ANALYSIS OF PATHOLOGICAL DEFECTS OF LOAD-BEARING MASONRY TECHNOLOGY IN LOW INCOME PROJECTS

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SUMMARY

The loadbearing masonry specifically that with unreinforced brick masonry walls has been widely used in low income projects in Southern part of Brazil. This article presents a statistical analysis of pathological defects in these projects. The pathologies were identified through the application of a systematic data collection method by direct observation, which produced a defect index per unit (CDU). The most common pathologies defects were cracks and inner infiltration of water. The causes of main defects were due to inadequate use of construction techniques, design mistake or a combination of both.

INTRODUCTION

There is a great dwelling deficit in Brazil, which is estimated in about 6,4 million houses (João Pinheiro Fundation, 2005). Around 96% of these dwellings are occupied by families with a net income less than five times of the minimum salary in Brazil (about AUD 1.100). In order to reduce this deficit the Brazilian government has launched lots of dwelling projects, among them two recent projects have been widely applied nationwide: the Residential Leasing Program (PAR) and the Apartment in Plan program (IP). From these two programs, promoted and financed by the Brazilian Public Savings Bank (CAIXA), a number of 14.207 dwelling units have been built so far in the State of Rio Grande do Sul (CAIXA, 2007).

Structural unreinforced masonry with ceramic bricks is the most applied building technology in these types of projects. According to data from CAIXA (2007), this technology was used in more than 70% of finished buildings in Rio Grande do Sul from both PAR and IP programs. And about 20% of all finished buildings were constructed with unreinforced masonry made of concrete blocks.

Along the process, NORIE (the building innovation research group of the Federal University do Rio Grande do Sul) has been playing an important role with several research programs together with local contractors and CAIXA itself. This present study is just one of these researches carried out by NORIE, and aims to analyse pathologic manifestations in those low income dwelling projects, the PAR and IP programs, built with structural unreinforced masonry.

The method used in this study has been applied in other States of Brazil through a network research project with others Federal Universities, in order to identify the main pathologic manifestations in each region and to analyse the differences in applying the structural masonry technology in these projects. This is justified by the fact that Brazil is a country with great climate and cultural differences in all regions, and that all projects have applied structural masonry with similar characteristics.

METHOD

Sampling

Eight low income projects were selected from the PAR and IP programs in Rio Grande do Sul, making a total of 1.034 apartments. These selected buildings were constructed by different contractors and all have applied the structural masonry process, either with brickworks or blockworks. Table 1 presents the selected projects with their main characteristics, while figure 1 shows a layout of a project from PAR4.

Table 1. Selected projects with their main characteristics

Projects	Number of Buildings	Number of apartments	Characteristics				
			Program	Age*	Height	Contractor	Masonry
IP1	56	56	IP	12	2 floors	E1	Concrete
IP2	62	62	IP	48	2 floors	E1	Concrete
PAR3	07	112	PAR	18	4 floors	E2	Ceramic
PAR4	10	160	PAR	07	4 floors	E2	Ceramic
PAR5	03	112	PAR	12	4 floors	E3	Ceramic
PAR6	03	132	PAR	24	3&4 floors	E3	Ceramic
PAR7	10	200	PAR	10	5 floors	E4	Ceramic
PAR8	10	200	PAR	07	5 floors	E5	Ceramic

* Age in months, from the conclusion of the building to the date of the diagnostic.

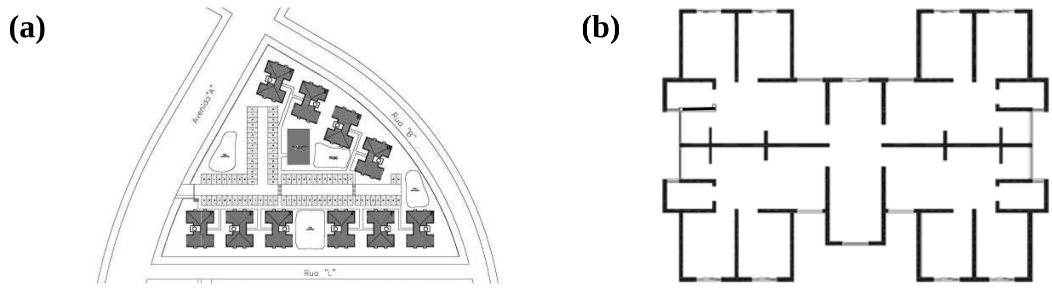

Figure 1. Illustrative example of project PAR 4: (a) layout of buildings and (b) plan view of a building with 4 apartments per floor

