Representation of Micropile Parameters Relations in Pre-Designing

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SUMMARY:
Because of several benefits (e.g. high flexibility during seismic conditions, easy and high speed in construction, small volumes of excavation due to small diameter, slim equipment for installation and etc.) Micropiles have been applied in new foundation construction as well as retrofitting of old and damaged structures.
The design of Micropiles consists of two basic aspects: the geotechnical load capacity evaluation and the structural load capacity and stiffness performance of the Micropile section (FHWA-SA 97-070). A primary selection of essential Micropiles parameters is vital for every designer in pre-designing as well as professional analysis methods (e.g. structural and geotechnical FEM, etc.).
This study has utilized simple equations to represent relations between several parameters (e.g. head distances grids in plan and micropile stiffness vs. soil stiffness constant (ks) and applied pressure values) to present some graphs by the aim of pre-designing simplification and more speed in selecting of primary Micropiles parameters.

Keywords: Micropile, pre-designing parameters, structural and geotechnical aspects.

1. INTRODUCTION

The long-term performance of Micropiles has been proven after the years of use in Europe, North America and all over the world. The use of Micropiles has grown significantly since their conception in the 1950s and in particular since the mid-1980s. (FHWA, 2000)

Micropiles have been used mainly as elements for foundation supports to resist both static and seismic loading conditions and less frequently as in-situ reinforcements for slope and excavation stability. (Bruce et al. 1995) Micropiles can withstand axial and/or lateral loads, and may be considered a substitute for conventional piles (See Fig. 1.1.) or as one component in a composite soil/pile mass, depending upon the design concept employed. (FHWA, 2000)

In general, a micropile is a small-diameter (typically less than 300 mm (~1 ft)), drilled and grouted replacement pile (Based on Fleming et al., 1985) that is typically reinforced. It can be constructed by drilling a borehole, placing the reinforcement, and grouting the hole. (FHWA, 2000) The construction method can be changed into steps including driving a casing, fixing the casing and grouting the hole, placing the reinforcement and installing a flange for better connection with the cap. (Fig. 1.2)

Figure 1.1. Micropiles can withstand axial and/or lateral loads, and may be considered a substitute for conventional piles.(Iran, MahmoodAbad, Narenjestan2- Southern site)

Figure 1.2. The recommended method for the micropile construction: a) driving a casing, b) fixing the casing and grouting, c) placing the reinforcement and d) installing the flange.

There are various types of Micropiles according to application, but all of them have similar parts in their bodies including: 1) the inner part (e.g. reinforcements and the grout), 2) the casing (e.g. a pipe, a hollow bar (Fig. 1.3)), 3) the neat cement grout, 4) the soil/grout mix and 5) the densified ground. These parts build an encouraged volume of a micropile body that we can entitle its cross sectional area with A_m.

In the Micropile design procedure, there are three principal steps including: 1) Internal–structural, 2) External–geotechnical and 3) Connection of pile to structure. (Cadden et al., 2008)

