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Effect of Waste Tire Crumb Rubber on the Damping Ratio and Natural Frequency of Mortar for Masonry Wall Applications

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ABSTRACT

This study investigated the effect of waste tire crumb rubber on the damping characteristics of mortar for masonry wall applications using the free vibration method. Beam specimens measuring 500 mm × 100 mm × 100 mm were prepared with different crumb rubber contents and two particle sizes, namely passing the No. 4 (4.75 mm) and No. 8 (2.36 mm) sieves. Free vibration tests were conducted using a cantilever beam configuration with a 15 N suspended load. The acceleration responses were recorded using a piezoelectric accelerometer connected to the Dewesoft data acquisition system and analyzed using the Fast Fourier Transform (FFT) and logarithmic decrement methods to determine the natural frequency and damping ratio. The results showed that increasing the crumb rubber content enhanced the damping ratio while reducing the natural frequency of the mortar specimens. The highest damping ratio of 4.16% was obtained for the specimen containing 60% crumb rubber passing the No. 4 sieve. These findings demonstrated that waste tire crumb rubber effectively improved vibration energy dissipation and showed considerable potential as a sustainable material for enhancing the dynamic performance of masonry mortar.

Keywords: *Mortar, Crumb Rubber, Damping Ratio, Natural Frequency, Dewesoft*

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INTRODUCTION

Mortar is an essential material in masonry wall construct Furthermoreion because it bonds individual bricks or blocks into a unified structural system. Besides providing adequate bond strength and transferring loads between masonry units, mortar also influences the structural response when the wall is subjected to dynamic loading. During its service life, masonry walls are exposed to various sources of vibration, such as traffic, construction activities, industrial machinery, strong winds, and earthquakes. These repeated dynamic loads may lead to crack development, reduce structural performance, and shorten the service life of masonry structures. Therefore, understanding the dynamic behavior of mortar is important for improving the durability and performance of masonry walls [1], [2].

One of the key parameters used to evaluate the dynamic performance of a material is the damping ratio, which indicates the material's ability to absorb and dissipate vibration energy. A material with a higher damping ratio can reduce vibration more effectively, resulting in lower vibration amplitudes and improved structural stability. Since mortar joints form an integral part of masonry walls, their damping properties have a direct influence on the overall vibration behavior of the structure. Consequently, studying the damping characteristics of mortar is

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essential for developing masonry systems with better resistance to dynamic loading [1], [2].

Recent studies have demonstrated that the damping performance of mortar can be enhanced by modifying its material composition. Chen *et al.* reported that mortar produced with polymer-emulsion-treated recycled brick fine aggregate exhibited improved energy dissipation because the modified microstructure increased internal friction during vibration [3]. Likewise, Chen *et al.* found that recycled brick fine aggregate treated with polymer emulsion significantly enhanced the damping performance of mortar under cyclic loading while maintaining satisfactory mechanical properties [4]. These findings indicate that material modification can improve the vibration resistance of mortar without compromising its structural performance.

Other researchers have focused on the application of damping materials in building systems. Seong *et al.* demonstrated that the use of viscoelastic damping mortar in composite floor systems increased the material damping capacity and reduced vibration transmission. Their study confirmed that damping-enhanced mortar can improve the dynamic performance of building components and contribute to better vibration control [5].

Experimental methods for evaluating damping characteristics have also been widely investigated. Chandan K.V. determined the damping ratio and natural frequency of engineering materials using the impact hammer method based on ASTM E756, while the vibration responses were measured using an accelerometer integrated with Dewesoft software [6], [7]. Similarly, Gu evaluated the dynamic characteristics of beam specimens using an accelerometer and vibration excitation system, demonstrating that vibration-based laboratory testing provides reliable measurements of natural frequency and damping ratio [8].

Based on these previous studies, the present research adopts the free vibration method to evaluate the damping characteristics of mortar intended for masonry wall applications. The vibration response is measured using a piezoelectric accelerometer connected to the Dewesoft data acquisition system. The recorded signals are then analyzed using the Fast Fourier Transform (FFT) to determine the natural frequency, while the logarithmic decrement method is employed to calculate the damping ratio. The findings of this study are expected to provide a better understanding of the vibration energy dissipation capability of mortar and support the development of masonry wall materials with improved dynamic performance [3]–[8].

