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PRELIMINARY ANALYSIS OF THE INFLUENCE OF CHANGING DISTANCE BETWEEN PILES ON HORIZONTAL ACCELERATION ELASTIC RESPONSE SPECTRA FOR PILE-SUPPORTED STRUCTURE

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In the professional literature, the seismic load of pile-supported structure is divided into kinematic seismic load and inertial seismic load from superstructure. Due to the deficiencies in the legal framework in Montenegro (standard MEST EN 1998 - official Montenegrin counterpart of the European seismic standard Eurocode 8), civil engineers when defining seismic load of the pile-supported structure in practice almost every time treat only inertial seismic load from superstructure. Except the problematic neglect of the kinematic seismic load, the way in which the inertial seismic load is defined is also problematic. Due to the deficiencies in the legal framework not only in our country but also worldwide, civil engineers for defining the inertial seismic load of pile-supported structures in practice use elastic and design (inelastic) acceleration response spectra, which are prescribed generally for structures neglecting type of their foundations. This is rather rough and unrealistic assumption. This paper presents part of the results of 2D dynamic analyses of soil-pile-structure interaction, which were performed using the modern Domain Reduction Method, with the aim of preliminary investigating the seismic response of buildings founded on piles. In particular, the presented results show how changing distance between piles affects to the horizontal acceleration elastic response spectra at the base level of analysed pile-supported RC frame. In this way, pile foundation characteristics influence on the intensity of the superstructure seismic load is indirectly analysed. As expected, preliminary analyses have shown that in case of small distance between the piles (2d or 3d), this influence can be very significant. In this specific case, when the piles at the lower end are fixed in the bedrock, that influence is favourable because smaller elastic spectral accelerations are obtained for the complete range of periods (less seismic load of the superstructure). Of course, for some general conclusions and proposals, it is necessary to perform a significantly larger number of dynamic analyses with different configurations and characteristics of the soil-piles-structure system and seismic excitations. It is planned for the next period.

Keywords: inertial seismic load, elastic acceleration response spectra, pile-supported structure

1 INTRODUCTION

In the professional literature, the seismic load of pile-supported structure is divided into kinematic and inertial component, although it is often forgotten that this separation of seismic load is only possible in the situation of linear-elastic analyses [1]. Kinematic seismic load is consequence of lateral soil movement during an earthquake. This lateral load (lateral distributed forces) act on the piles and its intensity is proportional to the relative displacement between the piles and surrounding soil. The movement of the piles caused by the earthquake-induced foundation soil movement is transmitted to the superstructure. Oscillation of the superstructure causes the generation of inertial seismic forces. These forces are transmitted to the piles via pile cap. Therefore, the piles are simultaneously exposed to the action of kinematic seismic load and inertial seismic load from the superstructure. The intensities of these loads are interdependent.

Due to the deficiencies in the legal framework in Montenegro (standard MEST EN 1998 - official Montenegrin counterpart of the European seismic standard Eurocode 8), civil engineers when defining seismic load of the pile-supported structure in practice almost every time, consciously or unconsciously, treat only inertial seismic load from superstructure. Except the problematic neglect of the kinematic load, the way in which the inertial load is defined is also problematic. Why? Due to the deficiencies in the legal framework in Montenegro, civil engineers for defining the inertial seismic load of pile-supported structures in practice use elastic and design (inelastic) acceleration response spectra, which are prescribed generally for structures neglecting type of their foundations. This is rather rough and unrealistic assumption. Designers very often have a problem to choose the appropriate ground type i.e. design acceleration response spectrum in the situation when the piles "pass" through a soft soil deposit greater thickness to the stiff soil layer in which they are fixed. In other words, it is not clear whether the soft soil deposit affects the intensity of the inertial seismic loading of the structure. Unfortunately, engineers who use other modern seismic standards in the world have the same problem [2].

Determining the elastic and especially inelastic (design) acceleration response spectra for pile-supported structures requires performing very complicated dynamic analyses of the soil-piles-structure interaction during an earthquake. Many factors and parameters must be properly defined in order to obtain valid results from these analyses. This is the reason why researches of this type are very rare [3-5]. In [5], the Domain Reduction Method (hereafter DRM) is used for 2D dynamic (seismic) analysis of the soil-piles-structure system (hereafter SPS system). On that occasion, horizontal acceleration elastic response spectra (hereafter HAERS) were obtained for different slopes of the incident SH waves. In this paper, using the same method and the same or very similar numerical models of SPS system, the influence of the change in the distance between the piles at a constant slope of the SH waves (0° with respect to the vertical axis) on the HAERS of the analysed pile-supported structure will be briefly analysed. It was adopted for the superstructure RC frame with 5 or 10 storeys. The aim of the paper is to prove preliminarily that these changes can have a significant influence on the seismic load of the structure founded on piles.

