NUMERICAL MODELLING OF CHICKEN-FOOT FOUNDATION

Vipman Tandjiria
Lecturer, Civil Engineering Department, Petra Christian University

ABSTRACT

This paper presents an analysis of the chicken-foot foundation using the finite element method. The foundation is considered as a reinforced concrete slab resting on a number of reinforced concrete pipes filled with and surrounded by in-situ soil. The soil and the pipes were modelled by isoparametric solid elements while the slab was modelled by isoparametric thick-plate elements. The study was intended to illustrate the basic mechanism of the chicken-foot foundation. Three cases have been considered for the parametric studies. The parameters investigated are thickness of slab, length of pipes and spacing between pipes. It is shown that such a foundation improves the behaviour of the raft foundation. It is also found that all the parameters used in the parametric studies influence the behaviour of the chicken-foot foundation.

Keywords: chicken-foot foundation, finite element, foundation.

INTRODUCTION

It is known that the chicken-foot foundation invented by Sedijatmo[1] has been implemented for many toll-road projects in Indonesia. The chicken-foot foundation consists of a reinforced concrete slab of 10 to 20 cm thick and a number of reinforced concrete pipes. The pipe has a diameter of 1.2 to 1.5 m, length of 1.5 m to 3.5 m and thickness of 0.08 m. The spacing between pipes is between 2.0 and 2.5 m. The pipes are filled and surrounded by in-situ soil. The details of the foundation are shown in Figure 1. The basic concept of the chicken-foot foundation considers the passive-soil pressure creating a stiff condition of slab-pipe system. This means that the thin concrete slab floats on the supporting soil and the pipes stay vertical due to the passive soil pressure[1]. The foundation was initially proposed to overcome displacement problems of structures resting on very soft soils.

In spite of the fact that the chicken-foot foundation has been successfully implemented in a number of projects, there have been many arguments on the performance of this foundation. In addition, only few investigations and numerical simulations of this foundation have been done. This study was carried out to provide a clearer explanation on the behaviour of the chicken-foot foundation.

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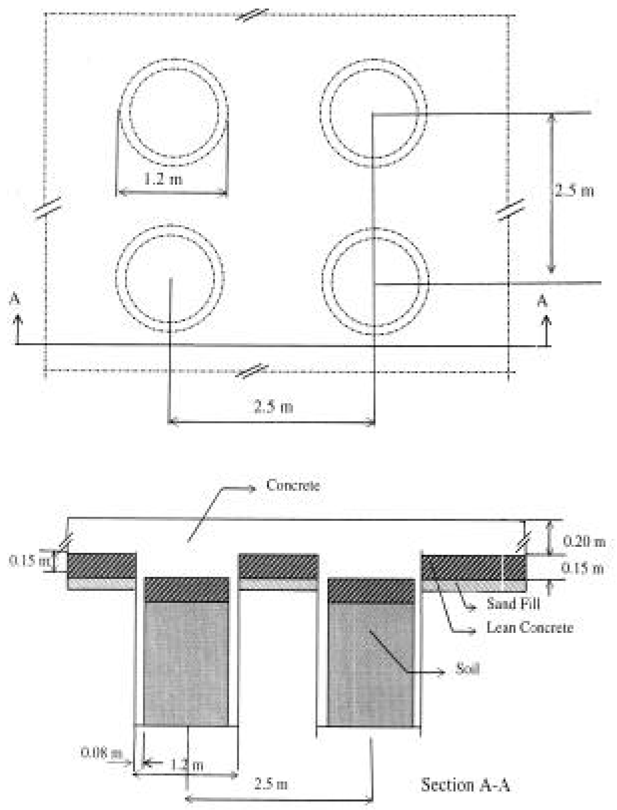


Figure 1. Chicken-foot Foundation

FINITE ELEMENT MODEL

The slab-pipe-soil system was modelled as a three-dimensional system using finite element method. The soil and pipes were modelled using 15-node and 20-node isoparametric solid elements whilst the slab was modelled using 6-node and 8-node isoparametric thick plate elements. Figure 2 shows the element details used in this study.