Method of the systematic collection of pathologic manifestations in the buildings

Data collection was done by applying the method of systematic collection of pathologic manifestations (by direct observation) developed by Richter (2007). This survey was done in the same manner in all visited units, through observation and registration of the pathologic manifestations of all walls (interior and exterior), ceilings, and floors. The application of this tool has resulted in a diagnostic, expressed by a Coefficient of Defects per Unit (CDU). It was possible, from this coefficient, to determine an index for each pathologic manifestation and to compare the buildings among them. CDU is calculated by dividing the number of pathologic manifestations by the total number of elements (equation 1).

CDU = number of pathologic manifestations/total number of units (1)

To get the number of elements it was considered each face (inner and outer) of a wall, ceiling or slab as a unit. For the number of pathologic manifestations, some criteria have been

considered: (a) cracks at 45^o, horizontal, vertical, and stair-shape cracks with more than one meter long were divided in one pathologic manifestation for each linear meter, and numbered and codified separately; (b) map-like cracks, were divided in one pathologic manifestation for each squarer meter, and numbered and codified separately; (c) moisture was considered only when the presence of water (by infiltration, condensation or by accident) was observed inside the apartment. And it was also divided in one pathologic manifestation for each squarer meter, and numbered and codified separately; and (d) in the case of a pathologic manifestation identified in both faces of the same wall, it was considered just once and accounted for the face with the greater impact. For instance, a horizontal crack identified in both faces of the same wall has been accounted just for the face with greater crack opening.

Selected sample units for each project represent 10% of the whole project units. This value of 10% for the samples statistically represents a reliability level of 95%. The units were symmetrically selected in each project.

Coefficients were compared through the ANalysis Of VAriance between groups (ANOVA) using software “Statistica – version 5.0”. This statistic analysis aimed to identify, among all collected data, what variables presented a significant statistic (with a reliability level of 95%) behaviour related to the accounted pathologic manifestations.

Method of the analysis of pathologic manifestations causes

Data collection of manifestation causes was done in three parts: (a) observation of construction techniques; (b) observation of the specific masonry projects; and (c) interview with the professionals who were involved with the construction, for example, building engineers. These studies were done after the presentation and discussion of the pathological manifestation defects data’s in each contractor. Eight projects, totalizing 1.243 apartments, were analysed, and all of them were built by the same contractors of the first study.

RESULTS AND DISCUSSION

Pathological Defects

Table 2 presents global CDU coefficients and CDU per element (slabs, inner and outer faces of walls), calculated from data collected in the all projects studied.

Table 2: Global CDU Coefficients and CDU per element

Project	$CDU_{AVERAGE}$	CDU per element		
		CDU_{SLAB}	CDU_{WALL} (EXTERNAL FACE)	CDU_{WALL} (INTERNAL FACE)
IP1	0.30	0.32	0.38	0.14
IP2	0.18	0.12	0.18	0.24
PAR3	0.82	0.49	1.31	0.72
PAR4	0.85	0.03	2.44	0.13
PAR5	0.98	0.49	2.21	0.26
PAR6	1.08	0.76	2.30	0.17
PAR7	0.39	1.00	0.13	0.05
PAR8	1.35	0.43	3.41	0.20

ANOVA of the CDU for each unit in the different assessed elements shows differences between CDU coefficients per project, per element and the interaction between these two variables is statistically considered as significant. Thus, it was verified a considerable difference between CDU coefficients of each project.

