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Analysis of Landslide-Prone Areas using the Microtremor Method in the Mandeh Region, South Coast of West Sumatra

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Abstract: Landslides are the downward movement of masses of soil and rock caused by slope instability. The instability develops when the balance of forces acting on the slope is disturbed. Mandeh area is one of the areas frequently affected by landslides. Based on these issues, mitigation efforts are needed to minimize losses due to landslides, which can be identified using the Microtremor method based on dominant frequency, amplification, and the seismic susceptibility index. The collected microtremor data were processed using the Horizontal to Vertical Spectral Ratio (HVSR) method to obtain dominant frequency, amplification factor, shear wave velocity, and seismic vulnerability index values, which were then used to assess landslide susceptibility in the study area, with data collection conducted directly in the study area. Landslide-prone areas in the Mandeh area, Koto XI Tarusan District, were identified as areas with dominant frequencies of 0.1 Hz – 3.85 Hz, amplification factors of 3.41, 3.67, 4.78 and 5.331, shear wave velocities of 120 m/s – 170 m/s, and seismic vulnerability indexes of 3.17537–5.456896. The areas that meet these criteria are located at research points TP2, TP7, T11 and TP14.

Keywords: Microtremor, HVSR, Landslide, Mandeh

1. Introduction

A landslide referrers to the displacement or ground movement -supporting material in the form of rocks, soil, and debris (a mixture of soil and rock grains) that moves down or out of the slope [1]. The principle of a landslide occurs when the force pushing on a slope exceeds the force holding it back. Rock strength and soil compaction contribute to the resisting force that maintains slope stability, while slope angle, groundwater conditions, additional loads, and the specific gravity of soil and rock materials increase the driving force acting on the slope [2]. According to [3], Natural factors include high rainfall intensity, which can erode the soil, resulting in landslides, or possibly

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due to subsurface lithology that forms an impermeable layer. Man-made factors include illegal logging, which leaves tree roots unable to support a slope, which can lead to landslides.

Pesisir Selatan Regency is an area located in the western part of West Sumatra Province, characterized by hilly terrain and steep slopes. Pesisir Selatan Regency experiences high rainfall intensity [4]. One area in Pesisir Selatan that has experienced landslides is Nagari Mandeh, located in Koto XI Tarusan District, Pesisir Selatan Regency, West Sumatra. Nagari Mandeh is dominated by hilly landscapes with steep slopes and variable elevations, creating geomorphological conditions that favor landslide occurrence, particularly during periods of high rainfall intensity or when slope stability is compromised. The slope of the Mandeh area ranges from flat to steep, with a gradient>40%. Based on geological maps, the South Coast has orgonosol, alluvial, regosol, andolos, postdolic, and latosol soil types. In the Mandeh area, the soil types are alluvial (Qal) and volcanic rock (Tomv).

One example is the landslide disaster that occurred in Pesisir Selatan Regency on March 7-8, 2024, resulting in casualties and traffic disruption [5]. If the risk of landslides is not addressed early, human activities such as construction and tourism development can worsen the soil conditions, increasing the risk of future landslides. Disaster mitigation is an effort that can be made to reduce the impact of disasters. One method in disaster mitigation is by identifying areas prone to landslides. The method in identification is carried out using the microtremor method. The microtremor method is a method based on the dominant frequency value of the soil and its amplification factor, producing a soil vulnerability index value that can be processed using the HVSR (Horizontal to Vertical Spectral Ratio) method to determine the structure of the soil layer. Microtremor measurements play an important role in efforts to mitigate earthquakes and landslides. This method is usually used to estimate the level of damage caused by earthquakes and can also be used to determine the condition of underground structures based on the dominant frequency and its amplification factor[6]. The HVSR method is a method available for grouping microtremor data by comparing the horizontal component of the microtremor signal to the vertical component. The processing result of this method is an H/V curve whose peak shows local information (site effect) in the form of dominant frequency values and amplification factors of waves recorded in the ground [7]

The results of several research studies[8], [9] in the Mandeh area and its surroundings have examined the threat of landslides based on geological conditions, slope morphology, rainfall intensity and land use characteristics. The results of this study have succeeded in identifying factors that contribute to the occurrence of landslides. However, information regarding the dynamic characteristics of the subsurface is still limited. There is a lack of studies regarding the evaluation of dominant frequencies, amplification factors, and seismic vulnerability indices using microtremor measurements in the Mandeh area. Therefore, microtremor measurements using the Horizontal to Vertical Spectral Ratio (HVSR) method are needed to characterize subsurface conditions and support a more comprehensive assessment of landslide susceptibility in Nagari Mandeh.