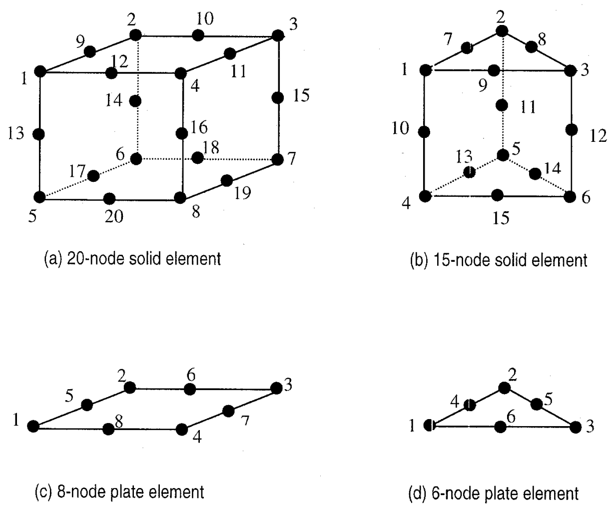


Figure 2. Solid and Plate Elements

Other details of the model adopted in this study were as follows:
(a) linear elastic homogeneous soil
(b) only four pipes below the slab
(c) uniform external loading applied on the slab

A number of parameters of the pipes have been selected in the parametric study. They are the slab thickness, the length of pipes and the spacing between pipes.

The displacement finite element method was chosen in this study. Three assumptions adopted in the displacement method are as follows:

1. displacement distribution is smooth within an element
2. the displacement at the interface between elements is compatible
3. the formulation of this method uses minimum potential energy criterion

The displacement at any point within an elements can be defined in terms of the nodal dis-placements as

$$\{u\} = [N]^T \{d\}^e \tag{1}$$

where

$\{u\}$ = displacement vector at any point within an element

$\{d\}^e$ = nodal displacement vector for the element

$[N]$ = shape function

The strain and the stress can be determined as

$$\{e\} = [B]\{d\}^e \text{ and} \tag{2}$$

$$\{s\} = [D]\{e\} \tag{3}$$

where

$[B]$ = strain displacement matrix (based on geometric property)

$[D]$ = material constitutive relationship matrix

$\{e\}$ = strain vector

$\{s\}$ = stress vector

A virtual displacement $d\{d\}^e$ is applied at the nodes to make the nodal forces staticaly equivalent to the actual boundary stresses and distributed loads.

$$d\{u\} = [N]^T d\{d\}^e \tag{4}$$

$$d\{e\} = [B]d\{d\}^e \tag{5}$$

The external work, W, can be definid as

$$W = \left[d\{d\}^e\right]^T \{F\}^e \tag{6}$$

Internal work per unit volume is

$$U = d\{e\}^T \{s\} - d\{u\}^T \{p\}$$

$$= \left[\{d\}^e\right]^T \left[[B]^T \{s\} - [N]^T \{p\}\right] \tag{7}$$

where $\{p\}$ is a distributed load vector.

Equating the external work with the internal work, and then eliminate $\left[d\{d\}^e\right]^T$ from both sides, the following formulation is obtained.

$$\{F\}^e = \int_v [B]^T \{s\} dV - \int_v [N]^T \{p\} dV \tag{8}$$

or substituting for $\{e\}$ and $\{s\}$ from (2) and (3)

$$\{F\}^e = \int_v \left([B]^T [D][B] dV\right)\{d\}^e - \int_v [N]^T \{p\} dV \tag{9}$$

Then, using the stiffness approach,

$$\{F\}^e = [K]^e \{d\}^e + \{F\}^e_p \tag{10}$$

where,

$\{F\}^e$ = total force vector at the nodes of an element

$\{K\}^e$ = stiffness matrix for an element

$$= \int_v [B]^T [D][B] dV \tag{11}$$

$\{d\}^e$ = displacement vector at the nodes of an element

$\{F\}^e_p$ = nodal force vector due to distributed loads

$$= -\int_v [N]^T \{p\} dV \tag{12}$$

The strain-displacement matrices and the material constitutive relation matrices for the elements used in this study are not discussed here. They can be found in[2].