1.1 Domain reduction method (DRM)

With the application of the DRM, extremely complex seismo-geological 3D numerical models which, in addition to local geological and topographical structures, also include earthquake source (fault) and the wave propagation paths can be formed and processed. Also, using the DRM 3D numerical models of the soil-structure system with realistic simulation of seismic excitation can be formed and processed, regardless of the fact that they do not include the source of the earthquake and the wave propagation paths. For this reason, DRM is very suitable for analysing the seismic soil-structure interaction.

The fundamental concept of the DRM involves reduction (decrease) of the foundation soil domain dimensions to a smaller zone around and below the analysed structure based on the change of the basic unknowns in the equation of motion of the system, assuming that the "free-field" seismic response of foundation soil is known. For reason of rationality, DRM is not analysed in detail in this paper. The formulation of this method is given in detail in [6-8].

2 METHODOLOGY

2.1 Input data

Fig. 1 shows one of the analysed SPS system consisting of a five-storey RC pile-supported frame and layered soil. The piles (d=1m) are at an equal distance from each other, which is 2d, 3d, 4d or 6d, so the frame is founded on 7, 5, 4 or 3 piles respectively. The geometric characteristics of beams, columns and piles are identical in the five-storey and the ten-storey RC frame. The characteristics of the all soil layers real geological profile (Budva) are obtained from [9].

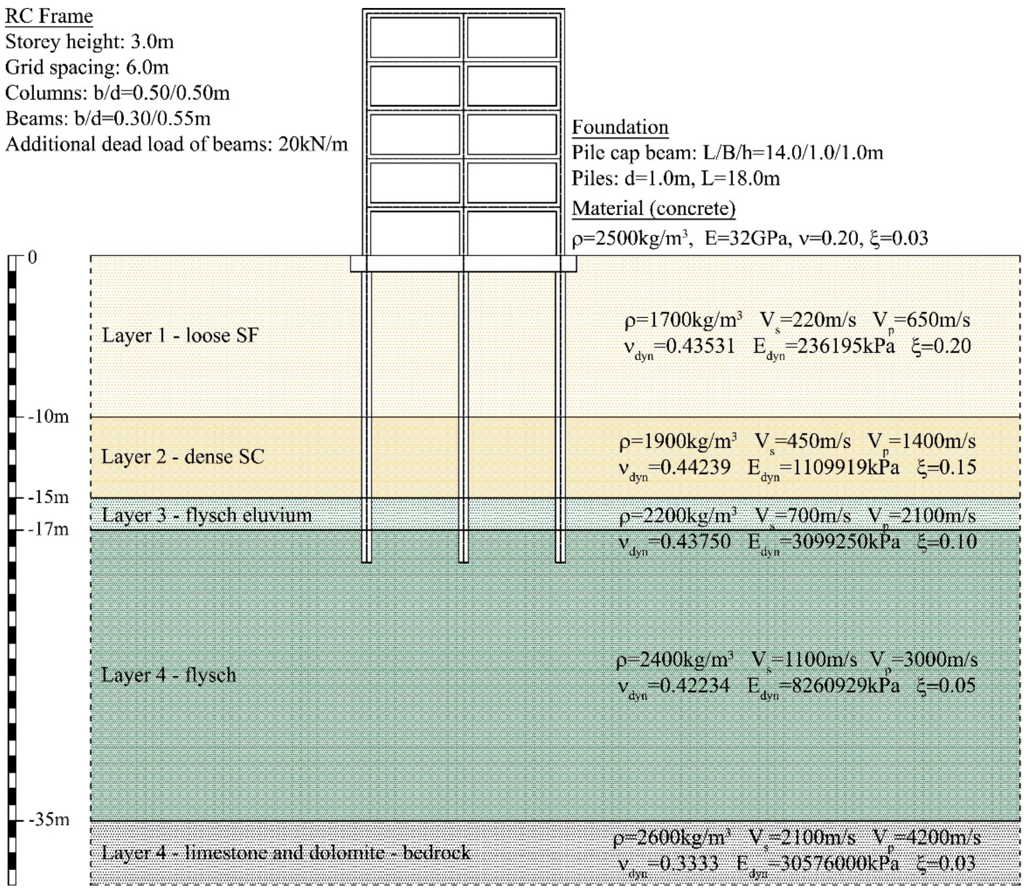

Fig. 1. Analysed SPS system (five-storey RC frame) with characteristics of all elements [8]

The seismic excitation at the bedrock level (z=-17m) is defined by the input accelerogram (Fig. 2). As already mentioned, the vertical convolution of SH seismic waves (input accelerogram) from the bedrock level to the ground surface was adopted.

