PERFORMANCE OF SAND-TYRE MIX AS THE BASE ISOLATION MATERIAL UNDER CYCLIC LOADING

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The earthquake related destructions in buildings is alleviated by uncomplicated methods with the implementation of sand-tire mix as the base isolation material below the footing. Rubber which is the major raw material for the elastomeric bearings shall be replaced with sand-rubber mix. The mix is placed below the footing to determine the deflections of the footing for trials such as 0%, 10%, 20%, 30 % and 50% crumb rubber (CR). Furthermore, the behaviour of the footing is studied with these trials under static and cyclic loading. The research is exclusively dealt to determine the energy dissipation capacity and stiffness degradation of the footing with and without base isolation material (sand-rubber mix). From the investigation it was evident that 30% crumb rubber combination have better seismic energy mitigating capacity.

Keywords: *Sand, crumb rubber, footing, static, cyclic, energy dissipation capacity, stiffness degradation*

1. Introduction

The concept of seismic isolation can be defined as a procedure to elongate the fundamental time period of vibration by providing dampers made of different type of materials. The ultimate aim of this process is to achieve a significant reduction in base shear which is the main cause of failure during earthquakes. Isolation of buildings and other facilities primarily against earthquake forces is being practiced for centuries [1]. Locally available materials, such as sand, saw dust, wood, rubber, marble and other similar items have been used for the purpose of isolation. Nevertheless, seismic isolation is being identified as a modern or innovative technology the fundamental concept behind isolation is far from being a recent development [2]. Figure 1 shows the country-wise seismic application, from which Japan is leading in the implementation of seismic isolation systems.

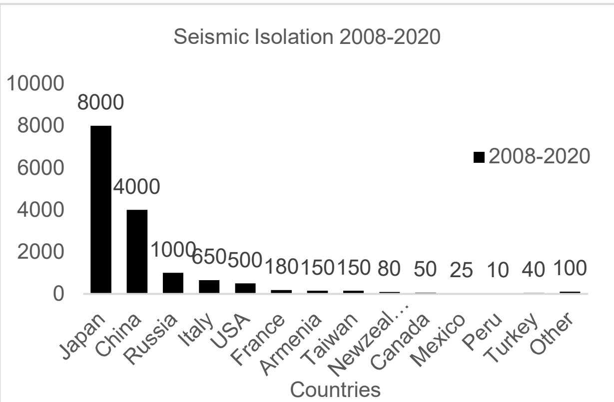

Fig. 1 – Increasing seismic isolated facilities [3 - 7]

The performance of an isolation system consisting of shredded-tire with sand in various proportions (in percentage) was investigated. The authors concluded that 50% by volume shredded-rubber - sand matrix is found to be an effective low-cost seismic isolation system [8]. The concept of rubber - soil mixture as a base isolating system. The authors concluded that this type of rubber-soil cushion effectively reduced the horizontal acceleration up to 60 % and that the vertical acceleration by 80% [9]. The application of a low-cost damping system was proposed consisting of the rubber-soil mixture up to medium-rise buildings. They observed a reduction in acceleration and inter-story drift, at different floor levels between 40 to 50% [10]. An investigation was undergone to determine the response of soil-tire mixture (tire-30%) when it is subjected to cyclic loading. For instance, by conducting a cyclic-triaxial test they reported that there is a decrease in shear modulus with the increase in tire content. Furthermore, they carried over-analytical analysis to determine the seismic response of the building using ABAQUS Software. The isolating layer with its thickness two times the width of the footing was taken for the analysis. Moreover, Time History Analysis was also performed. The authors reported that peak spectral acceleration was significantly reduced by 40% [11]. A huge quantity of worn-out tires is dumped in landfills which is a burning problem of society [12]. These tires are ground to crumb rubber, could be effectively used as the base isolation material. Researchers have started to investigate the usage of tire scraps as the base isolation materials alternative to other costlier isolators particularly for a developing country [13]. In the present investigation, the behaviour of sand-tire crumb mix

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as a base isolation material subjected to static and cyclic loading and the parameters such as energy dissipation capacity and stiffness degradation which is the key factor for the seismic event is studied [14,15].