To verify the significance between CDU coefficients of each project, multiple analysis of means given by the computer program. From this analyses, the CDU coefficients of projects IP1, IP2, and PAR7 are much lesser that those of other projects; however, these same coefficients did not present significant differences among them. On the other hand, the average CDU of project PAR8 is significantly greater than those of other projects, excepting that of project PAR6. It was also observed that the average CDU of projects PAR3, PAR4, PAR5, and PAR6 did not show significant differences among them; neither did the average CDU of projects IP1 and IP2.

The average CDU coefficients of project PAR7 indicate that this project presented the lowest coefficient comparing to other projects from PAR program. However, from the analysis of CDU coefficients of each element, is noted that nevertheless with the lesser coefficients in inner and outer faces of the wall, this project has the highest CDU for slabs compared to all projects.

Project PAR3 has a average CDU lower that those of projects PAR4, PAR5, PAR6, and PAR8. However, from the analysis of CDU coefficients of each element, it is observed that project PAR3 had the highest CDU for internal faces of the walls.

External Pathological Defects

Table 5 presents CDU coefficients for external faces of walls (façades) from all projects, separated in shape of each pathologic manifestation.

Table 5. CDU Coefficients of wall external faces

Project	CDU_{WALL} (EXTERNAL FACE)	CDU per type of pathologic manifestation					
		Map-like cracks	Horizontal cracks	Vertical cracks	Stair-like crack	Cracks at 45 degrees	Wider cracks
IP1	0.38	0	0.10	0	0	0	0.28
IP2	0.18	0	0.10	0.04	0	0.02	0.02
PAR3	1.26	1.04	0.22	0	0	0	-
PAR4	2.44	1.34	0.73	0.22	0.12	0.03	-
PAR5	2.21	2.21	0.0	0	0	0	-
PAR6	2.30	1.70	0.48	0.04	0	0.08	-
PAR7	0.13	0.02	0.10	0.01	0	0	-
PAR8	3.41	2.74	0.24	0.19	0.23	0.01	-

In terms of the pathologic manifestation types accounted for wall external faces, ANOVA of the CDU coefficients for each residential unit, one can note that differences between CDU coefficients for each type are significant. Therefore, the great difference between CDU coefficients for each type of pathologic manifestation can be verified. This significant difference between the identified types of defects in façades can be justified by the significantly greater number of map-like (figure 2-a) and horizontal cracks (figure 2-b) present in the external faces compared to other defects. This observation can be verified through the multiple analysis of means given by the computer program.

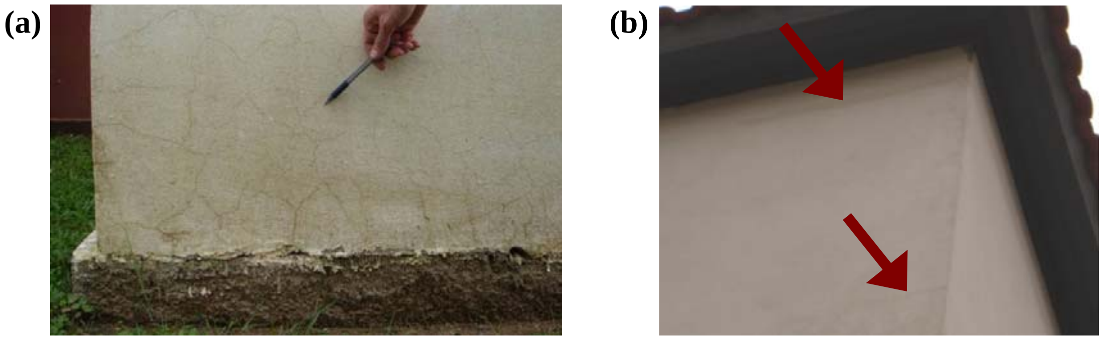

Figure 2. Illustrative example of main external pathological defects: (a) map-like cracks and (b) horizontal cracks

Map-like cracks identified in the façades of buildings presented a uniform distribution: crack lines crossed one another in angles of 90 degrees. According to Cincotto (1991), when map-like cracks have this particular distribution the problem might be because of mortar shrinkage. The cause could be linked to the inadequate proportioning of the mortar (such as too much fines), bad application (early surface finishing), and/or condition of exposition: wind and high temperature (Thomaz, 1989).

