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Synthesis on the Shear Wave Velocity of Engineering and Seismic Bedrocks in Northern Algeria based on Recent Experimental Investigations

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Abstract **–** In the field of civil engineering, knowledge of good rocky ground resistant to collapse minimizes the level of seismic risk, often known as the “engineering bedrock”. In lithology, it overlays a harder rock known as “seismic bedrock”. The latter is a transition zone between the earth's crust and the surface layers. It is sometimes impossible to carry out deep drilling and investigation techniques to define the engineering substratum for the foundations; in this case we rely on the seismic regulations. In Algeria, after the 2003 Boumerdès earthquake, seismology studies were expanded in order to better understand the Algerian crust on both the marine and continental sides. Furthermore, studies on seismic risk reduction in urban environments are increasingly focusing on the phenomenon of site effects or local amplification. Several experimental studies conducted in Algeria as part of seismic microzoning programs have defined the existence of these two substrate interfaces by identifying the natural frequencies of the ground. In this work, we describe the findings of numerous key research that reached the seismic bedrock in Algeria. It is classified as having two geological natures: Mesozoic with a shear wave velocity, Vs, less than 3000 m/s, and metamorphosed Paleozoic with Vs greater than 3500 m/s.

Keywords – Engineering Bedrock; Seismic Bedrock; Shear Wave Velocity; Site-Effects; Algerian Crust

I. INTRODUCTION

Seismic waves propagate throughout the earth's material from the seismic source, with propagation velocities controlled by its physicochemical composition and mechanical properties that vary with depth (e.g., [1]). On the surface of the earth, the various human installations of infrastructure and urban areas, industrial-nuclear sites, etc. are developing and accelerating, etc. The arrival of seismic waves on the surface of the earth and their interaction with buildings are the only origins of the seismic risk. The knowledge of the surface is an adequate means to predict "the level" of the interaction and to predict the level of the seismic risk; therefore, its reduction is possible. Nevertheless, the surface of the earth is the last function placed after several mechanisms of transformation of the seismic energy of the source.

$$O_s(t) = S_s(t) * P_s(t) * E_s(t) \quad \text{(I)}$$

with

$S_s(t)$ is the source function; $P_s(t)$ is the propagation function between the source and the site; $E_s(t)$ is the site effect.

The estimation of the site function, $E_s(t)$, is a major contribution to the limitation of the seismic risk, but its characterization requires experimental investigations and complex theoretical approaches linked to the local scale of the site; it is "the transfer function". In seismology, the definition of this member is a linear and/or non-linear representation of the relationship between the seismic signal recorded on the bedrock, called input, and the one recorded on the surface (or the site), called output. As its name indicates, the transfer function expresses the spectral change in the different frequency points of the ground physical parameter, such as acceleration. In seismology, the change is due to the presence of a geological medium containing a jump in mechanical properties such as seismic velocities, density, etc.

In Algeria, after the 1980 El-Asnam earthquake, the transfer function was based on one-dimensional (1D) theoretical modeling by considering a stratigraphic column of sedimentary layers overlaying a bedrock with a seismic wave velocity, Vs, of 1000 m/s. Such a detailed calculation can be found in the seismic microzoning study of the Ech-Chéliff, Algeria, region ([2]). After the Boumerdès earthquake in 2003, experimental progress in estimating the transfer function was initiated by [3]. In this study, a correlation between the site effects and the damage caused by this earthquake was evaluated to explain the role of the transfer function from the seismic source. Then, the two groups JICA and CGS introduced the transfer function in the seismic microzoning study of the Algiers-Boumerdès region by 1D modeling for a bedrock velocity of 700 m/s ([4]).

Seismic microzoning studies are actually multidisciplinary projects that require the assembly of several scientific works between the seismic source and the site of investigation. The realization of its project requires time and financing, which are impossible to carry out every time for ordinary constructions (buildings, bridges, motorways, etc.). For this reason, we base ourselves on the paraseismic regulations, a code in which we find a description defining Vs in the sedimentary layer and the bedrock with the type and the soil class. In Algeria, we base on "ALGERIAN PARASISMIC RULES, RPA 99 / 2003 version" (Table 1). In the present work, we treat the element of the bedrock in Algeria in the field of seismology through the recent studies (Fig. 1) devoted to understanding seismicity and improving the transfer function for the large strategic urban areas after the earthquake of Boumerdès, 2003, and others, for seismic risk limitation on its land.

