# Proposal for Modular Precast Bulk Warehouse for Brazilian Agricultural Frontier Farms

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## Abstract

*Brazil is one of the largest agribusiness producers in the world, however, Brazilian competitiveness is impaired when the agricultural product, at lower costs, reaches its destination at higher costs than global competitors due to the deficiency of the grain storage system and transport infrastructure. A viable alternative is the construction of a storage silo on the rural property, with low-cost prefabricated parts that can be transferred to other locations, with easy demobilization and assembly, if necessary. This paper has the objective to design a precast concrete silo with low weight, modular, structurally analyzed by the SAP 2000 V20 software, and presented the cost estimated at 15.6% of the cost of a conventional precast bulk silo, with the same storage capacity.*

**Keywords:** Bulk grain storage; grain storage; precast panel.

## 1. Introduction

Brazil is one of the largest agribusiness producers in the world, being the second in the production of soybeans, breaking consecutive records of the crop to crop production. However, Brazilian competitiveness is decreased when the agricultural product, with has lower costs, reaches its destination at higher costs than global competitors, due to the inefficiency of logistical factors (Buss *et al* [1]).

According to Rosalen [2] today, the main logistical narrow in Brazil are precarious infrastructure, with delays in grain deliveries and enormous lines of trucks at entrances to ports, and virtually nonexistent rail and waterway systems, poor quality roads, and outdated grain storage systems.

Each year the production grows up and the problems of the farmers remain the same, of all the grain that is harvested, about a quarter has nowhere to store. The static grain storage capacity in Brazil has not been sufficient to store the growth of crops over the years, with deficits in some regions, especially in those of recent incorporation into the production process such as the farms of the frontier agricultural (Vieira e Dalchiavon [3]).

With the expansion of agricultural borders in the cerrado region and northern Brazil (Figure 1), the distance to reach industrial centers and export ports have increased too much, making the problems related to the transportation of production got worsen.

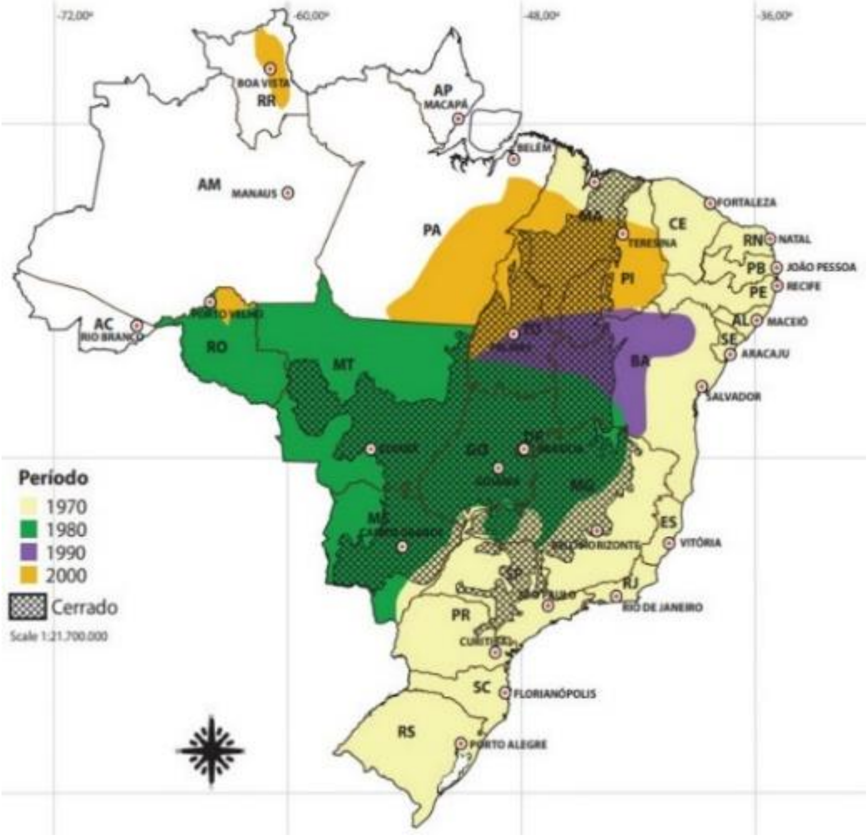

Figure 1 – Expansion of the agricultural frontier in Brazil

Easy access to storage facilities became extremely necessary due to increased distances and the unreliability of existing transport systems (Frederico [4]). Trading soybeans and corn at the final of the harvest in these regions of Brazil generate financial losses for the farmer because he is the price taker, just when the supply is high. Storing your harvest on the farm gives him the possibility to deal with his production when the price becomes more attractive. The storage units maintain the quality of grain and also prevent the loss, leaving the production system more efficient helping to reduce transport costs, and increases the markup of production (Resende, [5]).