METHOD

The overall research methodology adopted in this study is systematically illustrated in Figure 1. The experimental framework was carefully designed and developed to investigate the influence of waste tire crumb rubber incorporation on the dynamic damping characteristics of mortar specimens subjected to free vibration conditions. The research methodology involved several sequential stages, including material preparation, mix design formulation, fabrication of cantilever beam specimens, experimental setup development, instrumentation and data acquisition system configuration, free vibration testing, vibration response recording, signal processing, and dynamic parameter evaluation. During the specimen preparation stage, mortar mixtures containing different proportions and particle sizes of waste tire crumb rubber were produced under controlled laboratory conditions to ensure consistency and uniformity among all specimens. The experimental setup was arranged using a cantilever beam configuration equipped with appropriate measurement devices to capture the vibration response generated after excitation. The acceleration signals obtained from the piezoelectric accelerometer were continuously recorded through the Dewesoft data acquisition system and subsequently processed using the Fast Fourier Transform (FFT) approach to identify the natural frequency characteristics. Furthermore, the damping ratio was calculated using the logarithmic decrement method based on the decay response of the vibration amplitude. All experimental procedures were conducted following a systematic and controlled approach to minimize measurement errors and improve the accuracy, repeatability, and reliability of the obtained results.

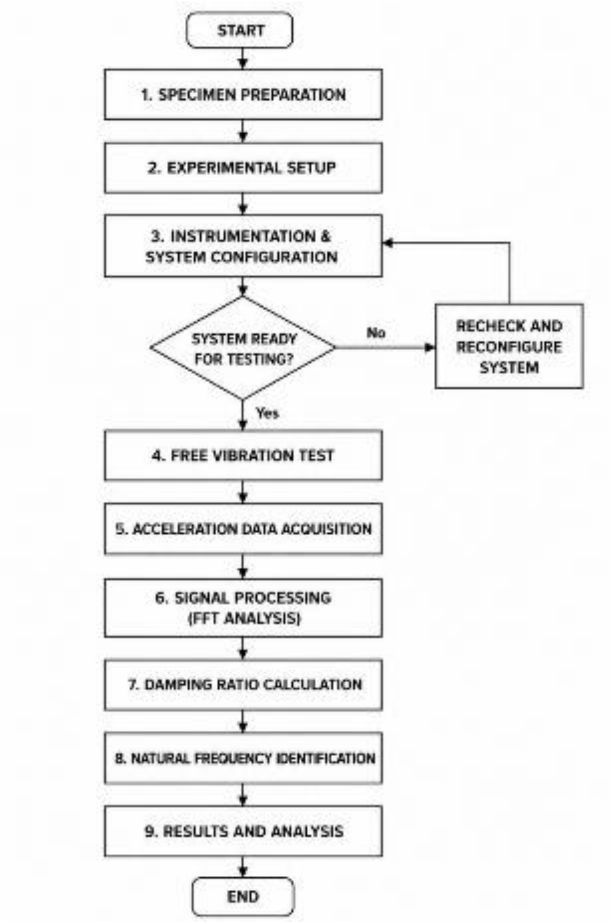

Figure 1. Flowchart of the experimental research methodology.

2.1 Experimental Procedure

The damping characteristics of the beam specimens were evaluated using the free vibration method, which is widely employed to assess the energy dissipation capacity of structural members subjected to dynamic excitation. The experimental program was conducted using a cantilever beam configuration instrumented with a piezoelectric accelerometer connected to a Dewesoft dynamic data acquisition system. The recorded acceleration signals were analyzed in both the time and frequency domains to determine the natural frequency and damping ratio of each specimen.

Prior to testing, each beam specimen was carefully inspected to ensure that no visible defects or damage were present. All experiments were conducted under identical laboratory conditions to minimize external disturbances and improve the repeatability and reliability of the measured responses. Each specimen was rigidly fixed to the supporting frame using high-strength bolts. A calibrated torque wrench was employed to apply an identical tightening torque to all bolts, thereby ensuring consistent boundary conditions throughout the experimental program and

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minimizing variations in the dynamic response caused by differences in the clamping conditions.

