Evaluation of effective parameters on soil layers seismic amplification ratios (A case study of Bam earthquake)

Évaluation des paramètres effectifs sur les ratios d'amplification sismique des couches de sol (Une étude de cas de tremblement de terre de Bam)

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ABSTRACT: The average of shear wave velocity in 30 m of top soil in boreholes is used in standard seismic codes like Euro Code and Iranian Earthquake Code (2800) for finding the soil layer type underlined by bedrock. At least 50% of observed seismic amplification ratio and surface destructions after bam earthquake did not verify the seismic codes expectations especially in locations of E type soil layers, the soil layer in which its shear wave velocity is about lower than 360 m/s having the thickness of 5 to 20 m underlined by a hard rock. In this research it is tried to find how stratifications and sub-layers can affect the seismic amplification ratio. The depth of bedrock, its determination criteria and the thickness of sub-layers were investigated by comprehensive analysis in several stages. In this procedure the EERA soft ware was used based on one dimensionally shear wave propagation theory in soil layers. In addition the effect of sub-layers thickness in detailed sensitive analyses was studied. Analyses with respect to amplification ratios in sub-layers that are classified as Euro Code and Iranian Earthquake Code (2800) based on their shear wave velocity, showed the considerable relation between the thickness of E, B and D type soil layers and seismic amplification ratios.

RÉSUMÉ : La moyenne de la vitesse des ondes de cisaillement à 30 m de couches de sol au-dessus des trous de forage est utilisée dans la norme des codes sismiques comme Code d'Euros et Code de Tremblement de terre iranienne (2800) pour trouve rle type de couche de sol soulignée parle substratum rocheux. Au moins 50 % du ratio d'amplification sismique observée et destructions de surface après le tremblement de terre de Bam n'a pas vérifié les attentes des codes sismiques surtout dans les lieux de couches de sol de type E, la couche du sol où sa vitesse d'onde de cisaillement est d'environ inférieure à 360 m/s avec l'épaisseur de 5 à20 m soulignée par une roche dure. Au travers de cette recherche, nous essayons de trouver comment les stratifications et les sous-couches peuvent influer sur le ratio d'amplification sismique. La profondeur du substratum rocheux, ses critères de détermination et de l'épaisseur des sous-couches ont été étudiés par analyse complète en plusieurs étapes. Dans cette procédure, le logiciel lEERA a été utilisé basée sur une théorie de la propagation unidimensionnelle des ondes de cisaillement dans les couches de sol. En outre, l'effet d'épaisseur de sous-couches a été étudié dans des analyses détaillées sensibles. Les analyses sen ce qui concerne les ratios d'amplification dans les sous-couches qui sont classés comme Code d'Euros et Code de Tremblement de terre iranienne (2800) basées sur leur vitesse de l'onde de cisaillement, a montré la relation importante entre l'épaisseur de couches de solde type E, B et D et les ratios d'amplification sismique.

KEYWORDS: amplification ratio, shear wave velocity, EERA software.

1 INTRODUCTION.

In theory, the term of site amplification refers to the increase in the amplification of seismic waves as they pass through soft soil layers near the earth surface. The increase is due to the low impedance of soil layers near the surface, where impedance is defined as the product of mass density of soil and the wave propagation velocity (Sefak2001).

Site effects (amplification of rock motions), source and path effects are coupled when response spectra are used to characterize the amplification ratios for a soil site modeled as nonlinear or elastic (Zhao 2010, Zhang 2010, Irikura 2010) .

The evaluation of site amplification effects is recognized as one of the most important activities of the seismology and earthquake engineering (Ferrari et all 2010)and the existence of soil amplification was amply demonstrated in many past destructive earthquakes (Tezcan 2002,Kaya2002,Ozdemir2002).

Joint evaluation of Athens(Greece), earthquake of 7 September 1999 shows that very stiff soils of the Athens basin compared to the nearby outcropping soft rocks have amplified the peak horizontal acceleration (Bouckovalas 2001, Kouretzis 2001).

Site effect-like amplification- is one of the most important factors in both seismology and earthquake engineering (Zhao 2009, Zhang 2009, Irikura 2009, Graizer 2009) .

The distribution of damage caused by earthquake ground shaking commonly reflects real differences in local soil conditions. Regional site conditions relevant for seismic hazard studies can be derived from various geologic, seismologic and geotechnical source (Kockar 2010, Akgun 2010,Rathje 2010).

Incoherences between seismic amplification that predicted by Earthquake Codes and observations after Bam earthquake (destructions of earthquake, primary analysis) show the importance of detailed analysis due to find blind spots. Field boring, soil sampling and several comprehensive analyses based on one dimensionally shear wave propagation theory with EERA software were done in this study.

