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GIS based V_{s30}, V_{sz} & $D_{bed\ rock}$ Mapping for the Shallow Sites of Islamabad, Pakistan

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***Abstract*-- The location of Pakistan is in a collision zone among the Eurasian and Indian plate boundaries. The geological framework of the Northwest Himalaya makes Northern Pakistan susceptible to frequent moderate to major earthquakes. The devastating earthquake of October 8, 2005 caused 87,000 deaths, 2.8 million displacements and financial loss of 200 Billion USD equivalent to 6% GDP of Pakistan. Islamabad is in seismically active region, the studies conducted for this region addresses the poor soil conditions, non-engineering construction practices and high level of seismic shaking. However, none of these studies provided readily available ground maps (top 30m time average shear wave velocity V_{s30}, average soil shear wave velocity V_{sz} & depth to bed rock $D_{bed\ rock}$) based on site specific geotechnical database. V_{s30}, V_{sz} & $D_{bed\ rock}$ are important parameters for the evaluation of dynamic site characteristics of shallow bed rock sites. In Pakistan, Uniform Building Code (UBC-1997) is currently practiced, and the site classification are defined using site specific V_{s30}. In this study, geotechnical borehole database of 57 sites of Islamabad was collected to develop GIS based V_{s30}, V_{sz} & $D_{bed\ rock}$ maps using Standard Penetration Test value (SPT-N). The borehole database includes, SPT-N, soil description and unit weight of soil for the Islamabad sites. In order to develop shear wave velocity (V_s) profiles, the available V_s-SPT empirical correlations were evaluated where both SPT-N & V_s measured data is available. The average of selected bounding correlations was applied to SPT-N database to develop representative Vs profiles. Using these V_s profiles, V_{s30}, V_{sz} & $D_{bed\ rock}$ GIS based maps were developed by applying Kriging interpolation in open source QGIS software. The proposed GIS maps can be used in preliminary earthquake design for seismic resilient earthquake design in Islamabad, Pakistan.**

***Keywords*- SPT; V_s; V_{S30}; V_{sz} ; Depth to Bed Rock ($D_{bed\ rock}$); GIS maps**

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I. INTRODUCTION

In event of earthquake, the surface dynamic site characteristics are predominantly controlled by local geology. The local site effects at surface are evaluated by implying the site specific small strain property known as shear wave velocity (V_s) [1, 2]. In current geotechnical engineering practice, the top 30m time average shear wave velocity (V_{s30}) is used to define local site effects. Using V_{s30} the site seismic coefficients (long and short period) can be calculated to define the design earthquake spectra at particular site. Based on calculated V_{s30} site can be classified into five (05) classes ranging from A to F, Table 1. This top 30m is considered relatively shallow in engineering seismology, however it is typical boring depth around the world for geotechnical investigations. In case of site, where soil profile comprises of number of layers, V_{S30} can be calculated as,

$$V_{s30} = \frac{30}{\sum_{i=1}^{n} \frac{di}{Vsi}} \qquad (1)$$

where d_i= thickness of each soil layer, V_{Si} = shear wave velocity of each soil layer and n is number of layers.

The shear wave velocity profile is developed using various geophysical tests [3, 4]. However, in many regions the most common and popular test is SPT. Shear wave velocity profile is developed using SPT-Vs correlations [5-9].

TABLE I SITE CLASSIFICATION CRITERIA

Class	General Description & Vs Criteria
A	Hard Rock with shear-wave velocity > 1500 m/s
B	Rock with shear-wave velocity to (760 m/s – 1500 m/s)
C	Very dense soil and soft rock with shear-wave velocity (360 m/s- 760 m/s
D	Stiff soil with shear-wave velocity (180 m/s-360 m/s)
E	Soil with shear-wave velocity < 180 m/s)
F	Site Specific evaluations

V_{s30} is widely practice for the deep sites, however, most recently a new site classification system is proposed based on time average soil shear wave velocity ($V_{s,\,soil}$) and depth to bed rock ($D_{bed,\,rock}$) for the shallow bed rock sites [8, 10].

