Influences of the Frames' Fill Masonry in the Buildings Structural Behavior

António Morais[1]

***Abstract*—** Under the CIAUD we have an ongoing project research called Influences of the frames' fill masonry in the in the buildings structural behavior." In this number of Artitextos the magazine started publishing the results and conclusions already made in research undertaken.

One of the important aspects to consider in the frame structures of reinforced concrete design is the influence that the masonry infill panels have the overall structural behavior and the distribution of efforts by structural components (columns and beams essentially). Traditionally, the contribution of the infill panels is not going into account and the underlying hypothesis is that it is possible simplification by the part of safety. For certain design scenarios, particularly in the case of seismic actions, it is recognized that problem is more complex, and there are situations where the filler panels can change in a decisively the behavior of the structure, including jeopardizing their safety.

In this article we present the structural results, in terms of efforts and deflections obtained in frames of buildings in two possible situations, with fill masonry walls and one without.

***Keywords*—** Concrete frames, Fill wall masonry, Numerical models, Resistant parameters.

I. Introduction

MASONRY walls are widely used in buildings as interior partitions and as façades (exterior sealing walls), but without being recognize any contribution to the resistance and structural stability of the building, at least at the level of calculation and design model. Interior walls are design to obeying to the fire and soundproofing regulations.

In general, the experimental results indicate an increased security level resulting from the presence of masonry. Several laboratory tests indicate stiffness increases, resistance to cyclic loads and energy dissipation capacity. The distribution of stresses in the structure, however, can be profoundly altered by the presence of the wall, and locally bring the most onerous effort than previous the structural model no filler.

Experimental results show the occurrence of frames filled, under certain conditions, pillars´ ruptures, which was not the case if frames without walls. Thus, the systematic evaluation of the possible effects of the walls in the various project scenarios, depending on their geometric and mechanical characteristics as well as the construction process, it seems of great practical interest, taking into account the possible lack of security, with the current sizing processes of framed structures. But given the importance of the subject, it must be conducting research on this topic.

In fact, the existence of masonry walls in reinforced concrete structures substantially change the overall behavior of buildings, in particular its frequency, absorb vibration and distribution of horizontal forces. The position of these enclose elements may also change the location of critical areas of the reinforced concrete structure and cause significant asymmetries of mass and stiffness.

It could be concluded to be fundamental to the development of building projects, deepen existing knowledge about the interaction of filling elements and frame structures of reinforced concrete. Two alternatives may exist: the adoption of constructive provisions ensuring the separation between the infill and the adoption of more sophisticated analysis models that most accurately as possible the actual behavior of the structure.

II. Approach to the Problem of Interaction Frame / Filling Wall

For partitions and enclose walls do not perform in a structural way, not interacting with the structural frames, the walls have to be built off the structural elements slabs, beams and columns); a joint that allows the free wall motion regarding the own masonry wall as a constructive element.

For filling´s walls and structural frames has in the design phase to make decision whether or not these walls participate in resistance to horizontal forces, also ensure some lateral bracing to the building. If you want the wall to play some structural work is necessary, that the wall is in any physical way connected to the floor slabs and beams. The simple friction between the slab or beam and the wall establishes a connection type so any load percentage is transferred to the masonry wall. mechanical system located in the top of the wall and anchored to the beam or floor slab upper increase the charge transfer effect and ensure best efficiency and durability of the operation; the effect remains to a value greater deformation. The horizontal load transfer will take place even if there are no physical links between the wall and the columns that delimit, since the relative deformation between floors introduces the division of horizontal load between the wall and the pillars.

António Morais[1] Professor, Faculty of Architecture, Lisbon University – FAUL, Portugal.

https://doi.org/10.15242/IIE.E1016007

The potential of filling walls of interaction with the structural frame has been ignored in the design of individual building structure, either by simplifying calculation, either because there are no appropriate models that address the realistic mode of interaction. However, the fill walls of the frames have effective capacity to equilibrate horizontal loads, including seismic origin, also intervene in the process of transferring horizontal loads to the foundation.

The filler walls limit the maximum horizontal displacement provided, at the top floor, thereby increasing the rigidity of the structure. This aspect is important in terms of constructive pathologies. When more rigidity is available in the building structural response, lower the deformation install. When smaller the deformations caused lower the strain on the coatings and finishes and better performance of these, with reduced installed cracking. It is overlooked aspects in the design and also in research. It is important to control the level of deformation installed in the structure, because the finishing and coating materials have to follow this deformation and are unable to follow from certain cracking levels is to reduce the amount of installed deformation of the structure, or limit the vertical and horizontal maximum deflection.

