International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:13, No:6, 2019

Analysis of the Influence of Reshoring on the Structural Behavior of Reinforced Concrete Beams

Keith Danila Aquino Neves, Júlia Borges dos Santos

Abstract**—**There is little published research about the influence of execution methods on structural behavior. Structural analysis is typically based on a constructed building, considering the actions of all forces under which it was designed. However, during construction, execution loads do not match those designed, and in some cases the loads begin to act when the concrete has not yet reached its maximum strength. Changes to structural element support conditions may occur, resulting in unforeseen alterations to the structure's behavior. Shoring is an example of a construction process that, if executed improperly, will directly influence the structural performance, and may result in unpredicted cracks and displacements. The NBR 14931/2004 standard, which guides the execution of reinforced concrete structures, mentions that shoring must be executed in a way that avoids unpredicted loads and that it may be removed after previous analysis of the structure's behavior by the professional responsible for the structure's design. Differences in structural behavior are reduced for small spans. It is important to qualify and quantify how the incorrect placement of shores can compromise a structure's safety. The results of this research allowed a more precise acknowledgment of the relationship between spans and loads, for which the influence of execution processes can be considerable, and reinforced that civil engineering practice must be performed with the presence of a qualified professional, respecting existing standards' guidelines.

Keywords**—**Structural analysis, structural behavior, reshoring, static scheme, reinforced concrete.

I. Introduction

CONVENTIONAL structural analysis of reinforced concrete buildings often does not consider the influence of construction processes in the design of structural projects. However, processes that occur during a building's execution can cause changes to the static scheme of its structural elements, generating specific loads for which those elements were not originally designed. In spite of this, there is little published research that evaluates a building execution's influence on the structure's behavior.

Vivacqua [2] verified in his studies the structural behavior of lower floors when upper floors are shored. For slabs with different dimensions, the construction cycles and levels were analyzed in order to verify their influence on structural elements and on the required amount of shoring. His results showed that quantity and positioning of shores modified slab bending moment reactions during the execution phase, and on slabs with smaller dimensions this influence had higher variations because less shoring was required.

Through numerical simulations that took into consideration the execution sequence of reshoring, formwork and concrete casting, Prado [3] studied the structural behavior of beams and slabs subject to execution forces. It was observed, from his results, that although the analysis performed on the beams generated significant bending moment variations when comparing execution to the designed behavior, the construction method sequence did not compromise safety. Highlighting that these variations were irrelevant in slabs, and although shear forces also changed, those had very high safety margins.

As per Medeiros [9], some contractors use the method of keeping an amount of shores on recently casted slabs or beam elements in order to minimize the effects of shoring removal. This procedure is known as reshoring and is defined by standard of [1] as a process to reduce initial loads and excessive deformation, provided that some guidance is followed. In addition, the ABNT NBR 15.696/2009 [5] standard establishes that reshoring designs must contain verification of the lower floor's load capacity when there is in different ages application of loads resulting from subsequent cast-in-place concrete; as well as verification of the upper floor's load capacity due to loads in different ages as a result of its lower level's shoring removal.

When not properly performed, this common practice can result in cracks (Fig. 1). Studies have shown that 70% of reinforced concrete structure failures are related to complications and errors during the execution phase, mostly due to excessive loads on shores and early removal of shoring and formwork systems [6].

The purpose of this research is to analyze how the use of non-designed reshoring can modify an element's support conditions and consequently change the necessary reinforcement values. Thus, the results of two distinct models were compared: one model considering the placement of reshoring during the construction phase and the other design model that does not predict the influence of construction processes.

II. Methodology

The purpose of this research is to perform numerical simulations based on practical situations. Therefore, the calculations were performed in the Brazilian commercial structural software TQS® Version 19.11.61.

