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P. Bhattacharya
Jadavpur University, India

S. P. Mukherjee
Jadavpur University, India

Biswajit Das
Jadavpur University, India

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Professor P. Bhattacharya
Civil Engineering Department
Jadavpur University
Kolkata-700 032, West Bengal, India
E-mail: pbcvl@yahoo.com
Ph.+91 98300504083
Fax no.: (91) 033-2414-6414

Professor S. P. Mukherjee
Civil Engineering Department
Jadavpur University
Kolkata 700 032, West Bengal, India
E-mail:sibapmukh@yahoo.co.in
Ph. No. +91 9831194637
Fax no.: (91) 033-2414-6414

Biswajit Das, P. G. Student
Civil Engineering Department, Jadavpur University
Kolkata 700 032, West Bengal, India
E-mail:dasbiswajit73@gmail.com
Ph. No. +91 9433079739
Fax no.: (91) 033-2414-6414

ABSTRACT

The present study was carried out to propose a relationship between shear wave velocity and N-value for the deltaic region of Kolkata. The relationship was derived from shear wave velocity determined from Cross-Hole test and SPT carried out at Rajarhat, Kolkata. The derived relationship was applied to evaluate the liquefaction susceptibility in terns of factor of safety against liquefaction for the subsoil deposits explored at Rajarhat, Kolkata area and the factor of safety obtained from the derived correlations was compared with those determined from Seed & Idriss (1971) and Andrus and Stokoe (2000). The shear wave velocity method (Andrus & Stokoe, 2000) of evaluating liquefaction potential of cohesionless soil produces lower factor of safety than the method based on SPT as proposed by Seed & Idriss (1971). The liquefiable zone was identified down to about 15m below GL beyond which the subsoil was found not to be liquefaction prone.

INTRODUCTION

Prediction of liquefaction resistance of soil from shear wave velocity is a promising alternative or supplement to the penetration based approaches according to its advantages (Andrus & Stoke, 1996). In situ measurement of shear wave velocity from seismic tests viz. cross hole test, down hole tests, SASW tests although gives precision in comparison to SPT test but often it is not economical to carryout such tests at all locations. Available correlation of shear wave velocity with 'N' values could therefore be of considerable advantage. Over the past decades several correlations have been reported viz. by Imai (1977) Ohto & Goto (1978), Seed & Idriss (1981), etc. Feasibility of evaluation of liquefaction resistance from shear wave velocity merits investigation as many factors such as relative density, soil fabric, prior earthquake strain affect, the liquefaction resistance and shear wave velocity in the same direction.

Over the last two decades, numerous studies have been conducted to get the correlation between shear wave velocity and liquefaction resistance by methods based on i) Combination of in-situ measurements of shear wave velocity and laboratory liquefaction study, ii) In-situ measured shear wave velocity and appropriate correlation between liquefaction resistance and iii) Other methods including penetration and shear wave velocity correlation.

Among the above mentioned procedures the third alternative has been preferred in the present study for Deltaic region of Kolkata city with a portion of alluvial plane located within the city. Based on the SPT value at different sites and limited results of cross hole tests conducted at these sites a correlation between shear wave velocity and SPT value has been established by regression analysis and compared with the available correlations. Based on this correlation susceptibility of subsoil to liquefaction for an earthquake magnitude of 7.5 has been obtained from shear wave velocity as outlined by Andrus & Stokoe (2000) and SPT based formulation proposed by Seed & Idriss (1971).

STUDY AREA WITH GEOLOGY AND SEISMICITY:

City of Kolkata originally grew in a North-South direction over the natural levee of the river Bhagirathi over a length of 50km. subsequently it has encroached into the back swamp and marshy land to the east by way of filling up of extensive areas, especially in Salt Lake and Rajarhat areas. Fig.1 shows location map of the study area at Rajarhat where huge construction activities are in progress. Geologically, the area around Kolkata city from a Bengal Basin and is under lain by quaternary sediments of fluvio-deltaic origin consisting of a succession of clay, silt & sand of varying texture from fine to coarse grain size. There are certain long narrow zones with predominant and representing old and abandoned river channels.

According to seismic zonetion though Kolkata lies in Zone III, most parts of the adjoining north & south area falls in Zone IV & V. The presence of major north-south and east-west faults terminating in the Burdwan, Murshidabad and Birbhum districts in the city’s backyard (only about 150 km away) adds to the seismic risk of city.