Islamabad is in seismically active region, the studies conducted for this region addresses the poor soil conditions, non-engineering construction practices and high level of seismic shaking and $V_{s,30}$ mapping [11-13]. However, none of these studies provided readily available ground maps (average soil shear wave velocity V_{sz} & depth to bed rock $D_{bed\,rock}$), which are significant parameters in earthquake engineering practice for the evaluation of dynamic site characteristics of shallow bed rock sites. In this study, geotechnical borehole data of 57 sites of Islamabad were collected from different projects. The collected data includes, SPT-N, soil description and unit weight of soil. Vs-SPT correlations were selected and applied to develop V_s profiles. Using these V_s profiles, V_{s30}, V_{sz} & $D_{bed\,rock}$ GIS based maps are prepared. The proposed GIS maps can be used in preliminary earthquake design for seismic resilient earthquake design in Islamabad, Pakistan.

A. STUDY AREA

The study area, Islamabad is located between Longitude [72°40′ & 73°28′ E] and Latitude [33°29′ & 33°52′ N] in Margalla ranges. These Margalla ranges are also consider as Part of Pakistan's Lesser Himalayas. Also, Islamabad is located in a seismically active zone of Main Boundary Thrust (MBT) and Panjal Thrust (PT) in north and Salt Range Thrust (SRT) to the south. Due to this tectonic configuration, folding, faulting and earthquakes has higher frequency. Area drains into southwards in River Soan by tributaries of Bedar Wali kas, Lei nullah and Jodh nullah.

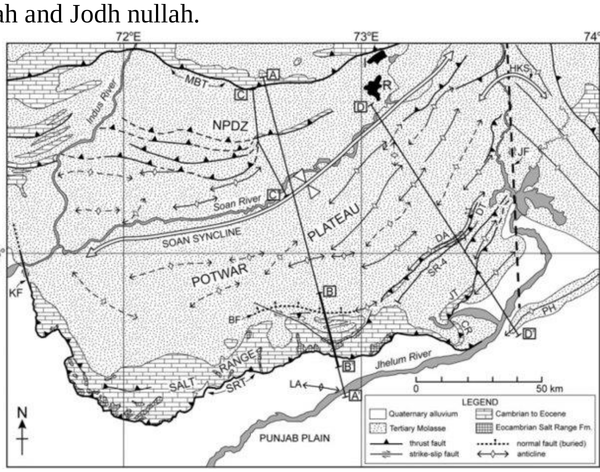


Fig. 1 Geologic & Seismic configuration of study area [14]

II. METHODOLOGY

The general methodology adopted for the development of GIS based maps includes following steps,

1. Collection & Digitization of borehole database.
2. Evaluation & application of SPT-Vs correlations.
3. Development of typical shear wave velocity profiles.
4. Calculation of V_{s30}, V_{sz} & $D_{bed\,rock}$ for each profile.
5. Development of GIS based V_{s30}, V_{sz} & $D_{bed\,rock}$

The collected geotechnical data include 57 sites SPT boreholes data and 04 sites shear wave velocity data as shown in Fig. 2. The SPT N data available with location of borehole, borehole depth, ground water location, soil stratigraphy was some time digitized for each depth interval from figures in the available geotechnical reports. In case the geographical coordinates of any site were unavailable in report, the site location name was used in Google Earth to extract the coordinates.

The digitized SPT-N values along with stratigraphy are converted to the Vs profile using SPT-Vs correlation. Currently, no SPT-Vs correlation is available for the geological conditions of Pakistan. However, numerous SPT-Vs correlations are available for the wide range of soils in literatures. Available correlations in literature were evaluated for clay [3, 15-20] and sandy gravel [16, 21, 22] soils by comparing with available measured V_s profiles. The selected correlations were applied to SPT-N data to develop V_s profiles.

