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Design, manufacture and construction of buildings with precast lattice-reinforced concrete slabs

Projeto, produção e execução de edificações com lajes pré-moldadas treliçadas

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Abstract

The use of precast lattice-reinforced joist slabs in reinforced concrete structures has advanced since the 1990s. Such slabs are produced in two steps: one at the manufacturing plant where the joists are made, and the other on site, when concrete topping is applied. These slabs offer several advantages over other systems, such as reduced consumption of building materials, lower labor costs, simplicity and speed of erection, easy installation of service conduits, lower self-weight of the concrete structure, versatility in use, and economy. The procedures involved in manufacturing the joists and assembling the slabs in various types of buildings in the region of São Carlos, state of São Paulo, Brazil are described and analyzed, and the results of interviews with manufacturers, designers and builders are reported. The data collected show that in most cases this system has been executed inadequately, without taking simple precautions that would have prevented many of the problems of quality and durability that usually arise during use.

Keywords: Lattice-reinforced joists, production, construction, quality, durability.

Resumo

O emprego de lajes pré-moldadas treliçadas nas estruturas de concreto armado ganhou impulso a partir dos anos 90. Sua construção passa por duas etapas principais: uma industrial na fabricação das joists treliçadas e outra, na obra, quando recebe o concreto para a confecção da capa. Seu uso se justifica pelas vantagens que apresenta em relação a outros sistemas, tais como a redução do consumo de materiais e da mão-de-obra, facilidade, agilidade e rapidez na execução, praticidade na confecção de instalações prediais, alívio do peso próprio da estrutura, versatilidade de aplicação e economia. Analisam-se os procedimentos de fabricação das joists e montagem dessas lajes em diversos tipos de edificações na região de São Carlos, São Paulo, além de feitas entrevistas com fabricantes, projetistas e construtores. Verificou-se que o sistema tem sido executado na maioria das vezes de maneira inadequada, sem cuidados simples que, se adotados, certamente melhorariam em muito os problemas de qualidade e durabilidade que quase sempre surgem na fase de utilização.

Palavras-chave: Lajes treliçadas, produção, execução, qualidade, durabilidade.

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1. Introduction

The constantly changing requirements of modern architecture and the growing need for rationalization in civil engineering drive the search for constructive systems that satisfy these aspects while ensuring the structure's ability to meet the requisites of load-bearing capacity, service performance and durability.

Until a few years ago, the structure most widely used in the construction of building slabs was the solid reinforced concrete slab. However, this slab required extensive formwork and falsework and had a high self-weight, making it unsuitable for today's requirements. A new slab system with precast lattice-reinforced joists began to be developed in Germany in the mid-20th century, using brick blocks as filler and a cement and sand topping. This new system was introduced in Brazil in the 1940s. Although precast lattice joists began to be manufactured in Brazil in the mid-1970s, they only came into widespread use in the 1990s (DROPPA JR, 1999 [1]).

The Brazilian NBR 6118 standard (2003) [2] defines precast slabs as "Slabs molded on site or with precast ribbing whose stress zone for positive moments is located in the ribs, between which inert material can be placed." This type of slab has been used extensively in civil engineering, especially in small and medium sized buildings, because it consumes less concrete and wood since it requires no formwork, and is safe and easy to build.

However, numerous factories have been set up, many of them lacking in technical expertise to produce these slabs or even to provide adequate technical support. Materials and elements are often of poor quality, building codes or fabrication, construction and control specifications are disregarded, and proper care is not taken in building the slabs. This leads to a variety of problems (insufficient reinforcement, use of inadequate concrete, incorrect height and incorrect assembly) and pathologies (unacceptable deflections, cracks, fissures, infiltrations, rebar corrosion, etc.).

Moreover, small and medium sized buildings are often constructed illegally, without qualified labor, without designs or with designs lacking in detailed specifications, and supervised by only one experienced builder.

In view of the above, a study was conducted in the city of São Carlos, interior of the state of São Paulo, Brazil, about the conditions involving the design, construction and problems of buildings constructed with this type of slab. To this end, visits were made to construction sites and slab manufacturing plants, and interviews were held with designers, manufacturers, construction site engineers, builders and workers (helpers, bricklayers, and master builders).

At this point, it is opportune to point out the lack of specialized literature that clearly and accurately shows aspects of the design and construction of this system. In Spain, for instance, there are papers such as that of Calavera et al. 1988 [3] that provide guidelines for designers and builders, and especially codes and detailed recommendations, such as the EF96 1996 [4] and EFHE 2004 [5] guidelines.

The Brazilian standards for these slabs are quite simple, providing few or no guidelines for their design or construction stages. Much of what is built today follows manufacturer instruction tables, technical catalogues and software. This finding was reinforced by a nation-wide survey involving mainly plane slabs constructed with precast lattice joists, which was conducted in 2009 by Avilla Junior [6], who reached some interesting conclusions:

- **a)** Many designers do not make designs using plane slabs with precast lattice joists, usually because they are unsure about how such slabs work, especially as stiff diaphragms, and also due to the lack of dissemination and paucity of specific technical literature. Moreover, they have no clear opinion about the economic advantages of the system compared to other systems, especially solid slabs.
- **b)** About 70% design the system for small and medium sized buildings of up to five floors; for taller buildings they prefer cast-in-situ solid slabs; and most of them consider spans of up to 6m competitive for these slabs.
- **c)** To design their slabs, they use structural calculation programs as often as they do manufacturer tables and software packages.
- **d)** The filler elements most commonly used are EPS blocks (85% of the total), followed by clay blocks (55%), and concrete blocks (5%). Removable plastic formwork is still rarely used. The sum total is more than 100% because many constructions use more than one type of filler.
- **e)** The pathologies most commonly found are cracks due to torsion of edge beams in slab panels, excessive strains, longitudinal cracks between the joist and the filler element, buckling of the upper chord of the lattice, and the appearance of bulges in the soffit of the slab (indicating the downward displacement of the filler during concreting).