The most relevant aspect is the smallest structural safety that occurs when it is not considered in structural terms the presence of filler walls of the frames. Disregarding padding walls of the building design cannot be on the safety considerations and wash the scaling which endangers safety of the building structure, that is, a scaling safety against. This question is of course worrisome caring a carful investigation. This is the purpose of the research program undertaken under the CIAUD.

Not pay attention to the analysis of the presence and the subsequent effect of frames´ fill walls originates distortions in efforts effectively developed in two different structure types.

So, the filler walls rigidify the frame where are located, therefore affect the destruction of horizontal forces in the several parts of including structure. Thus, considerable forces, over expected in a simple structural analysis, may be attracted to areas where there are filling walls, enhancing the cracking of this and, attention, leading to increased loads on their frames in which they operate (the fill walls).

Then it makes sense that this padding wall interaction is considered that an effective and realistic design is obtained, so that neither the wall filling or gantry to be overloaded efforts to put on the structural safety of both.

On the other hand, the most severe situation occurs when the meanwhile filling wall ruptures by cutting in a horizontal plane, caused an action mechanism on pillar potentially dangerous and here we designate by constraining effect at half height of the abutment. The next figure presenting schematically this mechanism [1].

The filling wall by breaking horizontally by cut displaced in this plane, however, the upper part of the wall remains on the upper part of the pillar, conditioning and preventing rotation of the cross-section of the pillar in all height where keep wall connected to the limit. The column deforms only free manner by rotation from the section where there is no longer connected to the column wall, or from disruption effected by cutting the filling wall. This rupture occurs generally in the middle area of the pillar height. It is this section so that installs the maximum bending moment, so, the exact opposite of what occurs when we perform scaling which does not consider the presence of padding wall, which, for this situation occurs at the ends of the column. We understand the seriousness of the situation: the armor to the maximum bending moment is not located where effectively the moment is maximum!

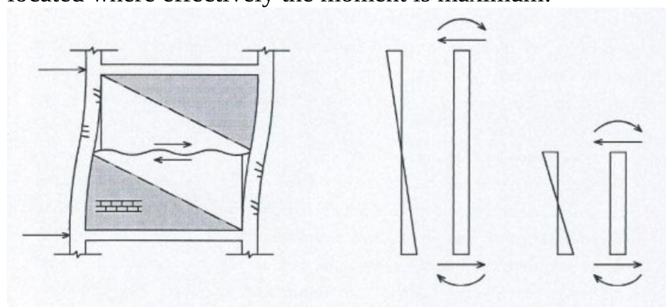

Fig. 1

The situation is aggravated because the value of the shear on the column is then also the half-height of the pillar and doubles the value. So, we scale for a given value of the shear develops not only on the projected section such as to worsen is the double value when considered in the calculation. Let's see how the next analysis model and very simple calculation.

The ability to withstand bending moment of the pillar is always the same, but since the plastic hinge forms now halfway up the column, then the arm of the strength corresponds to the shear which is now half, so that for the same amount of maximum bending moment, the shear force applied is now double. Not only the maximum shear develops now in another section, as, most importantly, now takes the double of the value considered in the dimensioning.

We conclude then, that the existence of filling walls not only changes the location of the sections where there are maximum values of bending moment and shear, as double the considered shear, assuming the absence of walls. It follows that no account of the action of filling walls that the failure to consider the action of filling walls puts structural safety problems. The distribution of stresses in the structure can thus be profoundly altered by the presence of the filler, and locally lead to bigger efforts that provided by the structural model without filling.

In this way, the evaluation system of the possible effects of the walls in the various design scenarios, depending on their geometric and mechanical characteristics as well as the construction process, it is of great practical interest.

The existence of masonry walls in reinforced concrete structures substantially change the overall behavior of buildings, including its own frequency, vibration dampening and distribution of horizontal forces. The position of these fillers elements can still change the location of critical areas of reinforced concrete structures and cause significant asymmetries of mass and stiffness.

It could be concluded to be fundamental to the development of building projects, deepen existing knowledge about the interaction of filling elements and frame structures of reinforced concrete. Two alternatives may exist: the adoption of constructive arrangement that ensures the separation between the elements of fillers and structure, or the adoption of model more sophisticated analysis which reflect the most accurately as possible the actual behavior of the structure.

