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SEISMIC MICROZONZTION OF CENTRAL KHARTOUM, SUDAN

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ABSTRACT

A preliminary seismic microzonation of Central Khartoum, Sudan is proposed. Khartoum, the capital of Sudan, is located at the confluence of White and Blue Niles. The city is heavily populated. The Central Khartoum with its high rise buildings is the center of governmental and business activities and is located on strip adjacent to the Blue Nile. Geological and geotechnical data indicated that the subsoil conditions at Central Khartoum are characterized by alluvial deposits underlain by Nubian Sandstone below a depth of 20 m. The alluvial deposits locally known as Gezira formations , consist of clays grading into silt and sand with depth. Macro seismic zonation of Sudan and its vicinities, developed by the authors, gave the ground acceleration at the bed rock surface. The effect of alluvial deposits at Central Khartoum on propagation of seismic motion parameters to the ground surface is investigated in this study. Correlations are proposed for pertinent cyclic soil properties such as shear modulus, damping, and shear wave velocity. The classical shear beam model developed by Idriss and Seed is used to study the effect of local soil conditions on ground motion parameters. In absence of strong motion records, artificial time histories of ground motion parameters are used. Plots showing the time histories of ground motion parameters at the ground surface are obtained. The results indicated amplification of ground acceleration of up to 1.15. Because of the presence of saturated loose to medium dense sand at some locations within Central Khartoum, the risk of earthquake-induced liquefaction is evaluated. The susceplity of subsoils in Central Khartoum to liguefaction is evaluated probabilistically by modifying the classical method developed by Seed and Idriss. The risk of earthquake-induced liquefaction is computed by combining the seismic hazard and the conditional probability of liquefaction. The study showed that the risk of liquefaction is low.

INTRODUCTION

Sudan is generally considered a country of low seismic activity. However; recent seismic activities in different regions within the Sudan warrant seismic hazard assessment of the Sudan. The country and its vicinity experienced one of the largest earthquake in recent history: The May 20,1999, 7.4 earthquake and its after shocks that hit Southern Sudan is the one of the largest in continental Africa in the instrumental era of earthquake recording. In additional to the Southern Sudan, major portions in Central Sudan also experienced earthquake recently (e.g. Earthquakes stroke Kordofan State in August 1, 1993 with a magnitude of 5.5 and in November 15, 1993 with a magnitude of 4.3). Central Khartoum is affected by all Seismic sources in Sudan and its vicinity though some sources , e.g. Kordofan State sources, are more sensible in Central Khartoum (Mohamedzein et al 1995). Alluvial deposits known locally as Gezira Formation underlie Central Khartoum. This formation includes a hard crust of fine grained soils underlain by saturated loose to medium dense sand. Given the recent earthquake activities and the vulnerable soil condition, an amplification of earthquake accelaration or soil liquefaction may occur in Central Khartoum. This fact is not appreciated by current design practice in Sudan. This is true regardless of the large amounts of investment in buildings and structures in Sudan as a whole and specially in Central Khartoum. The objective of this study is to quantify the local soil effects on the seismic risk of Central Khartoum.

STUDY AREA AND SUBSOIL CONDITIONS

Khartoum, the capital of Sudan, is located at the junction of the White and Blue Niles (the main tributaries of the River Nile). The Central Khartoum area lies on a strip adjacent and parallel to the Blue Nile (see Fig. 1). Subsurface data was collected from boring logs obtained from local consulting firms and research institutions. The data bank consisted of more than 100 borings. Based on the subsoil conditions the study area was divided into 3 zones as shown in Fig. 1. The borings revealed a typical subsoil profile that consists of Gezira Formation extending to the Nubian Sandstone (see Fig. 2). The Gezira Formation consists of clay at the surface grading into silt and sand with depth. The thickness of the fine grained soils (i.e. clay and silt) varies up to 8 m. Various types of sand extend below the fine grained soils down to the Nubian Sandstone found below a depth of about 20.0m. Free subsurface water level ranges from 4 m near the Niles to about 10 m away from the Niles.