The objective of this work was to analyze and evaluate the situation at construction sites using lattice girder slabs, addressing the issues of design, manufacture and construction procedures (construction details, difficulties encountered) observed on site.

Figure 1 – Cross sections of precast slabs

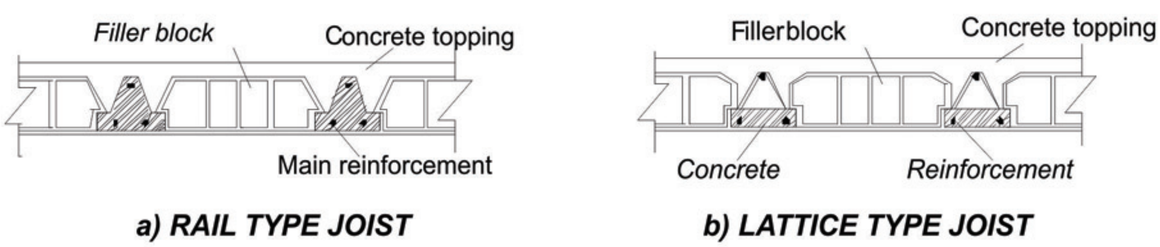
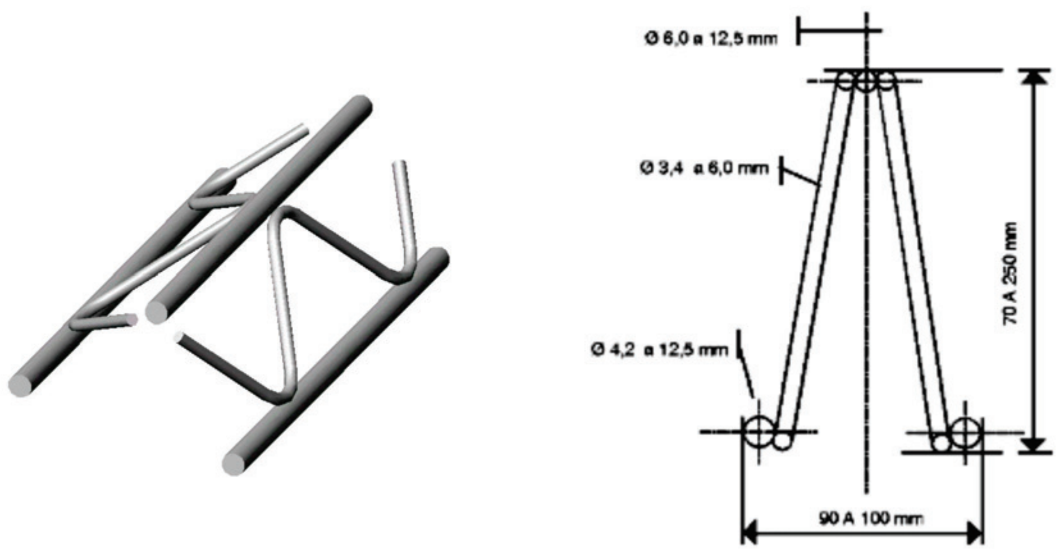


Figure 2 – Lattice reinforcement: general view and generic cross section



a) General view   b) Generic cross section

2. Constructive system using precast ribbed slabs

Precast ribbed slabs are an alternative to traditional structural systems. These slabs use precast rail- or lattice-type joists with filler elements between the joists, which may be clay blocks, EPS blocks, etc., tied together with an on-site cast concrete topping with distribution reinforcement bars.

The rail-type element, which is little used today, has a transverse section with an approximately inverted T-shape, with reinforcement composed of straight bars placed on the lower part and enveloped by concrete (Figure 1 a). Lattice joists (Figure 1 b) consist of a lower concrete slab reinforced with a spatial steel lattice.

Lattice reinforcements have two chords connected by equally spaced diagonals (Figures 2 a and 2 b). The upper chord consists of a steel bar and the lower chord of two bars. Its construction does not require formwork for concreting the topping and the remaining ribs, requiring only falsework to bear its self-weight and any accidental construction load. The filler elements serve as formwork for the fresh concrete topping.

The Brazilian standards NBR 14859-1:2002 [7] and NBR 14859-2:2002 [8] standardize the nomenclature of prefabricated slabs and establish the required conditions for receiving and using components to be employed in construction. The main advantages of these slabs are their transverse displacements, which are generally much larger than those of solid slabs, and in the case of one-way slabs, the loads on the edge beams are not distributed uniformly.

3. Design and manufacture of precast lattice-reinforced slabs

The manufacture of precast lattice slabs, albeit simple, requires careful attention to all the details to ensure the structure performs satisfactorily during its service life, without displaying pathologies resulting from the constructive process. Special care should be taken in leveling the supports, placing the reinforcements specified by the design, installing catwalks for the circulation of workers, materials and equipment, and in the laying, compaction and curing of the concrete topping.

