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MAPPING HAZARD POTENTIALS IN SEISMIC ZONES BASED ON GEOTECHNICAL DATA FOR DESIGNING TRANSPORTATION NETWORKS INFRASTRUCTURE

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Abstract. *On designing transportation networks, bridges, as infrastructures, are found to be spreading in many locations along freeways and roads. Thus, designing bridges should cover all expected load cases and accounts for various foundation soil profiles in a reliable manner. To achieve that, correct dynamic structural analyses of bridges are required. However, the latter analyses, to be reliable, require the knowledge of the expected dynamic response of the soil-foundation-bridge structure system, which demands the characterization of dynamic soil properties using geophysical methods in advance. Consequently, and with taking into consideration the associated social and economic losses upon having partial or total damage of bridges in vital transportation networks, the effect of having different dynamic behaviors for different soil profiles under seismic actions must be accounted for. In spite of that, a major basic problem that lies in reality is the insufficient knowledge about the soil behavior under seismic waves as well as the scarcity of data for the different sites before designing. This is the case especially when knowing that the national design codes account for large areas per a single seismic zone, which may thus include different soil profiles for different sites, and sometimes in the same site. This should eventually yield an error in estimating the design dynamic loads for different soil profiles and foundation systems lying in a single seismic zone.*

The introduced research herein generally studies the bridge foundations vibrations under seismic events. The paper proposes initiating a map that includes a hazard potential impact factor for the different areas having different soil profiles. The resulting map should categorize the hazard potential as per the geophysical data obtained from site investigations. The case study here is Alexandria Governorate in Egypt, assumed lying within the 2nd seismic zone as per the Egyptian design code. In contrast, the General Egyptian Authority for Educational Buildings, in its soil categorization map, divides this Governorate into nine regions with different soil profiles. The proposed approach counts on actual in-situ investigations, to derive the soil dynamic properties then the results are integrated into a dynamic model for the soil-structure interaction. Finally, the simulation results associated with statistical models for earthquake occurrence are used to obtain a seismic hazard potential impact factor for each region. Results can be used to trace the best locations for infrastructures as bridges lying within transportation networks.

1 INTRODUCTION

Bridge structures during their lifetime may in practice be subjected to severe dynamic excitations as earthquakes. Damage resulting from such excessive lateral loading and its location is usually unexpected. Thus, protection of strategic structures as bridges against excessive loading hazards from earthquakes has become actually one of the very essential targets for civil engineers and seismologists. This is the case especially on knowing that the economic and social effects of earthquake disasters can be efficiently reduced through a comprehensive assessment of seismic hazard and the associated risk for areas that have a history of earthquake occurrence events. Such assessments are usually reflected in design estimates of earthquake intensity loads to achieve a reliable earthquake-resistant design for new structures, and should eventually lead to increased public awareness, with a consequent upgrading of the existing structures and the corresponding engineering works [1].

However, the soil profile properties under any structure cannot be neglected in such an assessment since the soil underneath structures is undoubtedly the medium that transfers the seismic excitation to the structures foundations. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI) [2]. Moreover, studying the soil formation in any region, one can recognize that the geological conditions, topographic characteristics and climatic conditions play a vital role in such soil formation. Thus, soil is generally considered as a three-phase system (air, water and solid) causing significant changes in the system characteristics due to interaction of these phases under applied dynamic or static loads [3]. Accordingly, determination of dynamic soil properties is a critical requirement in geotechnical-earthquake engineering problems.

Dynamic soil properties namely shear wave velocity, variation of stiffness or modulus reduction and material damping with strain levels, and liquefaction susceptibility parameters are the primary input parameters for various dynamic studies and investigations. Generally, soil properties depend on different state parameters such as the state of stress, void ratio, confining stress and water content, stress history, strain levels, and drainage condition. In addition to the influence of the above mentioned parameters, dynamic soil properties are significantly influenced by the dynamic amplitude and frequency of the applied dynamic load. Thus, estimation of the dynamic soil properties as the shear modulus and damping characteristics requires correct consideration of all the above-mentioned influencing parameters. The latter estimations should thus be the key to both fundamental understanding of soil behavior and subsequently practical application of soil modeling programs.

Moreover, field evaluation of dynamic soil properties predominantly aids in the estimation of the shear wave velocity and implicitly the shear modulus at low strain level. Meanwhile, laboratory based evaluations helps in the estimation of a realistic range of dynamic soil properties (*e.g.* experiments carried out in a specific strain-controlled environment) at varying strain levels [3]. For example, the cyclic triaxial method has been the most widely used to measure the strength, deformation and dynamic characteristics of soils [3].

This paper outlines the effect of the foundation soil profile properties on the seismic response of loaded foundations of bridges. It is shown that this factor, varying from one location to another, requires careful consideration when deriving the design response spectra in national codes. Moreover, stiffness and damping parameters are assumed for different soil profiles and used in a structural dynamic model to observe the response of the soil underneath the foundation together with the foundation itself. This is done in order to see the amplification resulting from different soil profiles lying within a zone that is initially estimated in the national codes to have the same design loads for similar structures. Finally, based on the obtained results, a seismic hazard potential impact factor distribution map is obtained for different regions, categorized as per the soil profiles, lying within a defined single seismic zone in the national codes.

2 PROBLEM DEFINITION

Civil Structures such as bridges in transportation networks may be subjected to severe dynamic excitations as earthquakes. Thus, decent dynamic structural analysis and design of superstructures as bridges requires the knowledge of the dynamic response of the soil structure underneath. This in turn relies on the foundation soil dynamic properties. In spite of that, insufficient knowledge about the soil behavior in different areas under seismic ground waves is an annoying problem that must be better analyzed and well-studied by scientists editing national codes. The problem is even reflected in having a minimum number of categorized seismic zones in the national codes. This is the case such that each zone covers large areas including many regions with different soil profiles.

