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ANCHORAGE STRENGTH OF BEAM-PILLAR CONNECTIONS IN REINFORCED CONCRETE WITH BARS AND TYPE L CONNECTORS

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Abstract: The conventional technique of anchoring in reinforced concrete beam-column connections by simple adhesion with straight steel bars can result in extensive anchorage length, according to the amplitude of the requests, harming the economy and aesthetics of the architectural project by forcing the enlargement of the column. Known solutions for transferring stresses between steel and concrete include anchoring combined adhesion with mechanical devices: pins, hooks or bends. The design of the connections of structural elements is done by applying mathematical models proposed by the technical standards, whose different calculation methodologies can result in discrepancies in the predictive analysis of the anchorage resistance with potential impacts on the costs and safety of the building. This work investigates the factors that influence the resistant capacity of beam-column connections molded with right-angle bending bars, confronting the accuracy of the ACI 318 (2019) and NBR 6118 (2014) standards for estimating the resistance of the set to the stresses. After analyzing the test data collected in the specialized literature and comparing their results with the values estimated analytically by the calculation models of the aforementioned standards, it was concluded that both codes meet the safety requirements, with the NBR being more conservative. The anchorage length proved to be the main factor influencing the anchorage efficiency, together with coverage and the compressive strength of the concrete.

Keywords: Reinforced concrete. Beam-column connection. Anchoring. L connectors.

INTRODUCTION

In beam-column connections, simple adhesion anchorage may become unfeasible when the anchorage length required is greater than the dimension of the column. Among the possible solutions for the transfer of forces between steel and concrete to meet the design geometry, adhesion anchorage combined with mechanical devices made with steel bars in 90º bend, can significantly reduce the anchorage length required. A database collected in the specialized literature about pullout tests on specimens of beam-column connection elements in reinforced concrete is confronted with values of resistant capacity estimated by mathematical models provided for in the ACI 318 (2019) and NBR 6118 (2014) standards, to assess their accuracies and identify factors that have the greatest influence on resistance capacity. Other studies with a similar scope were carried out by Ajaam, A. et al. (2017), Ajaam, A. et al. (2018), Lima, N.W.B. (2019), Marques, J.L.G.; Jirsa, J.O. (1975), Searle et al. (2014), Sperry et al. (2015a;b) and Sperry et al. (2017).

APPLIED METHODOLOGY

The investigation was carried out through database formation with information collected in the specialized literature about pullout tests on specimens of beam-column connection elements in reinforced concrete (Fig. 1), definition of equations for estimating the resistant capacity according to the methodology of indicated norms, comparison of the experimental results with values determined according to the calculation models presented by the norms and analyzes of influential factors in the anchoring efficiency of the connection elements.

152 of the 337 experimental trials were extracted from the work of Sperry et al. (2017) related to elements molded under anchorage by bending at right angles, 58 with bars # 5 and 94 with bars # 8. The Annex presents Tables 2 and 3 with the list of data collected and identification of each specimen by a code standardized whose legend can be seen in Fig. 2.

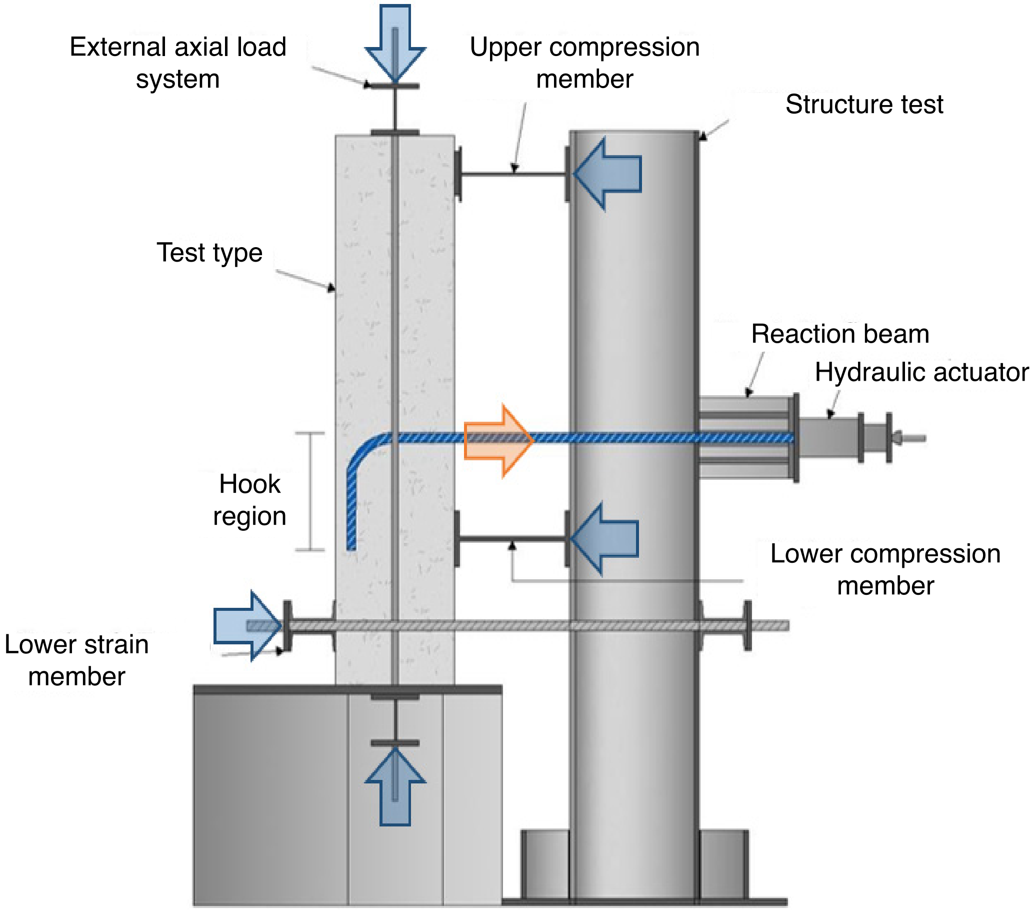


Figure 1. Schematic presentation of the tested beam-column model/assembly. Adapted from Sperry et al. (2017).

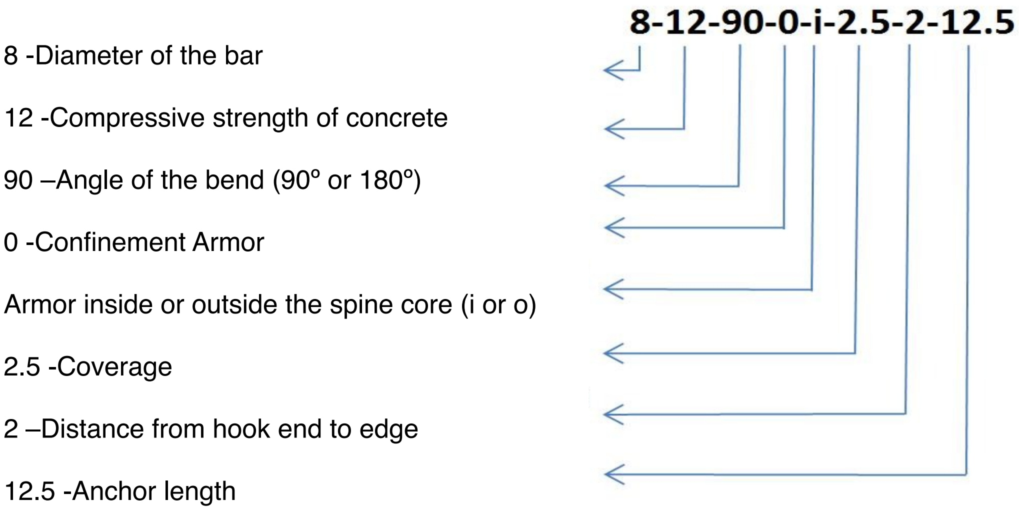


Figure 2. Specimen identification.

