SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

EFFECT OF DEPTH MODELING OF SOIL PROFILE ON AMPLIFICATION COEFFICIENT AND RESPONSE SPECTRA IN CASE OF ALGIERS SITES

Nourredine MEZOUAR[1] and Mohamed HADID[2]

ABSTRACT

The seismic hazard in Algiers is very high due to its vicinity to the active faults and the amplifying characteristics of local geological condition in its huge part. The site effects cannot be quantified without seismic profiles in term of shear wave velocity and the depth of the engineering bedrock.

In real Algerian practice, the specific geotechnical investigation doesn't provide complete information to characterize soil conditions especially the investigated depth which is fixed from static considerations. Algerian design practice (RPA99/2003) uses an oversimplified approach to soil classification close to 1994 UBC classification. Four site types are considered: S1, S2, S3 and S4 using geotechnical data especially average shear wave velocity over the upper few meters of a site profile. Application of this site classification system can misrepresent ground and structural motions.

The purpose of this study is to characterize the depth modelling of soil column between the bedrock and the free surface and investigate its effects on site amplification and response spectra. To do so, site response analyses for 36 sites collected in Algiers region were performed to evaluate earthquake ground motions. The input motions used are artificially generated from the density spectral function of the Keddara station records selected among the CGS stations that recorded during the 21 May Boumerdes earthquake. PS logging is conducted with down-hole method to a maximum depth of 100 meters in several boreholes.

The soil profiles are classified into four models depending mainly on their depth (real drilled depth, 20m, 30m and depth to bedrock). The effect of each model on the response spectra and the acceleration at the surface is studied. Response spectra can be significantly influenced by the soil model considered in case of stiff and rock sites. The effects are negligible in soft site. In term of amplification, the results given by the oversimplified approach used in Algerian design practice are quite different from the ones given by the fourth model i.e. depth of engineering bedrock. The model with 30m depth is the more realistic; it gives results close to the model considering the depth to engineering bedrock.

INTRODUCTION

Seismic site response and soil amplification are affected by the combined effect of the dynamic stiffness and thickness of sub layers. Algerian design practice (RPA99-2003) uses an approach to soil classification close to 1994 UBC classification. A geotechnical investigation should provide

[1] Associate Professor, Centre National de Recherche Appliquée en Génie Parasismique (CGS), Algiers, mezouer_n@yahoo.fr

[2] Professor, Ecole Nationale Supérieure des Travaux Publics (ENSTP), Algiers, hadid_mohamed2003@yahoo.fr

information about the soil types beneath the site and their physical and dynamic characteristics (i.e., density, depth, stiffness, Vs, impedance ratio, etc.) based on detailed in-situ tests, borings and sampling, and laboratory tests on recovered soil and rock samples. In a seismic environment, the geotechnical investigation would also need to evaluate the behaviour of the supporting soils under earthquake excitation and determine or predict the impact and consequences at free surface. Not only is it important to investigate the soil conditions, the general site conditions also merit deep scrutiny.

To assess the engineering geological structure of the study region, existing boring data were collected from 36 sites intended to important industrial projects. More than 180 boreholes with interesting geotechnical data and PS logging are collected for this analysis. A ground model with geotechnical and geophysical parameters and their variation both in vertical and horizontal directions (Depth, S wave velocity and Density) is done. These properties were set for each layer through their average values. This analysis enables us to get typical sections of the Study area. In real Algerian practice, the specific geotechnical investigation doesn't provide complete information to characterize soil conditions. Generally, for economic considerations, the total depth investigated is not sufficient to classify the site.

In this study, we deal with the effects of the profile depth on fundamental frequency of soil column through its amplification function, acceleration and response spectra at free surface using SHAKE program (Schnabel et al. (1972)). The study is based on the average S-wave velocity of four multi-layered soil profiles with different thickness. The Keddara event, recorded during the Boumerdes earthquake 2003 (ML=6.8) in Algiers region is used.