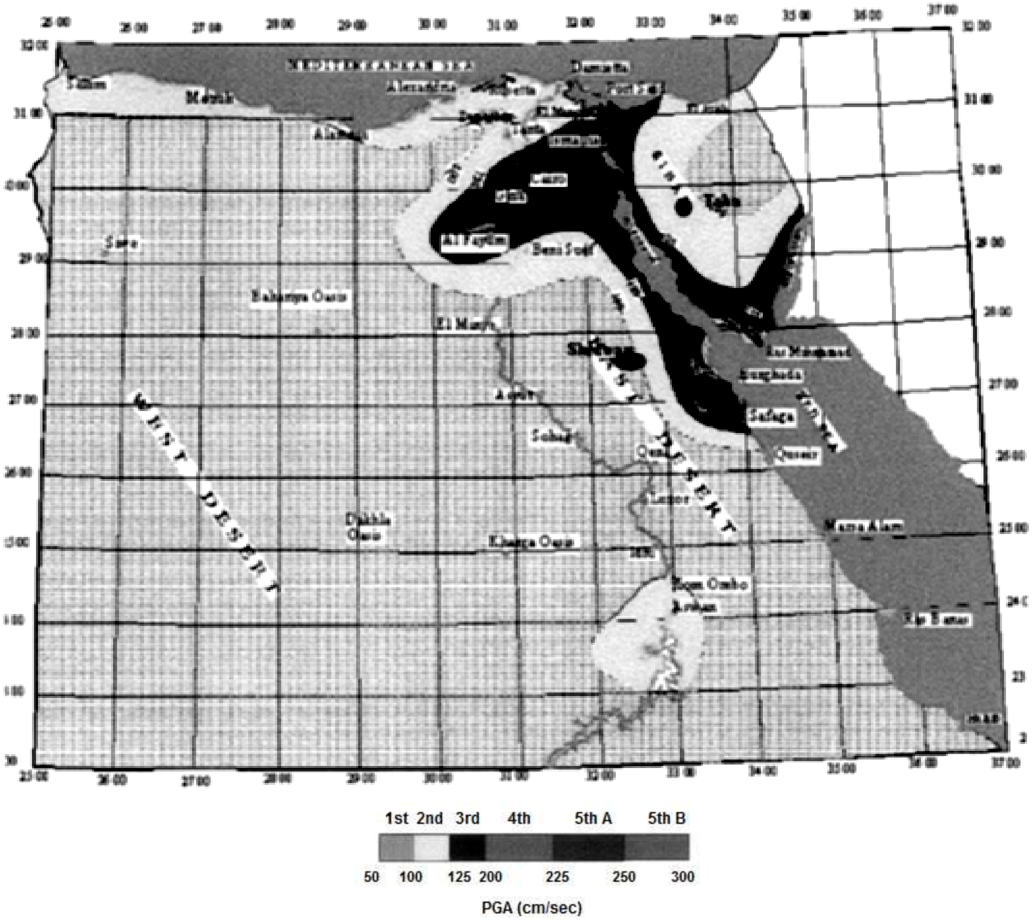

Figure 1: Seismic Zones as per the Egyptian Code of Loads [4]

In Egypt, for instance, the Egyptian Code of Design Loads [4] on designing structures supplies equivalent earthquake loads for defined seismic zones within the Egyptian territories. As shown in Figure 1. Each zone covers wide areas across the Egyptian lands such that it is expected and can be easily verified that many soil profiles with different properties lie undoubtedly in each zone. Consequently, the differences in soil profiles in areas as large as Alexandria Governorate and others are neglected. This is definitely unacceptable where different areas in Alexandria undergo different responses as evident from the descriptions of the buildings' tenants in different areas in the city after each earthquake or tremor occurrence.

Such problem should be urgently solved in order to avoid negative effects on designed and existing structures. Thus, the expected behavior of different soil profiles under seismic effect needs to be verified in advance. This application is important as it affects the design strategy of structures in general but mostly large and strategic ones including bridges. The loss of the latter structures not only would cause considerable life and economic losses but may sometimes initiates environmental hazards and economic impacts.

3 LITERATURE REVIEW

Subjected to similar testing conditions, a significant difference in the dynamic soil properties for characteristically different soils have been observed by earlier researchers[3].It has been observed that the dynamic soil properties are affected by many factors like: method of sample preparation in the laboratory (whether intact and reconstituted samples),relative density, confining pressure, methods of loading, overconsolidation ratio, loading frequency, soil plasticity, percentage of fines and soil type[3]. This should thus raise a flag of how important is considering the soil profile properties as a factor in design. In spite of that, the analysis of the dynamic soil properties is costly and may not be practical to apply for every borehole sample results, yet, using the SPT results may be helpful in anticipating such dynamic properties for the different samples [5].Earlier studies on the methodology of obtaining dynamic soil properties were presented by scientists and researchers to highlight the importance of each influencing parameter [3].

Moreover, over the past 40 years, a considerable progress had been made in understanding the nature of earthquakes and how the resulting damage takes place in structure, and consequently in improving the seismic performance of the built environment [6]. For instance, during a seismic event, ground motions propagating through the foundation soils transmit energy through the piles to the bridge superstructure. In turn, the bridge responds dynamically to these vibrations, and the resulting inertial forces are transmitted back to the soil through the pile foundations. This soil-structure interaction response of the bridge was modeled using foundation springs at the base of the pile caps. Figure 2 shows a schematic of a representative model (bascule pier) for analysis of the soil-foundation interaction and the model representing SSI in the global analysis of the bridge [7].

Furthermore, when subjecting piles to abrupt loads such as the case of seismic loads, piles may suffer structural damage that would threaten the integrity of the supported structures [8,9]. This is reflected in some cases where extreme effects sometimes took place after some seismic events tragically in terms of human lives losses, material and financial losses like what happened in Niigata earthquake (1964) in Japan and Izmit earthquake (1999) in Turkey [8,9].Thus, a suitable model for representing soil-structure interaction is needed in order to obtain the expectations for the transferred excitations to the main structure under seismic event [10].

Furthermore, Egypt is considered to be one of the few countries among the world where earthquake activity has been documented during the past 4200 years (*e.g.* in 1210 and 600 B.C. and A.D. 778,967,1303,1874,and 1899), with earthquakes destroying parts of big cities , such as Cairo and Alexandria [11]. Figure 3 shows the tectonic boundaries and the seismicity data of the Eastern Mediterranean Region [12]. The Acronyms on the map represent: AEG – Aegean Sea; Al – Alexandria City; CY – Cyprus; ERA – Eratosthenes Seamount; FL – Florence; IB – Ionian Basin; MR – Mediterranean Ridge; LEV – Levantine Basin; LF – Levant Fault; ND – Nile Delta. Red diamond indicates the location of Abo-Zenema area

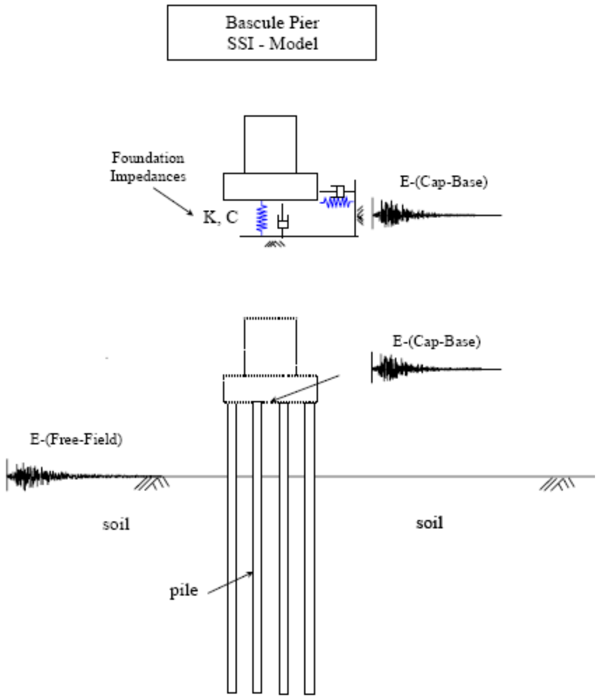

Figure 2: The local model for analysis of the soil-foundation interaction and the model representing SSI in the global analysis of the bridge [7].

