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Comparative Analysis between Ribbed and Steel Deck Slabs

William Wilson dos Santos[1], Lucas Marinho Buzatto[2], Jose Roberto Moreira Ribeiro Gonçalves[3], Fabiano Batemarco da Silva Martins[4], Marcelo de Jesus Rodrigues da Nóbrega[5], Hildson Rodrigues de Queiroz[6], Flavio Maldonado Bentes[7]

[1]Civil Engineer (UNISUAM), RJ, Brazil.
[2]Graduating in civil engineering (UNISUAM), RJ, Brazil.
[3]Master in Agricultural and Environmental (UFFRJ), Professor at IBMR Laureate and UNISUAM, Rio de Janeiro, Brazil.
[4]Master in Agricultural and Environmental (UFRRJ), Professor at UNIGAMA and Santa Úrsula University, Rio de Janeiro, Brazil.
[5]Post-Doctor in Civil Engineering (UERJ), Doctor in Engineering (PUC-Rio), Master in Technology (CEFET/RJ). Professor at UNIGAMA, CEFET-RJ and Santa Úrsula University, Rio de Janeiro, Brazil.
[6]Master in Mechanical Engineering (UFF), Specialist in Petroleum and Natural Gas Engineering (Universidade PETROBRAS), Professor at UNISUAM, Petroleum Engineer (PETROBRAS), Rio de Janeiro, Brazil.
[7]Doctor in Mechanical Engineering (UFRJ), Master in Mechanical Engineering (UnB). Senior Researcher (FUNDACENTRO), Rio de Janeiro, Brazil.

Abstract*—The work which is being presented have as objective compare two slab types that have your use turned to bigger spans. The goal is show up how the steel deck slab, even with low percentual of use, can offer benefits and superior advantages when compared to ribbed slabs, a type of slab that is used on long scale to hit the actual architecting demand, which requires even bigger spans. Besides that, the steel deck slabs can offer rationalized and versatile maintenance, complying with the demand, in view that the constructions are used to search for increasingly rationalized and a low period. The Steel deck utilization tends to grow because of the current interest of have a low-cost production and bigger efficiency. By the way, that system does not have a massified utilization because the current Brazilian cultural panorama majority watches for armed structures and put mixed structures on second plan because of having a predefined concept which they have even bigger cost. The article was based on careful bibliographic research, making it possible to define comparative variables of the two slab systems, ribbed and Steel deck. Analytical verification of the types of slabs studied was carried out. Analyzing the data to enable the description of the construction systems and comparative designs, focusing on methodology, performance, time, and financial scope.*

***Keywords*—Ribbed Slabs. Steel Deck. Reinforced concrete. Comparative analysis.**

I. INTRODUCTION

Brazil is one of the largest producers of iron ore in the world, but also a major producer of cement. Costa et al. (2016) points out that the association of concrete with steel bars is called reinforced concrete, widely used in construction in the country. There are also mixed steel-concrete systems in which rolled, bent, or welded steel profiles work together with concrete. In addition to these, there are hybrid structural systems, which are formed by reinforced concrete elements and purely steel or mixed elements of steel and concrete. Although Brazil is part of the world's largest steel producers, there is a large-scale use of reinforced concrete in civil construction. This is due to a strong cultural burden. Reinforced concrete is the most convenient material for Brazilian circumstances, in view of safety, to be relatively inexpensive and to be undemanding in terms of labor. However, Santos (2008) Apud Espíndola (2015) points out that the hegemony of concrete increased the gap between constructive practice and technical knowledge, disqualifying construction workers.

Structures made purely of reinforced concrete are mostly used in Brazil. The negative aspects that they present do not suppress their use on a large scale. However, about 70% to 80% of the works could be carried out in mixed steel-concrete systems, for both simple and bold structural systems. In Brazil there are three forms of mixed structures most used, which are mixed beams, mixed slabs, and mixed pillars. These structural elements have been gaining strength, and are being used in several types of constructions, mainly those that have a higher load on the structure, such as buildings and bridges, due to their dimensional accuracy, reduced weight and increased construction speed. (PINHO, 2013).