2. Methodology

The investigation is performed using locally available river sand which is classified as poorly graded sand as per IS 1498[16], shown in Figure.2. The ultimate aim of the research is to study the behaviour of the building subjected to static and cyclic loads. The building's response significantly depends on its elements such as beams, columns, footing, etc., Nevertheless, when the aspect of seismic action is considered, footing plays a vital role in affecting the behaviour of the building. The aim of the study is to apply crumb rubber as the base isolation material. The tire crumbs used for the study have to pass through 4.75 IS sieve % [17]. The research consists of five trials such as tire crumbs mixed with sand in percentages 0%, 10%, 20%, 30%, and 50% as shown in Figure.3. Thereafter, the capacity of the footing with and without base isolation material is studied. For instance, the experimental setup consists of a test tank of size 1m x 1mx 1m. The arrangement of the test tank consists of four dial gauges connected to the LVDT box. The load frame consists of a hydraulic jack which is hand operated in which the load cell of 5 Ton capacity is placed as shown in Figure.5. The readings of load and four dial gauge readings are displayed in the LVDT box. The schematic diagram of the load frame is presented in Figure.4. The model footing considered for the study is raft footing of size 30cmx 30 cm x 5 cm [18]. For instance, the test tank is filled with sand and compacted thoroughly to achieve a relative density of 85% for every 0.1 m and eventually filled up to the height of 0.8 m. In the first series of tests, the model footing is considered to be placed on the sand (without base isolation materials, 0% crumb rubber). The load is applied and its respective deflection of the footing is noted. The failure of the footing is reported as the punching failure undergone by the footing. Once the failure is identified, the load is applied reverse and its corresponding deflections are noted. In the second, third, fourth, and fifth series of tests the sand below the footing is replaced with

