

Correlation between standard penetration (N_{SPT}) and shear wave velocity (V_S) for young coastal sands of the Caspian Sea

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Abstract Nowadays, the dynamic properties of soil and study of its dynamic response in connection with the designing of the structures resistant against earthquake seems more critical day by day along with the increase of the structures' height and specialization of the civil operations. Since geophysical tests are often costly and time consuming, applying other tests results for estimation of Shear wave velocity is extremely useful. For this purpose, this paper focuses on determining and offering a relationship between the results of standard penetration test (SPT), which is highly quick, cost-effective, and common test, with shear wave velocity of soil. For this end, several boreholes with different depths were drilled in several coastal cities of the Caspian Sea, and SPT was carried out in them. Then downhole test for calculating shear wave velocity profile was performed in all the studied sites using the same borehole and, in some cases, by drilling a new borehole. After that, the data were analyzed for determining the correlation via a suitable statistical method. The results indicated that the obtained relationship is suitably compatible with the universal practical relationships presented for sandy soils and stands approximately in the upper limit of the relationships. It is noteworthy that although applying these relationships for the estimation of shear wave velocity in the coastal sands of the Caspian Sea for small projects and the initial phases of the average and big projects is recommended, it must be considered that direct geophysical methods must be employed in cases where this parameter seems more critical.

Keywords Correlation relationship · Standard penetration test · Shear wave velocity · Caspian Sea sands

Introduction

A key property required to precise estimation of the dynamic response of soil is the small-strain shear modulus, G_{max} , which is most often computed by measuring the shear wave velocity, where mass density (ρ) is calculated via applying $G_{max} = \rho \cdot V_S^2$. The importance of G_{max} has been widely recognized in ground motion prediction equations for a given site (Choi and Stewart 2005). For example, the next generation attenuation relationships include V_{S30} as a constant required for ground motion prediction, where V_{S30} is the average shear wave velocity in the upper 30 m (Abrahamson and Silva 2008; Boore and Atkinson 2008).

In addition, employing geophysical measurements are now common in geotechnical projects, where seismic events possibilities are high, although these tests are not always commonplace and there are older sites, which left only the geotechnical reports such as geological conditions, stratigraphical study, and SPT results.

Additionally, study of reciprocal vibrations of the structure and ground based on the dynamic properties of the structures and estimation of vibrations are of highest importance for building structures and buildings, which are not only susceptible to earth quake but also are exposed to road and railway vibrations.

Shear wave velocity in the ground is again one of the most important parameters needed for achieving this goal, which is gained through seismic geophysical tests. Shear wave velocity is utilized for designing machineries, determining natural dynamic period of soil and dynamic analysis of soil and structure.

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The need for estimation of shear wave velocity using soil mechanical properties and parameters has drawn the attention of many researchers in recent years due to the factors such as high expense of these tests compared to the common geotechnical tests, high time consumption, limitation of the accessibility of test site, explosion and lack of sufficient and enough space for using refraction method, problems caused by artificial vibrations themselves in urban and residential areas, etc.

Numerous researches and studies have been conducted in the field of accessing empirical relationships between shear wave velocity and soil mechanical properties. There are various relationships for the estimation of shear wave velocity in soil using uniaxial compressive strength (q_0), soil subgrade reaction coefficient (K_s), pre-consolidation pressure (P_c), Soil failure resistance in soil pressure meter test (P_s), and standard penetration test (N_{SPT}).

The standard penetration test is one of the simplest, cheapest, and most useful soil mechanical tests. Numerous soil properties and parameters such as unconfined uniaxial compressive strength, relative density, and soil internal friction angle can be estimated by using standard penetration test, which is one of the in situ tests and is conducted nearly in every geotechnical project.

Performing standard penetration test and using its results is approximately simple and easy. In addition, many investigations have been performed regarding the correlation between standard penetration number (N_{SPT}) and other mechanical properties of soil and resultantly, some relationships have been presented.

Regarding the above-mentioned material, it can be inferred that N_{SPT} is one of the most appropriate soil parameters for the estimation of shear wave velocity. Various investigations especially in Japan have been carried out in the area of the correlation between shear wave velocity and N_{SPT} .

Many investigations have been conducted in this field and the following investigations can be mentioned as striking ones: Ohsaki and Iwasaki 1973; Imai and Yoshimura 1975; Ohta and Goto 1978; Sykora and Stokoe 1983a, b; Lee and Hsien 1992. Furthermore, a considerable number of relationships have been presented for connecting SPT N values with shear wave velocity (V_s) in various soils, which are 28 relationships and are summarized in Table 1.