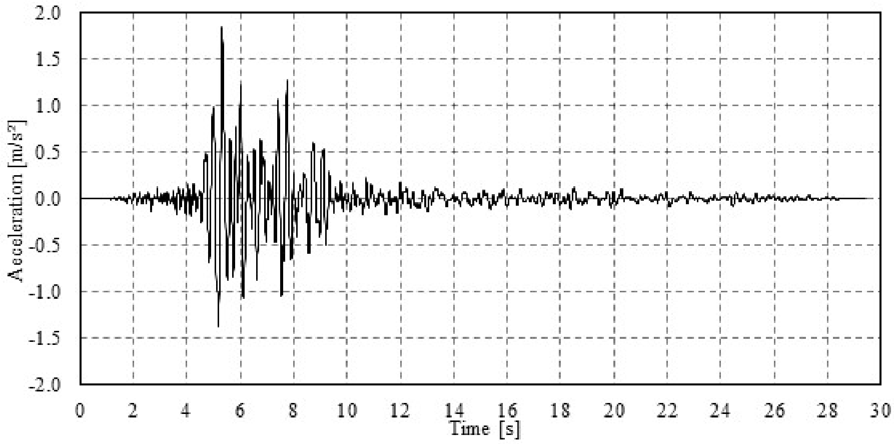

Fig. 2. Input accelerogram (26.09.1997., Assisi, province of Perugia, region Umbria, Italy, direction East-West, Mw=6.0, epicentre distance 21.6km) [8]

2.2 Model for numerical analyses

To obtain the results presented in this paper, the same or very similar numerical models, which are described in detail in [8], were used. For analysed SPS system 2D numerical models are formed in the FEM software Real-ESSI Simulator (Fig 3). As stated in [8], during the formation of these models, two additional (fictitious) soil materials must be defined. The first is DRM layer soil material. Second is Damping layer soil material. Both materials have the same material characteristics as material adopted for soil layer 1, except Rayleigh damping ratio ξ. DRM layer soil material has no damping i.e. ξ=0. For soil layers 1, 2 and 3 in which the generation of more pronounced plastic shear deformations can be expected during stronger earthquakes, higher values of the ratio ξ are adopted.

As stated in [8], elastic 3D hexahedral finite elements with eight nodes were used for modelling layered foundation soil and pile cap beam. For foundation soil, two identical vertical "screen" of this element (*B*=*L*=*H*=1m) are modelled. For pile cap beam, two identical vertical "screen" of this element (*B*/*L*/*H*=1.0/1.0/0.25m) are modelled. Interface finite elements are not modelled at the boundary between different soil layers. Elastic line (beam, 1D) finite elements (*L*=1m) with two nodes used for modelling all beams, columns and piles. Suitable geometric and material characteristics for these elements are adopted based on dimensions of their cross-sections and the concrete material characteristics (Fig. 1). In the performed 2D dynamic analyses all nodal displacements in the Y-axis direction are disabled (equal to zero).

As stated in [8], the linear-elastic, zero-thickness interface finite elements without damping are used for modelling the stress-strain interaction between the pile cap beam and foundation soil i.e. between piles and surrounding soil. These elements have constant normal stiffness (K_N) and unlimited normal compressive strength. It's about the elements they don't have tensile strength (stiffness). Their shear stiffness is constant until the shear strength τ_f is reached. After that, their shear stiffness is equal to zero. The well-known empirical solutions (see [8]) are used for calculating normal and shear stiffness of the applied interface finite elements.