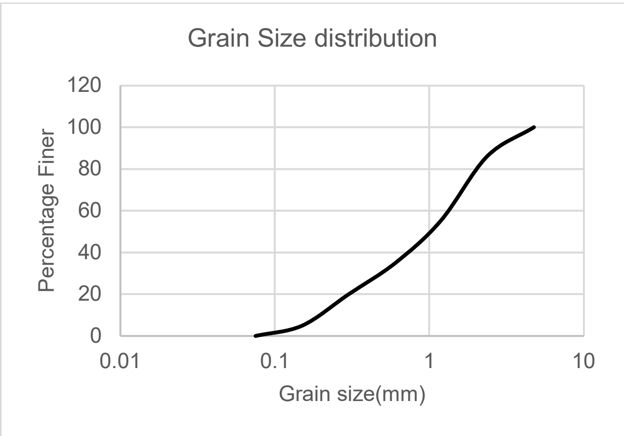


Fig. 2 – Grain Size distribution curve for Chennai city river sand

Fig. 3 – Sand-Rubber mix

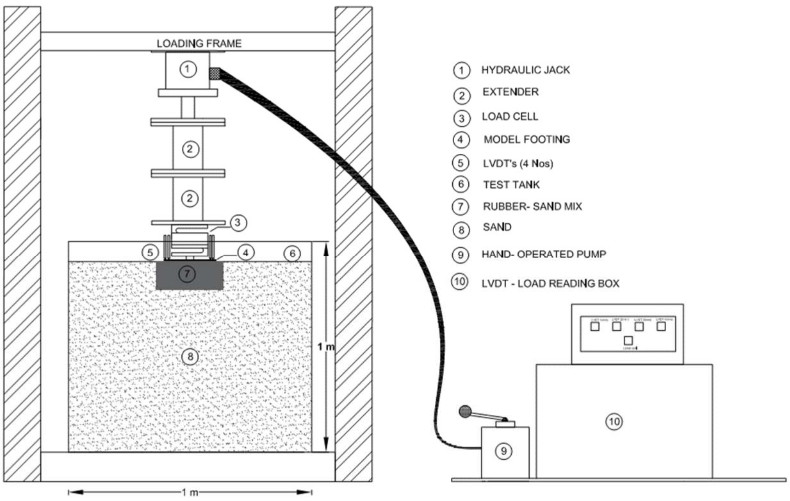


Fig.4 – Experimental setup

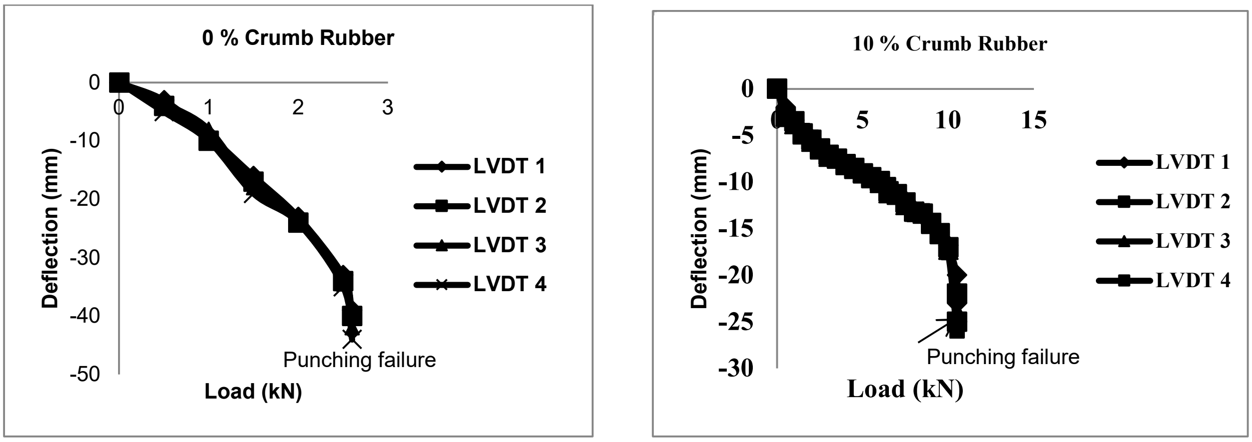
(a) (b)

Fig. 5 – (a)Loading Frame arrangements with Test Tank (b)Hand- operated pump and LVDT Box

sand-tire crumb mix which is placed in a depth of 30 cm [17] with crumb rubber in a proportion such as 10%, 20%, 30%, and 50%. The loading is applied using the hydraulic jack and the corresponding deflections are identified. In all the trials, load Vs Deflection graphs for cyclic loading is plotted. Substantially, the parameters such as energy absorption capacity and Stiffness degradation which is essential for seismic action are determined. The experiment is prolonged by conducting four cycles for every five trials until the failure of the footing and thereafter, the best combination of sand-tire crumb mix suitable for base isolation is reported.

