Analytical and Experimental Study of Adobe Reinforced Walls

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SUMMARY:
In the present work, the experimental tests results and the analytical models to estimate the capacity of three different retrofitting techniques for adobe walls are shown.
In order to compare the behavior of handmade specimens and industrialized pieces, five walls were constructed, two of them, with handmade pieces and three with industrialized adobes. The first wall corresponds to non reinforced elements and the other, reinforced by confined concrete elements, for each material, the last wall was reinforced with metallic mesh.
The walls were tested under cyclic loads until their failure. After this test, the walls were retrofitted with plastic mesh and tested again. The tests were performed to study hysteretic behavior of the retrofitting techniques.
The results are presented in terms of deformation, and stiffness degradation, energy dissipation capacity, and cracking patterns.

Keywords: adobe construction, retrofitting techniques, seismic evaluation

1. INTRODUCTION

The earth as a building material has been used since the beginning of civilization, specifically the case of adobe. The adobe construction methods have little changes over time, beginning of accumulated experiences of ancient builders, the results, in some cases, deficiencies in the manufacturing process and structural construction, its cause's fast deterioration in housing and inadequate structural behavior against natural disasters such as earthquakes, floods and cyclones.

The adobe construction has in recent years, a resurgence in some countries like Spain, France, Germany, Colombia, Peru and North America, not only for being a structural system accessible to low –income population but also by the growing interest in green building and natural resources respect, because this system has a lower energy consumption, in some countries have developed regulations that define the structural characteristics of structural systems based on adobe use: Clear examples are the National Building Regulations and Codes of Peru. Construction codes to built with adobe in New Mexico and San Diego California, USA Mexico does not have any regulations for this kind of building, although, according to statistics, currently about 15% of homes built in the country are of adobe.

The structural safety against earthquakes of adobe buildings is very important, as in the case of Mexico, a big part of its territory is active seismically, for this reason, the need to develop criteria for design, precision repair and security of adobe structures, proposing simple and low costs procedures for reinforcement.

2. ADOBE CONSTRUCTION IN MEXICO

At the end of the 20th century construction with cement and concrete grow up, and the use of adobe decreased, transforming in poor or rural architecture expression. According to the statistical results published by the National Institute of Statistics, Geography and Informatics (INEGI) in Mexico in 1970 adobe houses represented 30% of the total for 1980 fell to 21% being of only 15% in 1990.

Although in Mexico the use of adobe has decreased, in some states its use has been maintained or increased. Figures 1 shows the situation of adobe construction in Mexico.

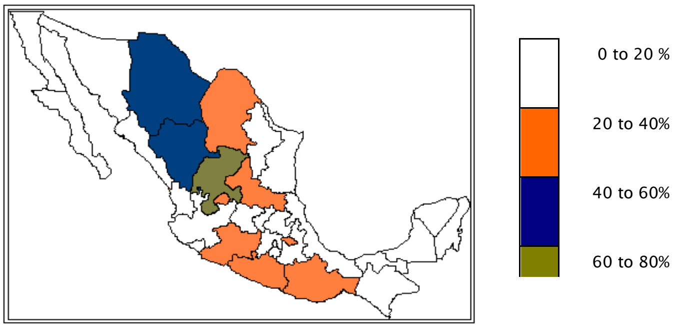

Figure 1. Adobe Construction in México (1990)

The states of Queretaro, Quintana Roo, Chiapas, Durango, Guerrero, Oaxaca and Zacatecas, show a positive growth rate in the construction of adobe, the first two have the particularity that this growth rate is higher tan the total of homes built in the state.

The states of Guerrero, Oaxaca and Chiapas, located in the southeast of the Mexican Republic have percentages of adobe buildings of 34.77%, 26.69% and 17.12%, respectively. However, in these entities municipalities with up to 90% of adobe houses are located. On the other hand, as shown in Figure 2 the epicenters of the earthquakes recorded in Mexico in 2011, the most seismically active area in the country coincides with these states.

