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Engineering Site Classification for Hilla City's Nadir Highway Project, Iraq: A Novel Correlation of Shear Wave Velocity and N-SPT Value

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ABSTRACT

Assessing earthquake risks is crucial. The risks come due to the great destruction caused by earthquakes, which depend heavily on the movement of tectonic plates. One technique for determining earthquake movement characteristics in a specific area is studying the shear wave velocity (Vs). This study uses an empirical equation tailored for clayey silt soils to explore the relationship between shear wave velocity (Vs) and Standard Penetration Test (SPT) N-values. Subsurface soil investigations are performed at the Nadir Highway intersection site in Hilla City. SPT-N values are obtained from four borehole wells alongside corresponding shear wave velocity measurements from Multichannel Analysis of Surface Waves (MASW). An empirical equation is developed through regression analyses of the collected data to relate the SPT-N values to Vs, facilitating the estimation of shear wave velocity based on SPT results. Vs-measured values are then employed to estimate the Vs-expected value at the site or at sites closely resembling it in terms of N-values in cases where Vs measurements are unavailable. Based on the Iraqi Seismic Code 303 and the estimated Vs value, the site is classified as class D (hard soil). This classification provides insights into the potential seismic behavior of the site and can be used to inform earthquake hazard mitigation strategies.

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تصنيف الموقع الهندسي لمشروع مجسر نادر في مدينة الحلة، العراق: علاقة جديدة بين سرعة موجة القص وقيمة N-SPT

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الملخص

إن تقييم مخاطر الزلازل أمر بالغ الأهمية. تأتي المخاطر بسبب الدمار الكبير الذي تسببه الزلازل، وهذا يعتمد بشكل كبير على حركة الصفائح التكتونية. يتم تحديد خصائص حركة الزلزال في منطقة معينة من خلال سرعة موجة القص (Vs). تستخدم هذه الدراسة معادلة تجريبية مصممة خصيصًا للتربة الغرينية لاستكشاف العلاقة بين سرعة موجة القص (Vs) وقيم اختبار الاختراق القياسي (SPT). أجريت تحريات للتربة تحت السطحية في موقع تقاطع جسر نادر في مدينة الحلة. تم الحصول على قيم SPT-N من أربع آبار حفر جنبًا إلى جنب مع قياسات سرعة موجة القص المقابلة من تحليل متعدد القنوات للموجات السطحية (MASW). تم تطوير معادلة تجريبية من خلال تحليل الانحدار للبيانات المجمعة لربط قيم SPT-N بـ Vs، مما يسهل تقدير سرعة موجة القص بناءً على نتائج SPT. تم بعد ذلك استخدام قيم Vs المقاسة لتقدير قيمة Vs المتوقعة في الموقع أو في المواقع المشابهة من حيث قيم N في الحالات التي لا تتوفر فيها قياسات Vs. بناءً على قانون الزلازل العراقي 303 وقيمة Vs المقدرة، تم تصنيف الموقع على أنه من الصنف D (تربة صلبة). يوفر هذا التصنيف رؤى حول السلوك الزلزالي المحتمل للموقع ويمكن استخدامه لإعلام استراتيجيات التخفيف من مخاطر الزلازل.

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Introduction

Soil shear wave velocity (Vs) plays a crucial role in designing geotechnical structures subjected to dynamic loads, which is frequently used to classify seismic site categories (Iraqi Meteorological Organization and Seismology, 2013). Vs measurement is applicable in both laboratory and on-site settings. There are two main categories of tests used to determine soil properties. In situ methods encompass the analysis of surface waves using multichannel surface wave test analysis (MASW), recording suspensions, conducting seismic cross-hole tests, and performing seismic refraction tests. On the other hand, laboratory tests, which require undisturbed samples, can include the resonance column test, the ultrasonic pulse test, and the piezometric bender element test (Kramer, 1996; Al-Nuaiemy et al., 2018; Al-Awsi et al., 2021; Mohammed et al., 2025).

The Standard Penetration Test (SPT) is widely employed for field testing due to its readily available equipment and ease of application. The number of SPT hits, denoted as N-SPT, can be correlated with shear wave velocity (Vs), identifying and confirming a relationship that has been supported and validated by multiple sources in the literature. This correlation enhances the reliability and convenience of the SPT method in field testing. In the early stages of laboratory research, efforts were made to develop correlations. With the increasing prevalence of field measurements of Vs and data availability, these connections have been further studied and refined. Additionally, the number of blows (N) in a Standard Penetration Test SPT is easily accessible at many geotechnical investigation sites. Establishing a dependable empirical correlation between Vs and N could prove immensely advantageous (Fauzi et al., 2014).

While laboratory tests generally provide higher-quality samples than 'undisturbed' soil samples, the impact of sample disturbance can be significant, especially in sandy soil layers, depending on the type of test being conducted (Al-Rubaiee and Hussein, 2022). Fortunately, on-site utilization of the dynamic SPT method allows for effective management and control of these issues. Developed in the late 1920s, this test has gained widespread use in various countries, including North America, Japan, and the United Kingdom. Its extensive use over the years has established the Standard Penetration Test (SPT) as a well-accepted practice in geotechnical engineering. The widespread application of the SPT has generated substantial data and numerous SPT-based correlations for sandy soils (Coduto, 2001). In these correlations, the SPT blow count (N-value) serves as a parameter for the in-situ characterization of field sediments. However, there are instances where a standard penetration test may not be feasible or accurate in assessing soil conditions influenced by factors such as depth and soil type. For example, soils with large-sized grains like gravel and rock can present challenges in obtaining reliable results through a penetration test. In such scenarios, alternative testing methods or specialized equipment may be required to accurately assess the soil's properties and characteristics.

The presence of even a few small rock crumbs can sometimes lead to unrealistically high and incorrect N values. Consequently, the correlation between SPT-N and Vs reflects an indirect relationship between the initial strength and stiffness of soils. This relationship has been extensively investigated in the past decades (Maibam et al., 2017). The composition of soil significantly affects the extent of the impact of earthquakes. Site classification and site-specific ground response analysis are two methods for evaluating ground motion characteristics. In either method, the shear wave velocity (Vs) emerges as the most crucial factor representing the resistance of the soil layers (Boore et al., 2011; Anbazhagan et al., 2016).