The use of bulk grain handling and storage is a worldwide tendency and in developed countries, bulk handling is widespread and integrated since the harvest. In Brazil, as the farmer improves his technological and cultural level, there is a tendency to manipulate his bulk production, as is already the case in some regions of the South and Southeast, where warehouses for the storage of bulk grains are classified into vertical elevated silos and horizontal silos according to the shape of the main storage structure (D'Arce [6]). It is normal to find justification for farmers not to invest in the construction of bulk silo storage on farms, on the reason that the cost prevents the operation. Most of them have a lack of knowledge about the real advantages of the bulk storage system on the farm, combined with the difficulties in getting the financial resources necessary for such an investment (CONAB [7]).

A viable alternative to the high-cost problem is building a storage silo on the farm, is use low-cost modular precast that can be transported to other locations, with easy demobilization and assembly, if necessary.

The objective of this paper is proposing a precast concrete horizontal bulk storage to be set up in farms in a period sufficient to wait for the mitigation of logistical narrows and the price of grains gets higher on the market with low cost of construction.

## 2. Bulk grain storage

Over time, grain storage systems have evolved greatly in technology, capacity, and form, from the most rudimentary and simple grain collectors to the most advanced systems, with high storage capacity and processing and handling speed (WEBER [8]).

A storage grain unit designed within technical parameters and conveniently located is one of the best options for making the production system more economical (SILVA [9]). According to Weber [8], storage units can be classified according to their location. The classification is described below and illustrated in Figure 2, below.

- Farm/Producer: Located within the rural property, they usually serve a single owner, being generally small or medium-sized.
- Collectors: Units that are at an average distance from rural properties and serve several producers.
- Subterminals: These units are located at strategic points in the logistics system, usually at transshipment points, rationalizing the flow of goods to minimize handling costs.
- Terminals: Located in consumer centers and ports, with high product turnover as the main characteristic.

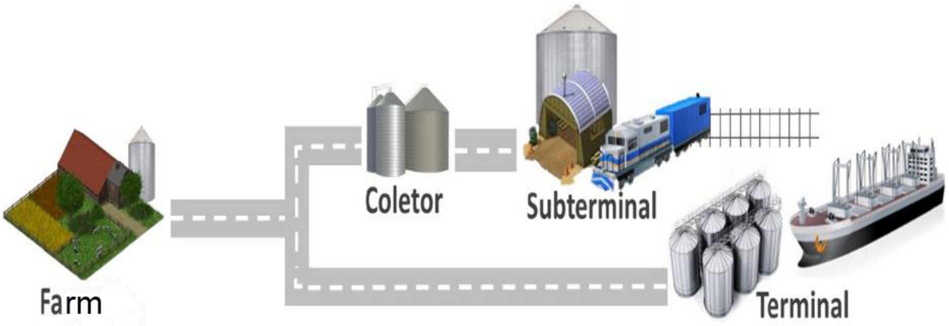

Figure 2 - Classification of storage grain units according to their location

The flowchart of a complete storage unit is shown in Figure 3. At the farm level, the structure of the storage unit is just the reception, storage, and shipping.

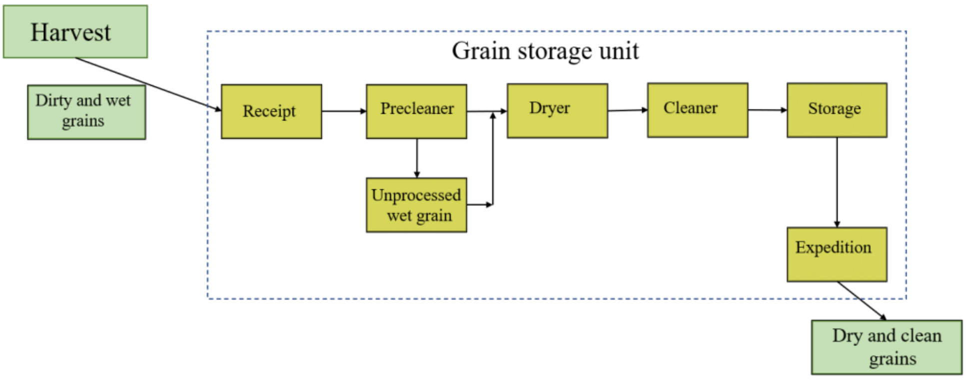

Figure 3 – Complete grain storage unit

The farm/producer storage units are located within the farm and are for the exclusive use of the owner, and should be designed, primarily, to receive wet and dirty grains (COGO [10]).

### *2.1 Bulk warehouse*

For Silva et al [11], bulk warehouses are rural or industrial buildings whose basic purpose is to store bulk products, sheltering them from external environmental influence with the internal environment of the silo, to conserve the main characteristics of the product, during the storage time.

In Brazil, horizontal silos are known as bulk warehouses (Figure 4) whose base is greater than the height (RASI [12]).

