MAT FOUNDATIONS FOR BUILDINGS UP TO FIVE FLOORS IN STRUCTURAL MASONRY

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With the coming progress in civil constructions, the search for rationalization and alternative methods and are becoming a common theme in the technical sector, especially when dealing with ventures of lower social classes. In these cases, the structure represents a relevant economy on the final cost of construction, therefore generates savings in material, work and time. One of the most used methods in low-budget ventures is the structural masonry. Many studies have been made on how to take advantage in search of good structural performance with low costs and no pathology incidence by optimizing the calculations of the walls and creating a mixture between this method and the foundations used. The purpose of this paper is to analyze the interface of the structural masonry system for buildings of up to five floors, with the variation of the mat foundation, cost analysis and influence of other subsystems, in the solution choice. Mat foundations formed by solid plates of concrete and grids, made with inert elements, were studied by diverse situations of elasticity and conditions of compression with distributed frames, welded screens and steal fibers. The structural designing was simulated by two softwares: TQS for grid analysis and SAP2000 for a finite element analysis, studying possible behaviors of base structures. In the executed constructions, measurements of the displacement were made through the installation of repression pins in diverse points of the mat foundation. The performance of the foundation on the displaced land, cut in many ways, can also be analyzed. With the results obtained it was possible to create recommendations in the use of this type of foundation with structural masonry, to have significant changes in the structure of the mat foundation for other building typologies, and to advance in the rationalization of solutions.

Keywords: mat foundation, masonry, rationalization

INTRODUCTION

One of the main features of the structural masonry is the saving it provides in the foundation project. This is possible because the loads achieve uniformity along the walls in every floor and arrive well distributed in the foundation.

According to Doria (2007), the foundation solution with beams and piles was considered cheaper than the mat foundation because the availability of machined concrete was scarce.

Nowadays, it’s possible to design and build mat foundation with savings especially when structural masonry is the building method of the venture.
In practice, what has been seen are buildings raised faster each day to make up for the tight schedules, due to high demand in sales. This benefits mat foundation because the slab will act as a complete floor with greater finishing quality when done, excavation is also minimized, or in some cases, eliminated, and there is no concern with the positioning of piles or reinforcements due to eccentric movements, which are common nowadays. In other words, significant speed can be reached for making the foundation with a consequent fast start of the elevation of the walls.

**BENEFITS AND LIMITATIONS OF THE USE OF MAT FOUNDATIONS**

The structural masonry system is based on the transfer of loads from the pavement floors to the foundation through walls in a direct way, without great concentrations of tension, because they get uniform due to the anchoring of the walls.

When the foundation is deep, there is a load transfer through the beams to the supporting points. These points of support, due to their rigidity, create regions of concentrated tension on the interface with the wall that if not properly dimensioned generates pathologies to the structure. This is called the arch effect. The advantage of the mat foundation is transferring the loads that are now uniform and well distributed directly into the soil without having rigid areas, avoiding concentration of tensions on the interface of the masonry, avoiding also special dimensioning or greater care with possible pathologies. Since there is no concentration in tension, these interfaces remain uniform, minimizing the differential displacement, which is easily absorbed by the rigidness of the mat foundation, as was verified in several monitored mat foundations.

However, as all shallow foundations, there are situations in which the mat foundations must not be used. The presence of elevated groundwater levels, landfills that were done with no independent compacting control, expanding or collapsing land, may turn this solution unfeasible. In order to apply, the support conditions of the land must be assessed. A continuous foundation over regions of cut land and landfills may result in differentiated displacement over the land mass; and special care must be taken to avoid surface erosion of the soil, which would put at risk the structure’s stability.