Horizontal cracks next to the last floor slabs occur with a certain frequency in buildings made of structural masonry (Duarte, 1998). These cracks are caused by shrinkage movements and contraction caused by variations in temperature throughout the whole height of the building. These movements lead to tensile and shear stresses in the walls, which typically cause horizontal cracks (Thomaz, 1989). Besides, the shortening of slabs – especially the last floor slab – caused by shrinkage, has the tendency to rotate the course bricks near to the slabs (ABCI, 1990). Cracks in walls can also occur if shrinkage is intense and beam elements have low structural tightness, particularly in external walls with openings of windows.

Internal Pathological Defects

Table 8 presents CDU coefficients for internal faces of walls from all projects, separated in shape of each pathologic manifestation.

Table 8. CDU Coefficients of wall internal faces

Project	CDU_{WALL} (INTERNAL FACE)	CDU per type of pathologic manifestation						
		Moisture	Horizontal cracks	Map-like cracks	Surface irregularity	Vertical cracks	Cracks at 45 degrees	Stair-like crack
IP1	0.14	0	0.03	0	0.10	0	0.01	0
IP2	0.24	0	0.14	0.01	0.05	0.04	0	0
PAR3	0.71	0.03	0.36	0.18	0.08	0.03	0.03	0
PAR4	0.13	0	0.07	0	0	0.04	0.01	0.01
PAR5	0.26	0.25	0	0	0	0	0.01	0
PAR6	0.17	0.08	0.01	0.01	0.03	0.02	0.02	0
PAR7	0.05	0	0.01	0.01	0.03	0	0	0
PAR8	0.20	0.19	0.01	0	0	0	0	0

In a general view, it was observed that differences between CDU coefficients for the type of pathologic manifestation identified in this element are significant from the statistic point of

view. This is justified by data analyses from the ANOVA for CDU coefficients (calculated for the all defects identified in the internal faces of the wall) of each type of pathologic manifestation. Comparing all CDU coefficients for each type of pathologic manifestation, it is noted that coefficients of horizontal cracks (figure 3-a) and those of moisture problems (figure 3-b) are significantly higher than others coefficients identified in the internal faces of the walls. This analysis is verified through the multiple analysis of means given by the computer program.

(a)

(b)

Figure 3. Illustrative example of main internal pathological defects: (a) horizontal cracks and (b) moisture problems

Horizontal cracks were identified in the internal faces of walls especially next to the last floor slabs, following the horizontal mortar joint approximately 20 cm under the ceiling. These horizontal cracks were also identified in smaller amounts in regions surrounding openings of windows, and these internal cracks are quite similar to those found in the external faces. This may be caused mainly by dilatation and contraction of slabs caused by temperature changes.

The presence of moisture in the internal faces of walls was mainly due to infiltration of rain water through horizontal and map-like cracks in the façades. This problem was identified particularly in projects PAR5 and PAR8. In project PAR5 this problem of moisture by infiltration was added to problems of moisture by condensation, which has led to mouldy environments in some units.

Pathological Defects in Slabs

Table 11 presents global and individual CDU coefficients, identified in slabs per type of defect in all projects.

Table 11. CDU Coefficients of slab

Project	CDU_P (SLAB)	CDU per type of pathologic manifestation			
		Interface cracks	Surface cracks	Surface irregularity	Moisture
IP1	032	0.32	0	0	0
IP2	0.12	0	0	0	0.12
PAR3	0.49	0.05	0.44	0	0
PAR4	0.03	0.02	0.01	0	0
PAR5	0.49	0.45	0.02	0	0.02
PAR6	0.76	0.72	0	0.04	0
PAR7	1.00	1.00	0	0	0
PAR8	3.41	0.43	0	0	0

ANOVA of the CDU coefficients for each type of pathologic manifestation in slabs shows that differences between these coefficients are significant from the statistic point of view.

