SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I4P101

Volume 11 Issue 4, 1-7, April 2024

Original Article

Modeling the Effect of Hole Diameter on Axial Capacity Columns Using ANSYS Software

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Received: 01 February 2024 Revised: 12 March 2024 Accepted: 07 April 2024 Published: 30 April 2024

Abstract - *The aesthetic demands from the architectural perspective in a building are often used as the main reason for installing drainage pipes or mechanical and electrical installations inside columns. Installing pipes on columns can cause a reduction in the cross-section area of the columns. SNI 2847-2013 code in article 6.3.4, the placement of channels or pipes inside columns is explained to be allowed, provided it does not exceed 4% of the cross-section area of the column. However, in practice in the field, the cross-section area of the installed pipes exceeds the limit set in the existing regulations. The purpose of the research is to determine the effect of hole diameter in columns on axial capacity. In this study, modeling of a column without and with variations of holes has been conducted using ANSYS Software. For perforated columns, there are 3 hole sizes: 1.5", 2", and 3" in diameter. The column cross-section size is 250 mm x 250 mm with a longitudinal reinforcement area of 1.3% and a length of 4 m. The analysis results show that the larger the diameter of the holes in the column cross-section, the lower the axial capacity. The reduction in axial capacity for perforated columns of 1.5", 2", and 3" is 2.27%, 3.42%, and 7.73%, respectively, compared to columns without holes.*

Keywords - *Column, Holes diameter, Axial capacity, ANSYS Software.*

1. Introduction

Columns are part of the building frame and occupy the most important position in the structural system of the building. If a column fails, it can result in the collapse of other related structural components or even the complete collapse of the entire building structure [1]. According to the Indonesian National Standard (SNI) 2847:2019 code, a column is a structural element whose function is to support vertical and horizontal loads from the building above it and then distribute these loads to the foundation [2]. Columns are usually made of reinforced concrete or reinforcing steel and have a cylindrical or square shape. In construction activities, columns are usually used to distribute building utility needs such as drainage pipes, mechanical and electrical installations, and other types of pipes installed in columns (see Figure 1) [3,4,5,6].

In SNI 2847-2019 code article 6.3.4, it has been explained that the placement of pipes in columns is permitted provided that they do not more than 4% of the cross-section area of the column, which is necessary for strength or protection against fire [2]. However, in practice in the field, the cross section area of the pipe exceeds the limits set in existing regulations. Adding pipes to columns without planning and not following regulations can result in the collapse of the building structure due to the column's inability to support the load.

Fig. 1 Column with drainage pipes

A few studies have been carried out; it was found that installing pipes in columns causes the axial capacity of the column. Bakhteri et al. [7] showed that using drain pipes inside columns not only reduces the load-carrying capacity of the columns but also poses several risks to the building's safety. An experimental study has been carried out by Bakhteri and Iskandar [8], where the impact of PVC pipe inside reinforced concrete columns in multi-story buildings significantly decreases the load capacity of columns. The experiment's findings suggested that the design of the column with the integrated drain pipe and the columns' strength should be regarded as half of their value. This study also suggests an alternative solution: instead of placing PVC pipe in the centre of the column's cross-section, use coated steel pipe. The strength of concrete columns with cross-section holes was assessed by Kassim and Ahmad [9]. The test results indicate that altering the diameter of the hole within the cross-section area has a major and significant impact on the load capacity; for example, a reduction of 5 and 1.8% in the cross-section area resulted in a decrease of 20 and 10% in the bearing strength capacity, respectively. While the distance between the connections has an insignificant effect on the outcomes, increasing the concrete compressive strength and reinforcement ratio does not demonstrate a significant impact.

Previous researchers did a numerical analysis. Using LUSAS software, Basravi [10] examined the impact of hole placement along short-braced columns made of reinforced concrete in multi-story buildings. The final strengths of the columns found in this investigation are contrasted with the findings of the laboratory testing of the identical columns and with the suggested design strengths. In summary, the analytical results demonstrated a considerable decrease in their load-carrying capacities, and the safety factors obtained were significantly lower than the nominal number often advised by several codes of practice. Meanwhile, Suku and Je [3] used ABAQUS software to model and analyse the impact of holes in reinforced concrete column structures. The outcome demonstrated that the model predictions for the maximum load, displacement, and crack pattern closely matched the experimental findings. According to the investigation, the frame strength was decreased by 5.43% until 15.56% for hole sizes ranging from 2% until 12% of the column cross-section area.