Imai and Yoshimura (1975) presented a relationship between shear wave velocity and some distinctive features of soil by studying 192 different soil samples. Sykora and Stokoe (1983a, b) demonstrated that V_s cannot be anticipated by using geological age and soil type. Sykora and Koester (1988) detected a strong statistical relationship between dynamic shear resistance and SPT in soil. Iyisan (1996) examined the effect of soil type on the relationship between SPT and shear wave velocity using the collected data from earthquake-prone areas of Turkey. Jafari et al. (1997) suggested a comprehensive chronological review on the relationships presented for connecting SPT N values with V_s .

The work of Ulugergerli and Uyanik (2007) is one of the most recent remarkable studies in this area, which presented a semi-empirical relationship between SPT N values and V_s using 372 samples collected from throughout Turkey. This relationship presented an upper and a lower limit rather than an average curve. However, the existing differences between the presented relationships are definitely caused by the geological differences between various regions. However, they can be risen up from the existing errors in measurement of V_s and N_{SPT} .

Conducted tests and collecting data

The major factor which controls the site effect is S-wave velocities of the surficial sediments. We can therefore estimate the site effect or the amplification characteristics from the S-wave velocities of the near surface layers. One of the most useful methods for obtaining V_s measurements is through borehole logging. The downhole test measures accurate and high-resolution S-wave profile and has been widely utilized in the most of countries. However, the high cost of borehole drilling has driven the alternative methods for estimating V_s values. One of the easiest ways to estimate them is to use an empirical relationship between N values of SPT (standard penetration test) and S-wave velocities. For instance, Ohta and Goto (1978) applied the quantification theory to about 300 pairs of N value and S-wave velocity, and proposed a formula which explained S-wave velocity as functions of N value, depositional age, depth, and lithofacies.

This study utilized data from a set of boreholes at coastal cities of the Caspian Sea sites where SPT N values and downhole test were obtained. A total of 36 boreholes in six cities were identified where N_{60} and V_s measurements were available from the same borehole. All of the data were collected between 2004 and 2009. Boring logs were provided in as-built drawings and were digitized by recording blow count and soil type for each SPT measurement, and the site stratigraphy was also digitized based on the site geologist's or engineer's interpretation of layer contact elevations. Soil type was based on visual classification, and properties such as plasticity index and fines content that could help quantify soil behavior are not known for all sites. In this section, statistics and figures of the obtained data will be presented after giving brief explanations regarding the experiments conducted in this research.

Standard penetration test (SPT)

In 1902, Colonel Charles Gow produced the 1-in. inner diameter sampling, which he used it for sampling the fine-grained soil of Boston, USA. Then in 1932, this sampler was standardized by a young engineer named Harry Mohr as a sampler