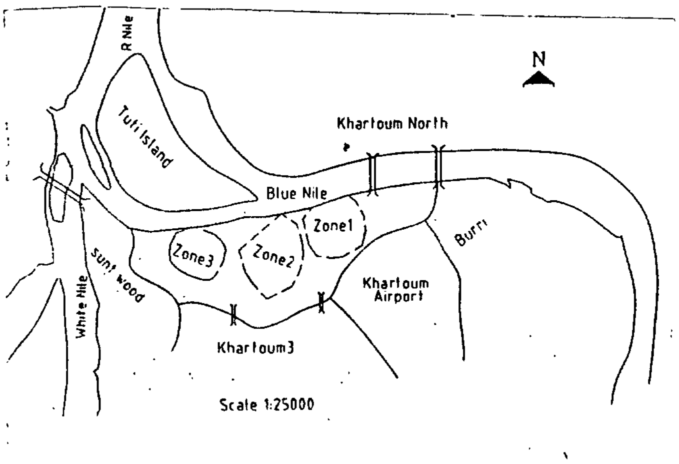

Fig. 1. Study area.

Depth (m)	Description	S.P.T N Values	Shear Modulus G (kN/m^2)
0.0	Sandy Clay.		18500
2.0	Brown silty sandy Clay.		6660
4.0	Greyish Clay .		6660
6.0	Clayey silty Sand.	13 12	69825
8.0 12.0	Loose to medium dense clayey silty Sand.	9 10 14 20	72450
16.0	Medium grained Sand.	12 7 12 14 2	72450
23.0	Medium dense Medium grained Sand.	20	108610
25.0	Dense coarse grained Sand. Bedrock	30	159000

Fig 2a Simplified soil profile for Zone 1.

Depth (m)	Description	S.P.T N Values	Shear Modulus G (kN/m^2)
0.0	Stiff brown silty Clay.		6480
2.0	Sandy Silt.		6480
5.0	Clayey Silt .	28	150000
9.0 15.0	Medium dense Fine to medium grained Sand.	19 25 14 17	102475
21.0		23 15 19 15 19 14 18 15	91600
25.0	Dense coarse grained Sand. Bedrock.	42	218000

Fig. 2b. Simplified soil profile for Zone 2.

Depth (m)	Description	S.P.T N Values	Shear Modulus G (kN/m^2)
0.0	Sandy silty Clay.		6480
3.0	Sandy clayey Silt.	29 30	154775
7.0	Medium dense poorly graded Sand..	22	118800
9.0 15.0	Loose to medium dense poorly graded Sand.	19 20 17 14 13	88500
18.0	Loose to medium dense poorly graded Sand.	14 15 13 11 13 20	79750
23.0	Medium dense Sand.	20	108610
25.0	Dense Sand Bedrock.	30	159000

Fig. 2c Simplified soil profile for Zone 3.

TECTONIC FEATURES OF SUDAN

Tectonic features of Sudan are associated with four major rift systems (Abdalla et al, 1997): (1) the Red Sea rifts, in the North-East of Sudan, (2) the East African rift in the East, (3) the Central African rift (4) and the Southern Sudan rift. Branches of these rifts within the Sudan include White Nile, Blue Nile, the Nile, Atbara River and Abu Gabra rifts.

SEISMIC HISTORY OF THE AREA

Seismic studies (e. g. Ambraseys and Adams, 1986, Abdalla et al. 1997) have shown that Sudan is relatively stable with occasional earthquakes of low to moderate magnitude that can give rise to damaging intensities. They also noted that the Southern States of Sudan are frequently subjected to moderate to high intensities of earthquakes. Earthquake felt in Central Khartoum were originated from different source zones : e.g. from rifts and faults in North Kordofan State (about 260 km West of Khartoum), rifts and faults in Southern States (about 800 km South of Khartoum), faults in Red Sea State (about 500 km North East of Khartoum), and induced earthquakes in Lake Nassir (Aswan Dam) in Southern Egypt (about 900 km North of Khartoum). Among all these sources the Hamrat Elwiz source (Latitude 14.9 ° and Longitude 30.3 °) in North Kordofan is the one that affects Khartoum area the most. The source has been active recently : e.g. an earthquake of magnitude of about 5.5 was felt in Khartoum on the morning of August 1, 1993. The duration of shaking lasted about 30 seconds. Four after shocks were felt, minor injuries were reported, however no building damage was observed. The same epicenter produced another shock of magnitude 3.0 that was also felt in Khartoum on November 15, 1993.