Additionally, when the hole was positioned 5 mm and 10 mm eccentric to the centre of the column cross-section area, the frame strength was decreased by 2.77% and 6.14%, respectively. When holes in the column have a ratio of 2% to 12% to the cross-section area of the column, the displacement of the frame also drops by 59.63% to 74.60%. The presence of eccentric holes in the column decreased the strength, displacement, and ductility of the frame structure.

With the purpose of validating full-scale experimental results, Negassa [11] carried out a numerical study of reinforced concrete columns with transverse holes using a Nonlinear Finite Element Analysis (NLFEA) ANSYS software program. The findings demonstrate that a linear estimation was made for the impact of a hole whose diameter was less than or equal to one-third of the column's breadth. Additionally, it was shown that a square-shaped hole reduces capacity by 5.69% more than a circular opening and that the horizontal opening position affects load-carrying capacity more than the vertical opening position.

Kwarteng et al. carried out the latest numerical investigation [12]. With the goal of thoroughly analysing their performance, this study examined the behaviour of square reinforced concrete-columns with embedded PVC pipes. The study addressed the dearth of noteworthy studies comparing hollow columns to embedded PVC pipes in terms of their effects and contributions to structural performance. The ABAQUS CEA 2020 program was utilized for numerical analysis in order to simulate the behaviour of embedded reinforced concrete columns. Overall, these results demonstrate that improved load-bearing capability is achieved with smaller implanted PVC pipe sizes. The study suggested that while implementing PVC-embedded columns, great attention should be paid to material composition and structural design. PVC pipe sizes should also be carefully chosen in accordance with project specifications and structural requirements.

The literature study above indicates that there is currently little numerical research done with ANSYS software to examine the impact of holes in reinforced concrete columns. As a result, it is crucial to use ANSYS software to conduct this numerical research. This study aims to ascertain how column hole diameter affects axial capacity.

2. Analysis Centric Column

A centric column is a type of column in a building that receives an axial load cantered on the geometric axis of the column. This axial load is parallel to the geometric axis of the column so that the column experiences pressure uniformly throughout its cross-section. A centric column has a uniform or equal cross-section at every point in its height.

According to the SNI 2847-2019, the formula for finding the maximum axial capacity of reinforced concrete columns in non-prestressed structural components with the number of ties (stirrups) [2]:

$$P_{n\,(max)} = 0.8\{0.85f'_c(A_g\text{-}A_{st})+f_yA_{st}\} \tag{1}$$

Because it uses calculations on a simulation scale, the use of reduction factors is ignored, so the formula becomes,

$$P_{n(max)} = 0.85(A_g\text{-}A_{st})+f_yA_{st} \tag{2}$$

Where:

A_g: gross cross section area,

A_{st}: area of longitudinal the reinforcement,

f'_c: concrete compressive strength,

f_y: yield strength of the reinforcement.

Because in this research, a simulation will be carried out using hole columns with longitudinal reinforcement (see Figure 2), Equation (2) is modified to calculate the axial capacity of hollow columns using the following equation:

$$P_{n(max)} = 0.85(A_g\text{-}A_{st}\text{-}A_h)+f_yA_{st} \quad (3)$$

With: A_h: cross-section area of the hole.

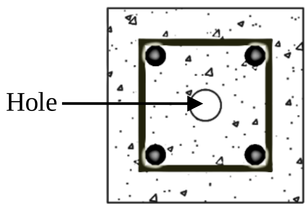

Fig. 2 Cross section of hollow column

3. Finite Element Modeling

Finite Element Modeling (FEM) is an approach to modeling a structure by dividing the original specimen into finite small elements, enabling the analysis of the structure to yield highly precise results. Among the limited number of commercially available software capable of addressing FEM problems, ANSYS software has been selected to fulfill the objectives of this study. The modeling and analysis of reinforced concrete columns are conducted using this tool [12].

