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Economic Technical Feasibility of Modified Geopier RAP

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Abstract: Rammed Aggregate Piers (RAP) by Geopier consists in a technique of soil improvement used for both granular and cohesive soils. This technique has some goals, such as: the increase of bearing capacity, the general improvement of stability of structures related to soil-structure interaction, and the reduction and acceleration of the displacements coming from consolidation. Its application, when used simultaneously with shallow foundations, can increase the bearing capacity and reduce the primary settlement, if it is compared to the same situation and soil without the use of this technique. The proposed modified RAP piles constitutes a simplified construction of the RAP pile that has been altered to be constructed with smaller diameters, about 15 cm, using steel slag as a granular material, and is performed using the SPT hammer as a compaction element. Its main objective is the application in foundations of buildings of medium to small size. This report the feasibility of the Modified RAP piles, through the design of different models of foundations normally applied in Brazil in a hypothetical geotechnical situation. The modified RAP piles for small diameters obtained a low cost, and it showed up to be viable and advantageous application.

Key words: economic viability, granular piers, soil improvement

1. Introduction

With the constant densification of urban areas, the possible areas to be constructed tend to present geotechnical geological characteristics lower than those already occupied [1, 2]. In this context, geotechnics have used soil improvement techniques, among other possible applications, for the construction of foundations. Many researches are developed under this scenario, but few studies are carried out involving medium to small buildings, mainly due to the fact that this constructive standard tends to be less expensive when it is compared to big buildings [3].

Beyond the commonly used foundation systems, such as pre-cast concrete piles, continuous flight augering piles, and piled shallow foundations, there is also the possibility of geotechnical solutions such as granular piles for less competent soils. However, this latter differs from the others by the way of acting and improving the soil [4]. Nevertheless, it should be pointed out that among the various possibilities of solutions for soil improvement, the best choice is due, for example: to the type of application, the type of soil to be treated, the geotechnical characteristic of the soil being improved, location, available construction techniques, and cost-benefits, among other factors. It is considered that in the scope of the improvement or reinforcement of foundation soil the most common objectives are: to reduce and to accelerate the displacements coming from the consolidation, to increase the geotechnical load capacity and general improvement of the stability of the structures in relation to the soil-structure interaction [5]. Thus, according to the objective to be achieved with the use of granular piles, the technique applied can be classified as treatment, reinforcement or improvement of the soil.

Since 1970, a variation of this type of foundation is commonly used in the Brazilian northeast [6], aiming the improvement of sandy soils, by means of

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compacted piles that generate a densification of the soil around the constructed element. This type of foundation can also be used in soft soil improvement.

Different nomenclatures have been used to designate compacted granular piles, since its most expressive use in the beginning of 1950s [7]. These nomenclatures are related to the constructive process according to the following examples: a) Sand and crushed stone piles; b) Cased-borehole method; c) Vibro-composite method; d) Substitution vibration method; e) GESC method (geosynthetics involving gravel cuttings, sometimes with binders in the filler material); and f) RAP (Rammed Aggregate Pier), patented by Geopier.

Aiming to determine the technical viability of a modified RAP pile, different types of foundations commonly used in Brazil were designed for a hypothetical geotechnical situation, in which the pile application would be plausible. For the economic feasibility study, the cost of implementing the solutions commonly used was compared to the cost of the modified RAP pile for the hypothetical geotechnical situation studied. Once the prices of taxes and fees for each material could vary per region in Brazil, it was not taken into account the Budget Difference Income (BDI) for the materials that composed all technique methods tested on this report.

2. Materials and Methods

The modified RAP pile, called Mini-RAP, is a new proposal studied by the Federal University of Viçosa and Federal Univeristy of São João Del Rei (Alto Paraopeba *Campus*) in Brazil. The pile is built with a small diameter, about 15 cm, less than those normally used for RAP Geopier®. First of all, it is excavated to the depth of the project and can be drilled by a manual or a portable mechanical tool. Second, the hole is filled with steel slag in successive layers of 30 cm in height. Third, the compaction is done by means of piling the steel slag using the 65 kg SPT hammer, applying about 17 blows (per layer), being equivalent to a compaction energy compatible with the intermediate Proctor, as can be seen in Fig. 1. There is also the possibility of compaction using electric mechanical hammer.

2.1 Geotechnical Field

For the development of the proposed objectives, data were obtained from a public construction, which will not be named for reasons of secrecy, from which was obtained access to the geotechnical data and to the foundation project and from that for the most loaded pillar was P24 with 60 tf. This pillar was used for the development of foundation studies in this report. The soil in the environment was characterized as silty clayey with fine sand of variegated color, without presence of water level.

