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Cyclic Dynamic Performance of BTRM-Strengthened and Unstrengthened Masonry Hydraulic Piers: An Experimental Comparison

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Abstract — This study experimentally investigates the cyclic dynamic performance of Basalt Textile Reinforced Mortar (BTRM)-strengthened and unstrengthened masonry hydraulic piers under dry and wet conditions. Six specimens, comprising three control and three BTRM-strengthened piers, were tested using a shaking-table setup under progressively increasing harmonic excitation. The primary objective was to compare the number of loading cycles sustained until failure and examine the associated failure mechanisms. The results demonstrated that BTRM strengthening substantially increased the cyclic endurance of the masonry piers compared with the unstrengthened controls. The control specimens experienced severe damage after relatively few loading cycles, whereas the strengthened specimens sustained considerably more cycles before failure. The observed failure of the strengthened specimens involved basalt textile rupture and internal separation of masonry units. The dry and wet specimens were also compared to examine the influence of water exposure on cyclic performance. The findings demonstrate the potential of BTRM strengthening to improve the resistance of masonry hydraulic piers to repeated dynamic loading.

Keywords- Masonry hydraulic piers; BTRM; Cyclic dynamic loading; Shaking-table testing; Failure mechanisms.

I. INTRODUCTION

Masonry remains an important construction material in many existing structures, including hydraulic structures that may be exposed to repeated environmental and operational actions. Masonry hydraulic piers can be vulnerable to lateral and out-of-plane loading because of the limited tensile resistance of masonry and the potential for cracking and separation along mortar joints. Improving the performance of these elements is therefore important, particularly when repeated loading may progressively damage the masonry and ultimately lead to failure.

Textile-reinforced mortar (TRM) has attracted considerable attention as a strengthening technique for masonry structures because it combines textile reinforcement with a cementitious mortar matrix. Previous experimental studies have investigated the effectiveness of textile-reinforced systems for strengthening clay masonry infill walls subjected to combined in-plane and out-of-plane actions [2], as well as the performance of innovative strengthening materials for brick masonry infills [3].

Research has also examined the application of basalt textile-reinforced mortar (BTRM) to unreinforced masonry walls, demonstrating its potential as a strengthening material [1], [9]. The broader application of TRM for strengthening masonry structures has also been reviewed, highlighting its potential benefits and relevant performance considerations [4].

Several studies have investigated the response of TRM-strengthened masonry under different loading conditions. The out-of-plane behaviour of masonry walls strengthened using textile-mortar systems has been experimentally examined [7], while other research has evaluated the diagonal-tension behavior of TRM-strengthened unreinforced masonry walls [5]. More recent studies have considered the in-plane and out-of-plane behavior of TRM-strengthened heritage masonry elements [8].

The performance of textile-reinforced mortars under cyclic loading has also been investigated experimentally, including their application to repairing and retrofitting masonry walls subjected to in-plane cyclic actions [10]. In addition, different fiber-reinforced materials have been compared for strengthening unreinforced masonry walls subjected to out-of-plane loading [6]. These studies provide a useful basis for understanding the performance of textile-base

d strengthening systems under different loading conditions. Despite these developments, the findings obtained from conventional masonry walls cannot automatically be applied to

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masonry hydraulic piers, which may differ in structural configuration and exposure conditions. In particular, the cyclic endurance of BTRM-strengthened masonry hydraulic piers under repeated dynamic excitation requires further experimental investigation. Water exposure is also relevant to hydraulic structures; however, its influence on the number of loading cycles sustained before failure should be evaluated experimentally rather than assumed from studies conducted under different conditions. A direct comparison of strengthened and unstrengthened specimens under both dry and wet conditions can therefore help clarify their relative performance within a controlled experimental program.

Accordingly, this study experimentally investigates the cyclic dynamic performance of unstrengthened control masonry hydraulic piers and BTRM-strengthened masonry hydraulic piers under dry and wet conditions. Six specimens were tested using a shaking-table setup, comprising three unstrengthened control specimens and three BTRM-strengthened specimens.

The specimens were subjected to progressively increasing excitation frequencies, and the principal performance measure was the cumulative number of loading cycles sustained before failure. The observed failure patterns were also examined to compare the responses of the control and strengthened specimens. The study therefore provides an experimental comparison of the cyclic endurance and failure mechanisms of BTRM-strengthened and unstrengthened masonry hydraulic piers under the investigated loading and exposure conditions.