3.1. Model Geometry

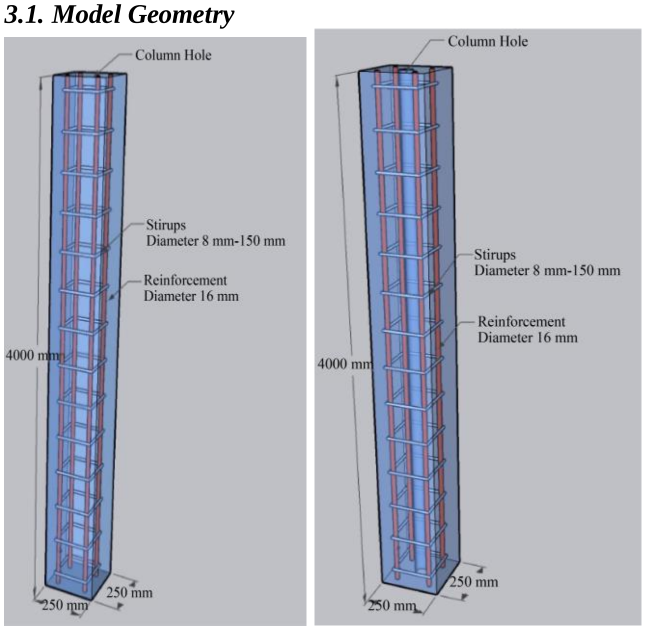

Fig. 3 The geometry of the column

The RC columns are full-scale and have a similar cross-section with dimensions of 250 mm by 250 mm and a height of 4000 mm, using 4 longitudinal reinforcements with a diameter of 16 mm and stirrups diameter of 8 mm with spacing of 150 mm. Detail the geometry of the column shown in Figure 3.

3.2. Material Properties

3.2.1. Concrete Material Assumptions

Concrete exhibits different behaviour in compression and tension, making it a quasi brittle material. The tensile strength of concrete ranges from 8% to 15% of the compressive strength, while a Poisson's ratio (ν) is commonly assumed for concrete 0.2. The concrete was modelled using SOLID65, an eight-node solid element. This element features eight nodes, each with three degrees of freedom [13-17]. The Input material properties of concrete are shown in Table 1.

3.2.2. Reinforcement Material Assumption

The properties, such as elastic modulus and yield stress, for the steel reinforcement employed in this Finite Element Method (FEM) analysis, are in line with the material properties specified for the experimental investigation. For the finite element models, the steel is assumed to behave as an elastic-perfectly plastic material, exhibiting identical behaviour in tension and compression. A Poisson's ratio of 0.3 was assigned to the steel reinforcement in this study.

The steel bar reinforcement is conceptualized as an axial rod element using the Spar Link Element (LINK8) discrete engineering model, which mimics the original characteristics but acts as a linear reinforcement [13-17]. This element features 2 points with 3 degrees of freedom at any given point in the x, y, and z directions, allowing for plastic deformation. It is assumed that the reinforcement can solely transmit axial forces and a perfect bond between the concrete and the reinforcing bars is presupposed. To establish this perfect bond, the link element for the steel reinforcing bar is connected between nodes of each adjacent concrete solid element, thereby ensuring that both materials share identical nodes. The stress-strain relationship model utilized for steel is the bilinear isotropic hardening model. The input material of steel reinforcement (LINK8) is shown in Table 2.

Table 1. Input material of concrete (SOLID65)

No	Properties	Value	Unit
1	Young modulus	21019	MPa
2	Poisson Rassio	0.2	
3	Bulk Modulus	11677	MPa
4	Shear Modulus	8757.9	MPa
5	Uniaxial Compressive Strength	20	MPa
6	Uniaxial Tensile Strength	1.5	MPa
7	Biaxial Compressive Strength	23	MPa

Table 2. Input material of steel reinforcement (LINK8)

No	Properties	Value	Unit
1	Young modulus	21019	MPa
2	Poisson Rassio	0.2	
3	Bulk Modulus	11677	MPa
4	Shear Modulus	8757.9	MPa
5	Yield Strength	240	MPa
6	Tangent Modulus	6500	MPa

