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TIME HISTORY NONLINEAR ANALYSIS FOR 2D MODELIZATION OF AN EXISTING BUILDING USING FLEXIBILITY AND DISPLACEMENT-BASED FORMULATION

The object of research is a distributed order processing system for a restaurant chain. The subject of the research is the analysis of the use of Redis for managing event queues in distributed systems.

When implementing a distributed order processing system in a restaurant chain with a possible load of up to 20,000 users per day, the Redis system was used. Management of 9 distributed subsystems was organized through Redis. This solution showed an increase in the performance of the system under heavy load (from 50 transactions per second), but the response time of the system in some cases of its operation was longer than without using Redis. When working systems using Redis, it is necessary to take into account the amount of data with which Redis will work, since it does not exceed the amount of RAM, the absence of differentiation into users and groups, and the absence of a query language, which is replaced by a key-value scheme.

This research is aimed at analyzing the operation of the system during trial operation under real load. We compared the operation of a configured system with Redis enabled and disabled. The main indicators for the analysis were the system response time and the maximum request execution time. The research was carried out for 2 weeks, the first week using the system settings with disabled Redis, the second – with enabled Redis. We selected 2 days with a similar load on the system to each other. Especially indicative are the results of comparing the durations of the longest queries, which show an almost constant value of the duration for the system in the mode of enabled Redis. The hypothesis of an increase in the system response time at low loads was confirmed, but this value not only leveled off at a load of 500 unique users but also became less at loads of 1000 unique users.

Keywords: *microservice, service-oriented architecture, order processing, Redis, software development, software engineering.*

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1. Introduction

Seismic assessment of existing structures through forced-based methods has gained increasing attention in the last ten years [1]. The use of such methods tends to be less demanding in terms of number of elements to take into account in the model to achieve convergence compared to the displacement-based formulation. However, a beam-column element needs to be modeled differently using these two elements to achieve a comparable level of accuracy. Some literature has shown that force-based elements are superior to standard displacement-based formulations in simulating geometrically linear response of frame members with material nonlinearity [2–4].

Interpolation of the element displacement field is not required and accuracy of the computed solution depends only on the numerical integration method used. [5, 6] demonstrate the non-requirement of element displacement field interpolation; on the other hand, the accuracy is due to the used numerical integration method.

The displacement-based approach follows standard finite element procedures where it is possible to interpolate section deformations from an approximate displacement field. Mesh refinement of the element is needed to represent higher order distributions of deformations.

The accuracy of the results using this approach is lost when inelastic behavior is modelled, the element is exact when with linear elastic and concentrated loading.

The force-based approach relies on the availability of an exact equilibrium solution within the basic system of a beam-column element. Equilibrium between element and section forces is exact.

Thus, *the aim of this study* is to show the effectiveness, accuracy and robustness of the force-based approach, thus allowing the gain in term size of the matrix and equation to be solved as well as the saving in time. Using this approach allows the young engineer to apprehend numerical modeling with ease.

2. Materials and Methods

Flexibility based formulation [7]. The plane frame finite element models are based on the Euler-Bernoulli beam theory [8] for geometrically nonlinear behavior [9]. In this case, the governing variables are the axial and transverse displacement fields $u(x)$ and $w(x)$, respectively, of the element reference axis that give rise to deformation fields:

$$D(x)=\left[\varepsilon(x)\chi(x)\right]=\left[u'(x)+\frac{1}{2}w'^{2}(x)-w''(x)\right]^{t}, \tag{1}$$

where $\varepsilon(x)$ is the axial strain at the reference axis and $\chi(x)$ is the curvature, with the prime denoting differentiation with respect to x. Displacements and strains are assumed to be small.

The nonlinear axial strain-displacement relation in Equation (1) forms the basis for the proposed geometrically nonlinear formulation. The corresponding stress resultants or internal force fields are:

$$f(x)=\left[N(x)M(x)\right]^{t}, \tag{2}$$

where $N(x)$ is the axial force and $M(x)$ the bending moment. It is assumed that the section constitutive relation:

$$f(x)=KD(x), \tag{3}$$

with

$$K=\begin{bmatrix} EA & 0 \\ 0 & EI \end{bmatrix},$$

where EA is the axial and EI the flexural rigidity.

