Feasibility Investigation on Rubberized Mortar for Frictional Base Isolation of Unreinforced Masonry Buildings

Imran Ullah[1,2*] Muhammad Usman[1] and Abbas Khan[2]

[1] School of Civil and Environmental Engineering, National University of Sciences and Technology (NUST), Sector H-12, Islamabad, Pakistan; imranullahdallan@gmail.com; m.usman@nice.nust.edu.pk
[2] Department of Civil Engineering Technology, University of Technology, Nowshera, Pakistan; imranullahdallan@gmail.com; abbasbjr57@gmail.com
* Correspondence: imranullahdallan@gmail.com

Abstract

Unreinforced masonry (URM) structures are highly prone to seismic events. Conventional base isolation is a technique to mitigate these events. However, middle-class people can't use conventional isolators i.e. elastomeric bearings, lead-rubber bearings, etc. for low-cost URM buildings because of their high expense. The Frictional base isolation system has a simple and inexpensive model that uses sliding surfaces to dissipate seismic energy and lowers the forces transferring to the superstructure from the foundation. Frictional base isolation is a new emerging technique requiring detailed research to develop the system. Few Frictional base isolation materials have been investigated that introduced the materials that are usually unavailable in the market. Control mortar, Rubberized mortar (fine), and Rubberized mortar (coarse) were studied in the current research. The compressive strength and coefficient of friction of the materials were investigated. High compressive strength and low coefficient of friction allow them to be used as Frictional base isolation material as per the available literature. Moreover, microstructural studies through microscope images were captured for analysis. Among them, the Rubberized mortar (fine) is considered to be better to practice as a Frictional base isolation material.

Keywords: Frictional base isolation material, unreinforced masonry buildings, seismic events, brick, dissipation, Rubberized mortar

1. Introduction

Masonry buildings are common housing units in seismic-prone regions of the world [1], [2], [3]. Mostly, unreinforced masonry (URM) buildings are vulnerable to seismic activities due to weak tensile strength that often leads to large structural damage through earthquakes [4], [5], [6]. To mitigate the vulnerability, base isolation is an effective strategy which is unfixing the building from ground shaking [7], [8]. Among several base isolation techniques, Frictional base isolation is interesting because of their simplicity and less cost [9], [10], [11]. The Frictional base isolation uses sliding surfaces to exhaust seismic energy to lower the forces transferred to the superstructure from the foundation [12], [2]. Latest studies have confirmed the effectiveness of Frictional base isolation in increasing the seismic performance of URM buildings that indicate a significant decrease in structural responses through seismic events [13], [14], [15], [12], [16], [17], [18], [19],

[20], [21], [22]. Different materials were tested as Frictional base isolation material. Ahmad et al., 2009 used a sliding surface between smooth coarse sand and recycled mortar (demolished waste in masonry housing) as Frictional base isolation material replacing cement in different percentages. The coefficient of friction of the surface determined was 0.36. They carried out an experimental and analytical analysis of effective seismic responses. The disadvantage of this isolation is that the sand surface is disturbed after few jerks of the earthquake [23]. Different sliding surfaces i.e., green marble and High-Density Polyethylene (HDPE) [μ= 0.08], green marble and geosynthetics [μ= 0.11], and green marble and green marble [μ= 0.09] were studied during experimental investigations [14] but (μ=0.15 to μ=0.40) is the optimum range for Frictional base isolation [24], therefore the frictional surfaces will cause extra sliding of the structure. A finite element simulation of Friction-base isolation was carried out in an investigation. The results imply that the performance of Friction-base isolation is much more effective in seismic wave transfer into the superstructure [12]. The frictional base isolation layer thickness was studied for Reinforced-Cut-Wall (RCW) and verified by installing a reduced-scale masonry wall model. Horizontal cracking of the isolation layer, diagonal cracking and slippage, and spalling of the isolation layer under extreme loading were studied. The cracks were observed only in the base isolation layer, showing that most of the damage will occur in the isolation layer without energy transfer to the superstructures [25]. A study was conducted for a large-scale experimental investigation of Frictional base isolation for developing countries. The isolation is encapsulation of sand grains between two PVC interfaces [μ= 0.2] for the dissipation of earthquake energy between the interfaces. A considerable decrease in accelerations and forces was observed experimentally as compared to fixed-base isolation [26]. The disadvantage of this isolation is that the PVC surface wears after a few jerks of earthquake. Very few research works are present regarding Frictional base isolation system i.e., few frictional base isolation materials have been investigated, therefore there is a need to investigate easily available materials to increase the material pool. This research focuses on the feasibility of Rubberized Mortar as Frictional base isolation material for URM buildings. The rubberized mortar has been tested in laboratory settings. The research tries to introduce the typical materials that are commonly used in the construction. The research work also used old tire rubber which is a step towards sustainability.

