Strip shape produced by 4 High cold rolling process simplified with a static model.

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Abstract*: The cold rolling process is one of the most important in the metal industry. The strips produced by this process are used in different applications. The quality and shape control of these products are very important factors during the production process. It is well known that the strip shape is influenced by: the rolling speed, strip width, forces, rolls deflection, etc. This work considers modelling a 4 high cold rolling process and obtains the strip profile, with a static model using an arc contact with springs representing the whole model. This idealized model was developed to reduce the computational time of the dynamic model being used. An arc is defined with the optimal dimensions to reproduce the process, taken into account concentrations of the stresses, forces and displacements at the work roll/strip contact; the arc used in the static model was meshed in accordance with the mesh of the work roll in the dynamic model. The arc in this model is helped by springs placed at the arc inner surface; the stiffness of the springs was calculated with previous measurements of the work roll deflection values. The results show that the arc static model reproduces correctly the roll profile and strip shape with an important difference in the computational time.*

Keywords*: Cold rolling, Flatness, Strip Crown*

1. Introduction

The cold rolling is a process where a metal strip is plastically deformed to a certain thickness with better surface finish and dimensional tolerance than the hot rolled strips. The process consists in a metal strip (steel) going through a rolling mill at room temperature. The strips used in the cold rolling must be previously hot rolled. Cold rolling decreases the thickness but also improves the surface finish.

Some cold rolled strips are used at the car industry and the house hold appliances; this is the reason why the surface finish and the shape control play are essential at this process.

1.1 Types of mills

There is a wide variety of mills used for the cold rolling process. The more common are the; two high, four high, six high and the Sendzimir mill, these are classified by the number of rolls composing the mill. It is important to mention that the shape control and surface finish can be affected by the mill configuration.

This study considers a 4 high mill composed by for rolls: two work rolls and two back up rolls, as it is showed in Figure 1. The work rolls are the small rolls which are in contact with the strip. The backup rolls are those supporting the work rolls.

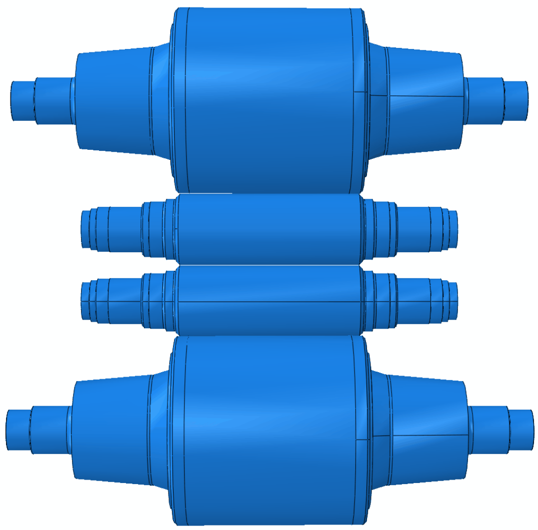

Figure 1. 4 High mill.

1.2 Shape control and flatness

The term shape applied to the rolled strips can be used to define the cross-sectional geometry of the strip or the ability of the strip to stay flat on a horizontal planar surface. The crown is defined as the difference in thickness between the center of a strip and its edges. (Roberts).

The flatness defects are common during the rolling process; they are principally grouped in four cases: quarter buckle, wavy edges, center buckle and short quarter. The shape of the strip is caused by the changes of the strip thickness profile during the rolling process, these thickness variations occur due the roll force distribution (Dieter). The Figure 2 shows a scheme illustrating how the flatness is produced by the profile evolution.

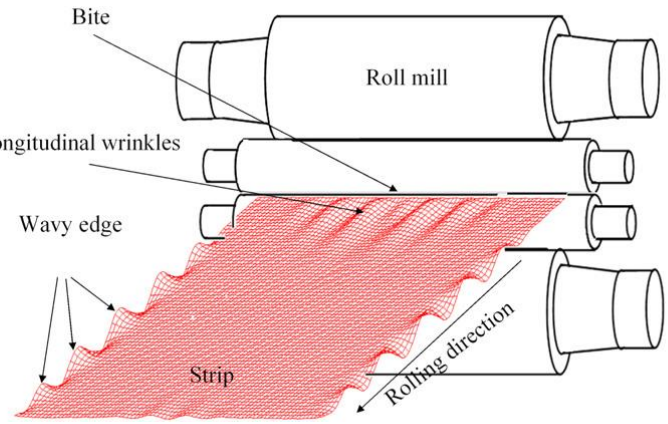

Figure 2. Strip flatness defects illustration (Abdelkhalek).