Figure 2 illustrates the experimental setup employed in this study. The test system consisted of a cantilever wooden beam with dimensions of 50 cm × 10 cm × 10 cm, a piezoelectric accelerometer installed near the free end of the beam, an FFT analyzer for signal processing, and a computer equipped with the Dewesoft software for data acquisition and vibration analysis. A concentrated load of 15 N was applied at the free end of the beam using a flexible cord to generate the initial deflection required for the free-vibration test.

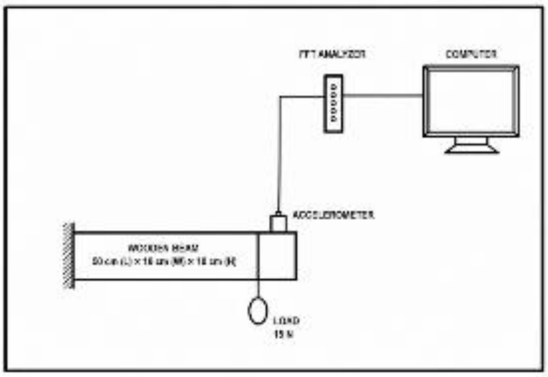

Figure 2. Experimental setup for the free vibration test of the cantilever beam.

A concentrated load of 15 N was suspended at the free end of the cantilever beam using a flexible cord to produce a controlled initial deflection. Free vibration was initiated by suddenly cutting the supporting cord with scissors while maintaining the same cutting position and release configuration for every specimen. This procedure ensured identical excitation conditions and minimized experimental variability among repeated tests.

The beam response was continuously monitored using a piezoelectric accelerometer installed near the free end of the specimen. The accelerometer was connected to the Dewesoft data acquisition system through the DEWE-USB interface. Prior to data acquisition, the hardware interface was configured in Dewesoft, and the accelerometer was assigned to Channel ID 2. The sensor sensitivity was entered according to the manufacturer's calibration certificate to ensure accurate conversion of the measured voltage signals into acceleration values. Data acquisition was subsequently performed using the Fast Fourier Transform (FFT) measurement mode, enabling simultaneous recording of the time-history response and frequency-domain characteristics of the beam. The acceleration response was continuously recorded immediately after the load release until the vibration amplitude decayed naturally to a negligible level, after which the recorded data were stored for further analysis.

To improve the accuracy and repeatability of the experimental results, each specimen was tested five times under identical loading, support, and environmental conditions. The measured responses from the repeated tests were averaged and used as representative values for subsequent analysis.

The recorded acceleration signals were post-processed using the Dewesoft software to obtain the time-history response and the frequency spectrum of each specimen. The natural frequency was identified from the dominant peak in the FFT spectrum, whereas the damping characteristics were determined from the decay of successive vibration amplitudes using the logarithmic decrement method. The damping ratio (ζ) was calculated according to Equation (1):

$$\zeta = \frac{1}{2\pi n} \ln\left(\frac{x_1}{x_{n+1}}\right) \tag{1}$$

where $\zeta$is the damping ratio, $x_1$is the first vibration amplitude, $x_{n+1}$is the vibration amplitude after $n$cycles, and $n$is the number of vibration cycles considered. The calculated damping ratios were subsequently compared among the beam specimens to evaluate their vibration energy dissipation capacity and dynamic performance.

RESULTS AND DISCUSSION

The damping characteristics of the rubberized mortar specimens were evaluated using the free vibration method. Beam specimens measuring 50 cm × 10 cm × 10 cm were prepared and tested under cantilever boundary conditions. A concentrated load of 15 N was suspended at the free end of each specimen using a flexible cord to generate the initial deflection. Free vibration was induced by suddenly cutting the cord, allowing the beam to oscillate freely. To improve the reliability and repeatability of the experimental data, each specimen was tested five consecutive times under identical experimental conditions. The vibration responses, including the natural frequency and vibration amplitude, were acquired and analyzed using the Dewesoft data acquisition system. The experimental setup for the damping test is shown in Figure 3.