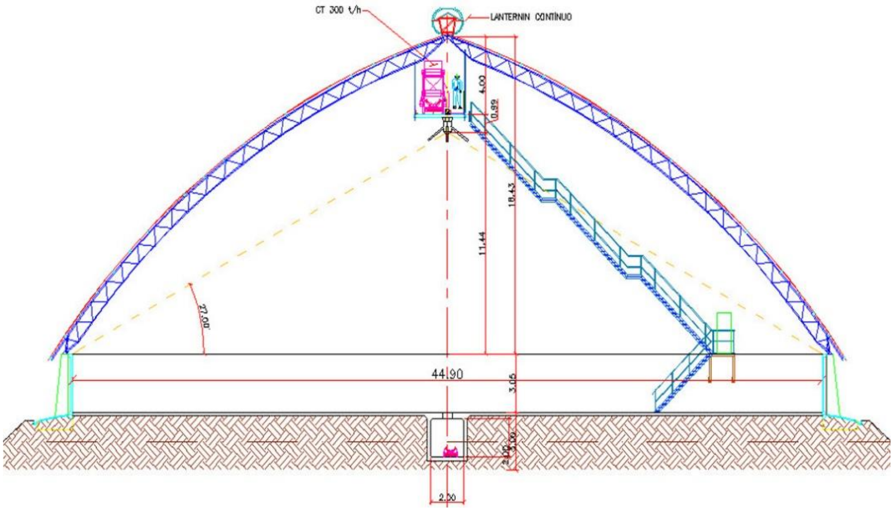

**Figure 4** – Cross-section of a horizontal silo

Gomes [13] states that horizontal silos have the following advantages, in addition to the low cost:

- Simple structural system;
- The storage of grains is done in heaps, over the concrete floor that was executed directly on the ground.

In Brazil, concrete precast is the system most used in the construction of horizontal silos (RASI [12]). The side and front of vertical panels (walls) are supported and fixed on the pillars, which are also precast, constituting an articulated structure (Figure 5) and easy to assemble.

Figure 5 - Assembly of the precast wall of a horizontal silo

Precast is a process that allows several assembly fronts to be operated at the same time, reducing construction time and costs. This build process takes advantage of the following characteristics:

- Inline production allows the reuse of molds; use of prestressing with pre-tensioned reinforcement;
- use of sections with higher mechanical performance;
- higher labor productivity and better quality control;
- Demountability of the construction;
- Low use of materials;
- The construction of the precast is independent of climatic conditions.

### *2.2 Load and pressure on the walls*

The grains stored make the pressure that acts on the vertical panels (walls) and the floor of the silo. Pressures perpendicular to the walls are known as horizontal pressures ($P_h$) and pressures parallel to the walls, which act on the floor, are known as vertical pressures (RASI et al [14]).

Gomes [13] recommends the use of the mathematical expression (Equation 1) to determine the horizontal pressures ($P_h$) on the walls of the horizontal silos.

$$P_h = \gamma \cdot h \cdot k \tag{1}$$

Where:

γ: grain specific weight; h: effective product height; K: lateral pressure coefficient - $P_h$ / $P_v$ ratio.

According to Calil [15], coefficient K (Lateral pressure coefficient) was defined as the relationship between horizontal and vertical pressures at any point in a granular mass. It is one of the necessary coefficients for determining the pressures exerted by the product on the walls and bottom of a silo. The limits of K, was indirectly determined by Gomes [13], are shown in table 1.

**Table 1 -** K limits as a function of the internal friction angle of the grain

| **K coefficient - MAIZE** | | |
|---|---|---|
| Φi (degree) | Inferior Limit | Superior Limit |
| 32 | 0,307 | 0,560 |
| 35 | 0,271 | 0,505 |

The specific weight of the most common agricultural product to store, according to the main world storage standards, can be found in Table 2.

Table 2 - Specific weight the most common agricultural product according to ISO, AS, DIN, and ABNT standards

| AGRICULTURE Product | ISO | | AS | | DIN | | NBR | |
|---|---|---|---|---|---|---|---|---|
| | $\gamma_m$ kN/m³ | $\gamma_c$ kN/m³ | $\gamma_m$ kN/m³ | $\gamma_c$ kN/m³ | $\gamma_m$ kN/m³ | $\gamma_c$ kN/m³ | $\gamma_m$ kN/m³ | $\gamma_c$ kN/m³ |
| Barley | 7,5 | 8,5 | 7,0 | 8,5 | 8,0 | | 7,0 | |
| Flour | 6,5 | 7,5 | 6,5 | 7,5 | 7,0 | | 5,0 | |
| Maize | 7,5 | 8,5 | 7,0 | 8,5 | 8,0 | | 7,5 | |
| Sugar | 9,0 | 10,0 | 8,0 | 10,0 | 9,5 | | 7,5 | |
| Wheat | 7,5 | 8,5 | 7,5 | 9,0 | 9,0 | | 7,8 | |

To determine the most unfavorable pressures, Calil [15] proposes, according to the Australian standard AS 3774: 1996 [16], for loading on the vertical panels of the silos, be determined using the lower and upper limits for each parameter. The appropriate limits for physical properties are shown in Table 3.

