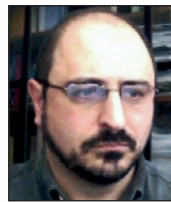


Assessment of cover to reinforcement in slabs using different spacer and tying distances

Análise da espessura do cobrimento de armadura em lajes com diferentes distanciamentos entre espaçadores e pontos de amarração



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Abstract

Given that the durability of structures is directly related to the thickness of the cover to reinforcement, it is essential to ensure minimum cover is achieved when building a structure. However, studies show that this is not always the case. One of the reasons for this problem is the lack of indication, in structural projects, of the positioning of spacers. This situation is compounded by the lack of standards and regulations on the use of spacers (i.e. minimum quantities and required layout). This study assesses three different spacer distances and two different tying distances in order to examine the influence of these factors in the cover to reinforcement. To achieve so, three slabs were prepared in situ using different arrangements. After demoulding, cover thickness was determined using a digital covermeter. It was observed that the factors investigated have a significant influence in the final cover.

Keywords: cover, spacer, tying, reinforced concrete.

Resumo

Uma vez que a durabilidade das estruturas está diretamente relacionada à espessura de cobrimento da armadura, é imprescindível que o cobrimento mínimo normatizado seja garantido durante a execução da estrutura. Entretanto, pesquisas comprovam que o cobrimento não está sendo alcançado. Dentre as razões para isto, aponta-se a falta de indicações nos projetos estruturais do posicionamento dos espaçadores. Esta situação se agrava pela falta de normatização e regulamentação do uso (quantidades mínimas e disposição necessárias) dos mesmos. Neste sentido, esta pesquisa tem como objetivo analisar três diferentes distâncias entre espaçadores e dois distanciamentos entre pontos de amarração a fim de analisar a influência destes fatores no cobrimento das armaduras. Para isto, foram concretadas lajes in loco com diferentes combinações. Após a desfôrma, os cobrimentos foram medidos com auxílio de um pacômetro digital. Constatou-se que os fatores estudados influenciam significativamente no cobrimento final.

Palavras-chave: cobrimento, espaçador, amarração, concreto armado.

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1. Introduction

Reinforced concrete has been undergoing ongoing improvements since the late 19th century and it is the most widely used construction material worldwide because of its cost-effectiveness, durability and multiple applications [1]. However, in the last decades, degradation phenomena in concrete structures that are only a few years old have become increasingly common [2]. This early decay may be a result of project design failures, project execution or the use of unsuitable materials in aggressive environments [1].

The problems associated with the durability of reinforced concrete structures are observed mainly in CO₂- and/or chloride-rich environments. Aggressive agents in the environment penetrate the concrete and may induce early decay, affect service performance and, in serious cases, cause structural failure [3].

Thus, the durability of a structural system consists of preserving the safety, stability and service usefulness of a given structure throughout its service life while considering the environmental conditions specified in the project [4]. This requirement is highly dependent on the characteristics of the concrete cover to reinforcement and its thickness [2].

While the porosity of concrete is a key element affecting the protection of the reinforcement, so is the cover thickness. The concrete layer, which is the distance between the nearest face of the concrete and the steel reinforcement, provides physical protection in the form of a barrier, as well as chemical protection in the form of a passivation layer created by the high alkalinity and the insulating effect of the concrete [5].

Failure to achieve the specified concrete cover is probably the greatest single factor influencing the premature corrosion of reinforcement [6], which is, in turn, the main type of deterioration

observed in reinforced concrete structures [7] and the most costly as far as maintenance if concerned [1]. However, engineers do not usually perceive the need for a proper cover as a priority and therefore do not give due consideration to ensuring it is obtained [7]. Still, one of the major problems associated with reinforced concrete structures is the failure to position the reinforcement with the correct cover of concrete, thus impairing the mechanical properties and the durability of the structure [8].

As far as the structural performance of slabs and beams is concerned, the global safety factor increases as the cover thickness decreases [9]. This is not the case, however, with durability, as a thicker cover improves the protection to the reinforcement [10]. Therefore, these competing factors must be balanced.

As a result, the design and execution of reinforced concrete structures must take into account the nominal cover prescribed by the applicable standard [4], which specifies a 10-mm tolerance for the minimum cover for each environmental aggression class. However, where a quality assurance system and strict tolerance limits during execution are in place, it is possible to adopt a value of 5 mm.

