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Vertical Fences in Housing Units: The Use of Prefabricated Panels

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Abstract: The performance of prefabricated reinforced concrete panels, used as internal and external vertical fences of isolated and twinned housing units, was evaluated in this study. The main innovative feature refers to its thickness: only eight centimeters, since panels with higher thicknesses are traditionally well accepted and used in civil construction works. The evaluations included project analysis, audits in ready and running housing, and manufacturing industry. In addition, technological control tests were carried out to characterize the materials and also to attest the quality of the construction system composed of this kind of panels. The buildings executed with this system are also destined to housing of social interest, and the cost of execution can be reduced in comparison to the conventional system using the process of industrialization of its components, in which control of losses is emphasized based on the principle of loss reduction. To collect the data, two institutions were selected: one in the state of Paraná and another in Santa Catarina. Similar methodologies are used by both companies: the manufacturing of the panel is made in the factory and after the transport and positioning of this panel in the definite place using a munck truck. The results obtained in all stages of evaluation showed a proper performance to the system, reaching the minimum levels required in the applicable standards. It should be noted that fire safety assessments were not considered in this study; it could be the focus of future assessments in order to clarify all doubts regarding the potential of the system presented.

Key words: construction system, prefabricated panel, performance evaluation, housing

1. Introduction

The search for new construction technologies and industrialized execution processes has been the alternative found by construction companies that intend to reduce costs, maintaining acceptable standards of quality and performance of housing units.

According to Oliveira and Mitidieri Filho (2012) [1], the concept of sustainable development fosters the idea of designing the building not only for construction and use, but also for its final phase, including the concept of deconstruction, dismountability, and recyclability, in addition to the Design Life (VUP) and Global Cost.

In this scenario, buildings composed of prefabricated reinforced concrete panels, mainly slender panels, stand out for their convenience regarding the processes of transportation, assembly, and, if necessary, disassembly and recycling, given that the elements that comprise them favor these aspects.

Currently, the method that employs prefabricated panels is used in the manufacture of internal and external vertical fences of housing buildings, and it may have a structural function or serve only as fence system and room partitions.

As presented in this study, the panels are produced in factories capable of rigorously controlling the production phases of the elements and quickly adjusting potential deviations. A common type of concrete was used, i.e., without incorporation of air or addition of fibers; the thickness specified in the project

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is eight centimeters. The concrete process may occur in metallic forms positioned on a vibrating table or on concrete tracks.

The typologies evaluated were isolated and twinned single-storey houses and submitted to the performance tests specified in ABNT NBR 15575-4 (2013), particularly for thermal comfort, acoustic, structural, watertight, among others tests. This study did not consider fire safety evaluations, which may be the focus of future evaluations in order to clarify any and all doubts in relation to the performance potential of the system presented herein.

2. Material and Methods

This evaluation is composed by the realization of project analyses, inspections in works during the execution phase and finished buildings, inspections in industrial units, as well as observing the results of characterization tests of the materials used and performance tests.

The intention was to prove the minimum conditions of livability, comfort, and durability of the buildings evaluated based on Guideline SINAT 002-Rev. 02 (2016) and Performance Standard ABNT NBR 15575-4 (2013). Further observations were carried out between 2012 and 2015, and the inspections were focused in the cities of Astorga/PR and São João Batista/SC.

The construction system is intended for building walls for housing units. The system is composed of massive prefabricated reinforced concrete panels, eight centimeters thick, compressive strength f_{ck} greater than or equal to 25 MPa, and specific mass amounting to (± 50) kg/m^3. No fibers or air incorporation are added to the concrete. In this construction system electro-welded meshes type Q-138, steel CA60 are used presenting sections with area of 1.38 cm^2/m, spacing between wires of 100 mm, and wire diameter of 4.2 mm.

Some use conditions and limitations may be mentioned, such as:

- Prefabricated reinforced concrete panels for use in walls cannot be totally or partially demolished because they have a structural function; and
- The construction system is limited to environmental aggressiveness classes I and II, rural and urban respectively.

After assembling the forms, the demolding agent is applied and the frame is positioned, executed with electro-welded screens and steel bars in the reinforcements, close to the places where there are concentrations of forces, according to the structural design of each building.

Following the assembly of the rebar, the components of the electrical installations (conduits and switch and socket boxes) and the spacers are positioned to ensure the covering of the rebar. The hydraulic installations are not embedded; they are positioned in shafts, enabling periodic maintenance procedures.

The concrete application in prefabricated panels is always carried out horizontally and can be performed in two ways: in metallic forms positioned on a vibrating table for consolidation or in concrete tracks, where the metallic form is positioned and locked, restricting the area of application of the concrete and forming the type of panel to be produced. In this case, the consolidation is carried out by means of an immersion vibrator.