GEOTECHNICAL AND GEOSEISMIC INVESTIGATIONS:

In the present study Geotechnical borehole data for about 30 locations were obtained from various construction organizations in Rajarhat area. In addition to that seismic cross hole tests were conducted at these site. The average soil profile with SPT values in this area is shown in Fig. 2 the ground water table is about 2.5m below ground surface. Such data suggests that the alluvial sequence generally starts with silty clay of different consistency up to a shallow depth and thereafter it is followed by loose sandy silt and silty fine sand. A typical cross section through the area of selected soil profile at site has been presented in Fig.2 with standard penetration test results. In addition to that at the location of boreholes limited number of seismic cross hole tests were conducted to obtain the variation of shear wave velocity with depth as shown in Fig.3.

Evaluation of the data from grain size analysis of particularly the non-cohesive deposits are given in Table-1. Sand sized material in the quaternary deposits is dominant in this area and these soils are represented by grain size distribution as indicated in the table.

Table 1. Grain size distribution and SPT

Layer	Description	Grain size		N value
		Sand	Silt	
IV	Sandy silt	26	70	7
V	Silty sand	85	15	32

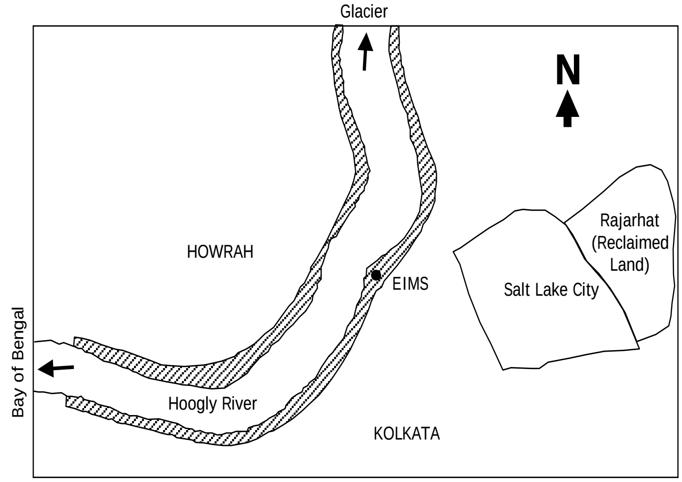

Fig. 1: Site plan

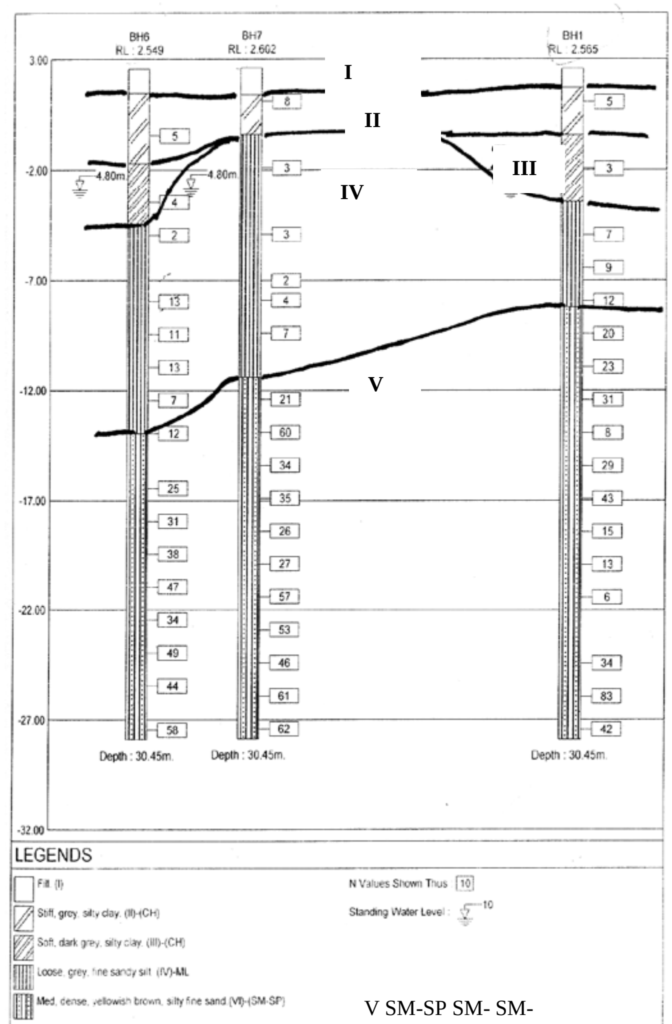

Fig 2. Sub-soil profile

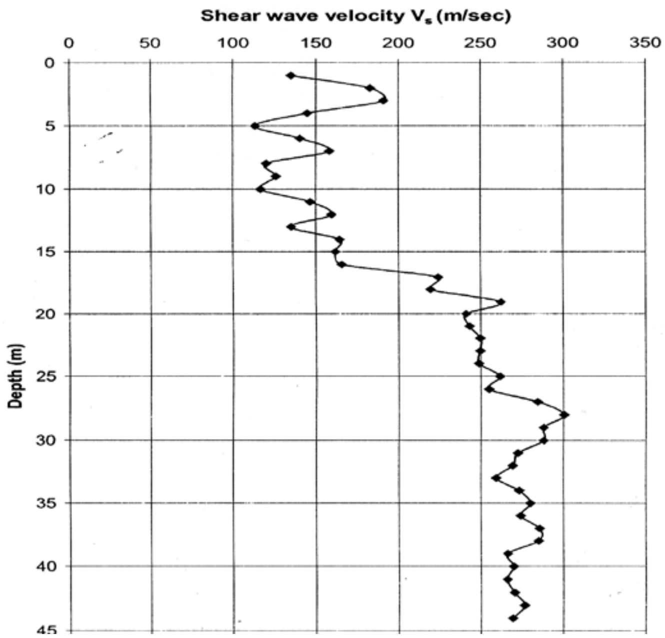

Fig 3. Variation of Shear Wave Velocity along Depth

CORRELATIONSHIPS BETWEEN SPT VALUE AND SHEAR WAVE VELOCITY:

Existing correlations between N and V_S used in the analysis are presented in Table-2.

Table -2 Existing Correlations

Author	Correlationship
Imai (1977)	$Vs = 91N^{0.337}$ for all soil $Vs = 80.6N^{0.331}$ for sands $Vs = 80.2N^{0.292}$ for clays
Ohto and Goto (1978)	$Vs = 85.35N^{0.348}$ for all soils
Andrus and Stokoe (2000)	$Vs = 93.2N_{60}^{0.231}$ for all soils
Nilsun Hasancebi and Resat Ulusay (2006)	$Vs = 104.79N_{60}^{0.26}$ for all soils