Whether in metallic structures or in reinforced concrete structures, the slab is an essential element in most buildings, often regardless of its size. In multi-storey buildings or with large spans, slabs are responsible for a high share of concrete consumption. Using solid slabs in the pavements, this portion usually reaches almost two thirds of the total volume of the structure. Therefore, there is a need for the introduction of other types of slabs, which are used to obtain technical, effective solutions that optimize the economic return. (SANTOS, 2015). Architectural evolutions have forced the increase in spans, and the high cost of forms, making massive slabs economically unfavorable, in most cases. Thus, the ribbed slab appears as a direct alternative. However, many other innovations are emerging to achieve this goal with increasing efficiency. Knowing that the ribbed slab is an improvement of the solid slabs, it is noted that they encounter similar problems, such that they, with regard to time and versatility, end up opening space for other methods to be introduced. Steel Deck slabs fill these gaps, because when it comes to speed, aesthetics, and versatility, they outweigh the benefits of ribbed slabs.

From this, the present article aims to make a comparison between two types of slabs, the ribbed ones, composed of reinforced concrete, and the Steel Deck slabs, a mixed slab, which also presents itself as a great alternative to the constant constructive evolutions, due to versatility, simplicity and speed at the construction site.

II. THEORETICAL FRAMEWORK OF SLAB SYSTEMS

The universal concept of slab according to Martins et al. (2018, p.198), is defined by taking the slab as a work of reinforced cement that constitutes a compartment ceiling or floor. This concept denotes great simplification; however, it also imbues great objectivity, accurately translating what is and what a slab is for. In the same sense, he argues that the slabs are structural elements, with two-dimensional behavior, responsible for transmitting the actions that act on it to the beams or directly to the pillars, in cases of slabs without beams, that is, it is a civil construction work. which serves as a basis for the construction of a ceiling or compartment floor.

2.1 Ribbed Slab Systems

The ribbed slabs (molded in place) have small transverse displacements, in addition to allowing a slightly more rational construction. It is known that the regions of the reinforced concrete elements submitted to bending efforts are almost always cracked, due to the low mechanical tensile strength of the concrete. According to Schwetz (2011, p. 20 and 29), it is for this reason that theories of reinforced concrete neglect the concrete's resistance to traction, attributing only the function of protecting the reinforcement, connecting it to the compressed areas, resistance to compression and to participate in the mechanism of resistance to shear forces and torsional moments.

This type of slab allows the structure's own weight to be reduced by suppressing in the stretched areas of the cross section, part of the concrete, which does not work in a structural way, remaining only a few sections of it, where the reinforcement will be grouped. The stretched regions, with concentrated reinforcement, are called ribs, creating the name ribbed slab.

The reduction of concrete through the hollow space between the ribs or its replacement by lighter materials reduces the consumption of concrete and the slab's own weight, as the volume of the concrete decreases, in addition, there is also an increase in inertia, since the slab has its height increased. However, Schwetz (2011) argues that this is due to the voids existing between the ribs presenting less resistance to torsion, which is the reason why a higher height is needed than the heights of other types of slabs. Furthermore, according to Tenório (2011, p. 5 and 6), this elimination of concrete that occurs below the neutral line, provides a better use of steel and concrete, since the tensile strength is concentrated in the ribs, and the materials of filling has the unique function of replacing concrete, without contributing to strength.

2.2 Steel Deck Slab Systems

A The mixed slab system results from the structural combination of two main elements: the metallic formwork (Steel Deck) and the concrete. The basis of this system is that its elements work together, taking advantage of each one of its best mechanical characteristics. The Steel Deck has a dual function, that of formwork for concreting, during construction and as positive reinforcement of slabs. (METFORM, 2019).

The metal formwork, which is incorporated into the concrete, generally has a trapezoidal or corrugated shape, designed to ensure greater stability of the structure both during construction and after curing the concrete, as shown in Figure 1.