2. Materials and Method

This research used a quantitative methodology and was conducted in Mandeh, Koto XI Tarusan District, Pesisir Selatan Regency.

2.1. Data Collection

The research was conducted in Mandeh, with 16 data collection points, spaced 200 to 400 meters apart, and each measurement at a point lasted approximately 40 minutes. A map of the sampling locations in Nagari Mandeh can be seen in Figure 1.

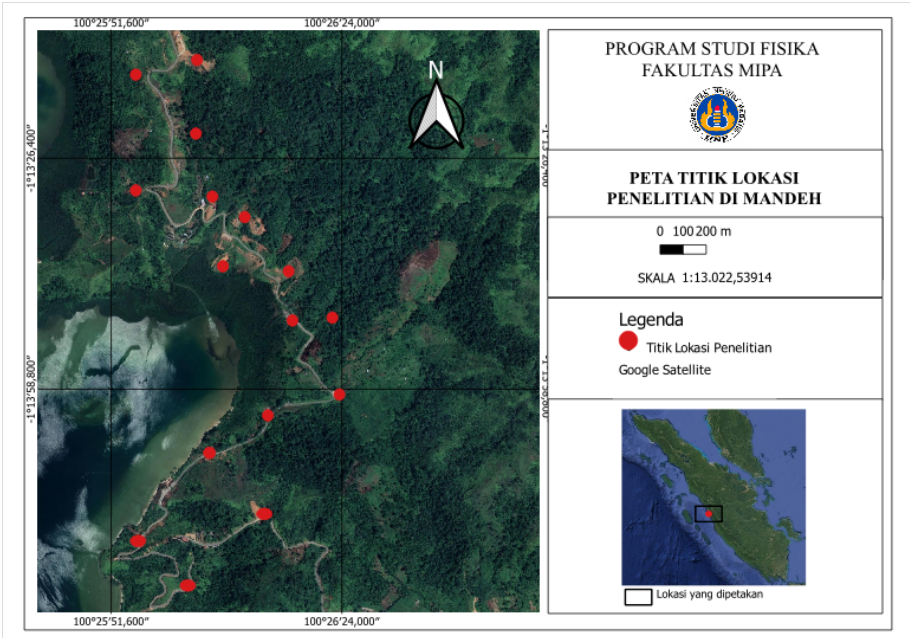

Figure 1. Research Location in Nagari Mandeh

Data collection was carried out using a set of 3D-MAE and Sysmatrack-M.AE Seismographs at 15 research points with a spacing of ±400 meters and using a sampling frequency of 200 Hz[10]. The data collection technique followed SESAME instructions. The average collection time from each research point was approximately 40 minutes. The S3S type seismometer is a tool designed to detect and record ground vibrations caused by earthquakes, equipped with measurement time information. In addition, the equipment used consisted of a laptop, connecting cables, GPS, and a compass. The data obtained was recorded as signal data in *SAF format. Microtremor data from the research was then processed using the HVSR method using Easy HVSR software. The result of this processing is an H/V curve that can show the dominant frequency and amplification factor at a research point.

2.2. Data Processing Techniques

Microtremor data processing refers to the SESAME European Research standard [11]. The microtremor signals obtained from the measurement results are processed using Easy HVSR software. This processing aims to eliminate noise in the microtremor data. The results of microtremor recording are in the form of signal data in sg2 format. Furthermore, the data is analyzed using the HVSR method by comparing the vertical and horizontal signal components using equation (1).

$$HVSR = \sqrt{\frac{[(S_{North-South})^2 + (S_{East-West})^2]}{S_v}} \quad (1)$$

where S_(North-South) is the amplitude spectrum of the north-south component, S_(East-West) is the east-west amplitude spectrum, and S_v is the amplitude spectrum of the vertical component. The processing results are in the form of an H/V curve which shows the dominant frequency value and amplification factor.