When all CDU coefficients are compared, it is noted that only the CDU coefficients of interface cracks are significantly higher than others CDU coefficients – surface cracks and irregularity and moisture problems. This analysis is verified through the multiple analysis of means given by the computer program.

Cracks in the interfaces were identified in two situations: as cracks and irregularities in the interface slabs-walls (figure 4-a) and in the interface slab-slab for concrete poured in situ or precast panel (figure 4-b).

(a)

(b)

Figure 4. Illustrative example of main pathological defects in slabs: (a) cracks in the interface labs-walls and (b) in the interface slab-slab for precast panel

In framed structural systems made of reinforced concrete, columns and beams impose a restriction to concrete shrinkage coming from the slabs. This situation is different in buildings made of structural masonry as these buildings do not have those structural elements to absorb such shrinkage loads, and slabs are free to deform - particularly on the top of the building (Duarte, 1999). Thus, it is necessary to use support joints to release these movements.

There were few horizontal cracks in the slab-wall interfaces in project PAR3, as the last floor slabs are cantilevered in the walls – differently from other projects. This cantilever has solved the problem of cracks in slab-wall interface. However, this project had the highest CDU coefficient for the internal faces of walls (mainly of horizontal cracks). Due to the cantilevering of slabs in walls (in this case without the top beams) there is an increase in the rotation loads on the course bricks near to the slab. These loads might have been the main cause of horizontal cracks identified in the internal faces of walls.

Pathological defects according to solar orientation

CDU coefficients of the projects PAR3, PAR4, and PAR7 were divided in two groups: (a) stronger incidence of solar radiation on the façade; and, (b) weaker incidence of solar radiation on the façade. Table 14 shows the results obtained from these two groups.

Table 14. CDU coefficients per solar orientation

Incidence of Solar Radiation	CDU_{GLOBAL}	CDU per element		
		CDU_{SLAB}	$CDU_{W\ (EXTERNAL)}$	$CDU_{W\ (INTERNAL)}$
Stronger	0.60	1.07	1.46	0.26
Weaker	0.69	1.17	1.67	0.30

ANOVA of CDU grouped by solar incidence, shows that all coefficients did not significantly vary wether considered the stronger or the weaker solar radiation. However, this analysis can change for later ages.

Pathological defects by floor

CDU coefficients of all PAR projects were grouped by the vertical position, as presented in table 15. Residential units were symmetrically selected in each project, as follows: ⅓ of ground floors, ⅓ of second floor, third floor and/or fourth, and ⅓ of last floor.

Table 15. CDU Coefficients per vertical position of the residential units

Vertical Position (Floor)	$CDU_{AVERAGE}$	CDU per element		
		CDU_{SLAB}	$CDU_{W (EXTERNAL)}$	$CDU_{W (INTERNAL)}$
Top floor (last one)	**1.00**	**2.59**	**2.14**	**0.32**
Intermediate(s) floor(s)	0.61	0.65	1.85	0.27
First floor	0.57	0.40	2.12	0.18

From data of ANOVA the CDU coefficients of last floors units are significantly higher than those of other floors. Besides, the slabs coefficients presented a great difference (from 2.59 to 0.40). This difference was small for external walls coefficient, and the internal walls of the last floor showed a higher coefficient.

Based on these values it is verified that main defects have occurred in the last floor. Attention to technical design detailing should be paid in this situation, particularly in the wall-slab interfaces.

Causes of Pathological Defects

The causes of pathological defects are often complex (Hendry, 2001). The main pathological defects in the masonry are cracks, which can be caused by excessive loads, restrained expansion, unaccommodated contraction, excessive deflection of the supporting structure, weathering, incompatibility of materials, poor workmanship, vibration, frame movement, foundation movements, and chemical change (Grimm, 1997). The study of these causes is very important to understand the reason of cracks in buildings.

