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SEISMIC RETROFIT OF BUILDINGS WITH BACKBONE DAMPERS

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Abstract. *Dampers have been effectively used in new designs and seismic retrofit of old structures in many parts of the world. The common seismic retrofit practice in Turkey is almost purely based on stiffening the structure with additional shear walls or adding braces to limit the excessive seismic drifts. Such an approach usually results in expensive interior works and enlargements of foundations. The stiffening of the structure typically results in attracting more seismic force. Utilization of dampers as seismic protection devices have not been so much popular in Turkey and have been considered to be used only in some few retrofits. However, use of seismic protection devices can significantly improve the structural response and reuse of the structure after the earthquake. A new type of damper system called backbone damper has been recently developed and tested at the laboratories of METU. The results of more than 1000 tests indicated that the response of backbone damper is stable under the same conditions and more than 20% damping can be achieved at story drifts of 10-20 mm of movements. The harmonic motion test speeds reached up to 400 mm/sec in some cases and a maximum frequency of 7 Hz is achieved during some tests. It shall be noted that the backbone damper has an internal displacement amplifier that helps the system to damp even at small movements. The dampers do not get damage at the end of tests and has the ability to re-center themselves. The solid model of the damper has been prepared using the ABAQUS software. The focus of the paper will be given to application of this new damper system to improve the seismic response of the existing structures. In this scope, one typical hospital building with different selection of damper performance has been investigated in the case study. Three ground motions have been applied to the structures with and without dampers. The ground motion records are scaled to have a equivalent design response spectrum curve. The results of non-linear time history analysis performed in LARSA 4D have indicated that the seismic response of the structures can be improved significantly in terms of displacments.*

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1 INTRODUCTION

In the last two decades, major earthquakes having M_w greater than 7.0 hit Turkey causing major damages and collapse of buildings. Almost all of these buildings have no additional damping system other than inherent damping due to reinforced concrete construction. In some cases, even if the load carrying frame system did not get damage, the masonry interior walls collapsed that prevent immediate reuse of the structure as shown in Figure 1. It has been known that the infill walls have less capacity to drift than a ductile reinforced concrete structure. The drift capacities of infill walls are around 0.3% - 0.5% and ductile structures can have drift capacities up to 4%-5% .

Figure 1. Excessive Drift Damages at Infill Walls, Van Earthquake 2011

The control of structural seismic displacements can be controlled by dampers [1], [2] and [3]. The focus of this paper is given to implement a new type of damper to minimize structural displacements during seismic events. In this scope, the prototype test results of new backbone dampers have been presented to propose a preliminary design equation for dampers. The dampers models in ABAQUS have been developed for analysis. Under three different ground motions a typical hospital framing system for a 10 story structure have been analyzed with different damper properties to identify the optimum design of dampers.

2 TESTS OF BACKBONE DAMPERS

Tests of backbone dampers have been performed at the METU Civil Engineering Department. The dampers have been tested under different frequencies. The layout of the damper have been presented in Figure 2. The damper consists of displacement amplifier with eccentrically loaded elastomeric bearings.