II. EXPERIMENTAL PROGRAM

1. Masonry Pier Specimens

Six masonry pier specimens were selected for the present experimental investigation to compare the cyclic dynamic performance of unstrengthened and BTRM-strengthened masonry hydraulic piers. The specimens were divided into two groups: three unstrengthened control specimens and three specimens strengthened using Basalt Textile Reinforced Mortar (BTRM). Each group included one dry specimen and two wet specimens to investigate the influence of water exposure on cyclic performance. The masonry piers had nominal dimensions of 1000 mm in height, 720 mm in width, and 175 mm in thickness. Each specimen was mounted on a reinforced concrete base to provide the required support conditions during testing. The geometry and dimensions of the masonry pier specimens are presented in Figure 1

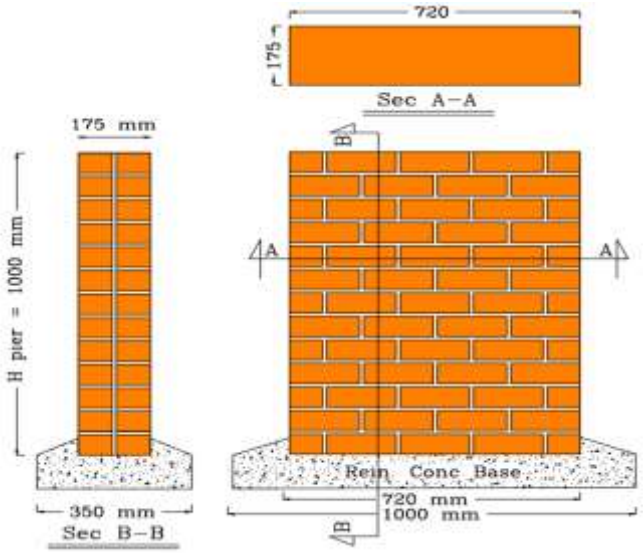


Figure 1: Geometry and dimensions of the masonry pier specimens

2. BTRM Strengthening Technique

The BTRM strengthening system consisted of a basalt textile mesh embedded within a cementitious mortar matrix. The mesh had a nominal grid spacing of 5 × 5 mm. The strengthening system was applied to both faces of the masonry pier, with the textile embedded between mortar layers of approximately 10 mm thickness each. The arrangement of the basalt textile mesh and its application to the masonry surface are shown in Figure



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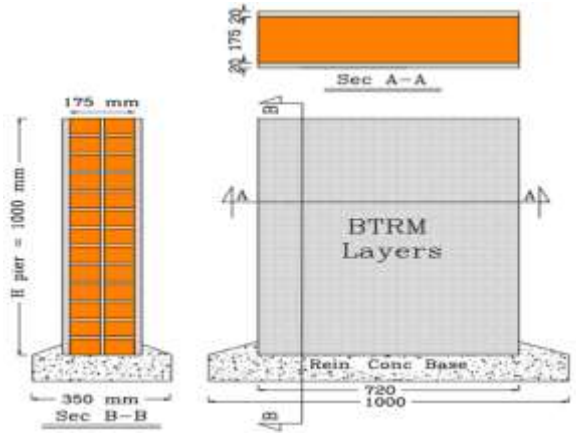


Figure 2: Basalt textile mesh and BTRM strengthening configuration

The purpose of the strengthening system was to improve the tensile resistance and integrity of the masonry piers under repeated dynamic excitation. The control specimens were tested without additional strengthening, providing a reference for evaluating the performance of the BTRM-strengthened specimens.

III. EXPERIMENTAL SETUP AND LOADING PROCEDURE

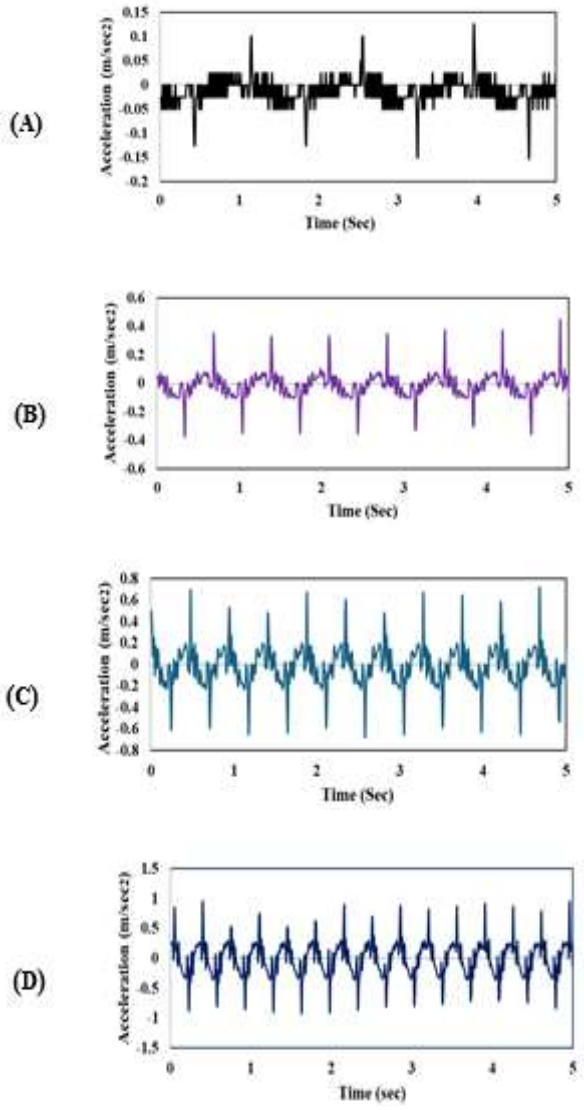
The dynamic tests were conducted using a shaking-table setup with a table measuring 1.2 × 1.2 m. A water tank was incorporated into the setup to simulate wet exposure conditions for the designated specimens.

