# Chapter 34

# Analysis of the influence of side linking son in concrete wall buildings

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**ABSTRACT**

The current regulations, NBR 16055:2012, defines concrete wall as self-supporting structural element, molded in loco, in which it contains a length greater than ten times its thickness, being able to withstand load in the same plane of the wall. In addition to Brazilian regulations there are several international codes, such as ACI 318:2019 - Building Code Requirements for Structural Concrete, and The Australian AS 3600:2009 - Concrete Structures. Each standard has its own formulation for calculating the strength of the concrete wall element. The Brazilian code and the Australian code converge in relation to adopting the contribution of lateral links to wall resistance. The North American code mentions only the top-base links. Similarly the structures in Structural Masonry, the walking of vertical loads can occur on the surface of the wall element, being possible to use the calculation models consolidated in structural masonry bibliographies (PIS, GIP and MPT), making this study valid for structural analysis of these two systems. Throughout this work, the results of the requesting efforts of each procedure were calculated and analyzed. Later, with the help of commercial software SAP2000, a structure was launched using the Three-Dimensional Portico Model, performing their respective numerical analyses. At the end of these analyses, it was possible to observe that the model without interactions between walls was able to satisfactorily perform the distribution of efforts for the structures adopted in this study, when compared with models with interaction between walls and numerical.

**Keywords**: Concrete walls, Side bindings, Calculation models.

## 1 INTRODUCTION

By presenting itself as an industrialized construction model, the system in Paredes de Concreto stands out as one of the possible processes to meet the need of the Brazilian housing market. After the publication of the regulation ABNT NBR 16055:2012 - Concrete walls molded on site for construction of buildings – Requirements and procedures, added to the consolidation of the program created by the Federal Government in 2009, My House, My Life Program (PMCMV), is notorious the growth of this constructive model in the national scenario.

In addition to the Brazilian regulations, NBR16055:2012, there are several international codes that regulate the adoption of the system in their respective countries, such as the North American, ACI 318:2019, and the Australian, AS 3600:2009. Each standard has a formulation for calculating the strength of the concrete wall element. However, the Brazilian and Australian codes converge in relation to adopting the contribution of lateral links to wall resistance, unlike the North American that mentions only the top-base links. Seeking to understand the performance of concrete walls, Doh and Fragomeni (2006) tested elements with different types of association, analyzing their behavior and cracking. The studies concluded that the consideration of walls with two flexion planes, that is, with lateral associations, results in a less conservative evaluation model for the system in Concrete Walls.

According to Wendler (2017), the construction methods, Structural Masonry and Concrete Walls, are structures that work in the same way, as a panel, in which the walking of vertical loads can occur on the surface of the wall element. Because these are similar structural systems, in addition to references in academic studies on the concrete wall model, consolidated bibliographies of Structural Masonry were used, considering the calculation methodologies Isolated Walls (PIS) and Isolated Walls Group (GIP) to determine the resulting vertical loading on each concrete wall.

The PIS calculation method considers each wall as an independent element, that is, there is no interaction with the other wall elements of the structure. Unlike the PIS, the GIP is formed by walls that behave in solidarity, but without interaction with other groups, in which they are usually delimited by the openings of the building (doors and windows). In addition to the vertical loading of each model mentioned above, the horizontal actions, wind and dissaprumo, were analyzed through the Isolated Walls procedure, in which it distributes percentages of horizontal loads according to the stiffness of each brace panel.

The Three-Dimensional Portico Model, called Nascimento Neto (1999), is the discretization of rigid nuclei in bar elements locked horizontally by the slabs, acting as rigid diaphragm (BRAGUIM, 2013). After Nascimento Neto (1999) validated the MPT and applied it in structural masonry buildings, Nunes (2011) adopted the same model, however for structures in Concrete Walls. In this study, the commercial software SAP2000 was used for the modeling of the Three-Dimensional Portico.

Because there are different methods to obtain the requesting efforts on the concrete walls, throughout this work the results of the requesting efforts of each procedure were calculated and analyzed. The plant of the studied building is practically symmetrical. Also on the building, the number of floors were changed in order to verify the influence of height on the behavior of the distribution of loads and to evaluate the contribution of lateral links.

The general objective of this study is to evaluate the influence of lateral linkage, comparing the requesting efforts of concrete wall elements, derived from the different calculation models (with and without interaction between walls and numerical).