The deduction of the equation for calculating anchorage strength in the model provided for in NBR 6118 (2014), followed the requirements of items 9.4.2.4; 9.4.2.5, 9.3.2.1 and 12.4.1, with n1 = 2.25; n2=1.0; n3=1; = Yo 1.4; and ratio of effective reinforcement by calculated reinforcement equal to 1. The final formula described in Eq. 1.

(SI) 1

In which: $fs,_{NBR}$ = Yield stress of NBR steel in MPa; f_{ck} = Characteristic compressive strength of concrete in MPa; $l_{b,nec}$ = Required anchor length in millimeters; ∅ = Bar diameter in millimeters; and α = Coefficient for calculating anchorage length NBR 6118.

The model equation proposed by ACI 318 (2019) was obtained by adopting the formulation explained by Sperry et al. (2017), adapted to the current version of the standard.

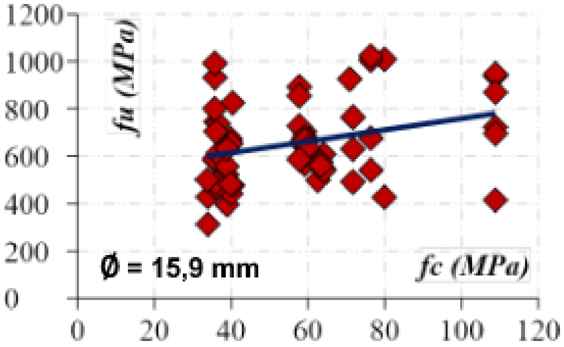
(SI) 2

In which: $fs,_{ACI}$ = Steel yield strength in MPa; l_{eh} = Anchor length in millimeters; f_c = Compressive strength of concrete measured in MPa; ψ_c = Anchor length factor based on concrete tension; ψ_o = Coverage-based anchorage length factor; ψ_r = Anchor length factor based on confining reinforcement; d_b = Nominal diameter of the bar in millimeters;

RESULTS OBTAINED AND DATA ANALYSIS

PRELIMINARY ANALYSIS

Based on the evaluations of the specialized literature, the variables of compressive strength of concrete were selected for analysis. (*fc*), required anchor length ($l_{b.nec}$), cobrimento (*c*) and bar diameter (∅), as the most influential in the experimental results. The experimental data were compared with estimated values through graphical analyses, contrasting the accuracy of the standards and verifying the safety levels of the design resistors from the analysis of trend lines of the generated scatter plots, as seen in Figure 2am to 2pm.



∅ = 23,4 mm

Figure 2-a. Graphic *fu* X *fc* - ∅ = 15,9 mm.

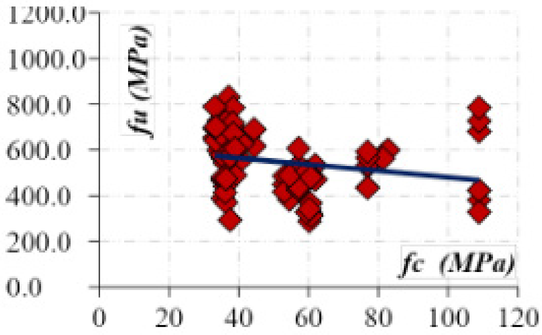


Figure 2-b. Graphic *fu* X *fc* - ∅ = 25,4 mm.

In the Voltage charts, the resistance (*fu)* X compressive strength of concrete measured (*fc*), with ∅ = 15,9 mm, a positive trend line of strength is observed for increases in concrete strength; conversely, with ∅ = 25,4 mm, suggest a negative trend. With the normalization of the anchorage length, it was observed that the trend line of the results returns to the upward direction, which seems to effectively indicate the strong influence of this parameter on the test results (Figure 2-g).

In the graphics: *fu* X $l_{b,nec,}$ we could see that there is a strong tendency to increase the resistance capacity related to the increase in the anchorage length, with an apparent greater influence for the smaller diameter. In the relation of the experimental resistance with the covering (*fu* x ***c***), there was a new divergence with ∅ = 15,9 mm showing an upward trend versus a negative trend for ∅ = 25,4 mm. The normalized analysis by $l_{b,nec}$ revealed a significant influence of this factor that reduced the slope of the trend line.

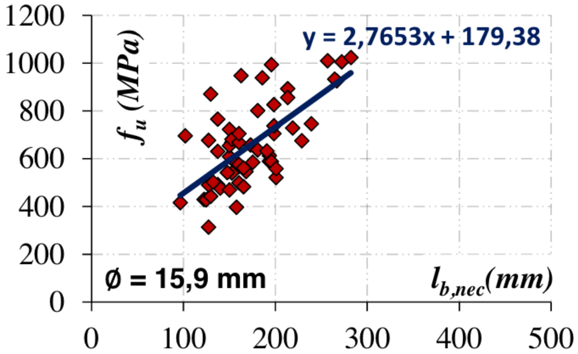


Figure 2-c. Graphic *fu* X $l_{b,nec}$ - ∅ = 15,9 mm.

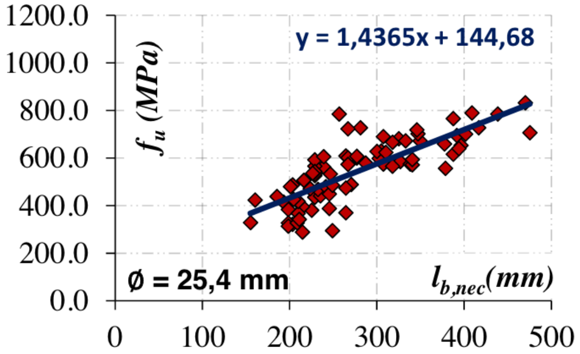


Figure 2-d. Graphic *fu* X $l_{b,nec}$ - ∅ = 25,4 mm.

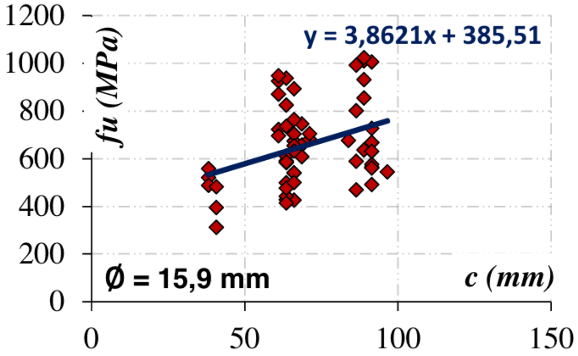


Figure 2-e. Graphic *fu* X *c* - ∅ = 15,9 mm.

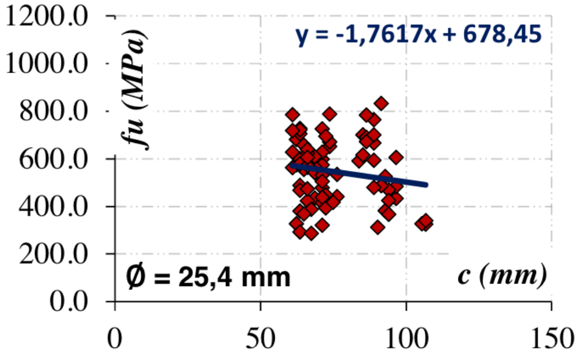


Figure 2-f. Graphic *fu* X *c* - ∅ = 25,4 mm.

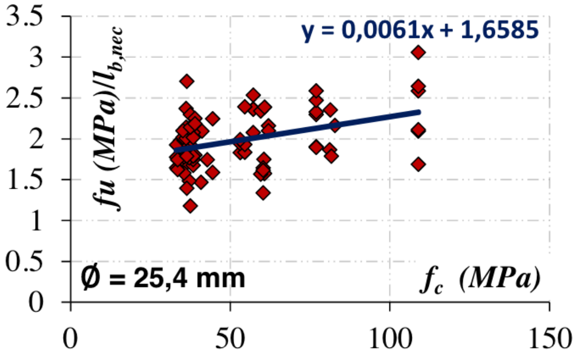


Figure 2-g. Graphic fu / lb,nec X fc - ∅ = 25,4 mm.