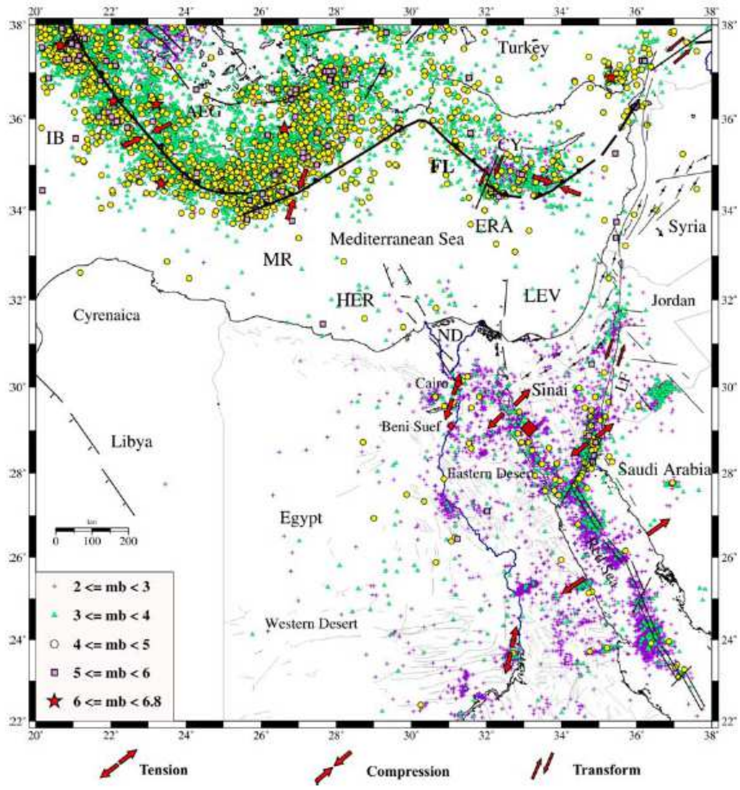

Figure 3: Tectonic boundaries of the Eastern Mediterranean Region [12]

The interaction of the African, Arabian, Eurasian plates and Sinai sub-plate is the main factor behind the seismicity of northern part of Egypt. All earthquakes occur at shallow depth and are concentrated at four seismic zones, these zones including the Gulfs of Suez and Aqaba, around the entrance of the Gulf of Suez and the fourth one is located at the south- west of great Cairo (Dahshour area). The seismicity map of the previous zones shows that the activity is coincided with the major tectonic trends of the Suez rift, Aqaba rift with their connection with the great rift system of the Red Sea and Gulf of Suez- Cairo-Alexandria trend [13]. As shown at figure (1), Egypt's Position on the map is considered to be hazardous seismic activity area.

4 CASE STUDY

The main study herein focuses on the Alexandria Governorate lying in the North West coast of Egypt on the Mediterranean Sea. The reason for that is that Alexandria city used to be the capital of Egypt for centuries ago before building Cairo, the current capital, and because Alexandria city lies close to the active seismic zones of the southern Mediterranean area. The General Egyptian Authority for Educational Buildings [14] in its soil categorization printouts divides the governorate into nine main regions as shown in Figure 4. The categorization comes from the fact that every region has its own soil profile. Thus, if one of the regions is exposed to an earthquake event, it is expected that the profile response across the whole region will be nearly the same but different from other regions. This information was documented for structural engineers to design efficiently the educational structures within each region.

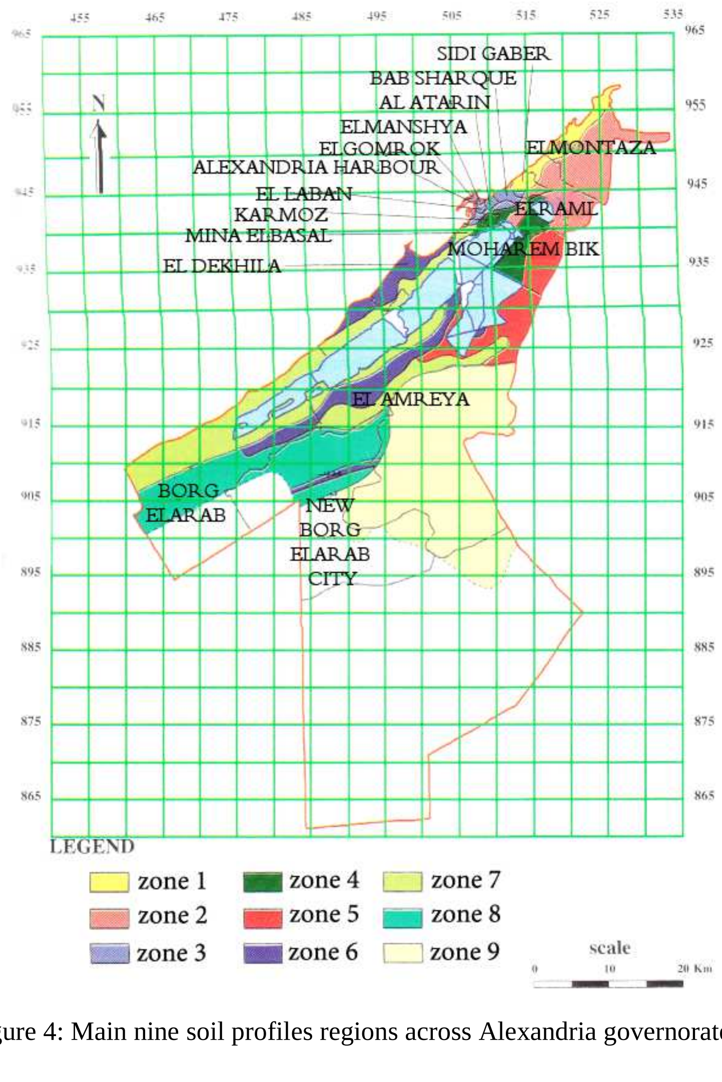

Figure 4: Main nine soil profiles regions across Alexandria governorate [14]

The research herein aims to identify the dynamic soil properties in the different regions in Alexandria city and incorporates the results in designing filters for the expected earthquake intensity in each region. On accomplishing the latter procedure, maps will be prepared for the whole Alexandria Governorate area, showing hazard potential areas for structures in the different regions. Moreover, modified response spectra design curves will be introduced for the design community in Alexandria taking into account the categorization as per the soil profiles. This is done by taking samples of borehole results for the different nine regions then estimating the dynamic soil properties for the studied soil profiles from boreholes results.

5 METHODOLOGY

Within the context of this paper, it is assumed that a set of similar bridges are needed to be built within a desired transportation network lying across Alexandria governorate. Each bridge is assumed bearing on portal frames as its supports. The foundation system of the bridges is assumed composed of piles lying under pile caps supporting the columns of the portal frames. The foundation system is assumed embedded in stratified soil profiles in the form of consecutive layers, as obtained from the borehole tests, as shown in Figure 5.