To have a comprehensive study in Micropile design, it is recommended to follow these steps (FHWA, 2000): (1) Review available project information (e.g. requirements of the job, pile loading requirements, pile layout constraints. special conditions such as available access and overhead clearance, presence of hazardous materials, environmental constraints, contractual requirements). (2) Review geotechnical data (e.g. obtain geotechnical/geological subsurface profile, estimate geotechnical design parameters, and obtain soil properties that determine corrosion protection requirements, identify problem areas if any). (3) Complete initial geotechnical pile design (e.g. estimate load transfer parameters (grout-to-ground bond) for the different subsurface layers and determine the pile bond length required to support the loading, evaluate pile spacing for impact to geotechnical capacity from group effects). (4) Complete pile structural design for the various component (e.g. pile cased length structural capacity (bar and/or pipe reinforcement with grout), pile uncased length structural capacity (bar reinforcement with grout), grout to steel bond capacity, transition between reinforcement types (cased to uncased section), strain compatibility between structural components/ductility, reinforcement splice connections (bar and/or pipe reinforcement), pile to footing connection). (5) Complete combined geotechnical and structural design considerations (e.g. anticipated settlement/required stiffness analysis, lateral load capacity/anticipated lateral displacement and combined stresses (axial + bending) due to lateral loading conditions, buckling of the pile/soil lateral support considerations). (6) Complete additional micropile system considerations (e.g. corrosion protection requirements, determine construction load testing and quality control program requirements, examine constructability and cost effectiveness of the design). (FHWA, 2000)
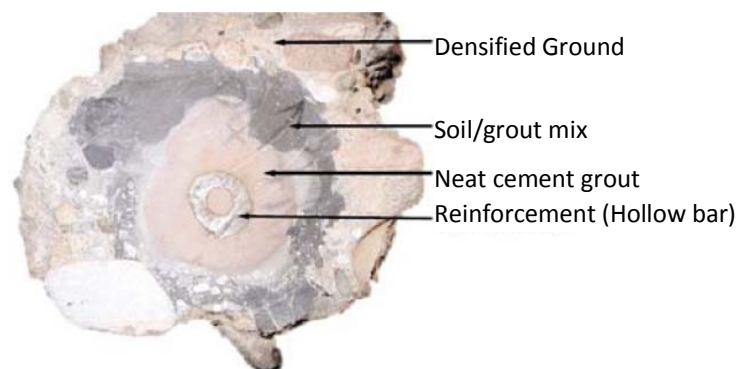
Figure 1.3. A sample Micropile section: the hollow bar, the neat cement, the soil/cement mix and the densified ground. (Astenbroich, 2001)
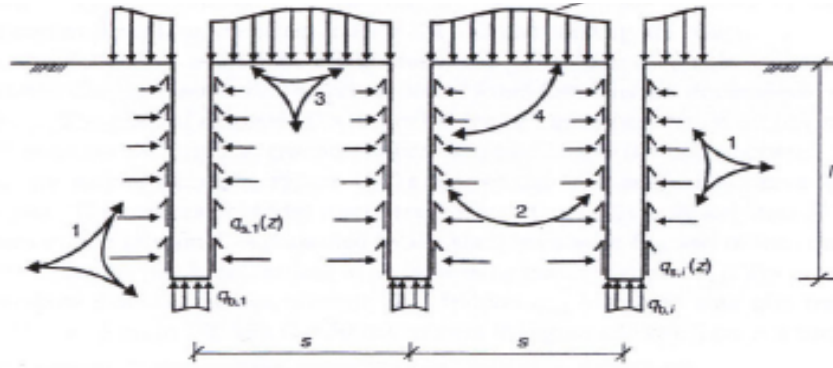
Figure 1.4. Four interactions that should be considered in a professional analysis of micropile-mat system: 1) soil-micropile, 2) micropile-micropile, 3) soil-mat and 4) micropile-mat. (Hemsly, 2000)

In a professional analysis, four interactions should be considered: 1) soil-micropile, 2) micropile-micropile, 3) soil-mat and 4) micropile-mat. (Hemsly, 2000) (See Fig. 1.4.)

In absence of a professional analysis that may take lots of time and generally is used for a conclusion and/or a control stage at the end of the design process, it seems that a pre-designing method to be more effective in the first phase of a feasibility study. Thus this study is going to utilize simple equations to represent relations between several parameters (e.g. head grid distances in the plan and the micropile stiffness vs. the soil stiffness constant (k_s) and applied pressure values) to present some graphs by the aim of pre-designing simplification and more speed in selecting the primary micropile parameters.

2. ASSUMPTIONS AND USED METHOD

In a pre-design process for a mat foundation participated with a group of Micropiles, it seems that a micropile designer needs to select some parameters of Micropiles, at first (e.g. the length, diameter, span between two Micropiles head and etc.), evaluating two principle aspects: Geotechnical and Structural. (Brouce et al., 1992)

Several methods are reported in the literature for computation of load-settlement behavior of a single pile under axial compression loading. The methods are typically divided in the following main categories (FHWA, 2001):
- Elastic methods.
- Load-transfer (T-Z) methods.
- Modified hyperbolic methods.
- Numerical techniques (including finite element and finite difference methods).

The load-transfer (T-Z) method is probably the most widely used technique to study the problem of single axially loaded piles, and is particularly useful when the soil behavior is clearly nonlinear and/or when the soil surrounding the pile is stratified. This method involves modelling the pile as a series of elements supported by discrete nonlinear springs (see Fig. 2.1), which represent the resistance of the soil in skin friction (T-Z springs), and a nonlinear spring at the pile tip representing the end-bearing (Qb-Z) spring. The soil springs are nonlinear representations of the soil reaction, T (or Qb for the pile tip), versus displacement (Z) as shown schematically in Fig. 2.1. Assuming the T-Z and Qb-Z curves are available, the axial load-settlement response can be obtained with the aid of a computer program such as FB-Pier. (FHWA, 2001)