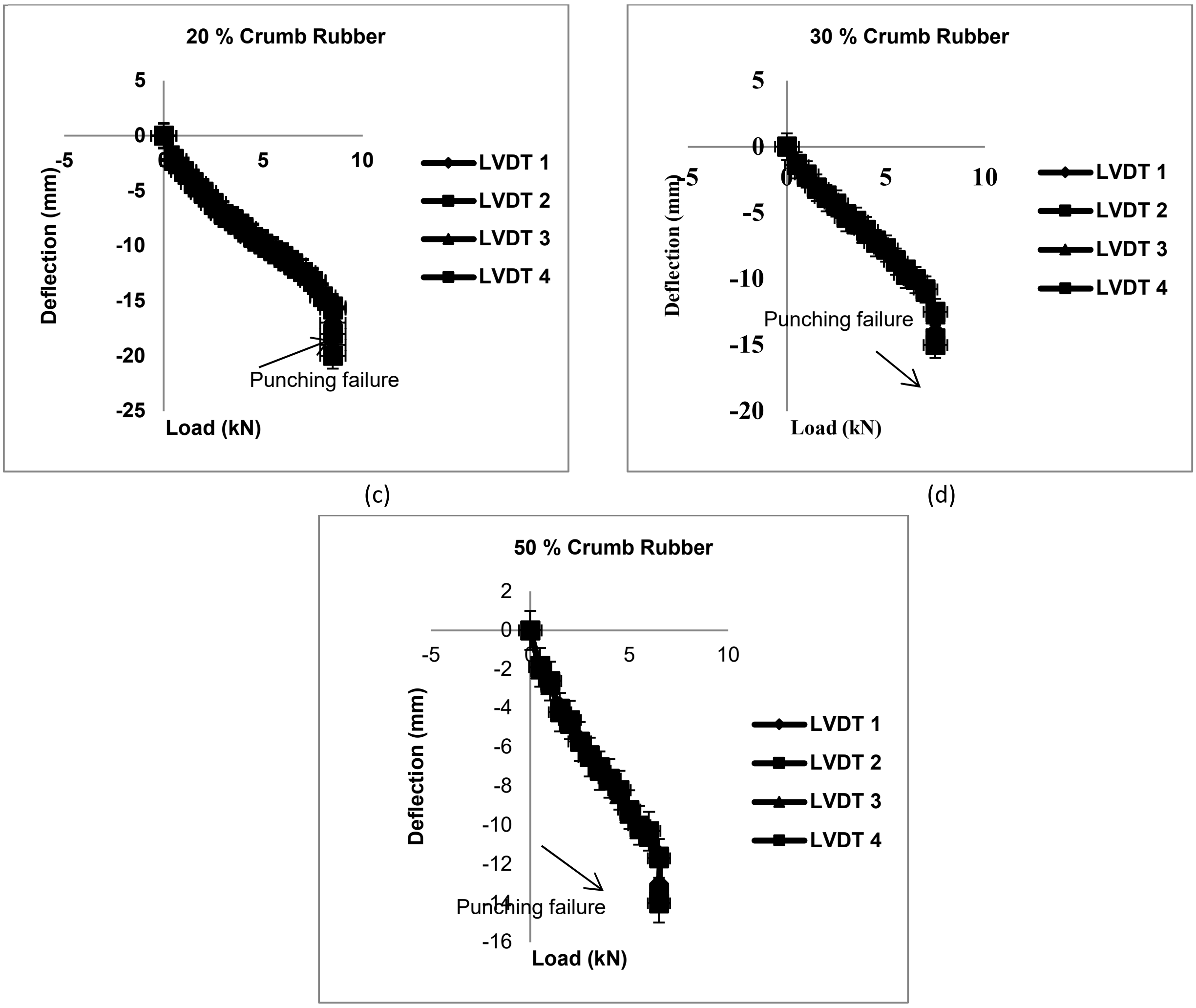
2.1 Static Loading

The model footing is loaded under each percentage under static loading and its respective deflections of four LVDT's placed on the footing are noted. Load Vs Deflection graph is plotted (Figure.6) for five different percentages. From the figures, it is evident that compared to 0%, 10%, 20%, and 50% CR, for 30 % CR, the rising trend in the graph is such that deflections are found to be sustained in all the LVDT's. The effect of punching failure has an influence on footing-column connection [19] and hence the behaviour of footing with respect to it is determined. From the investigation, for 0%, 10%, 20%, 30 %, and 50% crumb rubber, a maximum settlement of 35 mm is found for 0 % crumb rubber at 2.5 kN load and less settlement of 12.7 mm is determined at 7.5 kN load for 30 % CR.



(a) (b)

Fig. 6 continues on next page

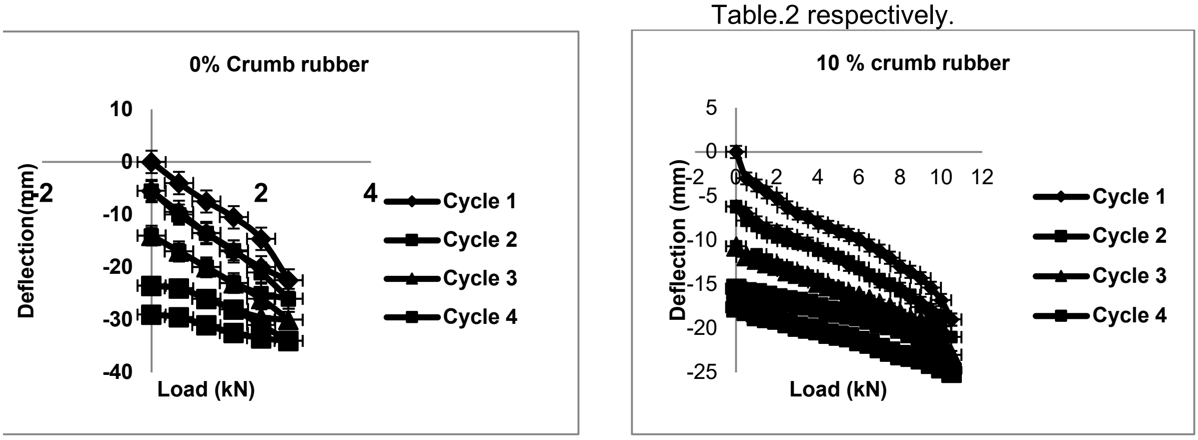


(e)