When working with mat foundation it is essential to avoid certain situations. This is possible by creating a Manual of recommendations for the use of this structure as a foundation solution. There must be information in this manual regarding the premise of the project, and the care that must be taken on the work site. Quoting: the roof necessarily needs gutters and channels to collect and transport the rain water to the draining system of the venture; after the unmolding, attention must be paid not to leave empty gaps between the concreted sidewalk and the external land, avoiding the penetration of rain water, which will remove more and more soil from under the mat foundation causing infiltrations; no kind of installation under the mat foundation should be allowed; the fitting boxes must be positioned according to the conditions indicated in Figure 1.
Besides these recommendations, when there is the presence of talus or unleveled ground, these must remain at least 2 m away, or the distance equal to the total height of landfill on the side of the mat foundation. This distance ensures that the pressure bulb of the mat foundation does not get were compacting was not assessed. An alternative for situations where these conditions are not possible is to force a support for the mat foundation at a lower level and at the same time support the unleveled ground with lean concrete, as shown in Figure 2. This allows the transition of loads into more homogenous material. It’s needed to analyze the interface between the lean concrete at the lower level and the compacted ground also.

There are still other precautions that must be taken but will not be presented in this paper. For the time being it was possible to make the use of this solution viable for buildings up to nine floors, despite these concerns.

MAT FOUNDATION CHARACTERISTICS AND DESIGNING MODELS
The mat foundation can be classified according to its geometry, framework, and rigidness. According to Velloso and Lopes (2004) the classification regarding geometry can be: flat, hollow-core slabs, box caisson, and with pedestals or mushrooms. As for the framework, it can be made in reinforced concrete with loose frames, metal fibers, screens or in prestressed
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This paper will present types of reinforced concrete mat foundations used in some constructions as case studies, as well as the designing models used.

The designing methods according to Velloso and Lopes (2004), for mat foundation are: Plate Over Ground Method from Winkler, Static Method, Designing As a System of Beams Over an Elastic Base, Finite Elements Method, Finite Differences Method and there is also the Method of Grill Analogy. In this paper the Methods of Finite Elements and Grill Analogy were used. According to Dória (2007) in the Grill Analogy Method, mat foundation is simulated by an equivalent grill composed of bar elements, where these represent slabs bands outlined by the specific size of the frames. In the Finite Elements Method, mat foundation is represented by plate type elements. In both methods, springs are used to simulate the upper ground.

The value of the springs is obtained by the coefficient of the vertical reaction (Ks) that can be calculated or supplied by a foundation designer. This coefficient directly influences the result of the foundation dimensioning, making it important for them to be precisely defined. Simulations were done for the same type of mat foundation supported by different kinds of soil, simulated for different values for Ks. The results are presented in Table 1.

### Table 1: Simulation results

<table>
<thead>
<tr>
<th>Consumption\Ks</th>
<th>15000kN/m³</th>
<th>11000kN/m³</th>
<th>8000kN/m³</th>
<th>6000kN/m³</th>
<th>3000kN/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>30,9</td>
<td>30,9</td>
<td>34,8</td>
<td>41,2</td>
<td>47,7</td>
</tr>
<tr>
<td>Steel (kg)</td>
<td>1376</td>
<td>1385</td>
<td>1436</td>
<td>1475</td>
<td>1570</td>
</tr>
</tbody>
</table>

**CASE STUDY**

The first example presented is of a mat foundation in hollow boxes, for buildings in structural masonry composed by ground floor, four pavements, and slab roof. This structure is composed by concrete ribs and EPS or inert material to save on concrete, as illustrated in Figure 3.
This type of mat foundation is ideal to ensure privacy on the ground floor because of the different level between the internal and external floors of the building, in which the windows are above the viewing angle from someone that is on the sidewalk, as shown in Figure 4. Furthermore, it allows all the fitting exits to go over the slab without needing to lower the slab or add special installations. Another advantage is the possibility of optimizing the framework through the use of screens or prestressed concrete.