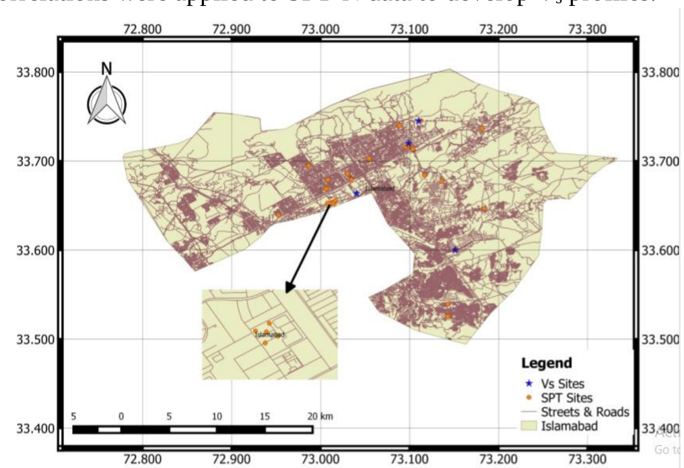


Fig. 2 Distribution of borehole data (SPT & Vs) used in current study

The V_{s30} was calculated from the developed Vs profiles. For all the sites the borehole does not extend to 30m depth, therefore, Boore [2] extrapolation model was used, which is mathematically expressed as,

$$V_{s30}=\frac{30}{\left(tt(dd)+\dfrac{30-d}{V_{seff}}\right)} \qquad (2)$$

where d = total depth of borehole/velocity profile

V_{Seff} = the last value of Vs in profile

and

$$tt(d)=\int_{0}^{d}\frac{dz}{Vs(z)} \qquad (3)$$

The value of SPT-N equal to 50 or 100 was considered as refusal and depth to hard strata or rock, $D_{bed\,rock}$. The V_{sz} represents the average soil shear wave velocity of the soil deposit.

Finally, all the calculated V_{s30}, V_{sz} & $D_{bed\,rock}$ were interpolated for the location where no sample data was available by applying the kriging method in QGIS [23].

III. Results and Discussion

The distribution of borehole data in terms of borehole depth is shown in Fig. 3. It is observed that 34% borehole consists of depth less than 10m, 38% ranges between 10-20m while 29% ranges between 20-24m. It can also be seen that none of the borehole in database exceed the 30m depth. This shallow depth of borehole reveals the shallow presence of stiff strata or bed rock.

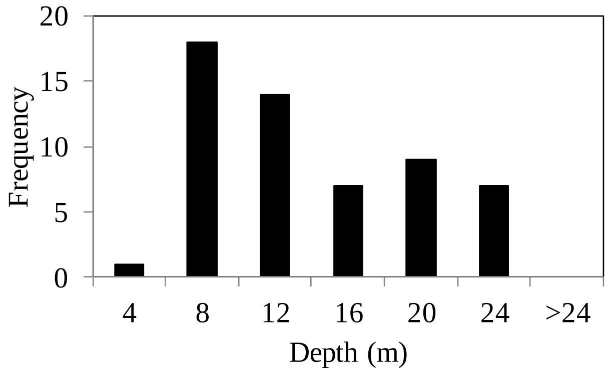
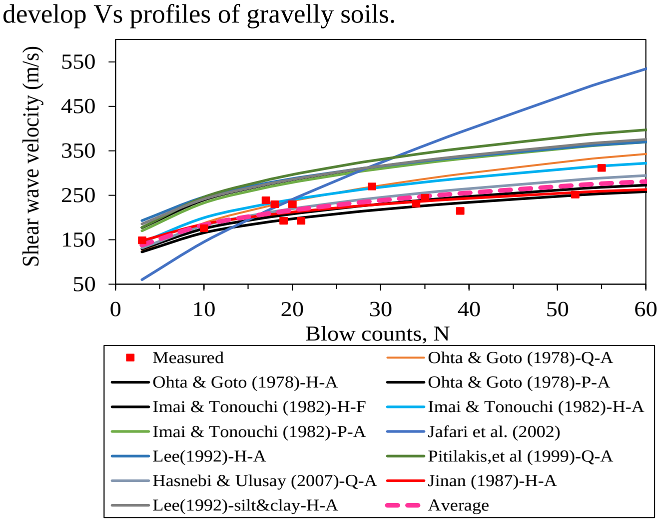


Fig. 3 Distribution of borehole depths used in current study

In available borehole database, the SPT was performed at an interval of 1.5m. The value of SPT-N equal to 50 or 100 was considered as refusal and depth to hard strata or rock. The detailed analysis of borehole revealed presence of clay and gravel materials in boreholes.