2.1. Flexibility method. If equilibrium is considered in the deformed element configuration in Fig. 1, the relation between nodal forces $\overline{Q}$ in the system without rigid body modes and internal forces $f(x)$ is:

$$f(x)=b\left[x,w(x)\right]\overline{Q}, \tag{4}$$

where

$$b\left[x,w(x)\right]=\begin{bmatrix} 1 & 0 & 0 \\ -w(\xi) & \xi & \xi-1 \end{bmatrix},\ \xi=\frac{x}{L}. \tag{5}$$

Is the matrix of displacement-dependent force interpolation functions. Since shear deformations are neglected, the shear force does not appear in Equation (4), but it can be determined a posteriori from the equilibrium condition (Fig. 1):

$$V=-Hw+T. \tag{6}$$

The weak form of the compatibility condition in Equation (1):

$$\int_{0}^{L}\delta F(x)D(x)\mathrm{d}x. \tag{7}$$

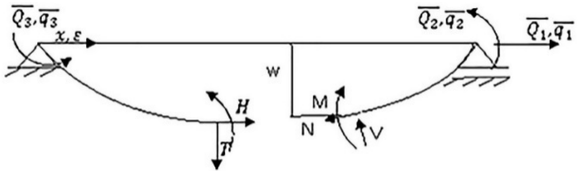

Fig. 1. Equilibrium in Deformed Configuration

Leads to three compatibility equations for the frame element without rigid body modes. one for the axial displacement $\overline{q}_1$ and two for the end rotations $\overline{q}_2$ and $\overline{q}_3$ in Fig. 1, the latter are identical with the linear case. The former becomes:

$$\int_{0}^{L}\delta N\left[u'(x)+\frac{1}{2}\left[w'(x)\right]^{2}-\varepsilon(x)\right]\mathrm{d}x=0. \tag{8}$$

After integrating the preceding expression by parts and accounting for the boundary terms. The compatibility condition for $\overline{q}_1$ reduces to:

$$\overline{q}_1=\int_{0}^{L}\varepsilon(x)\mathrm{d}x-\int_{0}^{L}\frac{1}{2}\chi(x)w(x)\mathrm{d}x. \tag{9}$$

Thus, the complete set of governing equations, the flexibility-based is:

$$\overline{q}=\int_{0}^{L}b^{*t}\left[x,w(x)\right]D(x)\mathrm{d}x, \tag{10}$$

with

$$b^{*}\left[x,w(x)\right]=\begin{bmatrix} 1 & 0 & 0 \\ -\dfrac{w(\xi)}{2} & \xi & \xi-1 \end{bmatrix}. \tag{11}$$

It is noted that each method has its advantages and disadvantages. In our case flexibility-based formulation present limits, namely the fact that it is well suited to one-dimensional elements rather than a case of continuum elements.

2.2. Displacement based formulation. *Displacement interpolation.* Assuming constant axial deformation and linear curvature distribution along the element length see Fig. 2 let's obtain:

$$\xi=\frac{x}{L},\ \begin{Bmatrix} u_a(x) \\ u_t(x) \end{Bmatrix}=\begin{bmatrix} \xi & 0 & 0 \\ 0 & \xi^3-2\xi^2+\xi & \xi^3-\xi^2 \end{bmatrix}\begin{Bmatrix} u_1 \\ \theta_2 \\ \theta_3 \end{Bmatrix},$$

$$\{U(x)\}=\left[N(x)\right]\{D\},$$

$\left[N(x)\right]$ represents shape fuction matrix.

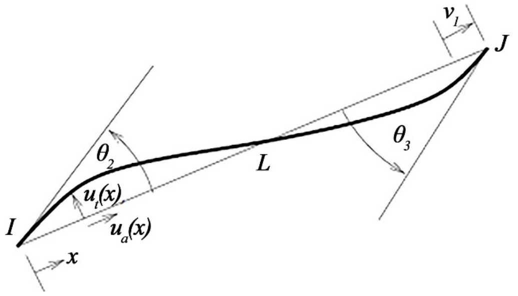

Fig. 2. 2D element

Strain-Displacement relationship:

$$\varepsilon_a = u_a'(x)\kappa(x) = u_t''(x),$$

$$\begin{Bmatrix} \varepsilon_a(x) \\ \kappa(x) \end{Bmatrix} = \frac{1}{L}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 6\dfrac{x}{l}-4 & 6\dfrac{x}{l}-2 \end{bmatrix}\begin{Bmatrix} u_1 \\ \theta_2 \\ \theta_3 \end{Bmatrix},$$

$$\begin{Bmatrix} \varepsilon_a(x) \\ \kappa(x) \end{Bmatrix} = \left[B(x)\right]\{D\}.$$