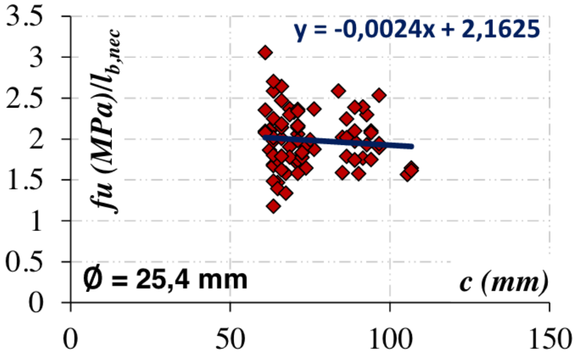


Figure 2-h. Graphic fu / lb,nec X c - ∅ = 25,4 mm.

It can already be seen that the anchorage length exerts a substantial influence on the behavior of the specimens. However, the parameters of the graphs above are not enough for a definitive conclusion, since there are numerous other variables that may be influencing the results.

SPECIFIC ANALYSIS

In order to identify the influence of each variable separately, graphs were generated for specific analyses, highlighting the variation of the experimental results as a function of the variation of the factors of interest, keeping the other parameters fixed. Straight lines resulting from the calculation methods provided for in the standards in confrontation in this study were inserted in each graph.

This way, it was possible to verify and analyze the accuracy of each model and its correlation with the parameters investigated.

Figures 3-a to 3-c present the results of the experimental strength as a function of the anchorage length with different cover thicknesses, and as a function of the concrete strength, with fixed variables. Figures 3-d and 3-e show the function of experimental strength normalized to anchor length by concrete strength and cover, with fixed variables. The red dashed lines demarcate the predicted resistance calculated using the ACI 318 (2019) methodology, while the green lines show the resistance calculated using the NBR 6118 (2014) methodology.

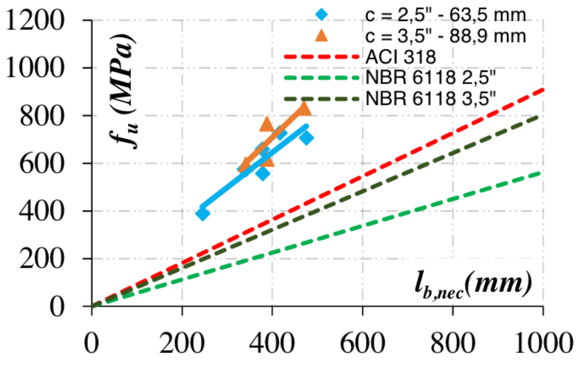


Figure 3-a. Graphic *fu* X $l_{b,nec}$ – varying the cover.

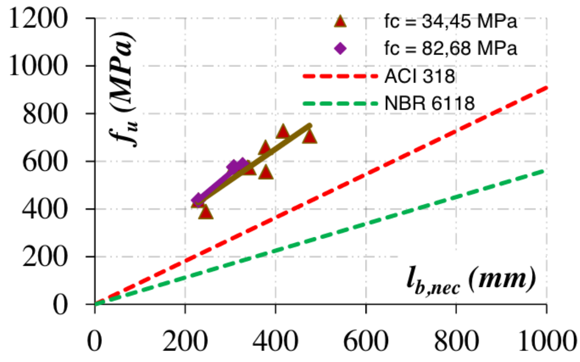


Figure 3-b. Graphic *fu* X $l_{b,nec}$ – varying fc.

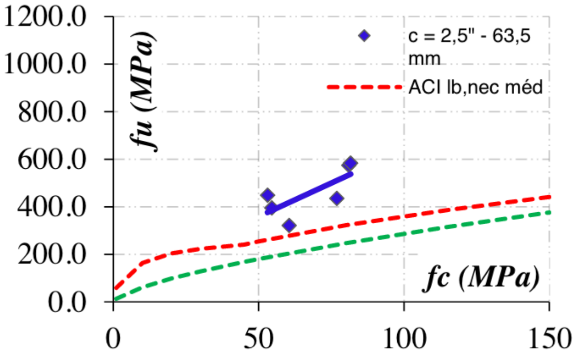


Figure 3-c. Graphic *fu* X *fc* – fixed variables.

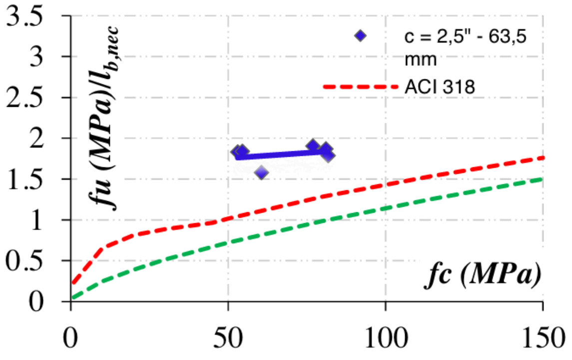


Figure 3-d. Graphic *fu / lb,nec* X *fc* – fixed variables.

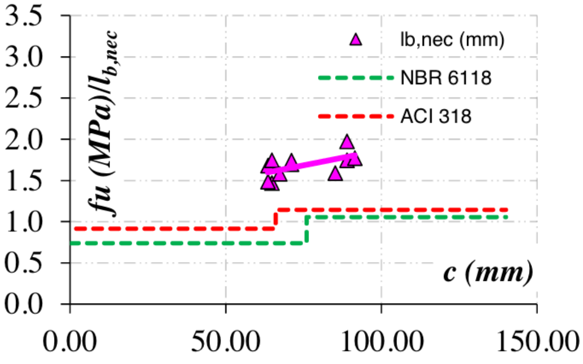


Figure 3-e. Graphic *fu* / $l_{b,nec}$ X *c* – fixed variables.

It was observed, even with the isolation of other influential variables, that the increase in $l_{b,nec}$ effectively implies an increase in experimental resistance. It was also found that NBR 6118 is highly sensitive to cover variation, to the point of showing a discrepancy greater than 200 MPa in the predicted strength, for an anchorage length equal to 1000 mm. On the other hand, the ACI estimates showed no variation due to the cover in the range of thickness studied. As for the results of the experimental strength with different values of compressive strength of the concrete, it was also possible to observe that with an increase in the $\boldsymbol{l_{b,nec}}$ there are progressive increases in experimental resistance.

To evaluate the strengths calculated by the methodology of the standards under study as a function of the measured concrete compressive strengths, the other variables were fixed. For this purpose, a group of specimens with small variations of lb,nec was selected, since there were no elements in the database with equal anchorage lengths, from which the average lengths were extracted. The selected specimens had 5" (63.5 mm) coverage as seen in Fig. 3-c. As a result, increases in experimental strength corresponding to increases in concrete compressive strength were observed.

The graphs of the experimental strength as a function of the measured concrete compressive strengths, prepared by normalizing the anchorage length, provide another indication of the relevance of lb,nec, in the composition of the strength calculation. Note that, excluding the anchorage length factor, the slopes of the experimental trend lines have changed considerably, as long as the other parameters are fixed, except for the compressive strength. This result reaffirms the strong influence of the anchorage length on the test results.

Finally, in the evaluation of the experimental resistance as a function of the cover, the other factors under study were fixed, (∅ = 25.4 mm; fc = 34.45 MPa; normalized lb.nec), verifying increases in resistance with the increase of thickness of the cover layer. The ascending trend line, contrary to what was seen in the general analyses, indicates that the cover effectively influences the experimental resistance.

In all the specific analyzes it was found that the results of the predictions of both standards are in favor of safety. It was emphasized that the methodology of NBR 6118 is more conservative than that of the ACI. The estimates, in fact, maintain wide safety margins, a condition that, on the other hand, works to the detriment of the economy.