Thus in the above table shear wave velocity has been correlated by several researchers with both measured and energy corrected 'N' and 'N_{60}' values. In the present investigation such correlation has also been attempted to find out by appropriate regression analysis carried out with the bore hole data and cross hole test results obtained at the site.

Based on the regression analysis carried out the following sets of correlations are obtained. The correlation coefficient (Cr) for each equation is also presented within brackets.

Based on Field N-value

$Vs = 126N^{0.194}$ (Cr = 0.869) (for all soils) (1)
$Vs = 138N^{0.164}$ (Cr = 0.793) (for sand) (2)
$Vs = 122N^{0.212}$ (Cr = 0.810) (for clay) (3)

Based on Energy Corrected N_{60}-value

$Vs = 104N_{60}^{0.221}$ (Cr = 0.788) (for all soils) (4)
$Vs = 110N_{60}^{0.20}$ (Cr = 0.639) (for sand) (5)
$Vs = 98N_{60}^{0.244}$ (Cr = 0.681) (for clay) (6)

EVALUATION OF LIQEFACTION POTENTIAL:

Liquefaction potential has been obtained in the present study on the basis of shear wave velocity Andrus & Stokoe (2000) as well as from 'N' & 'N_{60}' values as per Seed & Idriss (1971).

In order to compute the liquefaction potential following Andrus & Stokoe (2000) the shear wave velocity has been normalized with respect to the over burden pressure as given below:

$$V_{s1}=V_s(P_a/\sigma_v) \quad (7)$$

Further CRR has been estimated by the equation proposed by Andrus and Stokoe (1997) as

$$CRR = \left\{ a\left(\frac{V_{S1}}{100}\right) + b\left(\frac{1}{V_{S1}^{*} - V_{S1}} - \frac{1}{V_{s1S1}^{*}}\right) MSF \right\} \quad (8)$$

where,

$V_{S1}^{*} = 215$ m/s, for sands with FC ≤ 5%

$V_{S1}^{*} = 215 - 0.5(FC - 5)$ m/s, for sands with 5% ≤ FC ≤ 35%

$V_{S1}^{*} = 200$ m/s, for sands and silts with FC ≥ 35%

Curve fitting parameters a and b are given by

a = 0.022 and b = 2.8

Whether the soil is liquefiable or not can be checked by plotting the calculated CRR appropriately in the figures (Fig. 4.1 to 4.4) with respect to over burden stress corrected shear wave velocity.