Therefore, this article becomes useful to the technical and scientific community, because it contributes to the study on the comparative analysis between the results resulting from the distribution of vertical loads and horizontal actions according to the different methods of calculation, evaluating the particularities of the use of each model. The normal force tends to compress the concrete wall element, while the deflector moment acts by compressing one face and traction the opposite. With these two values determined, it is possible to obtain the maximum stress acting on each concrete wall, which has a direct influence on the dimensioning.

## 2 MATERIAL AND METHODS

For the analysis and comparison of the requesting efforts in the structure, aiming to analyze the influence of lateral links, two studies were conducted.

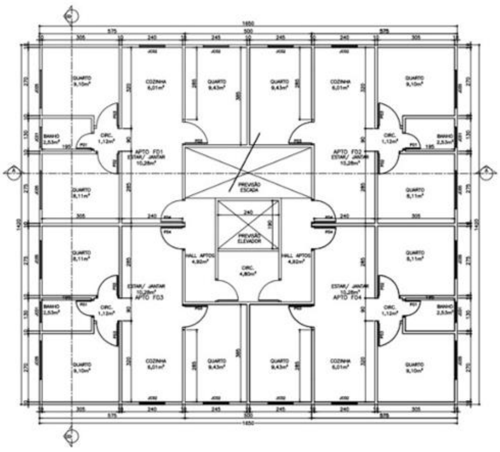
In the first analysis, called Study 01, the calculation models with and without interaction between the walls were used for the distribution of vertical efforts and horizontal actions in a 5-floor structure. For the first case, the PIS model was used to distribute vertical efforts and the Isolated Walls method, without contribution of the flaps, for the distribution of horizontal actions. The second case was adopted by the GIP and the Model of Insulated Walls with flaps, for the distribution of vertical and horizontal loads, respectively. With the results of the two cases obtained, the requesting tension was calculated in each concrete wall of the first floor, intending to compare the cases and evaluate the influence of the calculation model that adopts the interaction between walls before the method without interactions.

In Study 02, the requesting efforts, due only to vertical loading, for the three different methods (PIS, GIP and MPT). The structure used for this study was adapted from Study 01. Finally, there was the variation of floors of the building (1, 3 and 5 floors) in order to evaluate the behavior of the distribution of vertical efforts and the influence of the links between wall elements as height is added to the structure.

### Architectural Design

The architecture exposes requirements to enhance the advantages of the system in Concrete Walls, such as symmetry and modulation of dimensions. Both the ground floor and the type floor have four apartments of three bedrooms each, with a right foot of 2.60 meters.

Figure 1. Floor plan - Pavement Type (Adapted).



**Structural Elements**

The concrete walls contain a thickness of 10 cm, the minimum required by NBR 16055:2012 for buildings of characteristics presented previously. For the massive slabs of reinforced concrete, their thickness in the apartments is 10 cm. In the circulation area, the thickness adopted is 13 cm. The calculation model to determine the loading on the walls from the action of the slabs is the method of rupture lines or plastic charneiras.

The concrete, considered as isotropic material, to size this structure has characteristic strength to compression (fck) of 25 MPa, with secant elasticity modulus (Ecs) equal to 23800 MPa, Poisson coefficient (v) of 0.2 and specific weight (γ) in the value of 25 kN/m³.

**Vertical Loads**

The vertical loads adopted are subdivided into permanent (sum of the structure's own weight with the coating loads of the slabs) and accidental (overload of the slabs) according to NBR 6120:2019. Therefore, the following vertical loads were considered:

-Own weight structural elements: $\gamma = 25$ kN/m³;

- Slab coating: gL = 1.0 kN/m²;

- Accidental load on the slabs (circ.): qL1 = 3.0 kN/m²;

-Accidental load on slabs (fit:qL2 = 1.5 kN/m².

**Horizontal Actions**

Horizontal actions were adopted due to wind or dissaprumo, following the directions and perpendicular directions to the facades of the building. According to NBR 16055:2012, the horizontal action was used that provided a more unfavorable situation to the structure. Eccentricities for both wind and dissaprumo were excluded.

To calculate the characteristic wind speed (vk) it is necessary to determine the formula variables, $v_0$, S1, S2 and S3.