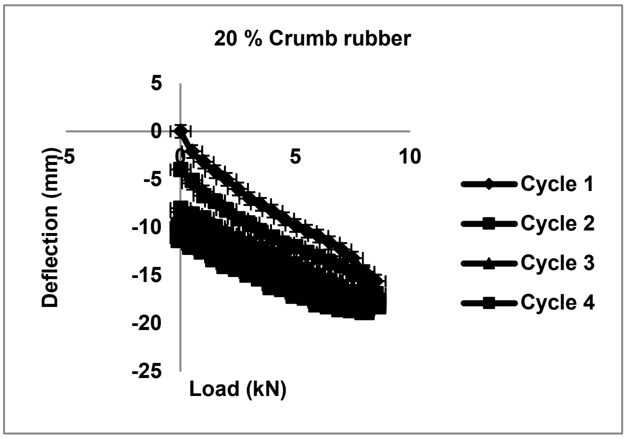
Fig. 6 – Load Vs Deflection graph for static loading (a) 0% crumb rubber (b) 10% crumb rubber (c) 20% Crumb rubber (d) 30% crumb rubber (e) 50% crumb rubber

2.2 Cyclic Loading

The objective of conducting the investigation for cyclic loading is to determine the energy dissipation capacity and stiffness degradation of the footing with the base isolation material exclusively. The loading corresponding to failure is classified into four cycles and in each cycle (Figure.7), loading is applied till the settlement is less than 0.02 mm/hr and gradually unloaded and its corresponding deflection is noted and the procedure is repeated until the failure of the footing [20]. The stiffness in a particular cycle is the slope of the tangent drawn to the curve at the base shear and the energy dissipation capacity is the area enclosed in the loop [15]. The values of stiffness degradation and energy dissipation Capacity is presented in Table.1 and Table.2 respectively.



(a) (b) Fig. 7 - continues on next page



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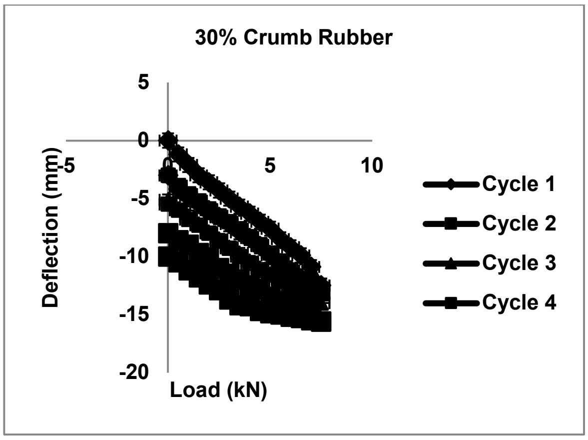

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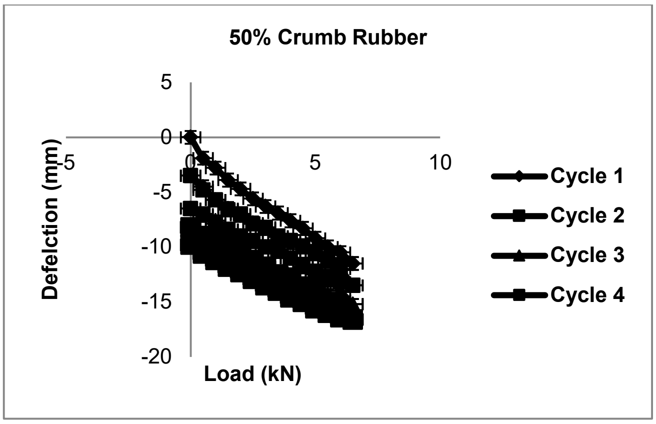

(e)

Fig. 7 – Load Vs Deflection graph for cyclic loading (a) 0% crumb rubber (b) 10% crumb rubber (c) 20% crumb rubber (d) 30% crumb rubber (e) 50% crumb rubber.