The external walls of the mat foundation are made of rows of structured masonry, which has structural and mold functions for the pouring of the concrete on the upper flagstone, as seen in Figure 4. The placement of the ribs was studied so that the masonry walls would not fall over them, in other words, they remained supported on the upper 0.08m slab and over inert material. This way, it can be considered that the loads from the walls are transferred to the lower 0.20m slab due to its spreading according to the height of the mat foundation. It is presumed that the mat foundation is rigid enough not to suffer flexion, therefore, that the ribbing works only with compression, assuring the distribution by area of the loads over the lower slab, which results in more uniform requirements and reduced frames. Figure 5 presents the loads entered in the software CAD/TQS.
The software CAD/TQS was used to model this loads through the grill analogy and the vertical reaction coefficient was supplied by the foundation consultant. The loads from the structured walls were calculated and entered in the model (Figure 5) and the loads distributed on the slab of the mat foundation were considered for permanent or accidental actions of 0.8kN/m² and 1.5kN/m², respectively. Besides entering the loads by area, a parallel process is done, taking into consideration the linear loads from the walls supported directly over the mat foundation, this way having two models and two results for comparison.

It is possible to obtain the area of steel necessary for each model after the grill processing and calculation of the loads. The framework is calculated through a mean value, considering 60% of the value of the moment of the processing with the loads per area and the other 40% considering the processing of linear loads. The result is used to calculate and design the frame of the lower slab. For the upper slab the minimum frame is considered. Figure 6 shows a typical section of the positioning of the grids on both slabs that compose the lost box mat foundation, as well as the connection framework between them.
Figure 6: Positioning of the mat foundation gridding

According to the given orientation, the fittings should exit over the mat foundation. In this typology, the fittings exit through the lateral walls (Figure 7). This way the lower slab does not suffer structural influence in case any repair is needed or a leak occurs.

Figure 7: Details of the fittings exits

Monitoring studies have been done at construction sites and the results confirm what was expected about the behavior of this structure. The displacement values were greater in landfill areas, but in transition areas, landfill and cut land, the differential deformation had more amplitude, yet in a linear form, which proves the rigidity of the mat foundation.

The second example is the mat foundation composed of a single slab (Figure 8), less rigid than the prior example, with less use of material but with a more complex framing due to the slab lowering. Used for typologies with ground floor, four pavements, and slab roof which have lower tension, requiring less rigidity of the mat foundation.

Figure 8: Mat foundation’s mold in single slab

It allows the premise of installations over the slab by the use of slab lowering (Figure 9), which makes it difficult for optimization with screens, but alternatively, optimizes the frame with the use of steal fibers.
Figure 9: Picture of the mat foundation showing leveling for fittings

For this type of mat foundation the CAD/TQS and SAP2000 softwares were used and such analysis validated both models since their results were similar, as demonstrated in figures 10 and 11.

Figure 10: Deformations (m) through SAP2000
Through the efforts analysis the framework for the slab is obtained. The framework is composed by upper and lower frames and due to the lowering of the installations a special framework was created to ensure the continuity of the loads as a single slab (Figure 12).

Through modeling on SAP2000, results were obtained of tensions in the structure, making it possible to perform the calculations with steel fibers. This way, great part of the existing frame was substituted, keeping the minimum grid only for regions with peaks of tension. Besides this, the special frames had to be kept to ensure a single body for the slab.

Besides the two examples mentioned above, there is a third mat foundation (Figure 13) that is made up of a single slab without slab lowering, which prioritizes the structural optimization but demands a specific disposition of the bathroom and special fittings with lateral exits.
Just as in the first example, in this kind of mat foundation it is possible to optimize the framework using a type of basic screen and loose frames only in the places that have greater requirements, or prestressed concrete, but always ensuring that the fittings do not go under the mat foundation’s slab.

CONCLUSION
Through this work it was shown that it is possible to design and build many types of mat foundations inexpensively, especially in ventures of structural masonry, where the cost of the structures is relevant for the final product.

Furthermore, this paper reflects practices and studies developed for low-budget, successful projects in the past six years as well as prime return of non pathology constructions.

REFERENCES