential

INTRODUCTION

Liquefaction phenomenon is observed in saturated cohesionless soils when there is a loss of strength and stiffness due to the increasing pore water pressure. This increase in pore water pressure causes reduction in effective stress under dynamic loading due to intense ground shakes or earthquake. Many factors that affects soil liquefaction phenomenon are magnitude of earthquake, intensity of earthquake, extent of an earthquake, peak ground acceleration (PGA), nature of soil and thickness of soil layers, fines content, relative dry density, bulk density, degree of saturation, porosity of soil, relative difference in water level, normal and effective vertical stress, grain size distribution, overburden pressure and shear modulus degradation (Youd and Perkins, 1978; Youd et al. 2001 Kramer, 1996; Tuttle et al. 1999).

Liquefaction potential of a soil layer to liquefy is expressed as factor of safety (FS) and is evaluated by taking base as simplified procedure suggested by Seed & Idriss (1971). Factor of safety (FS) against liquefaction is assessed by taking the ratios of seismic loading as cyclic resistance ratio (CRR) to resistance of soil as cyclic stress ratio (CSR).

In-situ SPT test are widely used over cone penetration test (CPT), Shear wave velocity test (V_s) and Becker penetration test (BPT) for determining Factor of safety (FS) of a soil layer at given site because of its simplicity and easiness as suggested by Youd et al., 2001. Factor of safety is mainly depends on vertical stress, effective vertical stress, peak ground acceleration (PGA), intensity and magnitude of earthquake, corrected SPT N-value, fines content and consistency limits of soils (Seed & Idriss, 1971; Seed et al., 1985; Youd et al.,2001).

If factor of safety against liquefaction is less than one then the soil layer may liquefy and if this value is greater than one then soil will not liquefy (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) by different approaches we access liquefaction potential of soil at a certain depth in soil layer. Soils susceptible to liquefaction are determined by simplified procedure of Seed & Idriss, Idriss & Boulanger and Tokimatsu & Yoshimi to compare the various results. In this article, an attempt has been made to determine and compare factor of safety (FS) against liquefaction along the depth at each typical bore hole along the Rapti Canal (at district Balrampur, Baharaich and Shravasti) based on above mentioned approaches.

THE STUDY AREA

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. Rapti main canal is 125 km in length and capacity about 95 cumecs. Rapti main canal travels along districts such as Balrampur, Baharaich and Shravasti.

The study area consist a Saryu barrage on river Saryu which is about 10 km upstream of North-Eastern railway bridge on Saryu river in Nanpara tehsil of district Baharaich and a rapti barrage on river Rapti near village Lachmanpur in Bhinga tehsil of district Baharaich.

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

Geologic Conditions and Seismicity

Balrampur is situated at 27.43°N latitude and 82.18°E longitude and having an average elevation of approximately 106 meters. Balrampur is situated on the bank of the river Rapti. The Balrampur 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 Shravasti (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.

Geotechnical Site Characteristics

Most of the factors namely SPT N-values, bulk density, wet density, specific gravity, ground water depth, fines content and consistency index, required for the calculation of factor of safety against liquefaction (FS) of the soil strata at different 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. Nearly 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 33.

ASSESSMENT OF LIQUEFACTION POTENTIAL

Liquefaction potential is evaluated by calculating factor of safety against liquefaction at different depths of a specific site and this factor of safety (FS) is calculated by taking ratio of cyclic resistance ratio (CRR) to cyclic stress ratio (CSR). The soil will liquefy if FS < 1 and if its value is greater than one then the soil will not liquefy and

Determination of CSR

Seismic demand of a given earthquake is expressed as Cyclic stress ratio (CSR) and this value is evaluated by using simplified procedure of Seed & Idriss (1971), Idriss & Boulanger (2006) and Tokimatsu & Yoshimi (1983). This CSR value mainly depends on peak ground acceleration, acceleration due to gravity, total vertical stress and effective stress.

Seed & Idriss method

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

Here r_d denotes stress reduction factor of soil profile.