- Region of greater Florianópolis: $v_0 = 43$ m/s;

- Flat or weakly injured terrain: S1 = 1.0;

-Category III and Class A: S2 = Variable;

-Multifamily residential buildings: S3 = 1.0.

**Study 01**

For Study 01, the parameters previously exposed were used to calculate the requesting efforts in the 5-floor structure. This analysis was performed using the calculation methods with and without interactions between the concrete walls.

The calculation models were applied in the building under study for distribution of the current loads. The following will be presented the distributions of vertical and horizontal actions taking into account the particularities of each method.

**Calculation model without interaction between walls (Study 01)**

By adopting the method without interaction between walls, by hypothesis of the model, each determined wall does not interact with the others.

After defining the variables and applying them in the respective calculation model, it was possible to obtain characteristic values for each wall of the 1st floor of the building under study.

**Calculation model with interaction between walls (Study 01)**

With the use of this calculation method, the walls interact with each other in the groups, delimited by the openings.

In the same way as in the previous model, after the distribution of vertical loads and horizontal actions it was possible to calculate the value for each wall of the 1st floor of the building under study.

**Combinations (Study 01)**

After obtaining the characteristic results of vertical loadings and horizontal actions for each method, the combinations were applied to define the calculation efforts. For the vertical actions, both the permanent loads (own weight of the structure and coating) and the utilization overload (main variable) were increased by the coefficient in the value of 1.4, according to NBR 8681:2004.

For horizontal actions, it was possible to observe that the efforts obtained by the wind in the X and Y directions are more unfavorable when compared to those of the dissaprumo. Therefore exclusively the actions resulting from the wind will be increased by 1.4, to obtain the calculation efforts.

**Tensions (Study 01)**

To verify the stresses on the concrete walls it is necessary to commend the efforts obtained by the vertical loads (normal force) with the horizontal actions (deflector moment), according to the equation below.

$$\sigma_{Cd} = \frac{N_{Cd}}{A} + \frac{M_{Cd}}{W} \qquad (1)$$

Being:
σCd: normal voltage for maximum compression condition;
NCd: normal force that generates maximum compression situation;
CdM: a deflector moment that generates a maximum compression situation;
A: cross-section area of the wall;
W: bending resistance module (W=I/y_máx).

**Study Model (Study 02)**

Study 02 will adopt the same loading parameters used in Study 01. For this evaluation, an adaptation of the building was made, varied its floors between 1, 3 and 5.

This behavior analyzed was the result of the adoption of the three different methods the PIS, GIP and MPT. The first two were performed following the same routine of Study 01. The numerical model was carried out with the help of the SAP2000 commercial program.

As the objective of this stage of the work is the comparison between the calculation models for the distribution of vertical loads (PIS, GIP and MPT), we chose to consider only 1 apartment for the numerical model.

The following figures show the structure with the variations of floors.

Figure 2: Study Model (MPT) - 1 Floor

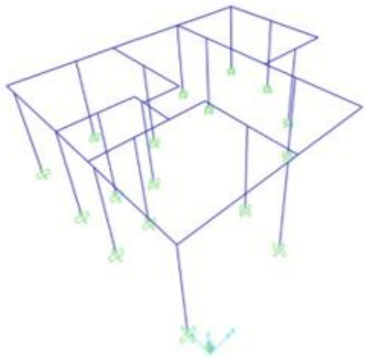


Figure 3: Study Model (MPT) - 3 Floors

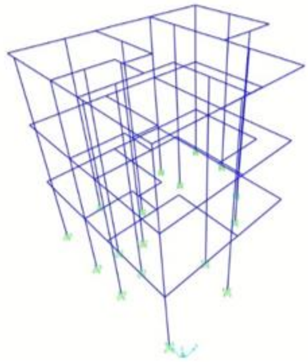
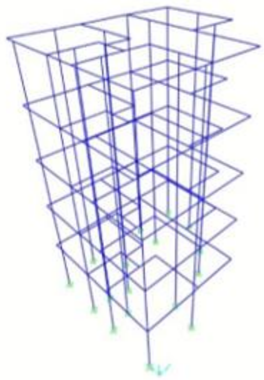


Figure 4: Study Model (MPT) - 5 Floors



## 3 RESULTS AND DISCUSSION

The results present the comparison of different calculation models, with and without interaction between walls and, finally, the numerical model. The results will be discussed well with the particularities of each method for the structure adopted in the respective analyses.