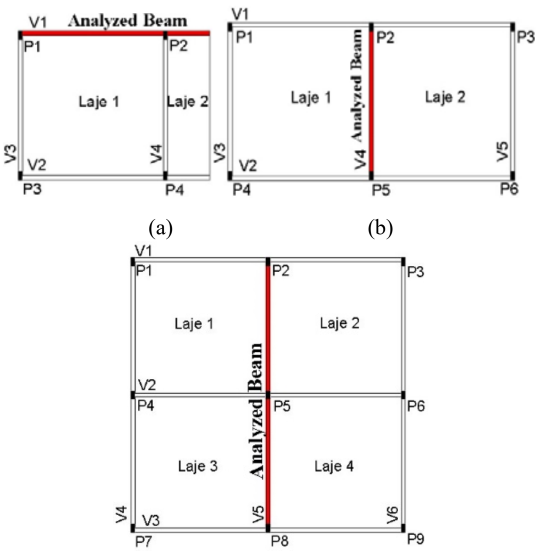
For the analysis of the beam's behavior, three models of buildings with two floors were considered. The influence of the placement of reshoring on the beam's structural behavior

Keith Danila A. Neves is with Goiás Federal Institute of Education, Science and Technology, Brazil (e-mail: kdanila@hotmail.com).
Júlia B. Santos is MSc. teacher of the Structural Engineering, Goiás Federal Institute of Education, Science and Technology, Brazil (e-mail: julia.santos@ifg.edu.br).

was analyzed assuming the most critical reshoring position for each model.

(a) (b)

Fig. 1 (a) Incorrect use of reshoring, (b) Crack resulting from negative bending moment due to shoring misplacement [4]



(c)

Fig. 2 (a) Model #1: V1 beam reshoring analysis, (b) Model #2: V4 beam reshoring analysis, (c) Model #3: V5 beam reshoring analysis

In Model #1 reshoring was analyzed on a beam with two supports and one free end, by placing it both at the beam's midspan between the supports and at the end of its overhanging member, as illustrated in Fig. 2 (a). In Model #2, the influence of reshoring was analyzed on a beam with two supports by placing it at the beam's midspan, as illustrated in Fig. 2 (b). As for Model #3, reshoring was analyzed on a continuous beam with two spans by placing it simultaneously in the middle of each span, as illustrated in Fig. 2 (c). It is worth noting that the computer program will determine the forces considering the structure as a single frame and not as isolated beams. Therefore, the models were chosen in order to try to replicate different structural behaviors.

The beam spans were varied in each model in order to compare data and evaluate if there is a critical span for reshoring's influence, as per defined variables. The beam spans for each model and their terminology are presented in Table I.

For each model and span value, the results were analyzed in two different situations: one design model and one execution model, each with reshoring and its position depending on each model.

The design models were calculated considering a concrete compressive strength of 25 MPa and environmental aggressiveness class II. First, this model was calculated and verified, respecting standards' requirements. The slabs were 10 cm high, with a live load of 0,5 kN/m² for the upper (roof) slab and 1,5 kN/m² for the lower (floor) slab, as per ABNT NBR 6120/1980 [7] guidelines. The beams were 14 cm wide, with pre-dimensioned heights equal to 10% of the span's length, which were later verified. Loads of ceramic brick masonry were added to the beams.

For the execution model, the same geometric conditions were considered for the structural elements to simulate how the design model would be constructed, but with different live loads and concrete compressive strength values. It is recurrently observed on construction sites that shoring removal is done as early as possible, due to execution's schedule prioritization. Therefore, in order to consider an execution model as close to reality as possible and considering the absence of specific values in current standards, it was considered that the remaining shoring would be inserted 14 days after concrete casting, immediately after the removal of the lower formwork and shoring.

Reference [5] establishes that in shore withdrawal a minimum removal (or relocation) cycle of 14 days should be considered. Thus, as the concrete has not yet reached its designed compressive strength, the slab and beam compressive strength was considered as 20 MPa. This corresponds to approximately 90% of the compressive strength value expected at 28 days with reference to CP II concrete strength gaining curve, as per NBR 6118/2018 [8] standard item 12.3.3.

Reference [5] also presents recommendations regarding structural dimensioning of shores, reshores or remaining shores, indicating a minimum working live load of 2,0 kN/m² during concrete placement, consolidation and finishing. Hence, this value was used as the live load in order to consider the loads that result from the floor slabs' execution stage, added to its self-weight.