Although the Brazilian standard states that the quality control must be clearly defined in the design, it does not indicate the parameters the project designer can use to adopt a given tolerance value. The designer is free to define and specify the tolerance in the design. Thus, any execution is free to claim it adopts strict controls and this often results in 5-mm tolerance values being used. However, studies indicate that a tolerance of 5 mm in the nominal cover does not reflect the cover distribution found in practice [7].

To make matters worse, the standard addressing the execution of reinforced concrete structures lists a single requirement to ensure the specified cover is achieved: the use of spacers [11]. However, there is no reference to their distribution and layout. The method used is part of

Figure 1 - Tying points 15 cm apart with spacers 60 cm apart

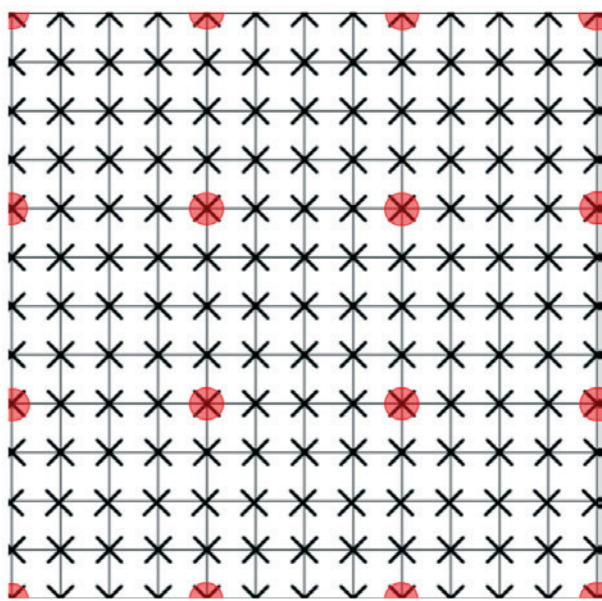


Figure 2 - Tying points 30 cm apart with spacers 60 cm apart

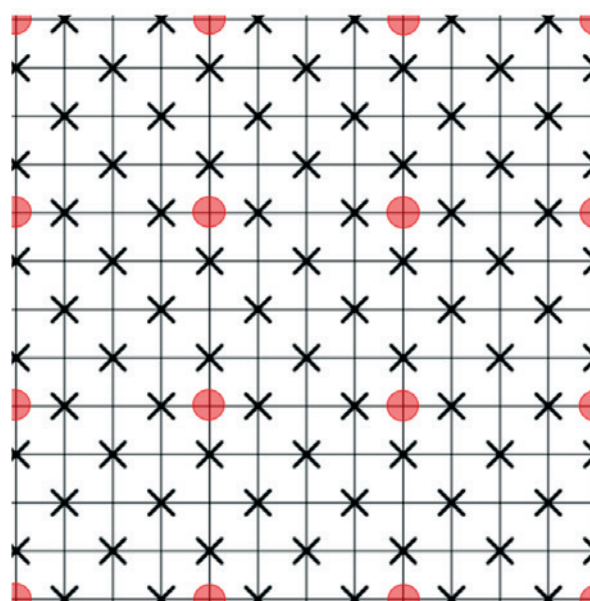


Figure 3 – Tying points 15 cm apart with spacers 45 cm apart

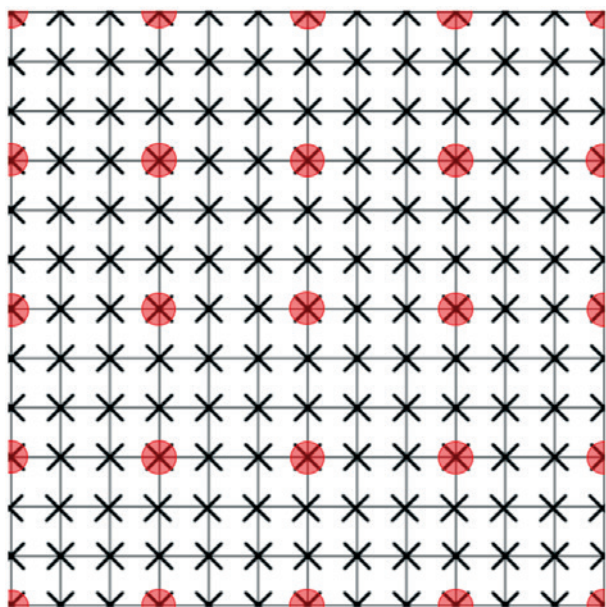
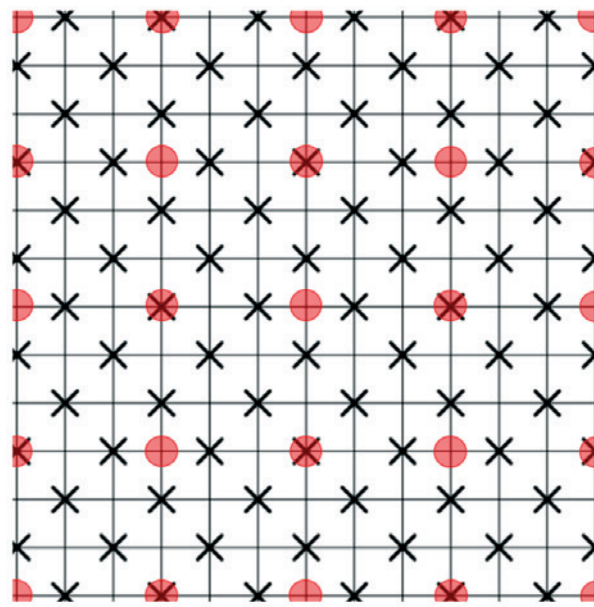


Figure 4 – Tying points 30 cm apart with spacers 45 cm apart



the execution. This is different from European standards, which specify the distribution of spacers according to the structural element and define minimum and maximum distances between them [12][13][14].

However, several international studies have shown that the actual cover achieved does not usually meet design specifications [6]. Research indicates that 90% of corrosion cases are a result of poor placement of the reinforcement [15]. A study in the city of Porto Alegre, Brazil, showed that 44% of the cover thickness values before concrete placement were below the value specified in the project. After placement, this increased to 50% [16].

The aim of this study is thus to analyze factors that may influence the achievement of cover according to standards by controlling the execution of reinforced concrete slabs. To do so, we controlled the tying of the steel reinforcement, the positioning of plastic spacers and the concrete placement in the slabs in order to analyze their effect on the resulting final cover.