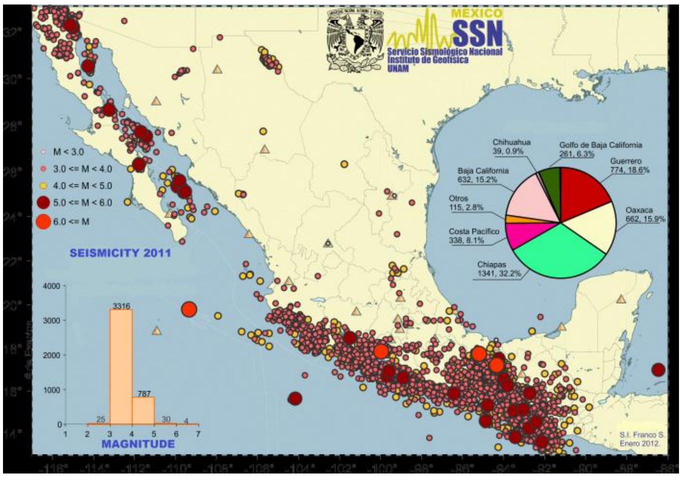

Figure 2. Earthquake epicenter distribution 2011

The States most exposed to seismic actions are largely using adobe as a building material besides being of those with major economic problems in the country.

3. OBJECTIVE

In the present work, the experimental tests results and the analytical models to estimate the capacity of three different retrofitting techniques for adobe walls are shown.

In order to compare the behavior of handmade specimens and industrialized pieces, five walls were constructed, two of them, with handmade pieces and three with industrialized adobes. The first wall corresponds to non reinforced elements and the other, reinforced by confined concrete elements, for each material, the last wall was reinforced with metallic mesh.

4. METHODOLOGY

As part of this study adobe pieces and low walls were tested, the adobe pieces were taken from different parts of the State of Mexico, industrialized and handmade, the resistance to compression and shear and modulus of elasticity and shear were determinate. Table 1 shows the results of this test.

Table 1. Mechanical properties of adobe ´pieces

Adobe Type	Place	Mortar	f*m (MPa)	E Prom. MPa	v*.MPa	G Mpa
Industrialized	Metepec	Type I	0.757	494.30		
Industrialized	Metepec	Type II	0.635	490.92	0.076	59.4
Industrialized	Metepec	Type III	0.352	428.21		
Industrialized	Metepec	Type II sand-soil	0.454	491.21		
Handmade	Valle de Bravo	Type I	0.427	308.51		
Handmade	Valle de Bravo	Type II	0.390	197.99	0.050	17.46
Handmade	Valle de Bravo	Type III	0.181	131.36		
Handmade	Amatepec	Type II	0.274	119.00	0.037	11.63
Handmade	El Oro	Type II	0.440	411.47	0.055	20.14
Handmade	Temascalcingo	Type II	0.369	76.00	0.037	5.97
Handmade	San Miguel Toto	Type II	0.448	2.481.51	0.042	13.01

For the construction of the models tested handmade bricks from Valle de Bravo town and industrialized adobe pieces from Metepec town were used.

5. SPECIMENS CONSTRUCTION

Five adobe walls 2.30 meters long and 2.30 meters high were built simultaneously. Fort he walls foundation beams of 0.45 x 0.20 x 2.80 meters were placed, except for the wall 5 where an I concrete shape was constructed as foundation, with a 0.45 x 0.20 flange and 0.70 x 0.45 meters web of 0.20x2.10 meters.

To the walls construction, the local building practice was reproduced. In all cases mortar type II was used, consisting of 1 part cement, 2 ½ of soil and ¼ of ground limestone, using the water necessary.
The Wall 1 was made with handmade adobe without reinforce, the wall 2 is also built with handmade adobe pieces, but in this case a reinforcement confined concrete elements were used (reinforced concrete) around the wall. The confined concrete elements were built with a cross section of 0.15 x 0.25 m. reinforced with 4 steel bars 0.95 cm in diameter and yield stress of, fy = 412 MPa.

The three remaining walls were built with industrialized adobe pieces, Wall 3 had no reinforce, wall 4 was reinforced with a reinforced concrete confined elements, similarly to the wall 2. In the wall 2, In the wall 5 was used as a reinforcing wire mesh (chicken wire) located horizontally along the joints, also placed small transverse walls of 0.65 m in length at both ends of the wall, to allow adequate anchoring of the wire mesh.

With these elements, to compare the lateral loads behavior of elements built with industrialized and handmade pieces were made, also evaluate the efficiency of confinement as a technique for repair and reinforcement adobe structures, finally wall 5 studies the effect to place small amounts of reinforcement along the horizontal joints.