Item 5.1 of the Brazilian standard NBR 14859-1:2002 [7] specifies that the design of a precast lattice slab should be composed of three distinct parts: the slab's structural design, its fabrication specifications, and a slab placement and assembly handbook.

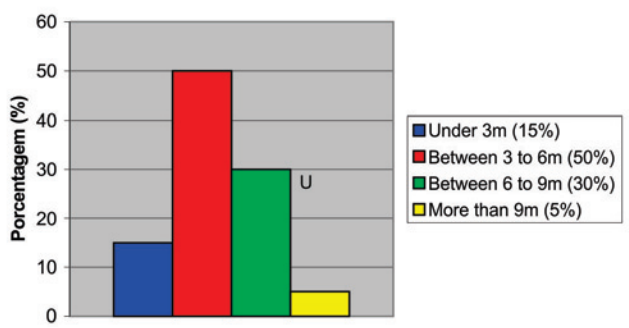
4. Field survey: results and analyses

The main objective of this study was to analyze and evaluate the situation of ongoing constructions using precast lattice slabs, particularly in the city of São Carlos, state of São Paulo, Brazil, focusing on the design, fabrication and construction procedures observed at the constructions sites, and to propose solutions for problems related to these aspects, whenever possible, in order to contribute to increase the technical knowledge of users of precast lattice slabs. With this objective in mind, visits were made to construction sites and slab manufacturers, followed by interviews with manufacturers, designers, construction site engineers, builders and workers, and a detailed photographic record was prepared.

4.1. Result of interviews with manufacturers of precast lattice-reinforced slabs

The purpose of the questions was to characterize the manufacturers and their plants' activities, determine the order of the most

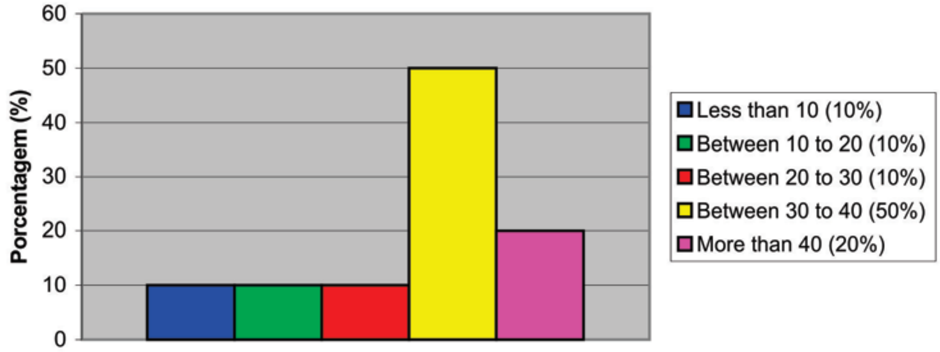
Graph 1 – Span lengths most commonly ordered



commonly commercialized spans, establish the processes, identify the most frequent problems, and hear their opinions.
Two thirds of the interviewed owners are civil engineers and all of them (100%) have worked in this sector for over 10 years. The manufacturers are businessmen who, in addition to manufacturing and selling slabs, also perform other activities such as the creation of building construction designs (100% of them), slab calculations (75%) and execution of construction projects (25%).
Today, the spans most commonly requested fall within the range of 3m to 6m (50% of the total), but there is a trend for the sale of joists for larger spans (30% between 6m and 9m), as shown in Graph 1.
All the manufacturers (100%) state that they design the slab to be fabricated and supplied to the client. In general, the owners are aided by one or two people, architects or engineers, to help in elaborating projects and in dimensioning and to meet the demand of orders. Dimensioning is done in-house and most of the manufacturers use software supplied by lattice manufacturers (75%), charts (50%) and structural dimensioning programs (25%). The sum is higher than 100% because some slab manufacturers use more than one procedure.
The plants that were visited usually do not work with stock, producing only on order. Steel lattices are normally stocked in warehouses without walls, piled on top of one another and not covered (75% of the cases).
The use of high early strength cement to produce joists is a practice adopted by 75% of the manufacturers. Half of the plants use concrete with a characteristic compressive strength of 20MPa while the other half used concrete with strength equal to 25MPa. Only 50% of the manufacturers admitted that they perform technological control of the concrete of their joists to ensure their strength and final quality.
In the casting of lattice joists, all of them stated they do not use spacers to ensure the reinforcement is covered; explaining that the lattice itself settles into the right position inside the formwork after the concrete is laid. Three quarters of the manufacturers stated that the coating is about 1.5cm thick, while 25% stated that the coating layer is thicker than 2cm. The joists are left in the formwork for an average of one day.
At most plants (75%) the concrete is laid in the formwork by hand, using buckets and wheelbarrows. Only one plant lays concrete through a mechanical system (Figure 3). Because the concrete for joists has a fluid consistency, all the manufacturers perform compaction by hand. Concrete is cured by wetting the joists three times a day for one or two days after concreting.
The filler material most commonly used is clay blocks, but 50% of the manufacturers prefer using expanded polystyrene (EPS) blocks because they are larger and lighter filler elements, break less and their strength is similar to that of clay blocks, thus increasing the plant's work productivity. The advantages attributed to clay blocks are their wide application in the market, easy handling and low cost.
All the interviewees stated that they give the client a detailed design of the slab assembly and instructions about the care to be taken in its execution, and 75% of them stated that they provide detailed instructions for the falsework in 90 to 100% of cases. Half of them supply not only guidelines about the falsework but also metal scaffolding.
Half the manufacturers stated that their plant engineer visits construction sites during the slab's assembly to oversee the work. One of them claimed that he visits construction sites in 90 to 100% of cases, while another stated that he makes such visits depending on the size and complexity of the slab.
All of them claimed that walls can be erected on the slabs provided information is available about the loads applied by the walls and that proper dimensioning and detailing is done.
The manufacturers consider the lattice-reinforced joist slab suitable for 70 to 80% of the constructions in the region of São Carlos, since it is an easy and fast system to set up, inexpensive, versatile, and facilitates the execution of electrical, hydraulic and sanitary installations.
The majority (75%) claimed that the main problem detected is incorrect assembly of the lattice slab, while the other 25% state there is no main problem. The second greatest problem the manufacturers (75%) mentioned is breaking or sagging of the filler element during concreting.
Other problems that appear less frequently are excessive strain, detachment of the ceiling overlay from the filler element, difficulty in com-