The following equations may be used to evaluate average values of *rd* (Liao and Whitman 1986).

$r_d = 1.0 - 0.00765z$ for $z \leq 9.15$ m.

$r_d = 1.174 - 0.0267z$ for $9.15 \text{ m} < z \leq 23$ m.

Where z indicates depth below ground surface in meters. Blake (1996) suggested following equation for computing stress reduction factor.

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

Where z is the depth below ground surface in meters.

Idriss & Boulanger Method

$$(CSR) = CSR / MSF = 0.65(\sigma_v a_{\max} / \sigma'_v)\frac{r_d}{MSF}$$

Here r_d is a function of depth of soil strata and this parameter may be evaluated by given relationships:

$$\ln(r_d) = \alpha(z) + \beta(z)M$$

$$\alpha(z) = -1.012 - 1.126\sin(z/11.73 + 5.133)$$

$$\beta(z) = 0.106 + 0.118\sin(z/11.28 + 5.142)$$

Here z is expressed as depth in meters and moment magnitude is denoted as M. The above equations are valid if and only if depth is less than 34m (z ≤34m). However if depth is exceeds beyond 34 meters (z≥34m), then the following equations are used to evaluate r_d.

$$r_d = 0.12\exp(0.22M)$$

Tokimatsu & Yoshimi Method

$$\text{CSR=}\ \tau_{avg}/\sigma'_v = \left(a_{\max}/g\right)\text{X}\left(\sigma_v/\sigma'_v\right) r_d r_n$$

σ_v and σ'_v are the initial vertical stress and initial effective vertical stress.

r_d and r_n are the correction factors in terms of depth and magnitude of an earthquake respectively.

The values of correction factors are formulated as given below:

r_d = 1- 0.015 z

r_n = 0.1 (M-1)

Here z is depth of sample below ground level. Table 1 shows the relationship among earthquake magnitude, number of cycles and r_n.

Table 1: Relationship among Earthquake Magnitude, Number of Cycles and r_n

Earthquake Magnitude	No. of Cycle	Value of r_n
5.5	3	0.47
6.5	6	0.54
7.0	10	0.60
7.5	15	0.65
8.3	25	0.72

Determination of CRR

Seed & Idriss Method

Rauch (1998), come up to the clean-sand base curve (fig 2) by the following equation:

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

The above equation is only valid for $(N1)_{60} < 30$. For $(N1)_{60} \geq 30$. 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:

$\alpha = 0$ for FC $\leq 5\%$

$\alpha = \exp\ [1.762\ (190/FC)]$ for $5\% < FC < 35\%$

$\alpha = 5.0$ for FC $\geq 35\%$

$\beta = 1.0$ for FC $\leq 5\%$

$1.5\ \beta = [0.991\ (FC\ /1{,}000)]$ for $5\% < FC < 35\%$

$\beta = 1.2$ for FC $\geq 35\%$

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

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

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.

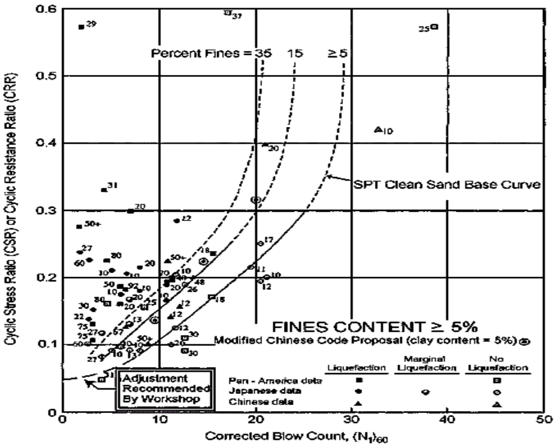

Figure 1: SPT Clean-Sand Base Curve for Magnitude 7.5 Earthquakes with Data from Liquefaction Case Histories (Modified From Seed Et Al. 1985)

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 σ'_{vo} approximately 100 kPa (1 atm), and *CN* should not exceed a value of 1.7