Table 3 - Appropriate limits for physical properties.

| **Property application** | | Peso especifico $\gamma$ | Relação Pv/Ph Coefficient K |
|---|---|---|---|
| **Flow type:** | mass | inferior | superior |
| | hopper | inferior | inferior |
| horizontal pressure - Ph | | superior | superior |
| vertical pressure - Pv | | superior | inferior |

According to ABNT NBR 6118: 2014 [17] – Brazilian Standard, the actions must be increased by the resistance factor of the actions. Calil and Cheung [18] presented in Table 4, a suggestion of values of the resistance factor of the actions, for designing of silos walls, according to NBR 6118: 2014 [17].

Table 4 – Resistance factor of the actions

| **ACTION** | | Ultimate limit states (ULS) | Serviceability limit states (SLS) |
|---|---|---|---|
| Permanent | | 1.4 | 1.0 |
| grain pressure | static | 1.4 | 1.0 |
| | flow | 1.4 | 1,0 |
| | special | 1.2 | 1.1 |
| thermic | | 1.4 | 1,0 |
| wind | | 1.4 | 1,0 |

### *2.3 Soil support*

To determine the vertical reaction of the soil, under a base slab (footing), Milani [19] states that this tension can be determined through relations with the allowable tension of the soil, and there are two ways to achieve the coefficient of the vertical reaction of the soil - $K_s^v$:

- Using the ratio with the SPT (Standard Penetration Test) results and the allowable stress of the soil;
- Using the ratio with the soil type and the allowable stress ratio.

Using the ratio with the SPT result, the allowable vertical pressure will be obtained through Equation 2, where the average SPT is the average of the SPT measured inside a pressure bulb when L = 1.5 B, where B the base of the footing (base slab).

$$\sigma_{alw} = 0{,}20 \cdot SPT_{average} \tag{2}$$

With the allowable vertical pressure ($\sigma_{alw}$) in kgf / cm², is possible to obtain the value of the vertical reaction coefficient of the soil - $K_s^v$ through Table 5, shown below, where Morrison [20] relates the value of $K_s^v$ with the allowable vertical pressure ($\sigma_{alw}$) estimated for the soil.

Table 5 - Values for the coefficient of vertical soil reactions - $K_s^v$

| Allowable vertical pressure (kgf/cm²) | $K_S^V$ (kgf/cm²) | Allowable vertical pressure (kgf/cm²) | $K_S^V$ (kgf/cm²) | Allowable vertical pressure (kgf/cm²) | $K_S^V$ (kgf/cm²) | Allowable vertical pressure (kgf/cm²) | $K_S^V$ (kgf/cm²) | Allowable vertical pressure (kgf/cm²) | $K_S^V$ (kgf/cm²) |
|---|---|---|---|---|---|---|---|---|---|
| 0,25 | 0,65 | 0,90 | 2,02 | 1,55 | 3,19 | 2,20 | 4,40 | 2,85 | 5,70 |
| 0,30 | 0,78 | 0,95 | 2,11 | 1,60 | 3,28 | 2,25 | 4,50 | 2,90 | 5,80 |
| 0,35 | 0,91 | 1,00 | 2,20 | 1,65 | 3,37 | 2,30 | 4,60 | 2,95 | 5,90 |
| 0,40 | 1,04 | 1,05 | 2,29 | 1,70 | 3,48 | 2,35 | 4,70 | 3,00 | 6,00 |
| 0,45 | 1,17 | 1,10 | 2,38 | 1,75 | 3,55 | 2,40 | 4,80 | 3,05 | 6,10 |
| 0,50 | 1,30 | 1,15 | 2,47 | 1,80 | 3,64 | 2,45 | 4,90 | 3,10 | 6,20 |
| 0,55 | 1,39 | 1,20 | 2,56 | 1,85 | 3,93 | 2,50 | 5,00 | 3,15 | 6,30 |
| 0,60 | 1,48 | 1,25 | 2,65 | 1,90 | 3,82 | 2,55 | 5,10 | 3,20 | 6,40 |
| 0,65 | 1,57 | 1,30 | 2,74 | 1,95 | 3,91 | 2,60 | 5,20 | 3,25 | 6,65 |
| 0,70 | 1,66 | 1,35 | 2,83 | 2,00 | 4,00 | 2,65 | 5,30 | 3,30 | 6,60 |
| 0,75 | 1,75 | 1,40 | 2,92 | 2,05 | 4,10 | 2,70 | 5,40 | 3,35 | 6,70 |
| 0,80 | 1,84 | 1,45 | 3,01 | 2,10 | 4,20 | 2,75 | 5,50 | 3,40 | 6,80 |
| 0,85 | 1,93 | 1,50 | 3,10 | 2,15 | 4,30 | 2,80 | 5,60 | 3,45 | 6,90 |

## 3. Materials and method

A practical system was proposed to install a horizontal, modular and portable, whose walls are composed of modular precast pieces in the form of an inverted "T" (cantilever wall), with a height of 2,600 mm, a length of 1,500 mm, and a width of 1500 mm (Figures 6). The support of the precast would be made by the bottom (bottom of the inverted “T”), directly on the ground, like a footing. The materials used were concrete Fck 30 MPa and the rebar with the tensile strain of 500 Mpa (CA 50A).

