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Research Article

KINEMATIC INTERACTION EFFECTS ON THE SEISMIC BEHAVIOR OF PILE GROUP

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ABSTRACT
The first step to design a deep foundation is its choice in terms of objectives. Economic, technical, operational, and environmental factors as well as general feasibility are most effective in regards to mentioned in the previous section. In this section we will describe the basic requirements for the design of piles. These needs include definition, basic knowledge, philosophy of designing, philosophy of safety factors and geotechnical data. The foundation transfers the top loads to soil of foundation, so as not to create too much stresses and additional subsidence. Thin and pillar piles are elements which transfer the loads to deeper layers vertically or slightly inclined. The piles are usually D/B>10 in which D is the depth of pile bottom and B pile cross. According to the clause no.7 of National Building Regulations if the ratio of width to height of foundation is less than 1.6m and its depth exceeds 3m we would have Deep Foundation. Each pile has three lifetimes include installation, set up, and constant loading.

Keywords: *Seismic Behavior*

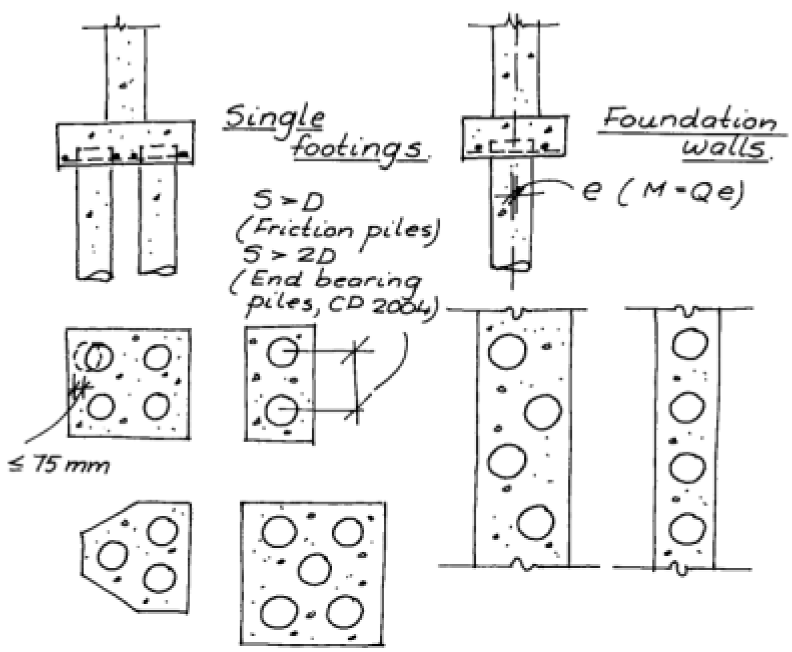
INTRODUCTION
Deep foundation system (pile) is recommended when at least one of the following conditions is satisfied:

1. Soil layers lack sufficient strength and also more strength soil layers could be found in the lower depths. In other words, even if the spread foundations are used and loading capacity couldn't be provided by the surface layers.
2. If the surface layers are subsiding, swelling, collapsing, or fluency or the structure is very sensitive to the subsidence
3. Despite the resistance of the surface layers of the soil, there is rinsing-problem, such as rinsing of the medial edge, or backpack bridges and coastal structures.
4. Large concentrated loads should be transferred to the soil so that tolerance of these loads by surface foundations, even extensively, is not possible
5. The level of groundwater in the area is high or it may be artesian pressure in the soil layers, so there is no possibility of construction of shallow foundations.
6. The presence of water in the soil and Offshore Structures.
7. Increasing stiffness of soil under machinery to control the amplitude of vibrations of the foundation and also control the natural frequency of the system.
8. Resistance against tensile forces or overturning of underwater foundations or prevention of overturn the high structures.
9. Create braces against horizontal forces and earthquake forces or shock absorbing in docks.
10. Controlling slip and ground run and increase of slopes stability.
11. Checking and removing the consequences of future construction in the vicinity of the existing projects or buildings.
12. In some cases, the piles without transferring the load directly cause to increase loading capacity, density and stiffness of the soil. In other words, grinding some piles with spaces, for example, on a checkerboard grid plan could be applied as a way to reform and strengthen the soft soil.

Piles are often used individually or in groups. The simplest group of piles may be formed by 2 or 3 piles which are connected together through cap or triple pile cap.