Idriss & Boulanger Method

Idriss and boulanger adjusted the SPT penetration resistance value for clean sand as follows:

$$(N_1)_{60CS} = (N_1)_{60} + \Delta(N_1)_{60}$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC} - \left(\frac{15.7}{FC}\right)^2\right)$$

The variation of $\Delta(N_1)_{60}$ with FC, estimated using above equation (11), is shown in Figure 19. The value of CRR based on $(N_1)_{60CS}$ for a moment magnitude of M= 7.5 earthquake having an effective vertical stress $\sigma'_{V0} = 1atm$ can be calculated using following equations:

$$CRR = \exp\left\{\frac{(N1)_{60CS}}{14.1} + \left(\frac{(N1)_{60CS}}{126}\right)^2 - \left(\frac{(N1)_{60CS}}{23.6}\right)^3 + \left(\frac{(N1)_{60CS}}{25.4}\right)^4 - 2.8\right\}$$

The use of these equations provides a convenient means for evaluating the CSR required to cause liquefaction for sandy and silty soil with any percentage of fine contents.

Tokimatsu & Yoshimi Method

CRR specified by Tokimatsu and Yoshimi is obtained from the correlation between shear stress ratio and SPT N_1-value for clean sands and sand having fines more than 10% and is given as below:

$$CRR = aC_r\left[\frac{16\sqrt{N_a}}{100} + \left(\frac{16\sqrt{N_a}}{C_S}\right)^n\right]$$

In which a = 0.45, C_r = 0.57, n = 14 and C_s is a parameter depending upon shear strain as mentioned in Table 10.

Table 2: Value of Cs Corresponding to Shear Strain

Shear Strain (%)	C_S
2	8
5	1
10	5
25	0

N_a is adjusted SPT N-value which value is obtained from following equation given as:

$N_a = N_1 + \Delta N_f$

Where ΔN_f is a variable depending upon the fines content as shown in Table 3

Table 3: Relation between Fines Content and Correction Factor for SPT N-Value

Fines Content FC (%)	ΔN_f
0-5	0
5-10	interpolate
>10	0.1X FC +4

Subsequently N_1 may be calculated from the following set of equations as given below:

$$N_a = \sqrt{\left(N_1 + \Delta N_f\right)}$$

$$N_1 = C_N N = \frac{1.7N}{\sigma'_0 + 0.7}$$

In above, C_N is a function of the effective vertical stress which is dependent on time and depth of sampling.

Table 4. Corrections to SPT (Modified from Skempton 1986) as Listed by Robertson and Wride (1998)

Factor	Equipment Variable	Erm	Correction
Overburden pressure	---	N	$(P_a/\sigma'_{vo})^{9.5}$
Overburden pressure	---	N	$C_N \leq 1.7$
Energy Ratio	Donut Hammer	E	0.5-1.0
Energy Ratio	Safety Hammer	E	0.7-1.2
Energy Ratio	Automatic-Trip Donut type hammer	E	0.8-1.3
Bore Hole Diameter	65-115 mm	B	1.0
Bore Hole Diameter	150 mm	B	1.05
Bore Hole Diameter	200 mm	B	1.15
Rod Length	< 3 m	R	0.75

Rod Length	3-4 m	R	0.8
Rod Length	4-6 m	R	0.85
Rod Length	6-10 m	R	0.95
Rod Length	10-30 m	R	1.0
Sampling Method	Standard Sampler	S	1.0
Sampling method	Sampler without liners	S	1.1-1.3

Determination of Factor of Safety (FS)

Liquefaction potential of a region is assessed by determining factor of safety against liquefaction (FS).

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

MSF is known as magnitude scaling factor which value is obtained by following equation:

$MSF = 10^{2.24}/M_w^{\ 2.56}$

Here M_w is earthquake moment magnitude.

Magnitude scaling factor defined by various investigator are given in table 4.