The strip flatness and the strip crown (Figure 3) are basic parameters during the flat strip production. The strip crown is calculated using equation 1:

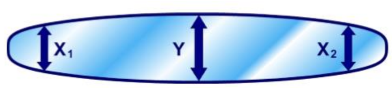

Figure 3. Crown definition (Miani).

$$C = Y - \frac{(x_1 + x_2)}{2} \qquad \text{Equation 1}$$

2. Modelling

This work is a simplification of a dynamic model created before; this model was elaborated with the intention to decrease the computational time of a 4 high rolling mill dynamic model. Both models were prepared in Abaqus/CAE; the dynamic model was solved using Abaqus/Explicit. The characteristics of the dynamic model and the static simplification are detailed below.

2.1 Dynamic model

The dynamic model recreates the cold rolling process by a 4 high mill. But this model uses a symmetry consideration in the horizontal and vertical axes to decrease the number of nodes, elements and computational time. The Figure 4 illustrates the resulting geometry of this model.

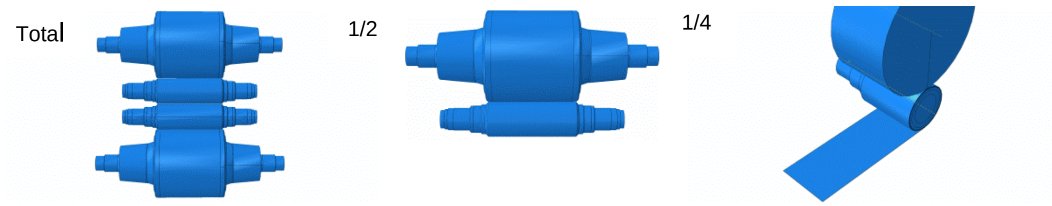

Figure 4. Symmetry conditions applied to the model

2.1.2 Dynamic model mesh

The mesh of this dynamic model is composed by 5,642,832 nodes and 5,248,108 elements (table 1); it is showed in Figure 5.

Table 1. Number and element type for Dynamic model.

Element type	Number
Linear hexahedral C3D8R	5,214,372
Linear wedge C3D6	33,736

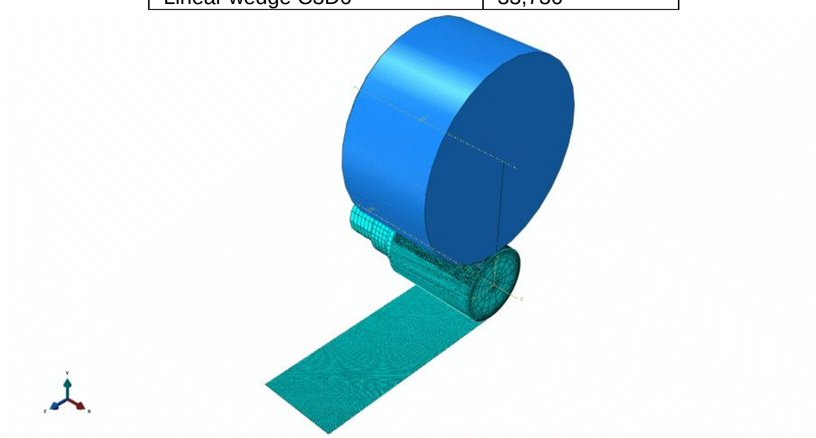

Figure 5. Mesh used for the dynamic model.

The elements in the strip use hourglass control: Stiffness.

2.1.3 Obtained profile

The work roll profile and the strip shape obtained by the dynamic model, replicated the real response of the 4 high rolling mill. The Figure 6 shows the obtained roll profile by this model.