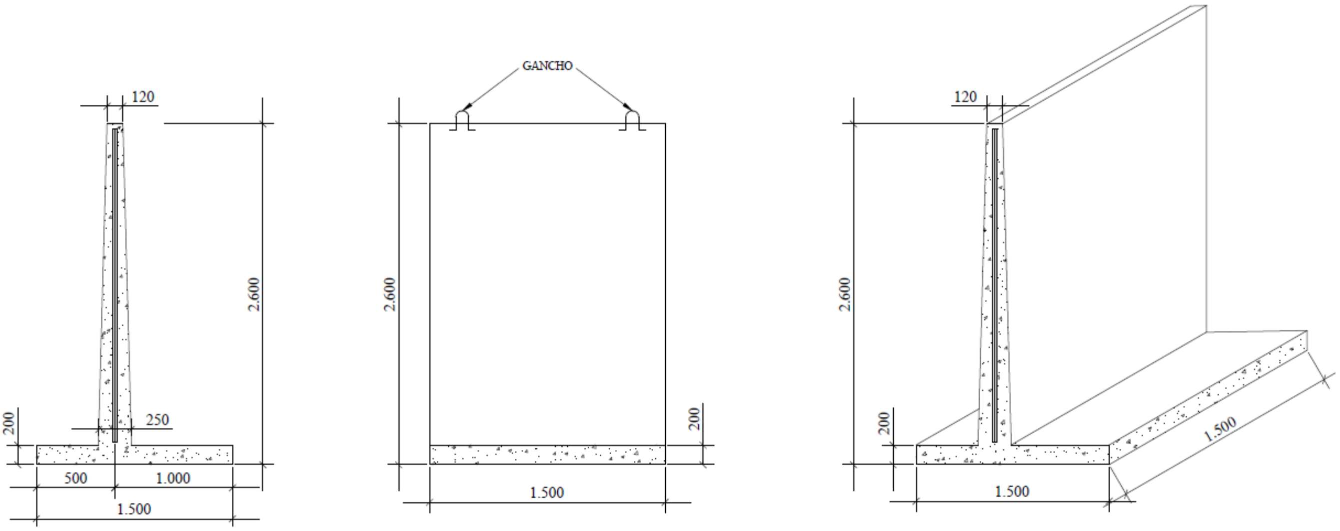

Figure 6 – Views of the precast walls of the horizontal silo.

To close the corners of the horizontal silo, a special precast piece will be used to match the walls in perpendicular directions (Figure 7), with the same technical characteristics as the precast panel of the silo wall.

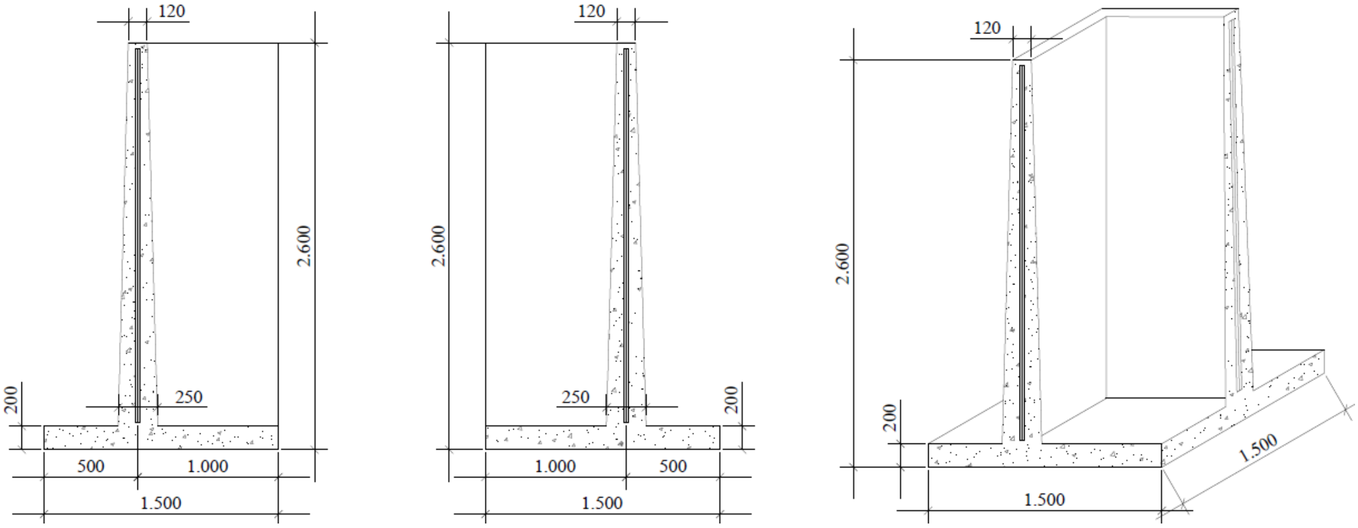

Figure 7 – Views of precast corner walls of the horizontal silo.