Imagine a simplified model in which we have simulated a pile with a spring with stiffness K_m which can be defined as following (see also Fig. 2.2.):

$$K_m = K'_s . A_m = f(K_s . A_m, K_f, K_c) \tag{2.1}$$
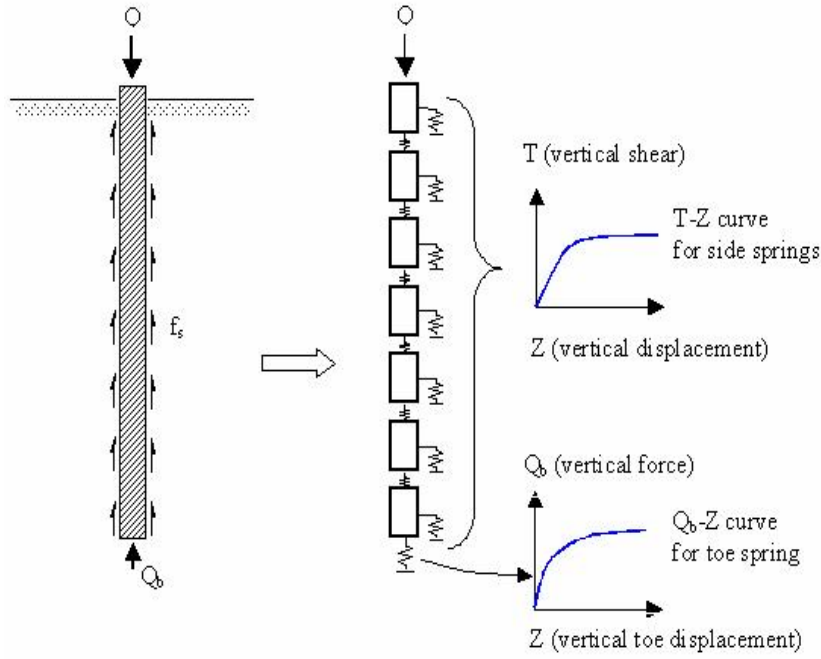
**Figure 2.1.** Idealized model used in T-Z load-transfer analysis. (FHWA, 2001)

Where

K_s (e.g. $^{kg}/_{cm^3}$): the primary soil stiffness coefficient (before improvement);

K'_s (e.g. $^{kg}/_{cm^3}$): the secondary soil stiffness coefficient (after improvement);

A_m (e.g. cm^2): the encouraged cross sectional area of improved soil as above-noted (Fig. 1.2): the bar, the neat cement grout, the soil/cement mix and parts of densified ground area;

K_f (e.g. $^{kg}/_{cm}$): the stiffness coefficient of the frictional improvement due to grouting;

K_c (e.g. $^{kg}/_{cm}$): the stiffness coefficient of the casings and the inner parts (the pipes, the grout and the reinforcement).

A_m and K_f are much related to the grouting method (e.g. the injection pressure, the cement particles grading and the mix formula as well as the soil type. Indeed it can be defined similar to $\alpha_{Bond\ Nominal\ Strength}$ (See (FHWA, 2001) for more details).

K_c is related to materials that are used in the micropile (e.g. the steel and the grout strength, the pipe size, the reinforcement bar size, etc.)

Note that K_m is the parameter that designer has to select it at first step according to above-named parameters or it should be estimated experimentally. Also group effects of Micropiles may be considered in this parameter, too. Finally, we could make a simplified model as shown in Fig. 2.2.
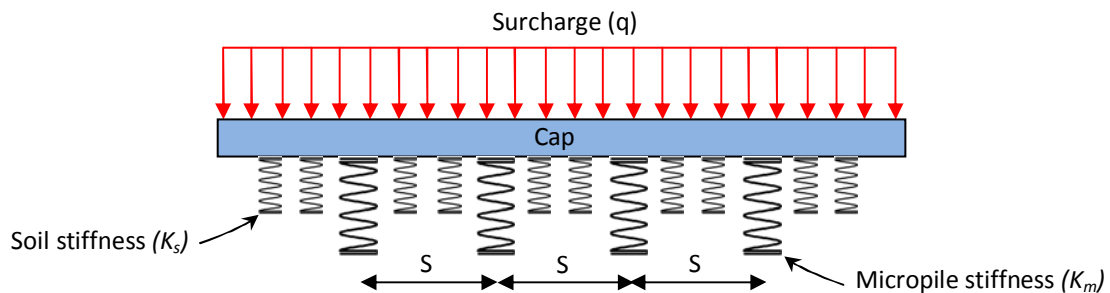
Figure 2.2. The simplified model used in the pre-designing analysis. Micropiles are simulated by springs with stiffness coefficients equal K_m. The soil is modeled by springs with stiffness coeficients equal K_s as usual.
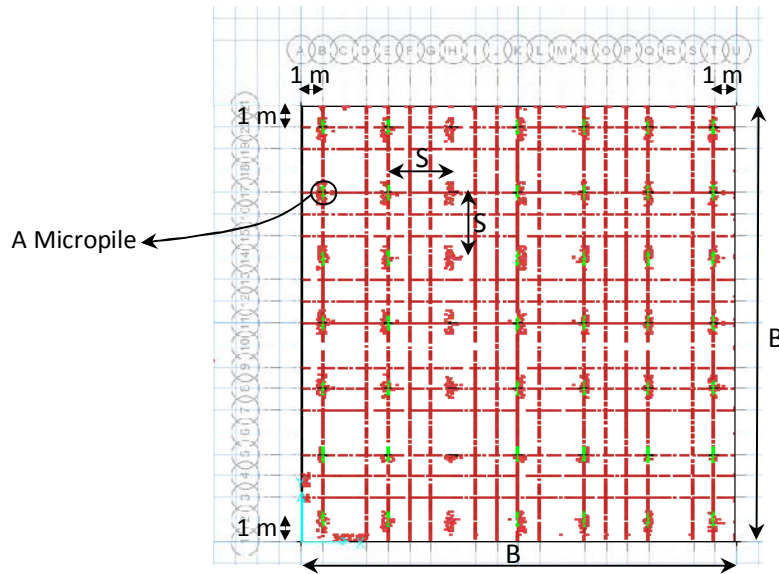
Figure 3.1. Definition of size parameters in a sample plan of a model used for pre-designing analysis.