Example of a Deep or Chest Foundation

Larger groups have more piles which are connected together through beams or caps.



Examples of Pile Group

Cap plays role of an expanded foundation:

- Distribution of topside power among the piles
- Tying the piles to one another and act as a single group

Sometimes single caps are connected together through the buried beams are buried which are similar to strip foundations but with different efficiency.

Section of piles includes circle, square, hexagonal, octagonal, hexagonal sixteen, H shape, and even the triangle shape that could be used as hollow or solid; wall of piles can be smooth or rough.

And top of pile can be sharp or flat. In some cases a sharp or flat shoes can be used on top of the pile. A tubular pile also can be used with an open and a closed tip.
Most piles are made of wood, concrete or steel. Each of these materials has their own positive and negative properties and limitations. Selection of a suitable pile depends on important parameters such as topside properties, its usage, loading, equipment and installations of piles, soil conditions, and the performance and durability of the pile material. Generally for choose of the pile, the following points should be noted:

a) Type of structure, topside properties, usage, and loading mode
b) Type and importance of the project
c) Pile diameter and length
d) Availability of materials and ease of preparation pile
e) Local soil conditions
f) The performance and durability of the materials in the pile in environmental conditions
g) Installation and equipment of pile
h) forecasting and considering of environmental factors during project execution

Piles with relatively large displacements are most suitable for use in marine structures. The prefabricated or pre-spin solid concrete piles could be used in shallow waters and are not applicable in deep waters, because the piles are very heavy and it is difficult to move them. In deep waters the tubular steel or prefabricated concrete piles should be used.
Like other geotechnical structures, in order to design the piles the interaction between pile and adjacent soil should be considered; and requires two sets of calculations. Calculation of the balance is the first step which determines the parts of the structure and geometry due to the resistance of the soil and the external forces.
The second step is related to the calculations which determine the degree of detail and special properties of structures resistance against the loads of bending moments and shear forces that are calculated through balance calculations.
Both calculation steps could be used according to the principles of limits and special modes in designing process. Special modes should be sufficiently critical because in case of taking place during the construction process as well as during operation over the lifetime of the wall under the worst loading conditions, do not remove it from the acceptable operation process.
Most of the previous research on the dynamic behavior of pile group has been done by the use of the elastic behavior of soils. However, it should be noted that due to severe earthquakes, and also due to the nonlinear behavior of the soil and distance between the pile and the soil many different effects on the response of the foundation could be occurred. Interruptions occurred during past earthquakes showed that the nonlinear behavior of the soil must be considered in the analysis of the pile.
In this case, the analysis should be carried out as time history in order to evaluate non-linearity of the soil and separation of pile and soil. In the recent years, researches have focused on the behavior of the pile groups. Nogami (1986-88) has studied the behavior of piles in a time history by the use of Winkler Model. Nogami *et al*., (1992) decided to do Time History Analysis of pile group through mass and damper systems. El Nagar and Nowak (1995-1996) have done the nonlinear time history analysis of pile groups by the use the Winkler hypothesis.
Maximum ground acceleration at the time of earthquake is a critical factor for designing and the main reason of damages that is calculated based on coefficient of g of acceleration due to gravity. Maximum velocity of particle on the earth is another critical factor in order to determine the rate of damages. Whereas frequency of vibration structure is close to frequency of vibration generator, resonance circumstance would be occurred. Studies showed that earthquake waves are composed of low frequency and high wavelength.
Whatever the structure is get away epicenter, damages would be negligible. It should be noted that at low frequencies, damping of vibration amplitude is higher, so that energy loss is proportional to the inverse square of the distance in volume waves, and is proportional to the inverse distance in surface waves.