SEISMIC MICROZONATION OF CENTRAL KHARTOUM

The effect of local soil conditions on seismic response of a site can be based on either stable or unstable soil during earthquake (Faccioli, 1977). In stable soils the seismic waves can propagate through the soil without appreciable loss of shear strength. In the unstable soils significant loss of shear strength occurs and produces failure such as in the case of liquefaction, large settlement and landslide. The seismic microzonation for Central Khartoum is based on both stable and unstable soil conditions. In the first case of stable soil the effect of local soil conditions on ground motion parameters is studied. In the case of unstable soil the liquefaction potential is assessed.

Effect of Local Soils on Ground Motion Parameters

The authors performed a seismic hazard analysis for Sudan and its vicinity (Abdalla et al. 1997). The results were presented in figures showing the expected peak ground acceleration (PGA) for a certain time of exposure and a prescribed risk level. The PGA values are of course at the surface of bedrock. The effect of local soil conditions on PGA in Central Khartoum is considered in this study. The following steps are followed. First the acceleration time history at the bedrock is simulated. Then the fundamental period of soil layers is estimated. Finally the time history of earthquake parameters at the ground surface is obtained. A computer program was written to perform these tasks.

Acceleration Time History at the Bedrock. Since Sudan is considered a low seismic region, no seismic recording stations were established and consequently no records of time history of ground motion parameters are available. In this study artificial time histories such as those given by Elhassan (1994) are used. The simulated acceleration time history is generated from a selected power spectrum function.. The model requires a specified peak ground acceleration (PGA) which can be obtained from the seismic hazard analysis of Sudan performed by the authors (Abdalla et al. 1997). Based on that study a PGA of 0.045g for a time of exposure of 50 years is used in simulation of acceleration time history. Figure 3 shows a simulated acceleration time history for Central Khartoum at the surface of the bedrock (about 20 to 25 m below the ground surface).

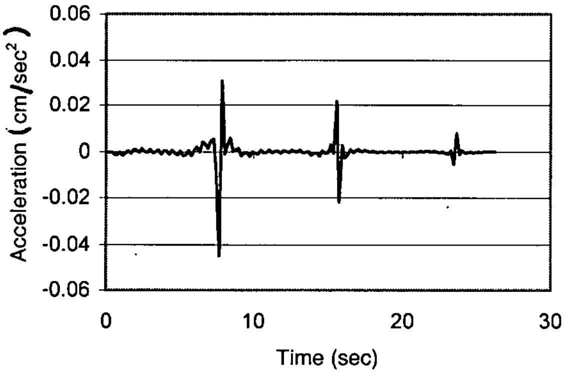

Fig. 3. Artificial acceleration time history at bedrock surface.

Frequency and Period of Soil Layers. The frequency or period of soil layers is one of the most important parameters in the determination of site response during earthquake (Zeng, 1996). Determination of soil frequency requires evaluation of seismic soil response, which is usually based on simple empirical and sophisticated analytical methods (Hodder and Graham, 1993; Faccioli, 1977). The simple empirical approach uses data collected from literature, soil and geological description and correlations with observed damage. The most sophisticated approach uses analytical and numerical tools combined with measured soil properties. The program SHAKE is based on this approach (Idriss and Sun, 1992).

In this study the classical shear beam model is used (Idriss and Seed, 1968). The parameters for the model such as shear modulus were obtained by empirical correlation (Table 1). The parameters used are shown in Fig. 2 for the three zones of Central Khartoum. For each zone the soil profile is divided into a suitable number of soil layers. The fundamental frequency of free vibration of soil layers is obtained by the solution of the eignvalue problem using Jacobi iteration method (Bathe, 1982). The solution also gives the mode shapes of vibration.

The frequencies corresponding to the lowest mode of vibration for the 3 zones are 1.9, 2.18 and 2.32 Hz, respectively. This indicates that the frequency of the soils in the three zones differ slightly. Therefore for practical purposes the Central Khartoum can be taken as 2.12 Hz which is the average value for the three zones. This value is in reasonable agreement to those proposed by Idriss and Seed (1968) and Zeng(1996) for a uniform soil layer.

Table 1. Emprical correleations for soil properties.