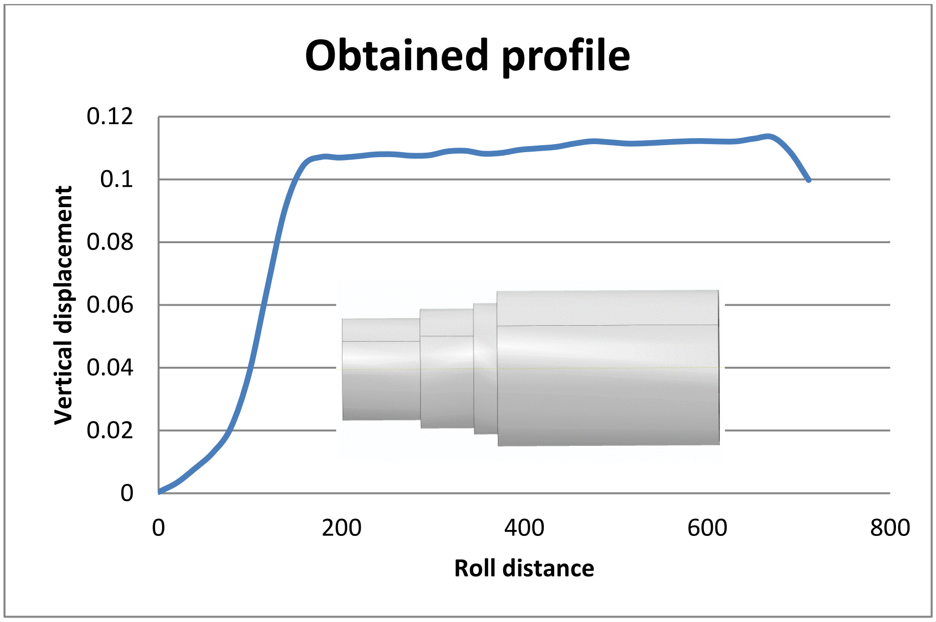

Figure 6. Work roll obtained profile with the dynamic model.

The experimental validation of this model was analyzed using a comparison between the load applied at the industrial process and the reaction force obtained with the dynamic model. The Figure 7 shows how the reaction force is changing at different times, stabilizing in the same value of the measured force.

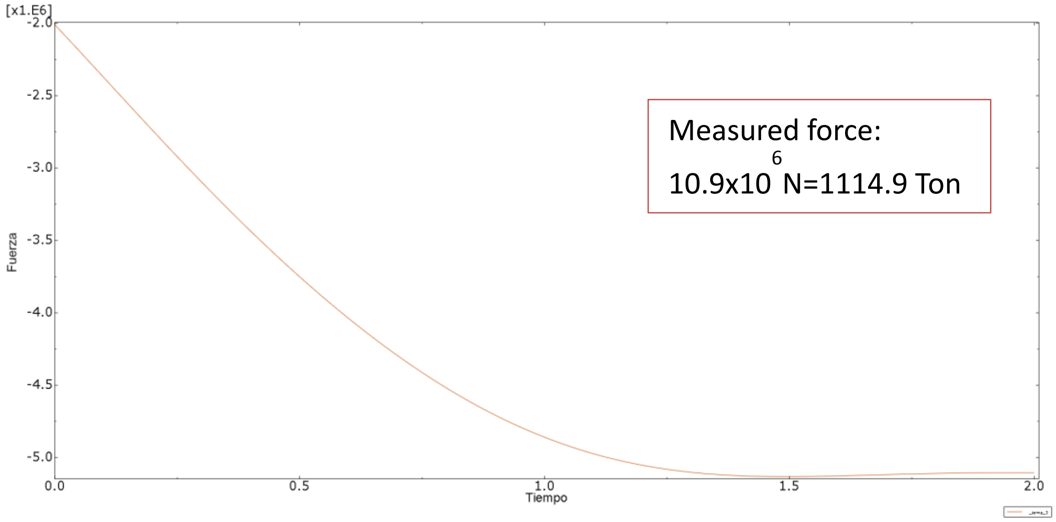

Figure 7. Comparison of the Reaction force (Dynamic model) and the Measured force (Industrial process)

2.2 Static model simplification

With the purpose of decrease the computational time of the dynamic model. Some simplifications were applied to the model. The model simplification is composed by an arc representing the outer face of the work roll and springs simulating the roll deflection (Figure 8).

Figure 8. Arc representing the work roll outer face.