2. Experimental program

2.1 Material and Methods

The materials used in this research include sand, Ordinary Portland Cement (OPC) Type I, and fine and coarse rubber particles. The sand was obtained from the Indus River bed with a fineness modulus of 2.7 which is in the standard range (2.3 to 3.1) of ASTM C136 [27]. The OPC Type-I of Cherat Cement Factory Nowshera was used as binding material in accordance with ASTM C150 [28]. Two types of rubber particles (fine and coarse) were obtained from old tires and used as 10% partially replaced with sand contributing to a low coefficient of friction.

2.2 Sieve Analysis of Sand and Fineness of OPC

Sieve analysis of sand and Fineness of OPC were performed at Concrete Lab, the University of Technology Nowshera by ASTM C136 [27] and ASTM C150 [28] respectively. The FM of sand is 2.7 and the Fineness of OPC is 93% which falls within the acceptable ranges of ASTM.

Table 1: (a) Sieve analysis of sand and (b) Fineness of OPC

Sieve Size	% Retained	Cumulative % Retained	% Passing
# 4	2	2	100
# 8	9	11	89
# 16	20	31	69
# 30	29	60	40
# 50	19	79	21
#100	10	89	11
Fineness Modulus (FM)			**2.72**

(a)

Sr.	% Passing	Fineness of OPC
1	95	
2	93	**93 ≥ 90**
3	92	

(b)

2.3 Sample Matrix and Compression tests

Three samples of 9’’×4.5’’×3’’ were cast for each test, and their average values have been taken as a result. Compression test was performed with the universal testing machine (UTM) at Material Testing Lab, the University of Technology Nowshera by ASTM C67/C67M-19 [29]. The brick specimen was tested flatwise i.e. the brick was in a stretcher position such that the load transferred perpendicular to the bed surface. The frog was properly filled with mortar and load was applied through UTM Fig. 3(a). The compressive strength was determined by dividing the load by the area. Samples’ Matrix, compression test results, and % water absorption have been given in Table 2. The % water absorption values have been taken from the literature.

Table 2: Samples’ Matrix and compressive strength (σc)

Sr.	Description	Mix ID	Nos.	Ingredients	%	σ'_c (psi)	$\sigma'_{c\,(ave)}$ (psi)	% Water Absorption
1	Control Mortar (1:4)	CM	12	Cement	20	2446	2575.33	9
						2550		
				Sand	80	2730		
2	Rubberized Mortar (fine)	RM_f	12	Cement	20	2050	2173.33	12
				Sand	72	2160		
				Fine rubber	8	2310		
3	Rubberized Mortar (coarse)	RM_c	12	Cement	20	2205	2056.67	16
				Sand	72	2050		
				Coarse rubber	8	1915		

(a) (b)