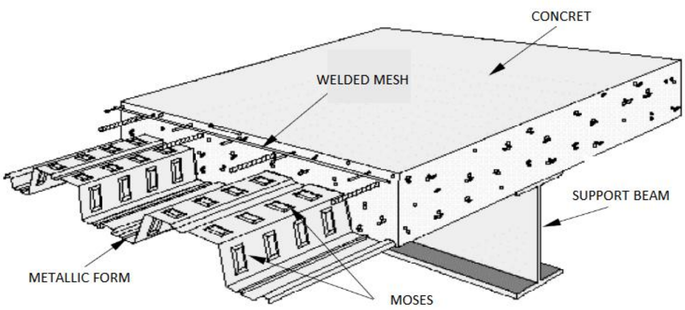

Fig.1: Elements of steel deck slabs

Source: Lemos, 2013, adapted.

In addition, the Steel Deck has wide ribs, allowing the use of Stud Bolts shear connectors, which allows the calculation of mixed beams and reduces the weight of the structure.

2.3 Elements of the structural slab system

The slabs are classified as two-dimensional flat elements, which are those where two dimensions, the length and width, are of the same order of magnitude and much larger than the third dimension, the thickness. They are also called surface elements. Its purpose is to receive most of the actions applied to a construction, usually people, furniture, floors, walls, and the most varied types of cargo that may exist depending on the architectural purpose of the space that the slab is part of. The actions are commonly perpendicular to the slab plane, and can be divided and distributed in the area, linearly distributed or concentrated forces. Although less common, external actions can also occur in the form of bending moments, usually applied to the edges of the slabs. (BASTOS, 2015, p.1).

2.3.1 Slabs as a Structural Element

The slabs are structures that receive forces that compress it vertically, perpendicular to the average surface, transmitting them to the supports. Therefore, they behave as a kind of plaque. In addition, they also act as a rigid horizontal diaphragm, as they distribute the horizontal actions to the structure's columns, in this sense, the slab has a sheet-like behavior. These behaviors are fundamental for the structure to be stable globally, especially in tall buildings. In addition, it is through the slab that the braced pillars rest on the bracing elements, ensuring the safety of the structure in relation to the lateral actions. (AVILLA, 2016. p.18).

Among the most varied functions of the slabs, Guerrin (2002), highlights two as the main attributed functions: resistance function; the slabs support their own weight and accidental overloads and the insulation function; they insulate the different floors thermally and acoustically.

2.3.2 Design constraints for Ribbed Slab and Steel Deck Slab

The ribbed slabs, molded in place, have traditionally received the analysis that admits them, simplifying them, as massive slabs, determining the soliciting efforts and transversal displacements through the use of tables, of slabs elaborated from the use of plate theory thin, which considers them in an elastic regime; it is important to highlight that in this case the slab outline beams are considered non-movable, in the vertical direction, not corresponding to reality. This method, which is included in some bibliographical references, is also based on NBR 6118 (2003), which allows ribbed slabs to be calculated as solid, provided that some recommendations regarding the dimensions of the table and ribs and also the spacing between ribs are observed. (TENÓRIO, 2011).

Regarding the Steel Deck slab system, according to the Brazilian Association of Technical Standards 8800 (2008), mixed concrete slabs with incorporated steel formwork are defined as being basically composed of two elements: metallic formwork and concrete formwork. These are those in which, after the concrete reaches its design resistance, the formwork acts together with the first to resist bending. In the initial phase, before the concrete reaches 75% of the specified compressive strength, the steel formwork supports the permanent actions and the construction overload in isolation. Steel shapes must be able to transmit longitudinal shear at the interface between steel and concrete. In the case of the mixed slab, the adhesion between the steel and the concrete are not considered sufficiently effective for the mixed behavior of the structure, being necessary to guarantee by mechanical connection, which comes through the dents in the steel forms and by the friction due to the confinement of the concrete in the recessed steel forms.

2.4 Constructive methodology of the ribbed slab

The ribbed slab system is characterized using plastic cubes or buckets. According to Vizotto (2010), there are two methods of installing the cuvettes. In the first, the vats are positioned on a wooden platform, like the solid slab, which receives the support of beams and props generally metallic.