The in-situ shear wave velocity profile is typically obtained through wave propagation tests using geophysical methods. However, conducting these tests in all locations can be highly economical. The number of blows (N) in a standard penetration test SPT is sufficient and convenient for many geotechnical investigation sites. Based on this, the empirical relationship between Vs and N, as proposed by Kirar et al. (2016), proves to be reliable and beneficial. The empirical regression equation boasts three advantages: convenience, efficiency, and economy. Despite the acceptability and convincing nature of the empirical relationship between SPT-N and Vs, which shows remarkable global agreement, it is region-specific and not universally applicable. Therefore, a thorough validation process is necessary before its use (Maibam et al., 2017).

Sitharam and Anbazhagan (2007) conducted a Multichannel Analysis of Surface Waves (MASW) seismic survey at approximately 38 sites located close to existing Standard Penetration Test (SPT) drilling sites. They used these data to establish a correlation between shear wave velocity and corrected N values in Delhi City. In a similar vein, Hanumantharao and Ramana (2008) measured shear wave velocity using Spectral Analysis of Surface Waves (SASW) for 80 sites at a depth of 20–32 m developing correlations between the values of Vs and N. Contrary to these studies, Iraqi Meteorological Organization and Seismology (2013) noted that geological age and soil type do not predict Vs, while the uncorrected SPT-N value remains most significant. In a more recent study, Hasan et al. (2020) applied an empirical equation likely suitable for clay soils, primarily focusing on the interconnection between Vs and SPT-N. A complementary investigation was carried out in the subsoil of a tower construction located in Erbil City. The investigation involved obtaining SPT-N values from three wells and their corresponding MASW measurements. The main objectives of the research are to establish a relationship between shear wave velocity and the number of standard penetration blows and to determine the site classification conditions in the study area. Rahman et al. (2016) employed a velocity of Vs to 30 m depth for seismic site characterization to estimate the local amplification factor for seismic waves throughout an earthquake using multichannel analysis of surface waves (MSAW) in Chittagong City, Bangladesh. From the results, the Holocene sediments in the city were classified as C, D, and E according to the NEHRP program. Anbazhagan et al. (2012) studied the relationship between SPT-N value and shear modulus using the MASW technique to estimate Vs and calculate layer densities. They established a relationship with a high regression coefficient and a low standard error.

Hilla City, situated at the center of Iraq, lies within the alluvial plain area, 100 km south of Baghdad. The study area, referred to as the Nadir intersection site in Al-Hilla City, is a flat region with a maximum elevation of 28 meters above sea level. Located in the center of Babylon Governorate, it spans between longitudes 44°25'00" and 44°25'20" E and between latitudes 32º36'40" and 32º26'53" N, covering an approximate area of 100 km^2. The investigation of the Nadir bridge site in Al-Hilla City entailed drilling four boreholes (Shelby and SPT) to appropriate depths until reaching firm soil for the precise location of the study area (Fig. 1).

The study aims to relate the number of SPT strokes, referred to as N-SPT, to the shear wave velocity (Vs) to establish a Novel Correlation of Shear Wave Velocity and N-SPT Value. The objective of this research is to conduct a comprehensive analysis of the geophysical and geotechnical data at the intersection of Nadir Highway in the city of Hilla.

Geology and Seismicity of the Study Area

Babylon Governorate is situated within the Pleistocene physiographic region, positioned between the Tigris and Euphrates rivers. This region is characterized by its geological instability, primarily due to the tectonic divisions that influence the area in Iraq. The shelf regions in Babylon are particularly known for their instability, which is a consequence of the ongoing tectonic activity affecting the region. This geological context underscores the importance of understanding the seismic and soil characteristics of the area for effective earthquake risk assessment and mitigation (Buday and Jassim, 1987; Al-Rubaiee and Al-Owaidi, 2022a).

The study area is marked by the presence of Quaternary sediments, which are prominently visible on the surface. These sediment deposits have accumulated through historical floodplain contributions from the Tigris and Euphrates rivers. Over time, these riverine deposits have played a significant role in shaping the landscape and resulting in the distinctive geological and geomorphological features observed in the region nowadays (Al-Rubaiee and Al-Owaidi, 2022b). Additionally, the region features deposits from shallow depressions formed and accumulated by floods, contributing to the geological diversity of the area (Euphrates Company Study, 1999). Notably, the lower part of the sedimentary plain, including the study area, contains Sabkha soils characterized by salt surfaces (Jedi and Al-Khalidy, 2023).

Iraq is situated at the northern edge of the Arabian plate, where it actively converges with the Eurasian plate, creating a tectonically active zone. This region is characterized by significant seismic activity due to the ongoing tectonic interactions. Specifically, the northern part of Iraq experiences high seismicity, reflecting frequent and intense seismic events. In contrast, the central and southern regions of the country experience medium to low seismic activity. However, there has been a notable increase in seismic activity across Iraq in recent years, indicating a trend of heightened tectonic activity throughout the country.

There has been a notable surge in interest in the construction of earthquake-resistant buildings in Iraq in recent times. Although the country is not directly situated in a region with recent earthquake hotspots, seismic research, studies, monitoring, and awareness have garnered significantly increased attention compared to the past two decades (Alsinawi and Al-Qasrani, 2003). Figure 2 illustrates the seismic map of Iraq's regions. The variation of color represented the value of the maximum ground acceleration of seismic zones.