2 THE EFFECT OF LOCAL SITE AND SOIL PROFILE STRATIFICATION ON AMPLIFICATION

The amplitude of seismic waves increase during they pass through soft soil layers near surface. This phenomenon is known as site amplification. That is the major factor that affects the earthquake damages.

Sub-layers worked like filters that damping off some seismic waves and amplify some others, so it may cause destruction of earthquake increased in small area. Sub-layers depth and their stiffness as well as their shear wave velocity can be effective on amplification ratio.

3 EARTHQUAKE STANDARDS & BUILDING CODES

Standard seismic codes like Euro Code and Iranian Earthquake Code (2800) use the average shear wave velocity in top 30 meters of soil profile to identify the soil category. In this regard soil profile is classified into 6 groups (A-F) in Euro Code as shown in Table1.

Table 1. Ground type based on Euro Code8.

Ground type	Description of stratigraphic profile	$v_{s,30}$(m/s)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface	> 800
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 - 800
C	Deep deposits of dense or medium- dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 - 360
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.	
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI= 40) and high water content	< 100 (indicative)
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A - E or S_1	

Average shear wave velocity from surface to depth 30 meters is calculated from Equation1. Each category of soils has a specified effect on seismic amplification and seismic force that induced to structures.

$$V_s = \frac{\Sigma(d_i)}{\Sigma\left(\frac{d_i}{V_{si}}\right)} \quad (1)$$

In this Equation V_s is average shear wave velocity, d_i is thickness of each layer and V_{si} is shear wave velocity for each layer.

This is the criteria for identify soil category in Earthquake standards and building codes. As noted above based on results of V_s equation the soil category identified and amplification is predicted.

E soil type is one of soil categories in Eurocode and Iranian Earthquake Code (2800) that include soft soil layers laid on stiff soil layers and show more amplification compared to other categories in Earthquake Codes.

4 CLASSIFICATION OF BOREHOLES IN BAM SITE

Observations after field boring, sampling and primary analysis of boreholes shows some contradictions between what expected according to Earthquake standards and Building codes and what happened during earthquake. Figure1 shows boreholes on Bam site and E soil type range (that specified by solid lines).

Based on Eurocode8 predictions amplification is expected only in boreholes of this area- E soil type- but significant amplification ratio was seen out of this area.

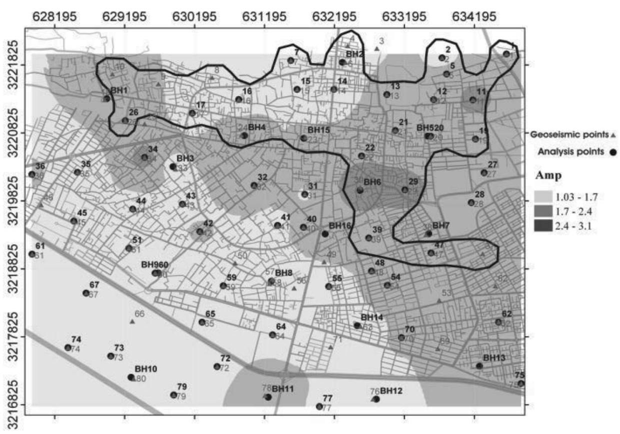

Figure 1. Bam site map and boreholes.

Also based on these contradictions two group of boreholes for more investigation specified:

1. Boreholes are not on E soil type area of Bam and results of analysis do not confirm Earthquake Codes predictions for amplification ratio (BH1, BH7, BH16).
2. Boreholes are not on E soil type area of Bam and results of analysis confirm Earthquake Codes predictions for amplification ratio (BH3, BH8, BH14).

All of the analysis have done with EERA software based on one dimensionally shear wave propagation theory. Detail of boreholes and soil layering include soil type and shear wave velocity along depth of each group of boreholes is shown on figure 2 &3.

In each borehole soil layers basin density, hardness, soil type and shear wave velocity are divided and detailed analysis was done for 14 time histories. These group of time histories based on earthquake magnitude, distance between station and earthquake epicenter, techtonic, PGA and fault type were selected. The list of seven couple time histories that selected for this study is shown in Table2.

Table 2. Analysis time histories.