2. Materials and experimental program

2.1 Choice of construction site

The construction site where this study was carried out belongs to a private company. It is a residential building with several stories, located in the city of Porto Alegre, in Brazil. It is an urban construction and it is classified as Environment Class II (moderate aggression) [4].

2.2 Choice of slabs

Studies indicate that the cross section of the reinforcement affects the final cover of the slabs. All things being equal, the thicker a

reinforcement, the greater the probability of meeting the minimum cover specified in the project [18]. Thus, $\phi 5,0$ mm reinforcements (the smallest diameter allowed by the standard, with the exception of welded grids) [4] are the most critical. Therefore, an attempt was made to reproduce and assess this critical situation, and the following configuration resulted:

The monitored specimens are solid reinforced concrete slabs, cast in situ, measuring 3.60 m by 2.60 m, 10-cm thick and with a designed cover of 20 mm. The reinforcement consists of CA 60 steel rebars, which measure 5 mm across and are laid out to form a grid with 15-cm openings. Plastic chairs and size 16 tying wire ($\phi 1.65$ mm) were used. Concrete placement was performed by a contractor using pumps and hoses. Pumped concrete properties were $f_{ck} = 25$ MPa, slump = 12 ± 2 cm, and coarse aggregate with maximum characteristic size = 25 mm was used.

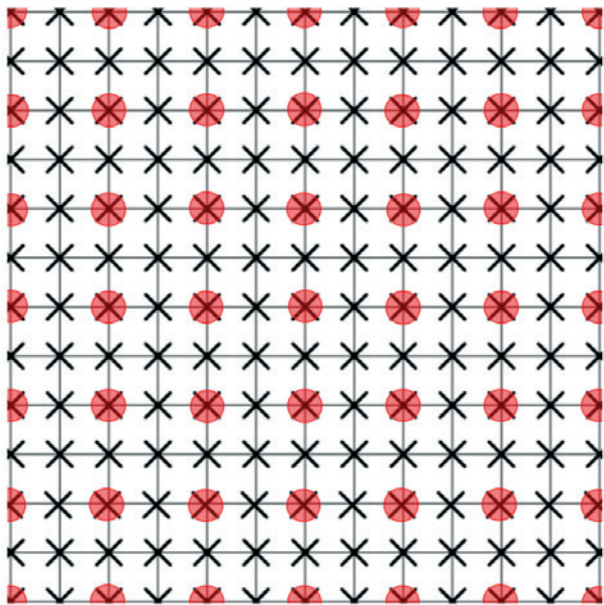
Eight equivalent slabs were selected (size, location on the floor, reinforcement ratio, mesh opening, etc.), distributed over two floors. On the first floor, the tying points were placed 15 cm apart and the spacers were placed at 30, 45 and 60 cm intervals, as shown in Figure 1, Figure 3 and Figure 5. One of the slabs was not controlled, on purpose (none of the factors). The same procedure was followed on the second floor, the only difference being the distance between the tying points, which was 30 cm, as shown in Figure 2, Figure 4 and Figure 6. In the figures, the X shows the tying point and the red circle is the position of the spacer.