For sealing and interlocking the pre-molded parts, a type of groove designed by Ravent [21] was designed, whose parts had a protuberance in the semicircular shape at all ends, on the left side (internal view) and in reverse, on the right side (internal view), an undercut in the semicircular shape, acting as a male-female fitting, with a radius of 15 mm.

The precast pieces were dimensioned according to the standard ABNT NBR 6118: 2014 [18] - Reinforced concrete structures - Procedure, and a load of according to ABNT NBR 6123: 1988 [22] - Forces due to the wind in buildings and the product loads (actions due to grains) were considered according to the recommendations of Gomes [13] and Calil [15], as shown in Figure 8.

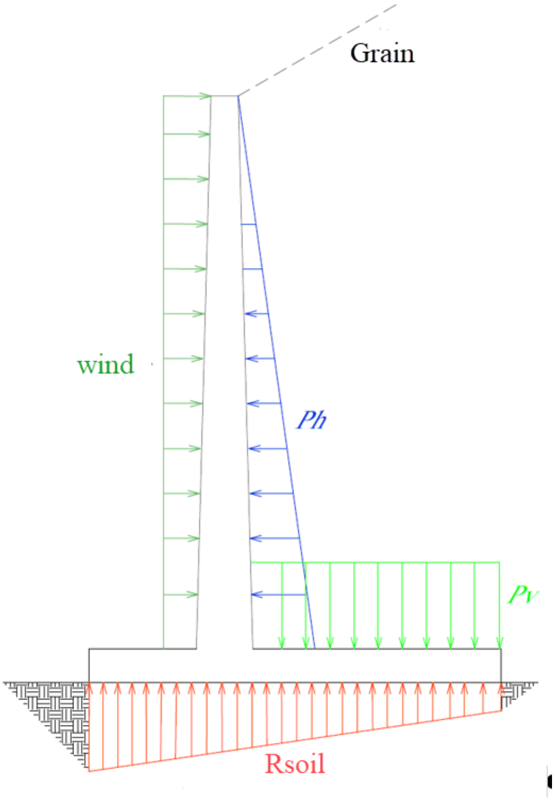

**Figure 8** – Representation of external forces acting on precast cantilever wall

The determination of the maximum horizontal pressure (Ph), according to Equation 1, the Table 1 - K limits as a function of the internal friction angle, Table 2 - Specific weight the most common agricultural product, Table 3 - Appropriate limits for physical properties, and Table 4 - Resistance factor of the actions:

$\gamma = \gamma u = 8{,}50\ kN/m^3$ (Tabela 2 - maize)

h = 2,40 m (Figure 6)

K = 0,56 (Table 1)

From table 4, we will adopt the coefficient 1.00 for the Serviceability Limit States (SLS)

The maximum horizontal pressure value:

Ph max = 11.46 kN / $m^2$ (Loading at height 0.00 m)

For the determination of the vertical pressure (Pv) that affects the internal part of the base of the precast part, according to the same considerations for the calculation of the horizontal pressure, we have got the value:

$P_v = \gamma_u \cdot h = 8{,}50\ kN/m^3 \times 2{,}40\ m \ \therefore$

$P_v = 20{,}40\ kN/m^2$

The wind pressure was not considered, because it is in the opposite direction to horizontal pressure.

To determine the vertical reaction of the soil, under the footing of the piece (inverted “T”), an allowable vertical pressure ($\sigma_{alw}$) = 1.00 Kgf / $cm^2$ which corresponds to the value of the vertical reaction coefficient of the vertical soil reactions $K_S^v$ = 2.20 Kgf / $cm^2$ or 11,767, 98 kN / $m^2$, according to Table 5 of MORRISON [20].

The structural verification of the precast piece was done by linear static analysis processed in the SAP 2000

V20 software. Figure 9 shows the discretized three-dimensional (3D), performed by the SAP 2000.

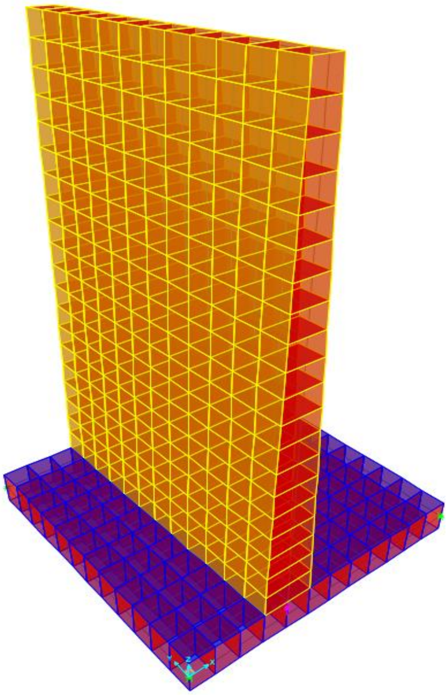

**Figure 9** - Discretization of the precast cantilever wall

## 4. Results and Discussions

With loads of horizontal pressure on the inner wall ($P_h$), vertical pressure on the horizontal part of the base ($P_v$), and the vertical reaction coefficient of the soil - ($K_s^v$), the cantilever wall was analyzed by the SAP 2000 V20 software.