GEOLOGICAL SETTING

The studied region belongs to the tellean chain of Algeria which is a part of the Mediterranean tectonic belt (Durand-Delga (1969)). Two structural zones could be distinguished:
Internal zones form a discontinuous band along the Mediterranean coast. In northern Algeria, it forms the coastal massifs of Chenoua and Bouzareah. These old massif rocks are thought to be Paleozoic.
External zones are composed of thrust sheet units mainly marl-limestone and sandstone. Their age ranges from Mesozoic to Cenozoic eras. These units are distributed in successive layers overlapping towards the south.

In terms of active tectonics the studied region lies within the African and Eurasian tectonic plates boundary. Consequently, many strong earthquakes has been occurred among them the recent earthquakes of El Asnam 1980 (M=7.3) and Boumerdes 2003 (M=6.8).

In term of lithology, the quaternary formations occupy a large surface in the Algiers coastal region. It can be observed as terrace shapes comprising sand, gravels and sandy clay. The quaternary terraces are subdivided into four periods corresponding to the principal quaternary transgressions: the Calabrian, Sicilian, Tyrrhenian and Versilian. In the east of Algiers, the terraces are characterized by milky quartz pebbles in reddish sand, with lenses of pebbles of limestone or beach sandstone. In the west of Algiers, the terraces are characterized, from bottom to top, by limestone pebbles, beach sandstone, and deposits, which are more or less solidified. The quaternary marine terraces are found in higher altitudes, 200 m in the east of Algiers and up to 325 m in the west (Djediat, (2000)). The marine terrace is the result of vertical movements related to the tectonic activity. Early Pleistocene is represented by red clay, while the Holocene is represented by dunes of beach sand.

GEOTECHNICAL SITE CONDITIONS AND SOIL INVESTIGATION

To assess the engineering geological structure of the study region, existing boring data were collected from several geotechnical reports (LNHC (2004), LNHC (2005), (LTPC (2005), (LTPC (2011) and sites intended to important industrial projects in the study area. The number of boreholes on which the engineering geology was assessed totalled 180, with a depth between 20 and 120m.

Based on the boring data and technical papers, the different geological strata found are classified from an engineering geology viewpoint.

For response analysis and amplification study, a ground model with geotechnical and geophysical parameters and their variation both in vertical and horizontal directions (Depth, S wave velocity and Density) is required (Kramer, (1997)). These properties were set for each layer through their average values. The frequency distributions of density for several kinds of soil units are done and the mean values are obtained. The PS logging was conducted with down-hole method to a maximum depth of 100 meters in several boreholes. From P wave velocity and S wave velocity, Poisson's ratio is calculated analytically. In this study, the average Vs and Poisson's ration for each classified unit of soil are calculated. The thickness of soil layers was identified at every drilled boring. The thickness of each one in all the study area is estimated with numerical interpolation techniques using 180 drilling log. This numerical interpolation is revised because of lack of data in some zones, basing on engineering experience of the region (older deposits don't cover younger layers, the surface outcrop is covered by weathered rock not fresh,…). This analysis enables us to get typical sections of the Study area. The different mean values (Density, Vs, and Poisson's ration) are summarized in table 2.

Table 1. Sub surface geology and different mean characteristics

Symbol		**S wave velocity (m/sec)**	**Poisson's ratio**	**Density (g/cm3)**
ap	Beach deposits and dune deposits	280	0.48	1.80
e	Slope deposit	300	0.45	1.80
a3	Alluvial deposit (sand)	240	0.49	1.80
a2	Alluvial deposits (clay)	270	0.44	1.74
q	Old alluvial deposits	300	0.45	1.81
qt	Marine terrace	330	0.45	1.90
p2c	Weathered Astien layers	310	0.45	1.92
p2c-f	Astian layer (marl, fresh)	450	0.43	2.02
p2l	Weathered calcareous sandstone	310	0.45	1.92
p2l-f	Fresh Calcareous sandstone	710	0.38	2.10
p1	Plaisancian layer (blue marl, weathered)	310	0.44	2.00
p1-f	Plaisancian layer (blue marl, fresh)	700	0.27	2.09
mi	Metamorphic rocks (schist, weathered)	490	0.33	1.89
mi-f	Metamorphic rocks (schist, fresh)	1100	0.25	2.55

EFFECTS OF SOIL MODEL ON SEISMIC SITE RESPONSE

The purpose of this study is to characterize the seismic input for the structural design which is depending on the model of soil column between the bedrock and the foundation soil (depth of engineering bedrock).