III. Analytical Models Used

A. Introduction

Among the significant developments in the field of numerical models for structural applications has the ability to thoroughly analyze structures composed of concrete frames and blocks, such as brick or block masonry panels. These models allow explicitly represent the masonry components: mortared or not.

The behavior of these components is characterized by building models based on experimental results of materials and joints, which provide the parameters necessary for their effective use. Although this type of model in order to be more suitable for research studies, this analysis provides valuable information about the structural behavior, which may for example form the basis for the validation and calibration simpler models susceptible of being used directly in the project structures.

In this study, a numerical finite element model was used to analyze the behavior of reinforced concrete frames of 3 floors, under the action of horizontal loads. The model Based on explicit representation of structural components, parts of reinforced concrete and blocks of infill panels, and the joints between them. They adopted nonlinear behavior models for masonry panels so as to simulate the rupture by twisting or sliding along the seams.

This type of model allows to evaluate the efforts on the parts of reinforced concrete, due ace considered actions, taking into account the contribution of the filler panels. a series of parametric studies were performed in which was varied the geometrical and mechanical characteristics of masonry panels in order to evaluate its influence on the structural behavior and induced efforts on the frame of the parts.

B. Masonry modeling

The study of reinforced concrete frames with masonry panels was based on a finite element numerical model based on the hypothesis batch medium. In this type of model, the joints between the masonry block and between the masonry and reinforced concrete elements are explicitly represented by the use of joining elements. It is thus distinguishing the distributed slot designs in the panels is similar to a continuous medium with a behavior which reflects the existence of the joints, but these are not included in the model individually. In this type of analysis continues, therefore, the division of elements does not match the joints.

Rather, the discontinuous models such as used in the present study, the separation between blocks is defined by finite elements together. These indications represent a direct and realistic way whether the interfaces between blocks and between blocks and concrete paeans. It is therefore possible to analyze the possibility of breakage by tensile stress or sliding along these surfaces of discontinuity, assigning ace joints properties joint element correspond ace contact direct block-block.

The use of models with explicit representation of the joints between blocks naturally involves a calculation effort higher than the simplified continuous models, since it is intended to obtain a much more detailed analysis of the voltage states and deformation in the various component elements.

C. Models of behavior of materials

In this study we are effected nonlinear analysis, taking into account different laws of behavior of the materials and joints. For the elements of reinforced concrete frames, it was considered only the elastic phase, so it has not examined the possibility of rupture induced applied loads. Thus, it is possible to compare the behavior of various hypotheses of filler panels, without interference of the nonlinear response of reinforced concrete parts. The non-elastic behavior of the concrete can be taken into account by using constructive models proposed by several authors.

For its part, to the blocks of masonry panels was considered the possibility of failure, having adopted a model of elastic-plastic type behavior. For block-block together and block-concrete were considered disruptions traction and cutting. Described then in greater detail, the adopted behavior models, and the necessary properties for the characterization of each type of model.

Reinforced concrete

As the pieces of concrete have been considered in linear elastic regime, these elements are characterized by two elastic constants:

-Modulo elasticity (Eb)
-Coeficiente Poisson (vb)

Masonry blocks

For masonry block assumed an elastic-plastic behavior with a falling criterion of the Mohr-Coulomb type [2]. In this test the cut resistant characteristics are cohesion (ct) and the internal angle (φt). It is defined also the tensile strength by (Rt) for the rupture of this type. In addition to the resistances, the elastic parameters are also defined: modulus of elasticity (Et) and Poisson coefficient (vt). The properties of masonry blocks are

set like this:

- Modulus of elasticity (Et)
- Poisson's ratio (vt)
- Internal friction angle (φt)
- Cohesion (ct)
- Tensile strength (Rt)

Joints

The model of the joints, both the horizontal and vertical masonry joints between the blocks, or the interfaces between the blocks and the columns and beams gantry are all represented by finite element joint. It adopted the more general formulation for this type of problems, which admits a numerical zero thickness, the thickness of any mortar included in the parameters defining the mechanical performance of the joint element. This approach is valid in all systems in which the thickness of the mortar is small relative to the size of the block, which is the case of masonry panels [3].