Fig. 1: (a) % Water absorption (b) Compressive strength in psi

2.4 Friction Tests

Friction Tests of samples were performed at the Material Testing Lab, the University of Technology Nowshera by ASTM D5321/D5321M [30]. A lower coefficient of friction (μ) leads to higher sliding displacement of buildings therefore the material is considered to be more suitable for Frictional Base Isolation [14]. The assembly for the Friction test consisted of three steel plates, four steel rods, and a load cell between the two plates Fig. 3(b). The load cell gives the normal load (F_N) applied on the inside bricks by tightening the nuts. The Friction force (F_f) was applied with UTM as in Fig. 3(d). The coefficient of Friction ($\mu = F_f/2F_N$) between RM_f & RM_f is smaller i.e. 0.389 among all the samples as per Table 3, (μ=0.15 to μ=0.40) is the recommended range for Frictional base isolation material [24]. Additionally, the compressive strength of RM_f is enough i.e. 2173 psi as per Table 2, Moreover, the % water absorption is greater but is in range, therefore the material surface (RM_f & RM_f) is more suitable for Frictional Base Isolation. The average coefficient of friction has been given in Table 3.

Table 3: Coefficient of Friction (μ)

Sr.	**Description**	**F_f (lbs)**	**$F_{f\ (ave)}$ (lbs)**	**F_N (lbs)**	**$\mu = F_{f(ave)}/2F_N$**
1	Control Mortar & Brick	3073.16 2550.5 3150.39	2924.68	2126.25	0.688
2	Control Mortar & Control Mortar	2865.98 2971.91 2450.51	2762.8	2127.25	0.649
3	Rubberized Mortar (fine) & Brick	1920.03 2180.34 1646.4	1915.59	2128.25	0.45
4	Rubberized Mortar (fine) & Rubberized Mortar (fine)	1830.45 1640.17 1500.71	1657.11	2129.25	0.389
5	Rubberized Mortar (coarse) & Brick	2000 2212.91 1793.76	2002.22	2130.25	0.47
6	Rubberized Mortar (coarse) & Rubberized Mortar (coarse)	2105.51 1750.32 1641.2	1832.34	2131.25	0.43

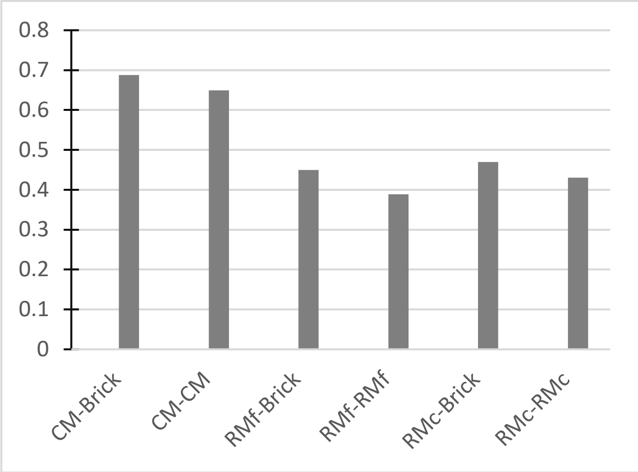


Fig. 2: Coefficient of Friction (μ)