2.2.1 Simplification Model components

As it was mentioned before the simplification model the model has two components.

a) Static Arc: This part represents the outer part of the roll, were the roll profile is measured. The thickness dimension, was obtained with the results of the dynamic model. It was obtained with the effect of the stress in the work roll as is shown in Figure 9.

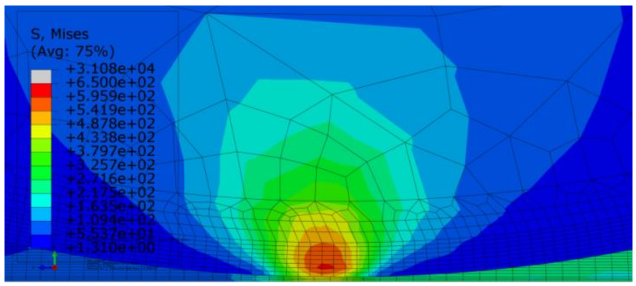

Figure 9. Stress distribution between the work roll and the strip.

The circumference of the arc represents 1/6 of the roll circumference. The longitude of the arc is the same as the roll table.

b) Springs: this model reproduces the roll deflection during the rolling process with springs located at the inner face of the arc (Figure 10).

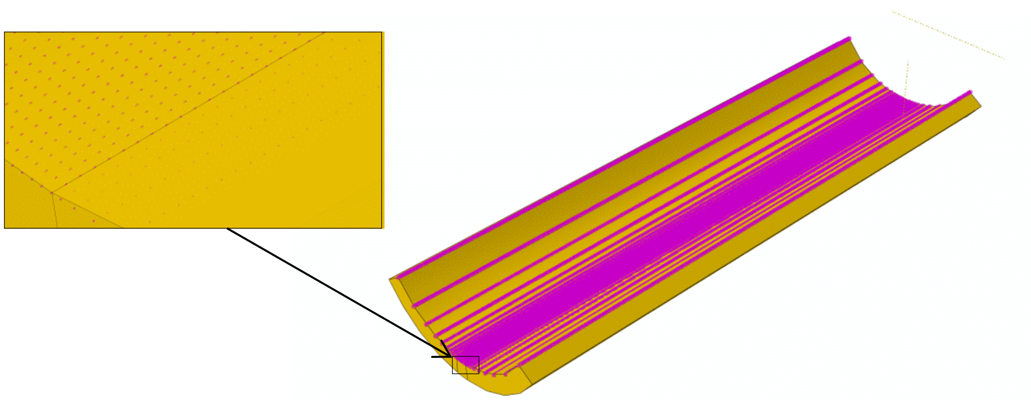

Figure 10. Springs distributed over the arc inner face.

2.2.2 Mesh

The mesh applied to this model tries to replicate the mesh used at the dynamic model, with some variations to decrease the number of elements (Figure 11 and 12).

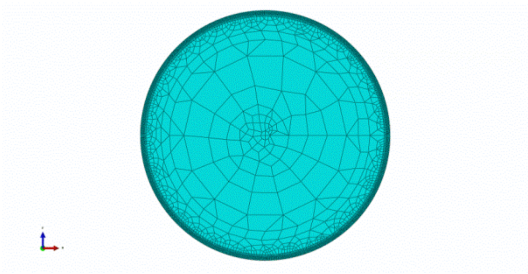

Figure 11. Dynamic model mesh.

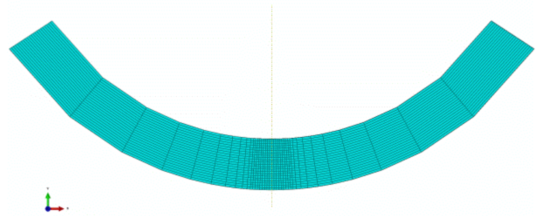

Figure 12. Arc mesh.

The elements of the mesh at the center of the arc are smaller than those at the edges, because the stress center, where the arc of contact between the strip and the roll is located. The mesh of the static model is detailed in table 2.

Table 2. Arc mesh description

Total number of nodes	638, 664
Total number of elements	594, 396
Type of elements	Linear hexahedral elements C3D8R

2.2.3 Boundary conditions and Load distribution

As a part of the simplification of the model, the strip is represented by a load applied as pressure at the arc of contact (Figure 13).