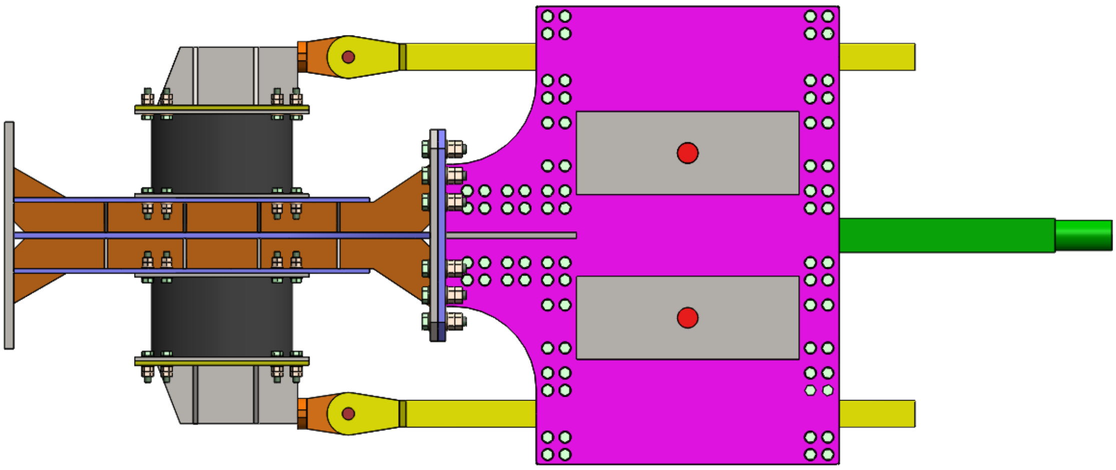


Figure 2. Layout of Damper

The test results of different sizes of the damper have revealed that the size of the elastomeric bearing plays an important role in targeting a certain energy dissipation per cycle. The energy dissipation per cycle can be simply measured by computing the area under the test curves as shown in Figure 3. The speed in tests or load rate does not change much the response. It shall be noted that at 2hz and at 25 mm piston displacement, the hydraulic unit reached its limitation of push and pull.

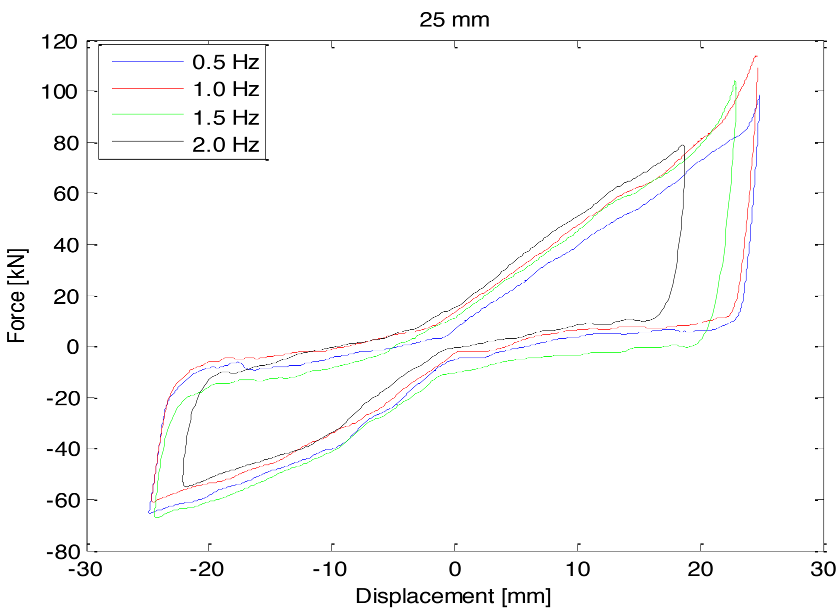


Figure 3. Test Curves

The test results have indicated that the damper is effective under a broad range of frequencies. Such benefit can yield to reduce the seismic response almost on all significant periods of the structure that may not be captured by application of seismic isolation. The damper tests have revealed that even under a steel casing has some oversize holes, it can still dissipate energy as targeted. The rehabilitation of steel casing with tighter holes ended up increasing the energy dissipation per cycle. In the future, a lower bound and upper bound EDC will be predicted based on the completion of the test program. The following results indicate that the EDC is a function of displacement and diameter of the elastomeric bearing.