EVALUATION OF CALCULATION METHODS

Table 1 presents the mean, standard deviation and coefficient of variation values for the ratio between the last experimental loads and those estimated by NBR 6118 (2014) and ACI 318 (2019) calculations. Analyzing the values of the ratio between the last experimental and estimated resistant stresses, it appears that the ACI 318 (2019) methodology showed the best fit, presenting both results closer to the experimental values and a smaller dispersion. For Hooks # 8, the mean, standard deviation and coefficient of variation are equal to 1.69, 0.06 and 0.04, respectively. Hooks # 5 had mean, standard deviation and coefficient of variation equal to 1.56, 0.05 and 0.03, using the ACI methodology.

In no two cases considered by the average there were values against insurance, regardless of the method of calculation. On the other hand, it is observed that there is a good margin for adjustments of the methodologies not related to the impacts on

		Average	Standard deviation	Coefficient of variation
Hooks # 8	$fu / fs,_{NBR}$	2,60	0,30	0,12
	fu / f_{ACI}	1,69	0,06	0,04
Hooks # 5	$fu / fs,_{NBR}$	2,31	0,16	0,07
	fu / f_{ACI}	1,56	0,05	0,03

Table 1. Statistics (Mean, Standard Deviation and Coefficient of Variation).

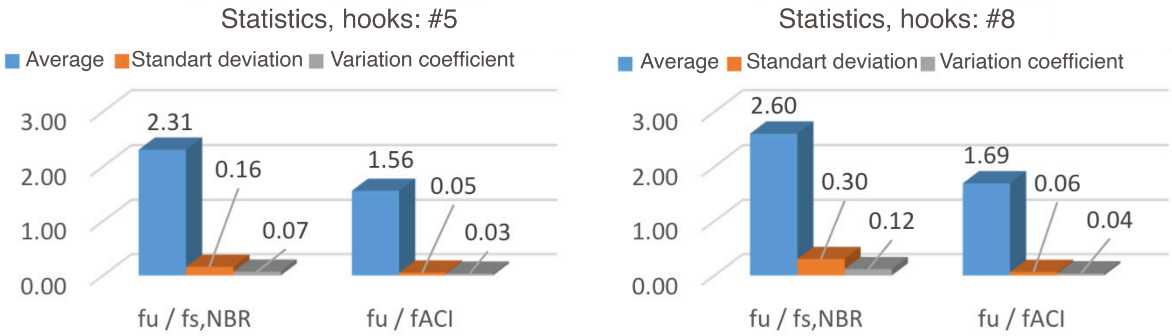


Figure 4. Mean, Standard Deviation and Coefficient of Variation.

the costs of the building. In this approach, the ACI methodology reached, on average, strength requirements 69% higher than the measured strength capacities, while NBR reaches an average estimate 160% higher than the experimental average. It is also noted that two results estimated by ACI have less dispersion, indicating a better fit and, therefore, more precision than the estimates made by the NBR methodology. Figure 4 presents the graphs of the dispersion measurements.

CONCLUSIONS AND RECOMMENDATIONS

The results show that the normative provisions are both in favor of security, when it comes to anchoring by means of bars with hooks in a challenging angle. It also indicates that the extent of the discrepancies between the estimates and the measured resistance values allows us to assume that there is considerable margin for optimization, in economic terms, eventually reducing the dimensions of the pillar and, therefore, minimizing the use of concrete, using lower rate. from steel in the anchor.

The formulas for calculating resistance in both standards, NBR 6118 (2014) and ACI 318 (2019), are suitable for predicting, with certainty, the necessary requests for the adequate dimensioning of beam-column connections in reinforced concrete with bars in hooks 90º. I verified that the NBR methodology is more conservative in comparison with the ACI, or that it represents a higher level of safety, to the detriment of two costs. ACI 318 (2019) has more accuracy and precision, a condition that translates into greater material economy.

The graphical capacity connections indicate the relevant influence of two factors investigated on the anchorage of concrete-column connections in reinforced built with ribbed bars with 90º hooks. Or necessary anchorage compression: $l_{b.nec}$, it is shown as the main factor of influence in the resistance of anchorage. The angle of inclination of the trend line of the graph: *fu* X $l_{b,nec}$ confirm that there are two mathematical models of both the validated standards, in which the value of the stress is directly proportional to the compression of the anchorage.

NBR 6118 exhibits great sensitivity to the variation of the coating, to the point of presenting a discrepancy greater than 200 MPa in resistance for a difference of 25.4 mm in the thickness of the layer, maintenance or compression of anchorage equal to 1000 mm. The ACI, on the contrary, did not present an estimate variation for the range of coating thicknesses analyzed. The coating proved, outwardly, to be more influential in the experimental resistance than in its own resistance to the compression of concrete.

Finally, it was observed that the methodology available in NBR 6118 presents an average estimate that is 160% higher than the experimental average, configuring less economy when confronted with the average estimated by ACI 318, around 69% higher than the measured resistance capacities. Both methodologies, in any way, can evolve without needing to be adjusted in order to promote positive impacts on building costs.

It is recommended, for future investigation and complementation of the present influence to elaborate an analysis of the stiffness of the beam-column ligation. Furthermore, it is recommended that in-depth statistical evaluations be carried out, through the use of multivariate analysis techniques and statistical methods suitable for research in situations involving multiple variables.

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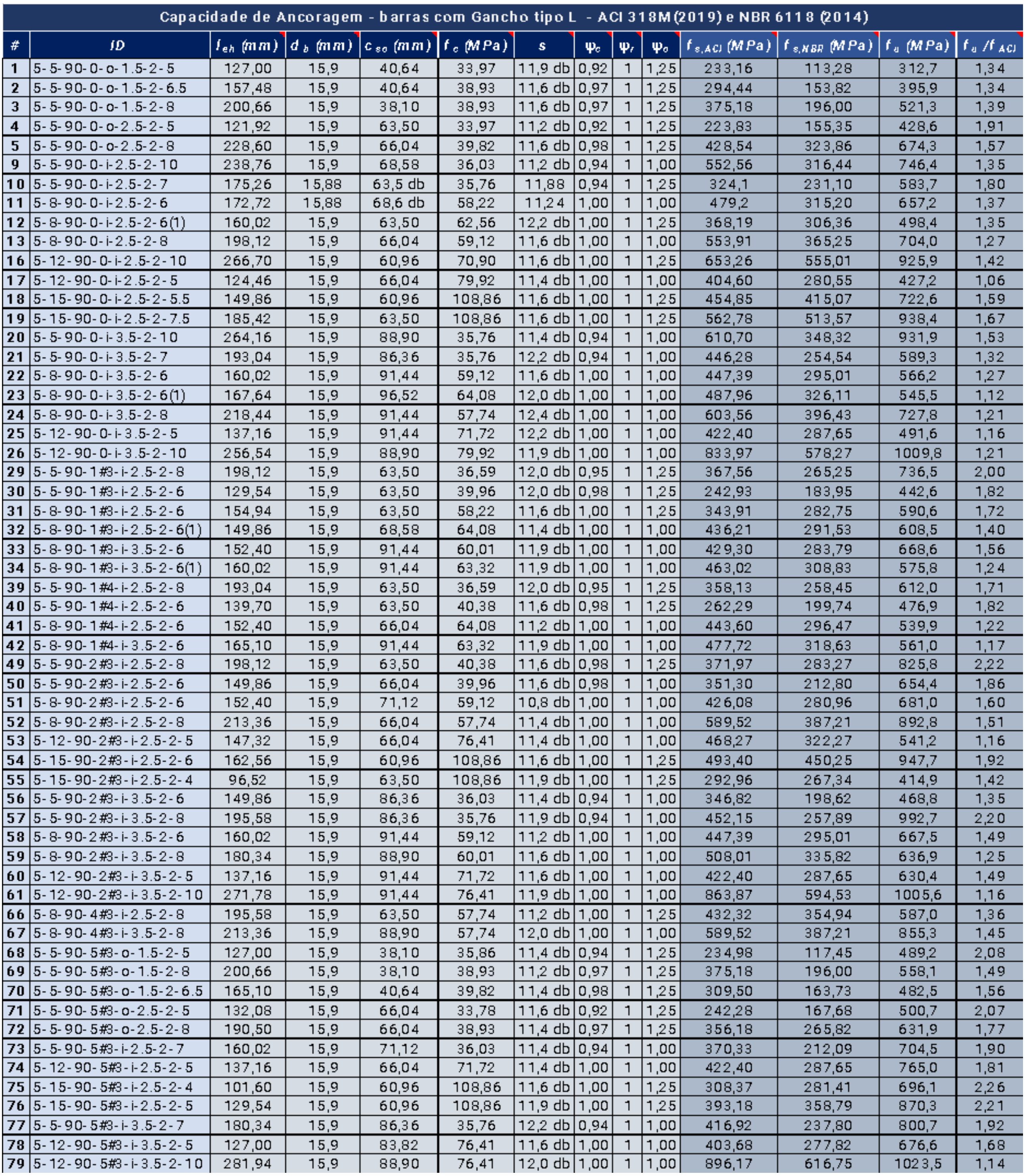
ATTACHMENTS