3. Results and Discussion

The results obtained from this study are the dominant frequency value (f0), amplification factor (A0), seismic vulnerability index (Kg), and shear wave velocity (Vs) in Nagari Mandeh, Koto XI Tarusan District.

3.1 Dominant Frequency

The dominant frequency or natural frequency is the frequency value that often appears so that it is recognized as the frequency value of the rock layer of the region so that the frequency value of the rock layer of the region so that the frequency value can indicate the characteristic value of the rock [12] Soil classification based on the dominant frequency value can be classified in the following Table 1.

Tabel 1. Soil Classification Based on Dominant Microtremor Frequency Values by *[13]*

Soil Classification Type	Type	Dominant Frequency	Soil Classification	Soil Description
I	IV	<2,5	Alluvial rocks formed from deltaic sedimentation are dominated by surface soil and mud layers that extend beyond a depth of 30 m.	Surface sediments in the study area exhibit substantial thickness.
II	III	2,5 - 4	Alluvial materials with a thickness greater than 5 m are dominated by sandy-gravel deposits, hard sandy clay, and loam.	The thickness of the surface sediment layer is estimated to range from 10 to 30 m, indicating a thick sedimentary cover.
III	II	4 -10	A 5 m thick alluvial deposit underlies the area and is composed of sandy gravel, hard sandy clay, and loam.	Surface sediments in the study area are classified as moderately thick, with thicknesses estimated at approximately 5–10 m.
IV	I	6,667-20	The subsurface is underlain by Tertiary or pre-Tertiary rocks consisting mainly of hard sandstone, gravel, and other resistant rock materials.	The sediment cover in the study area is minimal, and hard rock formations prevail beneath the surface.

According to [14], a high dominant frequency (f_0) is indicative of shallow, competent bedrock conditions, whereas a low dominant frequency (f_0) commonly corresponds to thick and relatively soft sedimentary deposits. The distribution of dominant frequency values is spread across several points in Nagari Mandeh as shown in Table 2.

Tabel 2. Classification of fo values in Nagari Mandeh

Research Focus	**Classification Type**	**Type**	**f_0**	**Kanai classification**	**Description**
T1, T9, T11	IV	I	6,667-20	The subsurface is underlain by Tertiary or pre-Tertiary rocks consisting mainly of hard sandstone, gravel, and other resistant rock materials.	The sediment cover in the study area is minimal, and hard rock formations prevail beneath the surface.
T3, T4, T7, T13	III	II	4 - 6,67	A 5 m thick alluvial deposit underlies the area and is composed of sandy gravel, hard sandy clay, and loam.	Surface sediments in the study area are classified as moderately thick, with thicknesses estimated at approximately 5–10 m.
T2, T5, T6, T8, T12, T14, T15	II	III	2,5 - 4	Alluvial materials with a thickness greater than 5 m are dominated by sandy-gravel deposits, hard sandy clay, and loam.	The thickness of the surface sediment layer is estimated to range from 10 to 30 m, indicating a thick sedimentary cover.
T10	I	IV	<2,	Alluvial rocks formed from deltaic sedimentation are dominated by surface soil and mud layers that extend beyond a depth of 30 m.	Surface sediments in the study area exhibit substantial thickness.

The dominant frequency values obtained are used to create a distribution map of dominant frequency value which can be seen in Figure 2. In the map in Figure 2, areas with low dominant frequencies are indicated by a blue gradient with a dominant frequency value of <2.5 Hz and green with a dominant frequency of 2.5 Hz to 4 Hz. Low dominant frequency values reflect the existence of thick sedimentary layers composed of relatively soft subsurface materials. Then a relatively moderate dominant frequency in the area is indicated by an orange gradient with a dominant frequency value of 4 Hz to 6.67 Hz. Areas with high dominant frequencies are indizated by red with a dominant frequency value of 6.667 – 20 Hz. At high dominant frequency values, they are included in the category of type I and type IV which consist of hard sandy rocks, gravel, and others, and are composed of thin sediment thickness and are dominated by hard rocks.