Figure 3. Damping test setup of mortar specimens under free vibration conditions

The testing process was conducted using the experimental apparatus, which generated recorded data during the measurement process. The recorded data were subsequently processed to determine the damping values of each specimen. The obtained damping results represent the performance response of the tested materials under the applied loading conditions. The processed damping values from all specimens are summarized and presented in Table 1 These results provide an overview of the damping characteristics obtained from the experimental investigation.

The recorded signals illustrate the time-history response of the specimens immediately after the suspended load was released. The vibration amplitude gradually decreased with time due to the inherent damping characteristics of the mortar. This reduction in amplitude indicates that the material dissipated vibration energy through internal friction and microstructural deformation during free vibration. Variations in the rate of amplitude decay among the specimens demonstrate differences in their energy dissipation capacities, which are directly related to the damping characteristics of each mortar mixture.

CIVED
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http://cived.ppj.unp.ac.id/index.php/CIVED

The acceleration responses recorded by the accelerometer were processed using the Dewesoft software to obtain both the time-history response and the corresponding frequency spectrum through Fast Fourier Transform (FFT) analysis. The recorded waveforms were subsequently used to determine the first vibration amplitude, the subsequent vibration amplitude after a selected number of cycles, and the damping ratio using the logarithmic decrement method. Overall, the recorded vibration responses confirm that the adopted free vibration method provides consistent and reliable data for evaluating the dynamic performance and damping characteristics of the mortar specimens.

Table 1. Results of damping test for waste tire crumb rubber modified mortar specimens

Rubber Content	Redaman		Damping	
	Pass #4	Pass #8	Pass #4	Pass #8
0	2.23		2.330	2.330
	2.38			
	2.386			
20%	2.664	2.508	2.841	2.640
	2.733	2.666		
	3.125	2.747		
40%	3.59	2.797	3.718	3.066
	3.72	3.598		
	3.832	2.805		
60%	3.900	3.517	4.016	3.475
	3.988	3.193		
	4.160	3.717		

Based on the experimental results summarized in Table 1, a regression analysis was conducted to investigate the effect of crumb rubber particle size on the damping characteristics of the mortar specimens. The analysis compared two rubber gradations, namely particles passing the No. 4 sieve (4.75 mm) and the No. 8 sieve (2.36 mm), to evaluate their influence on the measured damping ratios. The regression model was subsequently used to identify the relationship between rubber particle size and damping performance, as well as to determine the optimum particle size for maximizing vibration energy dissipation. The results of the regression analysis are illustrated in Figure 4.

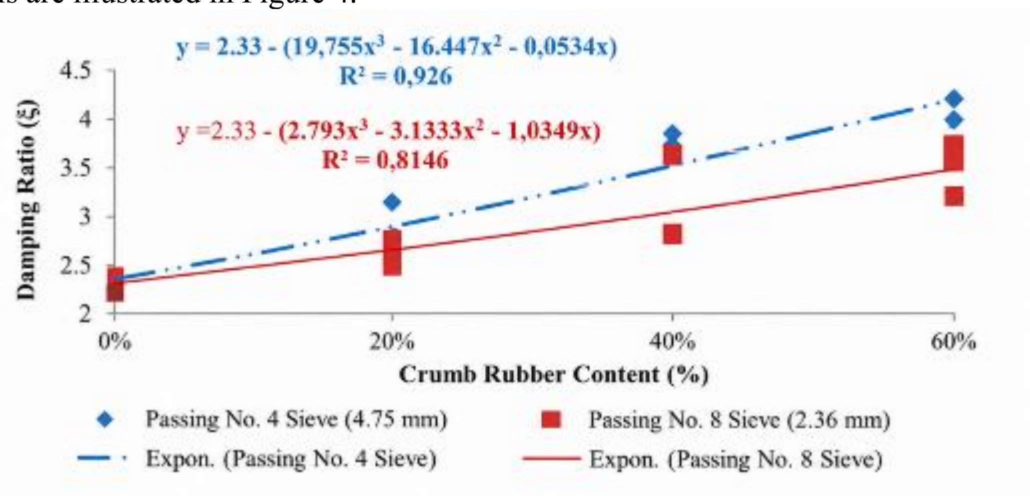

Figure 4. Regression curve of damping ratio values

CIVED
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The regression results indicate that the model for the No. 4 sieve specimens provides a stronger correlation with the experimental data than that for the No. 8 sieve specimens. The coefficient of determination (R^2 = 0.926) indicates that approximately 92.6% of the variation in the damping ratio can be explained by the variation in crumb rubber content, while the remaining 7.4% is attributed to other factors not included in the regression model. In comparison, the regression model for the No. 8 sieve specimens yielded an R^2 value of 0.8146, indicating that approximately 81.46% of the variation in the damping ratio is explained by the rubber content, whereas the remaining 18.54% is associated with other variables.