### Study 01 - Comparison between models

In this study it was possible to discuss and analyze the differences between the calculation models, comparing the stresses on the concrete walls.

Table 1 shows the comparison of the calculation stresses at each concrete wall of the building under study. According to Braguim (2013), differences in the value of 5% are considered excellent approximations. On the other hand, values between 5 and 15% are classified as good and, finally, differences above the limit of 15% the comparison is defined as bad.

The value of the limit of 15% was based on the γf3 coefficient, in which it considers possible misunderstandings of evaluation of the effects of actions, either by constructive problems or deficiency of the calculation model (BRAGUIM, 2013).

Thus, the cells in green demonstrate excellent approximations of the models. The ones in yellow represent a good result, and finally, the red ones, the bad results.

Table 1. Comparison of Calculation Stresses

| PAREDES DE CONCRETO | | | |
|---|---|---|---|
| TENSÃO NORMAL MÁXIMA DE COMPRESSÃO (tf/m²) | | | |
| ID | S/ interação σCd (tf/m²) | C/ interação σCd (tf/m²) | Diferença (%) |
| 1° PAVIMENTO | | | |
| PH01 | 92,83 | 107,10 | 15 |
| PH02 | 105,35 | 119,19 | 13 |
| PH03 | 104,79 | 97,97 | -7 |
| PH04 | 106,53 | 118,46 | 11 |
| PH05 | 87,88 | 107,35 | 22 |
| PH06 | 114,80 | 118,23 | 3 |
| PH07 | 55,50 | 94,08 | 69 |
| PH08 | 129,60 | 130,89 | 1 |
| PH09 | 114,80 | 118,23 | 3 |
| PH10 | 111,76 | 119,44 | 7 |
| PH11 | 106,53 | 118,46 | 11 |
| PH12 | 92,83 | 107,10 | 15 |
| PH13 | 105,35 | 119,19 | 13 |
| PH14 | 104,79 | 110,06 | 5 |
| PV01 | 114,10 | 100,09 | -12 |
| PV02 | 145,16 | 114,61 | -21 |
| PV03 | 129,68 | 114,80 | -11 |
| PV04 | 134,50 | 118,53 | -12 |
| PV05 | 129,68 | 114,80 | -11 |
| PV06 | 145,16 | 114,61 | -21 |
| PV07 | 114,10 | 100,09 | -12 |
| PV08 | 133,15 | 114,96 | -14 |
| PV09 | 133,15 | 114,96 | -14 |
| PV10 | 133,48 | 107,87 | -19 |
| PV11 | 150,86 | 130,96 | -13 |
| PV12 | 133,48 | 107,87 | -19 |
| PV13 | 140,59 | 126,21 | -10 |
| PV14 | 139,84 | 111,48 | -20 |
| PV15 | 125,81 | 99,39 | -21 |
| PV16 | 140,59 | 126,21 | -10 |
| PV17 | 121,74 | 97,88 | -20 |
| PV18 | 127,85 | 117,84 | -8 |
| PV19 | 127,85 | 105,75 | -17 |

Translation:
Paredes de concreto (concrete walls)
Tensão normal máxima de compressão (normal stress above compression)

Presented in Table 1, it is possible to observe that 9% of the concrete walls of the structure obtained excellent results for the comparison of the wall model with interaction in relation to the model without interaction. The approximations of the good values are 61% of the walls and, finally, 30% of the elements, bad.

Because it is a model that provides an industrialized construction, the standardization of the elements is of paramount importance for the viability of the system in Concrete Walls. Thus, the project will be carried out specifying the same thickness for all walls of the building. In a subsequent dimensioning, both for the model without and with interactions between the walls, the greatest resulting tension in the elements would be adopted, thus acting in favor of safety. Therefore, comparing the highest stress values of each model, we have:

- $\sigma Cd$=150.86 tf/m², for wall model without interactions;
- $\sigma Cd$=130.96 tf/m², for wall model with interactions;

Thus, the difference of the second value in relation to the first is in the order of 13%, that is, it is within the limit of a good approximation.