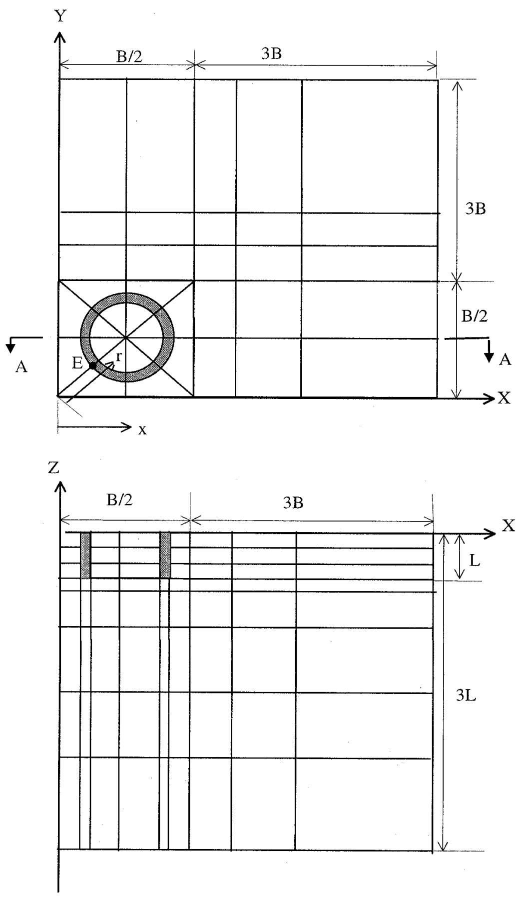
The parameters used in this study were as follows:

- initial thickness of slab = 0.1 m
- initial length of pipe = 2.5 m
- initial spacing between pipes = 2.5 m

Other parameters or dimensions of the foundation system were:

- width of slab (B) = 5.0 m
- outer diameter of pipes = 1.2 m
- pipe thickness = 0.08 m
- elastic modulus of surrounding soil (E_s) = 3 MPa
- Poisson's ratio of soil = 0.3
- elastic modulus of pipes = 25000 Mpa
- elastic modulus of slab = 30000 Mpa
- Poisson's ratio of concrete = 0.20

The finite element mesh of the chicken-foot foundation is shown in Figure 3.



Section A-A

Figure 3. Finite Element Mesh

NUMERICAL RESULTS

A. Comparison of Structural Behaviour between Chicken-foot and Raft Foundations

The results obtained from this study using the initial parameters listed in the previous section provide a comparison of the structural behaviour of the chicken-foot foundation and the raft foundation.

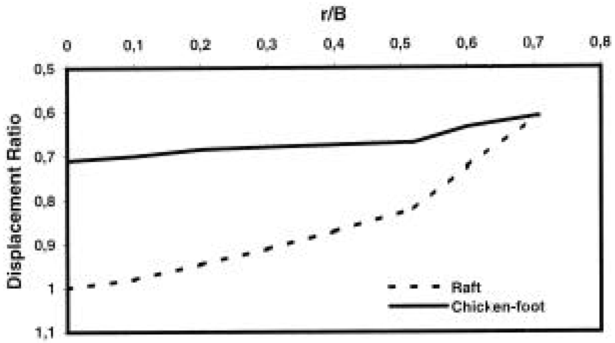


Figure 4. Displacement Ratio versus r/B

Figure 4 shows the displacement ratios of the chicken-foot foundation and the raft foundation along the diagonal of the raft. The displacement ratio is the ratio between the displacement of the chicken-foot foundation to the maximum displacement of the raft foundation. It can be seen that the maximum displacement of the chicken-foot foundation is only 70 % of that of the raft foundation. It is also noticed that the differential displacement obtained is 26 % of that obtained from the raft foundation. This supports the initial idea claimed by the inventor about the performance of this foundation to overcome excessive differential displacements for rafts on very soft soil.

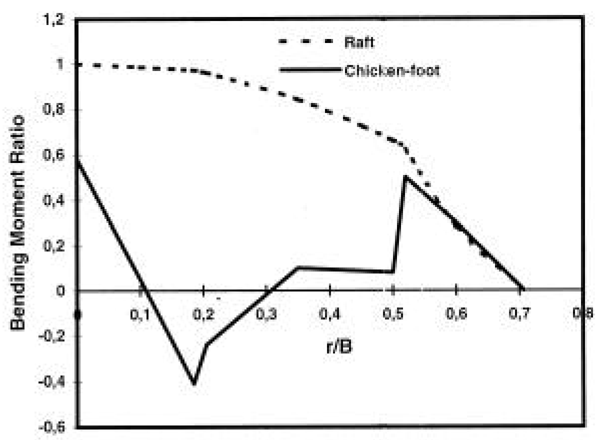


Figure 5. Bending Moment Ratio versus r/B

Figure 5 shows the bending moment ratios of the chicken-foot foundation and the raft foundation along the diagonal of the raft. The bending moment ratio is the ratio between the bending moment in the raft of the chicken foot to the maximum bending moment occuring in the raft foundation. In terms of the bending moments occuring on the raft, the raft foundation gives a pattern of bending moments which look like the pattern of bending moments of a simply supported beam under a uniform loading. On the other hand, the bending moments of the chicken-foot foundation fluctuate. The bending moments decline from the centre of the slab to the edge of the pipe near which they are negative. At the position of the pipe, the bending moments obtained are small and after passing the pipe, they increase suddenly before directly decrease to zero at the corner of the slab.