II. Definition

In the previous section, we used the term "bedrock" which is the origin of the transformation of the input signal into a different output. In nature, the bedrock is double and is mainly distinguished by its Vs. In Fig.2, illustrating this bedrock in terms of position relative to a geological medium, the first is called seismic bedrock and the second is engineering bedrock. In the following, we define each.

A. *Seismic Bedrock*

Geologically, the seismic bedrock is a hard rock, directly connected to the heterogeneous earth's crust and the discontinuity of the Moho of variable Vs; this one is sensitive to the shear modulus and density. According to the definition of the International Institute of Seismology and Earthquake Engineering (IISEE), the seismic bedrock is a layer with an interface where the source and propagation function together, $S_s(t)$ and $P_s(t)$, create an input signal. The following two conditions are required for the depth position of this seismic bedrock interface:

- The interface has a practically useful lateral extent, and the physical properties of the underlying layer do not vary along this interface.
- The layers deeper than this interface are much more homogeneous in comparison with the layers shallower than the interface.

According to the same source of definition, IISEE, the interface of this bedrock corresponds to the upper layer of the earth's crust.

B. *Engineering Bedrock*

According to the illustration of IISEE, the engineering bedrock overlies the seismic bedrock, with an interface between them. In this layer, Vs is estimated between 400 and 700 m/s, while in the seismic bedrock, it is considered 3000 m/s. The differentiation between the surface layer and the engineering bedrock requires several variable criteria, reflecting the state of professional practices and regulations in the region concerned ([5]).

III. Study of the Effects of Sites Constructed in Algerian Urban Areas

Several experimental studies within the framework of seismic microzoning in Algeria have defined the existence of these two substrate interfaces by identifying the natural frequencies of the soil. The seismic bedrock appears in the basin (Fig.1), of Cretaceous age, of a lateral extent outcropping in the Dahra and Ouarsenis massifs, where Vs is estimated at ~3000 m/s and re-examined in 2018 for a value between 2000-2600 m/s ([7]). The engineering bedrock identified in the Chéliff region has a Vs of 1000 m/s ([2]). Another analysis is mapped for the Algiers region by [8], where the explanation of the low frequency peaks was impossible by a bedrock Vs of 700 m/s, and the most adequate is that of a higher velocity, in the vicinity of 4000 m/s of Paleozoic metamorphosis outcrops in Bouzeréah Massif, Northern border of Mitidja Basin ([9]) and Djurdjura Massif (Fig.1). In the town of Blida (southern border of Mitidja basin), [10] also observed low frequency peaks and the layer of more than 300 m of Vs between 660 and 760 m/s is the origin of the amplification (Fig.1). In the town of Oued Fodda, middle Chéliff, [11] found results at high and low frequencies, variable with the underground topography of the seismic bedrock, of velocity between 2000 and 2600 m/s, topped by an engineering bedrock of ~1000-1400 m/s. In a recent study in Oran city (Fig.1), [12] defined the depth of the two bedrocks, the engineering composed of two layers, 400-950 m/s (Upper Miocene) and ~700-1400 m/s (Lower Miocene),

