

# SITE EFFECTS ON SEISMICITY IN KUWAIT

# A.W. SADEK<sup>1</sup>, A. AL-SHENNAWI<sup>2</sup> and H. KARAM<sup>3</sup>

## SUMMARY

The present paper is primarily concerned with identifying the areas in Kuwait in which soil formations are prone to amplifying ground motions, as well as evaluation of amplification of peak ground accelerations due to soil using computer programs for earthquake site response analysis. Based on the soil formation summary in Kuwait, a qualitative approach was employed to determine locations in Kuwait that are prone to ground motion amplification due to their soil formations, and a tentative map showing these areas was prepared. Acceleration amplification factors were obtained as the ratio of spectral accelerations at the top to those at the bottom of the soil formation. Amplification factors are presented for firm and weak sites. It was found that while for the firm sites, amplification factors reach only maximum values of 5, amplification factors in the weak sites may very well reach 15. This finding clearly confirms the effect of soil formation on amplification of ground motion.

# INTRODUCTION

Soil formations at one site may have a great influence on ground motion characteristics. Specifically, peak ground accelerations (PGA) values as affected by the site soil formations and their amplification, or deamplification, need to be determined. As is evidenced by observations of earthquake-induced damage, buildings on rock or compact soils might be subjected to lower lateral forces as compared to neighboring structures on deep soil strata. Apart from rigorous analytical studies, it is common to account for the soil amplification of ground motions either by specifying site-dependent response spectra or by specifying amplification coefficients for different soil formations.

The main objectives of the present paper are: (i) to identify the areas in Kuwait in which soil formations are prone to amplifying ground motions and (ii)to analytically evaluate amplification of PGAs due to soil using computer programs for earthquake site response analysis.

## SOIL FORMATIONS IN KUWAIT

The subsurface soils in Kuwait are essentially calcareous, medium dense to dense, primarily granular with discontinuous horizons of cemented silty sands. The interbedding is somewhat random, and it is difficult to separate discrete strata. The cemented zones of sand and silty sands are cemented with carbonates, sulfates, and locally, chlorides resulting from evaporation of shallow, saline groundwater.

<sup>1</sup>Senior Researcher, Kuwait Institute for Scientific Research, Kuwait. Email: <u>asadeq@kisr.edu.kw</u> <sup>2</sup>Geotechnical Engineer, Dar Al-Handasah, Egypt.

<sup>&</sup>lt;sup>3</sup>Research Associate, Kuwait Institute for Scientific Research, Kuwait.

These soils, known locally as *gatch* deposits, are generally characterized by low permeability that may result in the formation of hardpans that arrest perched groundwater.

Soil within Kuwait City is generally composed of loose surface sandy soil varying in depth between 1.0 and 4.0 m on average, underlain by a medium dense to very dense sand or silty sand layer.

The groundwater table under Kuwait City is shallow and ranges in depth from about 1.0 m near the coast to about 30 m further inland. The water table generally parallels the surface topography, which gently slopes from inland towards the coast [2]. The northern coastal area of Kuwait near Subiya is covered with a soft salty silty clay surface layer (to 1.0-m depths) known as sabkha. Such a layer also exists in the southern coastal area near Khiran.

A layer of soft to very soft silty clay or clayey silt is encountered in most of the coastal area in Kuwait from Subiya in the north through to Sulaibakhat Bay to Shuwaikh Port. This layer is missing in the coastal area from south of Shuwaikh Port to Mina Abdulla, where it reappears and extends to Kuwait's southern border. The thickness of this weak layer changes from one place to another. It is thicker in the northern area, say 4 to 12 m on average, and the thickness decreases to the south where it is 2 to 6 m thick on average.

The northern islands such as Warba and Bobiyan contain thick compositions of sabkha and soft silty clay or clayey silt, approximately 10 to 20 m thick.

### DEVELOPMENT OF A TENTATIVE MAP FOR SITE EFFECTS

Based on the above soil formation summary a qualitative approach, which is largely based on experience and engineering judgement, was initially employed to determine locations in Kuwait that are prone to ground motion amplification due to their soil formations, and a tentative map showing these areas was prepared (Fig. 1). The soil formations in Kuwait may be divided into two main zones, as follows.