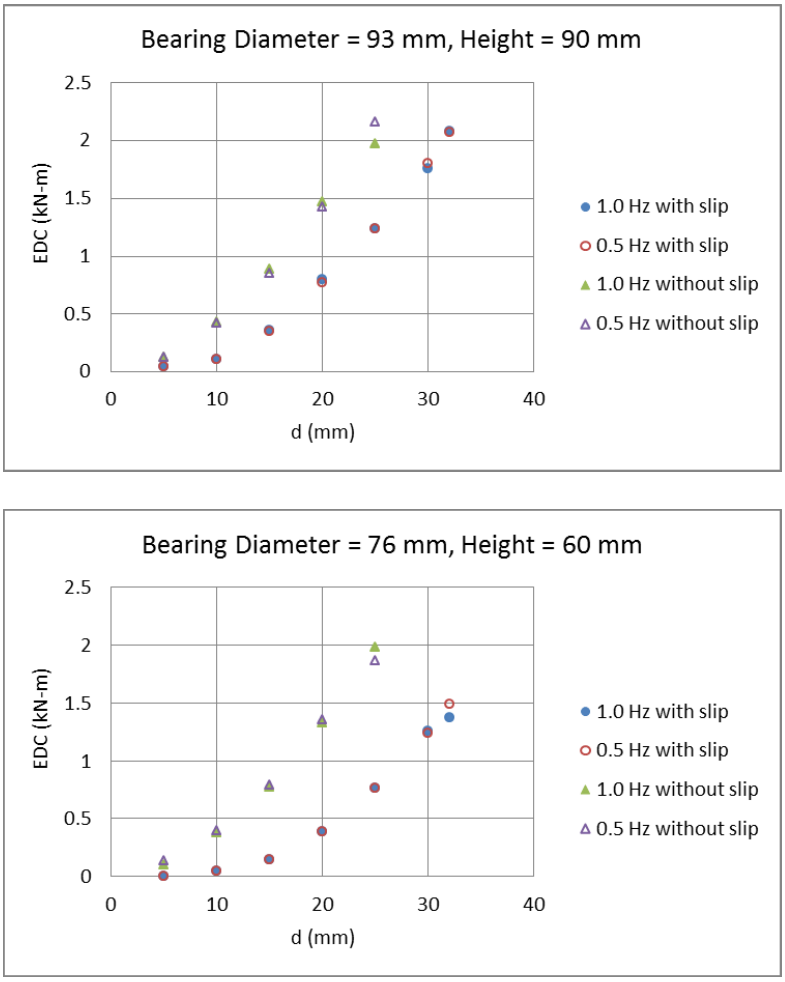


Figure 4. EDC – Test Results and Proposed Equation

The ABAQUS model of the bearings have been constructed. Initial simulations of test data have been completed. The model includes the rubber, steel shims and anchorage plates as shown in Figure 5.

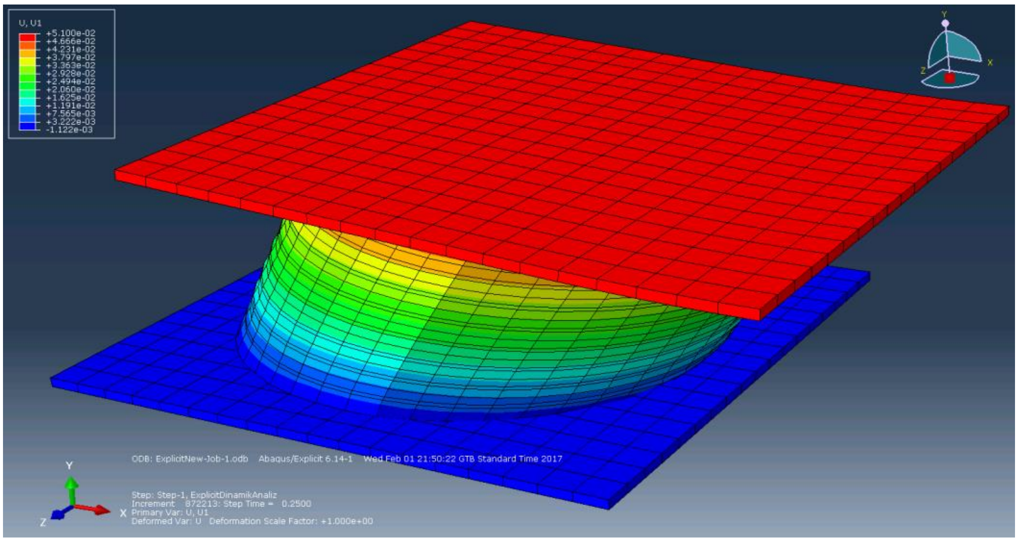


Figure 5. ABAQUS Model Under Construction

3 BUILDING IN ANALYSIS

The hospital building in analysis has a typical column spacing of 8 meters in plan. The story height of the structure is 4.5 meters and the number of stories are 10. The structure has a slab thickness of 200mm, column size of 900 x 900 mm and beam size of 600 x 700 mm. The framing system of the hospital is very typical compared to hospitals of Isparta, Izmir, Kocaeli, Manisa and Eskisehir ones.