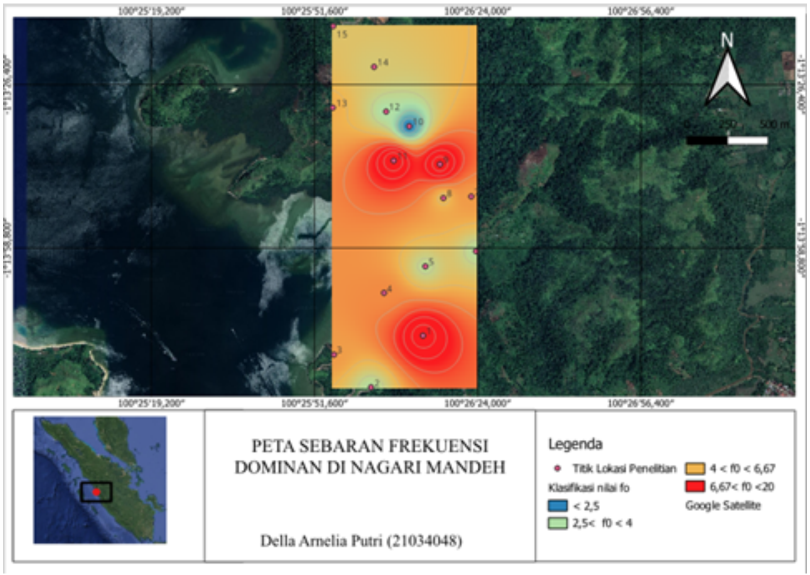

Figure 2. Map of the distribution of dominant frequency values in Nagari Mandeh

3.2 Amplifikasi (A0)

Amplification is the process by which seismic wave amplitudes increase due to significant contrasts in the elastic properties of subsurface materials. This phenomenon is typically observed when seismic waves propagate from a stiffer medium to a softer and less consolidated layer [15]. The amplification factor values are grouped into four zones: low, medium, high, and very high. The amplification values are classified in Table 3 below:

Table 3. classification of amplification values

Zone	Classification	Amplification factor value
1	Low	$A < 3$
2	Currently	$3 \leq A < 6$
3	High	$6 \leq A < 9$
4	Very high	$A \geq 9$

The soil amplification value is related to the impedance contrast between the surface layer and the underlying layer. If the impedance contrast is high, the amplification factor will also be high, and vice versa [7]. The amplification value from the Mandeh Area measurements can be seen in Table 4.

Table 4. Amplification Factors in Nagari Mandeh

Research Focus	Zone	Amplification factor value	Classification
T1, T4, T5, T6, T8,T9, T10, T12, T15	1	A< 3	low
T2, T3, T7, T11, T13, T14	2	$3 \leq A < 6$	Currently

These results indicate that the study area is divided into three zones based on amplification values: low, medium, and high. The obtained amplification values were then used to create a distribution map, as shown in Figure 3.