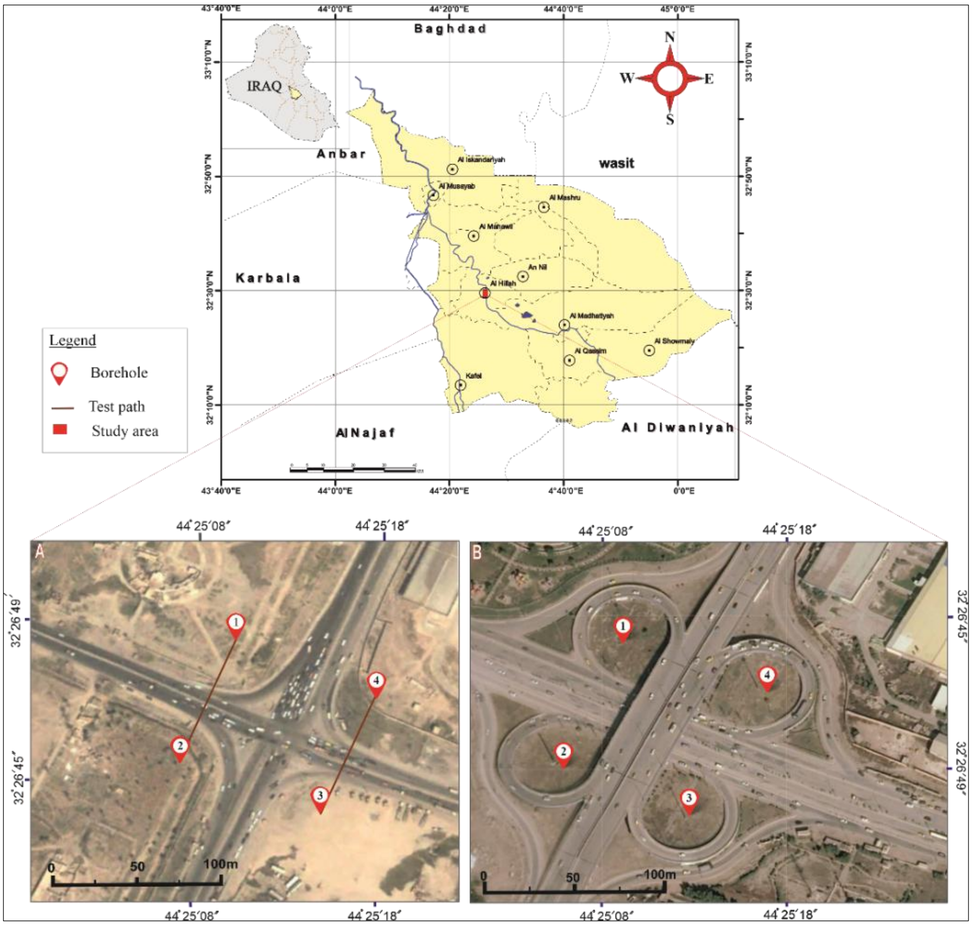


Fig. 1. Site of the study area. A- Before and B- After establishing the Nadir Highway.

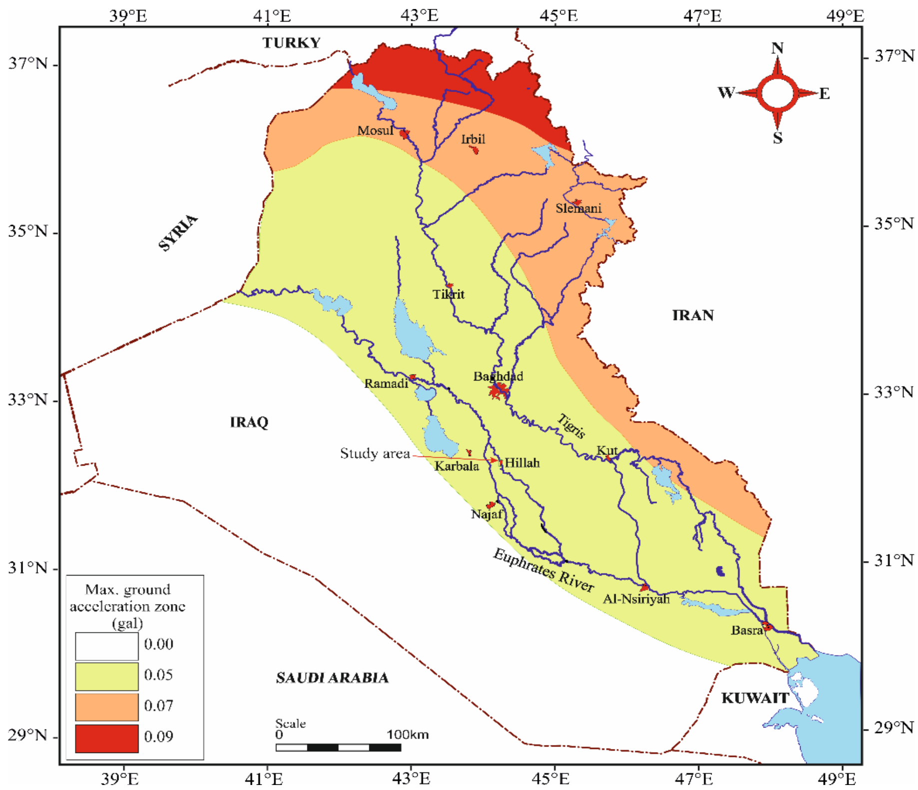


Fig. 2. Seismic zoning map of Iraq (modified after Alsinawi and Al-Qasrani, 2003).

Materials and Methods

Geotechnical Investigation

The consultants set up the borehole sites. All the tests for the disturbed (DS) and undisturbed (US) samples were sent to the Soil Mechanics Laboratory in the Consulting Office of the University of Technology in Baghdad, Department of Building and Construction. The collected samples represented 36 SPT samples, 40 DS samples, and 15 US samples.