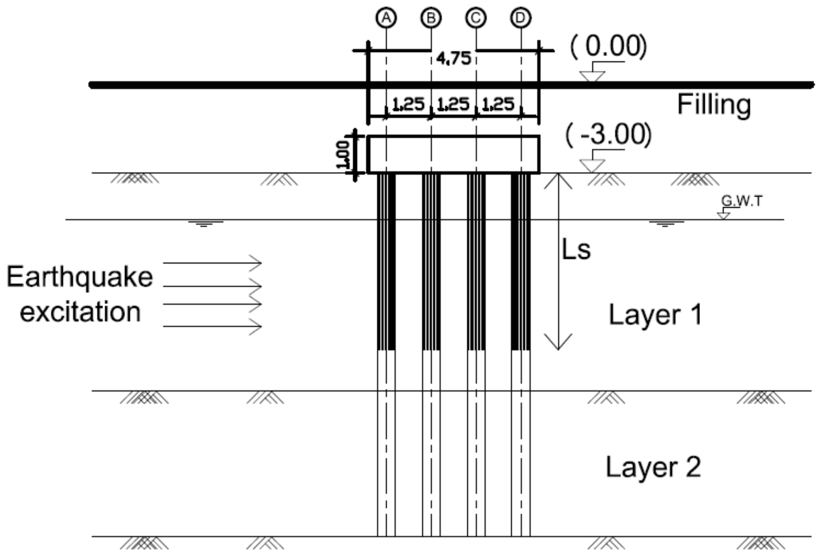

Figure 5: Typical Layout of the studied foundation system

5.1 Modeling

A shear building model, as shown at Figure 6, is chosen to represent the mathematical model of the soil-pile-cap system under earthquake excitation, where piles are divided along the vertical direction into horizontal strips. Moreover, developing the dynamic model for analyzing the soil-Pile-cap interactive response under earthquakes requires calculating stiffness for the pile group together with the soil wedge around it, estimating the mass of the interactive soil wedge surrounding the concrete piles during lateral excitation of the piles-cap system, and estimating the damping coefficients of the soil.

Furthermore, the length of the upper part of the buried pile that can be considered affected by seismic waves is defined as L_s. This affected length varies from soil profile to another according to the type of soil (dense sand, loose sand, soft clay, medium clay or stiff clay). The following Table (1) [15] indicates the design parameters n_h and K_h that are needed to evaluate L_s. This is the case where n_h is the horizontal subgrade reaction in the case of cohesionless soils, and K_h is the horizontal subgrade reaction in the case of cohesive soils.

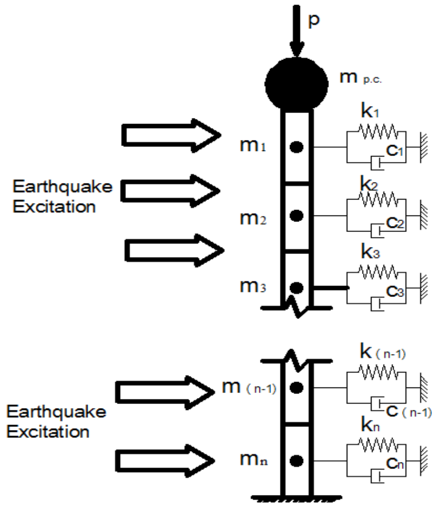

Figure 6: Shear Building model of interactive soil-concrete piles-cap system

Soil type		Site data			Design parameters			
		N	c	Ø	n_h (kN/m^3)		K_h	E_s
		Blows/0.3m	(KPa)	degrees	Dry	Submerged	KN/m^2	KN/m^2
Cohesion less soils	Dense	30-50		45°	15×10^3	9×10^3		
	Loose	4-10		30°	2×10^3	1×10^3		
Cohesive soils	Hard	20-60	150-250				18×10^3	25×10^3
	Stiff	8-15	50-100				6×10^3	8×10^3
	soft	2-4	15-30				1.5×10^3	2×10^3

Table 1: Suggested Soil Stiffness Parameters for use in a Preliminary Seismic Analysis [15]

In general, the length of pile shaft between the level of the pile cap and the assumed starting point of fixation, L_s, can be evaluated from the following equations [15] such that in case of cohesionless soil,

$$L_s = 1.8 \sqrt[5]{\frac{EI}{n_h}} \tag{1}$$

and in case of cohesive soil,

$$L_s = 1.4 \sqrt[4]{\frac{EI}{K_h}} \tag{2}$$

where E *is* the modulus of elasticity of concrete, assumed 24 *G*Pa for a cubic strength of 30 *M*Pa [16], and I is the moment of inertia for the concrete pile cross section.

5.1.1. Mass Estimates

The mass of each strip is assumed lumped as shown at Figure 7, where $m_{p.c}$ is the mass of the pile cap, and m_i is the mass of the i^{th} strip. The lumped mass of each strip is evaluated as per the volume of the strips and the surrounding interactive soil wedge, see Figure 7. Each mass is assumed to have a single degree of freedom such that the number of degrees of freedom is relative to the number of masses [10]. It is important to note that not all the full depth of each studied pile undergoes lateral vibration due to earthquake excitation, but rather the affected buried depth only.

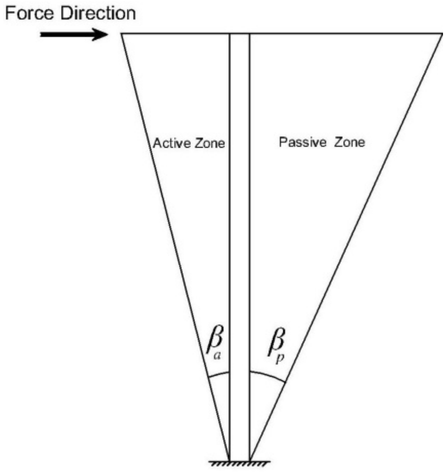

Figure 7: An elevation view showing the projection of the interactive soil wedge surrounding each concrete pile during lateral excitation of the piles-cap system [16]

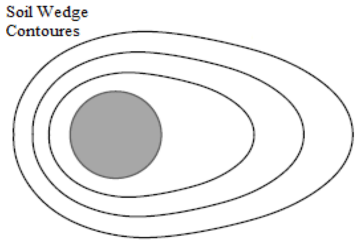

Figure 8: An example plan showing the effective soil wedge around the concrete pile in terms of contour lines [10]

This is the case such that the angles for the active and passive sides of the pile, β_a and β_p respectively, are obtained from,

$$\beta_a = 45 - \frac{\phi}{2} \tag{3}$$

and

$$\beta_p = 45 + \frac{\phi}{2} \tag{4}$$

where ϕ is the angle of friction of the sandy soil, and in the case of clay soil $\beta_a = \beta_P = 45°$.As evident from Figure 7, it can be easily concluded that the cross section of the interactive soil wedge is nearly elliptical or oval [17] such that the longer dimension of the oval ellipse can be obtained from

$$D_y = H \times (\tan \beta_a + \tan \beta_p) + d \tag{5}$$

and the shorter dimension can be assumed from

$$D_x \cong \frac{1}{2} \times H \times (\tan \beta_a + \tan \beta_p) + d \tag{6}$$

where D_x is the shorter oval ellipse dimension in the horizontal X-axis, and D_y is the longer oval ellipse dimension in the perpendicular horizontal Y-axis, and d is the pile diameter, and H is the full height of the concrete pile excluding the fixation length. Note that for large values of D_x and D_y, it is expected that the overlap between the effective soil surrounding each pile is large. Thus, it is advisory to draw the soil wedge for each pile in terms of contour lines as shown in Figure 8 and evaluate soil masses excluding the overlap areas or volumes for each strip.