3. PERFORMED ANALYSIS AND RELATED MODELS

We decided to experiment a square mat foundation in size B×B = 20×20 meters with 1 meter thickness. (See Fig. 3.1.) We have examined 144 models (according to Table 3.1) to test different Micropile head grid span (S), soil stiffness coefficient (K_s), Micropile stiffness coefficient (K_m) and various surcharge (q). We have considered the mat foundation as a weightless object (i.e. its weight equals zero) in all models to make more convenient in selecting q as $D+L$ loads in other thickness of foundation models.

**Table 3.1.** Various values are considered for different parameters in models.

Micropile Grid Span (S) (m×m)	Soil stiffness coefficient (K_s) ($^{kg}/_{cm^3}$)	Micropile stiffness coefficient (K_m) ($^{kg}/_{cm}$)	Surcharge (q) ($^{kg}/_{cm^2}$)
1×1	0.1	2500	0.4
2×2	0.6	5000	0.8
3×3	1.1	7000	1.2
	1.6	10'000	

We used CSI SAFE program to analyze constructed models. We found SAFE as a powerful tool for the analysis and design of concrete slabs and basemats, because for the first time, modeling, analysis, and design are all integrated in an easy-to-use object-based program that can handle simple or complex slabs and foundations. (CSI SAFE, 2002) We modelled the mat foundation with a slab lied on supports. This program uses some springs to model the soil under the mat foundation. In this regard, it takes a stiffness coefficient (Ks) to assign it to those springs.

We modeled a micropile with the spring constant in column support option. (See Fig. 3.2.) Column supports are modeled as linear elastic spring elements at the point object location. For wall and soil supports, the program generates equivalent mesh point linear elastic springs. Optionally, user can activate an iterative process to model no-tension conditions in the soil supports. The fundamental features of the support elements are as follows (CSI SAFE, 2002):
- Column supports have three degrees of freedom: one vertical and two rotational.
- Soil supports have a single vertical degree of freedom.
- The support elements are weightless.
- The support reaction values are produced at every supported mesh point.
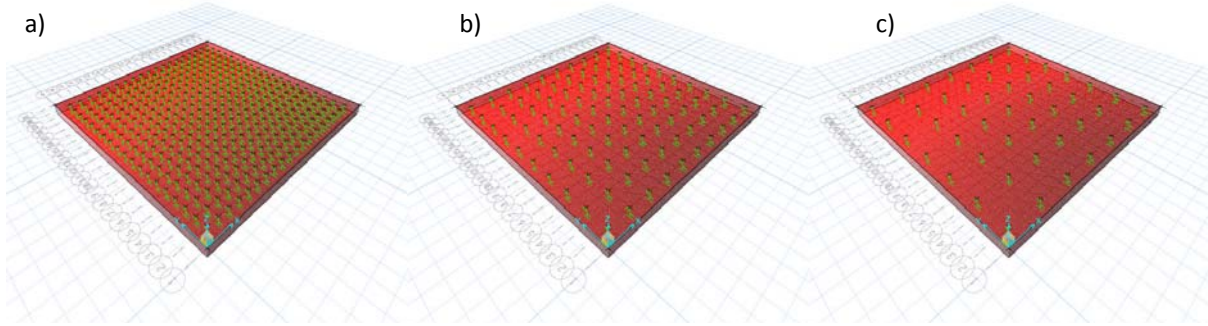
Figure 3.2. Three mat foundations participated with Micropiles which is modeled in this study in SAFE program environment. The red square shows mat foundation areas and the yellow points show locations of springs instead of Micropiles. There are three models with micropile span equal: a) 1x1, b) 2x2 and c) 3x3 meters.