In the second method, there is the practice of directly supporting the vats on the metal beams, not using the wooden platform, however this method must be carried out with great attention in the locomotion of the workers during the assembly of the slab and concreting, so that avoid slipping the vats and accidents. Each vat has an approximate mass of 3.3 kg. These molds resist the load of fresh concrete, reinforcement, small equipment, and workers on them. After positioning the vat, a release agent must be applied to allow the vat to be removed, giving the opportunity for reuse. The reinforcement is positioned with the help of spacers. To execute the ribs, inert material can also be used as a lost form in the form of boxes. Ceramic brick, cement block and EPS block (Styrofoam). These are the most used as inert materials and the boxes are mostly made of propylene or metal.

2.5 Constructive methodology of the Steel Deck slab

The system basically consists of the use of a collaborative metallic form, with reinforcement on the junction of the steel deck sheets and around the pillars, galvanized steel mesh in order to avoid cracking, filled with concrete, as shown in Figure 2.

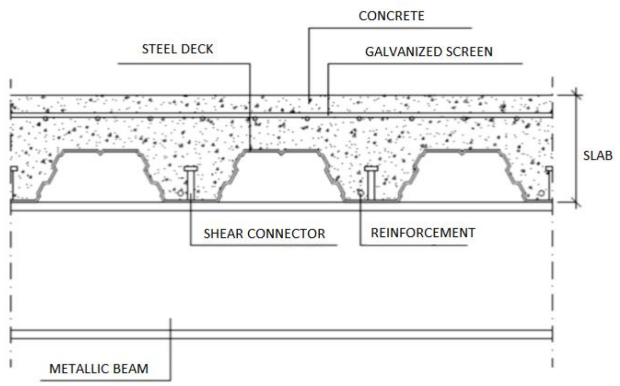

Fig.2: Steel deck slab

Source: Guimarães, 2016, adapted.

The plates are assembled from one corner of the buildings, creating the assemblers their own work platform with the first assembled plates. When they are placed in the final position, they are fixed before continuing to place the next ones, to avoid, for safety reasons, the existence of loose plates. (GUIMARÃES 2016, p. 37). According to Queiroz et al. (2012), for steel and concrete to work together, it is necessary to develop longitudinal shear forces. Although these materials have a relatively good adhesion, they are not considered in the dimensioning step, as they have little reliability. Therefore, the use of shear connectors should be provided according to the recommendations of ABNT NBR 8800: 2008. Stud Bolts are a type of shear connector that works by absorbing the longitudinal shearing efforts and prevent the vertical spacing between the slab and the beam. They are fixed to the upper beam table by means of electro-fusion. These must be fixed after the formwork assembly is finished, before pouring.

2.6 Evaluation results: performance and cost estimation

The performance of the slabs is quite different, the ribs have a high volume of thickness, which added to the ceiling height reaches a relatively high height between the floors, which causes some consequences in the installations and facades. In contrast, Steel Decks in limiting their height perform better for pipeline passage and installations becoming better at that point. In addition, Steel decks have better functionality with respect to architectural flexibility, due to their architectural versatility. In contrast, the ribs encounter difficulties in flexibility for wet areas, due to the limitations imposed by the passage of hydraulic installations. (MARTINS et al. 2018, p. 206).

Steel Deck systems have a lower cost than ribbed slabs, corresponding to a 20.0% difference in spans less than 6 m, however, for larger spans, the relative cost of the Steel deck type slab increases significantly, reaching a difference of more than 70%. To define the cost comparison, according to Martins et al. (2018, p. 205), considering the labor and using values extracted from the inputs and services table of the National System of Research on Costs and Indices of Civil Construction (SINAPI), taking the variable loads in two extreme situations, according with NBR 6120 (1980) the following is noted: Steel deck slabs have a lower cost than ribbed slabs for spans smaller than 6m, with an approximate cost for a span of 4m, for example, R $ 500, 00, while the ribbed slab is estimated to be approximately R $ 800.00. For spans much larger than 6m there is a high increase in the cost of Steel deck slabs, while in ribs, this cost does not increase as much. In a span of approximately 10 m, for example, the estimated cost of the Steel deck slab, reaches approximately R$ 2500.00 while the ribbed is estimated to cost approximately R$ 1500.00. (MARTINS et al. 2018, p. 205).

