Seismic Response Elimination of Structure by Using Passive Devices: An Overview

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1 Introduction

A planet like Earth has seen several catastrophic earthquakes over the last few decades, contributing to a growing loss of human life due to building collapse and severe structural damage [18]. The occurrence of this destruction throughout disasters indicates the high potential hazard, and structures such as high rises, shelter buildings, necessary parts, and commercial buildings should be designed very attentively to protect them from earthquakes [19]. Civil engineering has now widely accepted and implemented the structural modelling approach using seismic response control [23]. In recent years, substantial attention was paid to the research and development of dynamic control methods, such as passive control systems, active control systems, and semi-active control systems to enhance the wind and seismic response of structures, bridges, and piping systems [20]. Passive control devices do not require a power source. External power and function based on structurally linked sensors are needed for active systems. Semi-Active systems having external power supply and operations using structurally assembled sensors are used to corporate passive and active control systems [1]. However, passive control mechanisms control the vibration of objects while there is no power source. For heavy wind motion and earthquakes, all control systems may be used. Various piping materials provide minimal damping to the system when the stress is within standard code limits [2].

This review paper focuses mainly on passive dampers to apply to the piping system. It only studies application, advantage, and disadvantage, i.e., merits and demerits of passive dampers to 2-D and 3-D piping system and building structures. This review paper suggests the best applicable vibrational control device by comparing various criteria, as discussed in Tables 1, 2 and 3. Also, the paper gives

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Table 1 Technical and economic comparison of dampers

Sr. No	Parameter	Damper's				
		X-Plate Damper (XPD)	Fluid Viscous Damper (FVD)	Visco-Elastic Damper (VED)	Tuned Mass Damper (TMD [17])	Multiple-Tuned Mass Damper (MTMD)
1	Complexity	Simple mechanical devices	Complex	Complex	Simple mechanical devices	Complex
2	Number of damped resonances	Damps all	Damps all	Damps only one resonance	Damps only one resonance	Damps all
3	Sensitivity to resonance frequency changes	Sensitive	Not-Sensitive	Sensitive	Sensitive	Sensitive
4	Power or Electricity [1]	Do not require. (It works even when power gets off)	Do not require power	Do not require power	Do not require power	Do not require
		However, for sensors, an external power supply is required				
5	Manufacturing cost	Low	Medium	High	Low	Medium
6	Implementation cost	Medium	High	Low	High	High
7	Mass	Proportional to vibration energy	Proportional to stiffness	Proportional to stiffness	Proportional to target mass	Proportional to vibration energy
8	Implementation	Simple	Simple	Complex (tuning)/ engineering	Complex (tuning)/ engineering	Complex (tuning)/ engineering

Table 2 Comparative study of different types of passive dampers

Sr. No	Types of damper	Capabilities	Limitations
1	X-Plate Damper (XPD)	(1) Adds extra stiffness to the system (2) X shape of the device results in constant strain variation (3) Capable of a high level of energy dissipation (4) No frequent inspection is required [14] (5) Iterative response spectrum method is the best method for seismic response prediction of a piping system [6]	(1) Natural device frequency is dependent on the original XPD stiffness of XPD (2) The Energy dispersed through a pipe structure is dependent on XPD's thickness [14] (3) Dissipated Energy in a piping device depends on the rotation of the land (4) The efficacy of XPD even reduces, dissipated by the energy of the XPD [14] (5) Energy dissipated by damper is reliant on outside seismic energy impact to the structure that is i/p ground motion [15]
2	Fluid Viscous Damper (FVD) [14]	(1) Added additional dampers increase the overall input energy entirely dissipated by the rise in damping Energy (Ed) (2) The damping coefficient and the number of structural dampers used in the building shall reduce, compared to the non-linear one that stays stable for an $\alpha = 0.2$, to more effective use of this instrument and the economy (3) Non-linear damper specifications for the FVD damping constant, 125 times less than that needed for a linear system, minimizing the overall damping force required to maintain the highest response rate	(1) Filled types of fluid affects workability of FVDs (2) Fluid speed varies with change in flow characteristics, i.e., depends on the piston's shape (3) When $\acute{\alpha} \neq 1$, then FVD is not behaving as a liner (4) Linear FVDs are disadvantageous because they do not achieve a further reduction in the system response essentially