We inserted the predicted values for K_m (according to Table 3.1) as the vertical spring constants and we have chosen very small values (near to zero) for the rotating parameters. Moreover we did not consider the bending stiffness (equal zero), conservatively.

4. RESULTS

After performing analysis on the models according Table 3.1, we have derived two outputs from each analysis:
1) The occurred maximum soil pressure under the mat foundations,
2) The occurred maximum force in each micropile.

We showed a sample of performed analysis output in Fig. 4.1. There are both soil pressure diagram under the mat foundation (Fig. 4.1a) and the occurred deformed shape/displacements diagram at the mat foundation (Fig. 4.1b).
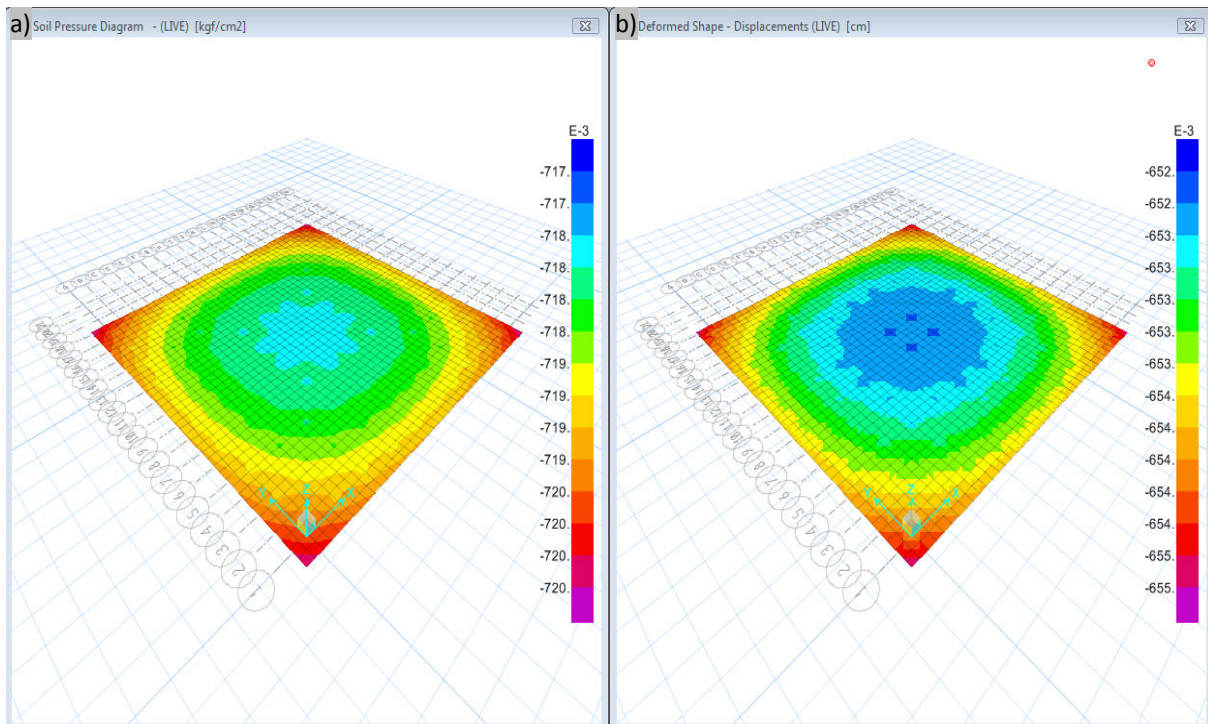
Figure 4.1. The SAFE output for mat foundation participated with Micropiles:
a) The soil pressure diagram, b) The deformed shape/displacements.