The analysis elements of this study are the beams of a standard floor plate. Considering execution sequence, the situation considered for analysis was the condition when the lower floor has already been completed and the upper floor is in execution. Thus, since the upper floor would be anchored, the self-weight of this floor's slabs and beams was disregarded. In order to simulate reshoring, eucalyptus posts with a diameter equal to 15 cm with beam roller supports were considered, aiming to simulate the beam's support condition during execution.

TABLE I
DIMENSIONS AND TERMINOLOGY DEFINED FOR EACH MODEL

Model 1		Models 2 and 3		
V1 Overhang Size (m)	Model	V4 and V5 Span size (m)	Model	Model
1	1-1	4	2-1	3-1
1,5	1-2	5	2-2	3-2
2	1-3	6	2-3	3-3
2,5	1-4	7	2-4	3-4
-	-	8	2-5	3-5

III. RESULTS

For better interpretation of the results, it is worth mentioning that the program simulates a structural frame subject to wind loads, the structure's overall weight and potential live loads. The forces obtained (bending moments, torsion, shear and axial forces) are transferred as envelopes of several loads, and then dimensioning and detailing of the structural elements are performed. Graphic results are presented for Model 1-1, Model 1-4, Model 2-1, Model 2-5, Model 3-1 and Model 3-5 only. As for the other results, they are described in the following text.

For the buildings in Model #1, the obtained results of reshoring's influence on beam bending moments for 1,0 m, 1,5 m, 2,0 m and 2,5 m overhangs are depicted in Figs. 3 and 4, respectively. The values of the longitudinal reinforcement bars are presented in Figs. 5 and 6. The points used as references for the analysis as well as the presentation of the results are schematically illustrated in the graphics.

The results for Model #1 show that for all cases, reshoring placement at the end of the beam's overhang resulted in a positive bending moment at point F that did not exist in the design model. In addition, the negative bending moment at point E reduced. On the other hand, placing the shores at the midspan between the supports caused a negative bending moment at A, and at point C a positive bending moment in the design model was inverted to a negative bending moment in the execution model.

For the 1,0 m overhang, the bending moment varied by 519,9 tf.cm at point C. For the 1,5 m overhang, the variation was 479,3 tf.cm. As for the 2,0 m overhang, the variation was 430,5 tf.cm, and for the 2,5 m overhang it was 368,6 tf.cm. In the execution models, the negative bending moment at point C decreased as the overhang distance increased. Conversely, the positive bending moment increased as the overhanging dimension increased, reaching 22 tf.cm for a 2,5 m overhang.

For all overhang sizes, the reinforcement bar needed at point C due to reshoring was four times bigger than designed. As for the span's positive reinforcement bars, while the bending moments were small, reinforcement bar values were not altered. At points B, D and E the values of rebars reduced in the execution model due to the reduction of bending moments (in Model #1).

For the buildings in Model #2, the points A, B, C, D and E were analyzed. The obtained results are depicted in Figs. 7, 8 and 10. Reshores at the midspan resulted in a negative bending moment, which increased as the span dimension grew. Variations in bending moments were the same for the 4,0 m, 5,0 m, 6,0 m, 7,0 and 8,0 m span models, with variations of 389,72 tf.cm, 777,27 tf.cm, 1882,40 tf.cm and 2492,69 tf.cm, respectively. In the other points, there was a reduction of the bending moment values compared to the design model.

In all execution model cases, the high bending moment variations at point C caused the required amount of negative rebar at this point to be significantly higher than initially designed. The quantities increased by 300%, 500%, 278%, 294% and 404% for 4,0 m, 5,0 m, 6,0 m, 7,0 m and 8,0 m spans, respectively.

For the buildings in Model #3, since the V5 beam is symmetrical, only points A, B, C, D and E were analyzed. The results obtained are depicted in Figs. 11-14.

Model #3's structural behavior was similar to that of Model #2, due to reshoring at the midspan. Reshoring at the midspan caused a negative moment, which increased as span size grew. For the 4,0 m, 5,0 m, 6,0 m, 7,0 m and 8,0 m spans, bending moment variations were equal to 296,99 tf.cm, 564,04 tf.cm, 949,88 tf.cm 1427,08 tf.cm and 1876,92 tf.cm, respectively. At the other locations, bending moments decreased when compared with the design model.