Parameter	Reference
$G\ (t/m^2) = a\ N^b$	Faccioli
For sand a=650, b=0.94	(1977).
For clay a=1400, b=0.71	Dowrick
For all soils a=1218, b=0.78	(1987).
$G= V_s^2$	Dowrick
V_s= 190 (m/s) for medium sand with fines.	(1987).
V_s = 60 (m/s) for loose saturated sand.	
V_s = 60 (m/s) for silt.	
V_s = 60 (m/s) for silty clay.	
V_s = 190 (m/s) for saturated clay.	
V_s = 100 (m/s) for sandy clay.	

Acceleration Time History in the Soil. Obtaining the time history of acceleration in the soil completes the dynamic response analysis. The normal coordinate transformation and mode-superposition of dynamic analysis (Clough and Penzein 1975) are used to evaluate the dynamic response of soil layers to bedrock excitation. The acceleration time history at bedrock and the results of the eignvalue problem (e.g. mode shapes and frequencies) are the input to the general response given by the Duhamel integral. The normal coordinate $Y_n(t)$ for the nth mode is given by:

$$Y_n(t)=(1/\omega_d)*\int_0^t ug(\tau)*e^{-\zeta\omega(t-\tau)}*\sin\omega_d(t-\tau)\,d\tau \quad (1)$$

ω = circular frequency .
ω_d = damped frequency, ζ = damping ratio
ug = bedrock acceleration.

The acceleration u (t) at any soil layer can be given by

$$u(t) = \sum_{n=1}^{N} \Phi_i^n * Y_n(n) \quad (2)$$

Where Φ_i^n is the mode shape at the ith level during the nth mode of vibration.

The resulting PGA at the ground surface is shown in Fig. 4 for Zone 1 (figures similar in trend are obtained for other zones). The effect of local soil conditions is clearly shown in the figure. The greatest amplification (about 1.15) is shown in Zone 1 with Zone 3 showing the least amplification (about 0.94). Zone 2 shows an amplification of about 0.98.

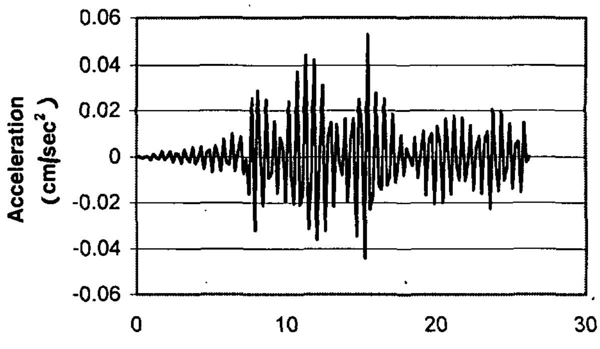

Fig. 4. Acceleration time history at the ground surface.

Seismic Risk Analysis of Liquefaction

Seismic risk analysis (SRA) involves two steps (Yegain et al. 1988): seismic hazard analysis (SHA) and seismic performance analysis (SPA). SHA deals with the probabilistic analysis of expected earthquake. SPA gives the probabilistic analysis of the resistance (in this case resistance to liquefaction).

Seismic Hazard Analysis(SHA). The steps of the seismic hazard assessment are well known (McGuire 1993). The steps out lined by McGuire (1993) will be used in this study .The earthquake history for Sudan given by Ambraseys and Adams (1986) was used to evaluate the seismic hazard for Central Khartoum. A recurrence model was developed to fit the available data. The following equation was obtained:

$$\lambda(t) = 2.23\ e^{-0.78\,M} \quad (3)$$

where λ = rate of earthquake occurrence per year,
M= Ritcher earthquake magnitude.

Simple calculations have shown that Khartoum area is affected most by the sources in North Kordofan State. Other sources contribute insignificant amounts of acceleration to Khartoum and can be ignored. For simplification the sources within North Kordofan are assumed to be represented by Hamrat Elwiz source (a distance of 267 km West of Khartoum). The attenuation relation can be based on that proposed by Schenk (1984) for more than 3500 records from all over the World. For Central Khartoum the relation can be :

$$\text{Log } a = 0.336\, M \quad 0.7975 \qquad (4)$$

Where a = is the ground acceleration in (cm/sec^2).

Using Equations 3 and 4, the relation between the annual rate of earthquake and the ground acceleration can be obtained. The results are plotted in Fig. 5 for discrete values of acceleration.