After 24 hours of concrete application, the demolding process commences, provided that the concrete has a minimum compressive strength of 12 MPa, and for each development the project must define the specific strength value of the concrete. The forms are then washed for use in another operational cycle.

The curing of the concrete panels used in the construction system is performed by sprinkling with water at least three times a day, during three days after the concrete application. Fig. 1 shows rebars positioned in the forms and the concrete application of the panel performed on the vibrating table for consolidation (Fig. 1).

Fig. 1 Rebars positioned and panel concrete application.

3. Panel Transportation and Assembly

The panels are transported and assembled *in situ* with the aid of a munck truck, which performs the lifting, moving, and positioning of the panel at the location specified by the project. Before fitting the panels, a mortar (1:3 trace) is applied to the interfaces between the panels and the foundation element. Some projects specify protruding steel rebars or metal inserts for corner connections, where after the joining of these elements by welding, a corrosion protection is applied (usually a painting with zinc-rich epoxy) and later release of the grout.

After the panel is placed in the definite location, with the aid of the munck truck, the plumb is inspected and the shoring is made with metal struts.

The alignment is obtained through the raft grooves. Next, the locking occurs between panels with type "C" clamps. These struts and locking clamps will only be removed three (3) days after grouting corner connections.

Fig. 2 shows the panels shored in the work and the details of the piece used and its dimensions (Fig. 2).

Joints are made to ensure the tightness of the facade water, especially in the areas of connections between adjacent structural panels, a procedure to which a depth limiter is inserted to occupy all the space between plate joints to prevent the leakage of the sealant and help compact the product by confinement. Afterwards, the sides and surface of the plates are cleaned and an elastic sealant of polyurethane is applied.

In the base areas of the panels that are in direct contact with the foundation element, cement-based waterproofing agents are applied in a strip of 1 m height throughout the perimeter of the building; then the acrylic sealer is applied on the entire surface, followed by acrylic-based Latex paint. Dry areas of the internal walls will be painted with a sealer and then painted again with PVA-based Latex paint. In wet areas (bathroom and laundry), the ceramic coating is used.

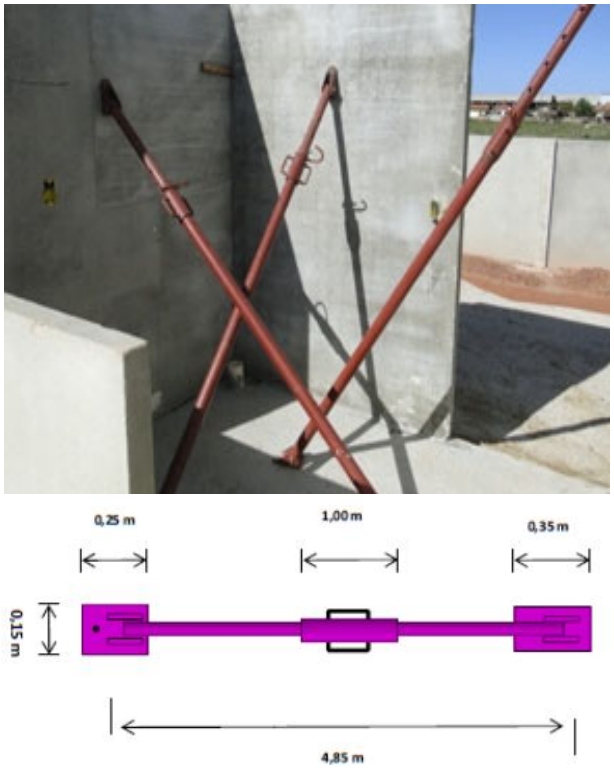

Fig. 2 Shoring and panel locking.

Fig. 3 shows buildings consisting of prefabricated reinforced concrete panels eight centimeters thick, finished and available for delivery to the owner (Fig. 3).

4. Technical Performance Evaluation

The technical evaluation presented in this study considered criteria regarding structural performance, watertightness, thermal performance, acoustic performance, durability, and maintainability. Criteria regarding quality control specific to the construction system were also considered.

4.1 Structural Performance

The characteristic strength specified for the concrete used in prefabricated concrete panels is equal to or greater than 25 MPa, as proven in concrete characterization tests performed in a laboratory installed in the plant.

Fig. 3 View of finished buildings.

The structural configuration is given by the composition of the structural panels responsible for building stability. The conclusion of the structural conception analysis performed by the estimating engineer and presented in the structural calculation memory suggests that the structural panels used as walls of the proposed construction system may receive the permanent actions and overloads expected for single-family and isolated single-storey houses, transferring them to the foundations in order to allow safety, stability, and the conditions of use, as long as the specific foundations design has been met.