In spite of this, a part of the engineering professionals, consider the cost consideration that evaluates the Steel deck slab by the square meter to be erroneous, because speed, cleanliness, reduction of manpower (since two people can assemble between 500 and 750 m² of slab / day) and construction time, among other factors, must be considered when calculating the cost. Brendolan (2010, p.1), states that about 50% of the cost is made up of steel sheet. Therefore, in the conventional solution, other items must be computed in the cost comparison, such as shoring and the execution time factor, because shoring has a relatively high cost and their assembly and disassembly as well. For him, it should also be considered if the type of slab used in the comparison influences the cost of the structure, if so, it must be considered in the cost estimate.

2.7 Comparative discussions: advantages and disadvantages

As for the ribbed slabs, Nervo (2012, p. 36 and 37), lists a set of advantages and disadvantages, the advantages being: The shapes have a continuous plane, with cutouts only in the connections with the columns, so they present simplicity in execution and the withdrawal of forms; lower consumption of wood and lower incidence of labor, for making shapes; reuse of form; easy pouring, as it has a unique cloth; greater versatility in the floor due to the absence of beams, offering ample freedom in the definition of internal spaces, which reflects a strong commercial appeal; savings in installations, since the design and execution of installations are facilitated, as it reduces the number of bends and eliminates the drilling of beams.

However, even according to Nervo (2012, p. 36 and 37), these advantages, to really have an effect, need a certain preparation on the part of the executor and the designers, as well as a better qualification of the workforce. The disadvantages listed by Nervo (2012, p. 36 and 37) are: Less rigidity of the structure to the lateral actions in relation to the other structural systems, due to the reduced number of frames. In certain cases, the presence of rigid cores is required in the region of the stairs and the elevator shafts; puncturing the slab by the pillars; somewhat complicated frame, mainly on the pillars and in their surroundings; in general, higher consumption of steel and concrete. Silva et al. (2018), also cites some disadvantages that should be considered. According to him, normally the total height of the building is increased and there is also a difficulty in terms of compatibility with other subsystems such as installations, fences, and others. In addition to these mentioned disadvantages, the ribbed slabs still have the need for shoring in any dimension that is made, generating the precision of waiting a considerable time to remove the struts, not allowing one to work under the newly concrete slab in the following days , and the service area should be kept isolated. Furthermore, in the situation of non-placement of inert material, the formwork execution time is long, in addition to requiring a large consumption of wood.

Steel deck slabs eliminate some of these drawbacks, making the processes involved in building even more streamlined. According to Lemos (2013), there are several advantages of the system in relation to reinforced concrete, where the ribbed slabs also fit. Some of them are: The steel plate is light, being easily handled and installed, allowing, therefore, greater constructive speed, giving financial return of the enterprise, in addition to working as a formwork for fresh concrete, and as it remains permanently, it eliminates the step of deforms; in many cases, it does not require the use of shoring; reduction of material waste; reduction or even elimination of the traction reinforcement in the region of positive moments; greater safety at work, as it works as a service and protection platform for workers who work on the lower floors; decrease in the weight and volume of the structure, with a consequent reduction in the cost of foundations.

In addition, the organization that the system gives to the construction site is a very positive point, since it is an industrialized element and its storage on site is more organized than, for example, the storage of forms for reuse. Another advantage that speeds up the execution time of the building is the ease of passing pipelines to the various building installations, in addition to having a high-quality finish on the slab. Furthermore, Costa et al. (2016) highlights the ease of installation, greater construction speed and the elimination, or reduction of the positive reinforcement in the finished slab, consequently reducing the cost, among other advantages.

The Steel deck system significantly reduces the execution time of the slab, we can mention as a recent example the construction of the Hotel Ibis, carried out in 2011, in the city of Canoas, Rio Grande do Sul. The seven-story project, with 30 meters of height, 15 wide and 40 long, it was built in just 67 days and 8 hours. During this period, the entire structure was completed, even the building's facade, saving approximately 60% of the time that would be required for the execution of the reinforced concrete structure for a work of this size. (LEMOS 2013, p. 23).