The masonry piers were secured to their reinforced concrete bases and installed on the shaking table before testing. The experimental arrangement used for the dynamic tests is presented in Figure 3



Figure 3: Experimental setup for the shaking-table tests.

Harmonic base excitation was applied at six progressively increasing frequency levels of 0.70, 1.40, 2.10, 2.80, 3.50, and 4.20 Hz, with 150 loading cycles applied at each frequency level. Accordingly, each complete loading sequence comprised 900 cycles. The six-stage sequence was repeated as required until specimen failure, and the cumulative number of loading cycles was recorded for each specimen. The BTRM dry specimen completed 17 loading sequences, corresponding to 15,300 cumulative loading cycles. The corresponding input acceleration time histories recorded from the shaking table at each excitation frequency are presented in Figure 4.



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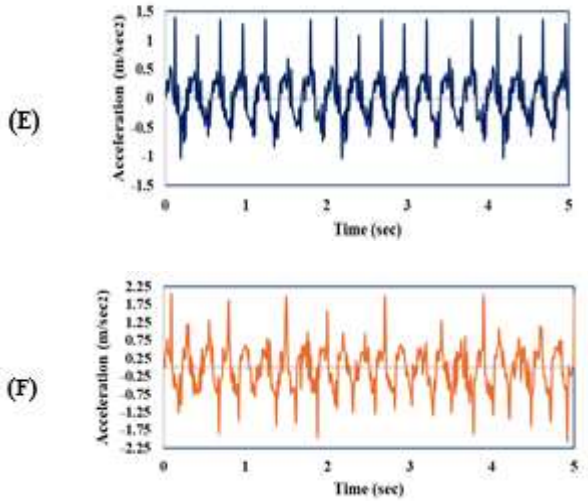


Figure 4: Input acceleration time histories of the shaking table at excitation frequencies of (a) 0.70 Hz, (b) 1.40 Hz, (c) 2.10 Hz, (d) 2.80 Hz, (e) 3.50 Hz, and (f) 4.20 Hz

IV. EXPERIMENTAL RESULTS AND DISCUSSION

1. Comparison of Cyclic Endurance

The cyclic endurance of the masonry pier specimens was evaluated based on the cumulative number of loading cycles sustained before failure. Table 1 summarizes the results obtained for the unstrengthened control and BTRM-strengthened specimens under dry and wet conditions.

Table 1: Comparison of cumulative loading cycles at failure for the control and BTRM-strengthened specimens.

Specimen	Condition	Cycles at failure
Control Dry	Dry	663
Control Wet (1)	Wet	470
Control Wet (2)	Wet	560
BTRM Dry	Dry	15300
BTRM Wet (1)	Wet	9900
BTRM Wet (2)	Wet	11700

The experimental results demonstrate a substantial difference in cyclic endurance between the unstrengthened and BTRM-strengthened masonry piers. The control specimens sustained between 470 and 663 loading cycles before failure, whereas the BTRM-strengthened specimens sustained considerably more cycles. Under dry conditions, the BTRM-strengthened specimen sustained 15,300 cycles, compared with 663 cycles for the control specimen. This difference indicates the improved resistance to cumulative cyclic loading provided by the BTRM strengthening system. A similar trend was observed under wet conditions. The two control specimens failed after 470 and 560 cycles, respectively, while the BTRM-strengthened specimens sustained substantially higher numbers of cycles. These results indicate that the improvement associated with BTRM strengthening was observed under both dry and wet conditions.