Table 1 The relationship between N_{SPT} and shear wave velocity

Author(s)	I.D.	All soils	Sand	Silt	Clay
Shibata (1970)	A	–	$V_S=31.7 N^{0.54}$	–	–
Ohba and Toriuma (1970)	B	$V_S=84 N^{0.31}$	–	–	–
Imai and Yoshimura (1975)	C	$V_S=76 N^{0.33}$	–	–	–
Ohta et al. (1972)	D	–	$V_S=87.2 N^{0.36}$	–	–
Fujiwara (1972)	E	$V_S=92.1 N^{0.337}$	–	–	–
Ohsaki and Iwasaki (1973)	F	$V_S=81.4 N^{0.39}$	–	–	–
Imai and Yoshimura (1975)	G	$V_S=89.9 N^{0.341}$	–	–	–
Imai (1977)	H	$V_S=91 N^{0.337}$	$V_S=80.6 N^{0.331}$	–	$V_S=80.2 N^{0.292}$
Ohta and Goto (1978)	I	$V_S=85.35 N^{0.348}$	–	–	–
Seed and Idriss (1981)	J	$V_S=61.4 N^{0.5}$	–	–	–
Imai and Tonouchi (1982)	K	$V_S=96.9 N^{0.314}$	–	–	–
Sykora and Stokoe (1983a, b)	L	–	$V_S=100.5 N^{0.29}$	–	–
Jinan (1987)	M	$V_S=116.1 (N+0.3185)^{0.202}$	–	–	–
Okamoto et al. (1989)	N	–	$V_S=125 N^{0.3}$	–	–
Lee (1990)	O	–	$V_S=57.4 N^{0.49}$	$V_S=105.64 N^{0.32}$	$V_S=114.43 N^{0.31}$
Athanasopoulos (1995)	P	$V_S=107.6 N^{0.36}$	–	–	$V_S=76.55 N^{0.445}$
Sisman (1995)	Q	$V_S=32.8 N^{0.51}$	–	–	–
Iyisan (1996)	R	$V_S=51.5 N^{0.516}$	–	–	–
Kanai (1966)	S	$V_S=19 N^{0.6}$	–	–	–
Jafari et al. (1997)	T	$V_S=22 N^{0.85}$	–	–	–
Kiku et al. (2001)	U	$V_S=68.3 N^{0.292}$	–	–	–
Jafari et al. (1997)	V	–	–	$V_S=22 N^{0.77}$	$V_S=27 N^{0.73}$
Hasancebi and Ulusay (2006)	W	$V_S=90 N^{0.309}$	$V_S=90.82 N^{0.319}$	–	$V_S=97.89 N^{0.269}$
Ulugergerli and Uyanik (2007)	X	${}^aV_{SU}=23.291 \ln(N)+405.61$	–	–	–
Ulugergerli and Uyanik (2007)	Y	${}^bV_{SL}=52.9 e^{-0.011N}$	–	–	–
Dikmen (2009)	Z	$V_S=58 N^{0.39}$	$V_S=73 N^{0.33}$	$V_S=60 N^{0.36}$	$V_S=44 N^{0.48}$
Pitilakis et al. (1999)	AA	–	$V_S=145(N_{60})^{0.178}$	–	$V_S=132(N_{60})^{0.271}$
Hasancebi and Ulusay (2006)	AB	$V_S=104.79(N_{60})^{0.26}$	$V_S=131(N_{60})^{0.205}$	–	$V_S=107.63(N_{60})^{0.237}$

with 18 in. and a hammer with 140 lb and dropping height of 30 in. This sampling method was introduced by Karl Terzaghi and Arthur Casagrande in one of the ASCE conferences and was standardized and presented in 1958 under ASTM-D1586 Standard (corrected in 1984).

SPT test involves dipping a standard sampler with 2-in. external diameter and 1-in. internal diameter due to falling of a 140-lb (63.5 kg) dropping hammer from 30 in. height (76.2 cm), which theoretically 60 % of the energy of this falling must transfer to the drill rods. The hammer’s blow count for penetration the sampler was recorded in three 15-cm interval, and the total values of the two last 15-cm together were recorded as SPT number or N_{SPT} .

Various factors such as normal stress, grain-size distribution, soil structure, hammer efficiency, drilling method, and other factors affect the SPT results, which some corrections have been presented for each of them. Some factors such as relative density of sand, geotechnical parameters of non-cohesive soils, bearing capacity, the potential for dynamic

settlement of sand, liquefaction potential, unconfined compaction strength (kPa), etc. can be estimated using corrected SPT number.

Numerous studies have been carried out in order to understand the limitations of this test and presenting reliable correction factors for adjusting the effects of factors such as normal stress, grain-size distribution, soil structure, hammer efficiency, drilling method, and other effective factors affecting the test results. Hammer efficiency is the key factor influencing N values, which depending on the hammer type ranges between 30 and 90 % (on average, it is taken as 60 %). The field and analytical data suggested that N values are directly proportionate to the transferred energy to the sampler (Seed and Idriss 1981). In the current research, several areas were selected in the southern coastal cities of the Caspian Sea regarding the fact that the purpose of this investigation is to determine the correlation between shear wave velocity and standard penetration test number in young sands of the southern coastal areas of the Caspian Sea.

The studied sites of these experiments were in several cities located in the south coast of the Caspian Sea including Tonekabon, Babolsar, Noor, Noshahr, Chaloos, and Ramsar. The maximum depth of boreholes of SPT test is 40 m. In this study, just the data regarding the sandy soils were collected based on the geological profiles of boreholes because of the fact that the goal of this research is focused on sandy soils.

In total, in this project, 36 boreholes were drilled in order to perform the standard penetration test and then to obtain the S-wave velocity profile through downhole test. The approximate locations of boreholes are presented in Fig. 1.

In addition, in order to identify and provide geotechnical reports in the area in question, handy digging test pits, standard penetration test, in situ density test and providing undisturbed samples for conducting laboratory tests such as determining moisture content, grain-size distribution, Atterberg limits test, and in situ direct shear test were carried out. Presenting these items in detail is beyond of the goal of this research. Furthermore, a picture of a borehole log, which was obtained from geotechnical operations that was carried out in one of the research sites of Noor City is presented as an example (Fig. 2).