Figure 3 – Concrete poured using a mechanism created by the manufacturer

Graph 2 – Number of building designs involving the use of lattice-reinforced concrete slabs



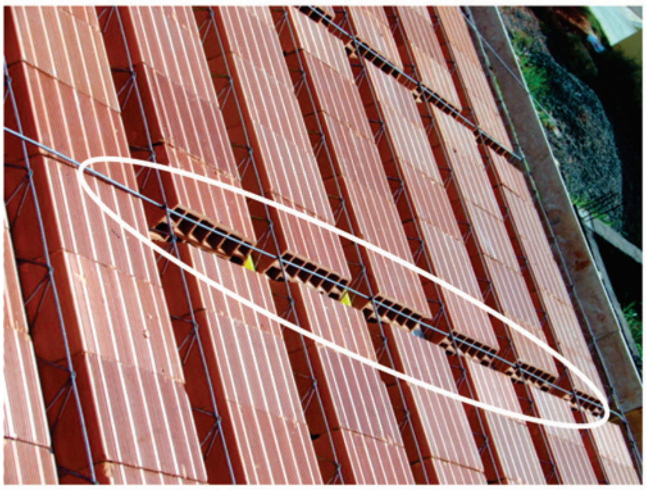
pacting the slab's concrete topping, longitudinal cracks between the rail and the filler element, cracks in the concrete of the roof slab, etc.

The manufacturers offered some suggestions to improve the execution of lattice-reinforced slabs: development of a new, cheaper filler element that does not break easily; a stricter code for slab materials and for the procedures to execute them; greater dissemination of technical material and information for worker training, and standardization of computer-aided calculation programs for the dimensioning of slabs.

4.2. Result of interviews with designers of lattice-reinforced slabs

The interviewees are architects (20%), civil engineers (50%) or people with technical or technological training (30%). Among them, 60% stated they do not engage in any activity related to lattice slabs other than their design, while the other 40% stated that, in addition to calculations, they also deal with the on-site construction of these slabs. Moreover, 30% design, execute and manufacture lattice-reinforced slabs.

Figure 4 – Transverse rib between clay blocks



All of them are familiar with the Brazilian NBR 6118:2003 [2] standard for concrete structures and the NBR 148591:2002 [7] and 14859-2:2002 [8] standards for prefabricated slabs.

The designers have widely varied experience. Half of them (50%) claimed they had already designed 30 to 40 construction projects using precast lattice-reinforced slabs, while 20% stated they had completed more than 40 designs. Graph 2 illustrates the distribution of the designers' professional experience.

Most of the designers (60%) work at the plant itself, where they perform the dimensioning (which consists of establishing the total height of slabs or the total height and quantity of reinforcement). The remaining 40% work in offices where they make their calculations and draw up designs at the request of the plants or the client himself.

The tools most commonly used by designers are structural software programs (80%), followed by software supplied by steel lattice manufacturers (60%), while one percent of only 30% stated they work with charts.

4.2.1. Remarks about total slab loading

All the designers consider 45 to 50% of the total load as the slab's reaction to each beam perpendicular to the direction of assembly, and half of them consider 15 to 25% of the load as the slab's reaction in the parallel beams, while another 20% do not consider any reaction of the slab in the secondary beams.

Most of them (90%) stated that they determine the slab's total height and the thickness of the concrete topping according to the NBR 14859-1:2002 [7] standard, which specifies the total height of the slab according to the standard height of the filler elements.

4.2.2. Falsework

Most of the designers (70%) stated that they draw up detailed designs of falsework and reshoring or at least offer information for the execution of falsework on site. Among these, 57.14% almost always perform this procedure (90% to 100% of cases), and 28.57% in 50 to 80% of cases. The distance between shoring rows varies from 0.90m to 1.50m.

Figure 5 – Transverse rib between EPS blocks

Figure 7 – Negative moment rebars for cantilever

4.2.3. Transverse ribbing

Most of the designers (80%) design ribbing in the two directions, though less often than one-way slabs. Transverse ribbing is considered in the calculations of 80% of the designers, while the other 20% consider them only constructively. Transverse ribs are usually arranged at 1-meter intervals between the filler elements (Figures 4 and 5) or inside channel blocks.

4.2.4. Negative reinforcement

All the designers adopt the procedure of designing the reinforcement for negative moments. This requires placing negative reinforcement and observing several details (Figures 6 to 9). Their correct position is on the upper surface of the slab, and topping should follow the minimum thickness specified by the NBR 6118:2003 [2] standard and be laid on the ribbing and not on the filler. Figure 8 shows details of the execution of a slab fixed to a side beam.