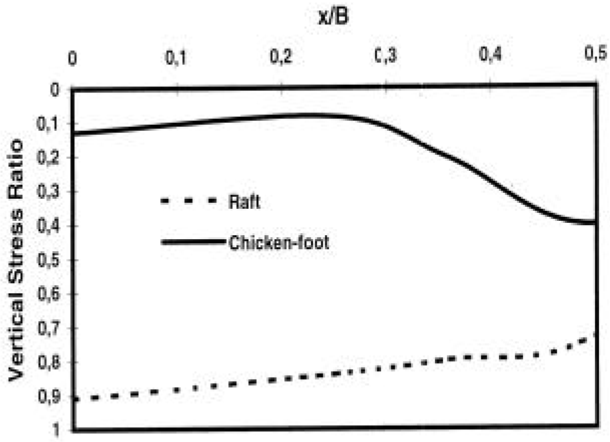
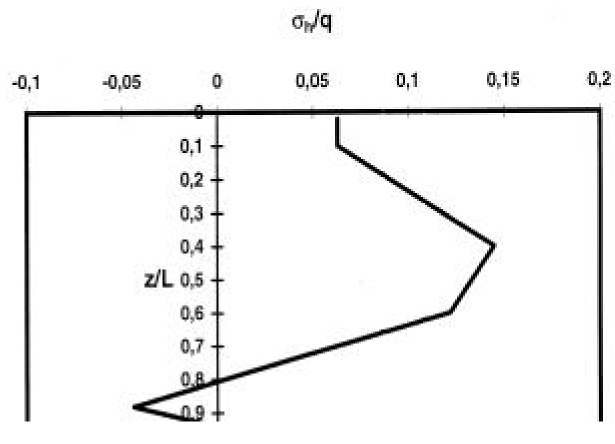


Figure 6. Vertical Stress Ratio versus x/B

Figure 6 shows that in the case of the raft foundation, the vertical stress ratio is nearly uniform over the width of the raft. The vertical stress ratio is the ratio of vertical stress, σ_z, to the applied pressure, q. In the case of the chicken-foot foundation, there is a significant variation of stresses between the centre and the edge of the raft. The stress is nearly 3 times larger at the edge. This is contrary to the idea of the inventor that a uniform ground pressure is created by the chicken-foot foundation[1]. However, the stresses created by the chicken-foot foundation are smaller than those yielded by the raft foundation. The lateral stresses along the length of the pipe are shown in Figure 7. This distribution is also different compared to the original concept of the chicken-foot foundation that is a triangular pattern [1].



B. Parametric Studies of the Chicken-foot Foundation

In the present study, parametric studies of the chicken-foot foundation have been performed. The following section will discuss the results of the parametric studies. The structural responses such as displacement and bending moment are dimensionless.

Figure 7. Lateral Stress alonng the Lengh of the Pipe

Case 1: <u>Slab thickness</u>

Figures 8a to 8c show maximum displacements, maximum differential displacements, maximum bending moments on the slab and percentages of total load taken by the pipes and raft versus thickness of the slab. The maximum displacements initially decrease with increasing slab thickness and after a slab thickness of 0.2 m, the displacements increase with increasing thickness of the slab. This is due to increase in the self-weight of the slab. The differential displacements initially decrease and then remain constant after a slab thickness of 0.3m. This results may suggest that a slab thickness more than 0.3 m is not recommended since further increase in the slab thickness does not reduce the differential displacement.

Varying the slab thickness influences the values of maximum bending moments. On one hand, there is a change of sign of the maximum bending moment at point E, i.e. from negative to positive bending moments after passing a slab thickness of 0.2 m. On the other hand, the maximum bending moments at the centre of the foundation (point O) increase with increasing slab thickness.