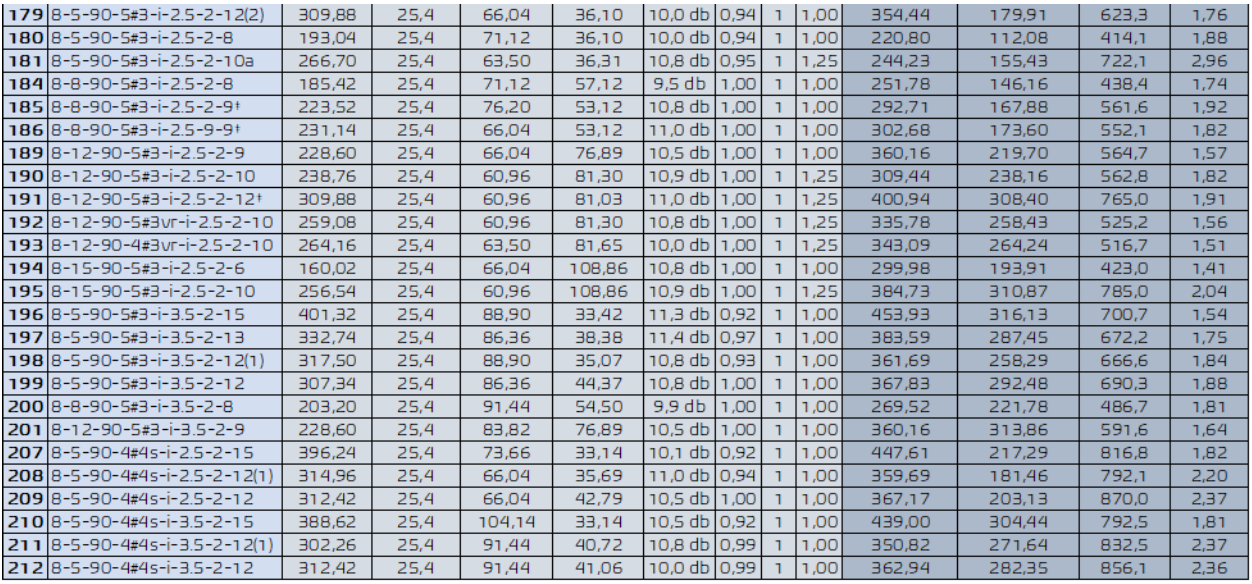
Capacidade de Ancoragem - barras com Gancho tipo L - ACI 318M(2019) e NBR 6118 (2014)													
#	ID	ℓ_{eh} (mm)	d_b (mm)	c_{so} (mm)	f_c (MPa)	s	ψ_c	ψ_r	ψ_o	$f_{s,ACI}$ (MPa)	$f_{s,NBR}$ (MPa)	f_u (MPa)	f_u/f_{ACI}
1	5-5-90-0-o-1.5-2-5	127,00	15,9	40,64	33,97	11,9 db	0,92	1	1,25	233,16	113,28	312,7	1,34
2	5-5-90-0-o-1.5-2-6.5	157,48	15,9	40,64	38,93	11,6 db	0,97	1	1,25	294,44	153,82	395,9	1,34
3	5-5-90-0-o-1.5-2-8	200,66	15,9	38,10	38,93	11,6 db	0,97	1	1,25	375,18	196,00	521,3	1,39
4	5-5-90-0-o-2.5-2-5	121,92	15,9	63,50	33,97	11,2 db	0,92	1	1,25	223,83	155,35	428,6	1,91
5	5-5-90-0-o-2.5-2-8	228,60	15,9	66,04	39,82	11,6 db	0,98	1	1,25	428,54	323,86	674,3	1,57
9	5-5-90-0-i-2.5-2-10	238,76	15,9	68,58	36,03	11,2 db	0,94	1	1,00	552,56	316,44	746,4	1,35
10	5-5-90-0-i-2.5-2-7	175,26	15,88	63,5 db	35,76	11,88	0,94	1	1,25	324,1	231,10	583,7	1,80
11	5-8-90-0-i-2.5-2-6	172,72	15,88	68,6 db	58,22	11,24	1,00	1	1,00	479,2	315,20	657,2	1,37
12	5-8-90-0-i-2.5-2-6(1)	160,02	15,9	63,50	62,56	12,2 db	1,00	1	1,25	368,19	306,36	498,4	1,35
13	5-8-90-0-i-2.5-2-8	198,12	15,9	66,04	59,12	11,6 db	1,00	1	1,00	553,91	365,25	704,0	1,27
16	5-12-90-0-i-2.5-2-10	266,70	15,9	60,96	70,90	11,6 db	1,00	1	1,25	653,26	555,01	925,9	1,42
17	5-12-90-0-i-2.5-2-5	124,46	15,9	66,04	79,92	11,4 db	1,00	1	1,00	404,60	280,55	427,2	1,06
18	5-15-90-0-i-2.5-2-5.5	149,86	15,9	60,96	108,86	11,6 db	1,00	1	1,25	454,85	415,07	722,6	1,59
19	5-15-90-0-i-2.5-2-7.5	185,42	15,9	63,50	108,86	11,6 db	1,00	1	1,25	562,78	513,57	938,4	1,67
20	5-5-90-0-i-3.5-2-10	264,16	15,9	88,90	35,76	11,4 db	0,94	1	1,00	610,70	348,32	931,9	1,53
21	5-5-90-0-i-3.5-2-7	193,04	15,9	86,36	35,76	12,2 db	0,94	1	1,00	446,28	254,54	589,3	1,32
22	5-8-90-0-i-3.5-2-6	160,02	15,9	91,44	59,12	11,6 db	1,00	1	1,00	447,39	295,01	566,2	1,27
23	5-8-90-0-i-3.5-2-6(1)	167,64	15,9	96,52	64,08	12,0 db	1,00	1	1,00	487,96	326,11	545,5	1,12
24	5-8-90-0-i-3.5-2-8	218,44	15,9	91,44	57,74	12,4 db	1,00	1	1,00	603,56	396,43	727,8	1,21
25	5-12-90-0-i-3.5-2-5	137,16	15,9	91,44	71,72	12,2 db	1,00	1	1,00	422,40	287,65	491,6	1,16
26	5-12-90-0-i-3.5-2-10	256,54	15,9	88,90	79,92	11,9 db	1,00	1	1,00	833,97	578,27	1009,8	1,21
29	5-5-90-1#3-i-2.5-2-8	198,12	15,9	63,50	36,59	12,0 db	0,95	1	1,25	367,56	265,25	736,5	2,00
30	5-5-90-1#3-i-2.5-2-6	129,54	15,9	63,50	39,96	12,0 db	0,98	1	1,25	242,93	183,95	442,6	1,82
31	5-8-90-1#3-i-2.5-2-6	154,94	15,9	63,50	58,22	11,6 db	1,00	1	1,25	343,91	282,75	590,6	1,72
32	5-8-90-1#3-i-2.5-2-6(1)	149,86	15,9	68,58	64,08	11,4 db	1,00	1	1,00	436,21	291,53	608,5	1,40
33	5-8-90-1#3-i-3.5-2-6	152,40	15,9	91,44	60,01	11,9 db	1,00	1	1,00	429,30	283,79	668,6	1,56
34	5-8-90-1#3-i-3.5-2-6(1)	160,02	15,9	91,44	63,32	11,9 db	1,00	1	1,00	463,02	308,83	575,8	1,24
39	5-5-90-1#4-i-2.5-2-8	193,04	15,9	63,50	36,59	12,0 db	0,95	1	1,25	358,13	258,45	612,0	1,71
40	5-5-90-1#4-i-2.5-2-6	139,70	15,9	63,50	40,38	11,6 db	0,98	1	1,25	262,29	199,74	476,9	1,82
41	5-8-90-1#4-i-2.5-2-6	152,40	15,9	66,04	64,08	11,2 db	1,00	1	1,00	443,60	296,47	539,9	1,22
42	5-8-90-1#4-i-3.5-2-6	165,10	15,9	91,44	63,32	11,9 db	1,00	1	1,00	477,72	318,63	561,0	1,17
49	5-5-90-2#3-i-2.5-2-8	198,12	15,9	63,50	40,38	11,6 db	0,98	1	1,25	371,97	283,27	825,8	2,22
50	5-5-90-2#3-i-2.5-2-6	149,86	15,9	66,04	39,96	11,6 db	0,98	1	1,00	351,30	212,80	654,4	1,86
51	5-8-90-2#3-i-2.5-2-6	152,40	15,9	71,12	59,12	10,8 db	1,00	1	1,00	426,08	280,96	681,0	1,60
52	5-8-90-2#3-i-2.5-2-8	213,36	15,9	66,04	57,74	11,4 db	1,00	1	1,00	589,52	387,21	892,8	1,51
53	5-12-90-2#3-i-2.5-2-5	147,32	15,9	66,04	76,41	11,4 db	1,00	1	1,00	468,27	322,27	541,2	1,16
54	5-15-90-2#3-i-2.5-2-6	162,56	15,9	60,96	108,86	11,6 db	1,00	1	1,25	493,40	450,25	947,7	1,92
55	5-15-90-2#3-i-2.5-2-4	96,52	15,9	63,50	108,86	11,9 db	1,00	1	1,25	292,96	267,34	414,9	1,42
56	5-5-90-2#3-i-3.5-2-6	149,86	15,9	86,36	36,03	11,4 db	0,94	1	1,00	346,82	198,62	468,8	1,35
57	5-5-90-2#3-i-3.5-2-8	195,58	15,9	86,36	35,76	11,9 db	0,94	1	1,00	452,15	257,89	992,7	2,20
58	5-8-90-2#3-i-3.5-2-6	160,02	15,9	91,44	59,12	11,2 db	1,00	1	1,00	447,39	295,01	667,5	1,49
59	5-8-90-2#3-i-3.5-2-8	180,34	15,9	88,90	60,01	11,6 db	1,00	1	1,00	508,01	335,82	636,9	1,25
60	5-12-90-2#3-i-3.5-2-5	137,16	15,9	91,44	71,72	11,6 db	1,00	1	1,00	422,40	287,65	630,4	1,49
61	5-12-90-2#3-i-3.5-2-10	271,78	15,9	91,44	76,41	11,9 db	1,00	1	1,00	863,87	594,53	1005,6	1,16
66	5-8-90-4#3-i-2.5-2-8	195,58	15,9	63,50	57,74	11,2 db	1,00	1	1,25	432,32	354,94	587,0	1,36
67	5-8-90-4#3-i-3.5-2-8	213,36	15,9	88,90	57,74	12,0 db	1,00	1	1,00	589,52	387,21	855,3	1,45
68	5-5-90-5#3-o-1.5-2-5	127,00	15,9	38,10	35,86	11,4 db	0,94	1	1,25	234,98	117,45	489,2	2,08
69	5-5-90-5#3-o-1.5-2-8	200,66	15,9	38,10	38,93	11,2 db	0,97	1	1,25	375,18	196,00	558,1	1,49
70	5-5-90-5#3-o-1.5-2-6.5	165,10	15,9	40,64	39,82	11,4 db	0,98	1	1,25	309,50	163,73	482,5	1,56
71	5-5-90-5#3-o-2.5-2-5	132,08	15,9	66,04	33,78	11,6 db	0,92	1	1,25	242,28	167,68	500,7	2,07
72	5-5-90-5#3-o-2.5-2-8	190,50	15,9	66,04	38,93	11,4 db	0,97	1	1,25	356,18	265,82	631,9	1,77
73	5-5-90-5#3-i-2.5-2-7	160,02	15,9	71,12	36,03	11,4 db	0,94	1	1,00	370,33	212,09	704,5	1,90
74	5-12-90-5#3-i-2.5-2-5	137,16	15,9	66,04	71,72	11,4 db	1,00	1	1,00	422,40	287,65	765,0	1,81
75	5-15-90-5#3-i-2.5-2-4	101,60	15,9	60,96	108,86	11,6 db	1,00	1	1,25	308,37	281,41	696,1	2,26
76	5-15-90-5#3-i-2.5-2-5	129,54	15,9	60,96	108,86	11,9 db	1,00	1	1,25	393,18	358,79	870,3	2,21
77	5-5-90-5#3-i-3.5-2-7	180,34	15,9	86,36	35,76	12,2 db	0,94	1	1,00	416,92	237,80	800,7	1,92
78	5-12-90-5#3-i-3.5-2-5	127,00	15,9	83,82	76,41	11,6 db	1,00	1	1,00	403,68	277,82	676,6	1,68
79	5-12-90-5#3-i-3.5-2-10	281,94	15,9	88,90	76,41	12,0 db	1,00	1	1,00	896,17	616,75	1023,5	1,14