Algerian design practice (RPA99-2003) uses an oversimplified approach to soil classification close to 1994 UBC classification. In this code, four site types are considered, S1, S2, S3 and S4. They are established from properly substantiated geotechnical data especially average shear wave velocity over the upper 20 meters of a site profile (Table2).

In real Algerian practice, the specific geotechnical investigation doesn't provide complete information to characterize soil conditions. Generally, for economic considerations, the total depth investigated is not sufficient. In this study, we deal with the effects of the profile depth on fundamental frequency of soil column through its amplification function and acceleration at free surface using SHAKE program (Schnabel et al, (1972)). The equivalent nonlinear behaviour is considered (Mancuso et al (1997), Pitilakis et al (1992)). The work is based on the average S-wave velocity of four multi-layered soil profiles with different thickness:

- The total investigated depth (model I),
- The depth considered in RPA99-2003 (model II),
- 30m beyond the ground surface according to the International codes (EC8, NEHRP 2000 Provisions) (model III)
- And the depth to bedrock or significant impedance contrast (model IV).

Table 2. Site classification of RPA99-2003

Type	Description	Average shear wave velocity, Vs
S1	Rock site: Rock or any geological unit	≥800
S2	Stiff site: Very dense sand and gravel deposits or/and over consolidate clay with depth between 10 and 20m	≥400 beyond 10m depth
S3	Soft site: Medium dense thick sand and gravel deposits or medium stiff clay	≥200 beyond 10m depth
S4	Very soft site: - Loosed sand deposits with or without slack clay layers - Slack to medium stiff clay deposits	<200 in a soil profile of 20m

Keddara event, recorded during the Boumerdes earthquake 2003 (ML=6.8) by the CGS (Algerian National Earthquake Engineering Research Center, CGS) strong motion array in Algiers region is used. Figure 1 shows the North-south and East-west components and their Fourier spectra (Laouami (2012)).