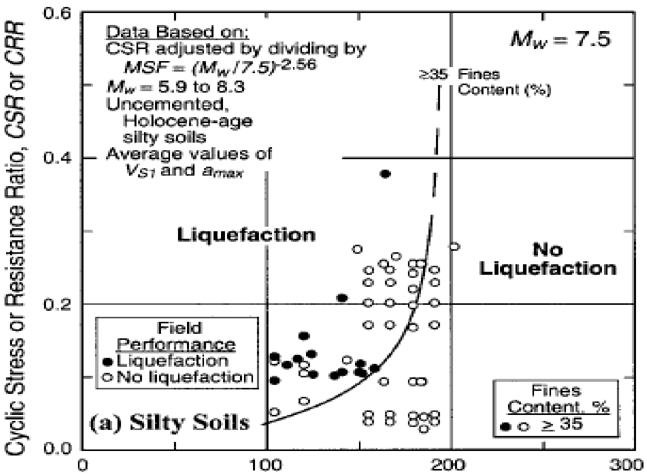

Fig. 4.1: Overburden stress-corrected SWV V_{s1} m/s

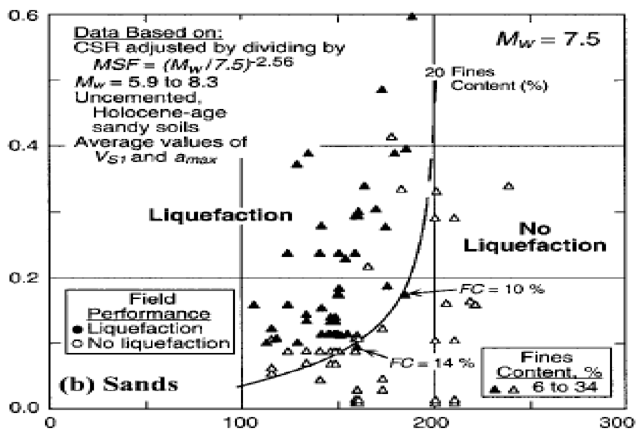

Fig. 4.2: Overburden stress-corrected shear wave velocity V_{s1} m/s

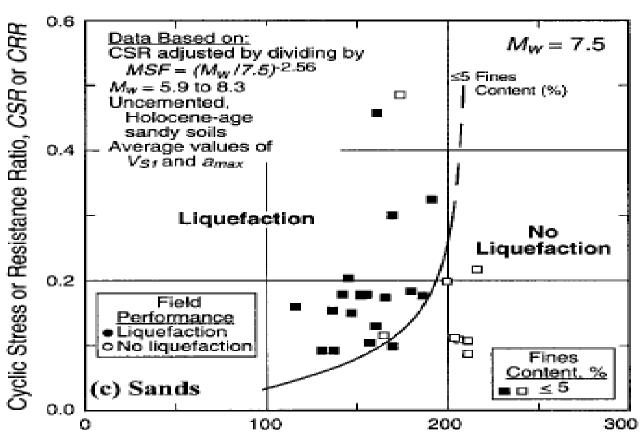

Fig. 4.3: Overburden stress-corrected shear wave velocity V_{s1} m/s

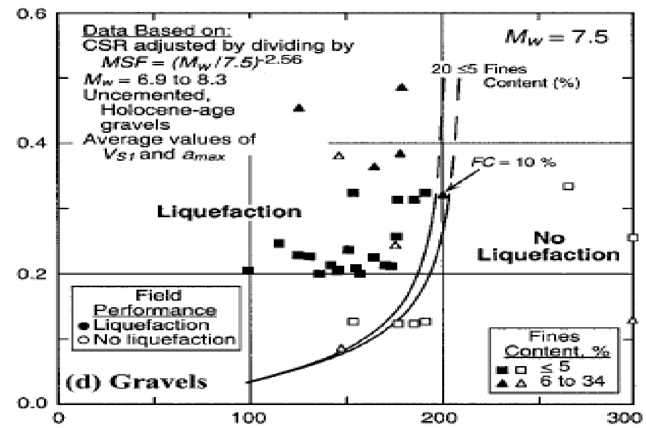

Fig. 4.4: Overburden stress-corrected shear wave velocity V_{s1} m/s

On the other hand the simplified approach proposed by Seed & Idriss (1971) has been followed to obtain liquefaction potential.