In order to certify compliance with the criteria of Guideline SINAT 002-Rev.02 (2016), soft and hard body impact tests were performed on pre-molded structural panels used as external and internal walls and also tests of actions transmitted by sudden door closures and soft body impact with 240 J energy, applied in the geometric center of the door skin, showing no displacement or tearing of the frame, nor rupture or loss of stability of the wall. The suspended load test was also carried out.

The proponent of new construction systems should always prepare specific structural projects for each development, verifying the overall stability of the building and its implementation. It should be emphasized that for each specific situation the proponent should conduct the land analysis and the specific projects of development foundations and structure.

4.2 Watertightness

Project analyses were carried out to evaluate compliance with the watertightness requirement of the wall system of external and internal moisture sources.

It is considered that the wall system meets rainwater tightness conditions due to its construction characteristics (prefabricated reinforced concrete panels, with fck = 25 MPa, and subsequent painting application) and the treatment with an acrylic-based waterproofing system, applied at the facade base with a

height of 1 m, counted from the floor slab, and also the application of ceramic coating on the walls of moist and wet areas. In some projects the sidewalk is an extension of the raft, with 60 cm width and 5 cm difference in elevation in relation to the internal floor of the building (Fig. 4).

The way the windows are fixed (screws and polyurethane sealing) meets the conditions for rainwater tightness in the interface area between the wall and the window. The watertightness of the internal walls in contact with water for use and washing is considered satisfactory, also because of the construction characteristics of such wall (reinforced concrete walls with f_{ck} = 25 MPa and application of ceramic coating). With respect to the watertightness of the joints (interfaces) between walls and internal and external floors, the projects of each development should provide floor trims and difference in elevation between the external and internal floors to minimize the contact of the water on the floor with the base of the wall. An acrylic-based waterproofing system is also applied to the floor slab to prevent moisture from capillary rise of the soil. The joints between facade panels (connections of the structural panels) were evaluated based on a project analysis, presenting satisfactory performance in relation to watertightness. It is recommended to perform the tightness test of the facade panels in the laboratory, before and after the thermal shock test, in order to prove the performance of the system, especially in areas of joints.

4.3 Thermal Performance

Computational simulations were performed with the Energy Plus software to evaluate the thermal performance of buildings that use the system that is object of this study. The simulations considered climate zones Z2 and Z3, contained in ABNT NBR 15,220 (2005) for the typologies of isolated and twinned single-storey houses and according to each type of architectural project.

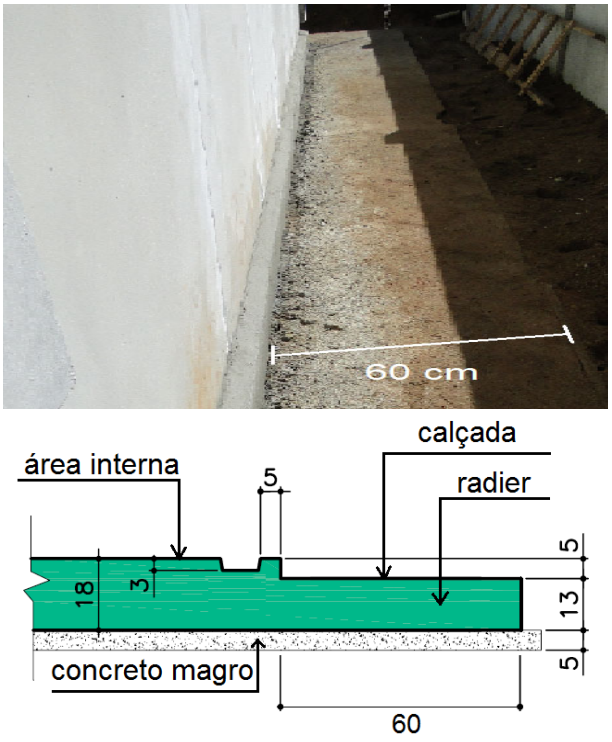

Fig. 4 Detail of the sidewalk pointing out the dimensions.

The typologies analyzed had areas between 60 m² and 78 m² and with ceiling height of 2.70 m; the covers evaluated were roofs with ceramic tiles or fiber cement, on attic and lining consisting of PVC boards 10 mm thick and concrete slab 10 cm thick. Considering the conditions established in Guideline SINAT 002-Rev.02 (2016), as well as the considerations mentioned in this study, the construction systems meet the thermal performance criteria. For other projects and other bioclimatic zones, specific analyses are recommended.