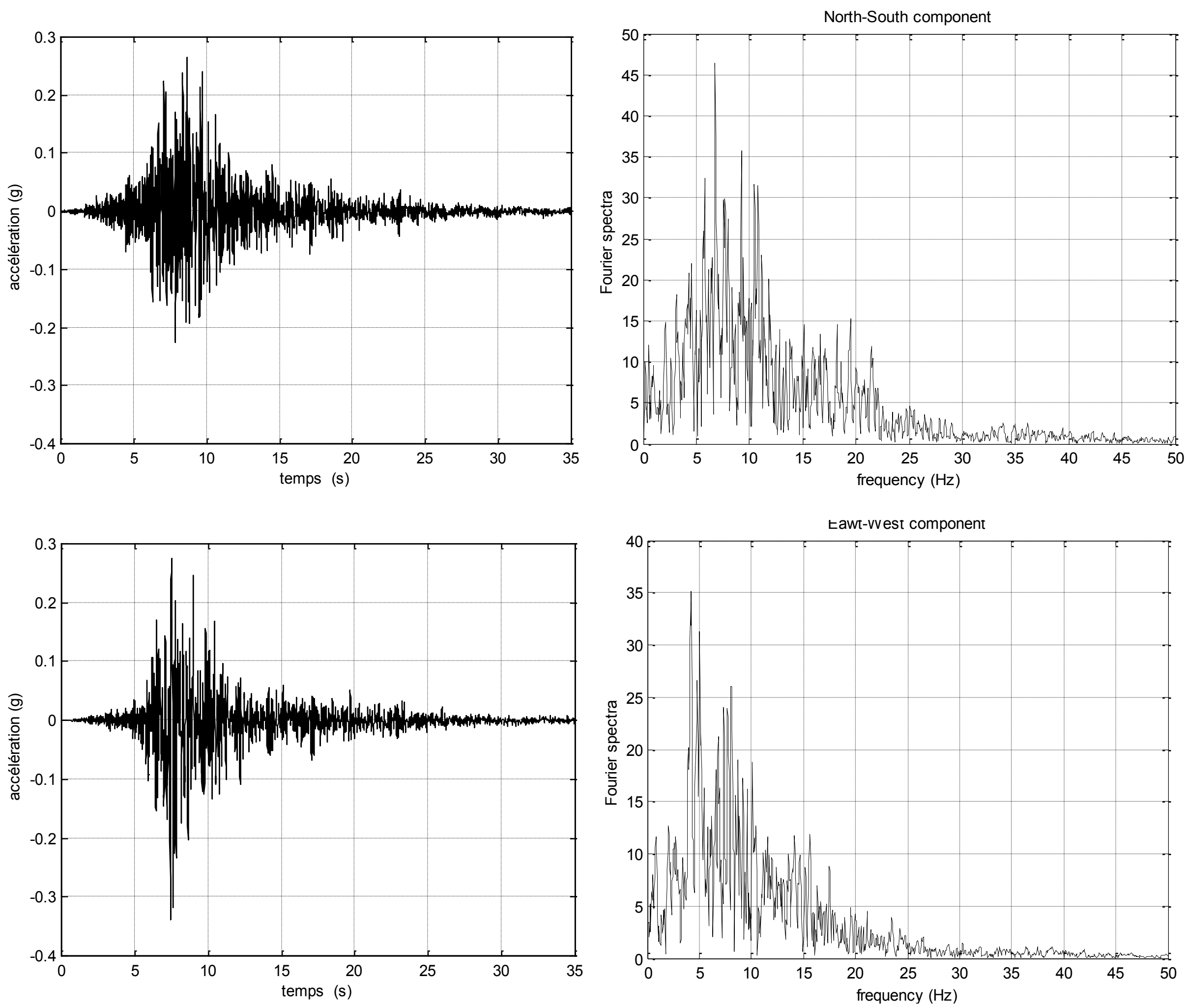

Figure 1. Recorded Acceleration at Keddara station, North-south and East-west components

The average acceleration, normalized to maximum acceleration of 0.25g, is used in different models as input applied in the bedrock to identify the local site effects.

In general, seismic bedrock may be defined as a rock with significant impedance contrast. In the present study, fresh schist (mi-f) is considered as bedrock. In several boreholes with more than 120m depth, the schist did not appear. In this case, fresh blue marl with a shear wave velocity higher than 700m/s is used as bedrock.

The response analysis was conducted in equivalent non-linear way. As there is no non-linear dynamic property of Algerian soils, the existing models in literature are adapted and used.

The study area was divided according to the depth of bedrock. In the north-west and north-east part, the schist (mi-f) with an average shear wave velocity of 1100m/s is found at depth less than 20m. For the rest of study area, the blue fresh marl is found at different depth (20-120m). The depth increases generally in the south part which corresponds to the north part of Mitidja basin. The blue marl (pl-f) is considered as engineering bedrock. The figure 2 shows some shear wave velocity distribution around the study area.