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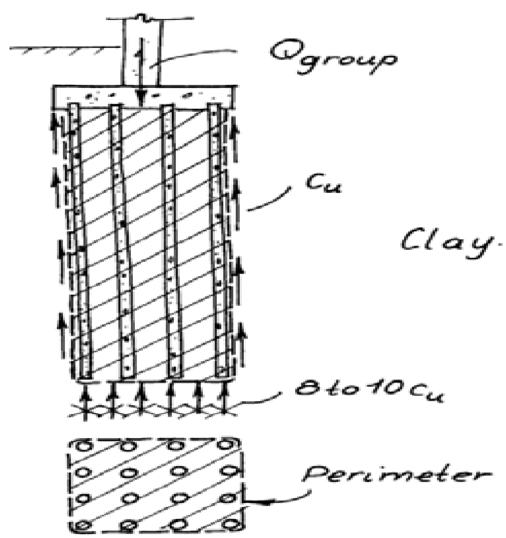
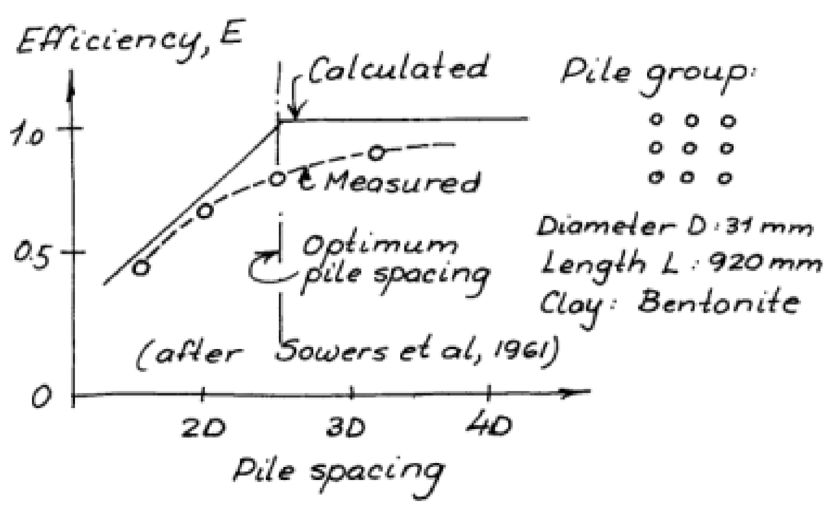
Earthquakes generally have a low frequency and number of cycles of stress is high. The frequency of vibration of structure - especially those which enter the structure into a nonlinear area – is recognized as an important factor in order to increase damages of the structure. Durability and the number of vibrations cause fatigue phenomena, so it means that large deformations in the structure could be occurred.
Faulting is the cause of an earthquake. In various fields of Civil Engineering and Construction study of urban vulnerability, due to the limited size of the structures and the very low probability of intersection of these structures with fault location, is inevitable.