4.2.5. Calculation of deflections

Calculation of deflections are made by 80% of the professionals, who use software programs, and 75% of them also specify counter-deflections. Deflection calculations consider the variables that lead to reduction of stiffness of the elements, especially cracking, creep and shrinkage. Calculation of total deflection is based on the immediate deflection, leading to an estimate of the final situation.

Figure 6 – Negative moment continuity rebar

Figure 8 – Penetration in a side beam

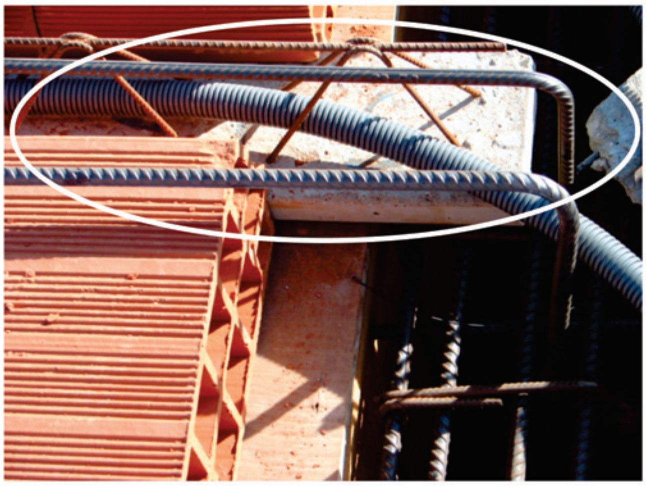


Figure 9 – Negative moment rebars

4.2.6. Building walls on lattice-reinforced slabs

All the designers (100%) see no problem in building walls on these slabs, provided the slab design includes the known loads and the slabs are properly designed to support them. The design must include specific details for their execution (reinforcement, arrangement of the slab elements, concreting, inverted beams, flat beams, etc.). The designers recommend the construction of walls begin only after the concrete topping is at least 14 days old, because before that it is the joists that bear the loads. They pointed out that when walls are supported parallel to the direction in which the joists are mounted, the load is distributed only along one element. In the case of transverse walls, if the slab is not designed correctly, the load imposed on it may force it too much and cause excessive displacements, cracks, fissures, or even cause it to collapse.

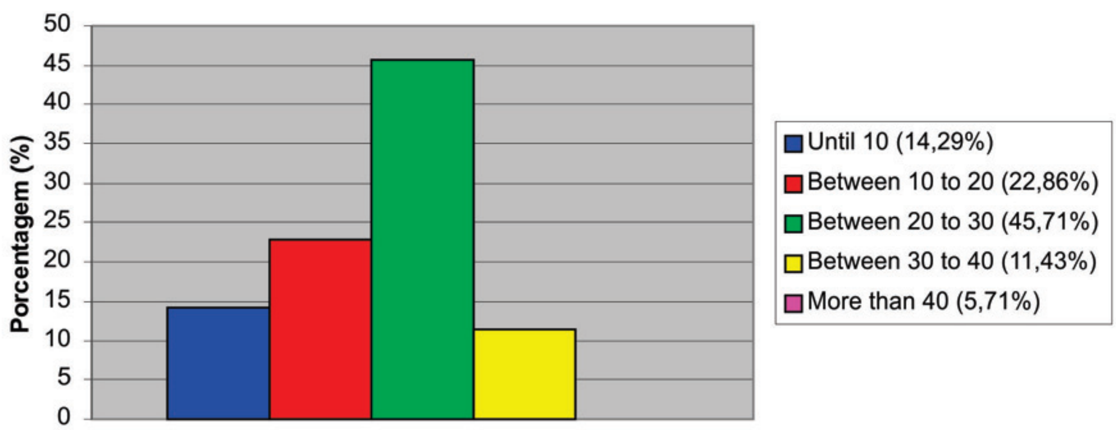
4.2.7. Opinions of lattice-reinforced joist slab designers

Seventy percent of the designers consider the lattice slab competitive for 6m to 9m spans. This analysis depends on the combination of use, load and span. Three designers (30%) consider it competitive for buildings with no more than four floors.
In the opinion of 40% of the designers, the best filler is clay blocks, because they cost much less than EEPS blocks, are widely available in the market, workers have more experience and knowledge to deal with this material, and it is easy and fast to execute. Another 30% stated a preference for EPS, claiming that the cost benefit ratio often makes its use more advantageous. Because it is light and easy to handle, EPS allows for greater jobsite productivity.
The main problem observed by a large proportion of designers (70%) with regard to lattice-reinforced slabs has to do with their inadequate execution, i.e., design specifications are disregarded, and important decisions are made on site. Breaking or sagging of filler during concreting is another major problem (encountered by 60% of designers). Other problems they mentioned are longitudinal fissures between joist and filler elements, excessive strains (50%), torsion on load-bearing beams, concrete compaction difficulties, overlay detachment, shrinkage of EPS blocks, difficulty in vertical lifting, insufficient topping on distribution reinforcement, the appearance of pockets during concreting, and wastage of materials, especially of clay blocks during transport and handling.
Fifty percent of the designers believe that more studies are required about the mounting of the slab on the concrete structure and the effects generated by this connection. Another fifty percent indicated strains as the factor of interest for more in-depth studies. Fissuring of the slab was a concern mentioned by 60% of the designers.