The high variations in the bending moments at point C for 5,0 m, 6,0 m, 7,0 m and 8,0 m spans resulted in more negative reinforcement at this location than initially designed. For the 4,0 m span, at point C, the initial dimensioning indicated a lap splice on the negative reinforcement bar, taking into account that its initial forces did not result in negative bending moment. Lap rebars in this span would then resist the negative bending moments caused by reshoring's presence. In the other cases, the increases compared to the design model were 500%, 500%, 525% and 495% for the 4,0 m, 5,0 m, 6,0 m, 7,0 m e 8,0 m spans, respectively.

As for shear forces in Model #1 points 'C' and 'E', the presence of reshoring resulted in forces that did not exist in the designed model. Alternatively, the presence of reshoring at points 'A' and 'E' decreased the shear forces. For Model #2 and Model #3, reshoring reduced shear forces at points 'A' and 'D', and at point 'C' it caused a shear force that was not designed for. Despite unpredicted shear forces, in all analyzed cases the transverse rebars were sufficient to absorb the generated forces.

IV. CONCLUSION

The results obtained in this research, in relation to the beam's load distribution, were as expected. That is, reshores at the overhanging part of the beam caused a positive bending moment which did not exist in the design, but reduced the negative bending moment at the overhang's column. On the bi-supported beams, reshores on the span caused a negative bending moment that did not exist in the design, but reduced the spans positive bending moment values.