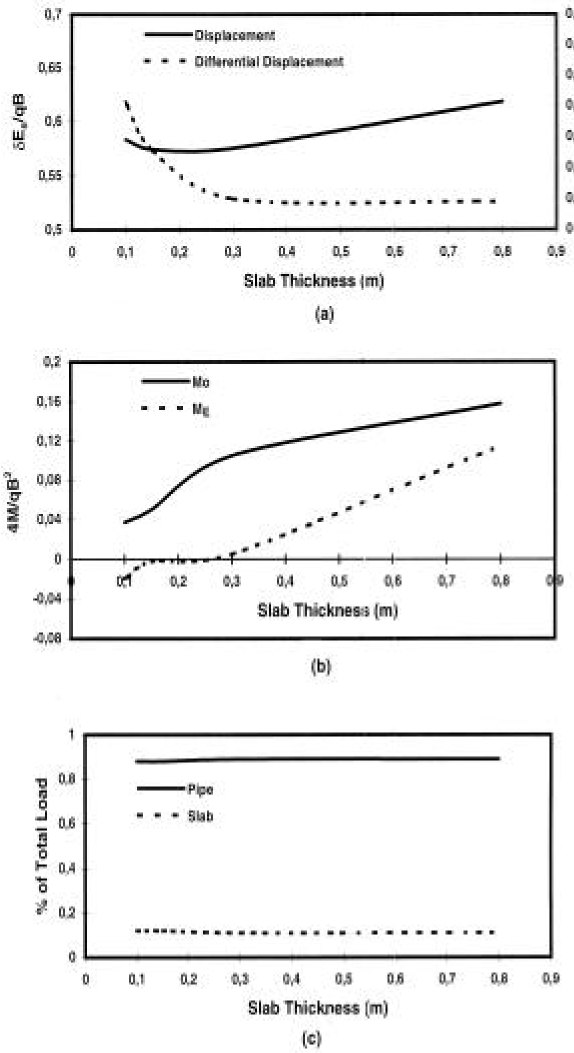


Figure 8. Structural Behaviour of Chicken-foot Foundation with respect to Slab Thickness

The percentages of total load taken by the pipes and the slab are almost constant for all the slab thicknesses considered. This may be due to the assumption of linear elastic adopted in the whole system.

Case 2: Length of pipe

Figures 9a to 9c show maximum displacements, maximum differential displacements, maximum bending moments of the slab and percentages of total load taken by the pipes and the slab versus the length of the pipe.

The maximum displacements, differential displacements and bending moments decrease with increasing length of the pipe. Further, it can be stated that the curves shown in Figures 9a to 9c are similar to those obtained for solid pile-group foundation[3,4] .

The percentages of total load taken by the pipes or slab in terms of the length of the pipes are identical with those obtained from the conventional analysis of pile-group foundation. Longer piles take more load[4] .

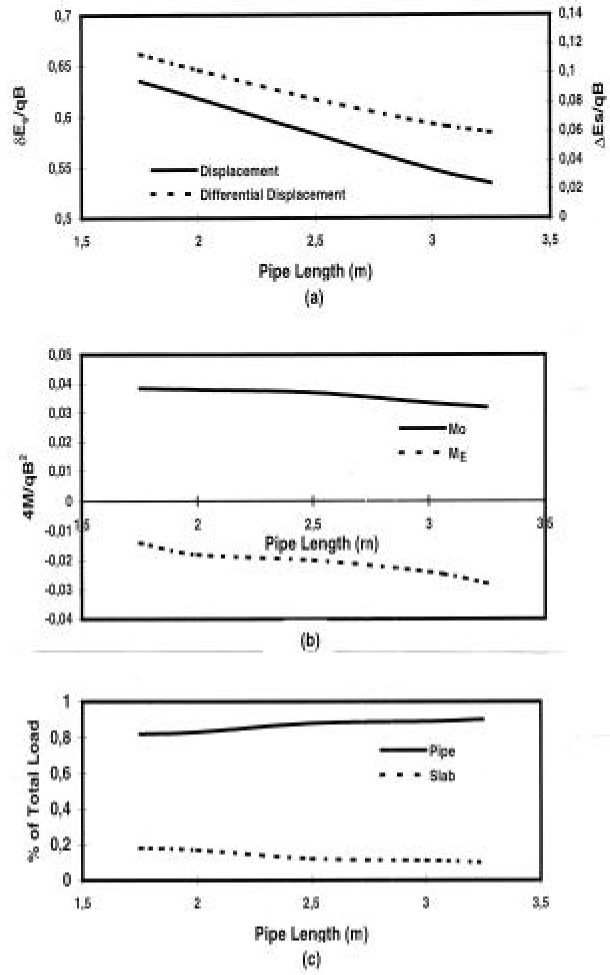


Figure 9. Structural Behaviour of Chicken-foot Foundation with respect to Length of Pipes

Case 3: Spacing between pipes

Figures 10 a to 10 c show maximum displace-ments, maximum differential displace-ments, maximum bending moments on the slab and the percentages of total load taken by the pipes and the slab versus spacing of pipes.