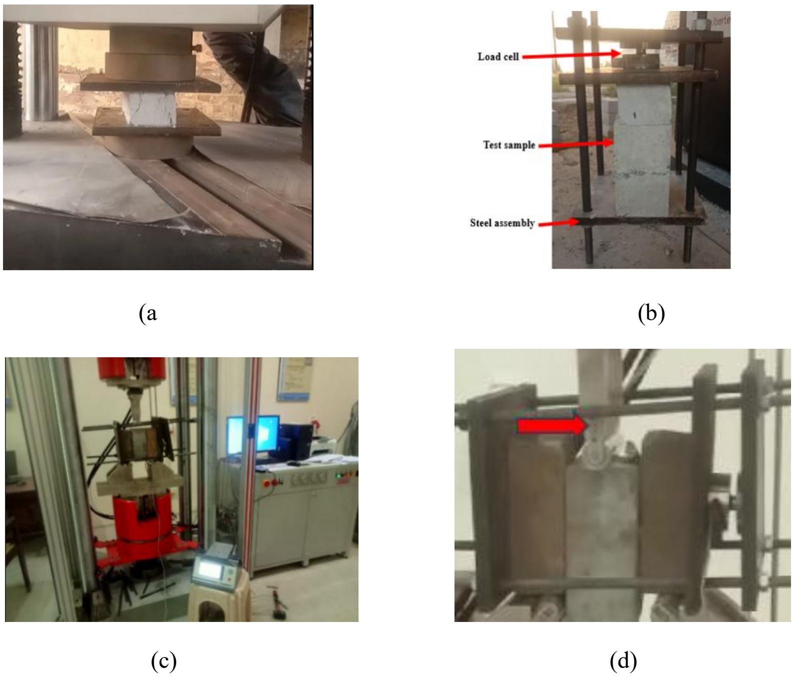


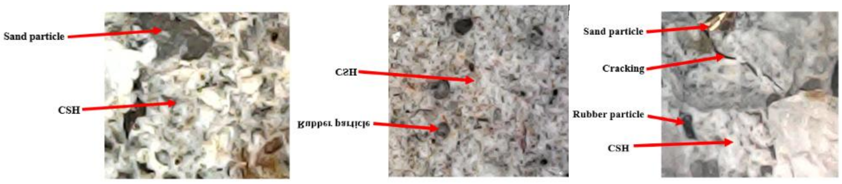
Fig. 3: (a) Compression test, (b) Friction test assembly, (c) Friction test, and (d) Friction test loading protocol

2.5 Microstructural study

A microstructural study was conducted using a Digital Microscope shown in Fig. 4(a). The microstructural study shows calcium silicate hydrate (CSH) gel formation, embedded sand, and rubber particles (coarse and fine). Sand is an inert material that generally does not react with cement but acts as filler material to give a compact mass resulting in high compression [Table 2]. Calcium silicate hydrate (CSH) is the formation of hydration of cement and water. CSH is the main strength-giving compound [Fig. 4(b)]. Calcium hydro-oxide may also form during hydration. Rubber does not react chemically to cement. Fine rubber acts as a filler material that may contribute to compressive strength. The filling property of sand is dominant over rubber filling property. Moreover, the rubber particles have a hydrophobic nature that also reduces the bond strength between cement paste and rubber particles [Table 2]. Additionally, cracking is observed in the Rubberized mortar (coarse) sample which reveals that the inclusion of coarse rubber into the mortar weakens the matrix.

Small voids exist within the mortar. The fine rubber particles embed well within the voids while the coarse aggregates cannot embed well within the voids due to larger size resulting in cracks generation [Fig. 4(d)]. The cracks weaken the mortar [Table 2].

(a)



(b) (c) (d)

Fig 4: (a) Digital Microscopic, and (b) images of control mortar, (c) Rubberized mortar (fine), and (d) Rubberized mortar (course)

3. Conclusion

Control mortar, Rubberized mortar (fine), and Rubberized mortar (coarse) were studied for their compressive strength and coefficient of friction. High compressive strength of at least 2000 psi and low coefficient of friction (μ=0.15 to μ=0.40) allow them to be used as Frictional base isolation material. The formation of CSH gel in microstructural studies validates the compressive strength results. Fine rubber acts as a filler material. The filling property of sand is dominant over rubber filling property. Moreover, the rubber particles have a hydrophobic nature that also reduces the bond strength between cement paste and rubber particles. Additionally, cracking in Rubberized mortar (coarse) weakens the matrix because of larger particle size than existing voids. Among the tested materials, Rubberized mortar (fine) has high compressive strength (2173 psi) and a lower coefficient of friction (0.389) therefore it is better to practice as a Fractional base isolation material although its compressive strength is less as compared to the control mortar but in range to support the structure.

4. Future Work

This research investigated the feasibility of Rubberized Mortar (fine) as a Frictional base isolation material. Future research work will investigate the effects of rubberized mortar on the superstructure of URM buildings on lateral displacement, energy dissipation, and stress distribution. Advanced numerical modeling will be performed to assess the load transfer mechanisms and other characteristics of the Frictional base isolation. Moreover, a comparison between numerical modeling and experimental work will be created to measure the efficacy of rubberized mortar-based Fractional base isolation structure against the fixed base structure.