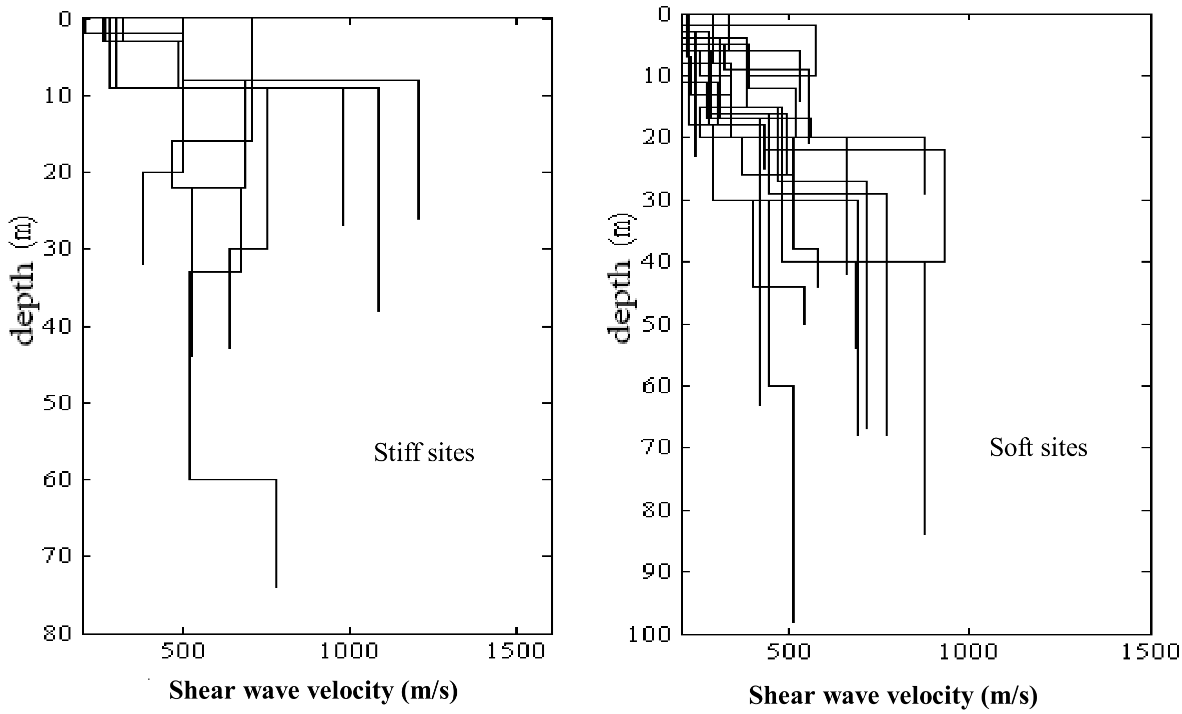

Figure2: Distribution of shear wave velocity

Considering different column samples where the engineering bedrock is schist (Vs=1100m/s). It's clear that those sites are considered as stiff-very stiff sites.

The depth to bedrock is lower than 15m in some area. Table 3 shows comparison between average shear wave velocities ($V_s = \sum h_i / \sum (h_i / V_{si})$), calculated and empirical frequencies for the models presented above. Two samples are taken for comparison.

The second sample has greater shear wave velocities. The calculated frequencies are comparable to the approached one. That's mean approached formula tends to reflect mean frequency of very stiff. The model IV gives higher frequencies (calculated and approached). Any depth more tends to reduce frequency, increases shear wave velocity.

The peak acceleration at free surface in table 4 is practically the same for all models with the lower value is obtained for the fourth model (IV) where the acceleration is amplified from 0.25g at the bedrock to 0.31 at free surface (24% of amplification). This is due to the input motion used which is considered as a near field (Laouami 2003) with a mean square frequency of 8Hz, very close to fundamental soil column frequency.

In this case, shallow engineering bedrock (very stiff soils), it is preferable to use model IV which is realistic and more economic.

Table3. Comparison between different models for schist seismic bedrock

Sample1					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	36	701	6.5	4.9	0.36
II	20	571	6.5	7.1	0.34
III	30	663	6.5	5.5	0.38
IV	9	378	7.0	10.5	0.31
Sample2					
I	26	514	6.5	4.9	0.34
II	20	443	6.5	5.5	0.34
III	30	553	6.5	4.9	0.36
IV	13	335	6.5	6.4	0.32

For soil columns with fresh bleu marl as engineering bedrock (Vs=700m/s), two cases are considered: depth to bedrock less than 20m and higher than 20m.

In the first case, several samples were taken from the soil model of study area. Blue marl is found at depth less than 20m with shear velocity higher than 700m/s.

Table 4 shows the results in term of average shear wave velocity, calculated and approached frequencies and the peak acceleration at free surface.