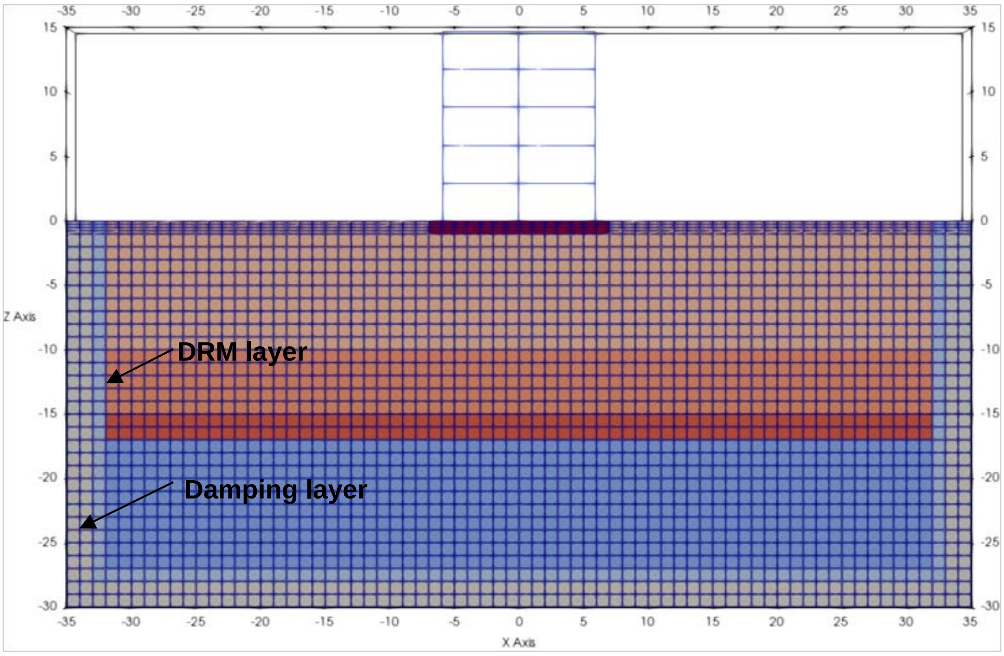

Fig. 3. One of the formed numerical models of analysed SPS system (five-storey RC frame) [8]

3 RESULTS

The following figures show the HAERS at the base level of RC frame with ξ=5% obtained in the performed DRM dynamics analyses. In those figures, the black solid line (Output) shows the obtained HAERS at the level of the bedrock, which is identical to the HAERS of the input accelerogram (Fig. 2). The black dashed line (Output_FF) shows the HAERS formed for the central point on the soil surface (x=y=z=0) for the model without RC frame and piles ("free-field" model), which was subsequently formed. Other lines show the obtained HAERS for the base level of RC frame i.e. for the central point of the pile cap beam in the cases with different distances between piles *s* and with different storeys of the RC frame (st5 or st10).

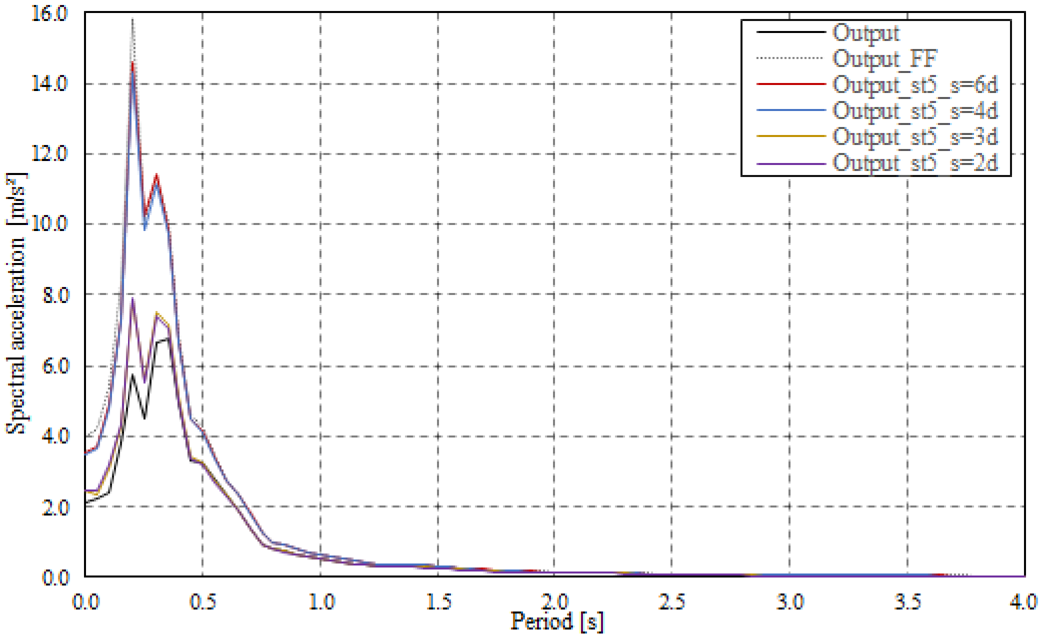

Fig. 4. Complete HAERS at the base level of five-storey RC frame with different distances between piles (ξ=5%)