However, the Steel deck system, like all others, has its negative points, some of which are: Need for a higher level of specialization of the workforce, which can lead to an increase in the cost of the system, due to the scarcity of workers available for its execution; lower resistance of the slabs in fire situations.

In addition, Lemos (2013) highlights another disadvantage of Steel deck slabs in relation to reinforced concrete slabs, as there is a need for a greater number of secondary beams, in cases where shoring or forms of great height are not used, due to limitation of spans before curing concrete.

Regarding sustainability, ribbed slabs mitigate the environmental impacts generated by constructions made of masonry by reducing the use of concrete and other materials, such as steel and wood, using forms that are reusable. Therefore, there is a smaller amount of these other materials, which contributes to a lower disposal for the environment. In the case of mixed slabs, a lower weight is observed, which reduces foundations and excavations, safeguarding the soil more, resulting in less soil removal. Consequently, Nakahara (2017) points out that this decreases the demand for truck trips for land extraction, reducing CO2 emissions, also decreasing the need for areas for disposal. Concomitantly, it is noted the sustainable effectiveness of the system with regard to the disposal of wood, as forms are part of the structure and there is the possibility of dispensing shoring, thus wood is no longer discarded, in addition to generating less debris and providing less leftover of material. When 1 shows a comparison of the two slab systems.

Table 1 - Comparison of Slab Systems

	Ribbed Slab	Steel Deck Slab
Cost	20% higher in spans of up to 6m. (disregarding secondary costs)	Spans larger than 6m the cost reaches 70% higher. (disregarding secondary costs)
Construction Height Characteristics	It has a great thickness. The sum of the thickness of the slab with the ceiling height establishes a considerable height between floors, causing consequences in the installations, facades, frames so on.	There are no height limitations and it is easy to pass the ducts to installations and, in return, asks for the fixation of a lower ceiling.
Shoring	Required in any dimension	Dismissed in most cases
Architecture Flexibility	It allows for a certain flexibility in relation to the layout of the designed architecture. However, for the wet areas of the building, this flexibility decreases due to the limitations imposed by the passage of hydraulic pipes.	They present excellent performance due to flexibility, permeability and monolithicity due to their architectural versatility
Lining finish	Lining should be used, either by applying cement paste to smooth the surface or plates to hide the pipe	Easy pipeline passage and ceiling fixing.
Time	Steel deck takes twice as long to assemble	Regarding the ribs, it takes half the time to assemble

Source: Martins et al, 2018.

III. METHODOLOGY

The article was based on an accurate bibliographic search, which made it possible to define comparative variables for both slabs, ribbed and Steel deck systems. In addition, analytical verification of the two types of slabs studied was carried out. The data collected were analyzed to enable the description of the construction systems and comparative designs, focusing on the methodology, performance, time, and financial scope.

IV. CONCLUSION

When comparing the two slab systems, it is clear that the Steel deck slabs show superiority in relation to the ribbed slabs, in different requirements, with greater versatility, speed, less time, ease of installation, architectural flexibility and; in addition, it fulfills the need for greater span spans. The low use of this system is due to some factors, such as the cultural factor, which concerns the great hegemony of reinforced concrete and the cost, which is the one that greatly influences the choice of any element of the construction. In addition, in most cases, budgets do not take into account some secondary costs, considering only the slab itself, creating a disturbance for the choice of the Steel deck slab, which besides being in recent use in Brazil, when not construction is considered as a whole, having a higher cost in larger spans.

Steel deck slabs are a great option, although they are still beginning in Brazil. The cultural reality of Brazilian construction is a supremacy of reinforced concrete. However, there is a tendency for mixed slabs to be more valued, as time and rationalization have been increasingly enhanced in buildings. This is likely to be the factor that will attract the most attention to this system. Therefore, there is a high probability that there will be a significant increase in the use of mixed slabs, so that they will gain prominence in the Brazilian market.

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