Downhole test

In this test, technique array of seismic detectors is deployed in a borehole and shots are fired from a seismic source (also hammer dropping can be used as a seismic source) located on the ground surface. Similar results to those obtained in standard seismic refraction and reflection surveys are observed, as each detector will record both the direct seismic pulse as it propagates downwards and later pulses reflected from interfaces within the rock mass. By moving the seismic source away from the top of the borehole, or moving the detector array within the borehole, it is possible to determine the source of each pulse train observed at an individual detector and produce a geological model that will fit the recorded data. A shear wave source can also be used, and the dynamic elastic moduli can be derived from the compressional (P) and shear (S) wave velocity data. In downhole tests, the arrival times of S and P waves were recorded using data-logger and also a three-component downhole seismometer by placing the seismometer in the borehole. Using these data, P and S waves' velocities could be directly calculated for each layer. In the

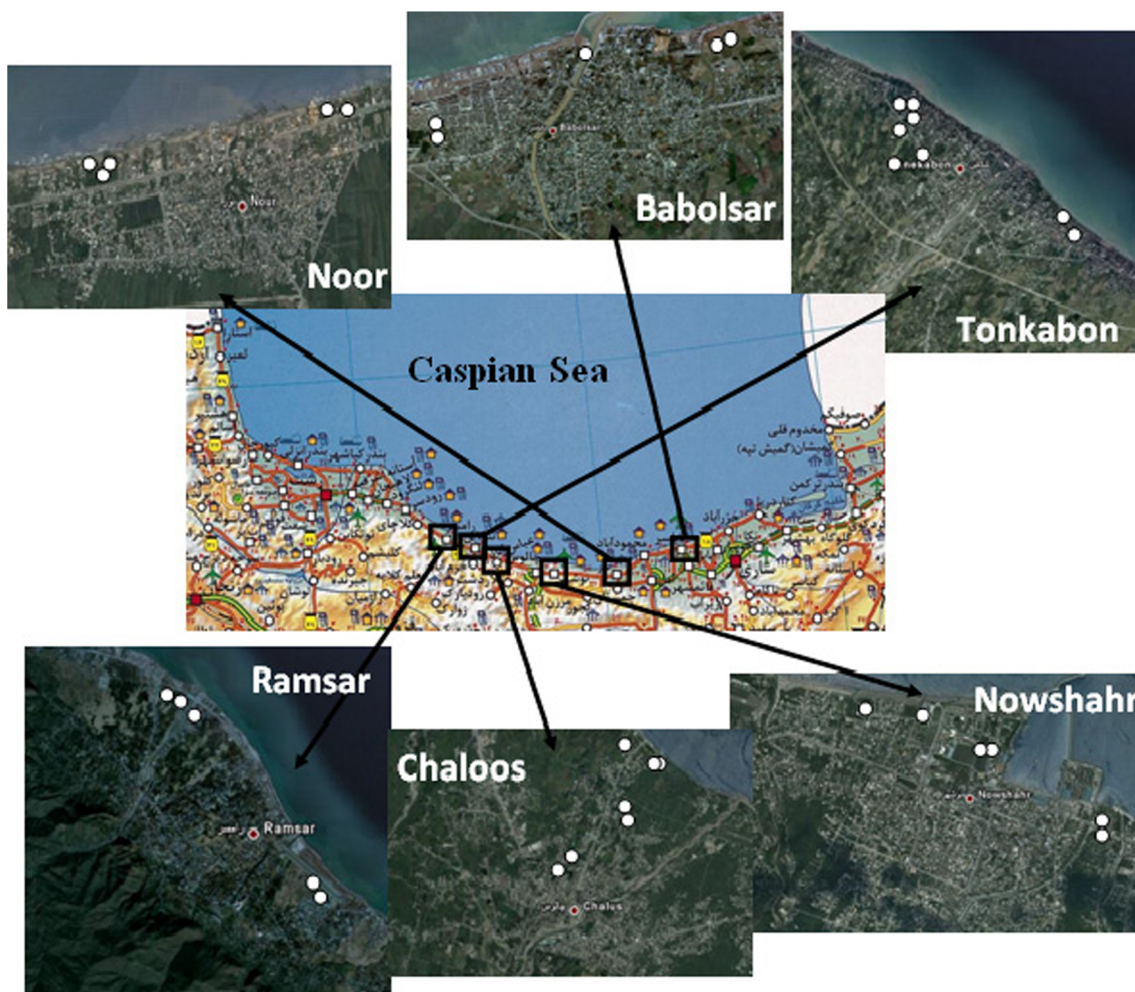


Fig. 1 The locations of studied sites in the southern coastal cities of the Caspian Sea