Figure 6. A Typical Hospital Complex in Turkey

Following the weak beam strong column design philosophy, the beams have been expected to reach their plastic moment capacities during design earthquake. In all analysis models hysteretic plastic moment rotation elements in LARSA 4D have been used to model the plastic end zones of the beams. The structural model of the hospital represents a selected part of the complex as shown in Figure 7. The model has 7 bays in long direction and 4 bays of slab in short direction.

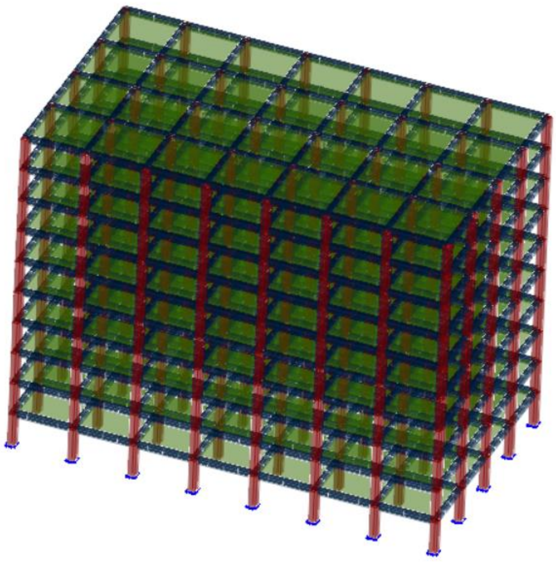


Figure 7. Three-Dimensional View of Model

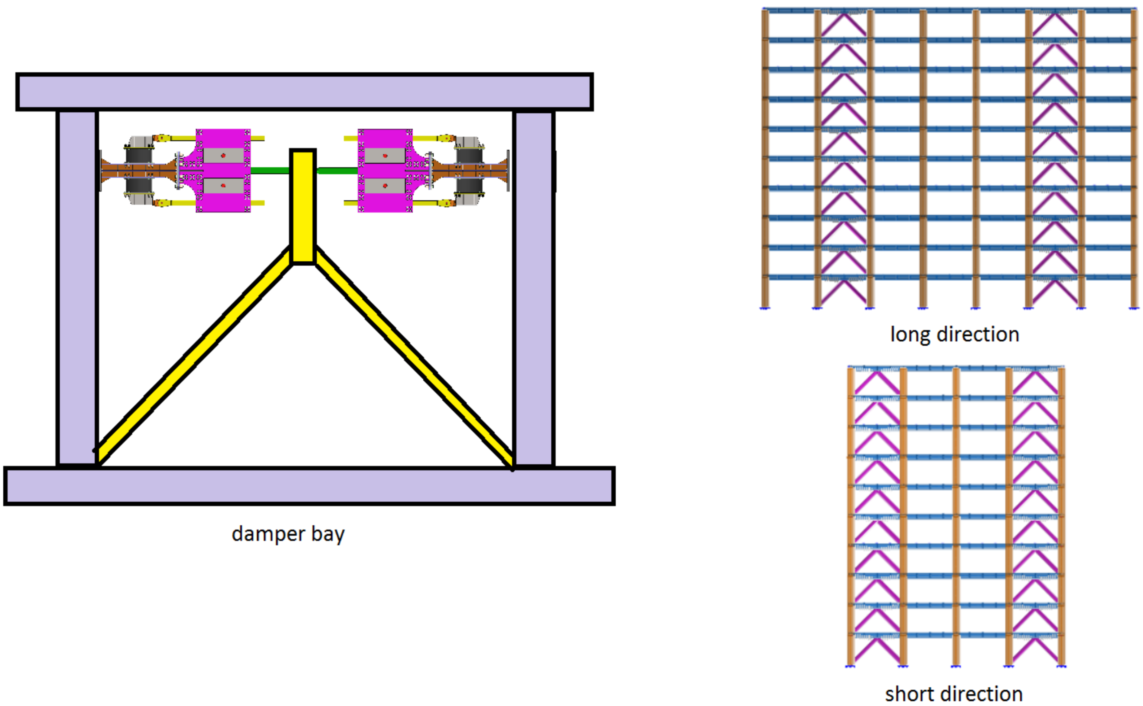


Figure 8. Damper Locations in a Typical Bay

Three ground motions made compatible to the design spectrum have been investigated in non-linear time history analysis. The design response spectra used in analysis is shown in Figure 9. Three earthquake records are made response spectrum compatible by scaling method.