Based on these causes, in this study, it was observed that some technical inadequacy and design mistakes were the reason of the major building cracks. This study is complex because cracks can be provoked by many factors. Right now, a deeper study to trace and identify the main root causes is undergoing.

To put it briefly, for now, the relationships between cause and effect are summarised on figure 5. In doing so, it was concluded that one pathological defect (effect) was caused by more than one technical inadequacy (A), design mistake (B) or a combination of both (C) (cause), and one of these causes alone could be responsible for more than one pathological defect.

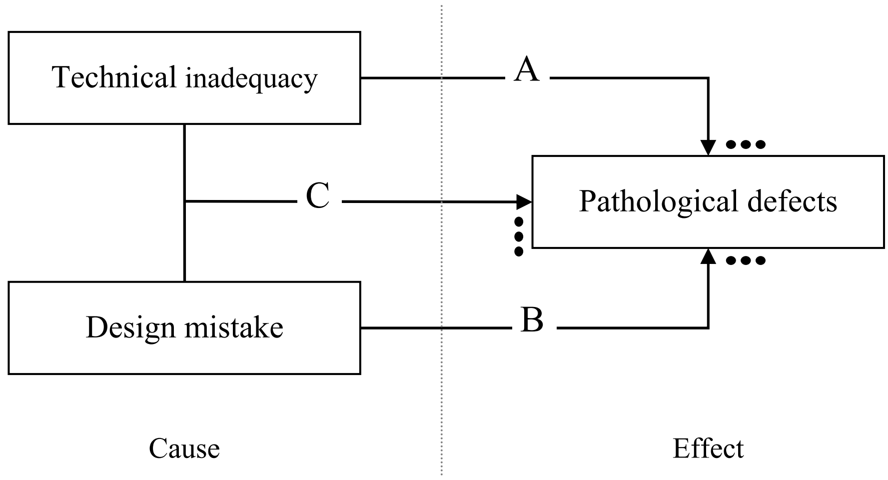

Figure 5: Relationship between cause and effect

The main design mistakes were: (a) inadequate support joint in the wall-slab interface of the last floor (necessary to release the shrinkage and temperatures stress); (b) insufficient control joints in the slabs and walls (necessary to reduce the movements of moisture and thermal variations), (c) insufficient top beams in the first and intermediate floors; (d) insufficient overlapping of both upper and lower window-beams; (e) insufficient grout points inside the vertical hollow bricks in the last floor (to strengthen specific wall junctions); and, (f) too many piping systems inside the slabs.

The main technical inadequacies were: (a) inadequate execution of wall junctions; (b) inadequate filling of bed and vertical joints; (c) insufficient filling of some window-beams; (d) excessive wall tearing, due to project changes made by the owner; (e) unevenness in the slabs panels and in some top beams supporting these slabs; and (f) top beams reinforcement with no overlapping in the corners.

Based on these problems, a lack of technical qualification from contractors has been observed. Though these major problems have been reported by the literature, some contactors have not incorporated some fundamental concepts of load-bearing masonry technology yet.

CONCLUSION

In general, the main defects identified in the units from projects PAR and IP were: exterior map-like cracks, moisture by infiltration in the interior faces of the external walls, cracks and irregularities in the slab-wall interfaces of last floor, and horizontal cracks in the internal and external wall faces of last floor.

After analysing all these defects, it was realized that all identified cracks do not jeopardize the structural performance of the buildings, as they are cracks with very small widths. However, once this study has been carried out at early ages, some of the cracks could jeopardize the structural performance at later ages.

By interviewing technical staff, discussions in seminars where all collected data in this research were presented, and observations in construction sites it was concluded that the causes of main defects were due to inadequate use of construction techniques, design fails or a combination of both.

Finally, the use of statistical analyses, through the CDU index, was very important to identify and quantify the most significant pathologic manifestations, which in practise can be applied to improve the overall quality of the projects. By the way, the method developed by the authors has just been applied in another regions of Brazil (north and south), and it is expected that results will be of help in understanding and comparing building defects, as both regions are quite different in climate and cultural construction techniques.

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