Ensure the operation of structure and pile group depends on its foundation. Obviously, the first step in the successful design of structure is to have sufficient and required information about the local soil, subsidence, resistance and the factors influencing them. Soil mechanics is considered as a principle in this case, and before applying rules, it is necessary to provide sufficient information such as type and engineering properties of the ground. Thus study of relatively deep soil in the project site could reduce the high costs of significant designs and or could remove risks of insignificant designs. Survey and evaluation of the ground (soil) as well as providing the required information could be useful in order to achieve a safe and economic design of foundation.
Pile Group in Clay





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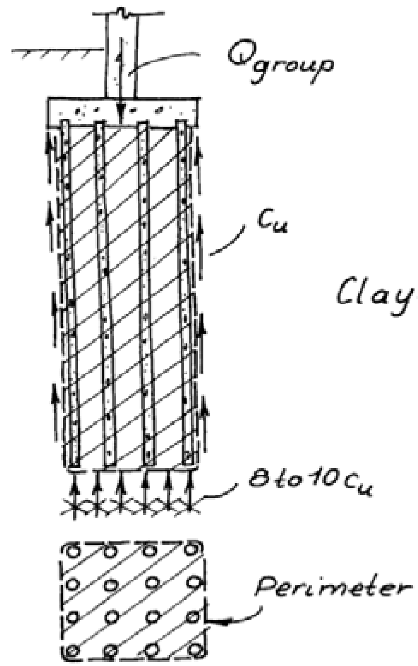
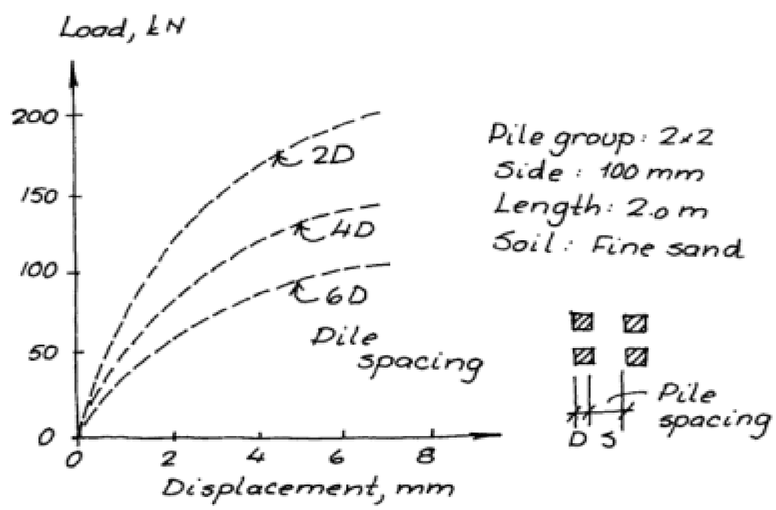
Pile Group in Sandy Soil