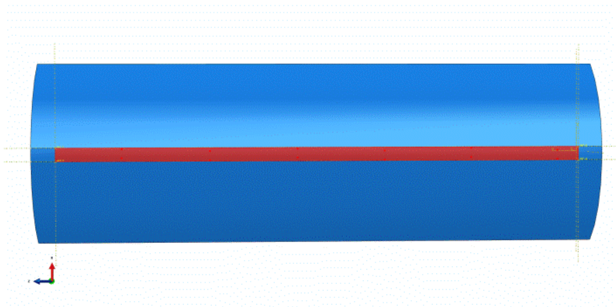

Figure 13. Load distributed at the arc of contact.

The arc inner face is covered with springs at each node. To calculate the spring stiffness was necessary to obtain the roll deflection in the dynamic model; using a node path at the center of the roll. The position of the node path is illustrated in the Figures 14 and 15.

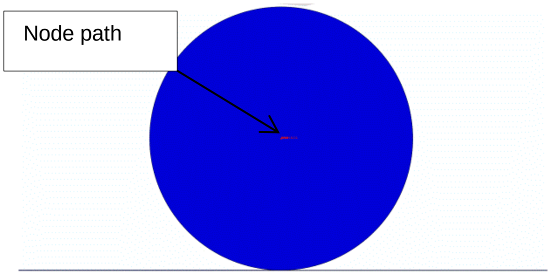

Figure 14. Node path position.

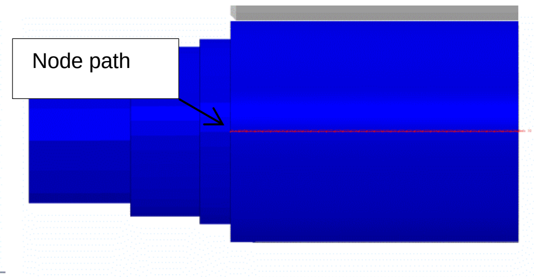

Figure 15. Node path position.

The vertical displacements of each node of the node path were graphed versus the roll distance from the edge to the center of the roll. This graph can be observed in Figure 16.

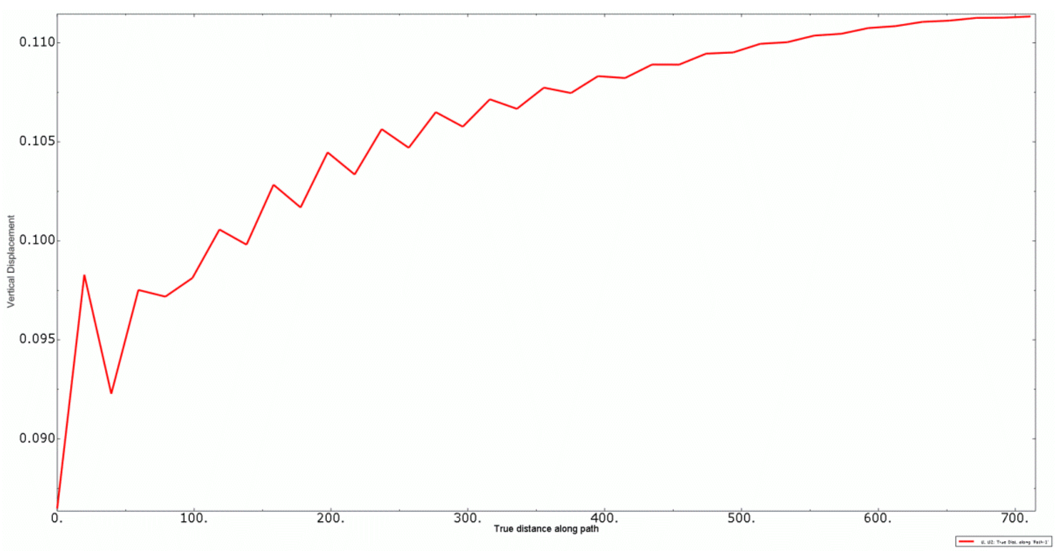

Figure 16. Roll deflection.

The “k” coefficients applied to the springs at the inner face of the arc, were calculated applying the Hooke´s law (Equation 2).

$$K = \frac{F}{x}$$ Equation 2

Where F is the reaction force obtained at the dynamic model and x is the maximum vertical displacement obtained in the roll deflection graph. These values where multiplied by 0.5 due the symmetry conditions.