We represent the graphs related to the soil stiffness coefficient K_s= 0.1 and 0.6 $^{kg}/_{cm^3}$ (for surcharges q=0.4, 0.8, 1.2 $^{kg}/_{cm^2}$) in Fig. 4.2. In continue, we represent the graphs related to the soil stiffness coefficient K_s= 1.1 and 1.6 $^{kg}/_{cm^3}$ (for the surcharges q=0.4, 0.8, 1.2 $^{kg}/_{cm^2}$) in Fig. 4.3. As the first tip, each graph has three axes including:
1) The maximum soil pressure (the left vertical axis),
2) The maximum micropile force (the right vertical axis) and
3) The Micropile stiffness coefficient (the horizontal axis).

Secondly, we need to use the pattern located in the left bottom part of each graph (e.g. using the red curves) if we want to derive the maximum soil pressure. Similarly, we need to use the right bottom pattern (e.g. using the blue curves) to derive the maximum micropile force.

Finally, there are three styles of curves including:
1) The continued/solid curves for the grid span 1×1m,
2) The dash curves for the grid span 2×2m and
3) The long dash curves for the grid span 3×3m.

5. AN EXAMPLE

Question:
Consider a mat foundation (20×20m) influenced by a surcharge (q) equals 0.8 $^{kg}/_{cm^2}$ lied on soil with k_s=0.6 $^{kg}/_{cm^3}$. We need to improve it by Micropiles to access allowable pressure equals 0.6 $^{kg}/_{cm^2}$. Select suitable micropile arrangement (e.g. the grid span, the stiffness and the max force).

Answer:
Because of the uniform surcharge, a uniform pattern of Micropiles is suitable. According to Fig. 5.1 (q=0.8 and ks=0.6), using Micropiles with the stiffness coefficient k_m=2750 $^{kg}/_{cm}$, we need to use grid spans equal 1×1m for the Micropiles (Point A). In this case, the maximum force of Micropiles is around 4200 kg (Point A'). (i.e. Follow the violet path in Fig. 5.1.)

As another alternative, we can use Micropiles with stiffness coefficient k_m=7500 $^{kg}/_{cm}$, using the grid spans equal 2×2m for the Micropiles (Point B). Thus in this case, the maximum force of Micropiles is around 9200 kg (Point B'). (i.e. Follow the Green path in Fig. 5.1.)
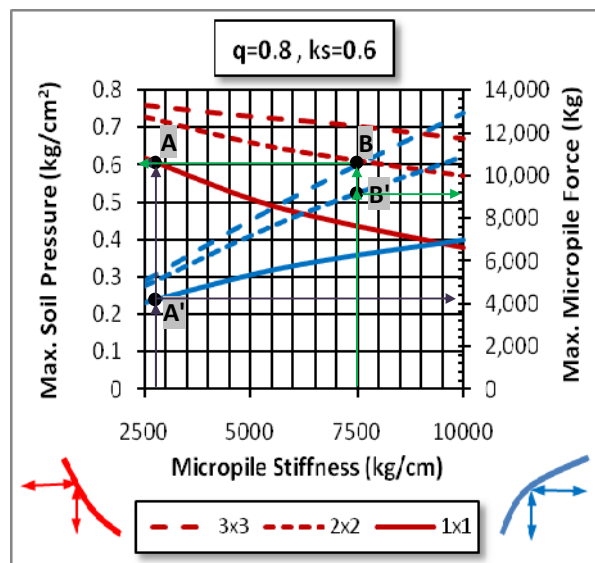