For the application of vertical and lateral loads, in the walls 1, 3 and 5 a concrete structural element located at the top of the walls was constructed, a C reinforce concrete shape with section 0.15 x 0.25 m. reinforced with 4 steel bars 0.95 cm in diameter and 0.64 cm stirrups diameter fitted to each 0.15m. as shown in Figure 3. The purpose of this element was to ensure an adequate load distribution and to prevent slippage of the wall with the application of lateral load.

5.1. Behavior specimen description

As a result of this first study, the first crack appears to low levels of lateral distortion, even to the reinforced walls, in the case of walls without reinforcement, starting of this point a fast decrease in the stiffness of the element appeared, however the resistance is maintained for low increases in the lateral distortion, which supports the resistance in the case of the elements confined.

The following is a brief description of the behavior observed in the test of each wall. Figure 4 shows the cracking pattern observed at the end of the test.

On the wall 1 the first crack was presented in the first load cycle, which spread rapidly in subsequent cycles, appeared predominantly horizontal cracking end of the wall, caused by the tension stresses due to the wall bending.

The wall deterioration was small compared to the other walls, this because movements were concentrated in a few cracks that opened and closed alternately, depending on the direction of load application, this caused a bending failure associated with rapid loss of strength and stiffness.

In the case of the wall 2, as in the other walls the first cracking appeared on the first load cycles; however in this case had a resistance increased to high levels of lateral deflection (about 0012). An appreciable increase of strength was observed with respect to the wall without reinforcement; however it is considered that the greatest contribution to the overall behavior of the confinement of the wall is the substantial increase in ductility and in the energy absorption capacity, which is important in structures built in seismic areas.

On the wall 3, there was a failure by diagonal tension. His performance was substantially better tan the handmade adobe pieces wall, in strength and in ductility; however their behavior must still be regarded as fragile. In this wall appeared diagonal cracking started in the third loading cycle and spread rapidly, causing a loss of stiffness and in higher levels of deformation the consequent loss of strength.

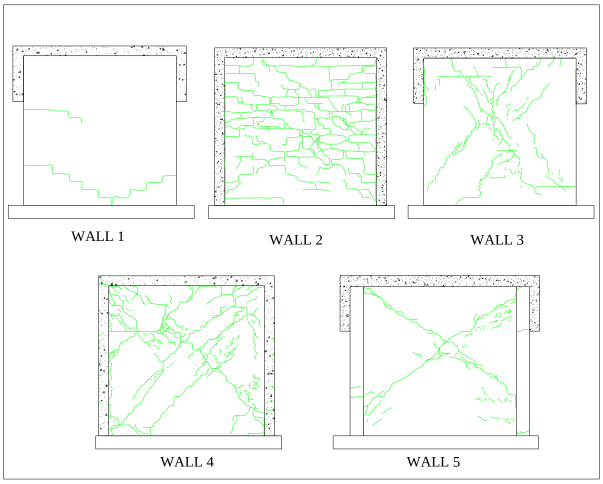

Figure 3. Cracks pattern in walls.

In the case of the wall 4, its behavior was similar to the wall 2, yielded a slight increase in resistance and a significant increase in ductility. The cracking started in the second loading cycle and rapidly advanced on the faces of the wall.

For strain levels near 0.01 the wall separation with the vertical elements of confinement were appeared, once this crack spread, the capacity of the element decreased.

Figure 4 shows the hysteresis envelopes of the different walls and Table 2 shows a comparison of the main results of the assay.