مشخصات خاک						پارامترهای مقاومتی																		
عمق (m)	نوع نمونه	تشریح نظری خاک	طبقه بندی خاک (USCS)	نمایندگی خاک (USCS)	میزان - تپوری		حدود اتیرک		رطوبت نمونه w (%)	وزن مخصوص خشک γ_{dry} (gr / cm ³)	عدد نفوذ استاندارد (SPT)	سه محوری					برش مستقیم		برش پاره	تک محوری				
					No. 4	No. 200	LL	PI				ϕ (deg)	C (kg/cm ²)	C' (kg/cm ²)	ϕ' (deg)	C_u (kg/cm ²)	S_u (kg/cm ²)							
30.5																								
31.5	D	ماسه بد دانه بندی شده	SP		100	3	N/L	N/P	7.16		31							31.23	0.06	گند				
32.5																								
33.5																								
34.5	D	ماسه بد دانه بندی شده	SP		88.83	3.17	N/L	N/P	7.33		33													
35.5																								
36.5	D	ماسه بد دانه بندی شده	SP		100	2.54	N/L	N/P	8.67		35													
37.5																								
38.5	D	ماسه بد دانه بندی شده	SP		91.15	2.04	N/L	N/P	8.11		44													
39.5																								
40	D	ماسه بد دانه بندی شده	SP		100	0.14	N/L	N/P	8.69		45													

Fig. 2 SPT log obtained in Noor City’s site

downhole method, the wave generation source was established on the ground near borehole opening and the transmitted waves’ receivers were adhered to the borehole’s inner walls in the required depths for recording waves.

Commonly, the explorative borehole is drilled in a location, which geologically can be the representative of the study area. For this purpose, in this research, it was tried to select the borehole’s location in the required area. Moreover, the focus was on determining the borehole’s location in a place, which is as far as possible from ambient noise sources, which generate environmental vibrations such as deep water wells, subway, etc., and also convenient access to equipment for carrying out the test on the selected point was another important factor.

In these tests, horizontal impacts of hammer on a metallic plate were employed, which was placed 2.5 m from the hole opening, for generating seismic energy to produce shear waves. In this task, it must be taken into account that the distances between the two endings of the beam and the borehole opening must be equal since, if so, the beam will be placed in a symmetrical position to the borehole opening and shear waves of higher quality will be generated and transmitted. It is noteworthy that in these surveys, an ABEM RAS-24 model seismograph and in-hole three-and-six- component receivers were utilized. The ABEM RAS-24 is a modular 24-channel, high-resolution, signal enhancement seismograph designed for shallow refraction and reflection surveys, and general geophysical exploration such as downhole test. Based on a “distributed” approach, like larger seismic systems used for oil and gas surveys, the ABEM RAS-24 is the first refraction/reflection seismograph to combine state-of-the-art 24-bit conversion with a flexible, expandable architecture that

provides the ease of use of a conventional system with the advantages of a distributed system.

Some logs obtained from shear wave velocity determination test were presented as an example in Table 2, and the applied equipment were shown in Fig. 3.

Table 2 The seismic waves’ velocities obtained from BH-4 borehole in Chaloos City

BH-4		
Depth (m)	Vp (m/s)	Vs (m/s)
1.0	389.6	165.8
2.0	480.9	204.8
3.0	577.1	247.4
4.0	655.5	284.0
5.0	711.2	310.7
6.0	754.7	332.0
7.0	786.5	344.4
8.0	818.5	360.2
9.0	852.7	377.9
10.0	884.7	393.5
11.0	905.4	404.3
12.0	913.6	406.8
13.0	918.2	407.8
14.0	919.8	406.5
15.0	923.4	406.6
16.0	–	–
17.0	–	–
18.0	–	–
19.0	–	–
20.0	–	–



Fig. 3 A picture of applied equipment in the downhole test

All in all, in this study, 23 downhole tests were conducted with different depths (maximum depth 35 m). It must be noticed that the number of downhole tests is less than the number of SPT tests. This is because in sites in which the SPT boreholes distances were small, the downhole test was carried out in the distance between two or more SPT boreholes so that their data can be applicable for all boreholes. However, this method was solely conducted in the areas, which firstly, had not gone through strong geological changes and secondly, the borehole distances were small.