Table 2 – Bars, number 5

Capacidade de Ancoragem - barras com Gancho tipo L - ACI 318M(2019) e NBR 6118 (2014)

#	ID	l_{eh} (mm)	d_b (mm)	c_{so} (mm)	f_c (MPa)	s	ψ_c	ψ_r	ψ_o	$f_{s,ACI}$ (MPa)	$f_{s,NBR}$ (MPa)	f_u (MPa)	f_u/f_{ACI}
80	8-5-90-0-o-2.5-2-10a	264,16	25,4	64,77	36,31	11,0 db	0,95	1	1,25	241,90	153,95	369,0	1,53
81	8-5-90-0-o-2.5-2-10b	248,92	25,4	63,50	37,48	11,0 db	0,96	1	1,25	228,90	148,17	293,5	1,28
82	8-5-90-0-o-2.5-2-10c	270,51	25,4	63,50	38,93	11,0 db	0,97	1	1,25	249,91	165,14	488,2	1,95
83	8-8-90-0-o-2.5-2-8	214,63	25,4	67,31	60,22	10,0 db	1,00	1	1,25	239,40	175,26	287,9	1,20
84	8-8-90-0-o-3.5-2-8	198,12	25,4	90,17	60,70	10,8 db	1,00	1	1,25	221,87	232,34	312,9	1,41
85	8-8-90-0-o-4-2-8	208,28	25,4	105,41	59,46	10,8 db	1,00	1	1,25	230,85	240,92	327,2	1,42
86	8-5-90-0-i-2.5-2-16	416,56	25,4	71,12	34,31	10,5 db	0,93	1	1,00	473,04	233,78	726,0	1,53
87	8-5-90-0-i-2.5-2-9.5	245,11	25,4	67,31	35,41	10,5 db	0,94	1	1,00	279,61	140,49	388,0	1,39
88	8-5-90-0-i-2.5-2-12.5	337,82	25,4	71,12	36,10	10,8 db	0,94	1	1,00	386,40	196,13	574,0	1,49
89	8-5-90-0-i-2.5-2-18	474,98	25,4	63,50	37,07	11,5 db	0,95	1	1,25	436,15	280,66	705,4	1,62
90	8-5-90-0-i-2.5-2-13	340,36	25,4	63,50	38,31	10,8 db	0,96	1	1,25	313,83	205,57	571,6	1,82
91	8-5-90-0-i-2.5-2-15(1)	378,46	25,4	64,77	40,72	10,6 db	0,99	1	1,25	351,41	238,08	556,1	1,58
92	8-5-90-0-i-2.5-2-15	377,19	25,4	64,77	42,79	10,5 db	1,00	1	1,25	354,64	245,25	658,3	1,86
95	8-8-90-0-i-2.5-2-8	214,63	25,4	72,39	54,50	9,6 db	1,00	1	1,00	284,69	163,98	394,6	1,39
96	8-8-90-0-i-2.5-2-10	245,11	25,4	72,39	53,05	10,0 db	1,00	1	1,00	320,77	183,94	448,8	1,40
97	8-8-90-0-i-2.5-2-8(1)	203,20	25,4	71,12	60,49	10,5 db	1,00	1	1,00	283,96	166,43	321,1	1,13
98	8-8-90-0-i-2.5sc-2tc-9‡	241,30	25,4	67,31	53,12	11,0 db	1,00	1	1,00	315,99	181,23	306,1	0,97
99	8-8-90-0-i-2.5sc-9tc-9	232,41	25,4	71,12	53,12	11,0 db	1,00	1	1,00	304,35	174,56	328,6	1,08
102	8-12-90-0-i-2.5-2-9	228,60	25,4	68,58	76,89	10,6 db	1,00	1	1,00	360,16	219,70	435,4	1,21
103	8-12-90-0-i-2.5-2-12.5	326,39	25,4	66,04	81,65	11,1 db	1,00	1	1,00	529,89	326,48	583,8	1,10
104	8-12-90-0-i-2.5-2-12	307,34	25,4	62,23	81,03	10,8 db	1,00	1	1,25	397,65	305,87	574,6	1,44
105	8-15-90-0-i-2.5-2-8.5	224,79	25,4	63,50	108,86	11,0 db	1,00	1	1,25	337,12	272,39	380,0	1,13
106	8-15-90-0-i-2.5-2-13	325,12	25,4	62,23	108,86	10,9 db	1,00	1	1,25	487,58	393,97	681,3	1,40
107	8-5-90-0-i-3.5-2-18	469,90	25,4	91,44	37,07	10,4 db	0,95	1	1,00	539,36	396,65	831,8	1,54
108	8-5-90-0-i-3.5-2-13	340,36	25,4	88,90	38,31	10,4 db	0,96	1	1,00	392,29	293,68	593,9	1,51
109	8-5-90-0-i-3.5-2-15(2)	387,35	25,4	88,90	35,69	10,5 db	0,94	1	1,00	442,35	318,81	765,0	1,73
110	8-5-90-0-i-3.5-2-15(1)	387,35	25,4	85,09	44,37	11,1 db	1,00	1	1,00	463,59	368,62	616,2	1,33
111	8-8-90-0-i-3.5-2-8(1)	198,12	25,4	92,71	54,50	10,0 db	1,00	1	1,00	262,79	216,24	382,4	1,46
112	8-8-90-0-i-3.5-2-10	248,92	25,4	96,52	53,05	10,0 db	1,00	1	1,00	325,76	266,85	484,6	1,49
113	8-8-90-0-i-3.5-2-8(2)	209,55	25,4	93,98	60,49	11,0 db	1,00	1	1,00	292,83	245,19	366,6	1,25
114	8-12-90-0-i-3.5-2-9	228,60	25,4	92,71	76,89	10,8 db	1,00	1	1,00	360,16	313,86	525,4	1,46
115	8-8-90-0-i-4-2-8	198,12	25,4	106,68	60,22	10,5 db	1,00	1	1,00	276,23	231,11	326,5	1,18
125	8-5-90-1#3-i-2.5-2-16	396,24	25,4	73,66	33,14	10,5 db	0,92	1	1,00	447,61	217,29	652,4	1,46
126	8-5-90-1#3-i-2.5-2-12.5	317,50	25,4	68,58	35,41	10,8 db	0,94	1	1,00	362,19	181,98	565,5	1,56
127	8-5-90-1#3-i-2.5-2-9.5	228,60	25,4	68,58	36,10	10,8 db	0,94	1	1,00	261,47	132,72	542,8	2,08