The last step is to evaluate Factor of Safety (FO.S) against liquefaction as:

$$FO.S = CRR/CSR$$

Liquefaction potential has been obtained for an earthquake magnitude of 7.5.

RESULTS AND DISCUSSION

Shear Wave Velocity from Existing and Proposed Correlationships

Fig-5.1 shows the variation of shear wave velocity (Vs) determined by correlations based on field N-value proposed by Imai (1977) and Ohto and Goto (1978) with the correlations obtained from regression analysis between borehole data and cross-hole test results. Fig. 5.2 shows the variations of shear wave velocity determined from various correlations based on energy corrected N_{60} – value proposed by Andrus & Stokoe (2000) and Nilsun Hasancebi & Resat Ulusay (2006). The curves obtained from the derived correlations in this study have also been shown along with them in the figures. It is observed that shear wave velocity determined from the general correlations proposed by Ohto and Goto (1978) and Imai (1977) applicable to any type of soils generally yield higher values of shear wave velocity than those determined from the cross-hole test data. In case of correlations proposed by Imai (1977) soils for all types as well as particularly for sand type and clay type have shown good agreement with proposed correlation. It has been observed that the curve obtained from the correlations of Imai (for all types of soils) and Ohto and Goto, (1978), are quite close. However, both of them are overestimating the results obtained from the cross-hole test data. Correlations proposed by Imai (1977) for different types of soils however are in close agreement with the cross-hole test results.

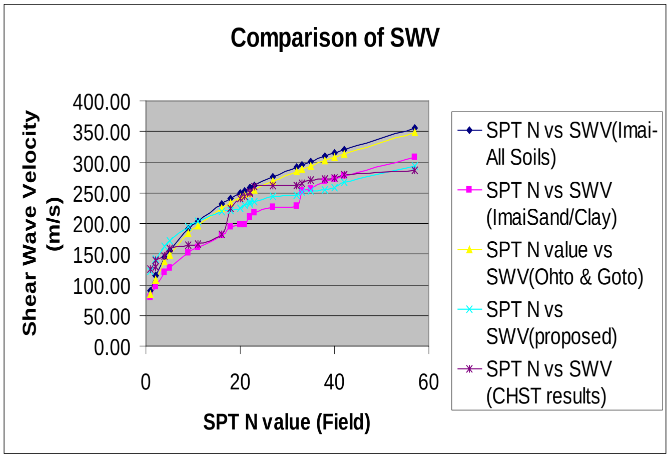

Fig. 5.1: Variation of shear wave velocity with field N-value

It is observed from Fig. 5.2 that shear wave velocity obtained from correlation proposed by Andrus & Stokoe (2000) underestimates those determined from cross – hole test data whereas shear wave velocity obtained from the correlation proposed by Hasancebi and Ulusay (2006) overestimates the shear wave velocity obtained from cross-hole test results.

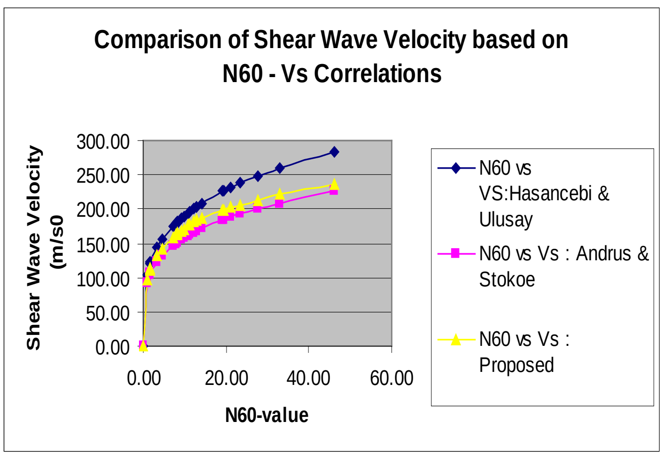

Fig. 5.2: Variation of shear wave velocity with energy corrected N_{60}-value

In deriving the correlations for the present study it has been found that higher correlation coefficient is obtained in case of uncorrected N – value compared to those for energy corrected N-values. This observation is in line with that of Hasancebi and Ulusay (2006).