Model parameter estimation

In this section, the best form of correlation relation between two parameters, namely N_{SPT} and S-wave velocity is presented. Numerous relations between SPT blow count, N_{SPT} , and S-wave velocity exist in the literature. Early efforts utilized laboratory results to develop relations, which were subsequently refined as field measurement of V_S became more routine and data became available. The early correlations based on field data often involved blow counts that were not corrected for energy, rod length, or sampler inside diameter.

Several forms of correlation relation are used by different researchers but Ohta and Goto 1978, using the results of correlation coefficients comparison, showed that the correlation equation in $V_S = aN^b D^c$ form is the optimum equation.

In addition, Lee in 1990 proved that if in correlation equation, soil type and geological effect are included, then the

correlation equation in $V_S = aN^b D^c$ form will have the biggest correlation coefficient, but considering the fact that N value is not independent from depth, therefore, this correlation equation, namely $V_S = aN^b$ is recommended in a second order form.

Both groups of these researchers believe that if the geological effect and soil type are included in the analysis of correlation equations then the role of depth parameter D will be higher than that of N value in the resulting correlation equations.

After that, Lee in 1992, through conducting a number of field and laboratory studies, indicated that for a given amount of N value, the shear wave velocity of cohesive soils is higher than that of non-cohesive soils even if the raw results are collected from different countries.

$V_S = aN^b D^c$ composite analysis model does not have the defects of $V_S = a(D+1)^n$ and $V_S = a(D)^n$ models. In other words, it determines the difference between shear wave velocities of the existing soils of the same depth in the area just by using changes of their N values.

Therefore, in general, it can be put this way that $V_S = aN^b D^c$ composite analysis model and $V_S = aN^b$ model are the optimal forms of correlation equations between N_{SPT} and V_S in first order and second order, respectively. However, the second presented model is more common since, in the majority of studies, the data acquired from experiments are analyzed in raw forms and without applying corrections' factors. For this purpose, the second model was used in this paper. Next, a summary of the mathematical extension of this statistical method will be explicated.

We applied the numerical method of sum of least squares for carrying out statistical analysis of the shear wave velocity results and N values and acquiring the optimum correlation equation between these two items:

$$V_S = aN^b \quad (1)$$

$$\underbrace{\ln V_S}_y = \underbrace{\ln a}_b + \underbrace{b \ln N}_{ax} \quad (2)$$

Then, by extending the above-mentioned equation (presenting the details of the mathematical extension phases of this formulae was avoided due to the irrelevance of this subject to the main subject of the paper), the following equations were obtained:

$$a \sum_{i=1}^n x_i^2 + b \sum_{i=1}^n x_i = \sum_{i=1}^n x_i y_i \quad (3)$$

$$a \sum_{i=1}^n x_i + b \sum_{i=1}^n 1 = \sum_{i=1}^n y_i \quad (4)$$

By putting N and $(V_S)_i$ in Eqs. (3) and (4), a system of two equations and two unknowns was gained, and by solving this system, b , a coefficients were obtained. In the paper, $V_S = aN^b$ model is selected for correlation relation because as it is mentioned before, it is the optimum model for raw (no corrected) N_{SPT} and S-wave velocity values.

From the combination of boring logs and S-wave velocity profiles, a total of 178 N_{SPT} values were available where V_S values were recorded at the same depth. It is worth to note that just the data from sand layers were collected as the propose of the paper is the correlation relation in this soil type. For some boreholes V_S values were not recorded at shallow depths where N values were available, and V_S values often were recorded deep in the profile where N_{SPT} was not recorded. Only the combinations where N values and V_S values were recorded at the same depth were included in the data sample. The standard SPT sampler was used for all of the borings.

After collecting data, a diagram of V_S in terms of N_{SPT} based on the statistical method which explained earlier were drawn. The results showed that the best estimation of model parameters using this data is $a=107.2$ and $b=0.34$, so the correlation relation between N_{SPT} and S-wave velocity in young sand of the south coast of the Caspian Sea could be written as $V_S = 107.2N^{0.34}$. In the following chapter, detail of data analysis and the results will be presented.

Data reduction and discussion

As it was earlier mentioned, the goal of this paper is to determine the correlation relationship between SPT N values and the S-wave velocity in the young sands of the southern coastal areas of the Caspian Sea. For this end, the data needed for this research were collected by drilling several boreholes in some coastal cities of the Caspian Sea and performing SPT test and then conducting downhole test for acquiring shear wave velocity profile of the underground soil.