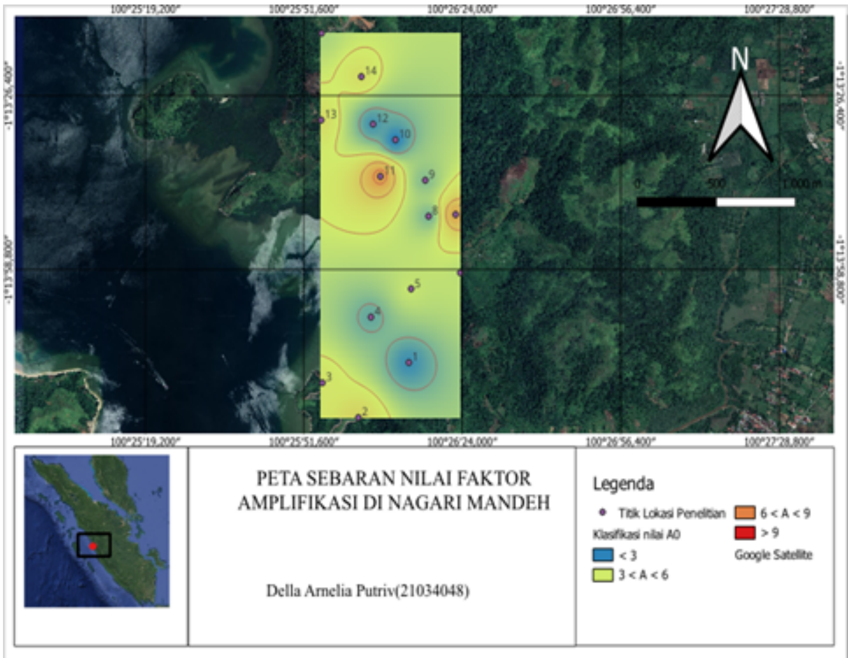

Figure 3. Distribution Map of Amplification Factor Values in Nagari Mandeh

The amplification factor values in Nagari Mandeh range from 1.161 to 5.331, with the lowest value at point T10 and the highest value at point T11. Based on the classification of amplification factor values, the study area can be divided into two zones, namely the low zone and the moderate zone. The study area with amplification factor values ranging from 1.161 to 2.87 is in Zone 1, with low amplification factor values at points T1, T4, T5, T6, T8, T9, T10, T12, and T15. The zone 2 area has moderate amplification factor values ranging from 3.24 to 4.28, covering research points T2, T3, T7, T13, and T14.

3.3 Seismic Vulnerability Index

The seismic vulnerability index indicates the ability of the surface soil layer to resist deformation. The value of the seismic vulnerability index indicates the stability of the soil structure; the higher the value of the seismic vulnerability index, the lower the stability of the soil structure. The seismic vulnerability index value is influenced by the dominant frequency value and the amplification factor value. The seismic vulnerability index value in Nagari Mandeh varies from 0.220162 to 5.456896 based on the analysis results in Table 5 .

Table 5. Seismic Vulnerability Index Nagari Mandeh

Research Focus	**Zone**	**Kg**	**Classification**
T1, T3, T4, T5, T6, T8, T9, T12, T13, T15	1	<3	Low
T2, T7, T10, T11, T14	2	$3 \geq A > 6$	Currently

Research points T1, T3, T4, T5, T6, T8, T9, T12, T13, and T15 have the lowest seismic vulnerability index values, ranging from 0.220162 to 2.94175. Research points T2, T7, T10, T11, and T14 have moderate seismic vulnerability index values, ranging from 3.17537 to 5.438224.

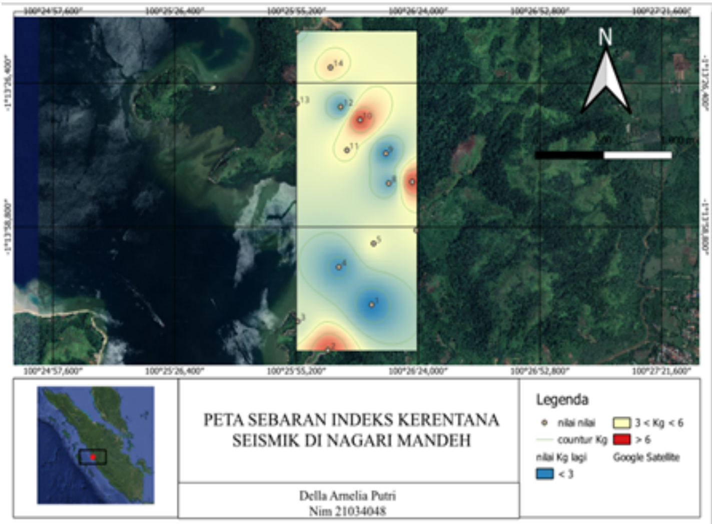

Figure 4. map of the distribution of seismic vulnerability index values in Nagari Mandeh

Based on the earthquake vulnerability index distribution map in Figure 4, it can be seen that the study area, based on the earthquake vulnerability index classification [18] in Nagari Mandeh, is dominated by a low earthquake vulnerability index, with values ranging from 0.220162 to 2.94175, marked in blue. This means that the study area has relatively thin sediment layers, indicating a low level of vulnerability. The earthquake vulnerability index is moderate, ranging from 3.17537 to 5.438224, indicated by a reddish-yellow color, suggesting that the soil layers in that zone begin to exhibit amplification in response to earthquake shaking. Moderate to high earthquake vulnerability index values indicate that the area has a higher potential for hazard and a greater risk of building damage during an earthquake.