Furthermore, the comparison between the two particle sizes shows that mortar incorporating crumb rubber passing the No. 4 sieve (4.75 mm) consistently exhibited higher damping ratios than mortar containing particles passing the No. 8 sieve (2.36 mm). This finding suggests that larger rubber particles are more effective in dissipating vibration energy under free vibration conditions.

The improvement in damping performance can be attributed to the viscoelastic properties of waste tire rubber. The incorporation of crumb rubber introduces additional internal interfaces and microscopic voids within the mortar, promoting greater internal friction and energy dissipation during vibration. As the rubber content increases, the damping ratio also increases, indicating an enhanced capacity of the mortar to absorb and dissipate mechanical energy.

Moreover, the elastic and flexible characteristics of waste tire rubber enable the mortar to undergo greater deformation while storing and releasing vibration energy more efficiently. This behavior contributes to delaying crack initiation and propagation under both static and dynamic loading conditions, thereby improving the overall dynamic performance and durability of the mortar.

In addition to the damping ratio, the natural frequency of each mortar specimen was also determined from the free vibration tests. The corresponding natural frequency results are presented and discussed in Table 2.

Table 2. Natural frequency test results of mortar specimens.

Rubber Content	Frequency (Hz)		Frequency (Average)	
	Pass #4	Polos #8	Pass #4	Pass #8
0%	40.04		39.03	39.03
	35.65			
	41.40			
20%	38.10	40.10	38.47	40.55333
	39.10	40.1		
	38.21	41.05		
40%	32.37	32.96	33.766	33.04
	33.54	32.47		
	35.39	33.69		
60%	30.65	30.27	30.41333	30.72333
	29.39	32.11		
	31.20	29.79		

Based on the results summarized in Table 2, the natural frequency of the mortar specimens exhibited a decreasing trend with increasing waste tire rubber content. This behavior can be attributed to the reduction in the modulus of elasticity caused by the incorporation of crumb rubber into the mortar matrix. Since the natural frequency of a structural element is directly proportional to its stiffness, a decrease in the elastic modulus leads to a reduction in the overall stiffness of the mortar specimens. Consequently, the rubberized mortar becomes more deformable and exhibits lower natural frequencies. This observation is consistent with the viscoelastic nature of waste tire rubber, which reduces material stiffness while increasing its capacity to absorb and dissipate vibration energy under dynamic loading conditions.