The values of the major bending moment were compatible with the strength of the piece (Figure 10) and the maximum horizontal displacement value was 5.2 mm (Figure 11).

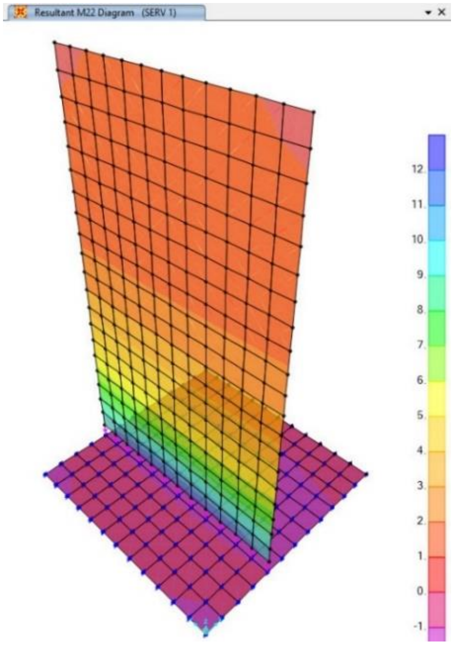

Figure 10 – M22 bending moment M22 [ kN.cm.]

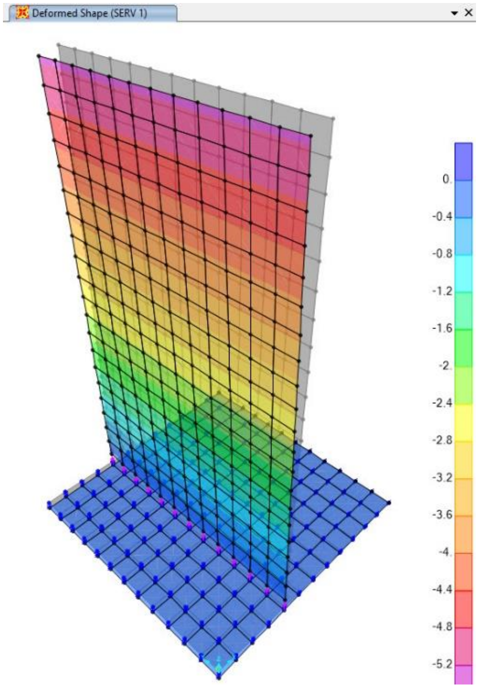

Figure 11 – Horizontal displacement on the X-axis [mm]

The maximum pressure applied to the soil by the footing of the cantilever wall was 52 kN / m², less than the allowable soil bearing pressure (Figure 12).

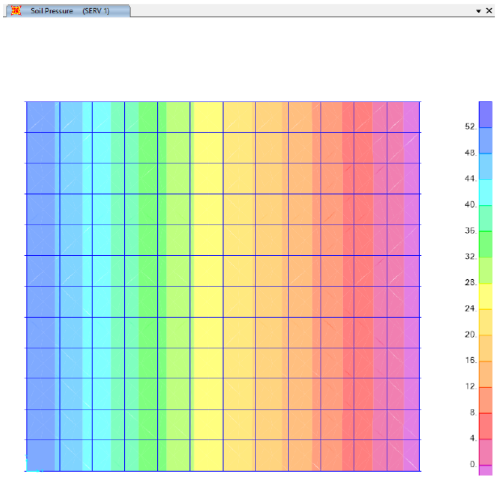

Figure 12 – Distribution of pressures in the soil at the footing of the cantilever wall [kN/m²].

The self-weight of the precast wall was estimated at 2,800.00 kg, with the volume of reinforced concrete, for all pieces (flat and corner pieces). The production cost of each piece, according to the cost standard spreadsheet for April 2020, from the Secretaria de Estado de Desenvolvimento Urbano e Obras Públicas – SEDOP – Governo do Estado do Pará / Brazil [23], for Fck 30 Mpa concrete, CA 50 rebar, and apparent mold is US$ 447.69 / m³, totalizing a cost per piece of US$ 501.41. The cost of the State of Pará was used because these precast pieces were destined for the agricultural frontier of Brazil. For the production of soybeans of 25,000.00 bags (1,500 tons) or 2,100.00 m³ of a medium-sized farm, respecting the proportions of the golden rectangle (1: 1,618), we have a silo with the dimensions of 17.00 m wide and 27.50 m long, with 54 precast pieces of the wall flat (Figures 6) and 04 precast pieces of the corner type (Figure 7), with a total of 58 precast pieces (Figure 13).