Table 1

Stiffness of the footing

Stiffness (kN/mm)	Cycle 1	Cycle 2	Cycle 3	Cycle 4
0% Crumb Rubber	0.158	0.130	0.178	0.083
10%Crumb Rubber	1.191	1.050	1.751	0.760
20%CrumbRubber	0.750	0.351	0.501	0.416
30% Crumb Rubber	0.553	0.830	1.125	0.785
50% Crumb Rubber	0.769	0.789	0.821	1.014

Table 2

Cumulative energy dissipation capacity of the footing

Cumulative energy dissipation capacity (kNmm)	Cycle 1	Cycle 2	Cycle 3	Cycle 4
0% Crumb Rubber	9.5	19.5	30.5	42
10%Crumb Rubber	10	21.5	33.5	46
20%CrumbRubber	12	24.5	35.5	48.5
30% Crumb Rubber	15	31	47.5	64.5
50% Crumb Rubber	13	26.5	40.5	55

3. Results and Discussion

3.1 Stiffness Degradation

Stiffness degradation has an impact on the ductility of the stiff buildings especially when the aspect of an earthquake is considered, where the stiffness degradation increases the ductility of the structures exclusively [21]. The increase in stiffness decreases the fundamental period of the building, hence the provision of the base isolation decreases the stiffness thereby increasing the fundamental period of the building [22]. The stiffness degradation behaviour of the footing is shown in Figure.8 for all five cases.