Table 5: Magnitude Scaling Factor Values Defined by Various Investigators

Magnitude M	Seed Et Al	Arango		Driss	Youd et al
		Based on Distant Liquefaction Site	Based on no. of Cycles by Seed Et Al		
1	2	3	4		
5.5	1.43	3.00	2.20	.21	.68
6.0	1.32	2.00	1.65	.77	.48
6.5	1.19	1.60	1.40	.44	.30
7.0	1.08	1.25	1.10	.19	.14
7.5	1.00	1.00	1.00	.00	.00
8.0	0.94	0.75	0.85	.85	.87
8.25	--	0.63	--	.78	.82
8.5	0.89	--	--	.73	.76

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.

Computation of Liquefaction Potential at a Typical Site

A typical site has been chosen near village Lalpur in district Balrampur. This typical site consist of three bore holes.

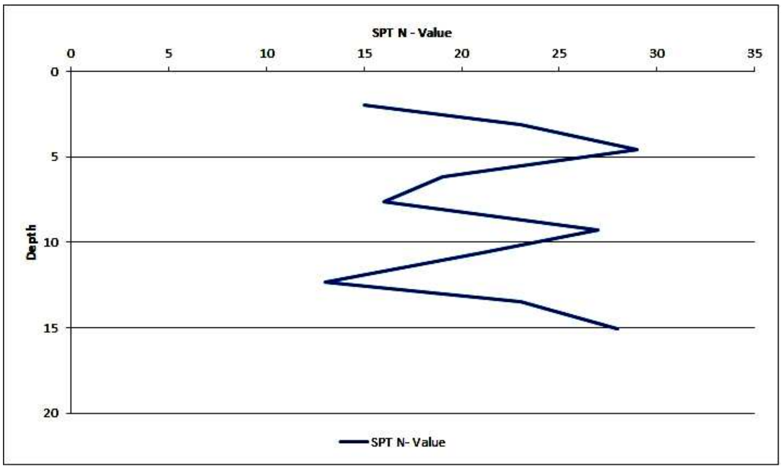

Figure 2: Depth Vs Corrected SPT N- Value

The details of subsurface soil conditions are tabulated in table 6 and corrected SPT N-values are plotted in Figure 2 of typical one borehole.

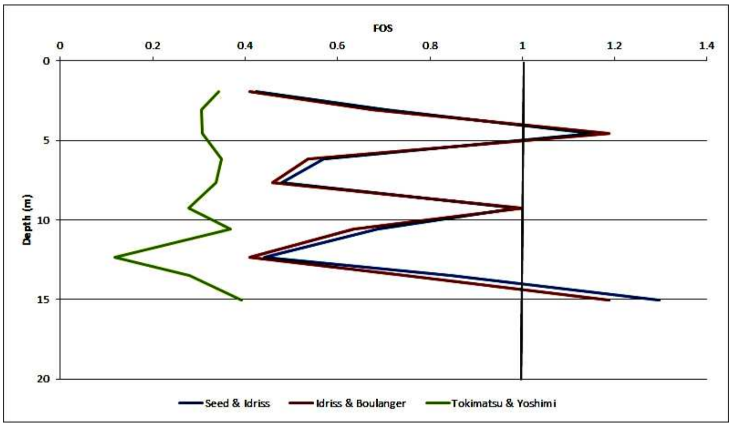

Figure 3: Depth Vs Factor of Safety Using Seed & Idriss, Idriss & Boulanger and Tokimatsu & Yoshimi Method

The soil deposits at this location consists of medium compress silt, inorganic silt, poorly graded sand, medium compress silt and silty sand. The Factor of Safety (FS) against liquefaction of moment magnitude 8.0 at this chosen borehole using equations given above. Factor of Safety (FS) at different depths in selected borehole are computed for earthquakes of magnitude $M_W = 8.0$ with value of peak ground acceleration of 0.24g.

The comparison among all methods are shown in Fig. 3 of a typical borehole.

RESULT AND DISCUSSIONS

Seeing the importance of Rapti main canal, this study attempts to evaluate compare the Factor of Safety (FS) for moment magnitude of 8.0 having peak ground acceleration 0.24g, using SPT based procedures.