Figure 5.1. An example for using of Pre-design graph for surcharge q=0.8 $^{kg}/_{cm}2$ and k_s=0.6 $^{kg}/_{cm}3$: The violet arrows/path (the points A&A') show the Micropiles with the stiffness coefficient K_m= 2750 $^{kg}/_{cm}$ and the green arrows/path (the points B&B') show the Micropiles with the stiffness coefficient K_m= 7500 $^{kg}/_{cm}$.
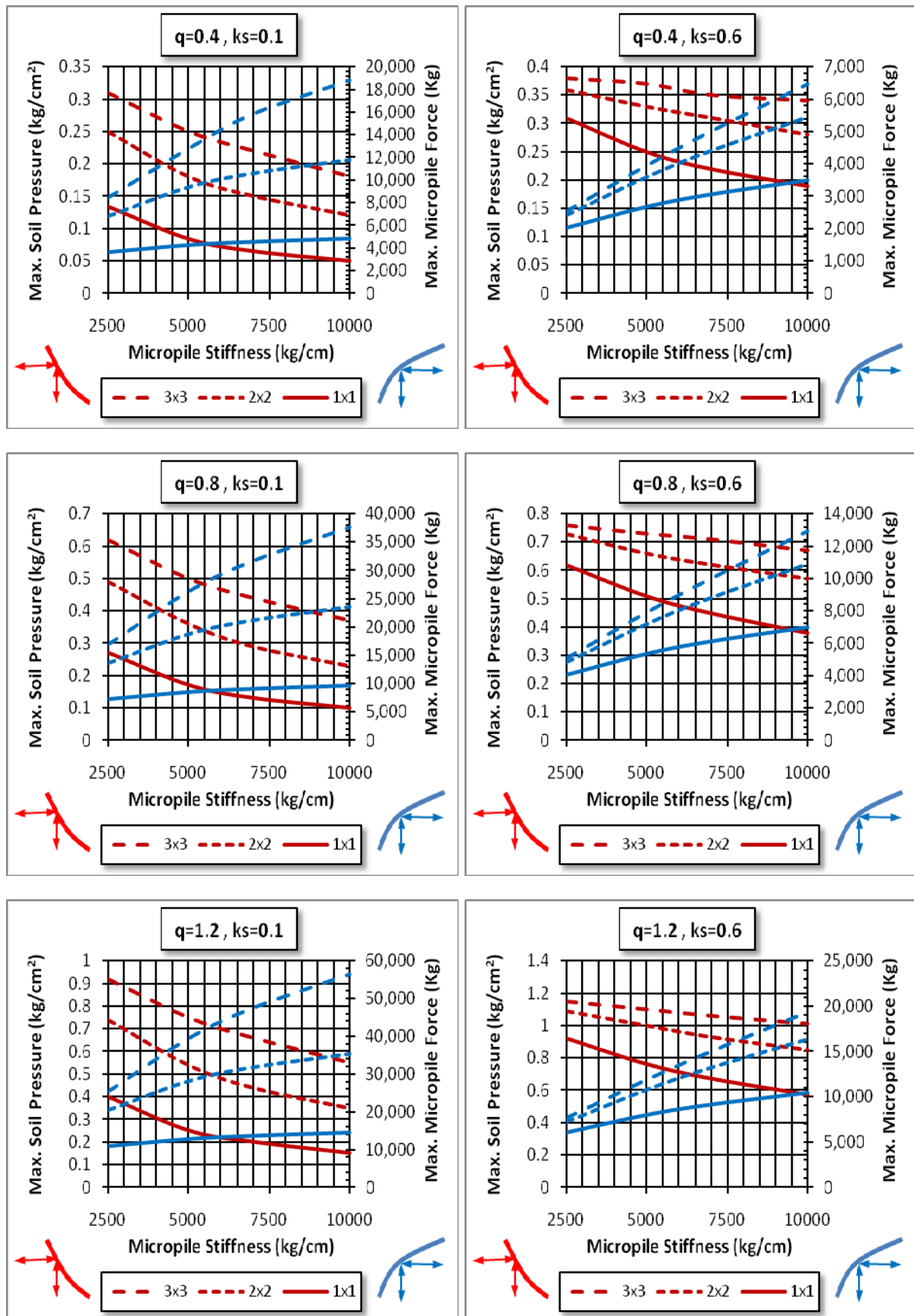
Figure 4.2. The Pre-design graphs including the allowable maximum soil pressure and the allowable maximum micropile force against the micropile stiffness in k_s=0.1and 0.6 $^{kg}/_{cm^3}$ for applied total surcharge q=0.4, 0.8, 1.2 $^{kg}/_{cm^2}$ in different micropile spans: 3×3m, 2×2m and 1×1m.
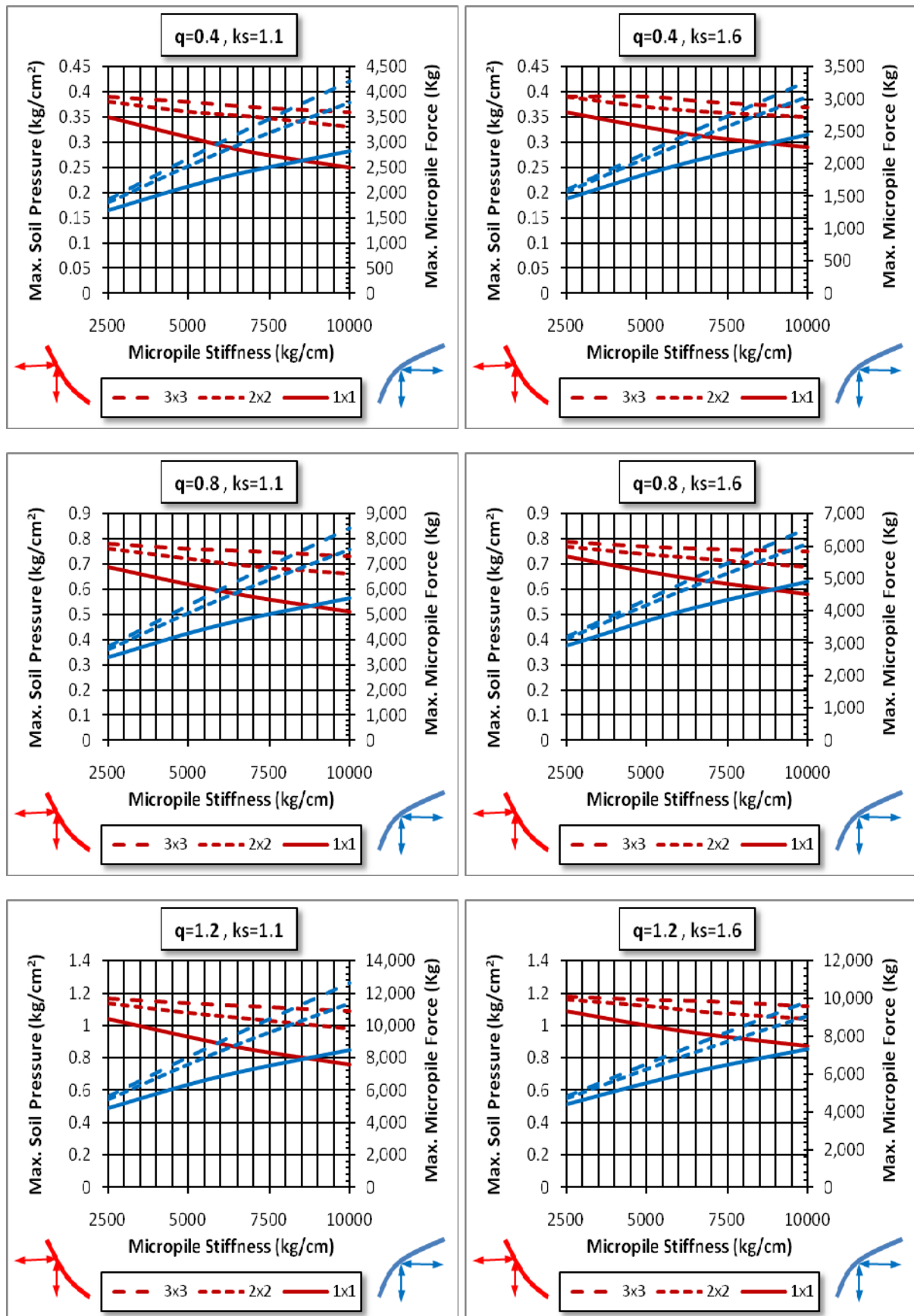
Figure 4.3. The Pre-design graphs including the allowable maximum soil pressure and the allowable maximum micropile force against the micropile stiffness in k_s=1.1and 1.6 $^{kg}/_{cm^3}$ for applied total surcharge q=0.4, 0.8, 1.2 $^{kg}/_{cm^2}$ in different micropile spans: 3×3m, 2×2m and 1×1m.