5.1.2. Stiffness Estimates

To calculate the stiffness parameters for the pile, the equivalent cantilever method of stiffness is used where the buried length of the pile affected by seismic wave is defined as L_s as explained earlier, see Figure 9. Similarly, on calculating the piles group stiffness for each strip, the affected buried pile length, L_s, is divided into strip elements with stiffness each of

$$k_i = \frac{12\,EI}{h^3} \tag{7}$$

where k_i is the single pile strip stiffness, E is the modules of elasticity, and h is the strip element height.

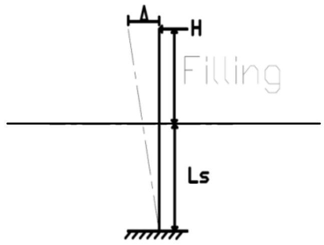

Figure 9: Equivalent Cantilever for foundation stiffness [15].

Moreover, the soil is model used as a linear hysteretic material of Young's modulus, E, Poisson's ratio, ν, material damping ratio, ζ, and shear velocity, v_s. Meanwhile, to calculate the single pile stiffness in the strips embedded in the sandy soil or clay soil, the geotechnical engineering software (*AllPile*) [18] is used. The software (*AllPile)* directly uses COM624S calculation methods for lateral analysis. For details on COM624, please refer to the FHWA publications [18,19]. In summary, COM624S uses the four nonlinear differential equations to perform the lateral analysis,

$$EI\frac{\mathrm{d}^4\mathrm{Y}}{\mathrm{d}\mathrm{Z}^4} + Q\frac{\mathrm{d}^2\,\mathrm{Y}}{\mathrm{d}\,\mathrm{Z}^2} + R - P\mathrm{q} = 0 \tag{8}$$

$$EI\frac{\mathrm{d}\,\mathrm{Y}}{\mathrm{d}\,\mathrm{Z}} + Q\frac{\mathrm{d}\,\mathrm{Y}}{\mathrm{d}\,\mathrm{Z}} = P \tag{9}$$

$$\frac{\mathrm{d}\,\mathrm{Y}}{\mathrm{d}\,\mathrm{Z}} = S_{\mathrm{t}} \tag{1}$$

$$EI\frac{\mathrm{d}^2\,\mathrm{Y}}{\mathrm{d}\,\mathrm{Z}^2} = M \tag{11}$$

where Q is the axial compression load on the pile, y is the lateral deflection of pile at depth z, z is the depth from top of pile, R is the soil reaction per unit length, E is the modulus of elasticity of the pile, I is the moment of inertia of the pile, and Pq is the distributed load along the length of the pile, P is the shear in the pile, S_{t} is the slope of the elastic curve defined by the axis of pile, and M is the bending moment on the pile.

5.1.3. Damping Estimates

Dividing the pile shaft length affected by seismic wave height into strips every 0.5*m*, the damping is assumed to be 3% in case of sandy soil and 2% for clayey soil [20,10]. In case of the presence of soft clay layers surrounding the pile shaft, the damping is assumed to be 1%, and neglected in case of filling layers.

5.1.4. Group interaction effects

Due to the fact that the distances between the piles are relatively small, it is expected that the interference between the soil wedges around the piles should result in reduction of the group total stiffness rather than summing the stiffness for each pile. Thus, a reduction factor for group effect is used [21]. Figure 10 shows the values of the P-multipliers (f_{m}) [21].

The f_{m} value, as indicated in Figure 10, decreases as the number of rows of piles increases. In addition, the f_{m} value decreases as well on decreasing the spacing of the rows. The values of f_{m} are relative to the load carried by each row of piles. The chart shows that the leading row takes most of the input energy. For piles spaced more than six diameters apart, the values of f_{m} are equal to 1.0, indicating that group interaction effects are negligible [21].

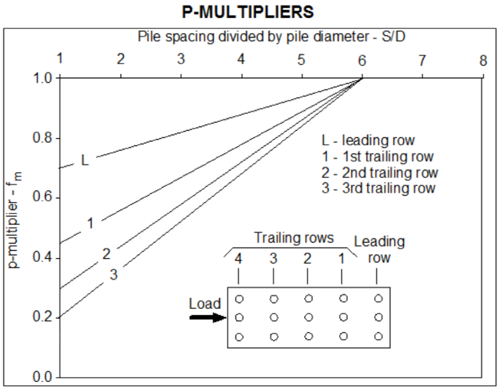

Figure 10: Piles group reduction factors [20].

5.2 Modeling Earthquake Excitation

An analytical model such as the state space model is applied for computing the dynamic response of the soil-piles-cap system studied. The soil-piles-cap system is then considered subjected to an earthquake along the buried depth of the pile. The seismic response of the system in different soil profiles is studied. The applied dynamic forces are assumed transmitted onto each pile through the buried part of the pile. In addition, the earthquake excitation is assumed to affect the piles-cap system along the buried depth of the piles. Thus, all strips under the soil top layer are excited with the same lateral excitation momentarily. This is the case where the seismic wave acting on the pile is assumed to have the same magnitude along the pile depth in the soil. Moreover, since the number of piles in the studied group is relatively large and the pile spacing, S, is equal to three times the pile diameter (relatively small), it is assumed that the lateral responses of all embedded piles will have the same phase. Furthermore, the dynamic time-domain responses of the shear building model of the system is obtained using a linear state space model using Matlab® software [22]. Thus, consider a linear structural model of the form:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}_d\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{b}f \,, \quad \mathbf{y} = \mathbf{C}_1\mathbf{x} + \mathbf{C}_2\dot{\mathbf{x}} + \mathbf{d}f \tag{2}$$

where $\mathbf{M}$, $\mathbf{K}$, and $\mathbf{C}_d$ are the mass, stiffness and damping matrices of the system, and $\mathbf{C}_1$, $\mathbf{C}_2$, and $\mathbf{d}$ are the output influence matrices for the displacement, velocity and the external force, f. Thus, one can write the model in a state-space form

$$\dot{\mathbf{q}} = \tilde{\mathbf{A}}\mathbf{q} + \tilde{\mathbf{B}}f \,, \qquad \mathbf{y} = \mathbf{C}\mathbf{q} + \mathbf{D}f \tag{3}$$