(continued)

Table 2 (continued)

Sr. No	Types of damper	Capabilities	Limitations
3	Visco-Elastic Damper (VED) [16]	(1) Passive control systems are viscoelastic dampers (VEDs), which can be integrated with relative ease in construction systems compared with other passive monitoring devices (2) VEDs are healthy substitutes in the renovation of old or demolished buildings to base insulation (3) It was appealing for steel frame structures (4) VEDs are used as suitable damping equipment for building buildings against dynamic charges such as earthquakes and wind charges due to their cost efficiency, high reliability, and sufficient energy discharges (5) VED is widely used for aerospace and military operations also [12]	(1) VED's results vary with changes in viscous material such as co-polymer and glassy substances (2) VED's should be investigated under 2D and 3D excitation for natural earthquakes, as they may vary results for displacement, acceleration, and support reactions of the piping system (3) VEDs are sensitive to effectiveness error in the natural period of real EQ and time history data
4	Tuned Mass Damper (TMD) [7]	(1) Easy computational implementation (2) Involves no complicated mechanism [17] (3) Energy dissipation occurs by the structural motion [25] (4) Successfully implemented all over the world for buildings, bridges, other Civil, and Mechanical systems	(1) Absorber mass takes up vibratory energy, leaving the central mass (building) almost static (2) Not very useful for earthquake excitations, which occur over the wide frequency range

(continued)

an idea on technical vs economic study with consideration of the piping system's stability, strength, and structural stability.

Table 2 (continued)

Sr. No	Types of damper	Capabilities	Limitations
5	Multiple-Tuned Mass Damper (MTMD) [7]	(1) MTMDs improve the response of structures during earthquakes [22] (2) These dampers with minimizing mass would offer better control during the wide range of frequency and eliminate the waste space during the installation of MTMDs (3) MTMD has created the uniform distribution of masses for economic reason (4) MTMDs are simple, more economical, and more authentic tactics for structural vibration control	(1) It is prone to error efficiency in the system's standard frequency and damping ratio (2) MTMDs damps response of the system over a particular bandwidth of frequencies

2 Literature Review

Structural management systems improve structures' power losses during shaking by transforming motorized energy into thermal energy. The following are various types of mechanisms for energy dissipation:

2.1 *Passive Response Control Systems*

Kumar et al. [16] commented that due to the increasing number of destructive earthquakes, research and seismic response control systems' production has taken on primary importance [21]. Passive control systems are now available worldwide, and thus accurate, useful, and economical devices and component modelling continue to be established in this domain for research. This document starts with the definition of static, active, and semi-active control systems and their contrast. In comparison, passive control mechanisms have benefits over others. A literature review of passive devices covers the devices' recorded history, complex nature, research, and study of these instruments integrated into the structural models. These systems' benefits and drawbacks are often addressed in several structures when retrofitting structures and first and recent implementations. The passive reaction control systems mentioned contain viscoelastic dampers, damping, viscous damping, friction dampers, modified mass dampers, tuned liquid dampers, tuned column dampers, super elastic

Table 3 Comparative performance of dynamic vibrational control passive devices

Damper	Criteria			
	Seismic and vibrational response elimination effect	Displacement reaction of structure	Energy acceleration displacement by the structure	Support Reactions
Tuned Mass Damper (TMD) [17]	(1) Impact sensitivity to a structure error or one in the TMD damping ratio (2) XPD is made up of Aluminum or steel, effectively minimizing the building's seismic response [15] (3) XPD is also more effective against blast load and seismic load. It decreases structural response, i.e., maximum displacement and story displacement [12]	(1) TMDs are less effective than MTMDs for reducing displacement and accelerating the complex piping system	(1) As compared to MTMDs, having less capability to energy acceleration displacement by structure	(1) TMDs are less effective than MTMDs for reducing the support reaction of the complex piping system
Multiple-Tuned Mass Damper (MTMD) [14]	(1) The use of MTMD for different characteristics has been proposed to improve the seismic response elimination of piping systems	(1) Displacement of a node of the piping system up to 29% in X and Z direction (2) MTMDs are more helpful in reducing displacement, acceleration of the complex piping system	(1) Significantly more Energy acceleration displacement by the structure as compared to a single TMD	(1) MTMDs are more advantageous than TMDs for reducing the support reaction of the complex piping system