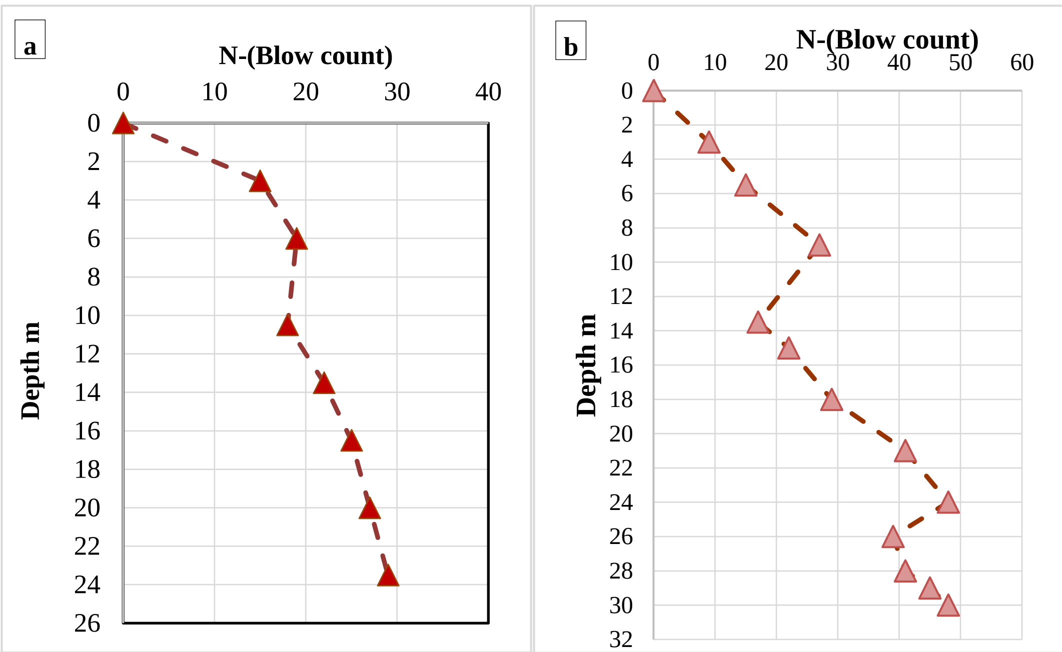
Further examination and testing are needed, according to American specifications, such as visual classification (ASTM D2488, 2017), specific gravity (ASTM D854, 2014), grain size distribution (ASTM D6913, 2017), and Atterberg limits (ASTM D4318, 2017). The collected samples were taken to the laboratory for comprehensive analysis and testing. This process involved determining the natural moisture content and measuring the unit weight of the samples, per the procedures outlined in ASTM Standard D2216 (2019). These tests are essential for understanding the physical properties of the material under investigation, particularly its moisture condition and density, which are critical for further geotechnical or material performance assessments. Due to the lack of changes in the soil and the similarity of its profile, borehole 2 is selected as an ideal borehole with coordinates as shown in Table 1, which shows the geotechnical and index properties of the soil in the study area.

Table 1: Coordinates of drilling boreholes in the study area.

Borehole	Latitude	Longitude
1	32°26'49.13"	44°25'9.50"
2	32°26'46.08"	44°25'7.42"
3	32°26'44.60"	44°25'10.87"
4	32°26'48.00"	44°25'12.87"

The standard penetration tests were performed along the excavation with a penetration length ranging from 1.5 m to 2 m. The standard penetration test methods and equipment are accomplished following (ASTM D1586, 1984).

Soil resistance is represented by the N-SPT value, which is determined by calculating the number of hammer blows required to cause a 3*6" penetration of the split spoon at the tip into the soil. The N-SPT value is the total number of blows for the last 2*6" penetration. Variations of N-values with depth for four boreholes in the project are presented in Figure 3.



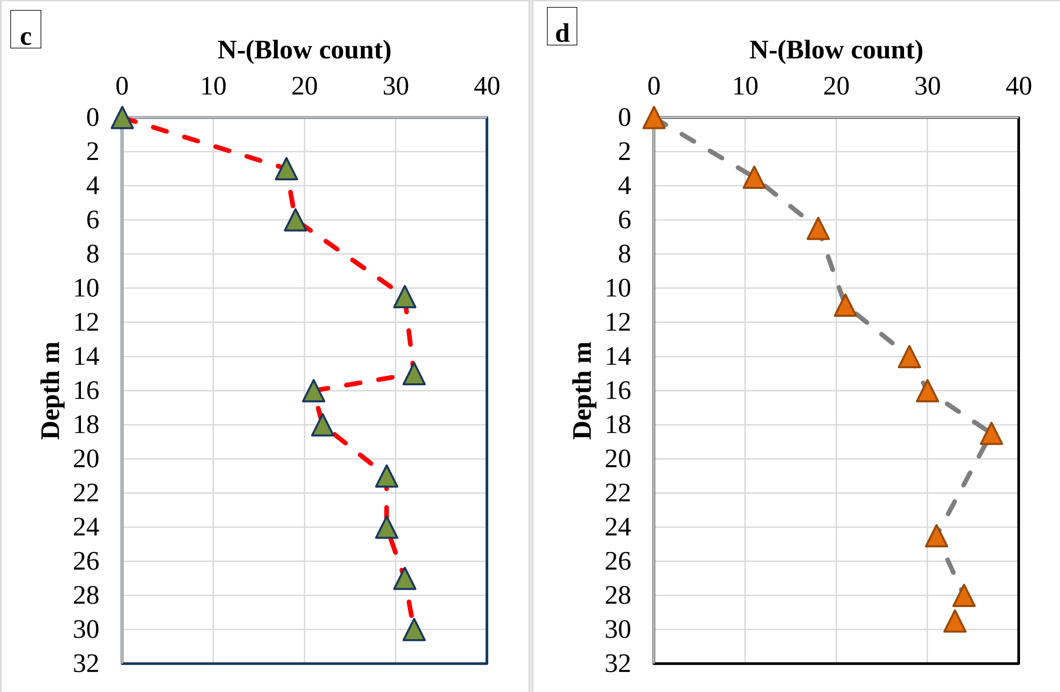


Fig. 3. Variation of standard penetration test (N) with depth for all boreholes of the project. a- BH. 1, b-BH. 2, c- BH. 3 and d- BH. 4

Geophysical Investigation

1. Multichannel analysis of surface wave method

The research proposes a specific relationship between Vs and SPT-N based on the geotechnical report of soil investigations, which includes field and laboratory tests conducted in four boreholes at the Nadir Highway project site in Hilla City. A geophysical field survey was undertaken in collaboration with a team from the Department of Civil Engineering at the University of Technology in Baghdad. The MASW survey is selected to acquire information about the characteristics and behavior of soil layers situated deeper than 30 meters beneath the ground level.

2. Used Instrumentation and its Accessories

This research utilized a digital multichannel seismograph, specifically the Terraloc Mark 6. It has 24 channels, allowing for multichannel data acquisition. It is a device with high accuracy in seismic recordings at shallow depths, depending on its specifications.

After completing the measurement process, the survey results can be shown directly in the field through the seismometer screen, and the data can be transferred from the seismograph to a personal computer through the serial port. One type of ground geophone for shear wave (S) recording is used for the MASW panel method (Fig. 4) (ABEM Instrument, 2009).

Fig. 4. Geophone (S) used in the MASW method.