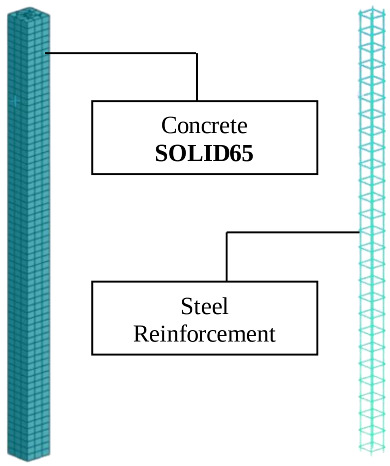

Fig. 4 Element types of ANSYS modeling

3.3. Boundary Condition and Loading

The boundary conditions of the column model are roller at the top and fixed support at the bottom. The axial loading was applied on the top surface of the column. The load application was conducted in a time-controlled manner through load steps. ANSYS will incrementally increase the load until reaching the final load value within a total duration of 1 second (at the end of the load step). The Boundary condition and loading are shown in Figure 5.

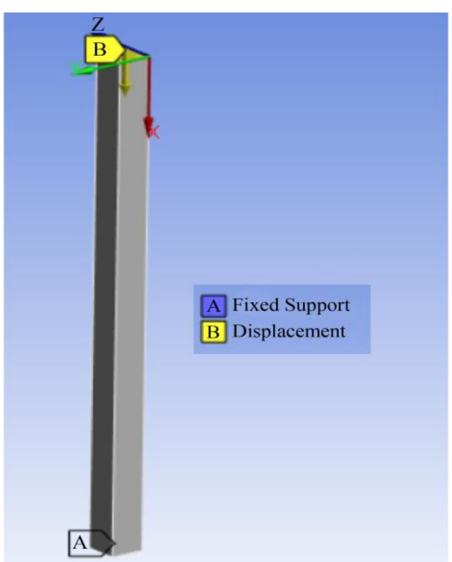

Fig. 5 Boundary condition of the column model

4. Results and Discussion

4.1. Axial Capacity of Column

The axial capacity that occurs in columns with different hole variations and the relationship between the percentage of hole area and the reduction in axial capacity can be seen in Figures 6 and 7.

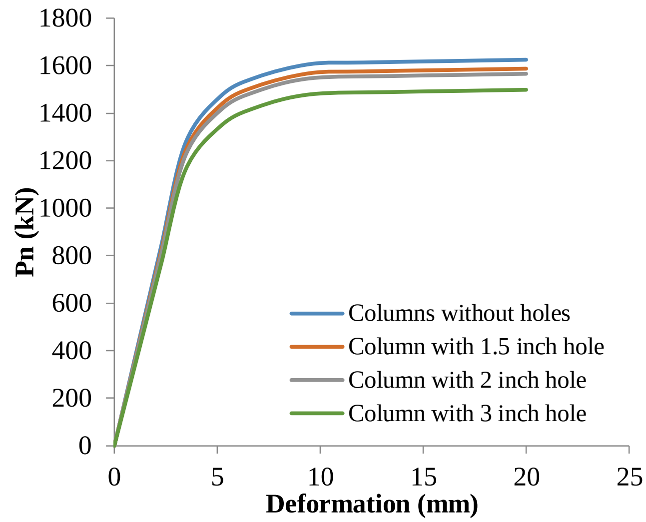

Fig. 6 The axial capacity of columns without and with holes

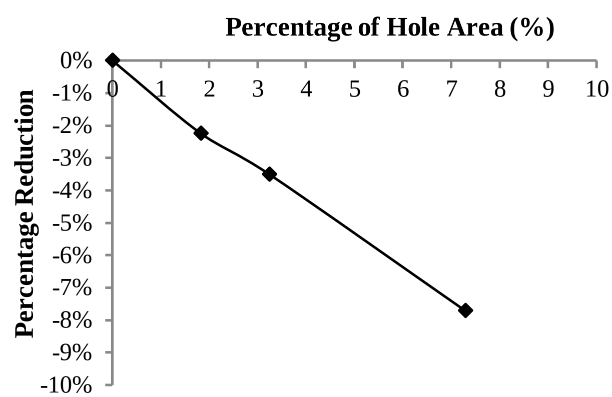

Fig. 7 Relationship between the percentage of hole area and the reduction in axial capacity

Figure 6 shows that the maximum axial capacity of the column obtained from the ANSYS software simulation with variations of a column without holes and column with holes diameters 1.5”, 2” and 3” are 1624.3kN, 1587.4kN, 1568.8kN, and 1498.8kN respectively. Meanwhile, Figure 7 it is shown that the percentage of holes used in this modeling for pipe diameters of 1.5", 2" and 3" are 1.82%, 3.24% and 7.29% respectively. The pipe hole diameter is designed to simulate conditions in the field (see Figure 1) as well as to validate the maximum limit of 4% SNI code [2]. From this figure, it can be explained that the use of 1.5", 2" and 3" pipes reduces the axial capacity of the column. The reduction in axial capacity for 1.5", 2" and 3" pipes is 2.27%, 3.42%, and 7.73% respectively.