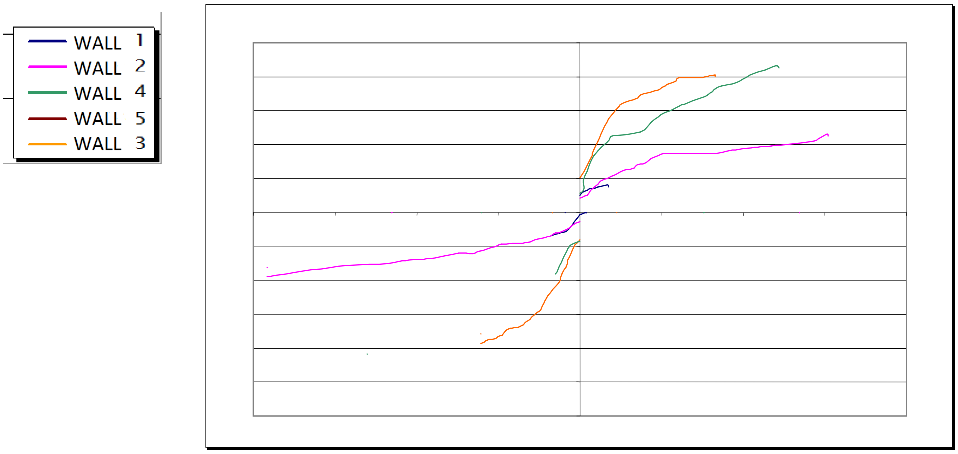

Figure 4. Hysteretical curves

Table 2. Lateral load test results.

Wall	Structuring	Adobe kind	Pattern failure	Elasticity modulus MPa	Max Stress MPa	Max Load KN	Max Load KN	Max Stiffness KN/m
1	Simple	Handmade	Bending	66.9	0.014	0.019	14.66	23137
2	Confined	Handmade	Shear	54.1	0.013	0.056	43.99	18333
3	Simple	Industrialized	Shear	129.6	0.092	0.121	83.41	39932
4	Confined	Industrialized	Shear	129.6	0.087	0.128	83.50	36664
5	Interior reinforce	Industrialized	Shear	149.1	0.081	0.137	89.23	44759

5.2. Repair Procedure

Next to the test, the walls were repaired, 1,3 and 4 using coating of cement – sand mortar and synthetic mesh as reinforcement (geogrids) TENAX brand. These items were tested with alternating cyclic loads. These walls were called 1R, 3R and 4R respectively.

5.3. Load devices

To applicant lateral forces a loading frame was built, it was made with steel beams 1 section, and placing a ENERPAC double acting hydraulic cylinder, with capacity of 890 kN in push and 427.7 kN pull. The hydraulic cylinder is operated by a hand pump high flow, where the charge transferred to the model is controlled with a digital manometer ENERPAC of 98. 1 KN, operated with a pump similar to that used in the application of lateral forces.

5.4. Implementation of the walls

To measure the deformation of the walls were placed 9 micrometers. On each side of the walls placed one micrometer and a diagonal direction in the vertical direction also another micrometer was installed on top of the walls, in the horizontal direction, finally, 4 micrometers were placed on an end wall, at different heights to control the lateral displacement of the element. Figure 5 shows the schematic of the instrumented wall.

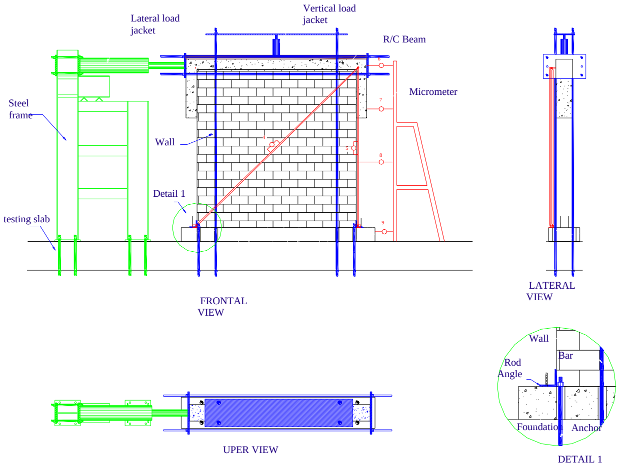

Figure 5. Instrumented wall

5.5. Test development

For the walls vertical and lateral loads were applied, the first to simulate the weight of the deck in a wall of the same dimensions in a typical home, the second was used to simulate seismic forces. According to its nature, the vertical load was always constant, meanwhile the lateral load was varying in magnitude and direction forming push-pull cycles. The test was monitored by successive increments of deformation. The parameters studied were the ultimate strength, ductility and hysteretic behavior to lateral loads.

5.6. Test results

The damage level in each element is controlled as a function of cracking observed in Figure 6 the cracking pattern of each wall at the end of the test is presented.