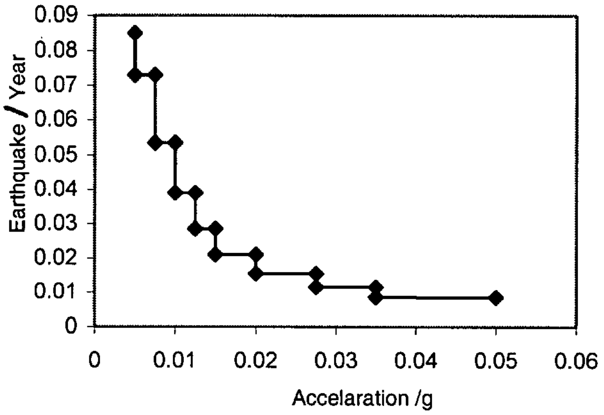

Fig. 5. Relationship between acceleration and annual rate of earthquake.

Seismic Performance Analysis(SPA). The response of local soils to shaking can be based on the classical liquefaction approach pioneered by Seed (e.g. Seed et al. 1983). The approach can be summarized as follows (Elton and Had Hamou, 1990). The resistance to liquefaction is given in terms of the critical cyclic stress ratio (CCSR), while the earthquake loading is expressed by the cyclic stress ratio (CSR). The latter is given by:

$$\text{CRS} = \tau / \sigma'_o = 0.65(\sigma_o / \sigma'_o)(a/g) r_d . \qquad (5)$$

Where τ = earthquake induced cyclic shear stress, σ_o = total overburden stress, σ'_o =effective overburden stress, a = the maximum peak ground acceleration given by Equation 4, and $r_d = 1 - 0.015\, d$, where d is the depth in meters.

CCSR can be evaluated from laboratory or field tests. The field tests are found to be the most reliable (Peck, 1979). Seed and DeAlba (1986), developed a World wide chart for evaluation of CCSR. The chart relates CCSR to Standard Penetration Test (SPT) N-values and can be expressed as:

$$\text{CCSR} = h\,(N,M,f) \qquad (6)$$

Where N = SPT N-value and f = the percentage of fines in the sand. Liquefaction occurs if CSR exceeds CCSR.

For the condition of equilibrium CCSR is equal to CSR, yielding:

$$a_c = (g / 0.65\, r_d)\,(\sigma'_o / \sigma_o)\ h\,(N,M,f) \qquad (7)$$

where a_c = the critical acceleration required to cause liquefaction (liquefaction can occur whenever a, as given by Equation 4, exceeds a_c). To evaluate a_c the function h (N,M,f) must be determined. For a given magnitude M and assuming the percentage of fines equal to 15%, h can be obtained from regression analysis using the function:

$$h\,(N,M,f) = \alpha\, e^{\beta N} \qquad (8)$$

The value of the constants were evaluated for different earthquake magnitude and were found to be: α = 0.114 to 0.989; β =0.69. Equation 8 depends on N. To account for uncertainties associated with N, Harr (1977) proposed a symmetrical beta distribution given by :

$$f\,(\text{N}) = \frac{(\text{N} - 0.6\text{N}_m)^{0.5} * (1.4\,\text{N}_m - \text{N})^{0.5}}{(0.25421\, \text{N}^2_m)} \qquad (9)$$

where N_m = the mean value of N.

The probability density function of critical acceleration $f_{ac}(a_c)$ can be evaluated from Equations 6 to 9 after the transformation of probability distribution of N as (Elton and Hadj-Hamou, 1990):

$$f_{ac}(a_c) = f_N(N) \frac{dN}{da_c} \qquad (10)$$

The above expression gives $f_{ac}(a_c)$ for a given zone and magnitude. A typical equation for Zone 1 and M= 6.0 is :

$$f_{ac}(a_c) = (1.01/a_c)\sqrt{c_1 c_2} \qquad (11)$$

Where $c_1 = 14.8 \text{ Ln } (a_c / 1.36)$, $c_2 = 10.56 \quad 14.58 \text{ Ln } (a_c / 1.36)$. The conditional probability of liquefaction given certain magnitude P[L|M] can be evaluated for a given zone from the probability density function of a_c as:

$$\text{P[L|M]} = f_{ac}(a_c) \qquad (12)$$

For all magnitudes Equation 12 can be integrated to give the cumulative distribution $F(a_c)$ as :

$$\sum_{\text{For all M}} \text{P[L|M]} = F_{ac}(a_c) \qquad (13)$$

A typical curve for cumulative conditional probability of liquefaction for Zone 1 is shown in Fig 6.