Figure 7, Figure 8 and Figure 9 shows the position of the spacers at 30, 45 and 60cm intervals.

2.3 Controllable factors

The first controllable factor, namely the tying points in the steel

Figure 5 – Tying points 15 cm apart with spacers 30 cm apart



reinforcement, was defined from the specification, which sets a maximum distance of 35 cm between tying points in slabs [4]. In compliance with this standard, the intersections of the rebars

Figure 6 – Tying points 30 cm apart with spacers 30 cm apart

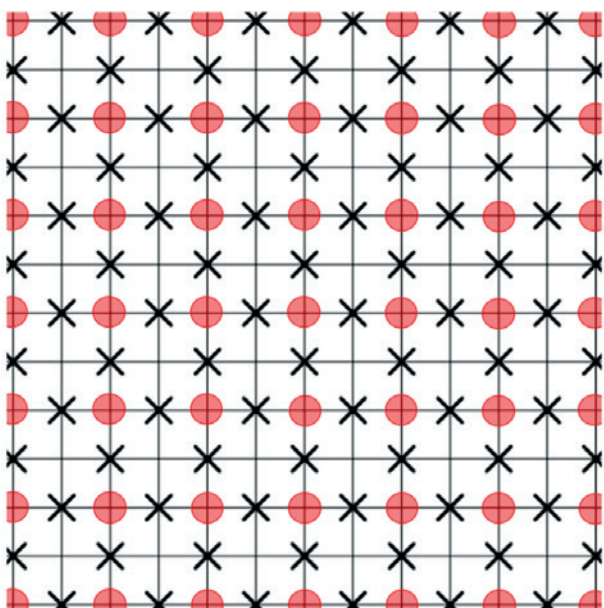
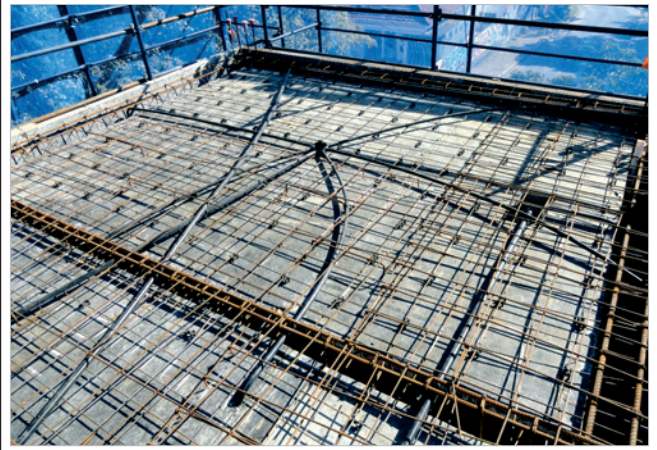


Figure 7 – Layout of spacers placed at 30 cm intervals in the construction site before concrete placement



were tied at 15- and 30-cm intervals, i.e. the minimum and maximum allowed distance according to the mesh opening.

The second controllable factor was the distance between the spacers. As there is no Brazilian standard addressing this issue, distances of 30, 45 and 60 cm were used, i.e. multiple distances in the mesh openings so that the spacer was placed at the intersection of the steel reinforcement, in compliance with the intervals (minimum and maximum values) specified in European standards [12][13][14].