In the field, the Multichannel Analysis of Surface Waves (MASW) method, a modern geophysical technique introduced by Park et al. (1999), is employed. It estimates the Vs velocity profile without intruding on or breaking the measured surface, making it a safe and convenient approach. The MASW is cost-effective and time-effective for estimating shear wave velocity. The survey utilized geophones (S-geophones) to capture destructive Rayleigh waves. The shear wave velocity is derived from the inversion of the Rayleigh waves' dispersion curves. The MASW method is considered one of the modern geophysical methods used in geoengineering investigations for engineering projects in the 0–30-meter range in depth. It is represented by two methods: the active method and the passive method. It is important to use a shear-velocity geophone with a frequency of 4.5 Hz for the active method. The survey setup included 24 geophones planted in a straight path on the surface at equal spaced 4 meters apart covering a path length of 96 meters to detect ground vibrations. As shown in Figure 5, the distance between adjacent geophones was denoted as X. In contrast, the distance between the source sledgehammer, weighing 10 kg (strike plate), and the first geophone (offset) is 4 m.

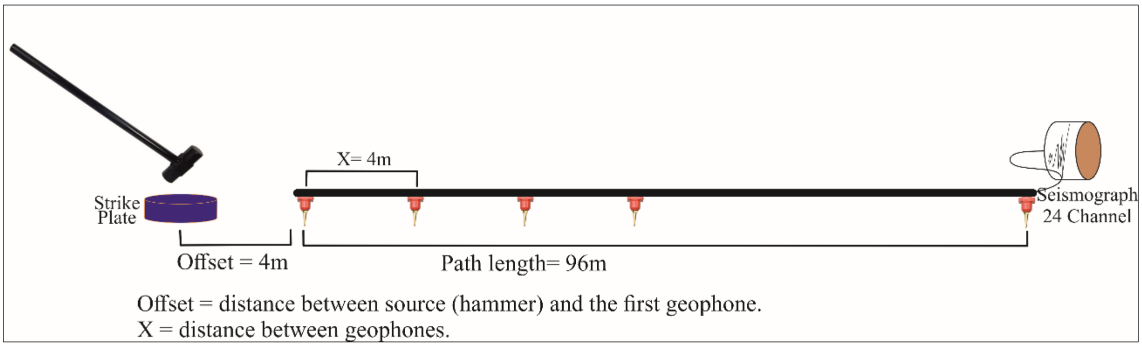


Fig. 5. Diffusion geometry of recording the MASW method.

Mechanical energy waves in three directions are artificially induced by striking the hammer on a strike plate and recorded by a seismograph.

The geophone converts this energy into an electrical signal, then transmits the signal as a wave to the seismograph. Subsequently, the recorded data are processed in the office (Saify and Al-Khalidy, 2023). For the MASW method, Reflex 2D Quick software is utilized to calculate shear velocity and layer thickness to obtain the research results.

The strike plate is positioned adjacent to the first geophone attached to the cable. This plate undergoes three strikes with a hammer to increase the signal-to-noise ratio. Following each strike, the geophone transfers and converts the mechanical energy into an electrical signal. This signal, in the form of a wave, is then transmitted to the seismograph. Subsequently, the office work for processing all the readings is completed according to the Multichannel Analysis of Surface Waves (MASW) method.

Results and Discussion

N-SPT and Vs. relationship with depths

Taking an example from the soil profile data for borehole 2 in Figures 1 and 2, the graphs illustrate the Vs (shear wave velocity) profile and the N-SPT (Standard Penetration Test) profile in situ. The Vs profiles were consistently recorded at 1-meter intervals. In contrast, N-SPT values were recorded in coarse sampling periods at various depths, aligned with the expected soil type, and with a distance of 1 meter or more. They choose the appropriate Vs value to correlate with each N-SPT value for statistical regression (Fig. 6).

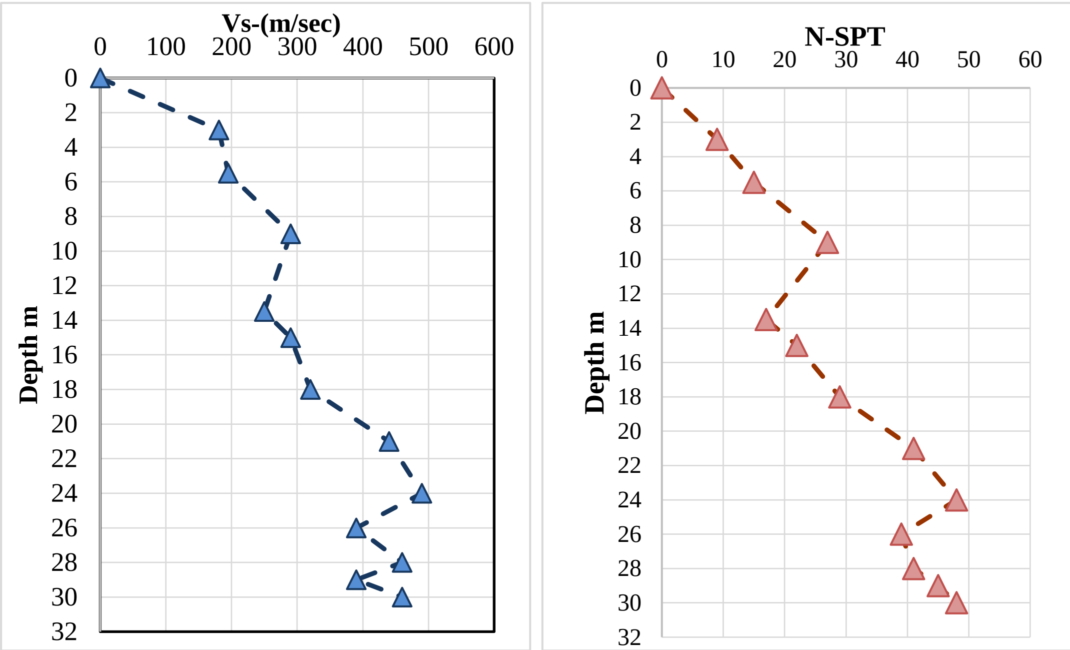


Fig. 6. Variation of N-SPT and Vs versus depths for BH. 2 in the site.

Proposed Empirical Equation for VS and N-SPT

The study used 40 data pairs (N-SPT and Vs) to assess all holes. To develop correlations, a simple regression analysis is conducted on the existing database. The study also proposed new relationships between uncorrected Vs (m/sec) and the corresponding N-SPT (Fig. 7).