(continued)

Table 3 (continued)

Damper	Criteria			
	Seismic and vibrational response elimination effect	Displacement reaction of structure	Energy acceleration displacement by the structure	Support Reactions
X-Plate Dampers (XPD) [14]	(1) Acceleration response reduction up to 44% (2) XPD decreases the seismic response of the pipe structure more efficiently (3) Vertical damper is more effective than a horizontal damper	(1) XPD effectively reduces displacement of inelastic behavior of the chosen structure and dissipates the i/p seismic energy of the structure [13] (2) More adaptive to a and b with a lower answer observed at a higher value of b (3) The pipe system's response has decreased to = 40 mm and t = 3.5 mm (4) The reaction reduces as the XPD's thickness increases	(1) In the operated piping device, the maximum energy is dissipated by XPDs (2) In contrast to Horizontal XPDs, higher Energy is consumed by vertical XPDs (3) The Energy of XPD distributed by the piping structures will depend on the XPD's thickness (4) The Energy of XPD distributed through the piping device is dependent on the feedback of the ground motion data (5) For XPDs with a lower value of one (i.e., half the height of XPDs and a higher value of b), a proportion of Energy dissipated by XPD is higher in a regulated piping device	(1) Significant reduction of support reaction up to 50% of without damper

(continued)

Table 3 (continued)

Damper	Criteria			
	Seismic and vibrational response elimination effect	Displacement reaction of structure	Energy acceleration displacement by the structure	Support Reactions
Elasto-Plastic Damper (EPD) [10]	(1) Response reduction is about 40% (2) EPD used to decrease the seismic response of the piping system [9] (3) It is an improved and cost-effective substitute for costly snubbers [9]	(1) Displacement at the horizontal damper's damping location is about $\frac{1}{3}$ rd—the displacement at the damper location of the vertical damper	(1) Significant amounts of Energy consumed by longitudinal damping deformation on the X-Plate	(1) Multiple Elasto-plastic dampers can be effectively applied for reducing the response of support reaction of the complex piping system subjected to 3-D EQ excitation
Fluid Viscous Damper (FVD) [14]	(1) Initial value of the damping coefficient (cd/cp) up to 5 rates of response reduction significantly. While the lower rate of reduction for further increases in the value of (cd/cp)	(1) Reduced from 0 to 20 in various time histories to improve the damping coefficient ratio (cd/cp)	(1) Important decrease in acceleration, moving, and reaction help for an FVD piping structure (2) Hysteresis loop shows Energy absorbed by the damper was good [24]	

Note Where a = breadth of dampers and b = width of dampers, (cd/cp) = damping coefficient dampers, such as memory metal dampers, and insulators. Active variable stiffness (AVS) systems using stand-by bracings, locking, and unlocking devices effectively minimize inter-storey drifts [4].

2.2 Passive Devices

Kumar et al. [14] suggest X-plate damper, viscous damper, viscoelastic damper, tuned mass damper, and a variety of tuned mass dampers among many passive control devices, and they are used for minimizing the 3-D pipe seismic reaction. Detailed experiments in this paper investigate the efficacy of dampers in 3-D piping structures exposed to the high intensity of artificial earthquakes. Compared with the similar scientific findings available on the Wen model, the scientific results indicated that this was in line with the X-plate's planned damping study. There is a significant reduction in the seismic interest response, such as relative propagation, acceleration, and assisting passive instrument pipes' responses. In general, passive devices are wildly successful and can be used for seismic response elimination, vibratory control, and the seismic reclassification of piping structures under some optimum criteria, including steepness damping.

2.3 Passive and Semi-active Devices

Kumar et al. [16] in their article aim to minimize seismic response and vibration regulation of piping systems in operation, fossil fuel industry, and passive and semi-active supplementary instruments. This article discusses an analysis of passive or semi-active additional systems' efficiency because of improvements in equipment parameters, various damper control algorithms, and the resulting optimal unit parameters. These instruments' efficacy in minimizing the piping system's reactions is tested by contrasting unregulated reactions with growing amplitudes under four distinct artificial earthquake motions. The findings revealed that the seismic response reduction, vibrational regulation, and seismic requalification of the piping structures with specific optimal parameters are highly successful and are feasible.