6. DISCUSSION AND CONCLUSIONS

Final results are presented in Fig. 4.2 and Fig. 4.3 as pre-design graphs including the soil pressure occurred under mat foundation and the maximum Micropile axial force outputs; However, we recommend these graphs just as a primary guide to select span of Micropiles related to soil parameters therefore some additional professional analysis should be performed after it for more economical and safety pattern.

In addition, following conclusions may be drawn from the study reported in this paper (refer to Fig. 4.2 and Fig. 4.3):

1- The increase in the Micropiles grid span cause the increase in the maximum micropile force as well as the increase in the maximum soil pressure occurred under the mat foundation.

2- It seems that, with increasing the Micropiles stiffness coefficient (e.g. k_m=2500 to 10'000 $^{kg}/_{cm}$), the increase in grid span of the Micropiles (e.g. 3×3m instead of 1×1m) creates a greater impact on the maximum micropile force increase.

3- It seems that, with increasing the Micropiles stiffness (e.g. k_m=2500 to 10'000 $^{kg}/_{cm}$), the decrease in grid span of Micropiles (e.g. 3×3m instead of 1×1m) creates a greater impact on the maximum soil pressure decrease.

4- A logical estimate of the micropile stiffness coefficient (k_m) has a vital role in this method; therefore we recommend continuing this study in a way in which more experimental experiences be associated with these results to present calibrated values for k_m according to different geotechnical aspects and constructional methods.

5- Assessing the group effects of Micropiles on the k_m value estimate can be considered as another vital subject that can complete this research results in future studies.

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