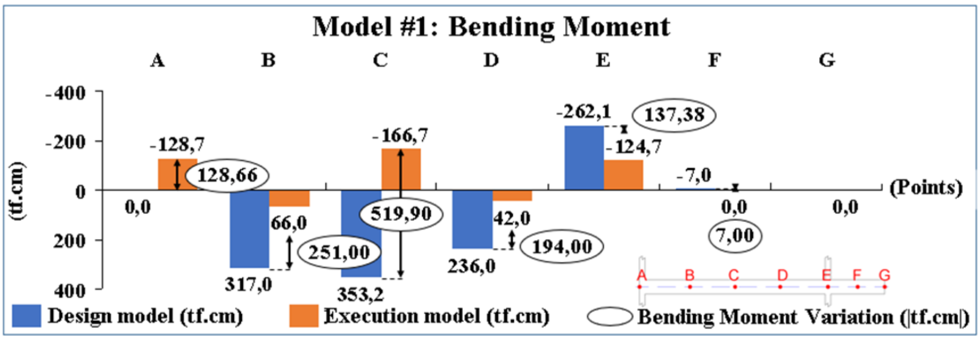


Fig. 3 Model #1 – Bending Moment at each point of the beam with 1,0 m overhang

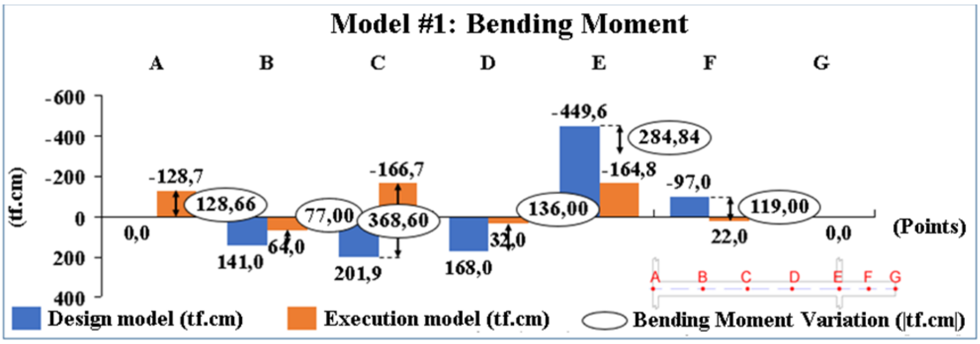


Fig. 4 Model #1 – Bending Moment at each point of the beam with 2,5 m overhang

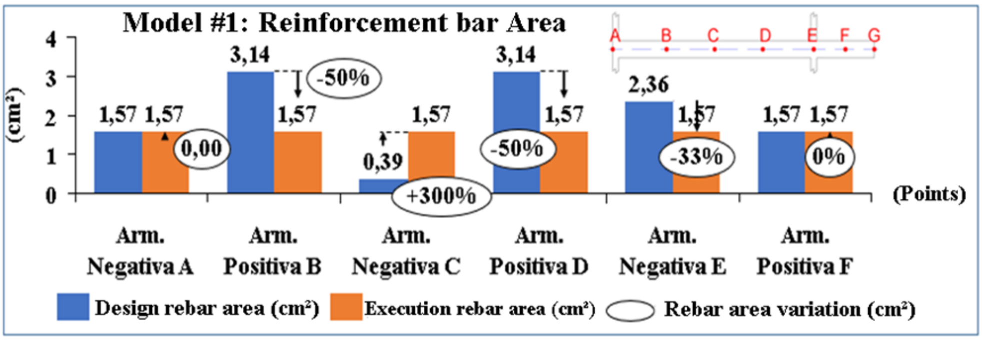


Fig. 5 Model #1 – Reinforcement bar area at each point of the beam with 1,0 m overhang

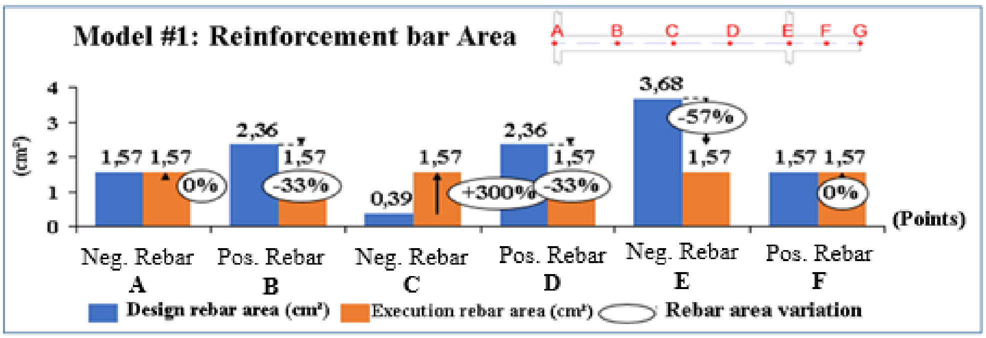


Fig. 6 Model #1 – Reinforcement bar area at each point of the beam with 2,5 overhang

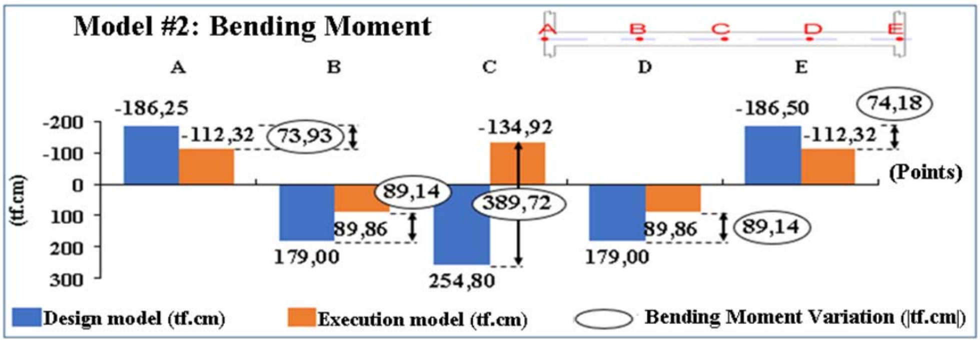


Fig. 7 Model #2 – Bending Moment at each point of the bi-supported beam with 4,0 m span