2.4 Measurements

After concrete placement, removal of the shoring and demolding of the slabs, cover thickness was measured. Measurements

Figure 8 – Layout of spacers placed at 45 cm intervals in the construction site before concrete placement

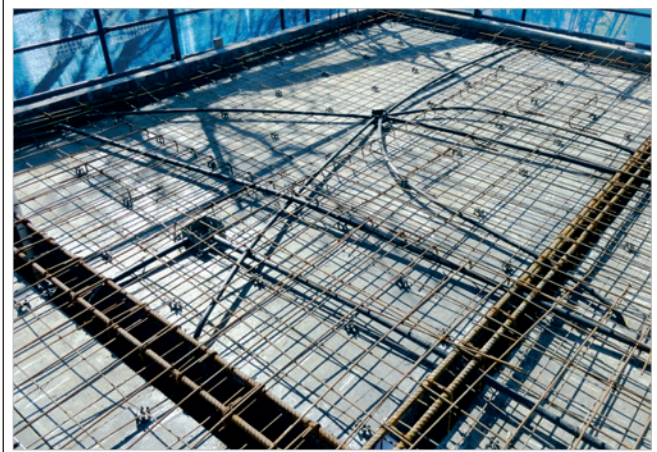


Figure 9 – Layout of spacers placed at 60 cm intervals in the construction site before concrete placement

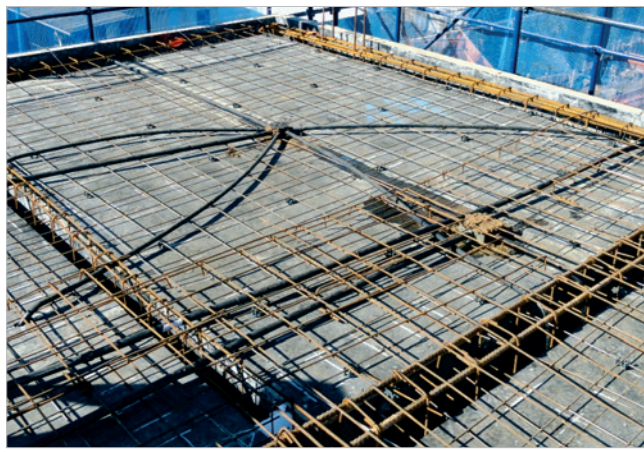


Figure 10 – Measuring the cover of the positive reinforcement of the slabs



were carried out using an electronic device that can locate the rebars by means of magnetic pulse induction, which generates a magnetic field where a difference in current can be translated as a measurement. The digital pachometer (covermeter) used shows the cover thickness with a precision of 3 mm in a depth range of 60 mm. However, when adjusted for the actual thickness of the measured reinforcement, the results provided by the device display greater accuracy [17].

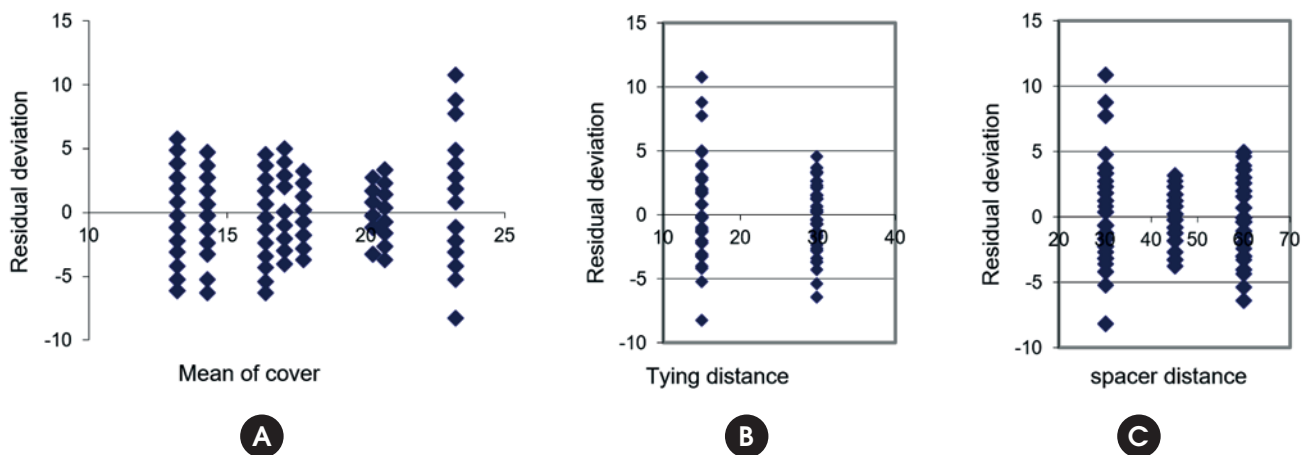
Measurements were made on the bottom surface of the slabs, as shown in Figure 10, in order to measure the positive reinforcement. Thirty-four cover thickness measurements were recorded at random in each slab. The two highest and the two lowest values were discarded, resulting in a total of 240 measurements.