Figure 6: Comparison of the observed failure patterns of (a) unstrengthened control specimens and (b) BTRM-strengthened specimens

Overall, the experimental observations indicate that BTRM strengthening substantially increased the number of loading cycles sustained before failure. The comparison of cyclic endurance, together with the observed failure patterns, demonstrates the potential of BTRM to improve the resistance of masonry hydraulic piers to repeated dynamic loading under the investigated conditions

V. CONCLUSION

Based on the experimental investigation of unstrengthened and BTRM-strengthened masonry hydraulic piers under dry and wet conditions, the following conclusions can be drawn:

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- **Improved cyclic endurance:** BTRM strengthening substantially increased the number of loading cycles sustained before failure. Under dry conditions, the strengthened specimen sustained 15,300 cycles, compared with 663 cycles for the unstrengthened control specimen.
- **Performance under wet conditions**: The wet control specimens failed after 470 and 560 cycles, whereas the wet BTRM-strengthened specimens sustained 9,900 and 11,700 cycles, respectively, based on the reported values. This indicates improved cyclic endurance of the strengthened specimens under the investigated wet conditions.
- **Influence of water exposure:** Both control and BTRM-strengthened specimens exhibited lower cycle counts under wet conditions than their corresponding dry specimens. This trend suggests that water exposure may adversely affect cyclic endurance, although the limited number of specimens should be considered when interpreting the results.
- **Observed failure mechanisms:** The control specimens exhibited significant cracking and separation along masonry joints. In comparison, failure of the BTRM-strengthened specimens involved rupture of the basalt textile and internal separation of masonry units, indicating that substantial damage eventually developed in both the strengthening system and the masonry substrate.

Overall, the experimental results demonstrate the potential of BTRM strengthening to improve the cyclic endurance of masonry hydraulic piers subjected to repeated harmonic excitation under the investigated conditions.

REFERENCES

1 Ibrahim, M., Galal, M., Kohail, M., Rashad, A., & ElShafie, H. (2022). Behaviour of unreinforced masonry walls retrofitted by using basalt textile reinforced mortar. Engineering Structures, 260, 114201. https://doi.org/10.1016/j.engstruct.2022.114201.

2 da Porto, F., Guidi, G., Verlato, N., & Modena, C. (2015). Effectiveness of plasters and textile reinforced mortars for strengthening clay masonry infill walls subjected to combined in-plane/out-of-plane actions. Mauerwerk, 19(5), 334-354.https://doi.org/10.1002/dama.201500673.

3 Martins, A., Vasconcelos, G., Fangueiro, R., & Cunha, F. (2015). Experimental assessment of an innovative strengthening material for brick masonry infills. Composites Part B: Engineering, 80, 328–342. https://doi.org/10.1016/j.compositesb.2015.06.012

4 Kouris, L. A. S., & Triantafillou, T. C. (2018). State-of-the-art on strengthening of masonry structures with textile reinforced mortar (TRM). Construction and Building Materials, 188, 1221–1233. https://doi.org/10.1016/j.conbuildmat.2018.08.039

5 Shabdin, M., Zargaran, M., & Attari, N. K. A. (2018). Experimental diagonal tension (shear) test of un-reinforced masonry (URM) walls strengthened with textile reinforced mortar (TRM). Construction and Building Materials, 164, 704–715. https://doi.org/10.1016/j.conbuildmat.2017.12.234

6 Deng, M., Dong, Z., Dai, J., & Zhao, X. (2023). Out-of-plane strengthening of URM walls using different fiber-reinforced materials. Construction and Building Materials, 362, 129597.https://doi.org/10.1016/j.conbuildmat.2022.129597.

7 Kariou, F. A., Triantafyllou, S. P., Bournas, D. A., & Koutas, L. N. (2018). Out-of-plane response of masonry walls strengthened using textile-mortar system. Construction and Building Materials, 165, 769–781. https://doi.org/10.1016/j.conbuildmat.2018.01.026

8 Liapopoulou, M., Bompa, D. V., & Elghazouli, A. Y. (2024). In and out of plane behaviour of TRM strengthened heritage masonry elements. Construction and Building Materials, 448, 138152. https://doi.org/10.1016/j.conbuildmat.2024.138152

9 Shamseldein, A., Elgabbas, F., & Elshafie, H. (2022). Tensile behavior of basalt textile-reinforced mortar (BTRM). Ain Shams Engineering Journal, 13(1), 101488. https://doi.org/10.1016/j.asej.2021.05.003

10 Torres, B., Ivorra, S., Baeza, F. J., Estevan, L., & Varona, B. (2021). Textile reinforced mortars (TRM) for repairing and retrofitting masonry walls subjected to in-plane cyclic loads: An experimental approach. Engineering Structures, 231, 111742. https://doi.org/10.1016/j.engstruct.2020.111742.

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