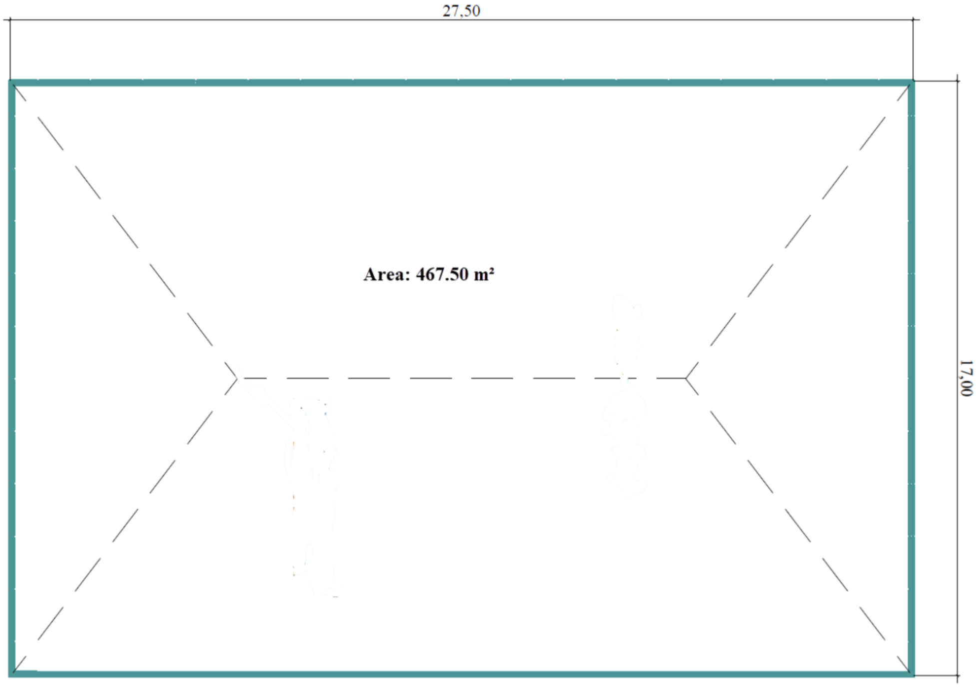

**Figure 12** – Silo designed with a capacity of 25,000 bags of soybean (1,500 tons).

The side view of the silo is shown in Figure 13, where it shows that the total height of the grains, respecting the 27.5º angle of the rest of the soybean, reaches 7.03 m.

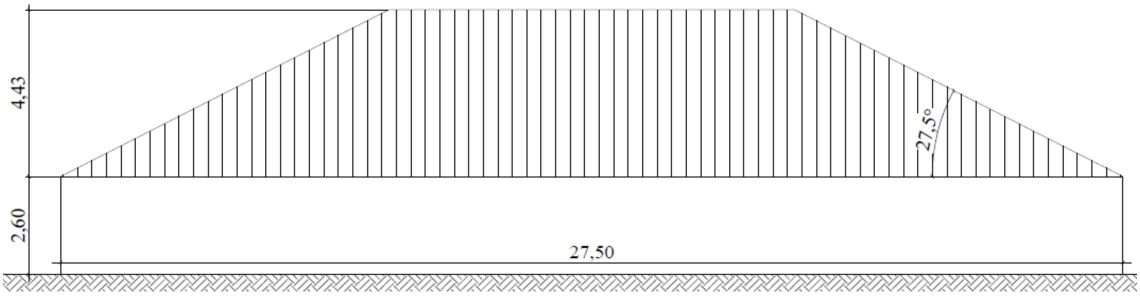

**Figure 13** – Side view of the full-grain silo

The budget cost of all precast parts of this configuration would be in Brazilian currency US$ 29,081.81 and adding the plastic canvas costs of 220 µ, it would reach the total value around US$ 29,500.00 or about US$ 1.18 / per bag. According to Viera Filho [24], the cost of conventional storage of soy or corn on a 1,500-hectare farm in Mato Grosso Estate was US$ 7.42 / per bag, that is, storage in a conventional silo would cost about 6.29 times the cost of a proposed warehouse or just 15.90 % of that cost.

## 5. Conclusion

The budgeted cost of building a silo with a maximum storage capacity of 25,000 bags of soybeans was US$ 29,500.00, making this investment economically viable, meeting the needs of the agricultural producer regarding grain storage.

The precast parts can be built on the farm site, reducing the cost of transportation and logistics.

This precast bulk warehouse is modular and removable construction and can be expanded according to the storage needs of the agricultural producer. In the event of changes in the grain production areas, the warehouse can be moved quickly.

This paper did not consider scenarios with variations in productivity and prices, which would make this study more credible for the analysis of economic viability. The study with variations in scenarios may be a potential future work.

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