The comparison of available correlations in literature for clay and sandy gravel soils are shown in Fig. 4. It can be seen that the measured Vs of clays lies within the Vs predicted by Ohta and Goto [16], Imai & Tonouchi Imai [17], Jinan [20] for geological age Holocene (H) & geological deposition Alluvium (A), therefore, the average of these bounding correlations is applied to SPT to develop Vs profiles. For the gravelly soils, the measured data points lie within the Andrus [22], Yoshida, et al. [21] and Ohta and Goto [16] correlations therefore, the average of these bounding correlations is applied to SPT to develop Vs profiles of gravelly soils.



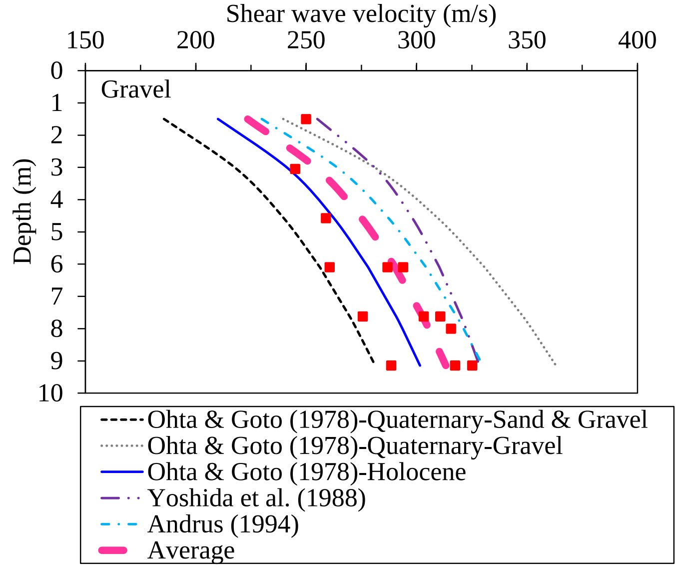


Fig. 4 Selection of SPT-Vs correlation for clay and sandy gravel soils using measured Vs data points

The proposed V_{s30} map is shown in Fig. 5. It can be seen that the V_{s30} ranges from 180~400m/s, predominantly Islamabad can be classified as site class D as per UBC & NEHRP [24, 25] site classifications which are currently practiced in Pakistan SP-BCP [26]. Site class D is considered stiff soil as per description in Table 1[24-26]. The proposed average soil V_{sz} map is shown in Fig. 6. V_{sz} ranges from 170-300 m/s. Also, the proposed map for the depth to bed rock is shown in Fig. 7. It can be observed that Islamabad has a shallow bed rock sites ranging from 4-24m. Manandhar, et al. [27] has shown that V_{s30} does not fit well in capturing the site amplification factors for shallow site, and proposed a new site amplification system based on V_{sz} & $D_{bed\ rock}$ for shallow bed rock sites. Fig. 6 & 7 clearly shows that there is a need to develop new classification system that is a function of soil depth average shear wave velocity, V_{sz} and depth to bed rock, $D_{bed\ rock}$.