where

$$\mathbf{q} = \left[\mathbf{x}^T \quad \dot{\mathbf{x}}^T\right]^T \tag{4}$$

is the state vector, $\tilde{\mathbf{A}}$ is the system state matrix which is dependent on the mass $\mathbf{M}$, damping $\mathbf{C}$, and stiffness $\mathbf{K}$ matrices of the structural system such that,

$$\tilde{A} = \begin{bmatrix} 0_{nDOF\times nDOF} & I_{nDOF\times nDOF} \\ (-M^{-1}K)_{nDOF\times nDOF} & (-M^{-1}C)_{nDOF\times nDOF} \end{bmatrix} \tag{5}$$

where nDOF is the number of degrees of freedom of the system. In addition, f is an excitation force, and $\mathbf{y}$ is a vector of measured responses. Moreover, $\tilde{\mathbf{B}}$ is the input influence matrix, $\mathbf{C}$ is the output influence matrix for the state vector $\mathbf{q}$, and $\mathbf{D}$ is the direct transmission matrix.

5.3 Numerical Example

The main core related to the problem herein is studying the effect of a seismic event on a standard soil-foundation-bridge structure system located in different locations within the Alexandria governorate. The numerical study herein is a pile cap of a bridge as shown in Figure 11, assumed to be located in all various nine soil profile regions around Alexandria governorate, Egypt. The pile cap is assumed carrying a vertical load of 7500*k*N from the frame column which is carrying the main girder of the studied bridge.

The pile cap design foundation level is assumed to be at (-3.00) from ground level, for all the nine assumed soil profile regions, as per the General Egyptian Authority for Educational Buildings [14], see Figure 4. The diameter for each pile is 0.5*m* with a capacity of each assumed to be 500 *k*N. The piles are distributed forming a 4×4 array under the pile cap where the spacing between piles, *s*, equals 2.5 times the pile diameter. Thus, the side dimension of the resulting square pile cap is 4.75*m*, as shown in Figure 11.

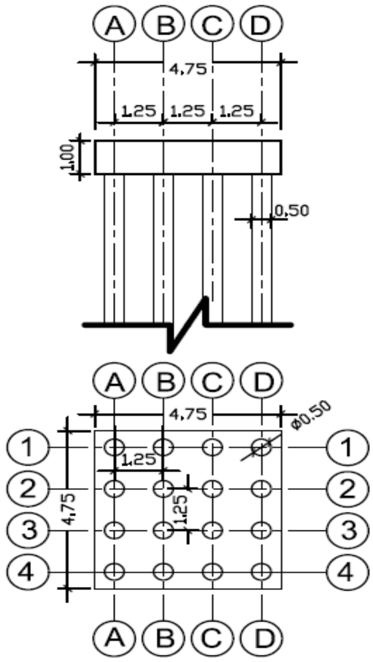

Figure 11: A layout of the studied foundation system

In addition, the studied bridge foundations are assumed to lie all in the same seismic active area as per the Egyptian Code [4], namely the second seismic zone of Egypt, corresponding to Alexandria governorate location on the seismicity map of Egypt, see Figure 1 [4]. The soil-foundation-bridge structure system is assumed subjected to an earthquake such as Aqaba (or Nuwaibaa) earthquake with a scaled max ground acceleration of 0.125*g*, corresponding to the max expected ground acceleration in the second seismic zone [4].

Furthermore, on applying the shear building model, the pile shaft is considered divided into strips of 0.5*m* height. The suggested soil-structure interaction dynamic model is applied on borehole samples taken among the nine zones of Alexandria, as shown in Figure 12. The stiffness factors for each borehole according to the pile length affected by seismic waves, L_s, are calculated as shown in Table 2. It is important to note that the number of strip elements differs from one borehole to another. In addition, on modeling the soil, the upper filling layers are neglected such the affected shaft length, L_s, starts below the filling layers, see Figure 9.