This analysis is in agreement with Corrêa and Ramalho (2003), in which they recommend the use of PIS and GIP methods for low-height buildings. It is worth the added in that the same authors suggest the GIP model for buildings of any size. For the PIS model, the recommendation is limited in small structures, where its negative effects are less noticeable.

It is possible to observe that the choice of the model without interaction between walls would be more conservative, because it has a higher value of requesting tension. Something that goes to meet Correa and Ramalho (2003), in which they classify the method as simple and very safe.

**Study 02 - Comparison between models**

For this study, comparisons were made between calculation models adopting only vertical loading, because they are low-height buildings.

Thus, the results arranged in Tables 2, 3 and 4 show the comparison between the three distinct models of calculation for the distribution of vertical efforts. Each table indicates the requesting vertical loading for the respective number of floors analyzed, including PIS, GIP and MPT, in addition to the difference of the first two methods in relation to the numerical.

Table 2. Comparative - Characteristic Vertical Resulting Efforts - (PIS x GIP x MPT) - 1 Floor

| COMPARATIVO MODELOS | | | | | |
|---|---|---|---|---|---|
| PAREDE | Nk (tf/m) | | | DIFERENÇA (%) | |
| ID | PIS | GIP | MPT | PIS/MPT | GIP/MPT |
| PH01 | 1,11 | 1,38 | 1,15 | -4 | 20 |
| PH02 | 1,41 | 1,66 | 1,58 | -11 | 5 |
| PH03 | 1,02 | 1,14 | 1,13 | -10 | 1 |
| PH04 | 1,40 | 1,60 | 1,52 | -8 | 5 |
| PH05 | 0,97 | 1,14 | 1,16 | -17 | -2 |
| PH06 | 1,52 | 1,59 | 1,66 | -9 | -4 |
| PH08 | 1,07 | 1,28 | 1,06 | 1 | 21 |
| PV04 | 1,24 | 1,28 | 1,38 | -11 | -8 |
| PV05 | 1,77 | 1,59 | 1,71 | 4 | -7 |
| PV06 | 2,02 | 1,60 | 1,83 | 11 | -13 |
| PV07 | 1,54 | 1,38 | 1,52 | 2 | -9 |
| PV09 | 1,77 | 1,60 | 1,63 | 8 | -2 |
| PV11 | 1,72 | 1,28 | 1,51 | 14 | -15 |
| PV12 | 1,65 | 1,38 | 1,61 | 3 | -15 |
| PV15 | 1,54 | 1,14 | 1,55 | -1 | -26 |
| PV16 | 1,78 | 1,66 | 1,69 | 6 | -2 |
| PV19 | 1,08 | 1,14 | 0,99 | 9 | 15 |

Translation:
Comparativo modelos (comparative models)
Parede (Wall)
Diferença (Diference)

Table 3: Comparative - Characteristic Vertical Resulting Efforts - (PIS x GIP x MPT) - 3 Floors

| COMPARATIVO MODELOS | | | | | |
|---|---|---|---|---|---|
| PAREDE | Nk (tf/m) | | | DIFERENÇA (%) | |
| ID | PIS | GIP | MPT | PIS/MPT | GIP/MPT |
| PH01 | 3,33 | 4,13 | 3,80 | -12 | 9 |
| PH02 | 4,23 | 4,97 | 4,43 | -5 | 12 |
| PH03 | 3,06 | 3,43 | 3,61 | -15 | -5 |
| PH04 | 4,20 | 4,79 | 4,70 | -11 | 2 |
| PH05 | 2,90 | 3,43 | 3,60 | -19 | -5 |
| PH06 | 4,55 | 4,78 | 4,77 | -5 | 0 |
| PH08 | 3,20 | 3,84 | 3,52 | -9 | 9 |
| PV04 | 3,72 | 3,84 | 4,03 | -8 | -5 |
| PV05 | 5,30 | 4,78 | 5,03 | 5 | -5 |
| PV06 | 6,06 | 4,79 | 5,46 | 11 | -12 |
| PV07 | 4,63 | 4,13 | 4,33 | 7 | -4 |
| PV09 | 5,30 | 4,79 | 4,77 | 11 | 0 |
| PV11 | 5,17 | 3,84 | 4,25 | 22 | -10 |
| PV12 | 4,96 | 4,13 | 4,63 | 7 | -11 |
| PV15 | 4,61 | 3,43 | 4,51 | 2 | -24 |
| PV16 | 5,35 | 4,97 | 4,70 | 14 | 6 |
| PV19 | 3,25 | 3,43 | 3,10 | 5 | 10 |