For the evaluation of the thermal performance the following parameters were considered: Absorbance to solar radiation of the external surface of the walls equal to: 0.3 (light colors), 0.5 (medium colors), and 0.7 (dark colors), listed in Guideline SINAT 002-Rev.02 (2016).

As an example, Table 1 presents a summary of the possible colors to be used in facades for the bioclimatic zones analyzed, which are the conditions to meet the isolated single-storey house typology with two and

three bedrooms, with ceramic roof tiles and PVC lining.

4.4 Acoustic Performance

The housing unit must meet the minimum criteria presented in Guideline SINAT 002–Rev.02 (2016). In a test performed, the acoustic performance presented satisfactory results, meeting the criteria for sound insulation provided by facade and ceiling elements. The acoustic performance evaluation was performed in a finished building (field test), considering the noise class II specified in ABNT NBR 15575-4 (2013).

The characteristics of one of the buildings tested are: area of 71.20 m²; facade wall composed of reinforced concrete panels 80 mm thick; "sliding" windows; two glass sheets 8 mm thick and with no shutter. The doors and door frames are made of wood and the ceiling is formed by roof with wooden structure, ceramic tiles (15 mm thick and density of 1700 kg/m³) and lining consisting of PVC boards (10 mm thick). Table 2 presents the synthesis of the results obtained.

Table 1 Necessary conditions for single-storey houses with the respective project typologies, to meet the requirements of Guideline Sinat 002-revision 2 [2].

Typology of the evaluated project	Bioclimatic zone	Color of the external finish of the facade walls			
		Standard condition (a)	With shading (b)	With ventilation (c)	With shading and ventilation (d)
Single-storey house with 2 dorm rooms	2	light or medium	light or medium	light or medium	light or medium
	3	light	light or medium	light or medium	light or medium
Single-storey house with 3 dorm rooms	2	light or medium	light or medium	light or medium	light or medium
	3	light	light	light	light or medium

(a) standard condition: rooms with ventilation only by infiltration through gaps in windows and doors, at a rate of one renewal of the ambient air volume per hour (1.0 Ren/h) and windows without shading;
(b) shading condition: external or internal sun protection that prevents direct sunlight from entering or reduces the incidence of global environmental sunlight by 50%;
(c) ventilation condition: ventilated environment at a rate of five renewals of the ambient air volume per hour (5.0 Ren/h);

Table 2 Summary of the results of the acoustic performance test, considering noise class II [3].

Fencing	$D_{2m,nT,w}$ (dB)	Required criteria (dB)	NOTE
Facade Front Dorm Room 1	26	≥ 25	It meets the minimum performance level
Facade Back Dorm Room 2	25		

4.5 Durability and Maintainability

Project analyses and tests were performed to evaluate the requirements considered important for the durability of the wall system at issue. The cement consumption, the environmental aggressiveness class, the compressive strength of the concrete, and the water-cement ratio were verified to ensure meeting the minimum quality of the concrete. The system of prefabricated reinforced concrete panels uses concrete with at least 300 kg/m^3 of cement, water-cement ratio ≤ 0.60, which is classified in concrete class C25 and in classes I and II of environmental aggressiveness. The nominal cover (cnom) for concrete panels is 25 mm, considering Class II of environmental aggressiveness, for fck = 25 MPa.

The project considers the preponderant aging and deterioration mechanisms related to concrete and rebars, specifying the characteristic of the concrete used in the construction system, complying with Guideline SINAT 002-Rev.02 (2016). Spacers are also used to obtain a nominal cover of 30 mm for the screen (Q138) composed of two 4.2 mm wires and centralized; these spacers are installed every 600 mm throughout the rebars, ensuring the minimum cover specified.

For each new development, an alkali-aggregate reaction test should be performed to support the choice of materials to be used in the concrete. In the case of the

construction system under analysis, as it is made up of concrete walls that have a structural and fencing function, the Design Life (VUP) specified for the structure is 50 years, which is the same for internal and external vertical fences. Guideline SINAT 002-Rev.02 (2016) is met regarding heat and thermal shock action since they are elements with homogeneous construction characteristics (solid concrete walls). Also, they have presented satisfactory results in the tests performed. The test was performed according to the specifications, following the dimensions of the specimens (2.40 m in length by 2.70 m in height) and the representation of the construction system, containing the joints between panels.

The maintainability was evaluated by ITA (Technical Evaluation Institution), considering the content of the Operation, Use, and Maintenance Manual of the building, prepared by the technology proponent, particularly analyzing the items related to the construction elements that compose or interfere with the prefabricated concrete wall system, specifying the precautions for the use and maintenance of the concrete wall system, including the definition of inspection schedules and the anticipation of wall painting procedures and frequency, replacement of components of hydraulic and electrical installations, among others.