2.4 Tuned Mass Dampers (TMDs)

Rahimi et al. [17] studied various vibration control devices. Because of the growing demand for buildings and high-rise buildings, it seems more necessary than ever to manage the structural vibrations under earthquake and other external dynamic forces. The vibration control instruments can be divided into passive control schemes, active, and hybrid. Popular technology for managing vibrations, minimizing damage, and

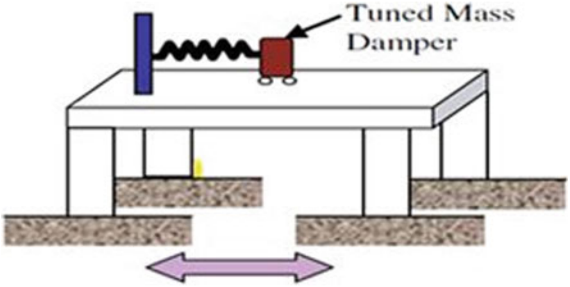

Fig. 1 Tuned mass damper and direction of displacement [11]

enhancing structural stability usually involves damping, vibration insulation, and management of excitation forces and vibration absorbers, but not limited to them. Due to their very basic concepts and relatively short performance optimization, tuned mass dampers (TMDs) have become a common means for protecting structures from unexpected vibrations, as demonstrated in many successful recent applications. This study provides fundamental analysis and compares the performance and comparative advantages and drawbacks of active, passive, foundational, and hybrid TMD control systems to protect buildings against earthquake or wind strength.

Notwithstanding the significance and recent development in this area, previous reports concentrated mainly on passive or active TMDs. Thus, this analysis examines the historical context of all forms of TMDs and the structural, methodological, functional, and economic variations in their systemic management implementation. Furthermore, a variety of knowledge limitations in the current studies within the field of study are identified and stressed. Between these research boundaries, we find that existing practices need to be strengthened to assess TMDs principal natural occurrence. Moreover, more sophisticated analytical methods for TMD and structures that take their non-linear behavior into account are increasingly needed, as this may significantly increase the forecasting of structural reaction and, in turn, maximize TMD. Figure 1 shows an actual configuration of TMD.

2.5 X-Plate Damper (XPDs)

Reddy et al. [8] studied the application of various dampers and discussed the elastic–plastic pressure of additional metal components with plastic deformation properties as the most efficient method for dissipating energy in a vibrant environment. An X-plate damper (XPD) is a system able to tolerate several periods of steady outcomes in high energy dissipation or damping. The paper focuses on numerical studies investigating the seismic effectiveness of an XPD on tubing, especially for industrial plants or facilities such as atomic and nuclear power plants, such as the chemical and petrochemical industry. In subjective floor motions, the pipes' seismic activity is measured by significant parametric changes of the damper properties (e.g., height, width, and thread of XPD). Research is reported on an XPD-equipped industrial piping system,

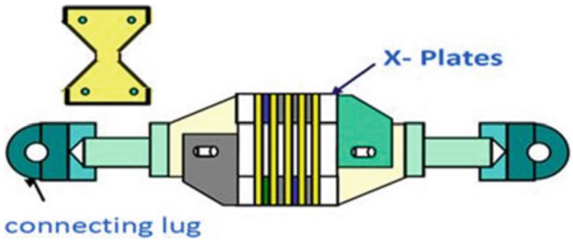

Fig. 2 Schematic representation of XPD [9]

and the respondent interest quantities include relative displacements, absolute accelerations, and piping system supporting responses. To calculate the XPD's earthquake performance, the managed device's sensitive volumes (XPD) are compared with the corresponding unregulated (XPD) pipe networks. The earthquake discharge in the piping system represented by the hysterical energy of the XPD is also measured and equal. The seismographic responses of piping systems can be studied very effectively by XPDs. Also, parametrically changing XPD characteristics and manipulating pipe system responses are challenging to achieve the desired XPD properties for a given piping system and ground movements. Hysteretic energy dissipation is then recommended to be used by an XPD to achieve the optimal XPD characteristics. The impact of the XPD features on the piping system's free vibration characteristics, which are critical for the design of piping systems using XPD, is also presented.