2.2 Foundations Models Compared

According to the geotechnical conditions that were previously presented in 2.1 and 3.1, there are some

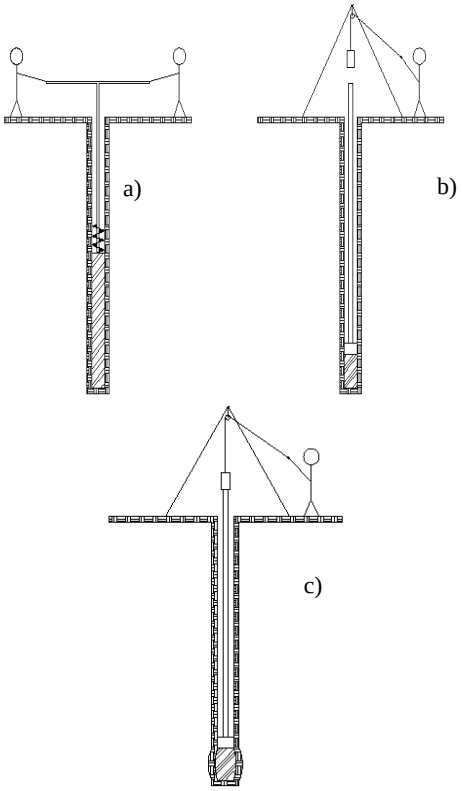

Fig. 1 Excavation and compaction scheme, a) Excavation using appropriate tool, b) Hole filled with steel slag by layer until it reaches up the top, c) Compaction using SPT hammer.

possibilities of foundations that are constantly applied in Brazil. The following foundation elements were listed: 1) auger piles 2) Continuous Flight Auger; 3) Root piles; 4) Pre-cast Concrete piles and 5) Superficial Foundation + Mini-Rap.

2.3 Methodology

Firstly, the projects were chosen for a medium-sized construction that presented a low to medium level of competence in the first depths. These projects were developed to study the foundation of the most heavily loaded pillar, by designing its foundation by the following methods: Décourt and Quaresma (1978) [8] for the cases of Auger Piles, Continuous Flight Auger and Root Piles Monteiro (1997) [9]; based on Aoki and Veloso (1975) [10] for Pre-cast Concrete Piles; and Lawton et al. (1994) [11] for Mini-RAP. After dimensioning, it was found out the average cost for those foundations and related the costs of each in order to verify the economic viability of the Mini-Rap pile. Furthermore, the cost of the construction of the Mini-RAP pile was also taken in consideration for this purpose.

3. Results

3.1 Geotechnical Studies

The data that was obtained from SPT test, which was carried out nearby the chosen pillar, were presented in the Table 1.

3.2 Results of Dimensioning

Table 2 shows the results of the geotechnical design for the different solutions proposed in 2.3. In Table 3, for each type of foundation studied, it was presented the section, pile length and the dimensions of the concrete footing block and also shallow foundation block type was presented for Mini-Rap.

3.3 Study of Economical Feasibility

The cost of the composition for the Mini-RAP pile was developed and it was shown in the Table 4 below, presenting a cost of R$ 28.01 (Brazilian currency) per meter.

The different costs obtained by a market research in Minas Gerais are presented in Table 5 containing input and construction. However, it should be emphasized that in Brazil there are some dispersions around these values, mainly due to the techniques and customs present, as well as the geotechnical formation present in each region.

Table 1 Results for the SPT test.

Layer	SPT N_{-30cm}	Soil Type
1	6	silty clayey with fine sand of variegated color
2	9	
3	14	
4	19	
5	26	
6	38	
7	59	-

Table 2 Results for different design proposed.

Type	Diameter (cm)/Depth. (m)	Method	Adm Load (tf)	Number of piles
Auger Piles	40/5	Décourt e Quaresma (1978)	12,9	5
Continuous Flight Auger	80/6		62,8	1
Root	40/6		38	2
Pre-cast	25x255	Monteiro (1997)	46,5	2
Shallow foundation + Mini-Rap	15/5	Lawton et al. (1994)	63*	5*

* For shallow foundations (145 x 145 cm) based on 5 Mini-RAP piles, a admissible geotechnical load capacity was obtained for the group equal to 63 tf and an estimated settlement of 28 mm.

Table 3 Type and dimensions of chosen foundations.

Type of Foundation	Diameter / Depth	Block Dimensions (cm)
Auger	40 cm / 5m	170 x 170 x 80
Continuous Flight Auger	80 cm / 6m	110 x 110 x 50
Root	40 cm / 6m	190 x 70 x 85
Pre-cast	25 x 25 / 5m	125 x 85 x 50
Shallow foundation + Mini-Rap	15 cm / 5m	145 x 145 x 60

Table 4 Composition of the cost for Mini-Rap Piles* without BDI.

Descrição	Unit	Income	Unitary Price	Input Price
Drilling and laying of materials, with equipment and machinery, for excavated pile with portable mechanical tool, of 15 cm in diameter.	m	0,407	2,54	1,03
Adjustment of metal rods and steel slag compaction with the use of a 65 kg mechanical hammer, electric motor.	m	0,407	0,11	0,04
Granulated steel slag and designed granulometry	kg	64,000	0,02	0,96
1 Mechanical Hammer Operator	h	0,611	10,50	6,42
5 Compaction and drilling assistants	h	2,037	6,50	13,24
1 junior Engineer	h	0,056	89,47	4,97
Auxiliary means	%	2,000	26,66	0,53
Indirect costs	%	3,000	27,19	0,82
			Total:	**28,01**

* Mini-RAP pile of 15 cm in diameter, excavated with portable mechanical tool and compacted with mechanical hammer of 65 kg with electric motor on tripod.