The seismic vulnerability index can indicate the vulnerability of an area affected by earthquakes or rock layer movements. Based on the data obtained, areas vulnerable to the effects of seismic activity or rock movement are referred to as weak zones. The area with the highest earthquake vulnerability is located at the research site T2, T7, T10, T11, and T14, with a value of 3.17537 to 5.438224.. If ground movement occurs in Nagari Mande and its surroundings, the area most likely to experience landslides are those located at research points T2, T7, T10, T11, and T14. This is also supported by the presence of soft soil layers in the first to second layers.

3.4 Shear Waves

Shear wave velocity can provide information about the mechanical properties and strength of soil materials, which are very relevant in seismic risk assessment. In the National Standardization Agency category[16], it can be seen that the top layer of the research area has a Vs value ranging from 120 - 550 m / s, the second layer of the research area has a Vs value ranging from 139 - 722 m / s, the third layer of the research area has a Vs value ranging from 170 - 1040 m / s, and the fourth layer of the research area has a Vs value ranging from 170 - 1450 m / s. The following classification of soil based on shear wave velocity can be seen in Table 6.

Table 6. Shear Wave Velocity in Nagari Mandeh

Layer	Research Focus	Velocity Vs	Site Classification
L1	T1,	$350 < Vs \leq 750$	The soil is very dense and the rock is soft
	T11, T12, T13, T15	$175 < Vs \leq 350$	Medium Soil
	T2, T3, T4, T5, T6, T7, T8, T9, T10, T14	$Vs < 175$	Soft Soil
L2	T1, T11, T12	$350 < Vs \leq 750$	The soil is very dense and the rock is soft
	T4, T8, T9, T13, T14, T15	$175 < Vs \leq 350$	Medium Soil
	T2, T3, T5, T6, T7, T10	$Vs < 175$	Soft Soil
L3	T1, T11	$750 < Vs \leq 1500$	Rock
	T8, T12, T14, T15	$350 < Vs \leq 750$	The soil is very dense and the rock is soft
	T2, T3, T4, T5, T6, T7, T9,13	$175 < Vs \leq 350$	Medium Soil
	T10	$Vs < 175$	Soft Soil
L4	T1, T11	$750 < Vs \leq 1500$	Rock
	T2, T3, T5, T6, T7, T8, T9, T12, T13, T14, T15	$350 < Vs \leq 750$	The soil is very dense and the rock is soft
	T4	$175 < Vs \leq 350$	Medium Soil
	T10	$Vs < 175$	Soft Soil

Based on the results of the data analysis in Table 6 from 15 measurement points, each consisting of 4 layers and a total of 60 Vs data points—it was found that the first layer (surface) had a Vs value <175 m/s at nearly all points in the study areas TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, and TP14, indicating that the top layer is dominated by soft soil, which is prone to landslides when saturated with water and subjected to strong vibrations. Layers 2 and 3 have Vs values ranging from 200 m/s to 700 m/s. Layers 2, 3 and 4 have Vs values ranging from 200 m/s - 700 m/s, indicating medium to dense soil, which is also prone to landslides when saturated with water and subjected to strong shaking.

4. Conclusion

Based on the research results, it can be concluded that Nagari Mandeh, Koto XI Tarusan District has dominant frequency value distribution between 0.25 Hz – 8.95 Hz, an amplification factor value between 1.161 – 5.331, a shear wave velocity value between 120 m/s – 1450 m/s, and a seismic vulnerability index value between 0.220162 – 5.456896. Moderate to high seismic vulnerability is dominant in areas with steep slopes. Low dominant frequency indicates the dominance of soft sediment material with a relatively large thickness, which has the potential to reduce slope stability and increase landslide vulnerability. Furthermore, high amplification factor values indicate less stable soil conditions and are more susceptible to landslides. Landslide-prone areas in Nagari Mandeh, Koto XI Tarusan District were identified in areas with dominant frequency values of 0.1 Hz – 3.85 Hz, amplification factor values of 3.41, 3.67, 4.78, and 5.331 shear wave velocity values of 120 m/s – 170 m/s, and seismic vulnerability index values of 3.17537- 5.456896. The landslide-prone area in Nagari Mandeh, was identified as an area with low dominant frequency values, low shear wave velocity values, high amplification factor values, and high seismic vulnerability index values. The areas that meet these criteria are located at research points TP2, TP7, T11 and TP14.

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