133	8-5-90-2#3-i-2.5-2-16	391,16	25,4	72,39	33,14	10,5 db	0,92	1	1,00	441,87	214,50	694,5	1,57
134	8-5-90-2#3-i-2.5-2-9.5	232,41	25,4	63,50	35,41	11,0 db	0,94	1	1,25	212,10	133,21	467,7	2,20
135	8-5-90-2#3-i-2.5-2-12.5	304,80	25,4	71,12	36,10	10,5 db	0,94	1	1,00	348,63	176,96	628,5	1,80
136	8-5-90-2#3-i-2.5-2-8.5	234,95	25,4	76,20	36,10	10,1 db	0,94	1	1,00	268,74	136,41	441,0	1,64
137	8-5-90-2#3-i-2.5-2-14	349,25	25,4	73,66	37,55	10,3 db	0,96	1	1,00	401,54	208,15	671,2	1,67
140	8-8-90-2#3-i-2.5-2-8	209,55	25,4	74,93	53,05	10,0 db	1,00	1	1,00	274,23	157,25	417,5	1,52
141	8-8-90-2#3-i-2.5-2-10	246,38	25,4	71,12	61,94	9,5 db	1,00	1	1,00	348,40	205,00	532,2	1,53
142	8-12-90-2#3-i-2.5-2-9	228,60	25,4	69,85	76,89	10,5 db	1,00	1	1,00	360,16	219,70	532,1	1,48
143	8-12-90-2#3-i-2.5-2-11	276,86	25,4	71,12	82,75	10,5 db	1,00	1	1,00	452,50	279,43	599,0	1,32
144	8-12-90-2#3vr-i-2.5-2-11	270,51	25,4	60,96	82,75	10,8 db	1,00	1	1,25	353,70	273,02	459,4	1,30
145	8-15-90-2#3-i-2.5-2-6	154,94	25,4	62,23	108,86	10,9 db	1,00	1	1,25	232,36	187,75	327,7	1,41
146	8-15-90-2#3-i-2.5-2-11	280,67	25,4	63,50	108,86	11,0 db	1,00	1	1,25	420,92	340,11	726,7	1,73
147	8-5-90-2#3-i-3.5-2-17	438,15	25,4	86,36	38,38	11,1 db	0,97	1	1,00	505,11	378,51	784,2	1,55
148	8-5-90-2#3-i-3.5-2-13	346,71	25,4	85,09	38,31	11,3 db	0,96	1	1,00	399,61	299,16	700,9	1,75
149	8-8-90-2#3-i-3.5-2-8	204,47	25,4	93,98	57,12	9,5 db	1,00	1	1,00	277,65	230,26	425,4	1,53
150	8-8-90-2#3-i-3.5-2-10	223,52	25,4	93,98	61,94	9,5 db	1,00	1	1,00	316,07	265,69	470,0	1,49
151	8-12-90-2#3-i-3.5-2-9	228,60	25,4	96,52	76,89	10,6 db	1,00	1	1,00	360,16	313,86	434,1	1,21
162	8-8-90-2#4-i-2.5-2-10	226,06	25,4	76,20	57,12	10,3 db	1,00	1	1,00	306,96	178,20	535,2	1,74
163	8-8-90-2#4-i-3.5-2-10	238,76	25,4	96,52	57,12	10,1 db	1,00	1	1,00	324,21	268,87	605,8	1,87
164	8-5-90-4#3-i-2.5-2-16	408,94	25,4	73,66	33,14	10,5 db	0,92	1	1,00	461,96	224,25	788,7	1,71
165	8-5-90-4#3-i-2.5-2-12.5	302,26	25,4	63,50	34,31	11,0 db	0,93	1	1,25	274,60	169,63	598,1	2,18
166	8-5-90-4#3-i-2.5-2-9.5	241,30	25,4	71,12	35,41	10,5 db	0,94	1	1,00	275,27	138,31	478,9	1,74
167	8-5-90-5#3-o-2.5-2-10a	264,16	25,4	66,04	36,31	10,9 db	0,95	1	1,25	241,90	153,95	473,2	1,96
168	8-5-90-5#3-o-2.5-2-10b	266,70	25,4	66,04	37,48	10,9 db	0,96	1	1,25	245,25	158,76	572,1	2,33
169	8-5-90-5#3-o-2.5-2-10c	276,86	25,4	66,04	38,93	10,9 db	0,97	1	1,25	255,77	169,02	606,1	2,37
170	8-8-90-5#3-o-2.5-2-8	215,90	25,4	71,12	59,46	10,3 db	1,00	1	1,25	239,30	174,81	505,7	2,11
171	8-8-90-5#3-o-3.5-2-8	200,66	25,4	88,90	60,70	10,5 db	1,00	1	1,25	224,71	235,32	479,3	2,13
172	8-8-90-5#3-o-4-2-8	210,82	25,4	106,68	60,22	11,0 db	1,00	1	1,25	235,15	245,92	340,8	1,45
173	8-5-90-5#3-i-2.5-2-10b	264,16	25,4	68,58	37,48	10,9 db	0,96	1	1,00	303,64	157,25	608,0	2,00
174	8-5-90-5#3-i-2.5-2-10c	266,70	25,4	63,50	38,93	11,0 db	0,97	1	1,25	246,39	162,82	600,4	2,44
175	8-5-90-5#3-i-2.5-2-15	393,70	25,4	66,04	33,42	10,9 db	0,92	1	1,00	445,31	217,09	640,0	1,44
176	8-5-90-5#3-i-2.5-2-13	345,44	25,4	60,96	38,31	11,3 db	0,96	1	1,25	318,52	208,64	718,4	2,26
177	8-5-90-5#3-i-2.5-2-12(1)	287,02	25,4	63,50	35,07	10,8 db	0,93	1	1,25	261,58	163,44	578,8	2,21
178	8-5-90-5#3-i-2.5-2-12	299,72	25,4	60,96	41,06	10,8 db	0,99	1	1,25	278,55	189,61	627,9	2,25
179	8-5-90-5#3-i-2.5-2-12(2)	309,88	25,4	66,04	36,10	10,0 db	0,94	1	1,00	354,44	179,91	623,3	1,76
180	8-5-90-5#3-i-2.5-2-8	193,04	25,4	71,12	36,10	10,0 db	0,94	1	1,00	220,80	112,08	414,1	1,88
181	8-5-90-5#3-i-2.5-2-10a	266,70	25,4	63,50	36,31	10,8 db	0,95	1	1,25	244,23	155,43	722,1	2,96