2.3. Frame building case study. An existing three-storey reinforced concrete building is studied using the nonlinear frame analysis. The building is in Bonefro, Italy [10], and is a good example of residential buildings of the 70's and 80's in Italy, prior to the introduction of the seismic code in the early 80's (Fig. 3). Foundation, floor and roof plans are shown in Fig. 4–7.

It is possible to deduce the equivalent rectangular beam (Fig. 8) which have the same inertia than beam with *T* form so having *b*/*d* and *h*/*t* (Table 1) it is possible to deduce *b*′/*b* [10].

The model built in Z_Soil is shown in Fig. 9.

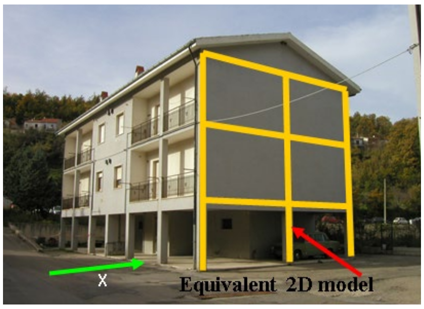

Fig. 3. Bonefro reinforced concrete 3-storey building

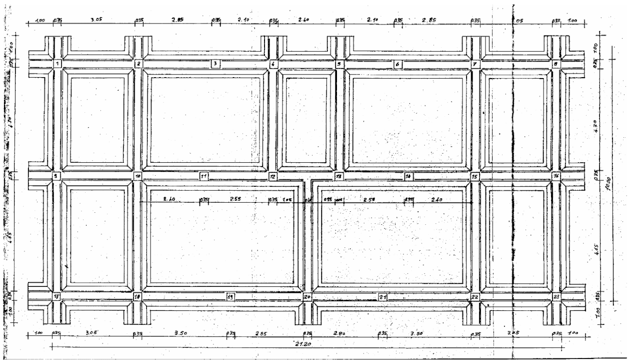

Fig. 4. Foundation plan of Bonefro building

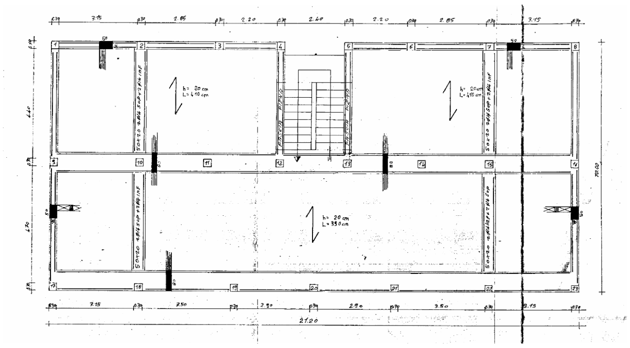

Fig. 5. First floor plan of Bonefro building

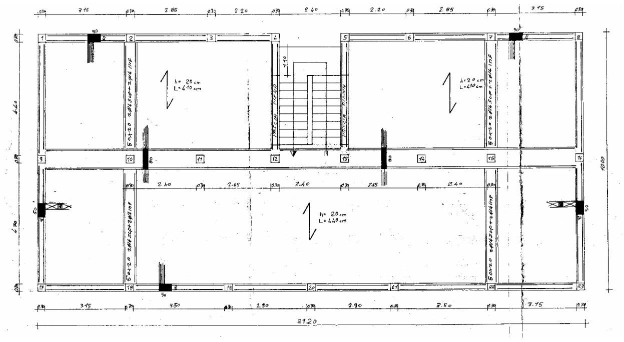

Fig. 6. Second floor plan of Bonefro building

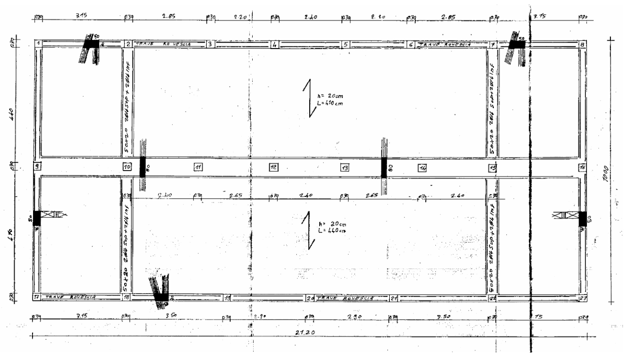

Fig. 7. Third level + roof plan of Bonefro building

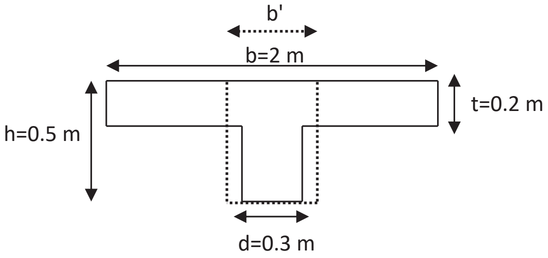

Fig. 8. Equivalent rectangular beam