In the first sample, with a total depth of 74m, the blue marl is found at 13m. The site classification according to RPA code classifies the model I as S2 and the rest as S3. Taking column with the total depth tends to increase its shear wave velocity and decrease its frequency (higher modes more important). This model tends to make flexible the soil column which induces a higher acceleration at free surface. The models II and III are comparable in term of classification (S3 but very near to S2), frequency and amplification. The model IV with significant contrast impedance classifies the site as soft which is not true. Investigating more depth is recommended, the RPA model (II) is enough but up to 30m gives same results.

The second sample with a total depth of 31m and significant contrast impedance at 14m gives practically same results. For relative flexible seismic bedrock (blue marl), found at depth less than 20m, the RPA (model II) makes good classification. In this case, taking deeper columns tends to increase mean shear wave velocity which does not guarantee more security.

Table4. Comparison between different models for marl with depth less than 20m as seismic bedrock

Sample1					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	74	559	4.0	1.9	0.52
II	20	317	4.5	3.2	0.44
III	30	388	4.5	4.0	0.45
IV	13	245	4.5	4.7	0.41
Sample2					
I	31	405	4.0	3.3	0.47
II	20	328	4.5	4.1	0.46
III	30	399	4.0	3.3	0.46
IV	14	267	4.5	4.8	0.43

In several samples taken from the soil model of study area, Blue marl is found at depth less than 20m but with very low shear velocity that it cannot be considered as seismic bedrock. The depth for the model IV is taken when the velocity riches values around 700m/s, because of this, the average thickness of this model is higher than 20m. Table 5 shows comparisons in this case.

In the first sample, the site classification depends strongly on the model. The total depth model, which is the same as the RPA model classify the site as very soft (S4) even we have Vs higher than 200 m/s beyond 10m depth. The 30m model and the model with significant impedance contrast classify the site as soft (S3). In the second sample, all the models classify the site as soft (S3).

In term of peak acceleration, the models III and IV amplify more than RPA model (II). The maximal acceleration at free surface is around the 0.56-0.60g for the two models III and IV because of important contrast and 0.48g for the RPA model which makes the column less rigid with reduced shear wave velocity but higher frequency (sample2) because of reduced depth (20m), whereas this kind of site (soft one) is supposed concerned by important amplification. In several samples, the more repeated frequencies are 2-2.5Hz which corresponds to depth higher than 20m.

As conclusion, in case of blue marl found at 20m or less depth with no significant contrast impedance at this depth, it's recommended to drill more than 20m to get real dynamic characteristics of the soil column and avoid amplification effects. The model III (30m) seems to be the adequate.

Table5: Comparison between different models with seismic bedrock depth more than 20m

Sample1					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	20	187	2.0	2.3	0.31
II	20	187	2.0	2.3	0.38
III	30	244	2.0	2	0.56
IV	32	254	2.0	2	0.60
Sample2					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	31	335	2.7	2.7	0.50
II	20	289	4.2	3.6	0.36
III	30	330	2.7	2.7	0.51
IV	35	354	2.7	2.5	0.42

The third category of profiles is those with blue marl as seismic bedrock found in depth higher than 20m. In this case, the calculated frequencies are the same for all models. There is no important difference between them and the approached ones. In case of total depth (important depth), the model gains in shear wave velocity without changing in rigidity. The RPA model (II) has the lower mean shear wave velocity and shows the biggest difference in calculated and approached frequencies. The peak acceleration at free surface of this model (II) is 15-30% less than other models. This is probably due to the impedance contrast which is not important at 20m depth. The models III and IV give close results in term of amplification, frequency and shear wave velocity.

In case of deep deposits with relative soft bedrock, several remarks can be enounced. The mean important one is the thickness of the model (topmost layer thickness). Generally 20m depth as it's recommended in Algerian code is a bad consideration. It tends to underestimate the real dynamic behaviour of the model. It gives less average shear velocities and less amplification in term of peak acceleration (tables 6). The model IV gives better representation but the bedrock is sometimes very deep (60m in sample2, table 6) which is not economic, the model III (30m) gives closest results to the model IV and we can conclude that this model is the best.