4.2. Comparison Analytical and Modeling

According to the SNI code, column axial capacity analysis is calculated using Equation (2) for solid columns and (3) for perforated columns. Comparison of analysis and modeling results is shown in Table 3 and Figure 7 below.

Table 3. Column axial capacity analytical and modeling

Column Hole Diameter (")	$P_{n\ Analytical}$ (kN)	$P_{n\ Modeling}$ (kN)	Error Percentage
0	1370.37	1624.30	15.63%
1.5	1339.62	1587.40	15.61%
2	1322.33	1566.90	15.61%
3	1264.66	1498.80	15.62%

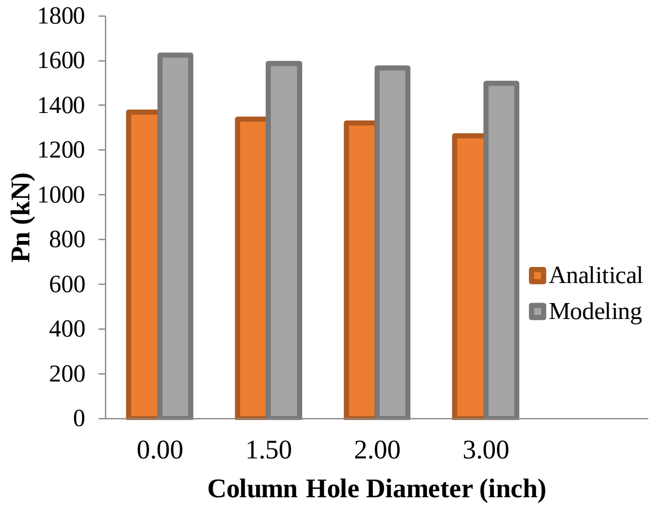

Fig. 8 Comparison diagram of analytical and modeling axial capacity of column

From Table 3 and Figure 8 above, it can be seen that there are differences in the results of the column axial capacity, which was calculated using analytical and modeling. This difference is due to the possibility of error, about 15.6% for columns without holes and perforated columns.

The modeling axial capacity results are higher when compared to the analytical. If the analytical results are used as a reference, the analytical to model axial capacity ratio is around 0.84 for columns without holes and perforated columns. This ratio is close to the reduction factor given in Equation (1) [2].

4.3. Stress Distribution

Stress is a measure of the intensity of force or reaction within that appears per unit area. A normal stress is considered positive if it induces tension and considered negative if it induces compression. The stress distribution of columns without holes and perforated columns with diameters 1.5", 2" and 3" is shown in Figures 9, 10, 11, and 12, respectively.