Disclosure of Interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] D. Losanno, N. Ravichandran, and F. Parisi, “Seismic fragility of base-isolated single-storey unreinforced masonry buildings equipped with classical and recycled rubber bearings in Himalayan regions,” *J. Build. Eng.*, vol. 45, no. September 2021, p. 103648, 2021, doi: 10.1016/j.jobe.2021.103648.

[2] Y. Suzuki, M. Tada, R. Enokida, and J. Takagi, “Feasibility of sliding base isolation for rubble stone masonry buildings in the Himalayan Mountain range,” no. July, pp. 1–11, 2024, doi: 10.3389/fbuil.2024.1432912.

[3] T. Royal, G. Society, and B. Geographers, “The Quetta Earthquake Author (s): C . P . Skrine Published by : The Royal Geographical Society (with the Institute of British Geographers) Stable URL : https://www.jstor.org/stable/1785962,” vol. 88, no. 5, pp. 414–428, 1936.

[4] S. D. Journals, “THE BALOCHISTAN EARTHQUAKE 2013 : EMERGENCE OF A NEW ISLAND IN THE ARABIAN SEA,” 2013, doi: 10.15436/JESES.2.1.3.

[5] I. Bahram and T. R. Paradise, “Seismic Risk Perception Assessment of Earthquake Survivors : A Case Study from the 2005 Kashmir Earthquake,” vol. 6, no. October 2005, pp. 403–416, 2020, doi: 10.4236/ojer.2020.95023.

[6] J. Bothara, J. Ingham, and D. Dizhur, “Understanding , Experience and Research on Seismic Safety of Low-Strength Loadbearing Masonry Buildings,” no. December, 2018.

[7] M. G. Melkumyan, “VISUAL AND INSTRUMENTAL MONITORING OF BASE ISOLATED BUILDINGS CONSTRUCTED IN ARMENIA AND EVALUATION OF THE PERFORMANCE OF VISUAL AND INSTRUMENTAL MONITORING OF BASE ISOLATED BUILDINGS CONSTRUCTED IN ARMENIA AND EVALUATION OF,” no. June 2009, 2018.

[8] A. Calabrese, D. Losanno, M. Spizzuoco, S. Strano, and M. Terzo, “Recycled Rubber Fiber Reinforced Bearings (RR-FRBs)as base isolators for residential buildings in developing countries: The demonstration building of Pasir Badak, Indonesia,” *Eng. Struct.*, vol. 192, no. April, pp. 126–144, 2019, doi: 10.1016/j.engstruct.2019.04.076.

[9] A. Ali *et al.*, “Investigation of five different low-cost locally available isolation layer materials used in sliding base isolation systems,” *Soil Dyn. Earthq. Eng.*, vol. 154, no. March, p. 107127, 2022, doi: 10.1016/j.soildyn.2021.107127.

[10] Y. Jiang, Z. Guo, S. Humayun, and Z. Chai, “Sliding bed joint for seismic response control of ashlar stone masonry structures,” *Eng. Struct.*, vol. 244, no. June, p. 112734, 2021, doi: 10.1016/j.engstruct.2021.112734.

[11] S. E. E. Profile and S. E. E. Profile, “Numerical Model for Dynamic Analysis of Structures with Seismic Base Isolation Using A Layer of Stone Pebbles NUMERICAL MODEL FOR DYNAMIC ANALYSIS OF STRUCTURES WITH SEISMIC BASE ISOLATION USING A LAYER OF STONE,” no. April, 2021.

[12] A. B. Habieb, G. Milani, T. Tavio, and F. Milani, “Low cost friction seismic base-isolation of residential new masonry buildings in developing countries: A small masonry house case study,” *AIP Conf. Proc.*, vol. 1863, 2017, doi: 10.1063/1.4992618.

[13] S. Brzev, “Seismic Isolation of Masonry Buildings - An Experimental Study,” no. September, 2017.

[14] R. P. Nanda, P. Agarwal, and M. Shrikhande, “Suitable friction sliding materials for base isolation of masonry buildings,” *Shock Vib.*, vol. 19, no. 6, pp. 1327–1339, 2012, doi: 10.1155/2012/106436.