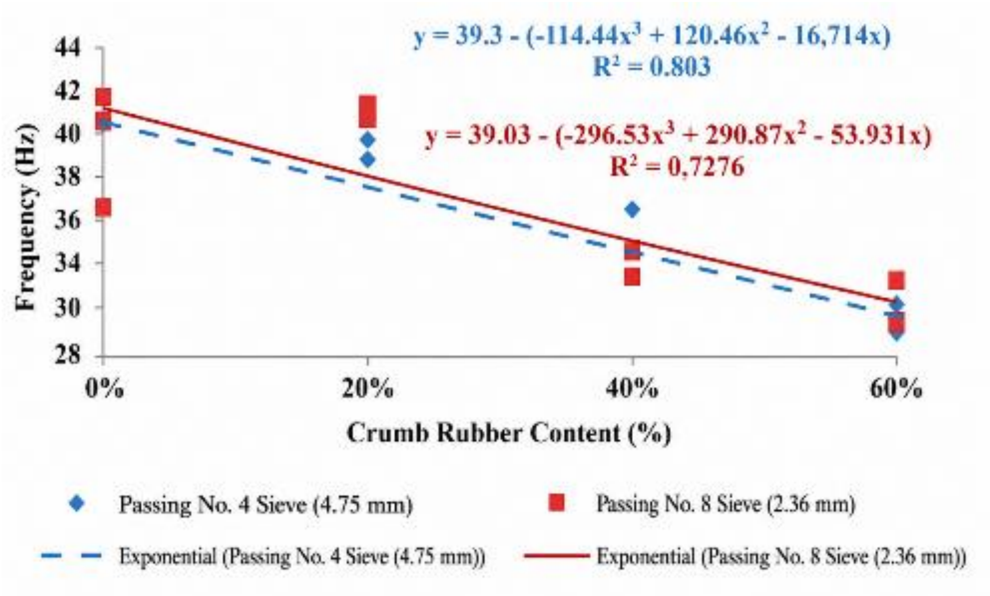

Figure 5. Regression curve of natural frequency values

Figure 5 illustrates the relationship between crumb rubber content and the natural frequency of mortar specimens containing crumb rubber passing the No. 4 sieve (4.75 mm) and the No. 8 sieve (2.36 mm). In general, the natural frequency decreased progressively as the crumb rubber content increased from 0% to 60% for both particle sizes. This trend indicates that the incorporation of waste tire rubber reduced the dynamic stiffness of the mortar specimens.

The regression analysis shows that the mortar containing crumb rubber passing the No. 4 sieve exhibited a coefficient of determination of $R^2 = 0.803$, whereas the mortar containing crumb rubber passing the No. 8 sieve produced an R^2 value of 0.7276. The higher coefficient of determination obtained for the No. 4 sieve indicates that the regression model provides a better representation of the experimental data and demonstrates a stronger relationship between crumb rubber content and natural frequency.

The continuous reduction in natural frequency can be attributed to the decrease in the modulus of elasticity caused by the incorporation of crumb rubber into the mortar matrix. Since the natural frequency of a structural member is directly proportional to its stiffness, the reduction in elastic modulus results in a corresponding decrease in structural stiffness. Consequently, mortar containing higher percentages of crumb rubber becomes more flexible, leading to lower natural frequencies.

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http://cived.ppj.unp.ac.id/index.php/CIVED

CONCLUSION

This study investigated the effect of incorporating waste tire crumb rubber with different particle sizes on the dynamic behavior of mortar through free vibration testing. The experimental results demonstrated that increasing the crumb rubber content significantly enhanced the damping characteristics of the mortar while simultaneously reducing its natural frequency. The highest damping ratio of 4.16% was obtained for the mortar containing 60% crumb rubber passing the No. 4 sieve (4.75 mm), indicating its superior ability to dissipate vibration energy. In contrast, the natural frequency decreased progressively with increasing rubber content due to the reduction in the elastic modulus and stiffness of the mortar matrix.

The improved damping performance can be attributed to the viscoelastic properties of crumb rubber, which increase internal friction and promote greater vibration energy dissipation during dynamic excitation. Furthermore, the presence of rubber particles modifies the internal microstructure of the mortar by introducing deformable interfaces that contribute to enhanced energy absorption and delayed crack propagation. Although the incorporation of crumb rubber reduces the stiffness of the mortar, the resulting increase in damping capacity provides significant benefits for structural elements exposed to repeated dynamic loading.

Among the investigated particle sizes, crumb rubber passing the No. 4 sieve exhibited a stronger correlation with the experimental results and produced higher damping ratios than the No. 8 sieve particles. This finding suggests that larger crumb rubber particles are more effective in improving the vibration attenuation capability of mortar under free vibration conditions.
The findings of this research demonstrate that waste tire crumb rubber is a promising and sustainable alternative material for enhancing the dynamic performance of mortar used in masonry wall applications. The utilization of recycled rubber not only improves vibration energy dissipation but also contributes to the recycling of end-of-life tires, supporting environmentally sustainable construction practices and circular economy principles.
Future studies should investigate the long-term durability, fatigue behavior, microstructural characteristics, and full-scale structural performance of rubberized mortar under combined static and dynamic loading conditions. Such investigations are essential to establish comprehensive design recommendations and facilitate the practical implementation of rubberized mortar in resilient and vibration-resistant masonry structures.

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