The following relationships with their correlation coefficients (r) are proposed between Vs (m/s) and N-SPT values, with an R2 value of 0.8969.

$$Vs = 29.711N^{0.7195} \quad (1)$$

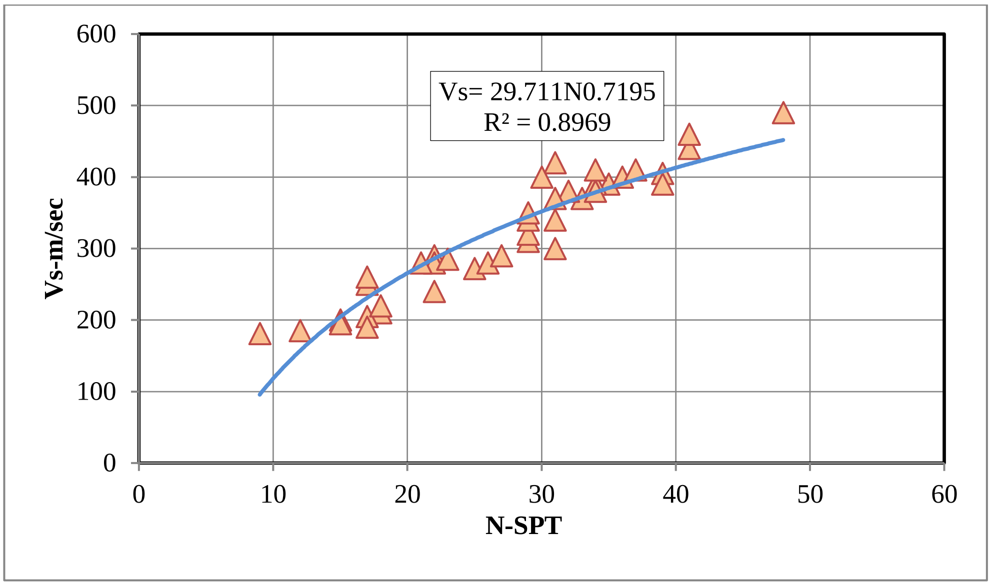


Fig. 7. Correlation between N-SPT and Vs.

Relationship Between Measured Versus Predicted Shear Wave Velocities

In Figure 8, a comparison is presented between the measured shear wave velocity (Vs) and the predicted shear wave velocity, Vs, as per Equation (1).

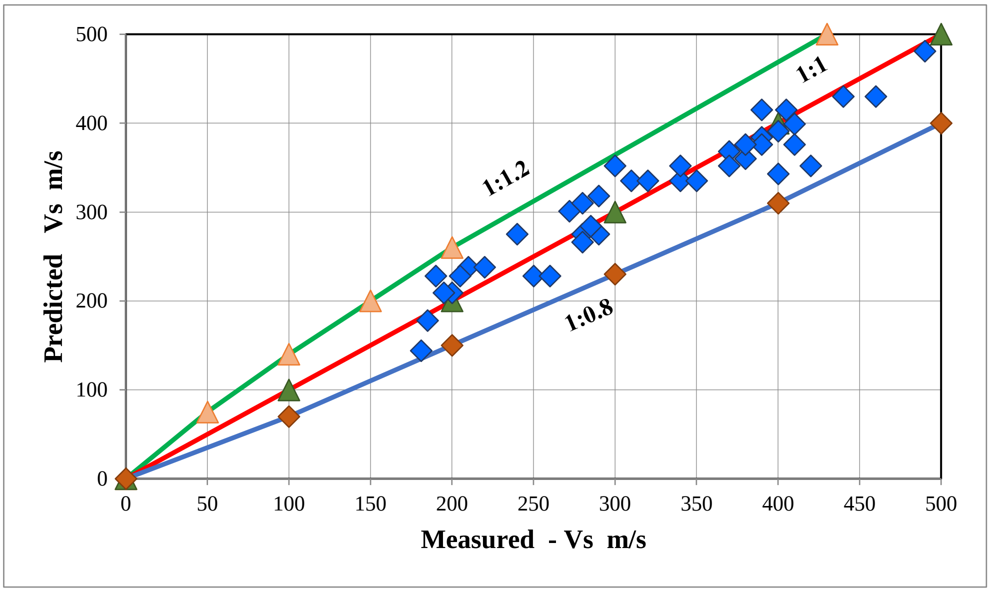


Fig. 8. Measured versus predicted shear wave velocities.

The data points plotted between the lines (each with a slope indicated in Figure 8) closely align with the 1:1 slope (red line), 1:1.2 (green line), and 1:0.8 (blue line). The shear velocity values depicted on the graph are consistently less than 500 m/sec.

Seismic site soil classification methods

Site soil and ground type conditions are important in determining the Seismic Design Category, and it is classified based on Iraqi and international standards, as shown in Table 2.

Several specialized techniques can be employed to accurately assess the soil type at a site from a seismic perspective. One of the methods recognized in the field is outlined in the Iraqi seismic code (PISC, 2013), which provides a systematic approach to classify soil based on its seismic properties. This classification relies on calculating the average shear wave velocity (Vs_{30}) within the upper 30 meters of the soil profile. By measuring the velocity at which seismic shear waves propagate through this soil layer, engineers can make informed predictions about the site's soil type and its potential seismic response. The Vs_{30} parameter serves as a key indicator in this method, as it correlates with soil stiffness and helps in categorizing the site according to seismic hazard assessments.

Table 2: Index and geotechnical properties of soils in BH 2.

Location of specimen		**Sample type**	**Index properties**			**Nature water content**	**Dry unit weight KN/m³**	**Specific gravity**	**Particle size distribution**				**SPT**
BH.	**Depth m**		**LL**	**PL**	**PI**				**Clay**	**Silt**	**Sand**	**Gravel**	
				%						**%**			
BH 2	1.5	DS	33	20	13	15		2.66	36	37	20	7	
	2.5	US	57	24	33	25	16.1	2.69	54	41	5	0	
	3.0	SPT	40	16	24	24							9
	3.5	DS	39	16	23	28		2.67	42	33	25	0	
	4.5	US			NP	9	17.93	2.64	2	1	97	0	
	5.5	SPT			NP	26							15
	7.5	SPT	60	22	38	22		2.69	56	32	12	0	27
	8.0	DS	61	21	40	24							
	9.0	US	59	21	38	25	15.80	2.71					
	10.0	DS	34	19	15	24		2.66	35	19	46	0	
	11.5	SPT	46	20	26	26							18
	12.0	DS	45	21	24	35		2.67	32	51	17	0	
	13.5	US	34	20	14	31	14.97	2.65	37	21	42	0	
	15	SPT	44	21	23	27		2.67	30	56	14	0	23
	16.5	DS	-	-	NP	25		2.64	8	9	83	0	
	18.0	SPT	-	-	NP	22							29
	19.5	DS	-	-	NP	26		2.64	9	9	82	0	
	21.0	SPT	-	-	NP	21							42
	22.5	DS	60	19	41	16		2.68	51	13	36	0	
	24	SPT	60	18	42	13							49
	25.5	DS	61	18	43	15		2.68	49	13	38	0	
	27.0	SPT	60	19	41	19							40
	28.5	DS	43	23	20	18		2.68	41	20	39	0	
	30.0	SPT	43	22	21	22							42