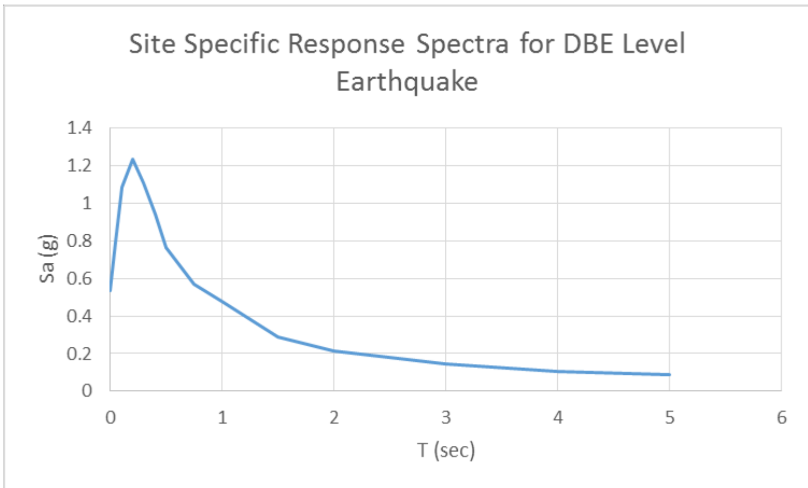
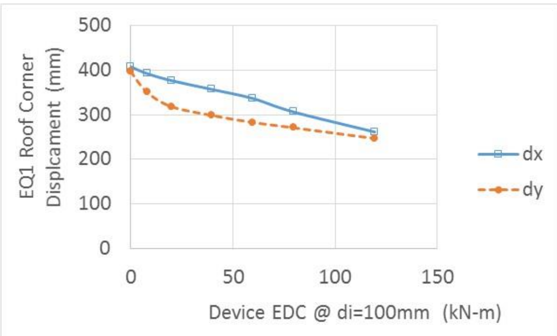
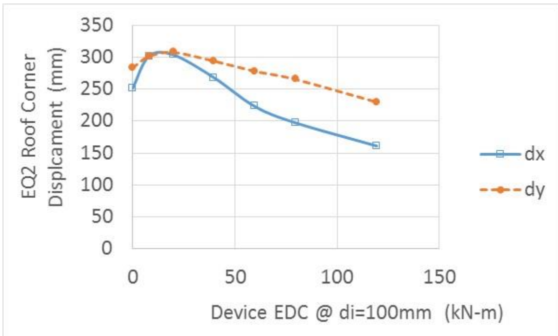


Figure 9. Response Spectrum Curve 475 Year Return Period Earthquake

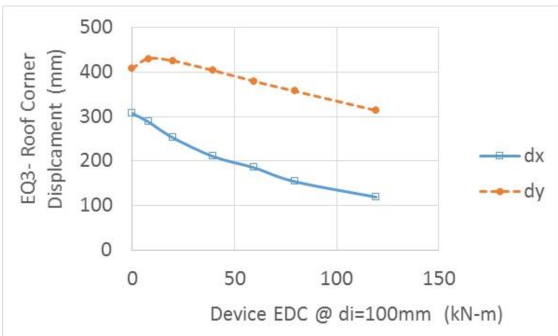
The results of non-linear time history analysis have indicated that the increase in EDC of the damper helped to minimize the seismic displacements significantly. The roof displacements cane be reduced to 60% of building without dampers as shown in Figure 10.