3. Results and discussion

The results obtained according to the proposed method are shown in Table 1. The data were checked using Kolmogorev-Smirnov (K-S) and Jarque-Bera (J-B) normality tests, which did not indicate any evidence of a non-normal distribution for a significance level of 5%. The results of the normality tests are shown in Table 2.

The residual deviations of the observation were also checked, as Figure 11 shows. It is possible to observe that, even though the dispersion of residual deviation is not constant, no huge variations are observed in the means of the measured cover in relation to

Figure 11 – Residual deviation: (a) cover thickness vs. mean of cover thickness, (b) of cover thickness vs. tying distance, (c) cover thickness vs spacer distance



the distance between tying points or spacers, which justifies the hypothesis required by the analysis of variance (ANOVA), i.e. that the distribution of the measured values should display the same dispersion but may show differences in mean values.

Thus, in order to check whether the data on controllable factors (spacer distance and tying point distance) indicates an influence on the response variable (cover thickness), an analysis of variance (ANOVA) was carried out with a significance level of 5%, as Table 3 shows.

The results show that the distance between the spacers and the

distance between the tying points influence the final cover of the structural element. However, no interaction was observed between these factors and they therefore operate independently.

Figure 12 shows the behavior of the two distances between the tying points assessed.

It can be observed that a distance of 15 cm between the tying points results in improved performance when compared with a distance of 30 cm. This is due to the fact that the mesh becomes stiffer when all points are tied.

The effect of spacer distances is shown in Figure 13, which dem-

Table 1 - Results of in situ cover thickness measurements

	Distance between tying points							
	15 cm			30 cm			Uncontrolled slab	
	Distance between spacers			Distance between spacers			L1	L2
	30 cm	45 cm	60 cm	30 cm	45 cm	60 cm		
Cover	21	21	15	19	17	20	16	11
	18	20	17	17	17	15	18	13
	19	22	15	20	18	18	15	14
	22	22	17	22	21	21	11	15
	26	21	19	19	20	16	7	14
	27	20	20	24	16	18	8	14
	31	22	17	20	16	15	14	13
	34	23	20	22	18	11	17	17
	24	17	13	19	18	18	11	17
	22	20	22	21	17	18	9	14
	25	17	21	18	16	19	10	12
	28	19	14	20	14	20	19	15
	26	19	22	22	20	16	16	14
	20	20	13	24	20	16	12	15
	22	20	14	24	19	16	16	15
	25	21	16	23	18	16	12	14
	19	22	17	21	19	17	13	13
	22	21	17	20	16	16	8	19
	21	22	17	19	15	17	17	17
	21	21	17	24	19	19	18	16
	32	21	15	20	18	19	17	13
	27	21	17	19	15	10	19	19
	25	21	19	20	17	13	17	11
	22	20	17	21	18	14	12	16
	20	19	14	20	19	15	15	9
	21	19	16	22	18	12	10	15
	15	19	17	20	19	15	12	16
	21	17	19	19	17	17	12	18
20	20	14	18	19	18	7	12	
20	20	20	23	19	16	8	8	

Table 2 - Normality test results for measurements

	Distance between tying points						Uncontrolled slab	
	15 cm			30 cm				
	Spacer distance			Spacer distance				
	30 cm	45 cm	60 cm	30 cm	45 cm	60 cm	L1	L2
K-S statistic (D30)	0.210	0.172	0.205	0.200	0.155	0.144	0.137	0.121
P value	>20%	>20%	>10%	>10%	>20%	>20%	>20%	>20%
Normality	YES	YES	YES	YES	YES	YES	YES	YES
J-B statistic (JB)	2.786	1.475	2.999	1.623	3.417	2.610	2.986	3.511
P value	24.8%	47.8%	22.3%	44.4%	18.1%	27.1%	22.5%	17.3%
Normality	YES	YES	YES	YES	YES	YES	YES	YES

Table 3 - Analysis of variance (ANOVA) of controllable factors

Source	SQ	GDL	MQ	F test	p-value	Sig
Spacer distance	825.64	2	412.82	60.97	0.00%	YES
Tying point distance	160.56	1	160.56	23.71	0.00%	YES
Spacer distance x tying point distance	33.64	2	16.82	2.48	8.63%	NO
Error	1178.13	174	6.77	-	-	-

onstrates that the cover thickness is inversely proportional to the distance between the spacers. In other words, a distance of 30 cm showed the best performance of all, while a distance of 45 cm resulted in better cover when compared with a spacer distance of 60 cm. This behavior is associated with the smaller gap between

the steel reinforcement. A narrower gap results in less deformation in a given material, in this case, the reinforcement.