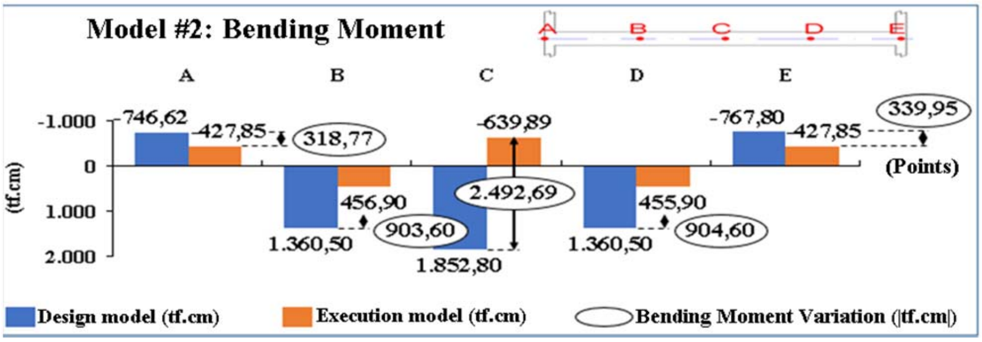


Fig. 8 Model #2 – Bending Moment at each point of the bi-supported beam with 8,0 m span

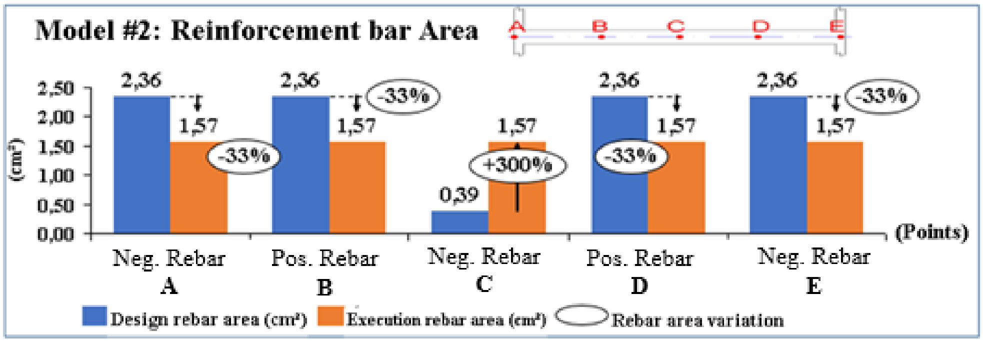


Fig. 9 Model #2 – Reinforcement bar area at each point of the bi-supported beam with 4,0 m span

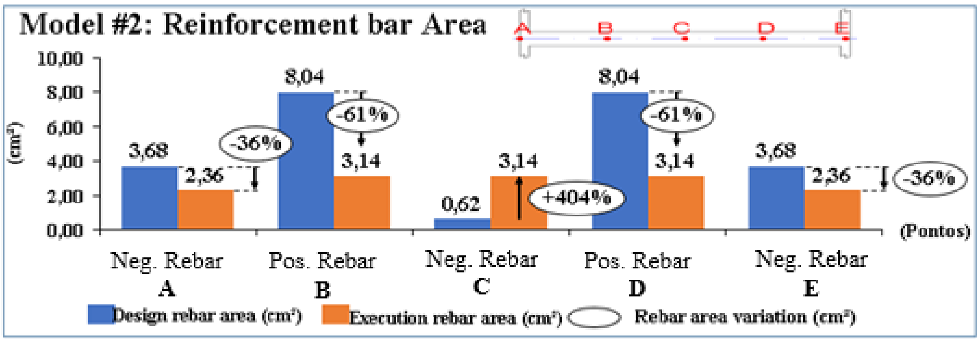


Fig. 10 Model #2 – Reinforcement bar area at each point of the bi-supported beam with 8,0 m span

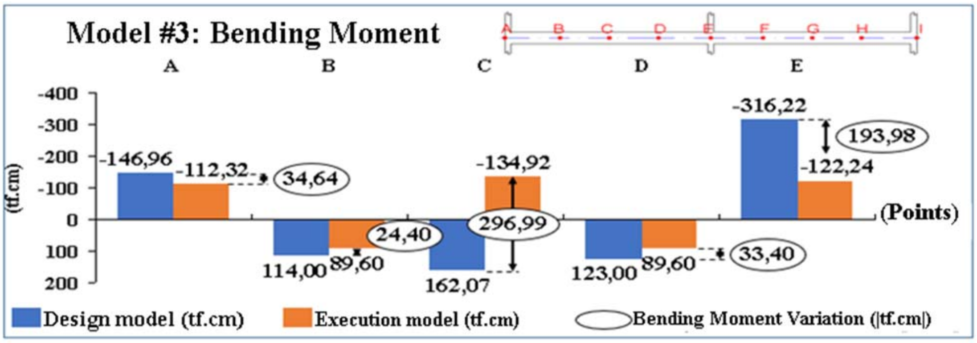


Fig. 11 Model #3 – Bending Moment at each point of a continuous beam with 4,0 m span