Table 1

Element's reinforcement details

Elements and characteristics	*b*, m	*h*, m	Reinforcement
Element 1	2.4	0.3	16Φ16 top; 16Φ16 bottom; 16Φ14 middle
Element 2	2.1	0.3	14Φ16 top; 14Φ16 bottom; 14Φ14 middle
Element 3	2.4	0.3	16Φ16 top; 16Φ16 bottom
Element 4	2.1	0.3	14Φ16 top; 14Φ16 bottom
Element 5	2.8	0.5	16Φ14 top; 24Φ14 bottom
Element 6	2.8	0.4	16Φ14 top; 20Φ14 bottom

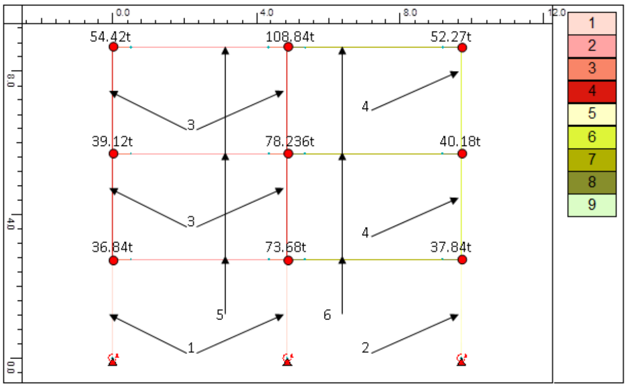

Fig. 9. Geometrical characteristics of equivalent 2D model

In our case $b/d=6.67$ m and $h/t=2.5$ m thus $b'/b=0.336$ m so $b'=0.672$ m.

Concrete $E=2.7e^7$ KN/m^2, $\upsilon=0.16$, $ft=300$ KN/m^2, $fc=3000$ KN/m^2.

Steel $E=2.1e^8$ KN/m^2, $\upsilon=0.2$, $ft=fc=500000$ KN/m^2.

3. Results and Discussions

The aim is a comparative study in the two formulations namely flexibility based and displacement based. The idea is to apply three different earthquakes in terms of duration and intensity and which are El Centro, Hollister and Friuli earthquake. These are applied separately on the equivalent 2D model of the existing building.

Fig. 10–12 shows the signal in format of acceleration vs time, of different earthquake used in this study.