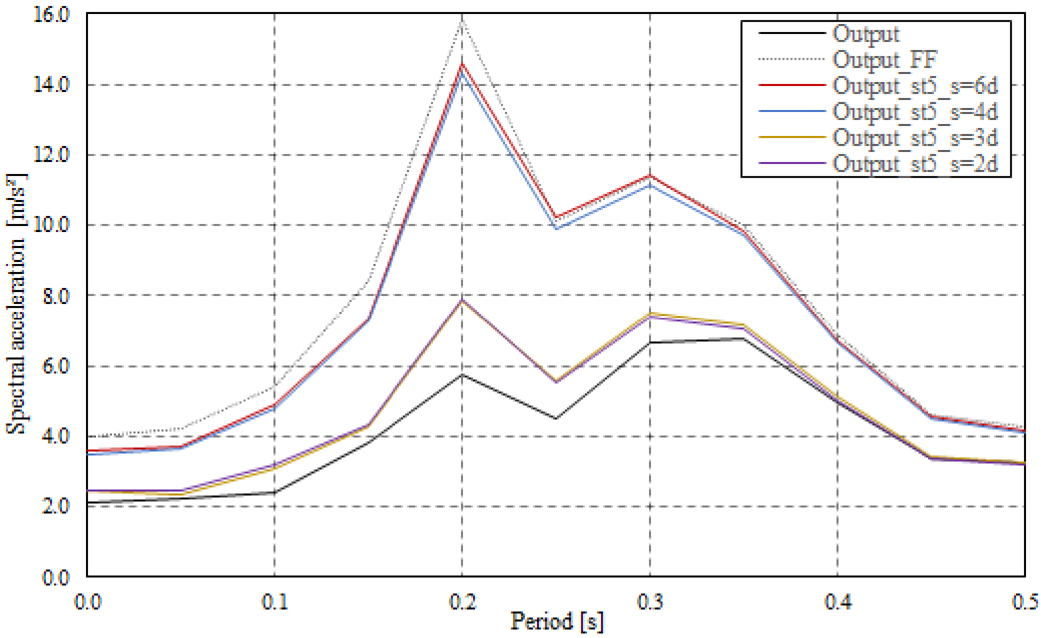

Fig. 5. HAERS at the base level of five-storey RC frame with different distances between piles for period from 0 to 0.5s (ξ=5%)

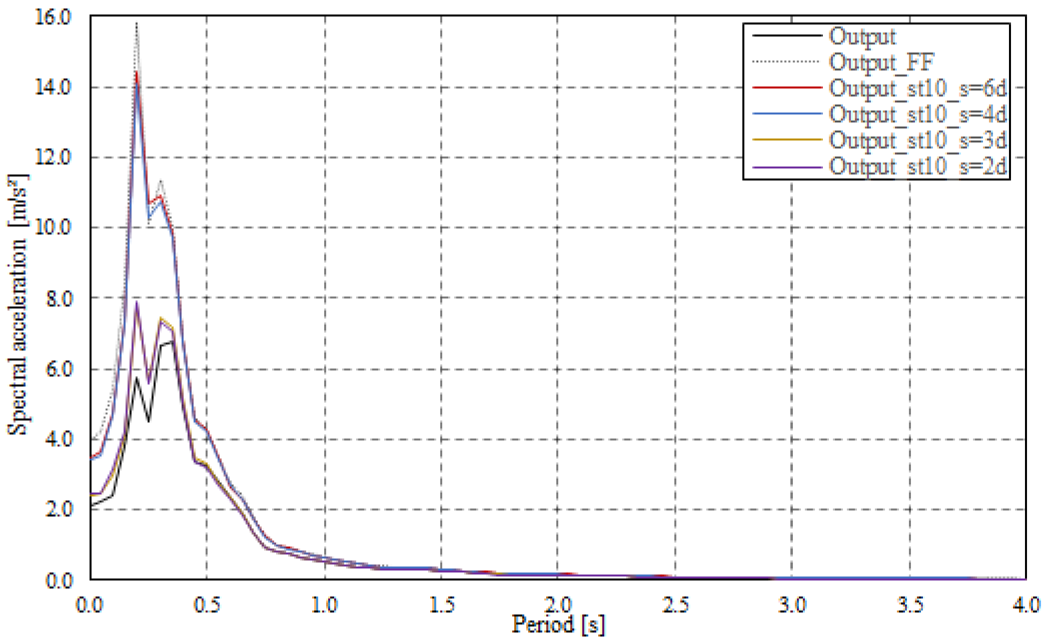

Fig. 6. Complete HAERS at the base level of ten-storey RC frame with different distances between piles (ξ=5%)