Table6: Comparison between different models for marl with more than 20m depth as seismic bedrock

Sample1					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	73	439	2.0	1.5	0.52
II	20	222	2.0	2.8	0.41
III	30	268	2.0	2.2	0.52
IV	29	262	2.0	2.3	0.51
Sample2					
Model	**H(m)**	**Vs(m/s)**	**Calculated F (Hz)**	**F=Vs/4H**	**Acc. at free surface (g)**
I	103	382	2.0	0.9	0.70
II	20	201	2.0	2.5	0.46
III	30	226	2.0	1.9	0.56
IV	60	299	2.0	1.2	0.64

For deep deposits with relative soft bedrock, (marl with more than 20m depth as seismic bedrock, more available and best quality data), we perform a comparison between the calculated response spectra for all models. To implement this check, the results are normalized to the one obtained in case of model II, (Algerian RPA model).

Figure 3 reports the result of the comparison. For soft soil, the RPA model (II) underestimates the amplification for frequencies higher than 3.7 Hz in the case of the model IV (depth up to the bedrock) and for frequencies higher than 4.5Hz in the case of model III (average of 4Hz). We consider this underestimating due in part to the Keddara signal taken as an excitation which is very energetic around these frequencies.

Also around 0.5-0.8Hz, the calculated response spectra from the model III (30m) overestimate the one calculated from the RPA model (dashed lines). This model tends to reduce the underestimation compared to the RPA model and it may be potentially useful for sites where depth to bedrock is important (model IV) and it is not economic to investigate in term of PS logging all this depth. It gives closest results to the model IV and we recommend the adoption of this model in the Algerian code.

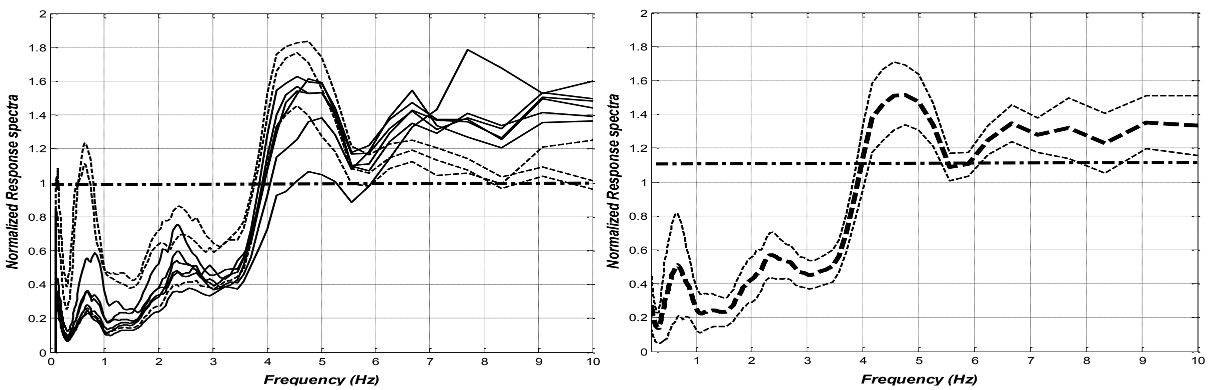

Figure 3. Comparison of response spectra considering different models

CONCLUSION

Seismic site response and amplification of ground motion are significantly affected by the combined effect of the dynamic stiffness and thickness of soil deposit. Algerian design practice (RPA99-2003) uses an oversimplified approach to soil classification close to 1994 UBC classification. Four site types are considered, S1, S2, S3 and S4. They are established from properly substantiated geotechnical data especially average shear wave velocity over the upper 20 meters of a site profile. In real Algerian practice, the specific geotechnical investigation does not provide complete information to characterize soil conditions. In this study, we deal with the effects of the profile depth on fundamental frequency of soil column through its transfer function and response spectra and maximal acceleration at free surface using SHAKE program.

The Keddara ground motion recorded in the 2003 Zemmouri earthquake and existing reliable geotechnical data including P-S logging (more 180 boreholes) provide an opportunity to assess and improve seismic site response and amplification of ground motion consideration. The study is based on the average S-wave velocity of four soil profiles with different depth: the total investigated depth, the depth considered in RPA99-2003, over 30m from ground surface and the depth to bedrock or significant impedance contrast.