Table 3 – Bars, number 8.



179	8-5-90-5#3-i-2.5-2-12(2)	309,88	25,4	66,04	36,10	10,0 db	0,94	1	1,00	354,44	179,91	623,3	1,76
180	8-5-90-5#3-i-2.5-2-8	193,04	25,4	71,12	36,10	10,0 db	0,94	1	1,00	220,80	112,08	414,1	1,88
181	8-5-90-5#3-i-2.5-2-10a	266,70	25,4	63,50	36,31	10,8 db	0,95	1	1,25	244,23	155,43	722,1	2,96
184	8-8-90-5#3-i-2.5-2-8	185,42	25,4	71,12	57,12	9,5 db	1,00	1	1,00	251,78	146,16	438,4	1,74
185	8-8-90-5#3-i-2.5-2-9†	223,52	25,4	76,20	53,12	10,8 db	1,00	1	1,00	292,71	167,88	561,6	1,92
186	8-8-90-5#3-i-2.5-9-9†	231,14	25,4	66,04	53,12	11,0 db	1,00	1	1,00	302,68	173,60	552,1	1,82
189	8-12-90-5#3-i-2.5-2-9	228,60	25,4	66,04	76,89	10,5 db	1,00	1	1,00	360,16	219,70	564,7	1,57
190	8-12-90-5#3-i-2.5-2-10	238,76	25,4	60,96	81,30	10,9 db	1,00	1	1,25	309,44	238,16	562,8	1,82
191	8-12-90-5#3-i-2.5-2-12†	309,88	25,4	60,96	81,03	11,0 db	1,00	1	1,25	400,94	308,40	765,0	1,91
192	8-12-90-5#3vr-i-2.5-2-10	259,08	25,4	60,96	81,30	10,8 db	1,00	1	1,25	335,78	258,43	525,2	1,56
193	8-12-90-4#3vr-i-2.5-2-10	264,16	25,4	63,50	81,65	10,0 db	1,00	1	1,25	343,09	264,24	516,7	1,51
194	8-15-90-5#3-i-2.5-2-6	160,02	25,4	66,04	108,86	10,8 db	1,00	1	1,00	299,98	193,91	423,0	1,41
195	8-15-90-5#3-i-2.5-2-10	256,54	25,4	60,96	108,86	10,9 db	1,00	1	1,25	384,73	310,87	785,0	2,04
196	8-5-90-5#3-i-3.5-2-15	401,32	25,4	88,90	33,42	11,3 db	0,92	1	1,00	453,93	316,13	700,7	1,54
197	8-5-90-5#3-i-3.5-2-13	332,74	25,4	86,36	38,38	11,4 db	0,97	1	1,00	383,59	287,45	672,2	1,75
198	8-5-90-5#3-i-3.5-2-12(1)	317,50	25,4	88,90	35,07	10,8 db	0,93	1	1,00	361,69	258,29	666,6	1,84
199	8-5-90-5#3-i-3.5-2-12	307,34	25,4	86,36	44,37	10,8 db	1,00	1	1,00	367,83	292,48	690,3	1,88
200	8-8-90-5#3-i-3.5-2-8	203,20	25,4	91,44	54,50	9,9 db	1,00	1	1,00	269,52	221,78	486,7	1,81
201	8-12-90-5#3-i-3.5-2-9	228,60	25,4	83,82	76,89	10,5 db	1,00	1	1,00	360,16	313,86	591,6	1,64
207	8-5-90-4#4s-i-2.5-2-15	396,24	25,4	73,66	33,14	10,1 db	0,92	1	1,00	447,61	217,29	816,8	1,82
208	8-5-90-4#4s-i-2.5-2-12(1)	314,96	25,4	66,04	35,69	11,0 db	0,94	1	1,00	359,69	181,46	792,1	2,20
209	8-5-90-4#4s-i-2.5-2-12	312,42	25,4	66,04	42,79	10,5 db	1,00	1	1,00	367,17	203,13	870,0	2,37
210	8-5-90-4#4s-i-3.5-2-15	388,62	25,4	104,14	33,14	10,5 db	0,92	1	1,00	439,00	304,44	792,5	1,81
211	8-5-90-4#4s-i-3.5-2-12(1)	302,26	25,4	91,44	40,72	10,8 db	0,99	1	1,00	350,82	271,64	832,5	2,37
212	8-5-90-4#4s-i-3.5-2-12	312,42	25,4	91,44	41,06	10,0 db	0,99	1	1,00	362,94	282,35	856,1	2,36

Table 3 - Bars, number: 8 (continued).