In this study, kinematic interaction of pile group has been evaluated under earthquake loading through three-dimensional finite element method. The studies presented in three steps, in the first step, a reference example has been explicitly studied. The second step includes the piles spacing affecting on the pile response, finally in the last step, the number of piles affecting on the pile group behavior are discussed.
The reference example of pile group of 3×3 with a space S = 3D (D = pile length) within a homogeneous soil with height H = 15m on bed rock, tip of piles is assumed to be free and length of pile is 10m with dimensions of 20×20 cm^2. Elasticity Modulus and volume mass are equal to E_p=2400MPa and ρ_p=2500kg/m^3 respectively. In regards to the soil, these values are assumed as E=8MPa‹ s =1700kg/m^3. Amortization of Pile and soil is considered about 10%. Earthquake loading is applied into the bottom of the model as a harmonic acceleration with frequency of f=0.67Hz (main soil frequency). There are elected 5304 eight- node elements.

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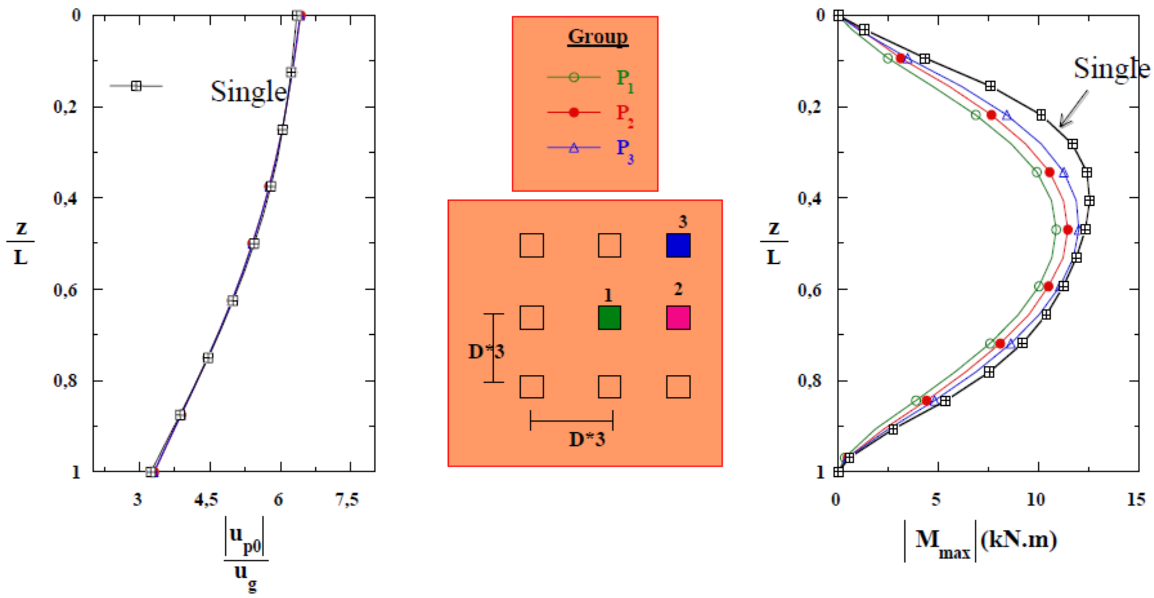
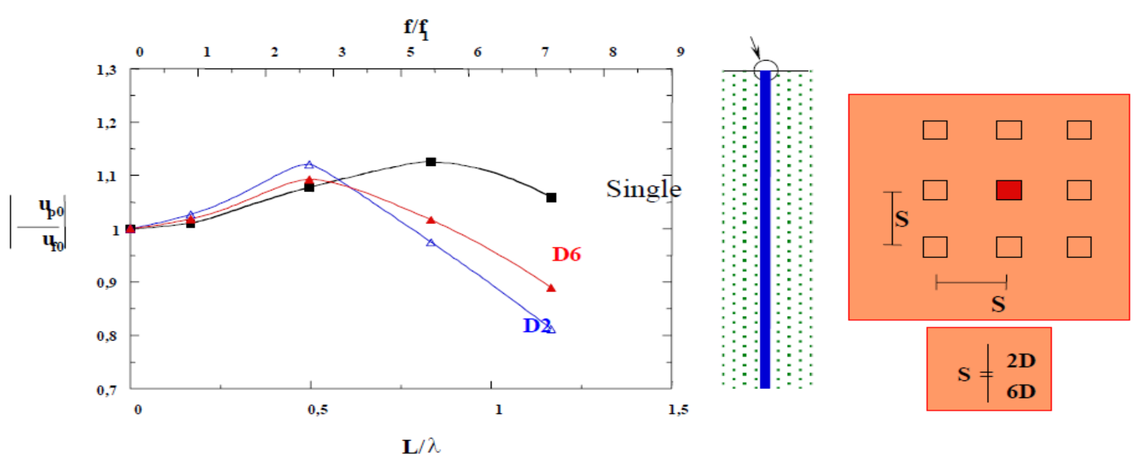
Height of selected element is considered based on λ/10 >Δz (λis wavelength)andΔt=0.005sec. studies show that displacement of pile group is close to single displacement; thus only near to the surface of the ground, displacement of pile group is a little more than the single pile. These results indicate that effects of group pile on the horizontal displacement of tip of pile could be dispensable for the base frequency.
You can also see that the bending moment in group pile is less than a single pile, and also the rate of bending moment in corner pile is more than this rate in the pile in center of the group. Thus the piles on the corner would be damaged more than the piles at the center.