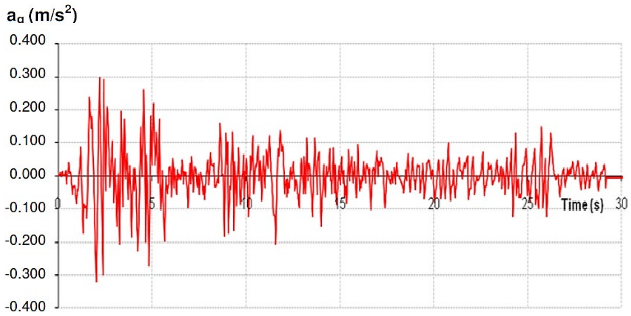

Fig. 10. El Centro earthquake [11]

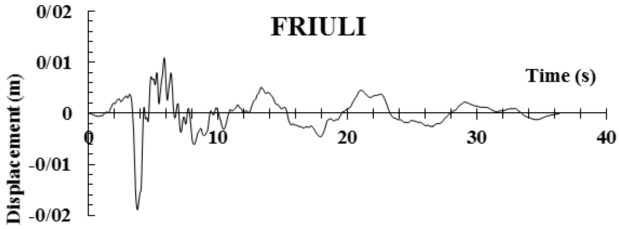

Fig. 11. Friuli earthquake

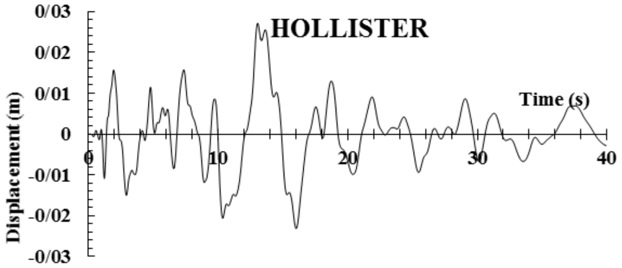

Fig. 12. Hollister earthquake

In order to deduce the responses of this the existing building using displacement and flexibility-based figures bellow show it clearly.

In Fig. 13–18 it is possible to notice that the result of the two approaches (flexibility and displacement based) are very close each other, which shows the robustness of the force-based formulation (flexibility based) hence our benefit from its key advantages.

From Fig. 4–7, it is possible to say that they clearly show the convergence between the force-based approach and displacement-based one in terms of nonlinear time history response of the structure. At different floor level under different earthquakes, namely El Centro Hollister and Friuli. Which demonstrates the effectiveness of force-based approach and its advantages, namely the drastic reduction in term of element number, consequently reducing the number of degrees of freedom as well as equations.

Unlike the classic approach embodied by displacement-based formulation where the numerical modeling will be more tedious than the previous one in the sense that it will have more elements to be integrated into the model and more equations to be solved.