- Zone 1: This zone includes most of Kuwait City, where most of Kuwait's population is concentrated. This zone is characterized by weak surface formations and a shallow groundwater table. This zone also includes other areas in Kuwait, which are mainly desert areas with loose, sandblown surface layers 2.0 to 4.0 m thick underlain by a dense to very dense sandy layer.
- Zone 2: The weak and soft clay formation in the northern coastal area extends from Warba and Bobiyan Islands and Subiya down to Shuwaikh Port, a 50- to 100-m margin running parallel to the coast. The southern coastal area from Mina Abdulla to the southern border has a similar margin. This zone includes all marine and offshore construction areas.

# COMPILATION OF REPRESENTATIVE BORING LOGS

To be able to perform earthquake site response analysis, it is essential to have sufficient detailed boring logs from across the State of Kuwait, representative of soil formations in different locations. For this purpose, an extensive literature review [3,4] was conducted and contact was made with engineering consultants and testing companies.

Compiled boring logs from different projects and building investigations were reviewed to select representative boring samples to be used in estimating the ground acceleration under earthquake action. The main criterion for selecting the boring samples was to cover most Kuwaiti soil formations and layering, such as weak silty or clayey soils, intermediate silty sand soils and dense and very dense sands. Another criterion considered in the selection was to cover most of the Kuwaiti areas subjected to building construction activities.

# PHYSICAL AND DYNAMIC PROPERTIES FOR KUWAITI SOIL TYPES

In general, physical and mechanical soil properties for the different soil types can be estimated either by choosing reasonable representative values from field and laboratory test results, or by estimation using empirical relationships between these properties.



Fig. 1. Map of areas prone to ground motion amplification.

A problem arises upon trying to estimate representative values of dynamic soil properties, such as shear wave velocity and related shear modulus. Such properties require specific field tests, which are not commonly performed in traditional construction work.

Several empirical equations relating the shear wave velocity (v<sub>s</sub>) and the standard penetration test value (N) were developed. One set of relations [5] is as follows:

- Clay:
- Sand:
- Gravel:

Where,  $v_s$  is the shear wave velocity in meters per second, N is the standard penetration resistance, and D is the depth below ground surface in meters. Another set of relations [6] is given in the following:

- •

- Sand and gravel:  $v_s = 1.151 * (62.14N^{0.219}H^{0.230}).$
- $v_s = 1.485 * (62.14 N^{0.219} H^{0.230}).$ Gravel:

where,  $v_s$  is the shear wave velocity in meters per second, N is the standard penetration resistance, and H is the depth of the soil in meters.

Figure 2 presents comparisons between the shear wave velocity values estimated from the three references [5,6,7].

After studying all the available sources for the shear modulus and shear wave velocity properties, it was concluded that Lew and Campbell [7] presents the most reliable values for the shear wave velocity covering the range of the different soil types and taking into consideration both soil resistance (N) and layer depth (Table 1). Therefore, it was decided to use it as a reference for the shear wave velocity values in the earthquake analysis.

Material	Shear Wave Velocity (m/s)	
	Mean	Deviation
Soft natural soil	159	17
Soft clay (depth > 3 m)	93	26
Soft clay (depth = $3 - 30$ m)	89	21
Intermediate natural soil	210	40
Firm natural soil	262	46
Non-engineered fill	156	17
Engineered fill	260	-
10 - 50% gravel (depth = 0)	312	-
10 – 50% gravel (depth = 1.5 – 18 m)	310	56
10 - 50% gravel with cobbles, 50% gravel (depth = 1.5 – 15 m)	480	123

 Table 1. Near Surface Shear Wave Velocities (Source:Lew and Campbell[7])



**Clay (SPT = 1)** 



**Clay (SPT = 10)** 

Fig. 2.a Comparison of shear wave velocity values for clay.









**Coarse Sand (SPT = 50)** 

Fig. 2.b Comparison of shear wave velocity values for coarse sand.



Gravel (SPT = 30)



**Gravel (SPT = 50).** 

Fig. 2.c Comparison of shear wave velocity values for gravel.

#### EARTHQUAKE SITE RESPONSE ANALYSIS

Simplified earthquake site response analysis is based on the equivalent linear approximation of the nonlinear stress-strain relationship. This approach consists of modifying the Kelvin-Voigt model for one-dimensional stress-strain to account for some types of soil nonlinearities. The nonlinear and hysteretic stress-strain behavior of soils is approximated during cyclic loadings.