[15] R. P. Nanda and M. Shrikhande, “Suitable friction sliding materials for base isolation of masonry buildings,” no. June 2016, 2012, doi: 10.1155/2012/106436.

[16] S. Jia, Y. Liu, W. Cao, W. Ye, and Y. Zhang, "Experimental study on the force-bearing performance of masonry structures with a marble-graphite slide seismic isolator at the foundation," *Appl. Sci.*, vol. 6, no. 11, 2016, doi: 10.3390/app6110345.

[17] A. B. Habieb, G. Milani, T. Tavio, and F. Milani, "Low Cost Frictional Seismic Base-Isolation of Residential New Masonry Low Cost Frictional Seismic Base-Isolation of Residential New Masonry Buildings in Developing Countries : A Small Masonry House Case Study," no. January 2018, 2017, doi: 10.2174/1874149501711011026.

[18] D. Losanno, N. Ravichandran, F. Parisi, A. Calabrese, and G. Serino, "Seismic performance of a Low-Cost base isolation system for unreinforced brick Masonry buildings in developing countries," *Soil Dyn. Earthq. Eng.*, vol. 141, no. May 2020, p. 106501, 2021, doi: 10.1016/j.soildyn.2020.106501.

[19] J. S. Dhanya, A. Boominathan, D. Ph, A. M. Asce, S. Banerjee, and D. Ph, "Performance of Geo-Base Isolation System with Geogrid Reinforcement," vol. 19, no. 7, pp. 1–13, 2019, doi: 10.1061/(ASCE)GM.1943-5622.0001469.

[20] K. Yuan, D. Gan, J. Guo, and W. Xu, "Hybrid geotechnical and structural seismic isolation: Shake table tests," *Earthq. Eng. Struct. Dyn.*, vol. 50, no. 12, pp. 3184–3200, 2021, doi: 10.1002/eqe.3505.

[21] A. Tsiavos *et al.*, "Large-scale experimental investigation of a low-cost seismic isolation for developing countries," 2020, doi: 10.1177/8755293020935149.

[22] J. S. Dhanya, A. Boominathan, and S. Banerjee, "Response of low-rise building with geotechnical seismic isolation system," *Soil Dyn. Earthq. Eng.*, vol. 136, no. May, p. 106187, 2020, doi: 10.1016/j.soildyn.2020.106187.

[23] S. Ahmad, F. Ghani, and M. Raghib Adil, "Seismic friction base isolation performance using demolished waste in masonry housing," *Constr. Build. Mater.*, vol. 23, no. 1, pp. 146–152, 2009, doi: 10.1016/j.conbuildmat.2008.01.012.

[24] T. Bibi and A. Ali, "To Investigate Different Parameters of Economic Sliding Based 1 Seismic Isolation System," pp. 0–39, 2022.

[25] 2023 Tayyaba et al., "To Investigate Different Parameters of Economic Sliding Based Seismic Isolation System," *J. Earthq. Eng.*, 2023, [Online]. Available: https://doi.org/10.1080/13632469.2023.2217935

[26] A. Tsiavos, A. Sextos, A. Stavridis, M. Dietz, L. Dihoru, and N. A. Alexander, "Large-scale experimental investigation of a low-cost PVC 'sand-wich' (PVC-s) seismic isolation for developing countries," *Earthq. Spectra*, vol. 36, no. 4, pp. 1886–1911, 2020, doi: 10.1177/8755293020935149.

[27] ASTM, "ASTM C 136-06: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," vol. 04, 2006.

[28] C150/C150M, "iTeh Standards iTeh Standards," 2018. doi: 10.1520/C0150.

[29] O. Standard, S. Heading, W. Thickness, and B. Load, "iTeh Standards iTeh Standards Document Preview," vol. i, pp. 1–6, 2019, doi: 10.1520/C0067.

[30] C. Ag-, B. Statements, and W. Pycnometer, "Standard Test Method for iTeh Standards iTeh Standards," vol. i, pp. 22–25, 2015, doi: 10.1520/D5321.