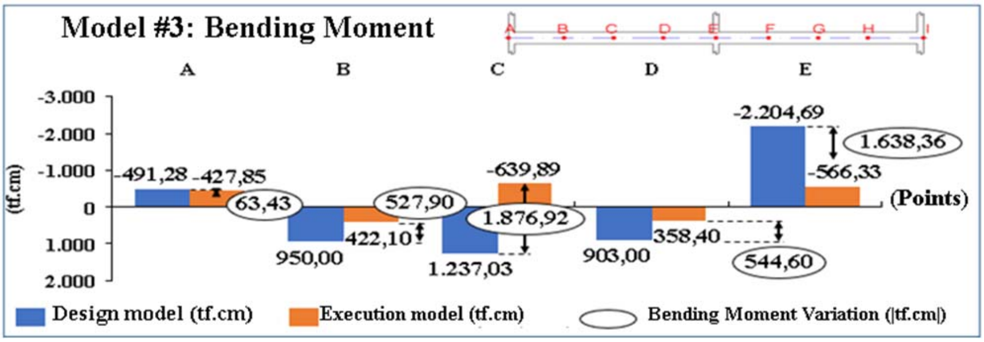


Fig. 12 Model #3 – Bending Moment at each point of a continuous beam with 8,0 m span

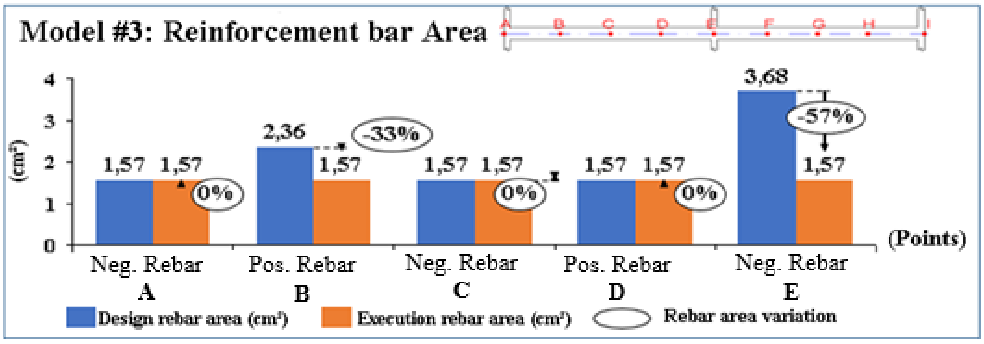


Fig. 13 Model #3 – Reinforcement bar area at each point of a continuous beam with 4,0 m span

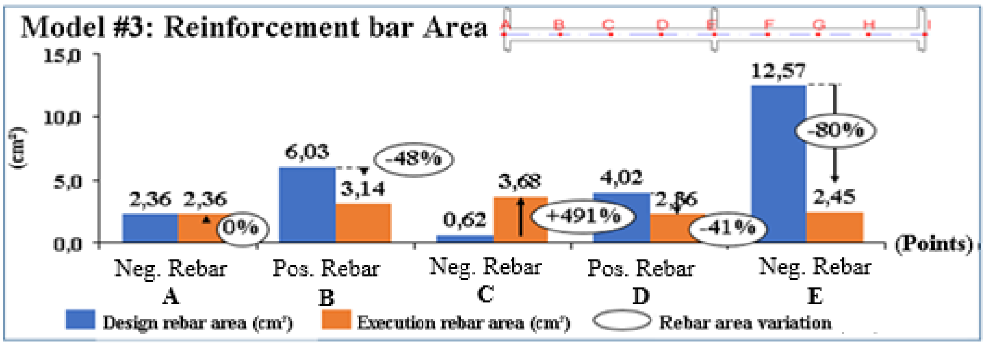


Fig. 14 Model #3 – Reinforcement bar area at each point of a continuous beam with 8,0 m span