5. Quality Assurance

Audits were carried out in manufacturing units and in works executed with the construction system of prefabricated concrete panels, verifying the quality control of the production process and compliance with Guideline SINAT 002-Rev.02 (2016). In the initial audit performed by the Technical Assessment Institution, the aspects of control described below were verified. Such aspects should be continuously controlled by the technology proponent.

- Receipt of materials and components (rebars and concrete — tests to verify the consistency and compressive strength of concrete at the demolding time and at 28 days);
- Sequences and quality of the production steps (cleaning and geometric control of the formwork; positioning and covering of the rebars; pouring of concrete; demolding, and curing);
- Sequence and quality of the assembly of frames and finishes such as ceramic tiles, waterproofing, painting, and texture application; and
- Sequence and quality in the assembling process of joints between panels.

The controls are based on technical documents that provide quality control of the projects, the receipt of materials, and wall molding. The technology proponent is responsible for the development of these technical control documents and for their application during the execution of the works, which was verified in the audited works.

The documents that prove the technological control of concrete and the traceability of information were also analyzed. One hundred percent of the batches of concrete delivered to the construction site are checked for consistency and compressive strength at the following times: 24 hours, 7 days, and 28 days. This control is done by an external technological control laboratory, and the tests are duly accredited. For the steel, the verification control of the product quality certificates is performed.

The control frequency and sampling of the materials that compose the reinforced concrete panels that are object of this construction system are:

- Constituent materials of reinforced concrete at each receiving batch (cart) for Cement (compressive strength, fineness, and blaine); Aggregates (granulometry and powder material); and Additive (product type and validity control);
- Concrete in fresh state at each application (reception, sampling, and slump);

- Concrete in hardened state at each molded specimen (curing and compressive strength test).

6. Final Comments

This study presented the potential for meeting the performance requirements of buildings composed of internal and external vertical fences produced with prefabricated reinforced concrete panels, especially with regard to their thickness of eight centimeters. Furthermore, the quality control criteria recommended for the proposed construction system were presented, which are aimed at ensuring compliance with the Design Life (VUP).

The project analyses and the results obtained in the tests performed suggested compliance with the applicable requirements of ABNT NBR 15575-4 (2013), with at least a minimum performance level.

Considering the above, the construction system addressed is understood to confer livability to the user, building durability, and that the fire safety assessments can be performed to clarify any and all doubts regarding the potential of the system presented herein.

The data presented in Table 3 shows the items evaluated, the criteria adopted, and the results obtained in relation to the analysis performed.

Table 3 Items evaluated, criteria adopted, and results obtained.

Item evaluated	Evaluation criteria	Results obtained	Required standard criteria	Performance level obtained
Structural performance	Guideline SINAT 002–Rev.2 (2016) - item 4.2.1	It meets ELU, ELS, impacts, and suspended load	According to item 3.1 of Guideline SINAT 002 rev.2	All items evaluated meet the minimum performance levels that are expected.
Watertightness	ABNT NBR 15575-4 (2013) item 10.1.1	VVE considered waterproof in the project analysis	According to item 3.3 of Guideline SINAT 002 rev.2	
Thermal performance	Guideline SINAT 002-Rev.2 (2016) item 4.2.4.2 and ABNT NBR 15.220 (2005)	It meets Z2 and Z3	According to Table 1	
Acoustic performance	ABNT NBR 15575-4 (2013) item 12.2.1.2	26 dB	≥ 25 dB	
		25 dB		
Durability and maintainability	Guideline SINAT 002-Rev.2 (2016) - item 4.2.6	It meets the VUP	≥ 50 years	

References

[1] Oliveira, Luciana Alves; Mitidieri Filho annd Claudio Vicente, O Projeto De Edifícios Habitacionais Considerando A Norma Brasileira De Desempenho: Análise Aplicada Para As Vedações Verticais, 2012, access on: May 11, 2017, available online at: http://www.revistas.usp.br/gestaodeprojetos/article/view/51022/55089.

[2] Roriz Engenharia Bioclimática, S/S LTDA (São Paulo), *Avaliação dos Níveis de Desempenho Térmico de Edificações Habitacionais com Paredes em Concreto*, São Carlos: Roriz, 2013, p. 15.

[3] Apoio Acústico (São Paulo), *Avaliação de Desempenho Acústico de Fachadas em Casa Isolada em Canelinha-SC.* (112nd ed.), Canelinha: Apoio Acústico, 2013, p. 31.