Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Natural Rubber Latex for Reducing Soil Brittleness Induced by Post-Compaction Moisture Reduction

Veena U[1][0000-0001-8554-686X] and Naveen James [1][0000-0001-5910-1103]

[1] Department of Civil Engineering, Indian Institute of Technology Ropar, Punjab – 140001
veenau1010@gmail.com

Abstract. High brittleness of soil is an unfavourable characteristic that leads to sudden failure of slopes and retaining structures without warning. Post-compaction drying of soil increases the brittleness, and the scenario becomes critical when shrinkage leads to the development of tensile crack. The present study attempts to use Natural Rubber Latex (NRL) to reduce soil brittleness caused by post-compaction drying. A number of samples with untreated and NRL-treated soils were compacted at dry of optimum and left for natural drying. Unconfined Compressive Strength (UCS) tests were carried out after drying periods ranging from 1 to 28 days. Soil brittleness is assessed in terms of strain associated with peak strength and energy absorbed before failure. A reduction in brittleness was observed when the soil was treated with NRL. Also, it was observed that the strain at peak strength remains unaffected by the post-compaction moisture reduction in NRL-treated soil. Hence NRL treatment can be considered a productive technique for mitigating brittleness-induced failure of geotechnical structures.

Keywords: Soil brittleness; post-compaction moisture reduction; Natural Rubber Latex

1 Introduction

Post compaction drying of soil results in very high strength due to the development of matric suction. At the same time, the reduction in moisture content causes the soil mass to act as a brittle material in which rupture occurs within a small strain without giving necessary warning. Most of the widely adapted chemical stabilisation techniques result in a further increase in the brittleness of soil [1]. In the last few decades, a number of studies have been performed to improve the ductility of soil by means of geosynthetic reinforcement [2–5] and natural or synthetic fibre reinforcement [6–9]. Even though geosynthetic and fibre reinforcement was proved to be effective in reducing soil brittleness, their manufacturing and field deployment are associated with complicated processes and demand skilled labour. The inclusion of rubber tyre chips is a reliable method of increasing ductility [10–13]. Since there is a chance of groundwater pollution due to the heavy metal leachate from tyre chips [14–16], environmental studies are required before implementing the technique in the field.

In this context, the need for an environment-friendly material which can be introduced into soil by a simple procedure made the authors think about the applicability of natural rubber latex (NRL) for inducing ductility in soil. Being a material of biotic origin, NRL can be considered as a sustainable and environment-friendly admix. It was observed that NRL could improve the ductility of freshly compacted soil appreciably [17]. The present paper investigates the efficacy of NRL treatment in maintaining the improved ductility in soil subjected to post-compaction drying. The experimental investigation was conducted by performing unconfined compression tests of untreated and NRL-treated soil samples after various drying durations.

2 Materials and Methodology

2.1 Material Selection and Characterization

The soil used for the experimental study was collected from a field nearby IIT Ropar. After air-drying and crushing the lumps, the soil was sieved through the 2.36 mm sieve to remove foreign objects. The index properties of the processed soil were calculated by conducting laboratory experiments following the corresponding IS codes. The grain size distribution of the soil is shown in Fig. 1(a). Fig. 1(b) shows the location of the soil in the plasticity chart [18]. Based on the fine fraction (fraction of soil passing 75µm sieve) and its position in the plasticity chart, the soil is classified as MI-CI. The index properties of soil are listed in Table 1. In order to understand the compaction characteristics, the light compaction test was carried out as per IS 2720 (Part 7): 1980 [19]. The maximum dry density and optimum moisture content obtained from the light compaction test are also given in Table 1.

The natural rubber latex is a hydrosol of fine rubber particles obtained by tapping Hevea Brasiliensis trees. For industrial use, the NRL is centrifuged and preserved with a small amount of ammonia. The NRL used in the present study was supplied by Ms Asiatic Rubber Industries, Kottayam, Kerala. The basic characteristics of the NRL used were tested as per the relevant IS codes and are given in Table 2.