Translation:
Comparativo modelos (comparative models)
Parede (Wall)
Diferença (Diference)

Table 4. Comparative - Characteristic Vertical Resulting Efforts - (PIS x GIP x MPT) - 5 Floors

| COMPARATIVO MODELOS | | | | | |
|---|---|---|---|---|---|
| PAREDE | Nk (tf/m) | | | DIFERENÇA (%) | |
| ID | PIS | GIP | MPT | PIS/MPT | GIP/MPT |
| PH01 | 5,55 | 6,89 | 6,78 | -18 | 2 |
| PH02 | 7,05 | 8,28 | 7,24 | -3 | 14 |
| PH03 | 5,10 | 5,71 | 6,18 | -17 | -8 |
| PH04 | 7,01 | 7,98 | 7,65 | -8 | 4 |
| PH05 | 4,84 | 5,71 | 6,03 | -20 | -5 |
| PH06 | 7,59 | 7,96 | 7,64 | -1 | 4 |
| PH08 | 5,33 | 6,40 | 6,21 | -14 | 3 |
| PV04 | 6,19 | 6,40 | 6,88 | -10 | -7 |
| PV05 | 8,83 | 7,96 | 7,64 | 16 | 4 |
| PV06 | 10,11 | 7,98 | 7,80 | 30 | 2 |
| PV07 | 7,72 | 6,89 | 7,27 | 6 | -5 |
| PV09 | 8,83 | 7,98 | 7,67 | 15 | 4 |
| PV11 | 8,62 | 6,40 | 6,76 | 27 | -5 |
| PV12 | 8,27 | 6,89 | 7,39 | 12 | -7 |
| PV15 | 7,68 | 5,71 | 7,20 | 7 | -21 |
| PV16 | 8,91 | 8,28 | 7,48 | 19 | 11 |
| PV19 | 5,41 | 5,71 | 5,42 | 0 | 5 |

Translation:
Comparativo modelos (comparative models)
Parede (Wall)
Diferença (Diference)

With the results presented, the analysis was first performed to compare the PIS and MPT. It is possible to observe that with the addition of floors, the amount of walls with bad approach increases.

For the comparison between the numerical model (MPT) and the GIP, it is possible to verify the contrary behavior, the greater the addition of pavements, the approximations between the concrete walls of these two methods improved.

This finding of the behavior of vertical loads also goes against Correa and Ramalho (2003), in which it indicates the use of the PIS method for small buildings, where its negative effects are less noticeable.

Adopting the same reasoning of Study 01, another verification is the use of PIS as a more conservative model, considering that the loading of this calculation method for a subsequent dimensionism is higher in relation to gip and MPT, both for 1, 3 or 5 floors.

## 4 CONCLUSION

At the end of this work it is possible to conclude that the choice of the calculation model directly interferes with both the requesting efforts and the stresses of the concrete walls. It is worth adding that this finding is also valid for buildings in Structural Masonry, because its structural behavior is similar to the system in Concrete Walls.

In general, it is noted that there is influence of lateral links for the distribution of loads in the concrete wall structure. However, in Study 01, it was observed that this interference does not have much impact when compared to models without and with interactions between concrete walls. It is possible to verify that there is a good approximation between the higher stresses obtained for the two distinct methods. The conclusion of this low interference of lateral links to the analyzed building is in line with the recommendation of Corrêa and Ramalho (2003) of the use of the PIS model for low-height structures.

The behavior observed in Study 02 reinforces the previous orientation, considering that with the increase of pavements, a qualitative worsening is evident in the PIS method in relation to the MPT model, when compared with the difference between GIP and MPT. Unlike PIS, GIP has its application indicated for buildings of any size.

Therefore, even the models without interactions between walls pointing out differences, it is possible to observe that the method was able to perform satisfactorily the distribution of efforts for the evaluated structures. Because these structures are low,they made it possible for their negative effects to be of a lower proportion. Although it is a simple model of stock distribution, it provides agility in the analysis linked with security, considering that the approach is more conservative among the three models. These characteristics contribute to the method being widely disseminated in the market for analysis of buildings in Concrete Walls of few floors.

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