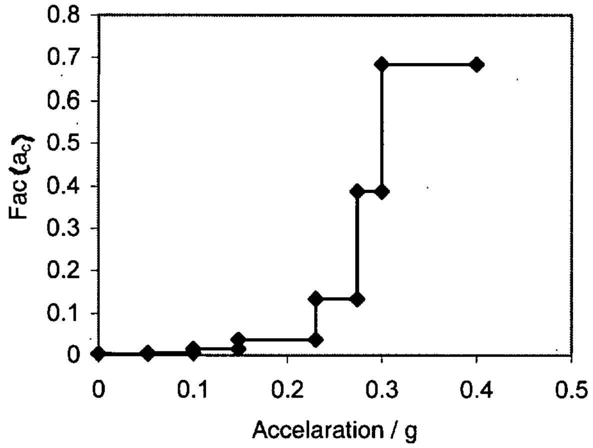

Fig. 6. Conditional probability of liquefaction and acceleration (Zone 1).

Seismic Risk Analysis of Liquefaction. The seismic risk analysis combines the seismic hazard analysis and the performance analysis to obtain the probability of liquefaction. The matrix approach presented by Whitman (1984) and Yegain et al. (1988) is used to obtain seismic risk of liquefaction. Straightforward multiplication and addition that combines the occurrence rate of earthquake (Fig. 5) with the conditional probability of liquefaction (Fig. 6) was used to obtain the total probability of liquefaction P[L]. The method can be summarized as follows: The number of earthquake causing liquefaction per year (NL) can be given from :

$$N_L = \sum P[L|M] * P(M) \qquad (14)$$

In which P(M) the probability that an earthquake of magnitude M, actually occurs. It should be noted that P(M) is actually the number of earthquake per year that will cause a certain acceleration *a* as shown in Fig. 5. The rate of liquefaction can be considered to follow a

n

earthquake that can cause liquefaction during time interval (0,t) equals :

$$P(n) = \frac{(N_L\, t)^n\, e^{-N_L t}}{n!} \qquad (15)$$

The probability of zero earthquake that will cause liquefaction (i.e. if n=0) is :

$$P(0) = e^{-N_L t} \qquad (16)$$

The probability of at least one event that will cause liquefaction in t years is the complementary function of Equation 16, i.e.

$$P(n \geq 1) = P[L] = 1 - e^{-N_L t} \qquad (17)$$

The values of N_L for the three zones were computed using Equation 14 and Figures 5 and 6 and the results are shown in Table 2. Using Equation 17 and Table 2, the risk of liquefaction for a time t for all the 3 zones is listed in Table 3.

Table 2. Values of N_L for the three zones

	Zone		
	1	2	3
N_L	0.00063	0.0002	0.00045

As expected the risk of liquefaction increases as the exposure time increases. The result indicated that zone 1 is the most susceptible to liquefaction, and zone 2 shows the least like hood of liquefaction, with zone 3 exhibiting intermediate response. This is attributed to the fact that the subsoil conditions in zone 1 consist of loose to medium dense sand, with sand in zone 2 is generally medium dense.

Table 3 : Probability of liquefaction Potential.

Time (year)	Probability of liquefaction Potential (%)		
	Zone 1	Zone 2	Zone 3
10	0.63	0.2	0.45
20	1.25	0.4	0.896
30	1.87	0.598	1.34
40	2.49	0.98	1.80
50	3.10	0.995	2.23
100	6.11	1.98	4.4
250	14.56	4.88	10.64
500	27.02	9.52	20.15
1000	46.74	18.13	36.24

CONCLUSIONS

The following conclusions can be inferred from the present study:

1. Rifts and faults in North Kordofan State have been very active recently. They are capable of producing damaging earthquake in the presumably low risk area of Khartoum.
2. The average fundmental frequency of soil layers in Central Khartoum is 2.12.
3. The alluvial deposits in Central Khartoum have the capability to increase the earthquake motion parameters by a factor of up to 1.15.
4. Geology and subsoil conditions of Central Khartoum show that potentially liquefiable saturated layers are available at different depths.
5. The probability of liquefaction for the three zones of Central Khartoum is quite different depending on the subsoil conditions. They show low liquefaction risk

REFERENCES

Abdalla, Jamal A., Mohamedzein Yahia E-A. and Abdelwahab, Abubakr [1997]. Seismic hazard assessment and zoning of Sudan. @Sudan Engineering Society Journal, Vol. 44, No .35, pp. 34-51.