PGA(T)	PGA(L)	Country	Earthquake
1.039	1.497	United States	Cape Mendocino
0.152	0.220	Turkey	Kocaeli
0.721	0.758	United States	Landers
0.473	0.411	United States	Loma Prita
0.565	0.871	Iran	Ardal
0.636	0.798	Iran	Bam
0.378	0.332	Iran	Tabas

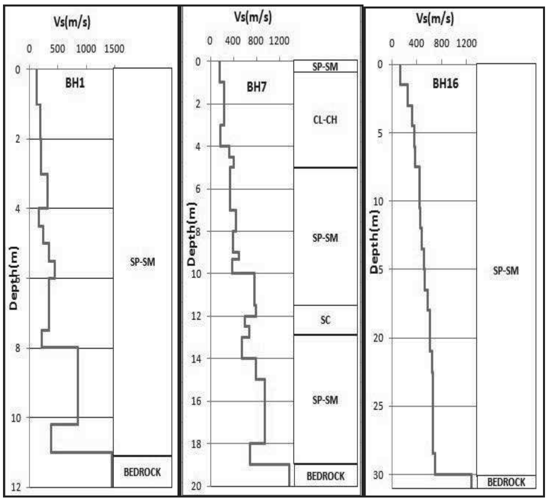

Figure 2. Soil profile and shear wave velocity along depth in boreholes of group1.

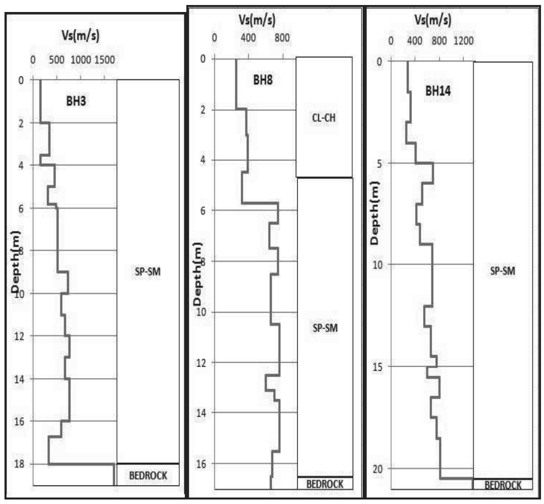

Figure 3. Soil profile and shear wave velocity along depth in boreholes of group2.

5 ANALYSIS RESULTS

In order to evaluate the ground response and amplification ratio of boreholes for study area based on one dimensionally shear wave velocity theory, 14 series of analysis -seven couple of time histories-have done.

As shown in figure 4 the general trend for them is similar and dispersion of amplification ratios in different time histories can be attributed to the effect of frequency content.

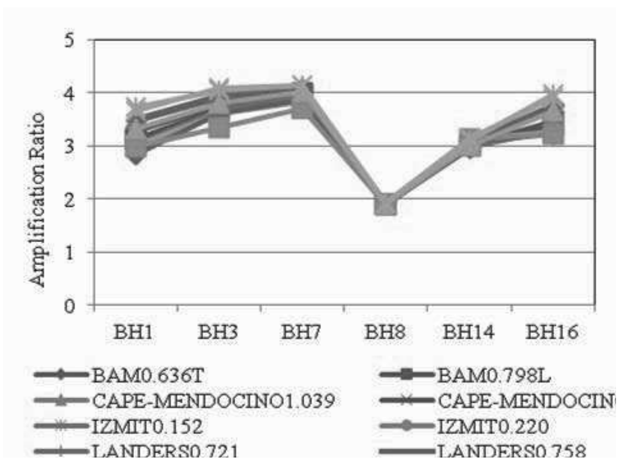

Figure 4. Amplification ratio of boreholes in different time histories.

According to correlation between PGA values and amplification ratio, PGA curves versus depth can show the effect of shear wave velocity variation on amplification ratio . In figures 5&6 compared with Figures 2&3 the effect of sudden changes in shear wave velocity of sub-layers on PGA ratio is clear.

Sub-layers thickness plus to their shear wave velocity affect on soil profile amplification ratio. It may be ignored in Equation 1 that used in Earthquake Codes for specify soil category and amplification ratio.

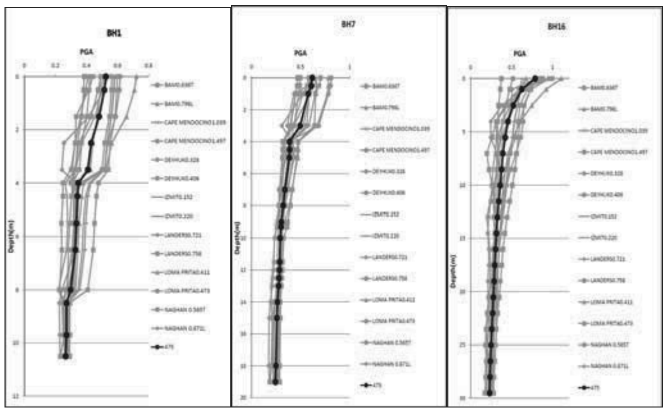

Figure 5. PGA curves for boreholes of group1.