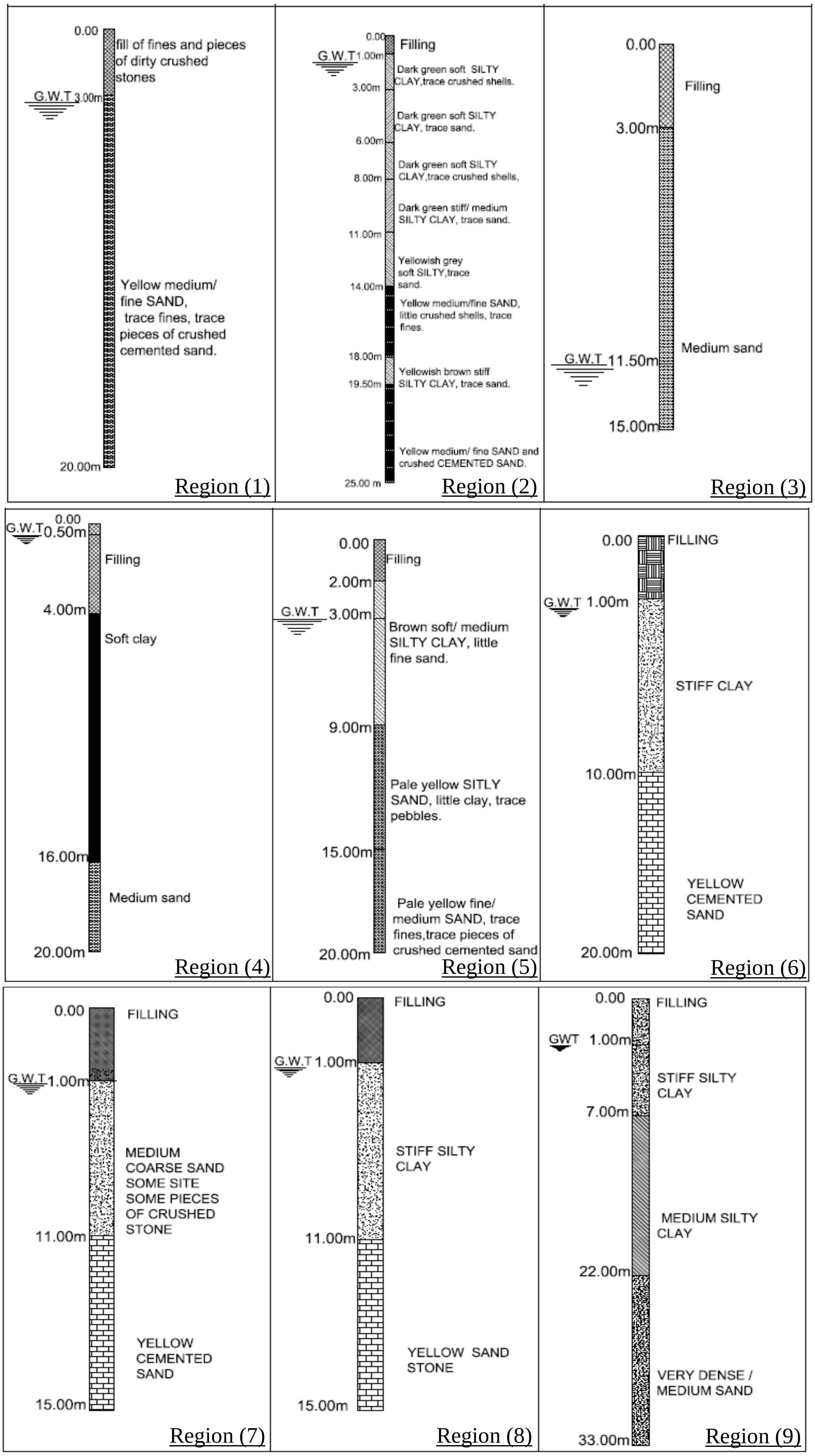

Figure 12: Borehole samples for regions (1 to 9) in the Alexandria governorate

Elements	Region (1) (L_s = 3m) k_i KN/mm	m_i Kg	D %	Region (2) (L_s = 4m) ki KN/mm	m_i Kg	D %	Region (3) (L_s = 3m) k_i KN/mm	m_i Kg	D %
Pile cap	-	57498.72	-	-	57498.72	-	-	57498.72	-
1	6187146	32818.8	3.00	651449.5	56152.7	1.00	3444531	69116.1	3.00
2	6120767	26473.2		625519.6	46926.2		3164192	54933.8	
3	5898289	20744.4		594367.5	38596.8		3049068	42070.2	
4	5553329	15341.7		559203.1	30740.6		2870829	30354.8	
5	5117255	846.33		520997.8	23820.7		2645321	16037.9	
6	-	-		480564.9	17595.9		-	-	
7	-	-		427004.2	11977.2		-	-	

Elements	Region (4) (L_s = 4m) k_i KN/mm	m_i Kg	D %	Region (5) (L_s = 4m) k_i KN/mm	m_i Kg	D %	Region (6) (L_s = 3m) k_i KN/mm	m_i Kg	D %
Pile cap	-	57498.72	-	-	57498.72	-	-	57498.72	-
piles only	57019.07	-	-	-	-	-	-	-	-
1	92958.67	37826.76	1.00	222969.1	56152.7	1.00	505889.7	35910.6	2.00
2	89858.98	31624.92		198388.6	46926.2		468439.7	28598.6	
3	86144.03	26026.04		180962.5	38596.8		427787.8	22158.3	
4	81877.8	20745.21		162778.6	30740.6		385234.4	16364.7	
5	77194.22	16093.83		144343.2	23820.7		341895.7	11135.3	
6	70253.57	11909.58		126032.7	17595.9		-	-	
7	61832.69	8132.82		108133.6	11977.2		-	-	

Elements	Region (7) (L_s = 3m) k_i KN/mm	m_i Kg	D %	Region (8) (L_s = 3m) k_i KN/mm	m_i Kg	D %	Region (9) (L_s = 3m) k_i KN/mm	m_i Kg	D %
Pile cap	-	57498.72	-	-	57498.72	-	-	57498.72	-
1	8354382	43643.4	3.00	328242.3	34721.7	2.00	4574839	33745.8	3.00
2	8264865	34707		303934.7	27653.7		4596255	27172.5	
3	7964271	26601.5		137803.6	21428		5299374	21123.7	
4	7498635	19219.4		124090.3	15827.5		4541985	15534.4	
5	6909680	10198.2		110135.8	10772.5		4472552	7862.2	

Table 2: Model properties for the soil-foundation-structure system in the different 9 regions

6 ANALYSIS OF RESULTS

On subjecting the loaded soil-foundation system with an earthquake loading such as the Aqaba Earthquake (Egyptian Red Sea Coast, 1995), see Figure 14, the different soil profiles effect on the system is studied. The earthquake records are scaled to a maximum ground acceleration of 0.125*g* as per the second seismic zone code assumptions [4], see Figure 1. The nine soil profiles regions as identified by the Egyptian Authority of Educational Buildings [14] were considered on modeling the dynamic model and obtaining the parameters in Table 2. The Power Spectral Density (PSD) of the dynamic response of the assumed pile cap, as shown in Figure 11, when considering each of the nine regions, are obtained and shown in Figure 13. The curves in Figure 13 clearly indicate variation in the response for the different profiles. For clayey soil profiles even with being on top of sandy layers that the piles penetrated, yet, the resulting PSD curves show that the vibration transferred to the structure from the loaded soil-foundation system in case of regions 2,4,5,6,8 will excite the lower mode shapes of the overlaying bridge structural system in the frequency domain 0 to 10 Hz. Meanwhile, the vibration transmitted from the loaded soil-foundation system in zones 1,3,7,9 will excite the higher modes indicating lesser risks of excessive excitations of the bridge structure.