Seismic Response of Pile Groups of 3 x 3
Response of two types of group pile as 3 x 3 and 2 x 1 in space of S=2D and S=6D is studied. It could be noted that the space between the group piles (3 x 3) and 2 x 1 could be neglected up to 0.5 (L / λ) = 1.



Pile Spacing Effects on Amplification of Surface
For larger ratios (L/λ) amplification for pile group was significantly less than a single pile. Reduction of amplification would be more with increasing the ratio of L/λ and reduction of pie spacing will be more. For example, L/λ= 1.17 and space is S = 2D, thus reduction of amplification for group piles of (3 x 3) 2 x 1 was 10 % (25 %).

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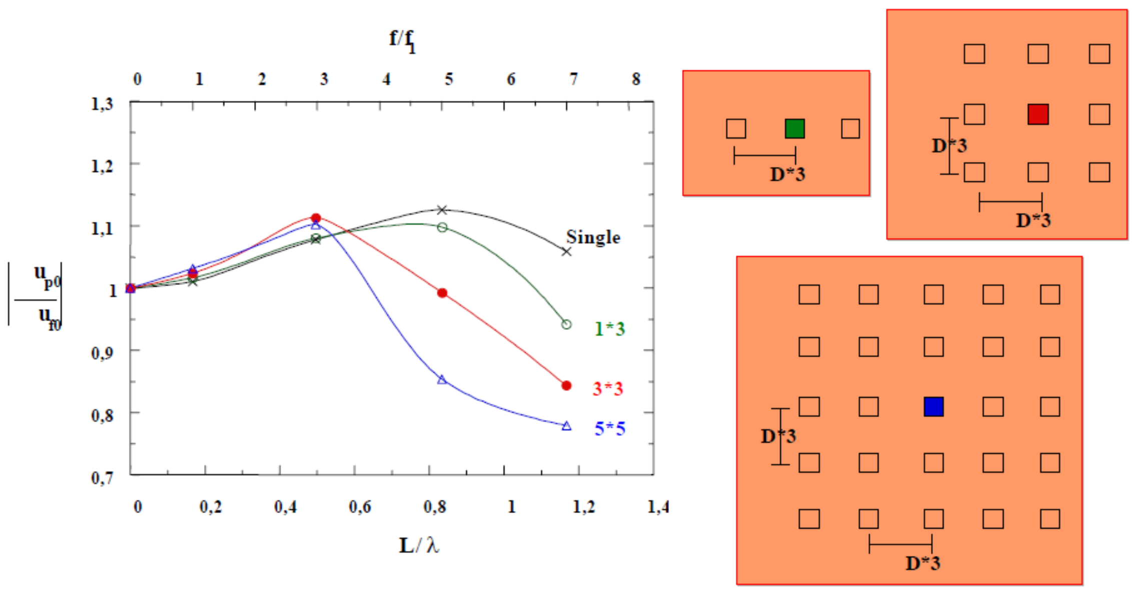
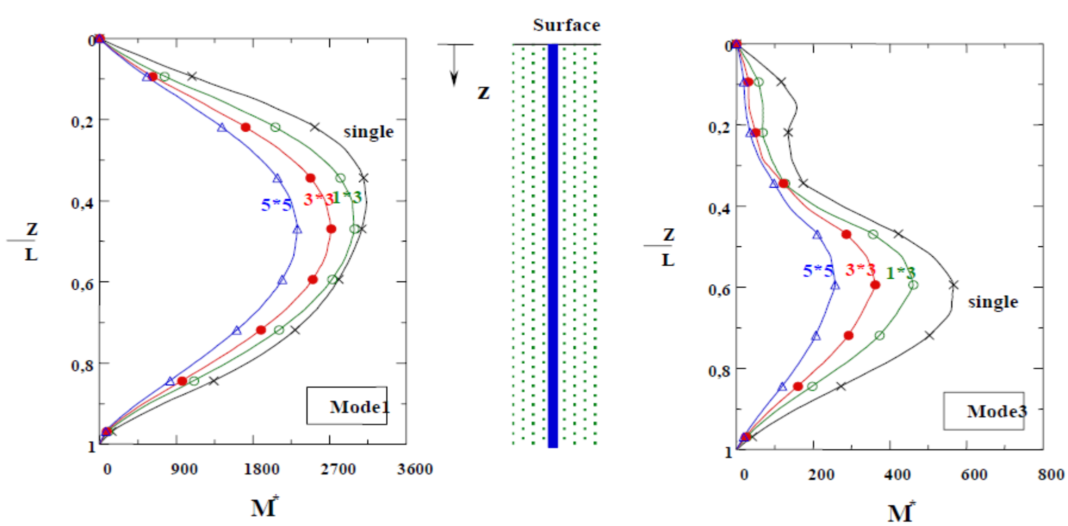
In addition, we found that reducing the space between the piles reduces the bending moment. For example, for the second frequency and space S=2D, reduction of the bending moment for the pile group (3 x 3) 2 x 1 relative to the single pile is 15% (50 %), the results are conformed to the results by Kaynia & Kausel (1982).
In order to study the effects of the number of piles on the behavior of pile group; there were considered five groups: 1x3, 3x3, 1x5, 5x5, 1x2. Graphs and tables showed that the effects of pile group could be neglected if $0.5 \leq L/\lambda$.in terms of $0.5 > L/\lambda$ the effect of pile group will be increased if the number of piles and L/λ are increased. Effect of pile group on 5x5 is very sensitive. For example, for this group, in terms of $L/\lambda = 0.8$, amplification on the tip of the pile is less than 27% of single pile and these results are conformed to the results rendered by Kaynia & Kausel (1982).