The joint role model is a model of elastic-plastic type, characterized by elastic parameters and resistant parameters. In the elastic phase, the deformation of the joint in the normal direction is defined by a normal stiffness given by

Kn = Ea / ea

Where Ea is the model of the mortar elasticity, and its thickness. Similarly, the rigidity in the tangential direction is given by

Kt = Ga / ea

Where Ga is the distractions module of the mortar given by

Ga = 0.5 * Ea / (1 + va)

Where va is the Poisson ratio of the mortar.

Stiffness kN characterized deformability of the gasket member in the elastic phase, establishing the relationship between normal stress in the joint element and component in the normal direction of the reactive displacement between each side of the joint. Like this,

σn = kn un

with normal un displacement of the joint, defined as the difference between the displacement between the respective nodal points on either side of the joint element.

Equivalently, the shear stiffness relates kt the cutting stress and tangential displacements of the joint

σn = kn ut

Being ut the difference between the tangential components of the displacement corresponding nodal points on each face of the joint.

The elastic layer of the joints is limited by the rupture and cut. When the normal stress on the joint tensile strength of the joint, R, produces a rupture by tensile stress, normal stress and shear stresses are canceled. The maximum stress in the joint is thus given by

σn < R

The convection signs adopted in this study corresponds to consider positive strains and tensile stresses, and negative compression.

The breaking by cutting along the joint is defined by Coulomb´s criterion which defines the maximum shear stress as

σt < c-sn tanφ

c is the cohesion of the gasket material, φ the angle of the joint friction, σn normal stress. Rupture by cutting is admitted as a rupture elasto-plastic type, wherein the shear stresses are reduced to the surface of transfer. On the contrary, the breaking traction, above, causes abrogation of tensions in the joint element.

In summary, for the gaskets, the properties are set:

- Normal Stiffness (kN)
- Stiffness tangential (kt)
-Angle of friction (φ)
- Cohesion (c)
- Resistance (R)

D.Analyzed cases

This study focused on the analysis of a reinforced concrete frame of 3 floors, with a span of 3m. Note that the concrete elements have been considered continuous. the two situations, frames with filling and without filling were tested. The aim was to get a benchmark of increased portal resistance by direct action of filling wall and also determine the increased stiffness, measured indirectly by the effective reduction in the maximum horizontal displacement at the top of the frame.

E. Mechanical properties

Are indicated then the mechanical properties assigned to the various materials in accordance with the behavior models.

Reinforced concrete
- Modulus of elasticity = 30 GPa Eb
- Poisson Ratio = 0.2 vb

Masonry blocks

- Modulus of elasticity	Et = 3 GPa
- Poisson coefficient	vt = 0.2
- Internal friction angle	φt = 20
- Cohesion	ct = 0.1 MPa
- Tensile strength resistance	Rt = 0.5 MPa

block-block joints and concrete-block deformability parameters

- Normal Stiffness	kN = 30 GPa / m
- Tangential Stiffness	kt = 12 GPa / m

strength parameters

- Friction angle	φ = 25
- Cohesion	c = 0,2MPa
- Tensile strength	R = 0,11MPa

F. Actions

The actions considered by the own weight, loads and horizontal loads at the level of the slabs. The own weight of the concrete structure and blocks have been calculated with the following volumetric weights

Concrete 25 KN/m^3

Blocks 20 KN/m_3

Overloads applied to the beams took the value of 20 KN/m. Horizontal actions were assimilated to horizontal forces applied at the level of the slabs of the floors and considered its phased implementation, up to a maximum of 75 KN.

IV. Analysis of Results

The comparison between the two situations, filled and unfilled, was made essentially in terms of efforts on the pillars and beams of reinforced concrete frame. The results allowed to obtain some conclusions about the mechanism of deformation and rupture that develops in both test situations, with and without gantry fill.

For horizontal loads of low value, the gantry and the wall has an integral assembly and operation, remaining connected together; the contact surfaces between the wall and frame keeps in constant contact with each other, without unhooking. Increased horizontal load causes increase in deformations and from certain load values , rupture takes place between walls and frame. The separation begins in the upper right corner of the top floor, therefore the contrary corner to the application of the horizontal load and then extends to the lower extends to lower floor and then to the rest of the contact zone between the wall and frame, with the exception of the corners where it installs compression; these are the corners where it is applied to horizontal force.

Then develops inside the filling wall an inclined strut, connecting the corners, which is subject to a compressive force and thus establishes the participation in the wall of the balance and resistance to horizontal force. The rigidity of the assembly to horizontal actions (lateral) then decreases, because of the cracks that begin to install the fill wall and the connection to the gantry.