One of the significant points, which is highly noteworthy is the fact that, however, N_{SPT} raw values for the amount of energy to be transmitted to the sampler, rod length, and borehole diameter were corrected, it was not corrected for the overburden factor. In addition, shear wave velocity obtained from downhole test also was not corrected for overburden effect. The reason is the fact that firstly, the formula of correction coefficient of overburden for N_{SPT} and V_S is completely similar and they only differ by an exponent; the calculation of that coefficient also requires various field and laboratory experiments. Secondly, the raw values were used in the majority of similar researches conducted throughout the world as well.

After collecting raw data from different studied sites located in Babolsar, Noor, Noshahr, Chaloos, Tonekabon, and Ramsar and applying required corrections for N_{SPT} , these data

were analyzed by the mentioned statistical method and the average diagram resulting from all the data was presented as the final correlation formula as follows. In addition, the obtained diagram along with the data points is presented in Fig. 4.

In statistics, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable (or “criterion variable”) changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables—that is, the average value of the dependent variable when the independent variables are fixed. In all cases, the estimation target is a function of the independent variables called the regression function.

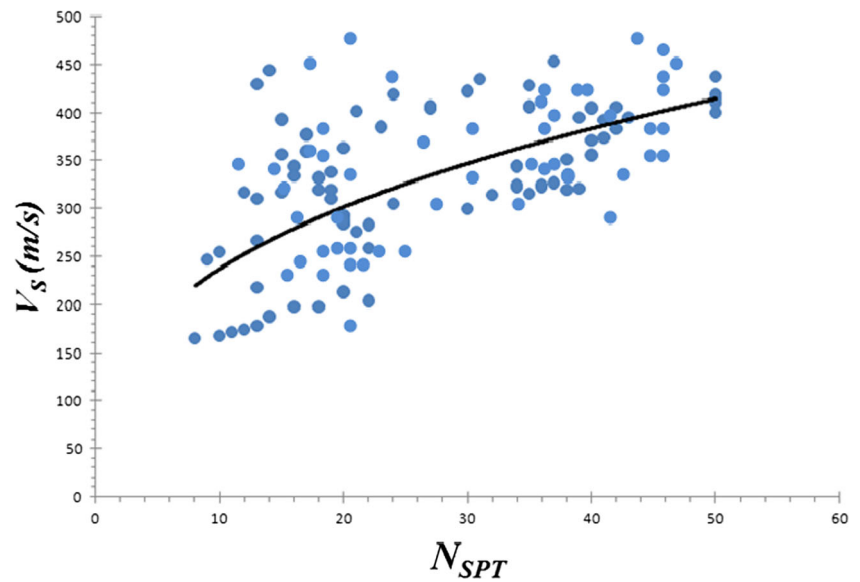
In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function which can be described by a probability distribution. Regression analysis is widely used for prediction and forecasting in wide range of scientific research from social sciences to engineering. Many techniques for carrying out regression analysis have been developed, familiar methods such as linear regression and ordinary least squares, etc.

In this paper, due to nature of data (observational data) and the form of correlation relation, power regression method is used for data analysis. As it is observed, the correlation coefficient of the data was obtained equal to $R=0.63$, which is an appropriate amount in these types of empirical studies. It is worth to mention again that 178 data points were extracted from data base which all were in sandy soil type. According to the acquired data and statistical analysis correlation relation between N_{SPT} and S-wave velocity in young sandy deposit of the southern coast of the Caspian Sea were drawn as follow:

$$V_S = 107.2N^{0.34} \left(\frac{m}{s} \right), \quad (R = 0.63) \quad (5)$$

In order to accredit and compare the acquired relationship with the other relationships proposed for the sandy soils throughout the world, a comparison was drawn between the results gained in this study and those of other researches in Fig. 5. For this purpose, the data acquired from this research and the gained correlation formula along with other presented relationships together were plotted on a diagram. It is worth mentioning that the presented relationships were extracted from Table 1 and only the relationships presented for sandy soils were considered.