This code estimates the average Vs-wave velocity in the top 30 meters of soil using equation (2). The resulting classification based on this estimation is outlined in Table 3.

$$Vs,30 = \frac{H}{\sum i = 1, N \frac{hi}{vi}} \qquad (2)$$

Where: *H*: total depth of soil less than or equal to 30 m. *hi*, *vi*: thickness and velocity of S-wave of the i^{th} layer, in a total of *N* found in the upper 30 m.

Table 3: Iraqi and International standards and ground types.

No.	**International and Iraqi Standards**	**Ground type**	**References**
1	Preliminary drift of Iraqi Seismic Code, 303	(A, B, C, D, E, F)	PISC (2013)
2	Federal Emergency Management Agency	(A, B, C, D, E, F)	FEMA (2010)

Seismic site soil classification for the Nadir Highway project

Per the Iraqi Seismic Code submitted to the Central Organization for Standardization and Quality Control in 2013, the classification of soil types for the Nadir Highway project can be established by analyzing the average S-wave velocity. The corresponding data is tabulated in Table 4.

To obtain these data, a series of geophysical surveys was carried out in Hilla City, yielding S-wave velocity measurements extending to depths of up to 30 meters. The results of these explorations are detailed in Table 5, offering valuable insights into the area's subsurface conditions and seismic characteristics. These S-wave velocity values are crucial for assessing soil behavior and seismic site response in geotechnical engineering applications.

Table 4: Site soil classification (after PISC, 2013).

Site class definition	Vs	N or Nch	Su
A- Hard rock	>1500 m/s	---	---
B- Rock	760-1500 m/s	---	---
C- Very dense soil or soft rock	370-760 m/s	> 50	> 100 kPa
D- Hard soil	180-370 m/s	15-50	50-100 kPa
E- Soft clayey soil	< 180 m/s	< 15	< 50 kPa
	- Each side section thickness greater than 3m for soil - profile of the following characteristics: Plasticity Index PI > 20. Water content W ≥ 40% Undrained shear strength *Su* < 25 kPa		
F- Soil types that require a special field assessment	Soil is exposed to the possibility of collapse. Silt and/ or clayey soil of high organic content. Clayey soil has a very high plasticity index. Very thick clayey soil of weak/ medium strength.		

Table 5: Seismic site soil classification for the Nadir highway project.

Site	Total depth of Geophysical Explorations (m)	Vs (m/s)	PISC, 2013
Nadir highway project	30	290	Class D

Conclusions

A new relationship between the values of N-SPT and Vs is found to calculate the predicted Vs indirectly, which can be used in the future for practical purposes. The shear wave velocity is calculated for thirty meters from the ground surface and soil layers at the study site.

Estimating Vs_{30} from recorded borehole logs can aid in assessing seismic risks in areas without geophysical measurements.

The current and proposed empirical equations are primarily influenced by the study area's geotechnical conditions, the quantity and type of processed data, and the methods used for geotechnical investigations and geophysical surveys. The relationship proposed in this study can be cautiously applied. However, its reliability increases significantly with comprehensive geotechnical and geophysical data, particularly around Hilla City.

The N-value and shear wave velocity (Vs) analysis for the subsurface layers provides insights into the site's response to seismic activity. For weak ground motions, the peak ground acceleration (PGA) values are unlikely to pose significant risks as indicated by the N-values shown in Figure 3. However, stronger ground motions could result in more notable impacts.

There is a potential risk of secondary soil phenomena, such as soil liquefaction, occurring at depths of 3.5 to 5 meters. This hazard requires careful attention from design engineers to prevent adverse effects. The observed decrease in N-values with depth reflects changes in soil lithology, which play a key role in predicting the site's behavior under varying seismic conditions.

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Conflict of Interest

The authors confirm that the manuscript has been read and approved by all named authors and that no other persons have satisfied the criteria for authorship but are not listed. We further confirm that all have approved the order of authors listed in our manuscript.

References

ABEM Instrument, 2009. Reference manual for ABEM Terraloc MK6. Sundberg, Sweden.

Al-Awsi, M.D., Khurshid, S.Z., and Ahmed, M.T., 2021. Ultrasonic method as a tool for geotechnical parameters estimation at proposed engineering site/ Western Iraq". Journal of Physics: Conference Series, 1818(1), 012010. https://doi.org/10.1088/1742-6596/1818/1/012010

Al-Nuaiemy, A., Al-Juraisy, B., and Al-Mafraji, M., 2018. The use of the seismic refraction tomography survey method and the multi-channel analysis technique of surface waves in the geotechnical assessment of the Al-Amal Apartments Site in Kirkuk, Northern Iraq. Iraqi National Journal of Earth Science, 18(2), pp. 89-104. https://doi.org/10.33899/earth.2018.159260

Al-Rubaiee, A.H. and Hussein, M.L., 2022. Effect of adding cement dust waste on the geotechnical properties behavior of selected gypseous soil in Al-Najaf City. Iraqi Geological Journal, 55(2A), pp. 165-181. https://doi.org/10.46717/igj.55.2A.12Ms-2022-07-28

Al-Rubaiee, A.K. and Al-Owaidi, M.R., 2022a. Assessment of heavy metal contamination in urban soils of selected areas in Hilla City, Babylon, Iraq. Iraqi Journal of Science, 63(4), pp. 1627–1641. https://doi.org/10.24996/ijs.2022.63.4.21

Al-Rubaiee, A.K. and Al-Owaidi, M.R., 2022b. Effect of Open Dump on Geotechnical Properties and Heavy Metal Concentrations of Soil in North of Hilla City, Babylon Governorate, Iraq. Pollution, 9(3), pp. 1015-1027. https://doi.org/10.22059/POLL.2023.353885.1758

Alsinawi, S.A. and Al-Qasrani, Z.O., 2003. Earthquake Hazards Considerations for Iraq, Fourth International Conference of Earthquake Engineering and Seismology,12-14 May, Tehran, Islamic Republic of Iran.