It can be seen that the maximum displacements initially decrease with increasing spacing and then increase after reaching a spacing of 2.5 m. In addition, closer spacings provide smaller differential displacements. Based on these results, the smallest spacing which meets the minimal spacing required for installation may be used in design although it can not provide the smallest maximum displacement.

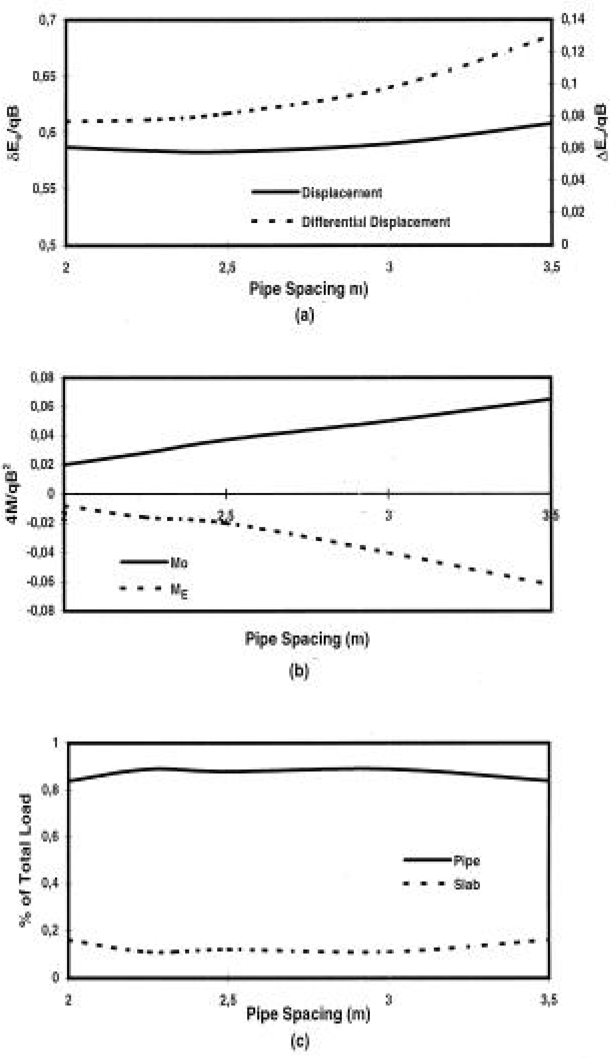


Figure 10. Structural Behaviour of Chicken-foot Foundation with respect to Spacing between Pipes

The maximum bending moments increase with increasing spacing between pipes as shown in Figure 9b.

The load taken by the slab and the pipes does not change significantly when the spacing is altered.

CONCLUSIONS

The behaviour of chicken-foot foundations has been investigated by means of the finite element method. Complete interaction effects among slab, pipes and soil have been considered in this study.

It can be concluded from the results obtained that the use of a chicken-foot foundation may provide a better performance compared to the raft foundation. It gives less maximum displacement and differential displacement. Furthermore, the maximum bending moments are also smaller than those of the raft foundation.

One of the important findings of this study is that the ground pressure created by the chicken-foot foundation is not uniform. The stresses being concentrated near the side of the slab.

Based on the results of the parametric studies, it can be concluded that with increasing slab thickness the maximum differential displacement decreases while the maximum displacement increases, especially for thick slab, the maximum bending moments tend to increase. The percentages of total load taken by the pipes and the slab are nearly constant.

The effect of increasing the length of the pipe is the general reduction in the maximum displacement, differential displacement and bending moment. The percentages of total load taken by the pipes increase with the increase in the length of the pipe.

The effect of increasing spacing between the pipes is a general increase in the maximum displacement, differential displacement and bending moment. The percentages of total load taken by the pipes and slab do not change significantly with spacing between the pipes.

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