By running a new analysis of variance (ANOVA), as shown in Table 4, when all possible combinations (2 distances between tying points and 3 distances between spacers, with a total of

Figure 12 - Relationship between the resulting cover and different tying point distances

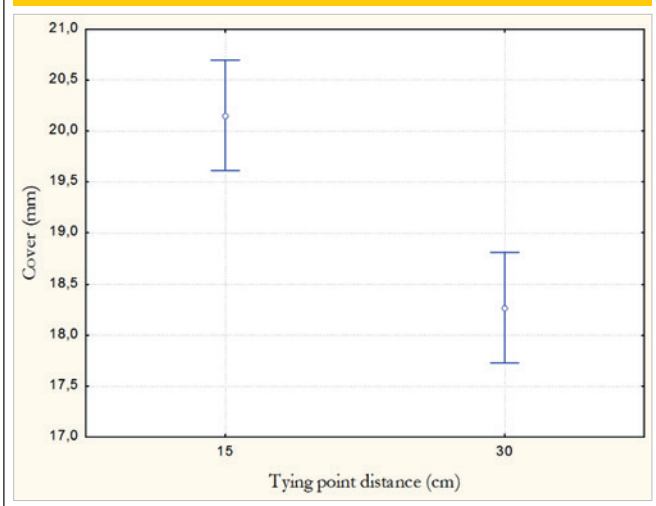


Figure 13 - Relationship between the resulting cover and the distance between spacers

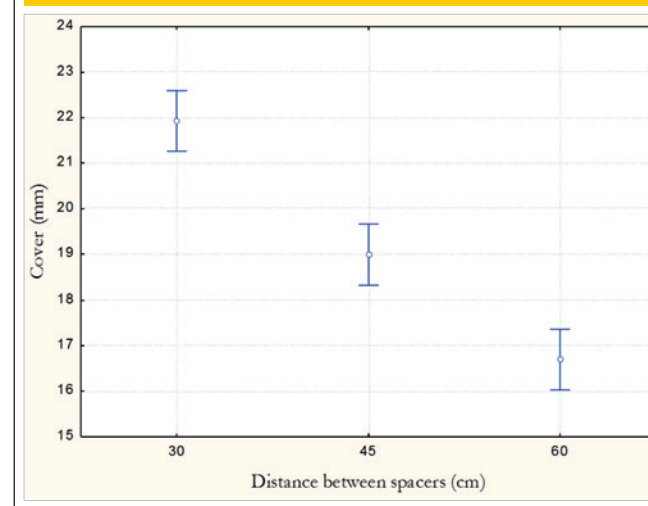


Table 4 – Analysis of variance (ANOVA) of all the possible tying combinations versus cover

Source	SQ	GDL	MQ	F test	p-value	Sig
Possible combinations	1019.84	5	203.97	30.12	0.0%	YES
Error	1178.03	174	6.77	-	-	-

6 combinations) are compared, a significant difference can be observed between these combinations, which reinforces the findings of Table 3.

Due to the existence of a significant difference between the possible combinations, in order to check for similarities between them, a comparison of the mean values in Figure 14 was made, which adopted as a cutoff limit a value that was three times that of the standard deviation of the mean values of the samples.

It can be seen that combinations A30E30 (30-cm distance between tying points and 30-cm distance between spacers) and A15E45 (15-cm distance between tying points and 45-cm distance between spacers) show the same behavior, just like combinations A15E60 (15-cm distance between tying points and 60-cm distance between spacers) and A30E60 (30-cm distance between tying points and 60-cm distance between spacers).

Figure 15 further corroborates the results discussed above. It shows that the behavior of controllable factors is inversely proportional to the cover thickness. The absence of interaction between the controllable factors is also illustrated by the fact that when the points of the different distribution levels are connected between the tying points, they do not cross.