As shown in Fig. 2, XPD combines single or multiple X-Plate combinations [3]. A review of the XPD-type research revealed that XPDs are mainly used in vibration management science and typically found on the structures' top floor. XPDs are especially strong for lightweight systems under wind excitement. Regarding XPDs' performance during the earthquake powers, it is weaker because not all modes of fundamental structural frequencies have been taken into account, and it is only tuned to the dominant frequency and is prone to uncertainty.

2.6 Elasto-Plastic Damper (EPD) and Form Memory Alloy Damper (SMAD)

Parulekar et al. [10] observed snubbers in piping systems of the nuclear power plants as they are costly, complicated, and need regular maintenance. Efficient, simple, economical, and trustworthy passive dampers like Elasto-Plastic Damper (EPD) and Form Memory Alloy Damper (SMAD) are inexpensive. They can be used to replace snubbers in piping systems because they preserve pipe stability and improve damping. A complicated piping model having internal pressure with and without two EPDs on the shake table is evaluated in this paper to measure the efficacy of multiple elastoplastic dampers in practical piping structures with 3-D earthquake excitation. Tests are often carried out with pipings only with a vertically attached EPD and only a horizontally bound EPD. Newark's time integration method performs linear and non-linear dynamical analysis of the piping system.

2.7 Viscoelastic Damper

Umachagi et al. [1] studied friction dampers as a robust friction system in energy dissipation. VED consists of a viscoelastic layer bonded with a steel plate with viscous material, i.e., Co-Polymers or Glassy Substances [1]. The simple steel structure behaves partially as a friction damper under seismic pressure. Experimental and computer findings indicate that the friction damper will improve the vibrational reaction to conventional architecture in innovative designs and the effectiveness of existing buildings when subjected to ground movement and friction to investigate the piping process. Dampers are effective based on their degree of excitation and environmental temperature. With the elevated temperature, energy dissipation reduces proportionally. Also, the authors correctly estimated the seismic response of structures using the stress-energy approach at different temperatures. Figures 3 and 4 show an assembly model of VED.

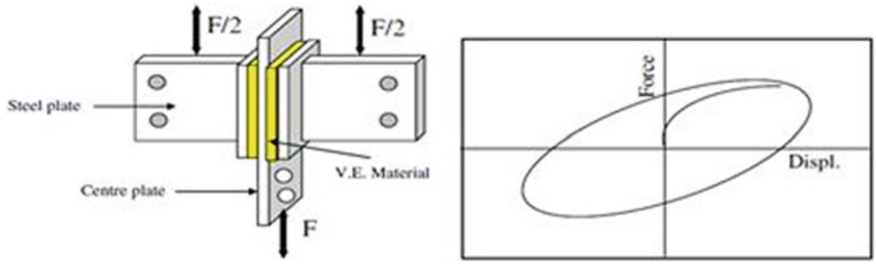

Fig. 3 Assembly model of VED and hysteric loop graph [11]

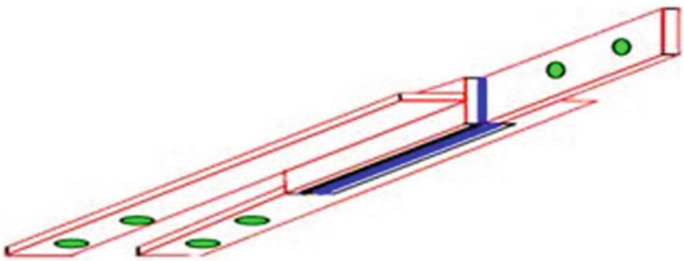

Fig. 4 Assembly model of viscoelastic dampers [13]

3 Practical Applications of Passive, Active, and Semi-active Dampers

3.1 Practical Applications of Passive Control Devices

(1) The lead-rubber bearing is the choice in Japan, the USA, and New Zealand, while vicious and steel hysteretic dampers are used in Italy.
(2) In the USA, the application has been mostly retrofitted to current structures with a seismic exclusion system, including Oakland's City Halls (LRB), Los Angeles (HDRB), San Francisco (LRB), San Francisco US Court of Appeals (Friction Pendulum).
(3) Two major earthquake isolation projects have been completed in New Zealand. This consisted of the restoration of the NZ Parliament building's separation, the corresponding Assembly Library, and the current NZ Museum. In this system, LRB is used.
(4) The US Club of Teaching Hospital in Los Angeles (LRB) in 1994, the Ministry of Post and Teleggy's data center (LRB) in 1995, and the Matsumura Science Institute building in Kobe in 1995 were the extraordinary success of three isolated buildings during earthquakes. These three buildings demonstrate the tremendous benefits of seismic isolation in actual earthquakes that these systems will continue to function without any disruption during and directly after an earthquake.