With the increased horizontal force, develops the process of separation between the contact surfaces, because more ruptures occur by cutting the fill wall. Efforts in the frame were growing as it processed the separation wall and frame.

With fill wall there is a significant increase in stiffness to horizontal actions. Indeed, for a horizontal force applied 25KN in filling wall frame have an installed horizontal deflection 0.57 mm, while the unfilled wall and frame for the same horizontal force already have a deflection of 4.7mm, which is significantly longer.

The significance of this finding is not only important in the structure aspect, but also in the construction approach, the level of performance of partition walls and facade. In effect the smaller the horizontal deflection installed, the lower will be the deformations installed in the partition walls and facade. Tensions installed on the walls will be lower depending on the deformation caused in the walls. for tension installed state in the walls of lesser value will be cracking occurring on the walls. It thus appears that the building performance improvement to increase the lateral stiffness of its structural system. The results showed that an effective and efficient because of reduced cost, to be able to increase the lateral stiffness is put masonry walls to fill the porticoes in its loading plane.

However, as mentioned above, the presence of such filler may cause rupture walls by horizontal cut on the wall and thereby doubling the maximum value of shear and relocate the sections occur where the maximum bending moment and shear. This effect has to be prevented from occurring, because doubles the maximum value of the shear and causes a brittle rupture and overloads adjacent columns, placing them also at risk.

The atrium and grip along the horizontal joint of the masonry turn it weak and therefore potentially rupture for generating a horizontal section at half the height of the wall should be adopted solutions to avoid this possibility. Especially in seismic zones should be provided for these systems. An effective solution for reinforce the wall.

The analytical results obtained allow us to conclude that the energy dissipation capability of the chassis assembly, filling gantry increases significantly. Indeed, the filling wall introduces some ductility of the gantry and wall together. Although the first rupture appears to reduced values of horizontal deflection, however, the value of the force responsible for the appearance of such rupture is considerably higher than gantry design maximum in a situation without a filler wall.

The sizing is a maximum force of 25 KN and rupture the frame with filling d wall appears to horizontal force of 42 KN.

The deflection corresponding to the first breakthrough was 3.4 mm whereas the wall rupture deflection was 9.3 mm. thus presents a non-negligible increase in ductility providing for the structural system porch and fill wall.

V. Conclusion

The study of frames of reinforced concrete, with and without filling masonry walls, shows that the presence of masonry walls inserted in the frame plan introduces significant changes in the distribution of the lateral stiffness of the structural system in the entire building.

The available computational means allow to analyze in detail the tension distributions within the various structural components, in particular masonry, and thus achieve the possible breakage of these components or interfaces between them, leading to consistent results with the data from the laboratory and the observation works.

The results confirmed the importance of filler panels in the overall structural behavior and distribution efforts in parts of reinforced concrete.

The consideration of masonry walls leads to a significant increase in the rigidity of the structure, and, in general, to a reduced effort on the pillars. The inclusion of the numerical models panels must, however, be made in a critical manner in order to not overestimate the filler contribution.

In particular, the results show that perfect binding event between the beams and lower floor panels leads to a decrease of excessive efforts on the columns, which may not have any practical reality.

Parametric studies which adopt progressively lower values for the parameters of resistant masonry joints led to a gradual increase in efforts in frame parts.

It was found that in the case of low tensile strength and shear joints, this process leads to the formation of a compression rod which can enter the panels major transversal efforts on the basis of the pillars. In particular situations, these efforts may be higher than those resulting from an analysis despising filling, due to the change of the horizontal forces transmission mode, caused by the presence of the panels. These effects tend to be more likely when the resilient characteristics of masonry shear and tensile are smaller.

The theoretical modeling also shows the negative effect of local abnormal situations, such as the existence of natural surfaces with low resistance to cutting, or reduced height filler panels. For this situation the value of the maximum shear doubles, putting at risk the structural safety of the building.

REFERENCES

[1] Morais, António, J.; Quintas, A.A.; Pedro, Januário - Study on the Geometrical Instability of the Building of the Church of Santa Maria La Mayor Y Real de Sar. XIV International Conference Le Vie Dei Mercanti, Naples.

[2] Paul, G.- A Modification of Coulomb – Mohr Theory of Fracture. J. Applied Mechanics (1961).

[3] Rocha, M. – Curso de Mecânica das Rochas . LNEC, Lisboa (1971)