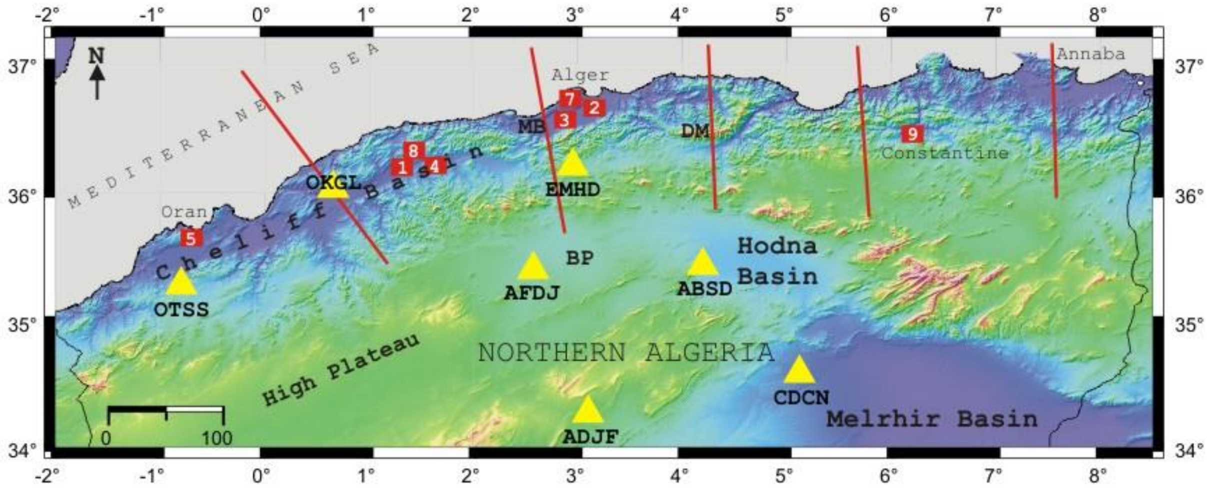

Fig.1 The spatial distribution of ADSN (Algerian Digital Seismic Network) Broad-Band stations (yellow triangles) involved in the lithological site-effects investigation [14]. The distribution of recent studies used for the current synthesis is represented by the numbered red squares. Red lines are SPIRAL project profile segments available from [18]. MB is for Mitidja Basin; DM is for Djurdjura Massif. Study N° 1 is by [7], 2 and 9 are by [8] and [13], 3 is by [10], 4 is by [11], 5 is by [12], 6 is an unpublished ANRH report, 7 is by [21], 8 is by [15].

interpretation of the results obtained in Chlef city by [6], judged to be the origin of low-frequency amplification in the low Chéliff overlaying the Cretaceous seismic bedrock with 1400-2500 m/s.

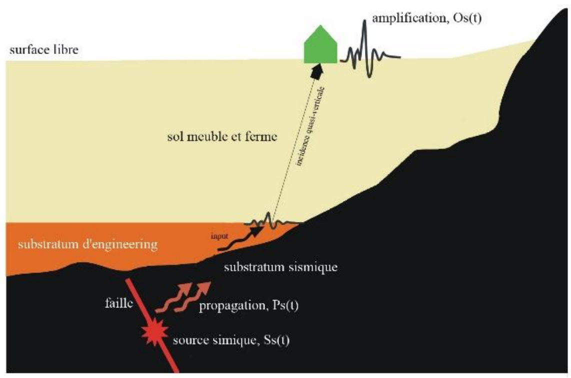

Fig.2 Illustration of the functions of equation (I) with the position of the seismic and engineering bedrocks according to IISEE (modified).

After the Mw =4.9 earthquake occurred in Mila province (Northeast Algeria) on the 7th of August 2020, [13] carried out ambient vibration measurements for H/V-technique in order to explain and characterize the El Kherba landslide induced by this seismic event (Fig.1). In their geotechnical analysis, they used the term "geotechnical bedrock" of marl formation, and has a Vs varying from 500 to 615 m/s. A recent study on site characterization of Algerian broadband seismic stations of ADSN by [14] allowed the estimation of Vs in seismic and engineering bedrock of installation sites of lithological site effects. In Fig.1, the spatial distribution of these stations (yellow triangles) is shown. In Fig.3, some of the results indicate the Vs, the two bedrocks with their corresponding depths, and the geological age. More details on the geological formation are given in [14].

Table 1. Soil classification according to RPA-99 version 2003.Vs_{10} is the velocity of S waves at 10 meters

Class	Description	Vs10 (m/s)
S1	Rocky: Rock or other geological formation characterized by an average shear wave velocity Vs >= 800m/s	$Vs_{10} \geq 800$
S2	Stiff : Deposits of very dense sand and gravel and/or over-consolidated clay 10 to 20 m thick with Vs >= 400 m/s from 10 m depth	$400 \leq Vs_{10} < 800$
S3	Soft :Thick deposits of moderately dense sand and gravel or moderately stiff clay with Vs >= 200 m/s from 10 m depth	$200 \leq Vs_{10} < 400$
S4	Very Soft : Presence of at least 3 m of soft clay. Loose sand deposits with or without the presence of soft clay layers with Vs < 200 m/s in the first 20 meters. Soft to moderately stiff clay deposits with Vs < 200 m/s in the first 20 meters	$Vs_{(20)} < 200$

IV. Other approaches

The definition of Vs of the seismic bedrock can be obtained by other methods based on the principles of natural or artificial active seismic. Here, we summarize four examples made in Algeria. The first case is the inversion of seismograms recorded by seismological stations in order to determine the parameters of the seismic source; among the results is the velocity model under the selected stations. Such an analysis can be found, for example, in the study by [15] (Fig.1), where the seismogram data has been filtered between 0.03 or 0.05 and 0.15 Hz, which means that the calculation will emerge from the deep estimates of the velocity model. The case considered in Table 2 shows the results in terms of seismic bedrock as the last layer of the earth's crust. Reference [16] estimated the depth of the earth's crust in Algeria by identifying the Moho beneath the BB-stations of ADSN, the seismic anisotropy measurements were obtained and interpreted by [17].