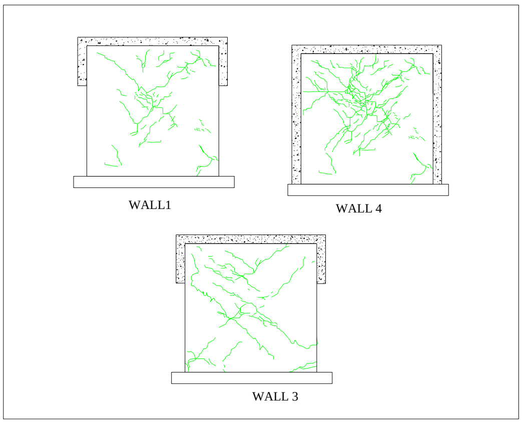

Figure 6. Cracks pattern.

The test results were plotted to construct the hysteresis curves. Figure 7 shows the hysteresis curves as a function of lateral load-angular displacement relationship for the different walls.

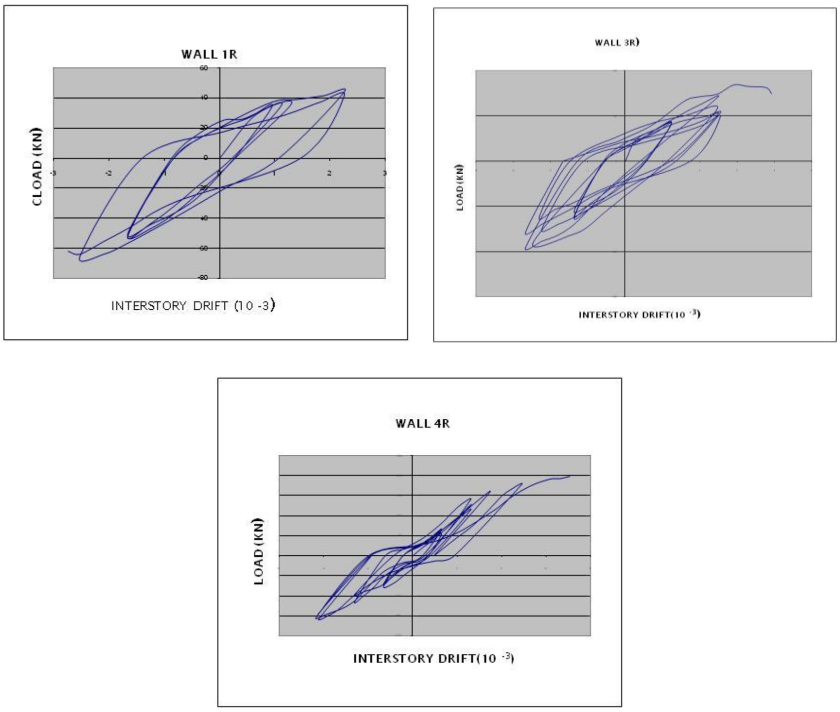

Figure 7. Hysteresis loops

Finally the responses envelopes obtained by joining the maximum peaks of the hysteretic cycle were presented. This graph were obtained for each wall and are shown in Figure 8, and compares the results of the repaired walls and the results of the original walls, also the comparison of the envelope of hysteretic cycles of the original walls and the walls repaired.