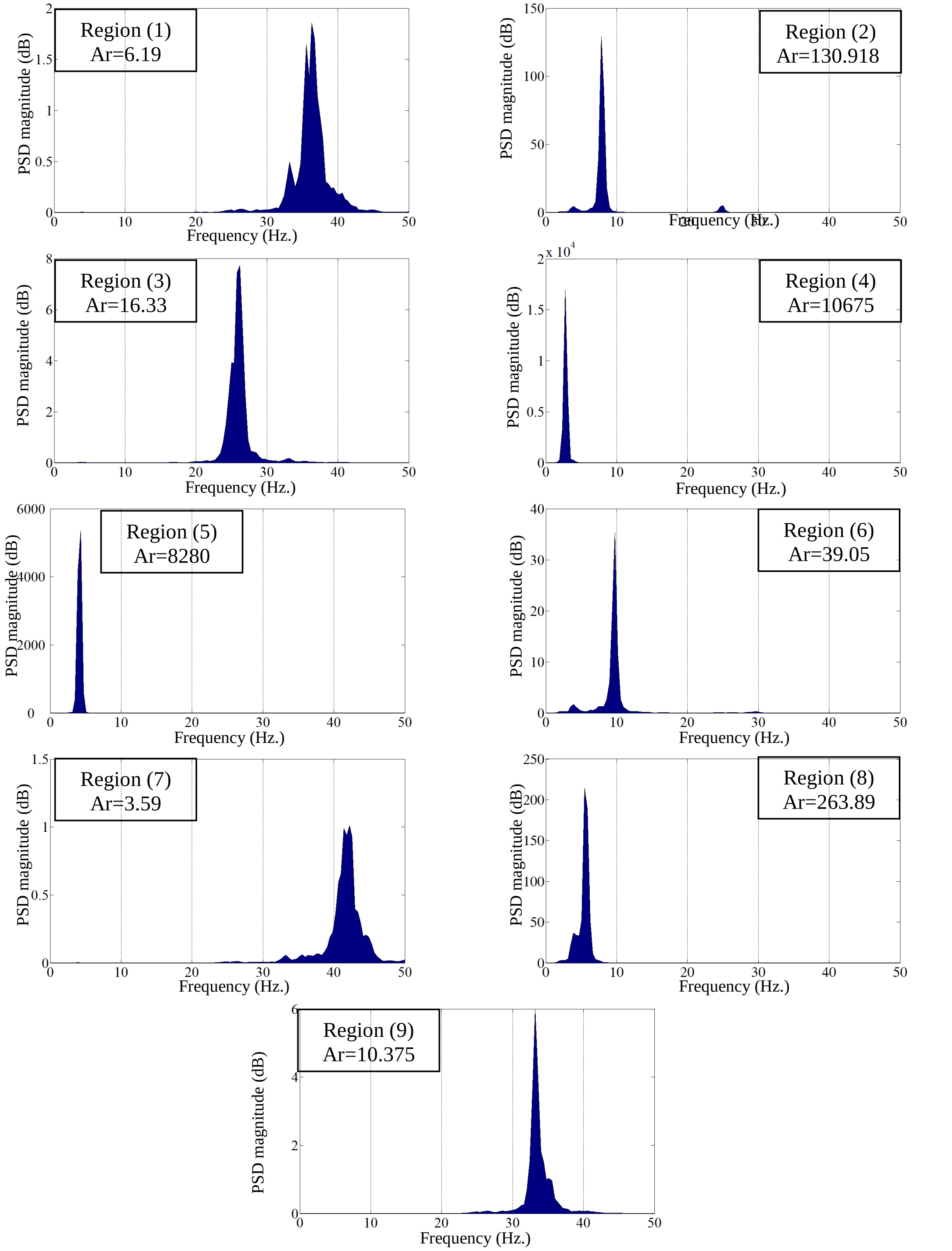

Figure 13: PSD for the loaded soil-foundation system for regions (1 to 9) in the Alexandria governorate

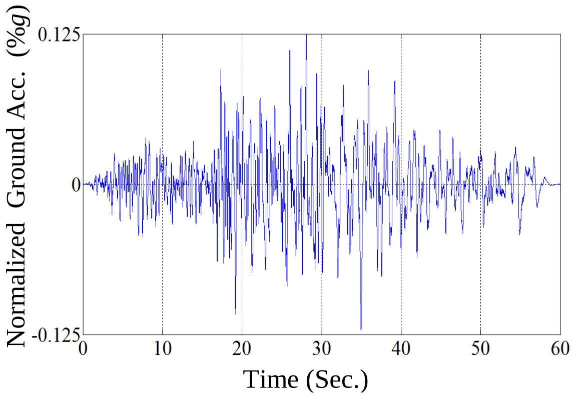

Figure 14: Normalized Aqaba earthquake ground acceleration time history (North-South direction)

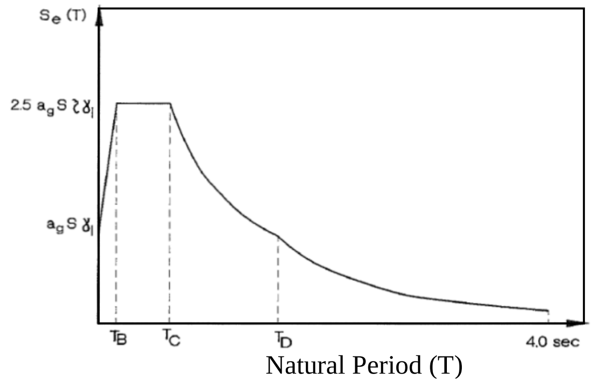

Figure 15: Design Response Spectra (ECOP 201 [4]) for the Egyptian Mediterranean shores

	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)	Reg. (7)	Reg. (8)	Reg. (9)
Fund. Freq.	36.613	8.021	25.929	2.754	4.171	9.662	42.341	5.638	33.607
Energy factor (*E*)	6.194	130.919	16.327	10675	8280.6	39.052	3.591	263.891	10.375

Table 3: Model properties for the soil-foundation-structure system in the different 9 regions

Furthermore, looking at Table 3, one can recognize that the energy output in the vibrations of the loaded soil-foundation system at the pile cap level, in terms of the areas under curves in Figure 13, indicates that the amount of energy released in case of regions 4 and 5 is much larger than the cases of zones 1,3,7,9. This is associated with fundamental frequencies as low as 2.754 Hz and 4.171 Hz for zones 4 and 5 respectively. The latter results in Table 3 should reflect the excessive vibrations for the bridge structures lying in regions 2,6,8, and especially 4 and 5. This is the case in contrast to finding that the national codes for loads, in its evaluation of the level of design forces for the different soil types soil types, assigns only an excess of 35% for the softest soils than the stiffest ones [4]. This is reflected in the design response spectra curve [4] as shown in Figure 15, where the maximum response spectra level is

$$S_e = 2.5 a_g \gamma_I S \eta \qquad (6)$$

where a_g is the ground acceleration, γ_I is the structure importance factor, η is the damping factor, and S is the soil factor that ranges between 1 to 1.35 for worst soil type cases in areas as Alexandria Governorate [4]. It is therefore a must to find an alternative indicator that grasps results from similar modeling as shown in this paper and the potential of having earthquakes in the designed bridge area. A seismic hazard potential impact factor (*SHIF)* can be thus evaluated from multiplying both the energy released from the pile cap vibration in the dynamic model, normalized to the energy released from the earthquake in the same frequency domain, and the probability of having an earthquake during the design estimated life time of the bridge structure or the transportation network such that

$$SHIF = E_n \times P(X_{eq} = 1) \qquad (18)$$

The latter earthquake occurrence probability can be evaluated from Elmasry (2008), and Elmasry and Elkordy (2010) [23,24]. The probability of earthquake occurrence within a 20 years lifetime estimate of a transportation network is assumed 18.8% yielding Table 4.

	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)	Reg. (6)	Reg. (7)	Reg. (8)	Reg. (9)
SHIF	0.156	3.299	0.411	268.952	208.6269	0.9839	0.091	6.649	0.261

Table 4: *SHIF* values for the different soil profile regions in Alexandria governorate

7 CONCLUSIONS

- The introduced research herein generally studies the dynamic response under earthquakes of a loaded bridge pile cap system together with the surrounding soil profiles. A dynamic soil-structure interaction model is used and identified.
- A hazard potential impact factor (*SHIF*) is defined and evaluated for different Soil profile regions assumed to be existing within the same defined seismic zone in the national design codes.
- The hazard potential impact factor (*SHIF*) is assumed critical when exceeding a unit value since it is dependent on the output energy amplification and the probability of earthquake occurrence.
- The paper proposes using the map, as shown in Figure 4, to better reflect the distribution of hazard expectations among different soil profile regions, the case study was Alexandria Governorate, Egypt.
- The resulting map should categorize the hazard potential as per the geophysical data obtained from site investigations.
- Actual in-situ investigations were used to derive the soil properties then the results were integrated into a dynamic model for the soil-structure interaction.
- Paper output results can definitely be used to trace the best locations for infrastructures as bridges, lying within national transportation networks, as well as better estimating the resulting hazard so as to raise the level of design forces when this is needed.

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