In Model #1, while in the design model there was only the negative bending moment on the overhang, reshores caused positive bending moments that increased as the overhang dimension also increased. In spite of that, the existing positive rebar was sufficient to absorb the bending moments generated in all cases. It was noted that the overhang size would need to be much larger than 2,5 m in order to generate a critical positive bending moment that would require more reinforcement than the design required. Therefore, it is concluded that safety will not be at risk regarding conventional overhangs, if reshores are unexpectedly placed at the end of the overhang.

In Model #2 and Model #3 reshores at the middle of the span caused alarming bending moments, with values that increased as the beam span size increased. Hence, for all analyzed cases, the designed negative rebar was insufficient to absorb such forces, and there were cases that the necessary reinforcement with reshores present was four times higher than design required.

When comparing Model #2 and Model #3 results, the negative bending moments caused by reshores were very similar in both models. However, bending moment variations were higher for Model #2 (bi-supported beam), since the central column's presence in Model #3 caused lower positive bending moments.

The reshoring models' results took into consideration that reshores would be used 14 days after concrete casting. However, practices are often known to use them too soon, when concrete's strength is low, which can cause results even more critical than those obtained in this work.

The unpredicted use of reshores had significant influence on the structural behavior of all analyzed beams. The results showed that construction reinforcement proved inadequate to resist the unpredicted forces caused by reshoring. It is concluded that reshoring analysis throughout a structure's execution should be conducted by a structural engineer.

References

[1] Associação Brasileira de Normas Técnicas. NBR 14931: Execução de estruturas de concreto – Procedimento. Rio de Janeiro, 2004.

[2] Vivacqua, M. Análise do efeito do escoramento de um pavimento superior sobre os inferiores, para lajes em concreto armado moldado "in loco". Thesis (Master of Civil Engineering) - Federal University of Espírito Santo, 92p. Vitória. 2009. Tese (Mestrado em Engenharia Civil) – Universidade Federal do Espírito Santo, 92p. Vitória, 2009.

[3] Prado, José Fernão Miranda de Almeida. Estruturas de Edifícios em Concreto Armado Submetidas a Ações de Construção. Thesis (Doctor of Structural Engineering) - Engineering School of São Carlos, University of São Paulo, 201p. São Paulo, 1999 Tese (Doutorado em Engenharia de Estruturas) – Escola de Engenharia de São Carlos, Universidade de São Paulo, 201p. São Paulo, 1999.

[4] Ieira, G. L. Influência da microfissuração causada por carregamento precoce nas propriedades mecânicas de concreto produzidos com diferentes tipos de cimento. Thesis (Doctor of Engineering) - Post graduation in Civil Engineering, 189p. Porto Alegre, 2008. Tese (Doutorado em Engenharia) – Programa de PósGraduação em Engenharia Civil, 189p. Porto Alegre, 2008.

[5] Associação Brasileira de Normas Técnicas. NBR 15696: Fôrmas e escoramentos para estruturas de concreto — Projeto, dimensionamento e procedimentos executivos. Rio de Janeiro, 2009.

[6] Simavorian, David. Análise do efeito do escoramento no comportamento de lajes de betão armado. Thesis (Master of Civil Engineer) - Technical Lisbon, 193p. 2015 Tese (Mestrado em Engenharia Civil) – Técnico Lisboa, 193p. 2015.

[7] Associação Brasileira de Normas Técnicas. NBR 6120: Cargas para cálculo de estruturas de edificações. Rio de Janeiro, 1980.

[8] Associação Brasileira de Normas Técnicas. NBR 6118: Projeto de estruturas de concreto – Procedimento. Rio de Janeiro, 2014.

[9] Medeiros, H. Alerta! Deformações excessivas. Disponível em <http://techne17.pini.com.br/engenharia-civil/97/artigo287361-1.aspx>. 2005 Access in May of 2019.