For different column samples where the engineering bedrock is schist (stiff-very stiff sites), the depth to bedrock is generally lower than 15m. In this case, it's realistic and economic to drill up to bedrock.

For soil columns with fresh bleu marl as engineering bedrock, two cases are considered: depth to bedrock less than 20m and higher than 20m. In the first case, the PRA classification is sufficient if the contrast impedance is found at the first 20 meters. When the blue marl shear wave velocity does not reach 700m/s at this depth, the RPA classification becomes no realistic. It's important to drill until finding this velocity value. The 30m depth seems to be enough to characterize the site.

The third category of profiles is blue marl as seismic bedrock found in depth higher than 20m (deep deposits). Generally, 20m depth as it's recommended in Algerian code is a severe consideration. It tends to underestimate the real dynamic behaviour of the model. It gives less average shear velocities and more amplification in term of peak acceleration. The depth to significant contrast impedance gives better representation but in some places it's very deep which is not economic. The model of 30m depth is a good approximation because of compromise between economy and significance.

In term of response spectra, the results preliminary indicate that for soft soil, the RPA model (II) underestimates the amplification for frequencies higher than 4 Hz. We consider this underestimating due in part to the Keddara signal taken as an excitation which is very energetic around these frequencies. The model III (30m) tends to reduce the underestimation compared to the RPA model and it may be potentially useful for sites where depth to bedrock is important (model IV) where it is not economic to investigate in term of PS logging all this depth. It gives closest results to the model IV and we recommend this model as a reference in the Algerian code.

REFERRENCES

Djediat Y (2000), "Effects of the Quaternary Seismicity on Tyrhenian Marine Terraces of Algiers Littoral", Symposium on the Dynamics of active faulting in the Mediterranean region", USTHB, Algiers *October 9-11.*

Durand-Delga M (1969), "Mise au point sur la structure du Nord-Est de la Berbérie", *Publ. Serv. géol. Algérie* 39 : 89–131.

Kramer S.L. (1997), "Geotechnical Earthquake Engineering", *Prentice Hall, New Jersey*.

LCTP Laboratoire Central des Travaux Publics, (2005), "Données géotechniques et géophysiques de sols de sites Algérois" (CD).

LCTP Laboratoire Central des Travaux Publics, (2011), "Données géotechniques et géophysiques de 10 sites dans la région d'Alger" (CD).

LNHC Laboratoire National de l'Habitat et de la Construction (2005), "Campagne de reconnaissance géotechnique et géophysique de sols de la région d'Alger".

LNHC Laboratoire National de l'Habitat et de la Construction (2004), "Banques de données géotechniques et géophysiques de sols de différents sites d'Alger" (CD).

Laouami N, Slimani N, Bouhadad Y, Chatelaina JL and Nour A, (2006) "Evidence for fault-related directionality and localized site effects from strong motion recordings of the 2003 Boumerdes (Algeria) earthquake: Consequences on damage distribution and the Algerian seismic code" *Soil Dynamics and Earthquake Engineering* 26: 991–1003

Laouami N (2012) "Banque expérimentale de données sismiques", rapport interne, CGS *National Center of Applied Research in Earthquake Engineering*.

Mancuso C., Silvestri F.. and Vinale, F. (1997), "Soil Properties Relevant to Seismic Microzonation", First Japan-Turkey Workshop on Earthquake Engineering, Microzonation and Geotechnical Hazard (2):82-113, Istanbul Technical Univ.

Pitilakis K., Anastasiadis A. and Raptakis D. (1992) "Field and Laboratory Determination of Dynamic Properties of Natural Soil Deposits", Proc. 10th World Conference on Earthquake Engineering, Madrid, (5):1275-1280.

Schnabel, P.B., Lysmer, J. & Seed, H.B. (1972), "SHAKE – A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", Report No. EERC 72-12, University of California Berkeley.