Fig. 4 The variation of N_{SPT} values in terms of shear wave velocity in the young sands of the coastal areas of the Caspian Sea



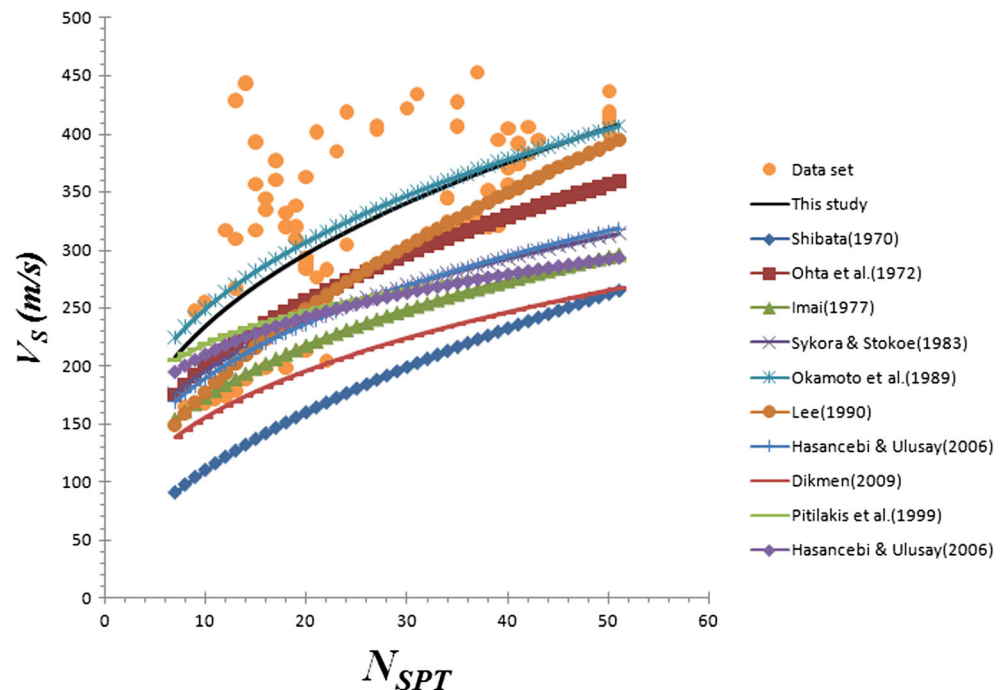
Also, as it can be observed in Fig. 5, the relationship presented based on the investigations conducted in this research differs greatly from the relationships of the investigations conducted in other countries and it approximately stands in their upper limit. By focusing a little more on Fig. 5, it can be figured out that the formula of Okamoto et al. in 1989 is the closest relationship to the presented relationship (Jafari et al. 1997). Therefore, it can be stated that a lot of the existing empirical relationships are not appropriate for sandy soils of the southern coastal areas of the Caspian Sea, and this issue

justifies the significance of carrying out some researches in this area within country.

Conclusion

In this paper, the correlation between two valuable parameters, namely standard penetration and shear wave velocity was determined in the young sand deposits of the coastal areas of the Caspian Sea. This was carried out through drilling several

Fig. 5 The variation of N_{SPT} in terms of shear wave velocity obtained from proposed equation compared to the other relationships suggested for sandy soils



geotechnical boreholes, conducting standard penetration test, and also performing downhole test in order to calculate shear wave velocity. The examination of previous studies in this field showed that if in correlation equations the soil type and geological effects are considered, then the correlation equation in $V_S = aN^b D^C$ form will get the maximum correlation coefficient. However, regarding the fact that N values are not independent from depth; therefore, the $V_S = a N^b$ correlation equation is recommended in the second order. It was proved that the S-wave velocity of unconsolidated alluvial sediments is sensitive to changes in depositional environments and resultant geotechnical properties. Especially, the V_S basically depends on solidity or the bulk density. However, the surficial sediments which recently deposited under coastal or fluvial environments showed a different trend. The results of this study showed that trends of data in all sites and cities were almost similar which proved all sandy layer deposit in the same sedimentary environment. The good correlations described between V_S and solidity should allow the application of these results in the evaluation of depositional environment analysis as well as the geotechnical evaluation of alluvial sediments. As a result, due to dispersion of data uncertainty in V_S computed using the proposed relations is much larger than the uncertainty associated with geophysical measurements of V_S . The comparison of the results of this paper with those of the relationships presented by other researchers for sandy soils also suggested that, however, the obtained relationship is different from other relationships and approximately is placed in the upper limit of relationships; it follows a trend which is completely similar to those of others. In conclusion, it is worth mentioning that regarding the existing uncertainties in the geophysical methods and their other limitations, applying this relationship is recommended for the estimation of shear wave velocity in the sands of the coastal areas of the Caspian Sea for small projects and in the initial phases of average and big projects.

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