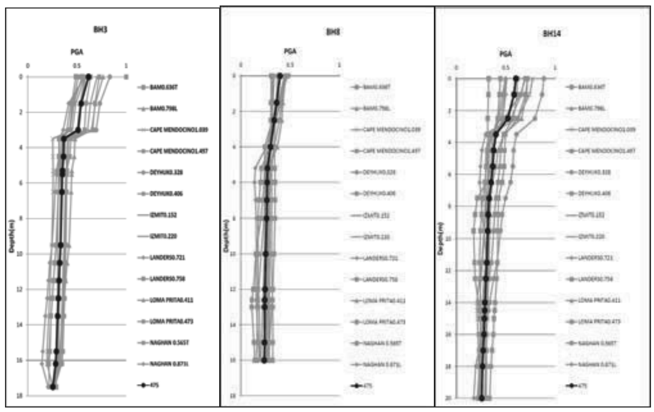

Figure 6. PGA curves for boreholes of group2.

According to previous explanation and PGA curves compared with shear wave velocity of soil sub-layers, effect of sub-layers thickness from different categories of Euro Code takes into consideration. Also divided sub-layers of each borehole along its depth that marked with shear wave velocity is shown in figure7.

More accurate comparison between these boreholes indicates effect of very soft soil layers on amplification ratio. All boreholes in group 1 area, have a very soft sub-layer in soil profile -its shear wave velocity is between 0-180 m/s(D category in Euro Code)- but in boreholes from group 2 except BH3 there is not any sub-layer from this category. It is necessary to consider that E soil type area borders were got from refraction method and it is not an accurate method.

On the other hand errors might occur during analysis with EERA software because limitations like linear analyzes.

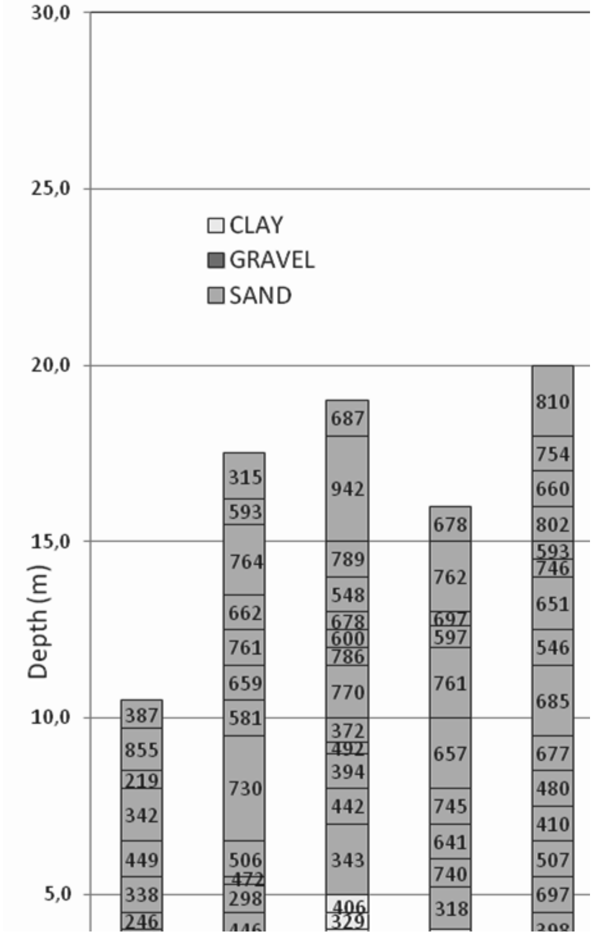

Figure 7. Soil profile of boreholes.

6 CONCLUSION

Seismic amplification studies was done in Bam site after 25 December 2003 earthquake based on one dimensionally shear wave propagation theory with EERA software.

Review of amplification ratios in different boreholes in and out of E soil type borders with considering sub-layers effect that include thickness and shear wave velocity gives the following results:

- In boreholes that show more amplification ratio, thickness of stiff sub-layers compared to soft sub-layers is significant.
- In boreholes that aren't placed on E soil type area according to Euro Code, but amplification ratio is significant, very soft soil layers was seen (D category), but in other boreholes out of E soil type area that amplification ratio is not significant, very soft soil layers (D category) was not seen.

Amplification of seismic waves leads to more extensive damage, so Earthquake Codes should be review for more accurate estimate of amplification ratio in site. Amplification is excepted when seismic shear wave pass through stiff soil layers near bed rock to soft soil layers near surface.

As the noted above current method based on average shear wave velocity and Euro Code limitations for shear wave velocity ranges, thus it ignore from parameters like divided sub-layers properties include thickness, shear wave velocity and very soft soil sub-layers or very stiff soil layers effect on amplification ratio. This study revealed the deficiencies of current earthquake codes and it emphasizes on effect of sub–layers properties on amplification ratio.

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