In order to check for the efficiency of these combinations in ensuring that the specified cover is achieved, a statistical analysis that took into account a normal distribution was carried out. Given that the Brazilian standard [4] specifies a tolerance of 10 mm in the execution of the cover, the probability of values falling outside the tolerance range was calculated, i.e. those values below 15 mm and

above 35 mm, for all combinations studied and for uncontrolled situations, which are listed in Table 5.

The data show that all combinations, including the uncontrolled slabs, fall within the upper cover thickness threshold. However, for the lower threshold, the combinations with 60-cm spacer distances do not meet the minimum cover thickness values prescribed by the Standard as they have a high probability of resulting in unsatisfactory values. Still, the probability in this case is far lower than what is observed in uncontrolled slabs, which may exhibit non-compliance values in excess of 63%.

4. Conclusions

The results obtained and the analyses in this research only apply to the sample investigated, which correspond to a worst case scenario.

Therefore, the results indicate that:

- The distance between the spacers and the distance between the tying points have a significant influence on the resulting cover of the frame in slabs.

Figure 14 – Comparison of the cover means of the possible combinations

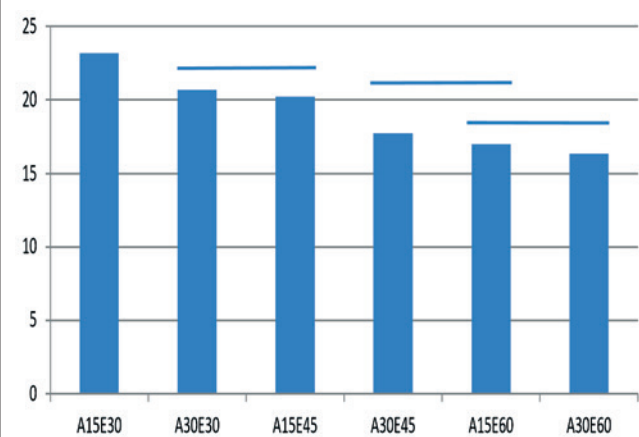


Figure 15 – Relationship between the distance between spacers, distance between tying points and cover

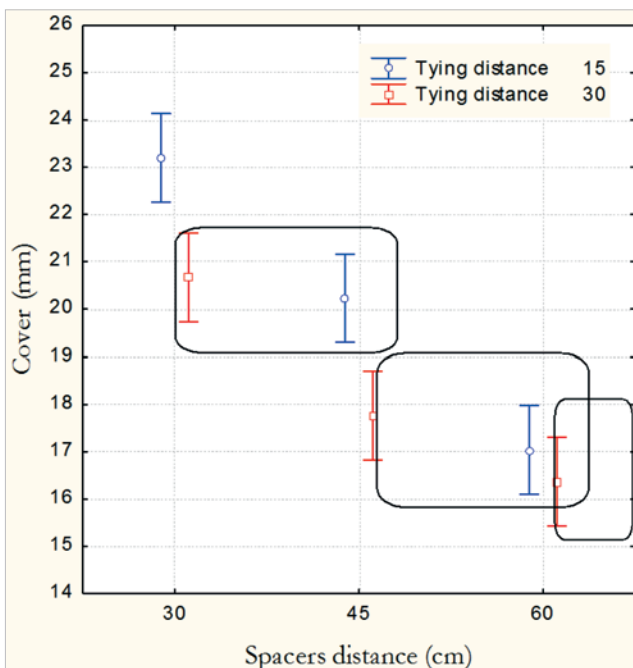


Table 5 – Occurrence of non-compliant values

Tying distance	15 cm			30 cm			Uncontrolled slab		
	Spacer distance	30 cm	45 cm	60 cm	30 cm	45 cm			60 cm
Mean		23.20	20.23	17.03	20.67	17.77	16.37	13.75	13.75
SD		4.29	1.52	2.54	1.95	1.68	2.61	3.27	3.27
% ¹ < 15 cm		2.8%	0.0%	21.2%	0.2%	4.9%	30.0%	64.9%	64.9%
% ¹ > 35 cm		0.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

¹ Probability of values occurring.

- There is no interaction between the distance between the spacers and the distance between the tying points.
- The control factors (distance between spacers and distance between the tying points) are inversely proportional to the cover thickness, i.e. smaller distances result in a better achievement of the cover.
- When the distance between the spacers and the tying points is controlled, the probability of achieving satisfactory cover is higher.

5. Acknowledgements

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