4.3. Analysis of the answers of master builders who use lattice-reinforced slabs

Thirty-five construction sites were visited to interview master builders. A good number of them (45.71%) have built 20 to 30 buildings with lattice-reinforced slabs; 14.29% were still on their first jobs

Graph 3 – Number of buildings constructed by the master builders using lattice-reinforced concrete slabs



(up to 10) and 5.71% had wide experience with this type of slab, and had worked on more than 40 building constructions. Graph 3 illustrates the results of these interviews.

4.3.1. Dimensioning, design and visits of engineers to construction sites

Most of the master builders (94.29%) stated that the slabs were mostly designed at the manufacturing plants, by the manufacturer or a designer. All the master builders (100%) always had Access to the designs, which in most cases were very detailed and contained all the information required to build the slab, from falsework up to its removal.

Most of them stated that the plant engineer rarely visits the construction site during the assembly of the slab to check the quality of the work prior to concreting.

4.3.2. Lattice node weld breaks and placement of utility conduits

Most of the master builders (94.29%) stated that they had never seen a weld break in a lattice node during the slab mounting and concreting process. All of them use the concrete topping to embed electrical conduits and pipes, especially when the filler material is clay blocks.

4.3.3. Filler material

The master builders prefer working with clay blocks (80%). However, the 20% who think working with EPS is better highlight the fact that it is a lighter element, more practical and faster to install. The main disadvantages are difficulties in applying mortar, in the horizontal transport of concrete during the pouring operation, and the debris produced by cutting and breakage of the blocks.

4.3.4. Concrete topping pouring, compacting and curing procedures

At the construction sites of small and medium sized buildings, the concrete is laid using buckets and wheelbarrows. Other resources were mentioned, such as concrete pumping trucks, cranes and crane buckets. Concrete pouring and leveling are done with aluminum slats, shovels, floor squeegees, hoes and masonry trowels. As for compaction, 34.29% of the master builders use barrel vibrators with the vibrator head in the horizontal position.

All the master builders (100%) perform curing: after concreting is completed, the slab's surface is wetted until water puddles are formed. This procedure is applied for about three days, two to three times a day, and complete drying is expected to occur in 15 to 21 days. No comments were made about the appearance of cracks in the topping after curing was completed.

4.3.5. Building walls on slabs and inverted beams

All the master builders build walls on these slabs, and 94.29% of them do so both in places where there already is a wall on the same plumb on the lower floor and in places without such a wall. In some cases, a distribution reinforcement of wire mesh is placed under the wall, and in other cases inverted beams (which are taller than the height of the slab), or plane or flat-top beams (same height as the slab) are made, or additional joists are juxtaposed at the points where the walls will be erected. Almost a third (31.43%) of the master builders stated that in some cases they had seen fissures appearing in the slab under the walls, especially when the walls were supported transversally to the direction of the joists.

4.3.6. Wire mesh reinforcement in slab topping

A large majority (82.86%) of the master builders claimed they use reinforcement in the slab (in 85 to 100% of cases), while the remaining 17.14% do not do so in most cases. Those who use reinforcement state that it designed by the slab manufacturer or the designer. The details, quantities and instructions on how to execute the reinforcement are usually included in the design specifications, but in some cases changes in reinforcements are made on site due to constructive requirements and to the subjective opinions of the master builders themselves.

4.3.7. Opinions of master builders

The majority of master builders (77.14%) believe that construction time is shorter when using of lattice-reinforced slabs than other types of slabs. Among those who do not share this opinion, two thirds took as the basis of comparison the prefabricated slab with reinforced concrete joists. The other third compared the lattice-reinforced slab to the solid slab, stating that the reduction in time depends on planning the construction for this use and that this depends on the number of slabs to be repeated.

Most of the master builders (88.57%) stated that the quantity of wood used for formwork, falsework and reshoring decreased substantially with the use of lattice-reinforced slabs. The majority (94.29%) consider that the assembly of lattice-reinforced slabs is usually faster and more practical than other types of slabs. Practically all of them stated that this is the most suitable system for small and medium sized buildings (up to 4 floors).

A good number of them (74.29%) cited the most serious problems as breakage, cracking or sagging of the filler during concreting and difficulties in compaction.

4.4. Overall analysis of the responses

4.4.1. Competitiveness of lattice-reinforced concrete slabs

Although designers and master builders consider the lattice-reinforced slab a highly competitive system, especially for 6m to 9m spans, most manufacturers state that the spans normally sold range from 3m to 6m. A tendency was also found for an increase in the use of joists for spans larger than six meters and the construction of larger buildings (four to eight floors).

Most of the people who build lattice-reinforced slabs consider that both the construction time and the amount of wood employed is considerably less than with other types of slabs, and that this system is inexpensive, fast, practical and versatile.

4.4.2. Procedures employed by user groups

One point that was clear is that the people who design the slab to be manufactured and supplied to the client are staff at the factory

itself (manufacturers and designers). This means that dimensioning of the structure (foundations, columns and beams) is usually done separately from the slab design, by different designer and calculation engineers, and the slab and structure's joint behavior is not evaluated.
The design tools most commonly employed are charts and software packages supplied by lattice manufacturers, which may lead to excessive displacements since these charts do not consider the strain limit states (CARVALHO et al. 2000 [9]).
The dimensioning tools normally used are charts and software supplied by lattice manufacturers. CARVALHO et al. [9] expressed concern about the fact that the charts used to dimension lattice-reinforced slabs do not present coherent values for the definition of deflections and strains to which the slab is subjected. Some designers use structural software programs.
It can also be concluded that in general, lattice-reinforced slab designs are well detailed and contain all the information needed for their construction, from the placement of falsework to its removal. However, according to the master builders, the plant engineer rarely visits the construction site to oversee the work being done and to okay the slab for concreting, contradicting the statements of 50% of the manufacturers.