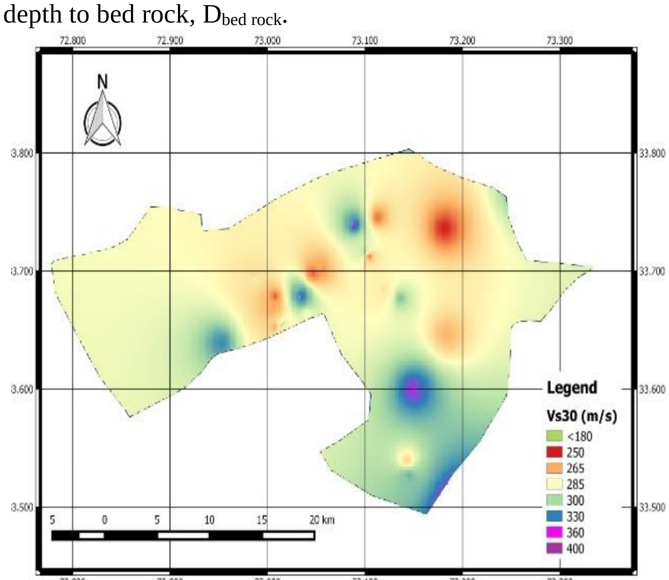


Fig. 5 Proposed V_{s30} Maps for the Islamabad

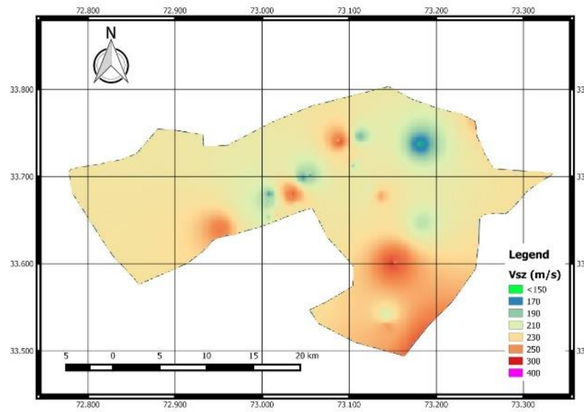


Fig. 6 Proposed V_{sz} Maps for the Islamabad

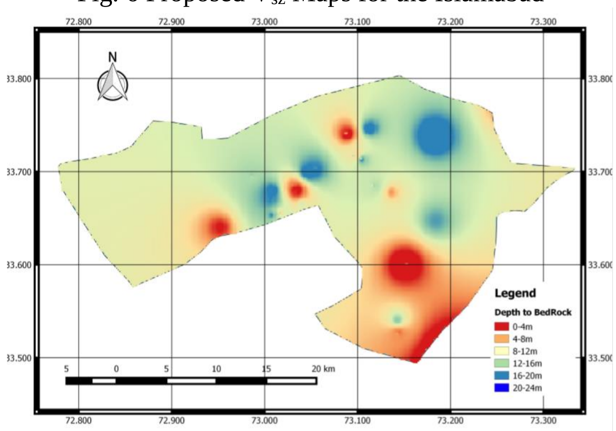


Fig. 7 Proposed $D_{bed,\ rock}$ Maps for the Islamabad

IV. CONCLUSIONS

In this study, based on the borehole SPT data of 57 sites, GIS based maps for V_{s30}, V_{sz} & $D_{bed\ rock}$ are proposed using SPT-Vs correlation. It is found that for 90% of Islamabad area V_{s30} values ranges from 240-360m/s, V_{sz} values ranges from 200-280m/s and $D_{bed\ rock}$ ranges from 8-20m. Islamabad predominately can be classified as seismic site class D, which is stiff soil condition as per SP-BCP (2007). The proposed GIS maps can be readily used to classify the seismic site classification in Islamabad for seismic resilient earthquake design in Islamabad, Pakistan.

$D_{bed\ rock}$ maps reveals the shallow bed rock ($D_{bed\ rock}$ <30m) nature of Islamabad sites. Since, V_{s30} fails to capture site effects (amplification factors) to define design response spectra, therefore, it is recommended to develop new site classification system and corresponding amplification factors as a function of V_{sz} & $D_{bed\ rock}$. Further studies are warranted to conduct the parametric study of V_{sz} & $D_{bed\ rock}$ using suite of nonlinear ground site response analysis that can lead to new site classification system for shallow sites of Islamabad.

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