Anbazhagan, P., Bajaj, K., Reddy, G.R., Phanikanth, V.S., and Yadav, D.N., 2016. Quantitative Assessment of Shear Wave Velocity Correlations in the Shallow Bedrock Sites. Indian Geotechnical Journal, 46, pp. 381–397. https://doi.org/10.1007/s40098-016-0181-y

Anbazhagan, P., Parihar, A. and Rashmi, H.N., 2012. Review of correlations between SPT N and shear modulus: A new correlation applicable to any region. Soil Dynamics and Earthquake Engineering, 36, pp. 52–69. https://doi.org/10.1016/j.soildyn.2012.01.005

ASTM D2216, 2019. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. West Conshohocken, PA: ASTM International.

ASTM D2488, 2017. Standard Practice for Description and Identification of Soils (Visual-Manual Procedures), ASTM International. West Conshohocken, PA: ASTM International.

ASTM D4318, 2017. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West Conshohocken, PA: ASTM International.

ASTM D6913, 2017. Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. West Conshohocken, PA: ASTM International

ASTM D854, 2014. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. West Conshohocken, PA: ASTM International.

ASTM, D1586, 1984. Standard test method for penetration test and split-barrel sampling of soils. Annual book of ASTM standard, D1586, Vol. 04.08.

Boore, D.M., Thompson, E.M. and Cadet, H., 2011. Regional Correlations of VS30 and Velocities Averaged Over Depths Less Than and Greater Than 30 Meters. Bulletin of the Seismological Society of America, 101(6), pp. 3046–3059. https://doi.org/10.1785/0120110071

Buday, T. and Jassim, S., 1987. The Regional Geology of Iraq, Vol. 2. Tectonism, Magmatism and Metamorphism. University of Mosul.

Coduto, D.P., 2001. Foundation Design: Principles and Practice, 2nd ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Euphrates Company Study, 1999. Euphrates General Company for Studies and Designs of Irrigation Projects. Branch of Study of Reducing Groundwater Levels in Hilla City.

Fauzi, A., Irsyam, M., and Fauzi, U.J., 2014. Empirical correlation of shear wave velocity and n-spt value for Jakarta. International Journal of GEOMATE, 7(1), pp. 980-984. https://doi.org/10.21660/2014.13.3263

Federal Emergency Management Agency (FEMA), 2010. Earthquake-Resistant Design Concepts, an Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. CreateSpace Independent Publishing Platform.

Hanumantharao, C. and Ramana, G.V., 2008. Dynamics soil properties for microzonation of Delhi, India. Journal of Earth System Science, 117(S2), pp. 719–730. https://doi.org/10.1007/s12040-008-0066-2

Hasan, A.M., Mawlood, Y.I., Ahmed, A.A. and Ibrahim, H.H., 2020. Correlation of Shear Wave Velocity With SPT-N For a Tower-Building Site at Erbil City. Journal of Duhok University, 32(2), pp. 235-245. https://doi.org/10.26682/csjuod.2020.23.2.19

Iraqi Meteorological Organization and Seismology, 2013. Retrieved December, from http://meteoseism.gov.iq/index.php?name=Pages&op=page&pid=168

Jedi, Z. and Al-Khalidy, A., 2023. Comparing the Results of Geotechnical Tests with the Well Seismic Survey to Find the Dynamic Modulus of Elasticity for the Surface Soil Sections in Hilla City. Iraqi Geological Journal, 56(1), pp. 228–233. https://doi.org/10.46717/igj.56.1E.17ms-2023-5-27

Kirar, B., Maheshwari, B.K., and Muley, P., 2016. Correlation Between Shear Wave Velocity (Vs) and SPT Resistance (N) for Roorkee Region. International Journal of Geosynthetics and Ground Engineering, 2, 9. https://doi.org/10.1007/s40891-016-0047-5

Kramer, S.L., 1996. Geotechnical Earthquake Engineering, Prentice Hall, Upper Saddle River.

Maibam, U., Hooda, O.K., Sharma, P.S., Mohanty, A.K., Singh, S.V. and Upadhyay, R.C., 2017. Expression of HSP70 genes in skin of zebu (Tharparkar) and crossbred (Karan Fries) cattle during different seasons under tropical climatic conditions. Journal of Thermal Biology, 63, pp. 58–64. https://doi.org/10.1016/j.jtherbio.2016.11.007

Mohammed A., Al-Mufarji, M., Al-Heety, A., Othman, B. and Abdelrahman, K., 2025. Determination of elastic moduli for the geotechnical site characterization using compressional and shear seismic refraction tomography at the proposed site for Baba Gur-Gur University, Northeastern Kirkuk, Iraq. Iraqi National Journal of Earth Science, 25(1), pp. 304-326. https://doi.org/10.33899/earth.2024.146087.1221

Park, C. B., Miller, R. D. and Xia, J., 1999. Multichannel analysis of surface waves. Geophysics, 64(3), pp. 800-808. https://doi.org/10.1190/1.1444590

Preliminary Draft of Iraqi Seismic Code, 303 (PISC), 2013. Central Organization for Standardization and Quality Control (COSQC). Ministry of Construction and Housing.

Rahman, M.D.Z., Siddiqua, S. and Kamal, A.S.M., 2016. Shear wave velocity estimation of the near-surface materials of Chittagong City, Bangladesh for seismic site characterization. Journal of Applied Geophysics, 134, pp. 210-225. http://dx.doi.org/10.1016/j.jappgeo.2016.09.006

Saify, Z.M.J. and Al-Khalidy, A.A.L., 2023. Engineering, Geophysical Investigation of a Multistory Building, at Hilla, Iraq, Utilizing the MASW Method. Iraqi Geological Journal, 56(1), pp. 217–227. https://doi.org/10.46717/igj.56.1E.16ms-2023-5-26

Sitharam, T.G. and Anbazhagan, P., 2007. Seismic hazard analysis for the Bangalore region. Natural Hazards, 40, pp. 261–278. https://doi.org/10.1007/s11069-006-0012-z