3.2 Practical Applications of Active Control Devices

(1) AMD at Chuo-Ku, Tokyo's 4 m frontages, with a total height of 33 m, is located inside Kyobashi Seiwa house. The 11-story structure consists of rigid steel panels. The upper floor is spaced apart with two AMDs. The first AMD is 4-tonne weight, and the second has 1-tonne weight. Two AMD's were also intended to monitor the structure's torsional reaction. A hydraulic pump of 22 kW powers the masses. On the 6th floor and the 11th floor, the controls are located in the basement. On the first level, the machine is supplied. It is the first AMD on the house in the world.
(2) Deux is situated in Chiyoda-Ku, Tokyo, on ANDO Nighikicho. It is constructed of solid steel frameworks and has 14 floors and two floors of the basement. The weight of the construction is 2600 t-f above the ground. Two-way AMD is positioned at the top of a TMD on the top floor of the building. A petroleum damping system damps time. The TMD is 18 t-f, and the AMD's have two t-f each. The Deux method uses the idea that the TMD has the minimum power, at least if the active control system fails.
(3) Shinjuku Tower's Trigon is situated in the 264.100 m^2 floor area of Tokyo's Shinjuku-Ku Tower. The construction is made of steel and concrete frameworks

partly strengthened. There is a building of 52 floors plus five basements with an overground weight of 130,000 t-f. The roller pendula weight on the 36th floor is mounted on three control systems. Every control weight is 110 t. The pendulum has an overall length of 110 cm. The modified time is 3,7258 s, with a pendulum engine power of 75 kW.

3.3 Practical Applications of Semi-active Control Devices

(1) The first semi-active controlled 5-story Kajima Shizuoka Building was constructed in Shizuoka, Japan, in 1998. Each damper can develop a maximum damping force of 1000 KN.
(2) In Osaka, Japan, a 27-story Luxa Osaka building was constructed in 1999 and employed semi-active TMD.
(3) An 11-story building, CEPCO Gifu constructed in Gifu, Japan in 2000, used semi-active dampers.

4 Conclusions

Every passive device has been used for different piping system geometry, support condition, and EQ forces. The permanent consideration for analysis depends on the minimum optimal response in support, displacement, and accelerations. The minimum optimal parameter will be, to some extent, varying with types of industrial problems. Hence, for minimum optimal solutions, every type of analysis is required to be done. It has been observed that:

(i) Passive dampers effectively decrease the bending moment, shear force, and effectively increase the structure's axial force [13]
(ii) Viscous, Viscoelastic, and X-plate dampers can reduce the seismic responses of the piping structure more effectively [26]
(iii) MTMD and TMD frequency changes with the fundamental model frequency of the piping system [7]
(iv) MTMD and TMD are less powerful to minimize the seismic reaction of the piping system than other passive instruments [7]
(v) Hence, the piping system is made per industrial demand to meet seismic and vibrational control of the complex piping system. For that purpose, X-Plate damper, VDs, and VEDs are more preferable.
(vi) VDs are not affected by natural frequency, but on the other hand, VEDs are affected by the same.

This article has observed that active TMD performance is significantly better than passive TMDs in reducing the structural response, particularly in storage displacement. Even when the dominant excitation frequency is similar to the framework's fundamental frequency, the active TMDs showed good quality. Active TMDs for human relaxation modes such as hear and torsional modes should also be considered. All these recommendations endorse active TMDs in contrast to passive TMDs as the optimal alternative. However, it should be noted that while AMDs are comparatively cheaper, they have higher running costs, mainly as a result of the energy source needed for their activation [25].

The appropriate design and implementation of MTMDs for adequate damping, and the required mass ratio for torsional and shear modes in structures are vital topics frequently overlooked in the literature. MTMDs value is that the optimum parameters can be better obtained due to their spatial distribution, but it was evident that experimental evidence on their optimal architecture and operation is minimal [7].

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