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.

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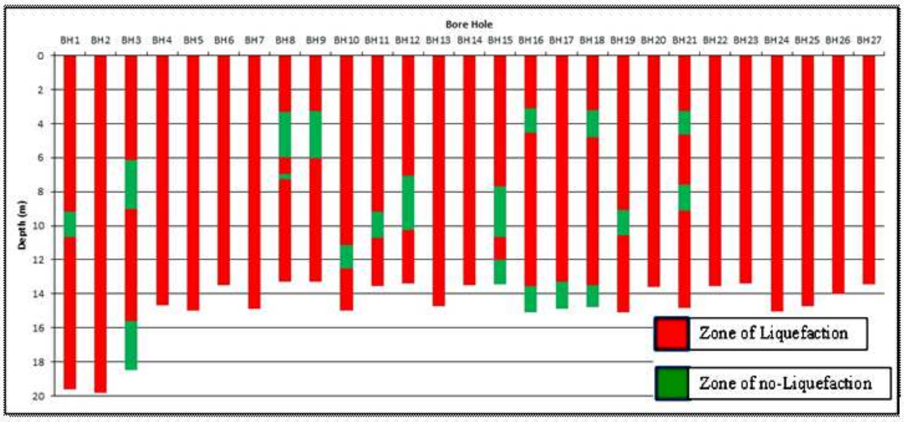

Figure 4: Depth Wise Liquefaction of Each Bore hole using Seed & Idriss Method

Figure 5: Depth Wise Liquefaction of Each Bore hole using Idriss & Boulanger Method

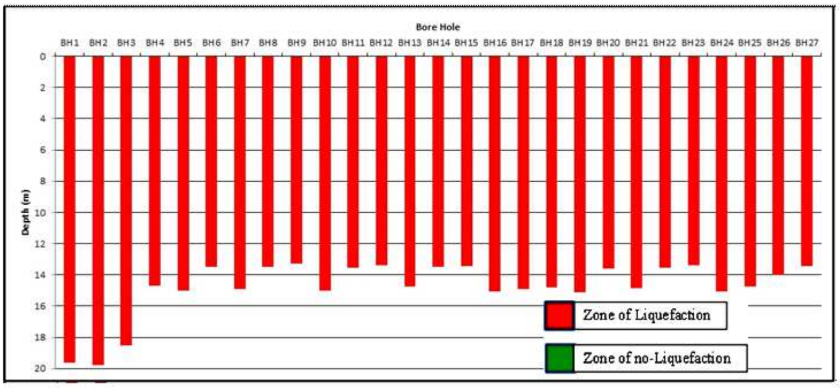

Figure 6: Depth Wise Liquefaction of Each Bore Hole Using Tokimatsu & Yoshimi Method

Table 6: Mechanical Grading and Consistency Limit of a Typical Site

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.	1.95-2.25	0.0	0.4	1.2	1.2	27.2	70.0	0.0	-	-	NP.	ML
2.	3.10-3.40	0.0	0.0	0.0	9.33	70	20.67	0.0	-	-	NP	SM
3.	4.55-4.85	0.0	0.0	0.0	9.2	71.6	19.2	0.0	-	-	NP	SM
4.	6.15-6.45	0.0	0.0	0.0	0.0	11.2	88.8	0.0	32	24	8	ML
5.	7.65-7.95	0.0	0.2	0.0	0.8	12.2	86.8	0.0	31	26	5	ML
6.	9.25-9.55	0.0	0.0	0.0	9.4	72.2	18.4	0.0	-	-	NP	SM
7.	10.60-10.90	0.0	0.0	1.6	1.4	2.0	95.0	0.0	38	28	10	MI
8.	12.35-12.65	0.0	5.0	3.0	20	67	5.0	0.0	-	-	NP	SP
9.	13.50-13.80	0.0	0.0	0.0	4.4	72.2	23.4	0.0	-	-	NP	SM
10.	15.05-15.35	0.0	0.2	0.0	0.6	10.4	88.8	0.0	32	25	7	ML