The equivalent linear shear modulus, G, is taken as the secant shear modulus, Gs, which depends on the shear strain amplitude  $\gamma$ :

$$G_s = \tau_c / \gamma_c \tag{1}$$

where,  $\tau_c$  and  $\gamma_c$  are the shear stress and strain amplitudes, respectively. The equivalent linear damping ratio,  $\xi$ , is the damping ratio that produces the same energy loss in a single cycle as the hysteresis stress-strain loop of the irreversible soil behavior.

### SITE RESPONSE SOFTWARE

After detailed comparison, it was decided to use the EduShake program [8] due to its simplicity and accuracy. EduShake is a computer program for seismic ground response analysis of horizontally layered soil deposits. EduShake features a Windows-based graphical user interface (GUI) that both simplifies and speeds the analysis and interpretation of seismic ground response. EduShake is based on the parent programs SHAKE (i.e., SHAKE85 or SHAKE91). It allows data to be input and checked faster and more easily, performs analyses more quickly, and interprets results much more easily and efficiently than previous versions of SHAKE.

### SOIL AMPLIFICATION FACTORS

A convenient way of presenting the results of the rigorous earthquake site response is the response spectrum curves of acceleration at different sites. Comparison of spectral acceleration values at the top and bottom of a soil formation of a given site gives a quantitative assessment of the amplification of ground motion due to site characteristics. Acceleration response spectra at the top and bottom of five sites with firm soil formations and classified as Zone 1 of the soil amplification map were obtained for three different earthquakes to eliminate the dependence of results on the specifics of the particular earthquake. Similar curves were obtained but for four sites with weak soil formations and classified as Zone 2 in the soil amplification map. To make the comparison more visible, results are presented in the form of acceleration amplification factors obtained as the ratio of spectral accelerations at the top to those at the bottom of the soil formation. Amplification factors for the firm sites amplification factors reach only maximum values of 5, amplification factors in the weak sites may very well reach 15. This finding clearly confirms the effect of soil formation on amplification of ground motion. Average amplification factors in firm and weak sites are shown in Fig. 5.











c. EQ3.

Fig. 3. Soil amplification factor spectra for firm soil.



Period (s)



Period (s)



Fig. 4. Soil amplification factor spectra for weak soil.



Fig. 5. Average soil amplification.

#### CONCLUSIONS

A pilot study was conducted to identify the effects of soil formations on earthquake motions in the State of Kuwait. Two zones were identified based on qualitative assessment of soil formations across the country. Detailed site response analysis was conducted for sample sites in the two zones and amplification factors were obtained. Findings confirmed the qualitative zoning and indicated that weak soil zone is prone to appreciable amplifications in the earthquake motions.

#### REFERENCES

- 1. Sadek, A.; S. Abdul-Salam; A. El-Shinnawy; N. Al-Enezi and H. Karam. 2002. Seismic risk assessment of building constructions in Kuwait: Final Report. Kuwait Institute for Scientific Research, Report No. KISR 6446, Kuwait.
- 2. Ismael, N.F., M.A. Mollah and O. Al-Khalidi. 1986. Geotechnical properties of cemented soils in Kuwait. *Australian Road Research* **16(2):** 94-104.
- Al-Mutairi, N.; E. Attiogbe; W. Eid; R. Awny; M. Al-Shaleh; S. Al-Bahar; E. Al-Mesfer; and A. Abduljaleel. 1995. Waterproofing of building basements in Kuwait (Vol. I). Kuwait Institute for Scientific Research, Report No. KISR 4610, Kuwait.
- 4. Hydrosoil. 1977. Soil investigation for Sulibikhat Bay. Ministry of Public Works, Major Projects Report, Kuwait.

- 5. Sykora, W. 1987. Examination of existing shear wave velocity and shear modulus correlations in soils. Waterways Experiment Station, Vicksburg, Missouri.
- 6. Ohat, Y., and N. Goto. 1979. Empirical shear wave velocity equations in terms of characteristic soil indexes. *Earthquake Engineering and Structural Dynamics* 6: 167-187.
- 7. Lew, M., and K. Campbell. 1985. Measurements of shear wave velocity. Relationships between shear wave velocity and depth of overburden, pp. 63–76.
- 8. EduPro Civil Systems. 1999. ProShake: Ground response analysis program. EduPro Civil Systems, Inc., Redmond, Washington.