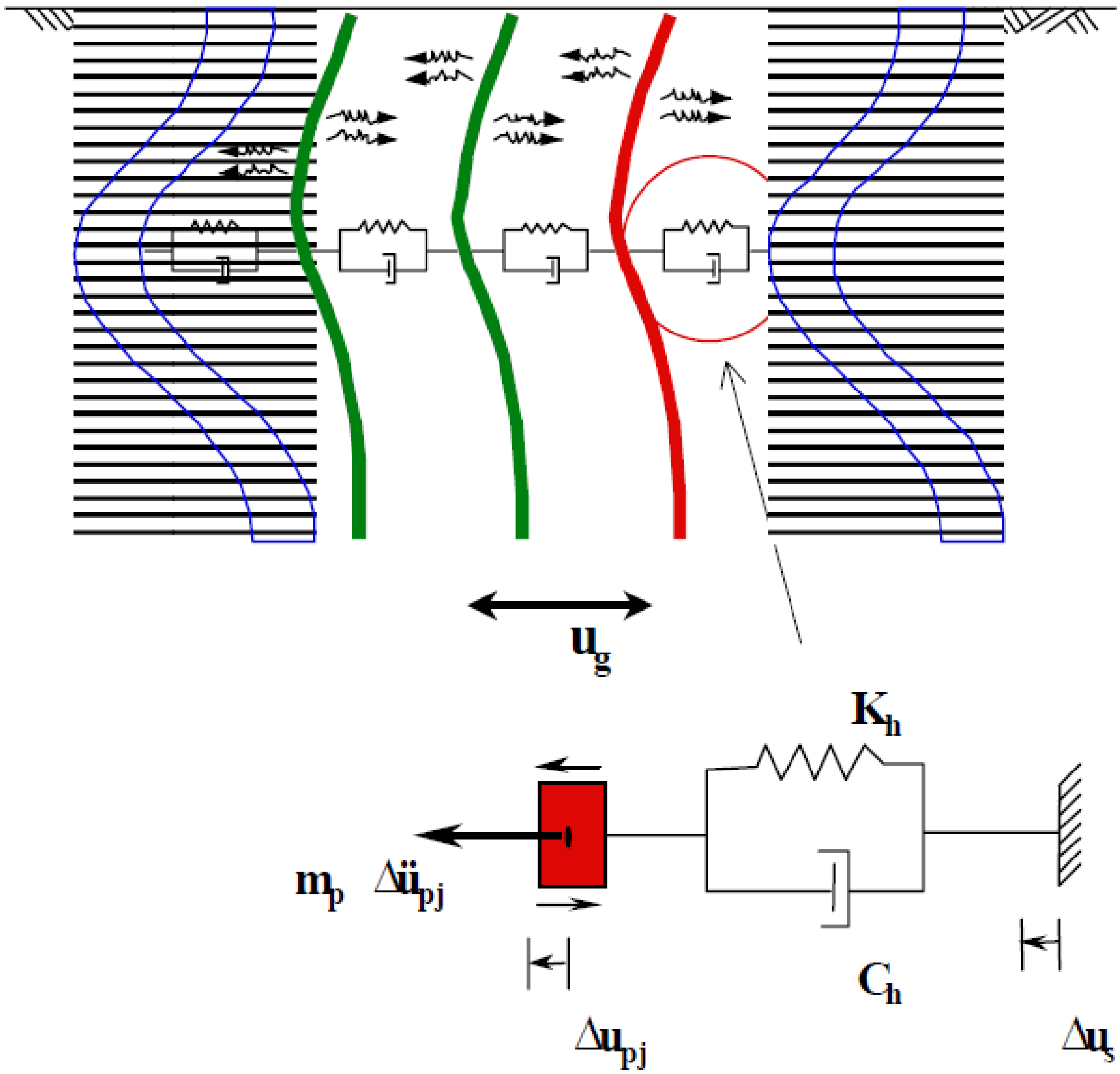


Effect of the Number of Pile on Amplification on the Surface
The bending moment of pile will be reduced considerably if the number of piles is increased. For example, for pile group 5 x 5 and for the fourth frequency, maximum bending moment in the central pile is about 36% of bending moment in single pile.



The Effect of the Number of Piles on the Bending Moment

Study of the cap of bending moment into the central pile for 3 × 3 pile group through Winkler Model and Finite Element Method (provided by Gazetas 1982-1992) shows that the results of both methods for the base frequency is similar. But for frequencies greater than base frequency, the results for bending moment by Finite Element Method is less than the results obtained by Winkler Model. For 4th frequency in Winkler Model, the maximum bending moment (M * max) is about 370, but through Finite Element Method rate of 130 is obtained.



Kinematic Interaction Model for Pile and Soil (Winkler Model)

To find the cause of difference between both methods, results of the bending moment for group pile 3 x 3 is 4% lower than the single pile. The graphs indicate that a pile group with high number (5 x 5) has more effects (compared to pile group with less numbers). Also increases of the bending moment in the pile group 5 x 5 could be understood in pile no. 3 as compared to the single pile.

The space among the pile groups and efficiency of piles in the group has been investigated by this study. Further studies show that if there is greater space among the piles in a pile group, so the efficiency of pile group will be increased.

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