4.4.3. Problems and pathologies pointed out by users

An overall analysis of the responses leads to the conclusion that breakage, cracking or sagging of the filler element during the slab installation process, characterized by the formation of bulges on the soffit of the slab, is the main problem or pathological manifestation of lattice-reinforced slabs.

4.4.4. Users' suggestions for study

The manufacturers are more concerned with the cost factor and suggested the development of a new filler material that is stronger and cheaper. They are also concerned about the inadequate construction of slabs.
For the designers, the fitting of the lattice-reinforced slab onto the structure and the effects of this connection, its behavior in terms of displacements and its interaction with the other elements of the structure, are aspects that deserve a more in-depth study. Their second most frequent suggestion was about strains.
All these points are related to the fact that structural and slab designs are created separately, by different professionals, indicating that the slab designer and the engineer who does the calculations for the building only interact with each other when larger projects are involved or their responsibility for them is greater. This fact may compromise the final quality of the building.
The master builders presented a few suggestions for study. One of them was about the vertical lifting of materials, especially for taller buildings with larger spans, by dividing the longer joists into two sections that can be joined during the concreting stage without compromising it. Another concern they mentioned was about the compaction of the concrete topping.
Additional suggestions were improved detailing of the connections between the slab and the beams of the structure and definition of the correct counter deflection values, as well as how to apply them, since the specified value is difficult to execute due to the excessive stiffness of the lattice joist. This means that, upon lifting the joist at its central point, its ends are also lifted and do not come to rest on the beam formwork or on the brickwork.

Figure 10 – Falsework system

5. Visits to lattice-reinforced slab factories

Some plants do not allow interviews or photographs to be taken. The manufacturers made it clear that authorizing visits might lead to the leakage of important information about the plant's characteristics to competitors, or might even be a checkup in order to denounce irregularities. Therefore, only four lattice-reinforced slab factories were visited.
These plants are located in the proximities (50%) or inside industrial districts (50%). Their premises are lots on which metal warehouses have been erected without side walls, plus an enclosed area for the waiting room, locker rooms, kitchen and offices for the owners and designers. It was found that, with the exception of one plant, the factories had the various stages involved in the production scattered randomly about the lot, without a rational organization of the joist fabrication process.

6. Visits to construction sites using lattice-reinforced slabs: observations and recommendations

Thirty-five construction sites were visited, some of them where the slab was being mounted and others where it had already been concluded, but was minus its finish. The purpose of these visits was to interview the master builders responsible for slab construction and to observe the mounting procedures, identify difficulties and problems encountered by the workers, verify errors of execution and the appearance of pathological manifestations.
Most of the sites visited were of ground floor and two-floor houses (82.86%), followed by residential buildings with four or more floors (11.43%) and commercial establishments (5.71%). The houses, without exception, had slabs filled with clay block, while three of the four buildings (four floors or taller) used EPS as slab filler.

Figure 11 – Falsework bars supported on boards

6.1. Storage of materials

At most of the construction sites, the joists and filler elements were stored haphazardly in inadequate places, exposed to the weather and subject to accidental damage. They were piled up sloppily and a large number of cracked or broken clay blocks were found. In a few cases (14.29%), the materials were stored in a well organized way in safe covered places.

6.2. Falsework

The first step in the installation of a slab is the placement and locking of falsework (Figure 10). Before this is done, the floor must be properly aligned and leveled. The supporting base for the falsework must be firm and strong to ensure it does not give way under the weight of the concrete that will be laid. The ideal support is an underlayment or a floor slab. When the supporting base is the ground itself, it should be well compacted to ensure that it will not give way under the weight of the load. It is incorrect to place falsework directly on the ground; instead, each leg of the falsework should be placed on a wooden board (Figure 11).
The critical condition of lattice-reinforced slabs is not when they are already completely loaded and the concrete has hardened, but when the concrete is being laid on the rib-filler element set. In this situation there is already a considerable load (about 50% of the total), which is borne only by the rib, whose height is limited. It is therefore crucial that the scaffolding be sufficiently stiff to prevent the occurrence of bending in this phase, because if it does occur, the system will already be produced with deflections that will be perpetuated during the entire life of the structure.

6.3. Placement of lattice joists

During slab construction, the errors detected involve joist placement. When they are supported on concrete structures (beams), after the slab and beam set is concreted simultaneously, the joists should penetrate the set by at least 5cm or at most half the width of the beam. However, what was observed at almost all the sites was that, in the regions of support, the joists penetrated less than 5cm into the beams. At most of the construction sites where the joists were supported directly on the brickwork, no support was made nor was a steel bar used to form a bond beam.

6.4. Placement of filler elements

After the placement of the joists, the filler elements are installed. Filler elements are fabricated in different shapes and sizes especially to fulfill certain constructive requirements and to avoid cutting on site and wastage of material. No difficulties or problems were detected in this stage.

6.5. Application of counter deflections

Another problem found in the installation of the slab was the application of counter deflection, as mentioned earlier. In certain cases, the amount of counter deflection applied did not meet the design specifications, and it was clear that the team responsible for the falsework had difficulty in applying the counter deflection. The load applied by the falsework was such that it lifted the ends of the supporting joists.