This obtained coefficient “k” was also divided into the number of springs located at the arc. The zones where the strip does not interact with the strip used a K 1000 times bigger than the one located at the center.

3. Results and discussion.

The mesh used at the static arc is simpler than the one used at the dynamic, but trying to replicate the structured applied for the dynamic model. Table 3 shows the differences between the two meshes.

Table 3. Differences between the two models mesh densities.

	Dynamic	**Arc Static**
Number of nodes	5,642,832	638, 664
Number of elements	5,248,108	594, 396
Element type	Linear hexahedral (C3D8R) and Linear wedge (C3D6)	Linear hexahedral (C3D8R)

Due the difference in the number of elements used at the meshes from the dynamic model and the static model, the computational time of the analysis varies drastically, changing the time form days to minutes.

The resultant profiles obtained by each model are very similar; the comparison of these profiles can be seen in Figure 17. It can be observed how the arc static model can replicate the response of the dynamic model and therefore the cold rolling process.

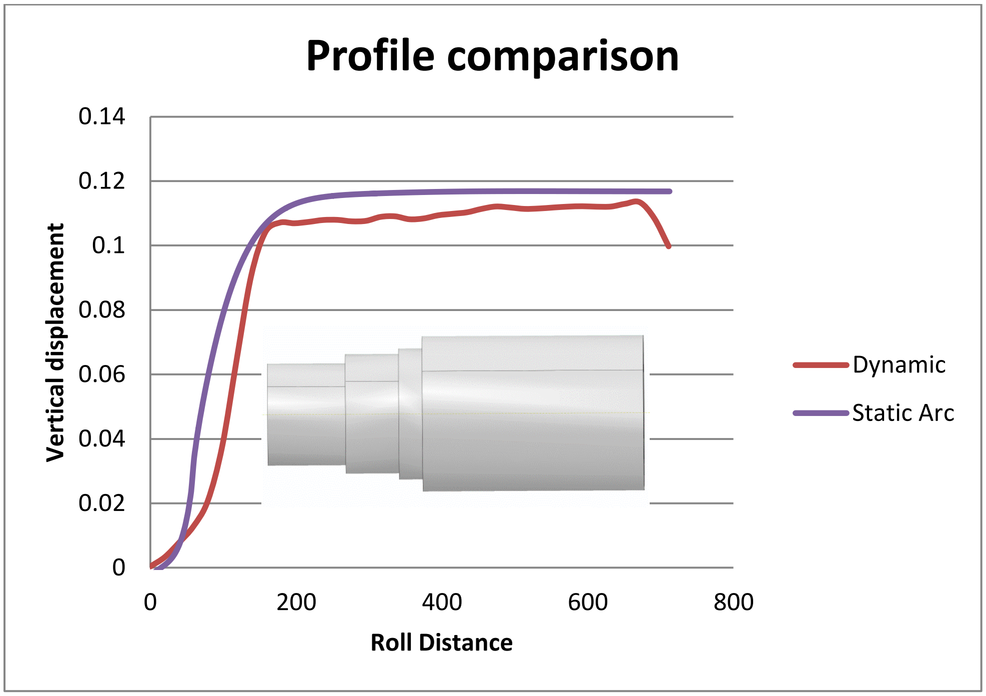

Figure 17. Comparison of the static and dynamic profile.

4. Conclusions

The static simplified model replies correctly the profile obtained at the cold rolling process. This works probes a new way to reproduce the strip shape obtained at the cold rolling with a minimum number of nodes and elements. Using a static arc to represent the roll flattening, as well as a springs to recreate the work roll deflection and the backup roll support.

The computational time changes from days to minutes, making the arc simplification a convenient tool to reproduce the cold rolling process. The table 4 shows the different CPU time and Increments of the Dynamic model and the Arc Static model.

Table 4. Differences between the two models CPU time and Increments.

	Dynamic	Arc Static
CPU time	291, 851	4, 816.2
Increments	886, 952	17

Both models were running in a computer with two Intel® Xenon® CPU X5650 @ 2.67 GHz, and 64 GB of RAM.

The thermal part of the simulation will be added to this model, to recreate how the heat flow interferes with the strip crown.

5. References

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6. Acknowledgment

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