(a)



(b)



(c)

Figure 10. Reduction in Seismic Displacement with Increase in EDC. (a) ground motion artificial (b) groumd motion 1 and (c) ground motion 2
(dx = short direction, dy = long direction)

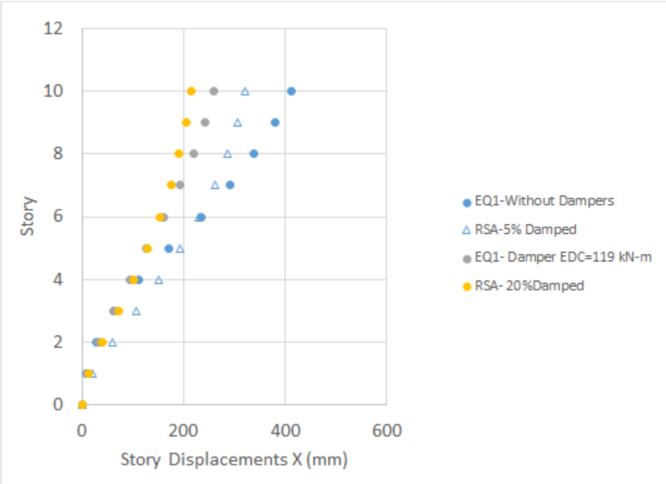
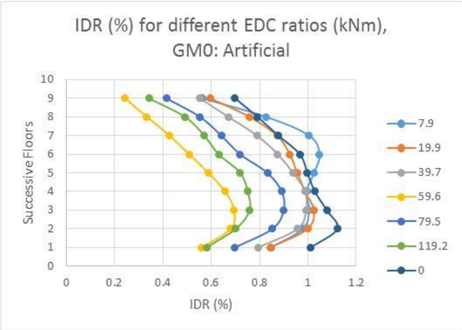


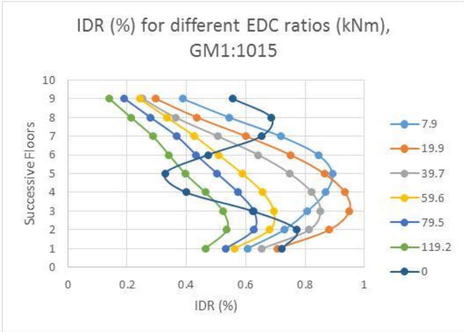
Figure 11. Comparison of Elastic and Dynamic Analysis

The elastic dynamic analysis is called “RSA”. The RSA have been conducted for two different cases. In all RSA analysis, dampers are not physically modeled but effect of dampers has been reflected on response spectra curve by applying a correction factor to the 5% damped response spectra curve. The first model has been run with 5% damped response spectra and the second with 20% damped response spectra curve. The comparison of results of non-linear time history analysis with and without dampers indicate that in the worst scenario earthquake the reduction in displacements are similar to the ones for the RSA-20% damped case. For other cases, the damping of the structure is much higher than for the case determined for EQ1, worst case out of three. Evaluation of story displacements of non-linear time history analysis and elastic dynamic analysis showed some acceptable difference still keeping similar level of story displacements.

The interstory drift ratio (IDR) has been investigated for the case where maximum roof displacement is recorded. The findings for artificial ground motion and ground motion 2 have the same pattern of results while ground motion 1 has a different pattern an indication of diversity in ground motions even if they are all compatible to the response spectrum curve. As expected, the increase in EDC helps to minimize the IDR while the results purely depend on the ground motion characteristics that need to be further investigated and an unsolved discussion among the international experts. We are well aware that the ground motion selection may not be the perfect one but still is in good correlation with elastic time history analysis as shown in Figure 11. Such an observation increases the confidence level on the selected ground motions.



(a)



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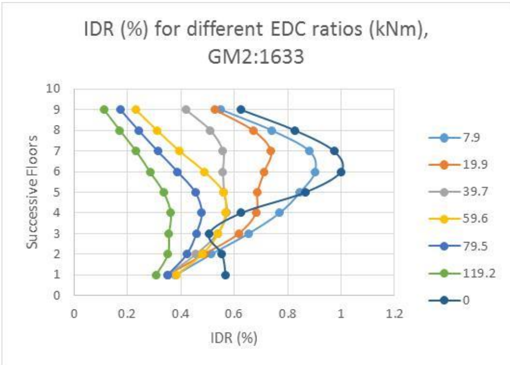

(c)

Figure 12. IDR Results (a) ground motion artificial (b) ground motion 1 (c) ground motion 2

4 CONCLUSIONS

The results of the tests and analysis with dampers are still under research and this paper covers a short presentation of some early promising findings. Under these circumstances, the following conclusions are gathered.

- The backbone damper can reduce the seismic displacements up to 60% of the building without dampers.
- The backbone dampers can significantly increase the overall damping of the building to more than 20%.

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