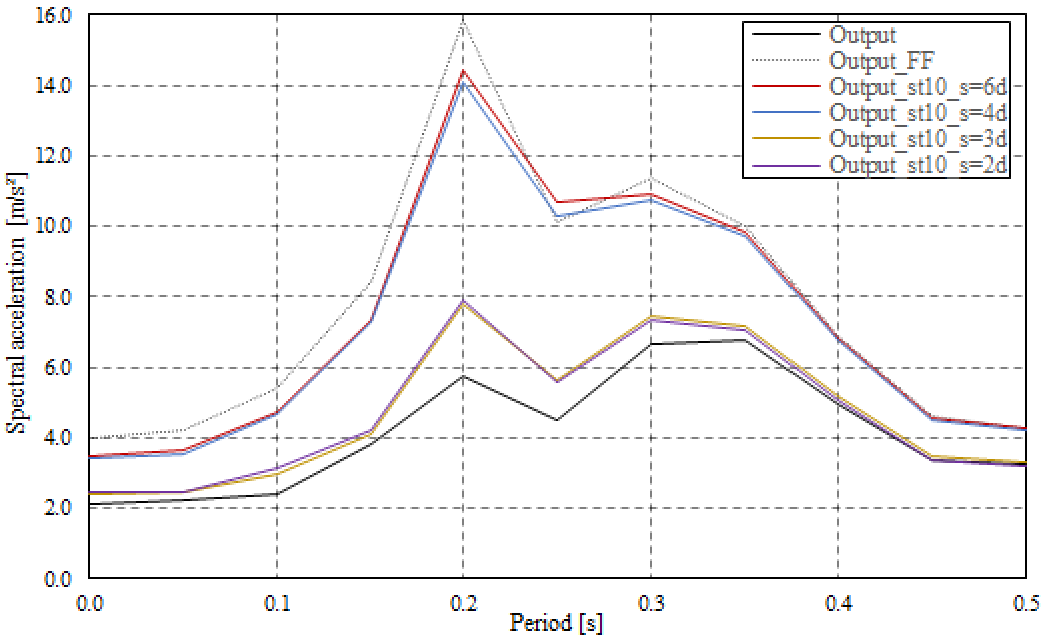

Fig. 7. HAERS at the base level of ten-storey RC frame with different distances between piles for period from 0 to 0.5s (ξ=5%)

4 CONCLUSIONS

Examining the outcomes of the performed DRM dynamic analyses, several interesting observations can be made. First of all, it can be stated that almost identical HAERS were obtained at the base level of the five-storey and ten-storey RC frame. So, in this particular example, the change in the storey number of the RC frame does not affect the results of the analyses i.e. does not affect the shape obtained HAERS. Secondly, for distances between piles 6d or 4d, HAERS at the base level of RC frame are very similar to the HAERS denoted by Output_FF. Obvious, in these cases, the piles "follow" the movement of the surrounding soil during an earthquake and almost do not affect the seismic excitation of the superstructure (RC frame). Inertial seismic load of the RC frame is very similar to the seismic load to which the RC frame would be exposed if it was founded on shallow foundations at a depth of z=-1m. Since the piles "follow" the movement of the surrounding soil during an earthquake, the kinematic seismic load has low intensity. Thirdly, for distances between piles 3d or 2d, horizontal spectral accelerations are practically equal and at the same time significantly smaller than the horizontal spectral accelerations in the situations where the distance between piles is 6d or 4d. This means that the superstructure is exposed to a significantly lower inertial seismic load. It is clear that in situations with distances between piles 3d or 2D, the influence of the piles that are fixed in the bedrock on the seismic load of the superstructure is very significant. Fourthly, for distances between piles 3d or 2d, the piles significantly "resist" the movement of the surrounding soil during an earthquake. Therefore, there is a significant relative displacement between the surrounding soil and the piles, so the kinematic seismic load of the pile-supported structure becomes very important.

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