Table 5 Cost per meter for different pile types.

Type	Diameter (cm)	R$/m
Auger	40	99.22
Continuous Flight Auger	80	334.96
Root	40	381.62
Pre-cast	25x25	121.80

Using the projected data presented in Tables 2-5, the implementation cost of the different foundation proposals for the studied pillar was tabulated, as shown in Table 6.

Table 6 Cost for implementation of different solutions proposed without BDI.

Type	R$ total of Piles	R$ concrete block	R$ shallow foundation	R$ general total
Auger	2.480,5	1.988,3	-	4.468,8
Continuous Flight Auger	2.009,8	520,3	-	2.530,1
Root	4.579,4	972,2	-	5.551,7
Pre-cast	1.218,0	456,9	-	1.674,9
Shallow foundation + Mini-Rap	700,2	-	555,1	1.255,3

4. Discussions

First of all, it is pointed out that in the case of Mini-RAP pile the purpose of its use is to improve the properties of the surrounding soil to the pile in order to allow the insertion of a shallow foundation that is able to support the load of the pillar maintaining the values of its settlement within the permissible range.

According to the result of the survey presented in 3.1, it can be observed that the first 3 meters of the geotechnical profile have a mean SPT N of the order of 9.6, that is, a medium to low competent soil, with a minimum cohesion for being bored without itself-closing. Therefore, this soil profile is coherent for the application of the Mini-RAP piles.

Based on the geotechnics and load of the pillar under study, it was found out the bearing capacity of different elements of proposed foundations, determining the dimensions considered most convenient. It was verified that the solution by Continuous Flight Auger, with only one pile, presented the greatest geotechnical bearing capacity. In the pre-cast concrete pile solution, designed to be set at a lower depth and also with a much lower section, the bearing capacity was about 74% of the Continuous Flight Auger and its group (2 piles) overcome about 48% the CFA. With regard to Mini-RAP, since it has a small diameter a result not so expressive was expected for its bearing capacity, estimated for the group (5 stakes) in 4 tf. This bearing capacity is mainly due to its side resistance and its value was about 6% of the bearing capacity for Continuous Flight Auger. It is convenient to report that a group of load tests on Mini-Rap, presented in an initial and ongoing research on this one, has presented, for similar conditions, bearing capacity much higher than that found by the application of the method of Lawton et al. (1994), which was used in the design of the geotechnical admissible load. However, the major objective of this pile model is to generate a soil improvement, as previously discussed. It is also worth mentioning the fact that there are no models available to measure the improvements imposed on the

surrounding soil for this pile model (Mini-RAP), but this analysis is one of the main objectives of ongoing studies on Mini-RAP.

For the cost obtained for the solution using the Mini-RAP pile, it can be verified that it presented about 33% of the lowest value presented by the others, which in the case was the Pre-cast concrete pile. It should be emphasized that the relationship between costs will remain practically the same. The economic feasibility analysis of the Mini-RAP should be in agreement with the number of piles selected because although it was less expensive, depending on the load demanded, it may be necessary to build such a larger number of piles (Mini-RAP). Moreover, this fact would make it impossible to apply them due to small spot under shallow foundations. Thus, to justify its purposes, which are buildings of medium to small size, it is required less geotechnical bearing capacity and, consequently, fewer piles. Analyzing the total cost of implementation of the propositions, it can be observed that the Mini-RAP piles in relation to the most expensive proposal (Auger), presented a 356% lower cost and that in relation to the second cheaper one (pre-cast concrete pile) a difference of 33% which represents, approximately, a value of R$ 419.57. Thus, it is observed that for a condition of higher pillar load and for the same geotechnical condition, the application of the pre-cast pile will become the most viable. Once again, for this cost and solution the pile group, by a simplified analysis, would support about 63 tf, that is, the technical and economic feasibility of the Mini-RAP piles is tied to its initial proposal: to meet soils of low to medium competence and loads from buildings from small to midsize.

5. Conclusions

The purpose of the application of the Mini-RAP pile was feasible and advantageous since its original indication (medium to low load) and cohesive soils of medium to low geotechnical bearing capacity were respected. According to the results found, the Mini-RAP pile was the cheapest solution, being considered technically and economically viable for the analyzed situation. It was also noticed a relevance in the use of materials that compose it, since the use of steel slag follows the bias of the concept of sustainable and environmentally correct product with a cost for the diameter of 15 cm equal to R$ 28.01 per linear meter. Moreover, it was not considered Budget Difference Income (BDI) for the materials that composed all technique methods tested on this report once the prices of taxes and fees for each material could vary per region in Brazil.

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