Ambraseys, N. N. and Adams, R. D. [1986]. Seismicity of the Sudan. @Bull. Of the Seismological Society of America, Vol. 76, pp. 483-493.

Bathe, K. J. [1982]. Finite Element Procedures in Engineering Analysis. @ Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Clough, R. W. and Penzein , J. [1975]. Dynamics of Structures. @ McGraw-Hill Book Company.

Dowrick, D. J. [1987]. Earthquake Resistance Design for Engineers and Architects. @ John Wiley & Sons.

Elhassan, Yassir M. [1994]. Structural response to earthquake ground motion in Sudan. @ MSCE Thesis Presented to the Department of Civil Engineering, University of Khartoum, Khartoum, Sudan.

Elton, D. J. and Hadj-Hamou, T. [1990]. Liquefaction potential map for Charleston, South Carolina. @J. of Geotech. Engineering Division, ASCE, Vol. 116, pp. 244-265.

Faccioli, E. [1977]. Bases for a methodology of seismic microzonation. @ Consultants Report to UNESCO, Mexico City.

Harr, M. E [1977]. Mechanics of Particulate Media: A Probabilistic Approach. @McGraw Hill Book Co, New York.

Hodder, A. P. W. and Graham, M. Z. [1993]. Earthquake microzoning from soil properties. @ J. of Earthquake Spectra, Vol. 9, No. 2, pp. 209-231.

Idriss, I. M. and Sun J. I. [1992]. Users manual for SHAKE91.@ Department of Civil and Environmental Engineering, University of California, Davis.

Idriss, I. M. and Seed, H. B. [1968]. Seismic response of horizontal soil layers. @J. of Soil Mechanics and Foundation Division, ASCE, Vol. 94, No. SM4, pp. 1003-1031.

McGuire, R. [1993]. Computation of Seismic Hazard. @In Global Seismic Hazard Assessment Program for the UN/IDNDR. Domenice Giardini and Peter Bashman (Eds.). Annali di Gefisica, Special Issue: GSHAP Technical Planning Volume of ILP, Vol. XXXVI, No. 3- 4, pp 181-200.

Mohamedzein, Yahia E-A., Abdel Gabbar, M., and Elsharief, Ahmed M. [1995]. Probabilistic evaluation of liquefaction potential of Central Khartoum. @Proceedings of the First International Conference on Earthquake Geotechnical Engineering, Tokyo, Japan.

Peck, R. B. [1979]. Liquefaction potential: Science versus practice. @J. of Geotech. Engineering Div., ASCE, Vol. 105, pp. 393-398.

Shneck, V. [1984]. Relations between ground motion and earthquake magnitude, focal distance and epicentral intensity. @J. of Engineering Geology, Vol. 20, NO. 1.

Seed, H. B. and DeAlba, P. [1986]. Use of SPT and CPT tests for evaluating the liquefaction potential of sands. @Use of Insitu Tests in Geotechnical Engineering, ASCE Geotechnical Special Publication #6, S. P. Clemenece (Editor), pp. 281-301.

Seed, H. B., Idriss, I. M. and. Arrango, I. [1983]. Evaluation of liquefaction potential using field data. @J. of Geotech. Engineering Div., ASCE , Vol. 109, pp. 458 484.

Whitman, R. V. [1984]. Evaluating calculated risk in geotechnical engineering. @J. of Geotech. Engineering Div., ASCE, Vol. 110, pp. 145 188.

Yegain, M. K., Marciano, E. A., and Ghahraman, V. G. H. [1988]. Integrated seismic risk analysis for earth dams. @ Report No. CE 88-15, Dep. Of Civil Engineering Northeastern University, Boston.

Zeng, X. [1996]. A simple procedure to calculate the fundamental frequency of horizontal soil layers. @ Geotechnique, Vol. 46, No. 4, pp. 757-760.