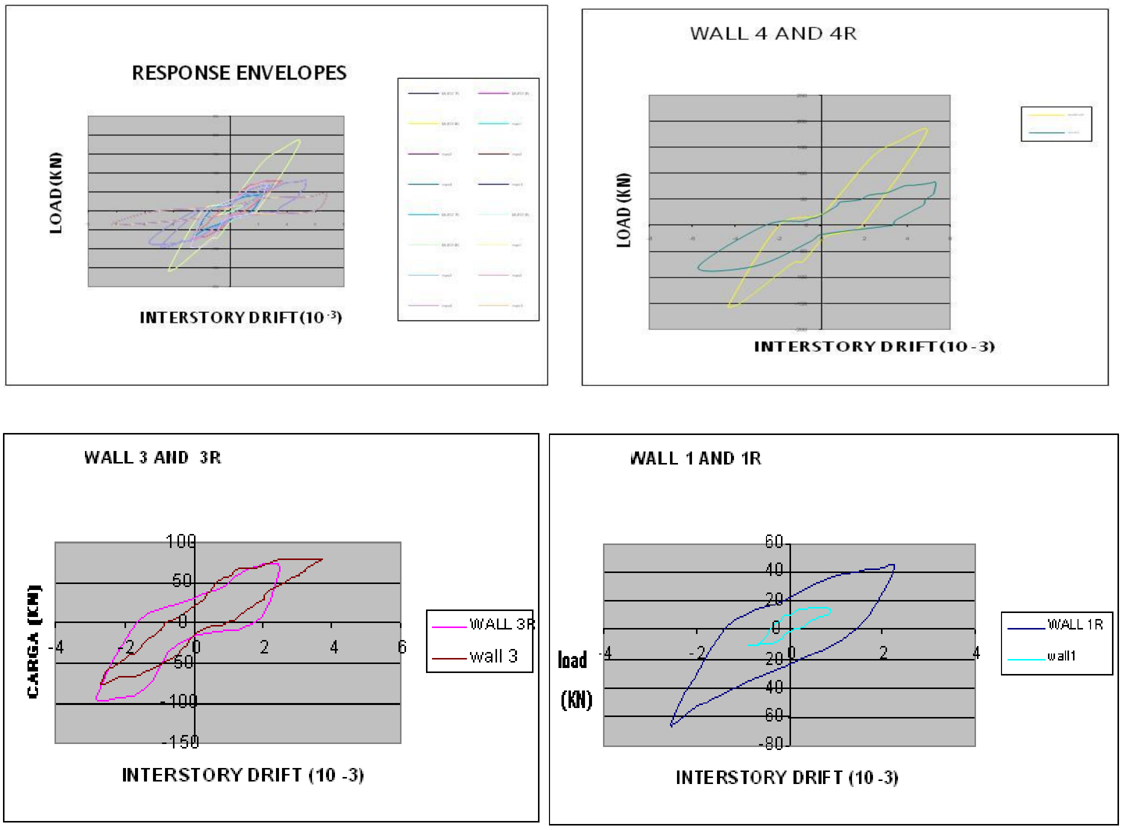

Figure 8. Response Envelopes

Table 3. Results of the test of walls with lateral loads 1R, 3R and 4R.

Wall	Structuring	Adobe kind	Pattern failure	Elasticity modulus MPa	Cracking Stress MPa	Max stress KN	Max Load KN	Max Stiffness KN/m
1R	Simple	Handmade	Bending	114.3	0.026	0.082	63.72	29654
3R	Simple	Industrialized	Shear	117.7	0.092	0.138	95.63	32712
4R	Confined	Industrialized	Shear	132.2	0.087	0.230	153.7	38564

6. ANALYSIS OF RESULTS

In this test, at all cases the first cracking occurred in the first load cycle, however in contrast to the wall without reinforcing mesh, the propagation of cracking was limited.

The initial cracking 1R wall showed was dispersed on the faces of the wall, principally in a diagonal direction, however to distortions around of 0.002 horizontal cracking starts in the ends of the wall, caused by the tensile stress product of the deflection in the wall, which spread rapidly, eventually resulting in failure of the element. There was no significant damage to the wall because the damage was concentrated in the lower parts, which in turn manifest as cracking open and close depending on the direction of load application, this caused a bending failure associated with a rapid loss of resistance and stiffness. Nevertheless, a significant increase in resistance of reinforced wall of more tan three times that of the original wall, but remains very limited ductility.

In the case of wall 3, the first cracking appeared on the first load cycles, and the fault was caused by bending.

The Wall 4R failure occurred by diagonal tension associated with shear stresses, in this case the behavior was improved the strength and ductility, cracking started in the first little charge cycles but its spread was limited and it was not until final stage of the test when it was observed a significant cracking, associated with loss of the coating on some localized areas. In this case the wall increased its resistance in the order of 84% without loss on stiffness.

7. CONCLUSIONS

This paper concludes that the use of plastic mesh provides a methodology to appropriate relief, accessible and compatible with the technologies used in building construction with adobe.

The main advantages are: its cost and its resistance to weathering.

The behavior of the walls reinforced with this kind of material is considered satisfactory and can be used as a repair, because as noted in the case of the wall was achieved 3R restore the original strength of the element and where the walls 1R and 4R is increased substantially.

During the development of this test in 1R and 3R walls was observed that its failure originated by lack of anchorage to the foundation, so special care must be taken to anchor the mesh.

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