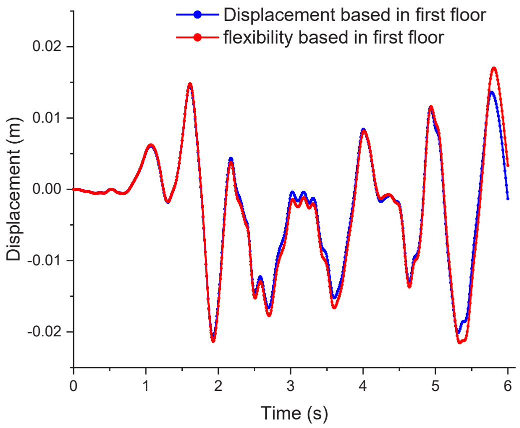

Fig. 13. Response at first floor of Bonefro building to El Centro earthquake

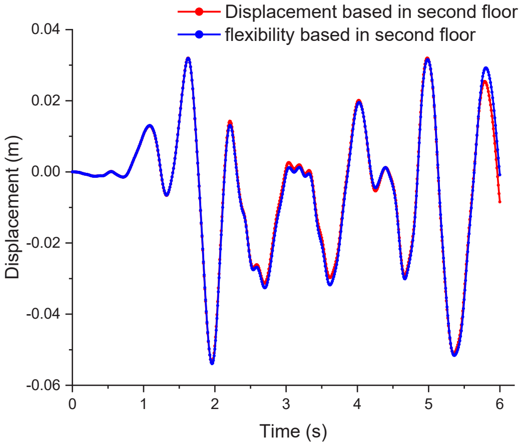

Fig. 14. Response at second floor of bonefro buiding to El Centro earthquake

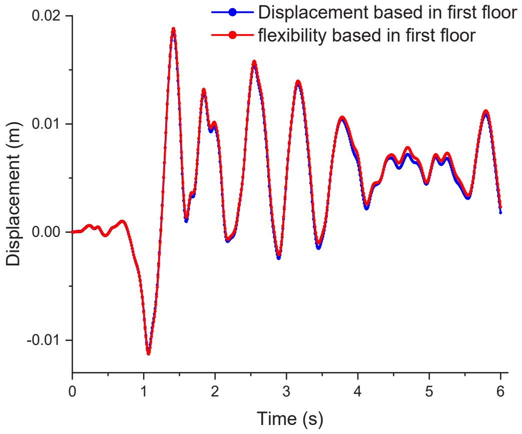

Fig. 15. Response at first floor of Bonefro building to Hollister earthquake

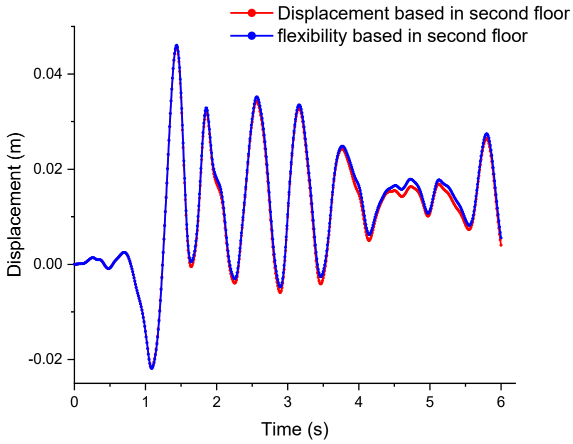

Fig. 16. Response at second floor of Bonefro building to Hollister earthquake

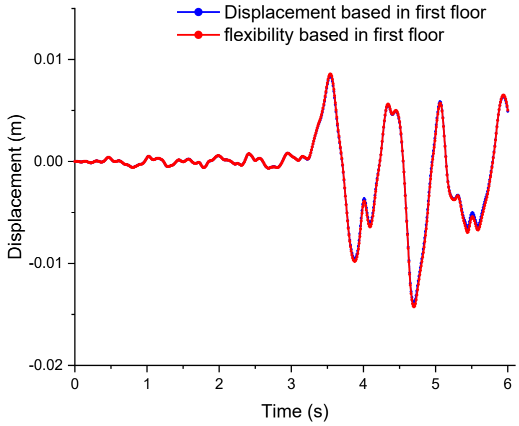

Fig. 17. Response at first floor of Bonefro building to Friuli earthquake

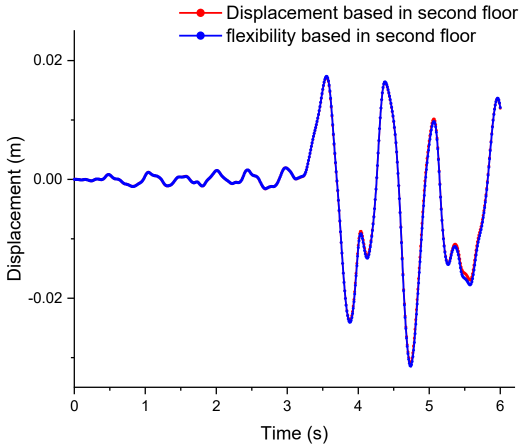

Fig. 18. Response at second floor of Bonefro building to Friuli earthquake

Hoping that in the near future, more approaches of this kind will emerge especially for soil modeling, which is of capital importance because it makes the numerical model closer to the reality.

4. Conclusions

The element formulation is based on force interpolation functions strictly satisfy element equilibrium and, thus, belongs to the category of flexibility-based elements. The use of exact force interpolation functions in the element requires fewer elements for structure non-linear behavior representation, and gives good numerical results without difficulties.

In our study, the choice of an existing building is not trivial, because the comparison of a building already constructed is more relevant than one, which is not. Because of the necessity to take into account reinforcement details as well as concrete age, thus making the convergence if it exists more imposing, which is shown by our results.

Nonetheless, the element offers significant advantages over existing stiffness-based approaches, since no discretization error occurs and all governing equations are satisfied exactly. Consequently, fewer elements are needed to yield results of comparable accuracy. This is demonstrated with the analysis of several simple example structures by comparing the results from flexibility and stiffness-based elements.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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