6.6. Installation of embedded utility conduits

The electrical conduits and hydraulic pipes should be embedded in the slab without reducing its load-bearing capacity. The placement of conduits depends on the distribution of points for ceiling lights, light switches, electrical outlets, fuse box, water outlets and foul drains.
In slabs with EPS filler, the electrical installations can be made using a thermal blower to open a channel through which to pass the conduits under the compression flange and fixing the conduit box inside the block. This avoids compromising the concrete section of the flange.
In the case of stiff elements such as cellular clay and concrete blocks, the conduits should pass through the holes of the material whenever possible. VIZOTTO (2001) [10] does not recommend embedding utility conduits or pipes inside the lattice or in the slab's concrete topping.

6.7. Placement of complementary reinforcements

Complementary reinforcements should be placed according to the slab design specifications (gauge, number and position). The bars of the transverse or locking ribs are placed first. Then, the constructive reinforcement is tied transversally to the main joists in the upper chord of the lattice. Lastly, the negative or upper tensile reinforcement is supported on the distribution reinforcement. Special care must be taken during the installation and concreting to prevent the reinforcements from shifting out of place, making sure they remain in the position specified by the design and respecting the required topping. To ensure correct topping, the NBR 6118:2003 [2] standard recommends the use of spacers. If electrowelded wire mesh is used, the slab design specifications should indicate the type of mesh, type of interlock between the meshes and the position of each mesh on the slab.

6.8. Cleaning and final inspection

Before the concrete topping is laid, it is essential to clean the elements that make up the slab, especially at the interface between the ribs and the concrete to be laid, removing dust, dirt, grease, soil, oil or any other substance that may impair the transfer of shear by the contact surface. The engineer in charge should make an inspection of the work before authorizing the concreting.

6.9. Concreting of the topping

At the moment of concreting, incorrect procedures were observed at most of the construction sites. The concrete was almost always laid even when there were puddles of water at some points of the slab, and when concreting could not be completed in one day, no care was taken to ensure the proper adherence between new and old concrete.
At most of the sites (65.71%), the concrete topping was not compacted, contrary to the recommendation of GASPAR 1997 [11], i.e., that for the slab to perform its structural function properly requires the topping to be consolidated with the concrete of the joist, forming a monolithic structure.
Curing was done normally, by wetting the surface thoroughly about three times a day for three consecutive days after concreting. The recommendation of spreading a plastic tarp or a chemical product on the slab to retain water is not followed at construction sites.

7. Conclusions

The results of the survey about the design, fabrication and construction of slabs with lattice joists were presented. The opinions of manufacturers, master builders and designers responsible for calculating, dimensioning and executing these slabs were recorded. This study attempted to characterize the user groups, determine their opinions about the system's competitiveness and potentialities, compare the processes involving lattice-reinforced slabs, determine the most frequent pathologies, and put forward suggestions for studies.
The visits also aimed to detect errors in the fabrication process of the elements that make up the slab and in the construction of the slabs, in order to propose solutions or procedures to correct or minimize these errors.
It was found that the precast lattice-reinforced slabs supplied to clients during the period of this survey were calculated (designed) by the slab manufacturers and designers, demonstrating that the dimensioning of the other elements of the structure (beams, columns and foundations) may have been designed separately from the lattice-reinforce slab.
Although designers and master builders considered the lattice-reinforced slab competitive for spans exceeding six meters, most of the manufacturers stated that the spans most commonly sold range from three to six meters.
The main problem observed in the field survey were bulges formed on the soffit of precast lattice-reinforced slabs, which are characteristic of breakage or sagging of the filler element at some point, especially when clay blocks are used. Fissures in the slab, concreting pockets and excessive strains were also among the problems most frequently found at these construction sites.
Another difficulty identified was the application of counter deflections; it is difficult to reach the specified value, especially if it is high, because the ends of the joists usually become detached from their supports.
Additional problems encountered were the non-placement of spacers to ensure the proper topping of the lattices, geometric incompatibility between the filler element and the lattice joist, the lack of experience of the people who mount lattice slabs, lack of concrete compaction, inadequate storage and transportation of joists (from the plant to the construction site), deficiencies in design details, lack of overseeing of the construction work by qualified professionals (engineers), absence of distribution reinforcement in the concrete topping, etc.
Several suggestions for the study of some aspects of lattice-reinforced slabs were also recorded during the field survey, i.e., the development of a stronger, lighter and cheaper filler element; evaluation of the joint behavior of the lattice-reinforced slab and the structure; a more precise evaluation of strains; and the development of simple methods to facilitate slab assembly.
Precast lattice-reinforced slabs are being used increasingly in buildings in a period when civil engineering is continuously seeking to rationalize production processes. Allied to this is the search for economic systems that also generate buildings with a good standard of quality.
However, for lattice-reinforced slabs to become ever more competitive requires the adoption of measures to improve their design, production and construction processes, as well as the development of studies aimed at improving techniques, procedures and materials. Moreover, all those involved in the process of fabrication, design and construction of lattice-reinforced slabs should take the necessary measures to reduce difficulties and prevent errors that lead to pathological problems.
This study collected important information to add to the existing body of knowledge about precast lattice-reinforced concrete slabs, contributing to help manufacturers, designers, engineers and construction workers to carry out their work according to the requisites of quality, durability and reliability and building codes. During its service life, the lattice-reinforced slab should perform its function without exhibiting pathologies or problems, ensuring its users' safety and comfort.

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