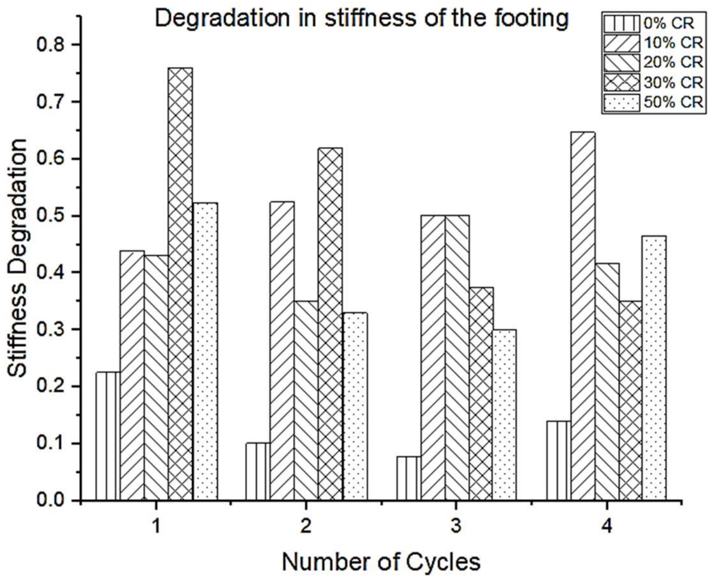

Fig. 8 – Stiffness degradation

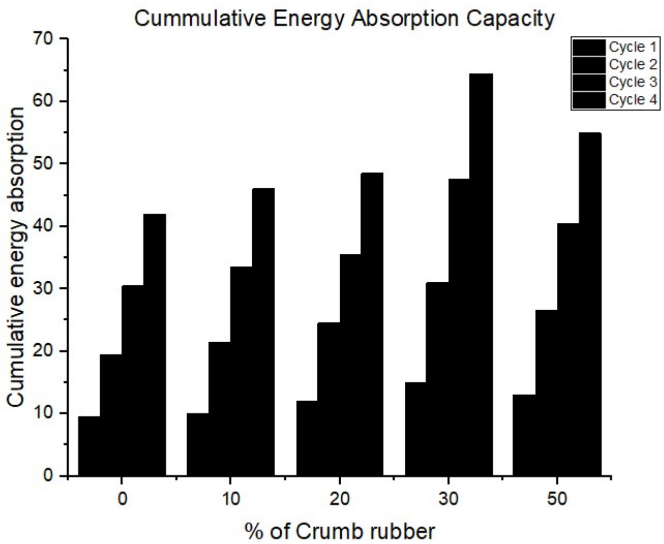

Fig.9 – Cumulative energy Dissipation capacity

3.2 Energy Dissipation Capacity

The increase in energy absorption capacity increases the ductility of structures to prevent brittle failures in earthquakes [23]. The seismic isolators have the capacity to absorb the earthquake energy exclusively [24]. In the current research, the combination of sand and rubber with 0%, 10%, 20%, and 50% crumb rubber the energy absorption capacity is higher with 30% crumb rubber exclusively in which ductility is achieved. The cumulative energy dissipation capacity of the footing is shown in Figure.9 for all five cases.

4. Conclusion

- The applications of seismic isolation in the structures effectively dissipate the earthquake energy without transmitting the seismic shocks into the superstructure thereby making the building active during the seismic action.
- Incorporating seismic isolation methods even in a single storey building has definite advantages in saving of precious lives and property.
- The application of ancient base isolation techniques is very much essential to mitigate the seismic hazards in an economical way by the usage of readily available source material.
- The evolution and the rapid application of automobiles have led to the disposal of dumped waste tyres and it is a challenging task to be considered as it would eventually pose a serious environmental and health risk. Therefore, these hazardous wastes could be effectively applied for the seismic isolation in the structures.

- Though the initial stiffness with 30 % crumb rubber increases the degradation in stiffness is attained at the end of the final cycle which is a promising aspect to be considered. Nevertheless, the stiffness trend is fluctuating in 0% CR, 10% CR and 20% CR and moreover, in 50% CR, the drop in stiffness is not attained. Hence the best mixture as the base isolation material is reported to be 30 % crumb rubber with 70% sand (by weight). From the investigation, it is evident that 30 % CR withstand earthquakes by dissipating the earthquake energy in compared to other proportions effectively.
- The only drawback of this investigation is that the work is to be applied in real time buildings and hence this research would be a research problem for future researchers to find out real-time applications of the proposed base isolation material.

REFERENCES

[1] N. Makris, Seismic Isolation: Early History, Earthquake Engineering and Structural Dynamics, 2018, **48** (2), 1-16.

[2] B. Carpani, Base Isolation from a Historic Perspective, 16th World Conference in Earthquake Engineering, Santiago Chile, January (2017), Paper No. 4934.

[3] A. Martelli, M. Forni, (2010). Seismic isolation and other anti-seismic systems: recent applications in Italy and worldwide, Seismic Isolation and Protection Systems (SIAPS), Mathematical Sciences Publishers (MSP), Berkeley, CA, USA.

[4] A. Martelli and M. Forni, P. Clemente, (2012). Recent worldwide application of seismic isolation and energy dissipation and conditions for their correct use, In: Proceedings on electronic key of the 15th World conference on earthquake engineering, Lisbon, Conference programme, 52.

[5] A. Martelli, P. Clemente A. Stefano, M. M. Forni and A. Salvatori (2014). Recent Development and Application of Seismic Isolation and Energy Dissipation and Conditions for Their Correct Us, Perspectives on European Earthquake Engineering and Seismology,34,449-488. Retrieved on Monday, 22 November 2020 07:56:20 PM

[6] R. Skinner, I. Robinson, W. H., McVerry G H, 'An Introduction to Seismic Isolation, Wiley Publishers, 1993.

[7] M. Walters, Seismic Isolation- The Gold Standard of Seismic protection, Structure Magazine, 2015. Retrieved from https://www.structuremag.org/?p=8770 on 6 July, 2020 09:25:40 AM

[8] S. Bandopadhyaya, A. Sengupta and G. R. Reddy, Experimental Investigation into Natural Base Isolation System for Earthquake Protection, 7th International Conference on Case Histories on Geotechnical Engineering, Chicago, 2013. Paper.No.4.10 b

[9] H. Tsang Ho, M. Sheikh, M. Neaz. & N Lam, Rubber Soil cushion for Earthquake Protection, Australia Earthquake Engineering Society Conference, Australia, (2007), pp. 1-7.