The second example treated here are the results of the SPIRAL scientific project, among which the objective is to image the deep structures in Algeria, the sea, and the continental part with a set of five profiles ([18]; Fig.1). An example of a result for the profile of Annaba ([19]), which illustrates the superposition of the layers and the increase in V_P from 8000 to 2000 m/s. Regarding the seismic bedrock, the minimum value is considered to be 2000 m/s. In an unpublished report by ANRH to define the seismic velocities in the mountain of Bouzegza (from Djurdjura Massif in Fig.1) of a metamorphosed Paleozoic formation and outcropping on the surface, the results showed that the rocky site has a value of V_P of 5000 to 7000 m/s. To estimate the value of Vs, we considered the same ratio between the two velocities used by [20]: $Vs^2=V_P^2/3$, which gives Vs of the seismic bedrock sought between 2900 and 4000 m/s. In their numerical analysis to provide a 3D model of the Algiers-Chenoua geological structure of the metamorphosed Palaeozoic, [20] obtained a Vs of 3900 m/s.

V. The bedrock in RPA-99 version 2003

As we indicated in the introduction, it is sometimes impossible to carry out deep drilling and investigation techniques to define the engineering bedrock for the foundations. In this case, we are dependent on the seismic regulations, RPA-99 version 2003 is the guide used in Algeria. It contains several definition chapters for each type of construction and floor. Table 1 summarizes the different four classes and types of soil with the corresponding Vs, including the bedrock at 10 meters higher or equal to 800 m/s, which is classified as "rock soil.

VI. Conclusion

Through this synthesis of the scientific work carried out in Algeria, we can say that the seismic bedrock in Algeria is double: the first is Mesozoic, mainly Cretaceous, with Vs lower than 3000 m/s, and the second is a metamorphosed Paleozoic outcropping in the area of Grande Kabylie (Bouzeréah Massif, northern border of Mitidja Basin, and Djurdjura Massif; Fig.1) with a Vs higher than 3500 m/s.

Table 2. Depth and velocity of S waves in the seismic bedrock obtained by [15] considering three seismological stations of the ADSN

Station	Depth (m)	Vs (m/s)
OKGL	2000	1260
OJGS	3000	2210
EMHD	600	1170

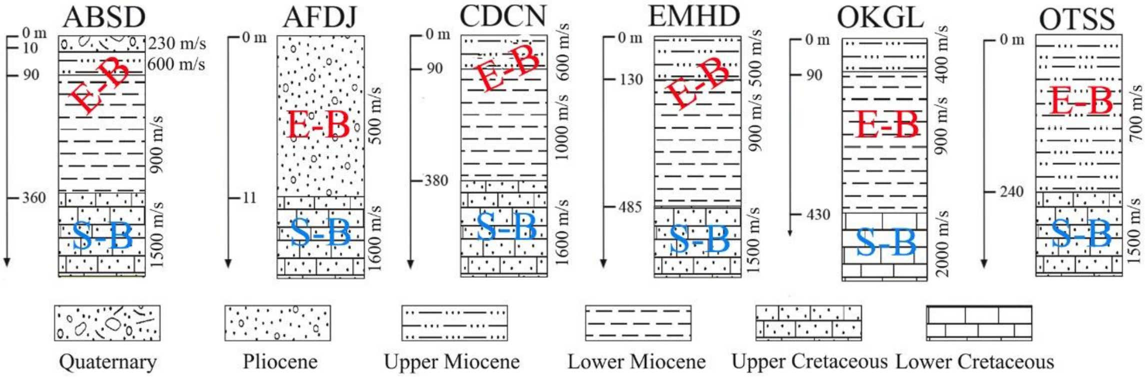

Fig. 3 Example of site characterizations of BB-stations of ADSN showing the seismic bedrock (S-B) and engineering bedrock (E-B) modified from [14]. The spatial distribution of the considered BB-stations by lithological site effects is plotted in Fig.1.

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