LIQUEFACTION SUSCEPTIBILITY OF THE SUBSOIL

CRR Vs Shear Wave Velocity for Different Percent Fines

The cyclic resistance ratio (CRR) has been plotted with overburden stress corrected shear wave velocity adopting the procedure suggested by Andrus & Stokoe (2000) and derived correlation. The curves have been drawn for FC≤ 5% (Fig. 6.1), FC=20% (Fig. 6.2). FC≥ 35% (Fig. 6.3). It is observed from the figures that CRR increases with percent of fine content, thereby reducing the liquefaction potential in all cases as is expected.

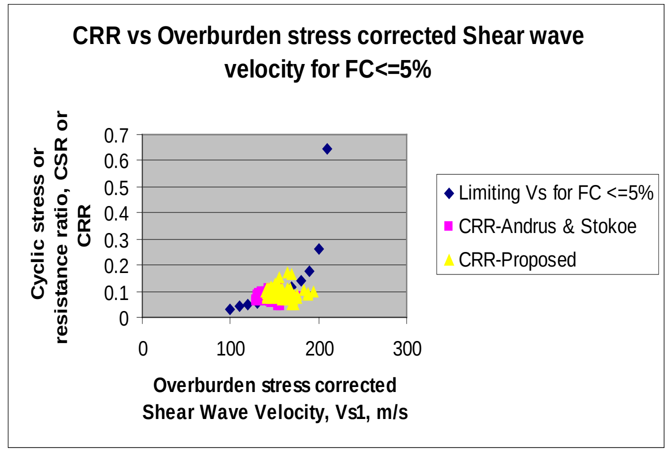

Fig. 6.1: CRR vs Overburden stress corrected Shear Wave Velocity for FC≤5%

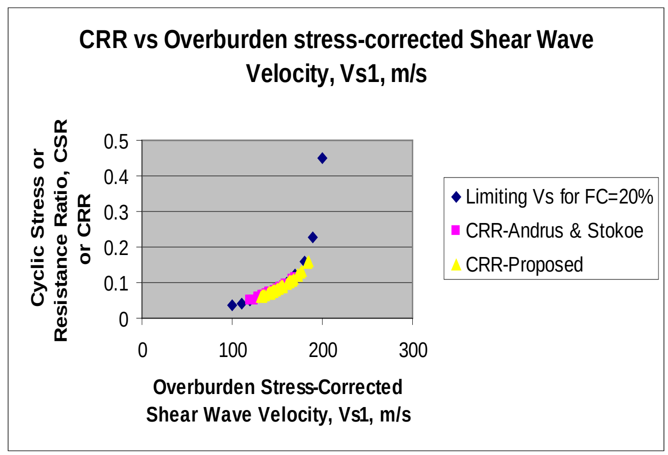

Fig. 6.2: CRR vs Overburden stress corrected Shear Wave Velocity for FC=20%

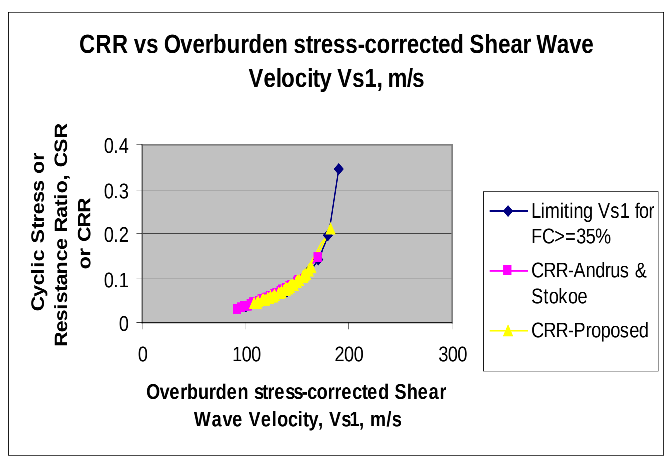

Fig. 6.3: CRR vs Overburden stress corrected Shear Wave Velocity for FC≥35%

FACTOR OF SAFETY AGAINST LIQUEFACTION:

Factor of safety against liquefaction has been also determined by the methods proposed by Seed and Idriss (1971) based on energy corrected N – value and Andrus and Stokoe (2000) based on shear wave velocity. Typical depth wise plot of factor of safety (F.O.S.) obtained by different methods has been shown in Fig. 7.1 and 7.2 for different borehole locations for the area. In general, in case of methods suggested by Seed & Idriss (1971) based on N_{60}, it is observed that the subsoil is liquefiable down to a depth of 15m–20m below GL as factor of safety against liquefaction falls below unity in this region of subsoil. Beyond this depth, the subsoil appears to be non-liquefiable as factor of safety becomes greater than unity in this subsoil region. On the contrary, the method suggested by Andrus & Stokoe (2000) based on shear wave velocity yields factor of safety less than unity along the entire depth of subsoil explored. The factor of safety obtained from the derived correlations also agrees with results obtained from Andrus and Stokoe (2000). Thus it appears that factor of safety against liquefaction is generally underestimated when it is derived on the basis of shear wave velocity.

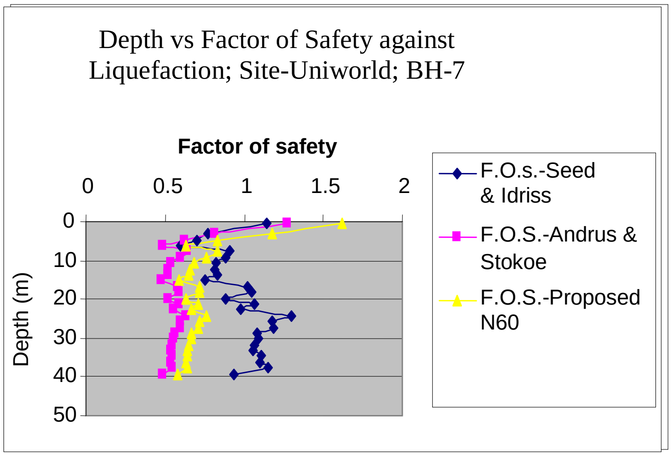

Fig. 7.1: F.O.S. against Depth (m) for the Project Uniworld BH-7

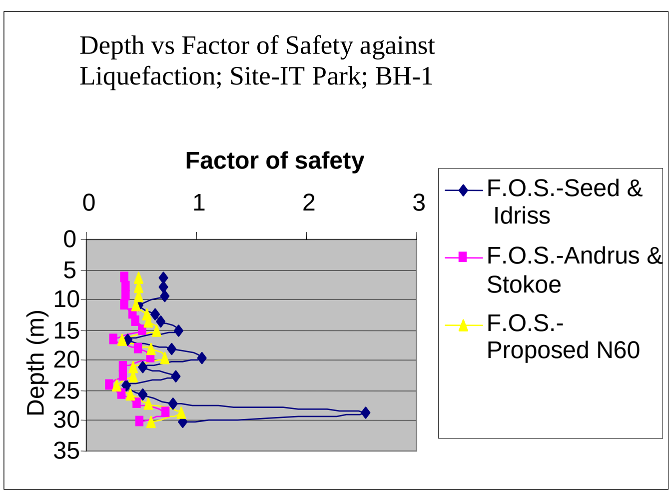

Fig. 7.2: F.O.S. against Depth (m) for the Project IT Park BH-1

CONCLUSIONS

The following conclusions may be drawn from the present study

1. The proposed correlation may be reasonably used for deltaic region of Kolkata to assess shear wave velocity from field N-value. The correlations proposed by Imai (1977) for different types of soil are in close agreement with the cross-hole test results.
2. Field N–values yield higher shear wave velocities whereas the energy corrected N – values results in lower shear wave velocities. Shear wave velocity obtained from derived correlation on the basis of N_{60}-value is close to those obtained as per Andrus & Stokoe (2000) in all the cases.
3. The CRR and corresponding factor of safety against liquefaction increases with increase in fine content for the same N_{60} – value.
4. The sub-soil deposit existing down to 15 m to 20 m below G.L. appears to be liquefiable for an earthquake magnitude of 7.5 or higher since analysis by both Seed & Idriss (1971) and Andrus & Stokoe (2000) shows factor of safety less than unity in this region. Factor of safety against liquefaction is however underestimated when it is derived on the basis of shear wave velocity.

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