[10] A. Panjamani, M D. Ramegowda,, and D. Rohitiii,, 'Low cost damping scheme for low to medium rise buildings using rubber soil mixtures, International Workshop on Geotechnics for Resilient Infrastructure, Japanese Geotechnical Society Special Publication, The Second Japan-India Workshop in Geotechnical Engineering, 2015.

[11] J. S. Dhanya, B. Adimoolam and S. Banerjee, Response of Soil-Tyre Mixture subjected to Cyclic Loading, 16th World Conference on Earthquake Engineering, Santiago, Chile, 2017. Paper No. 1662. Retrieved on Monday, 18 December 2020 07:46:20 PM

[12] T. G. Chiaro, A. Palermo, G. Granello, A. Tasalloti, C. Stratford and L. J. Banasiak, Eco-rubber seismic-isolation foundation systems: a cost-effective way to build resilience, Pacific Conference on Earthquake Engineering, New Zealand Society of Earthquake Engineering, Sky City, Auckaland, New Zealand, Paper.No.196. Retrieved on Thursday, 15 October, 2020 07:46:20 AM

[13] J. Cici Jennifer Raj, J. and S. Suppiah, Seismic isolation using scrap tire rubber pads, Materials Today: Proceedings, 2020. Retrieved from https://doi.org/10.1016/j.matpr.2020.09.176 on Wednesday, 22 October 2019 06:27:10 PM

[14] S. Arulselvan, S. and K. Subramanian, Experimental Investigation on Three Dimensional RC Infilled Frame - RC Plane Frame Interactions With Slab for Seismic Resistance, American Journal of Applied Sciences 2008, **5** (4), 328-333.

[15] E. B. Perumal Pillai (1995), 'Influence of Brick Infill on Multi-Storey, Multi Bay RC Frames', *Ph.D. Thesis,* Coimbatore Institute of Technology,Coimbatore. Retrieved from http://hdl.handle.net/10603/108330 on 28 November, 2020, 11:25:40 AM

[16] IS 1498-1970. Classification and Identification of soils for general engineering purposes, First revision, Reaffirmed 2007, Bureau of Indian Standards, New Delhi.

[17] J.S. Dhanya, J. S., Adimoolam, B. and Banerjee, H., Performance of Geo-Base Isolation System with Geogrid reinforcement,ASCE 2019, **19**(7) ,1-13.

[18] B. E. Garhy, A. Galil, A. F. Youssef and M. A Raia,., Behavior of raft on settlement reducing piles: Experimental model study, Journal of Rock Mechanics and Geotechnical Engineering, 2013, **5**, 389-399.

[19] Sang-Sup Lee,1 Jiho Moon, Keum-Sung Park,1 and Kyu-Woong Bae, Strength of Footing with Punching Shear Preventers, Scientific World Journal, 2014, Article ID 474728, 1-15. Retrieved from http://dx.doi.org/10.1155/2014/474728 10 February, 2021 09:40:40 AM

[20] M. V. Sreedhar and A.K.P Goud. Behaviour of Geosynthetic Reinforced Sand Bed Under Cyclic Load, Proceedings of Indian Geotechnical Conference, December 2011, Kochi. (Paper No. J-049)

[21] A.K. A Chopra, and C. Kan, Effect of stiffness degradation on ductility requirements for multi-storey buildings, Earthquake Engineering and Structural Dynamics, 1973, **2**(1), 35-45.

[22] M. Ferraioli and A. Mandara, Base Isolation for Seismic Retrofitting of a Multiple Building Structure: Design, Construction, and Assessment, Hindawi, Mathematical Problems in Engineering ,2017. Article ID 4645834

[23] Yun-Yun Xu, Zhen-Rong Lin and Tao Zhang, Design features and significance of the ductile reinforced concrete frame structure, Design, Manufacturing and Mechatronics, 2015, 183-189. Retrieved from https://www.worldscientific.com/on 16 February, 2021 08:25:40 PM

[24] L. Olariu, F. Olariu, and Sarbu, D. Base Isolation Versus Energy Dissipation for Seismic Retrofitting of Existing Structures, 12th World conference on earthquake engineering, Auckland, New Zealand, 2000.Paper. No.1333.

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