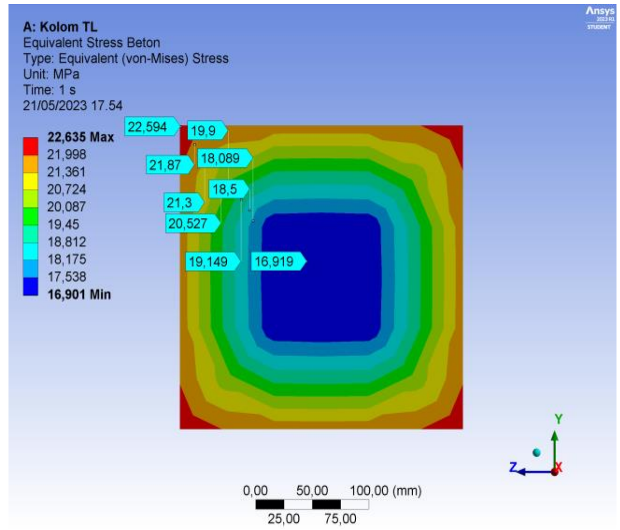

Fig. 9 Columns without hole

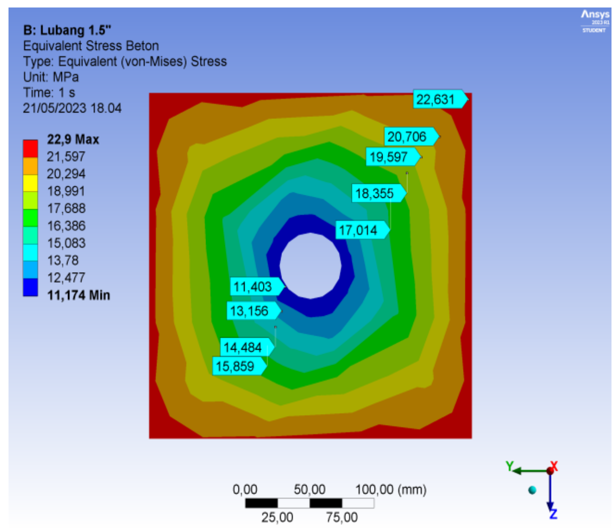

Fig. 10 Column with hole diameter 1.5"

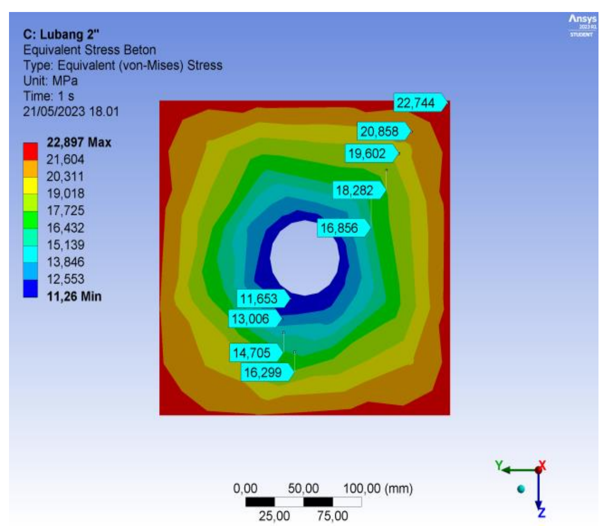

Fig. 11 Column with hole diameter 2"

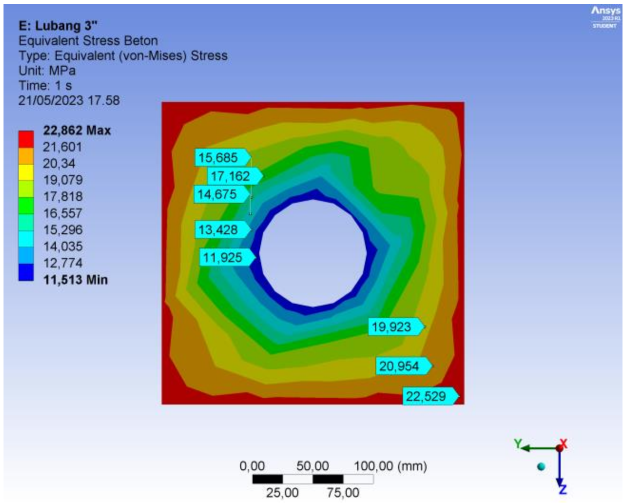

Fig. 12 Column with hole diameter 3"

From the images above, it can be seen that compressive stress occurs in the cross-section of the column (positive mark). The maximum compressive stress occurs at the column support, which is indicated by the red contour. The column is considered to have failed because the stress exceeds the uniaxial compressive strength of concrete 20MPa (see Table 1).

The concrete stress values in columns without holes and with holes with a diameter of 1.5", 2", and 3" are 22.64MPa, 22.90MPa, 22.86MPa and 22.897MPa, respectively. It can be seen that the maximum stress in the column without holes is smaller than in the column with holes, although the change is small.

5. Conclusion

Based on modeling carried out using ANSYS software, it shows that the larger the hole in a reinforced concrete column, the smaller the axial capacity of the column to carry the load. The results of column modeling with a variation of 1.5" hole, 2" hole, and 3" hole show that the percentage value of axial capacity reduction is 2.27%, 3.42%, and 7.73%, respectively.

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