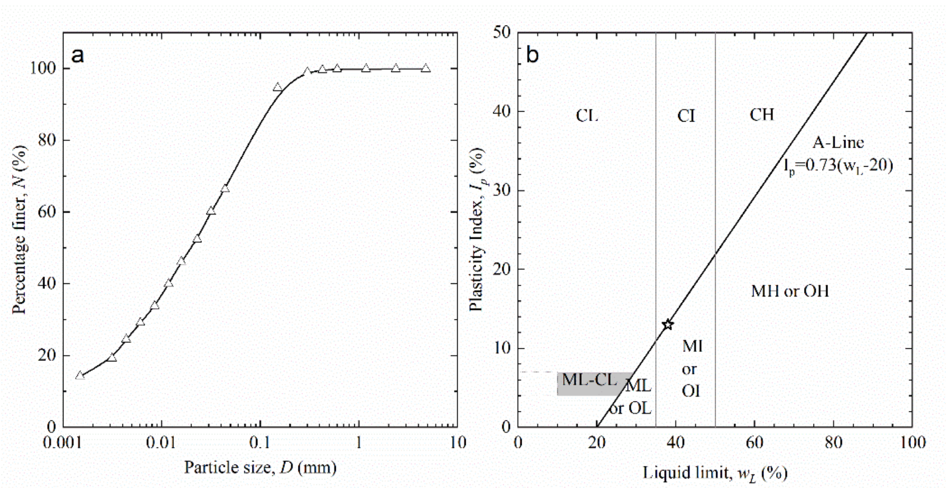

Fig. 1. (a) Grain size distribution (b) location in plasticity chart of the selected soil.

Table 1. Index properties of selected soil

Property	Value
Specific gravity, G	2.63
Sand size fraction (%)	21
Silt size fraction (%)	63
Clay size fraction (%)	16
Liquid limit, w_L	38%
Plastic limit, w_P	25%
Plasticity Index, I_p	13%
IS classification	CI-MI
$\gamma_{d\ max}$ (g/cm^3)	1.79
OMC (%)	15%

Table 2. Properties of natural rubber latex used for the study

Parameter	**Value**
Dry Rubber Content (% by mass)	60.1
Total Solids Content (% by mass)	61.8
Coagulum Content (% by mass)	0.015
Sludge Content (% by mass)	BDL*
Alkalinity as Ammonia (% by mass)	0.74
Koh Number	0.86
Mechanical Stability Time (sec)	726
Volatile fatty acid number	0.05
Copper content (Ppm of total solids)	1.4
Manganese content (Ppm of total solids)	BDL

2.2 Experimental Work

A series of UCS tests were performed to evaluate strength-deformation characteristics of local soil with and without NRL treatment after various drying periods. The sample preparation method and the details of UCS tests are explained below.

Sample Preparation. All the samples were prepared with a diameter of 38 mm and a height of 76 mm. The target dry density of soil was chosen as 95% of maximum dry density, which is considered as the presumable field density that can be achieved with

* Below detection limit

currently available types of equipment [20]. The moulding water content of the untreated sample was selected as that corresponding to 95% of $\gamma_{d\ max}$ in the light compaction curve on the dry of optimum. In the case of NRL-treated samples, instead of water, NRL was mixed with dry soil such that the resulting water content is the same as that of untreated samples. The NRL content, which gives the target moulding water content, was determined by calculating the water contents of samples prepared with various percentages of NRL, as explained by Veena and James [17]. Fig. 2 shows the variation of sample moulding water content with NRL content in different types of soils. Here the NRL content indicates the quantity of NRL as a percentage of soil dry weight. The parameters chosen for sample preparation are given in Table 3.

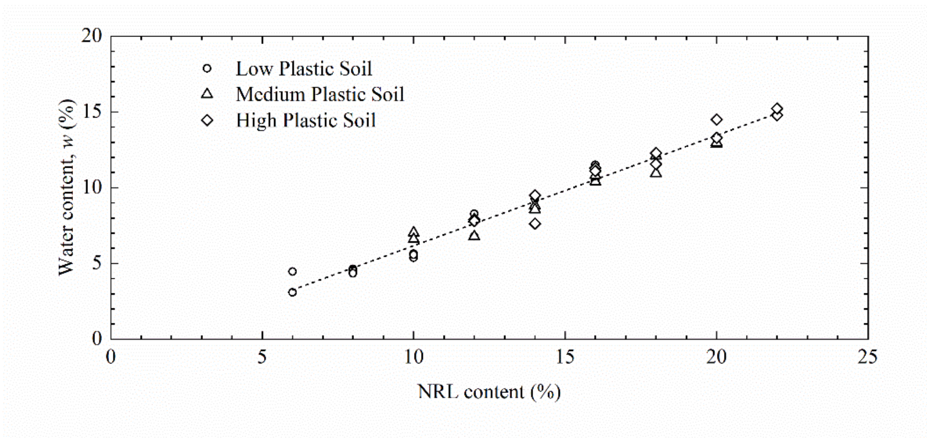

Fig. 2. Variation of moulding water content with NRL content [17]

Table 3. Sample preparation parameters

Parameter	Untreated sample	NRL-treated sample
Dry density, γ_d (kg/m^3)	1698	1698
Water content, w (%)	11	-
NRL content (%)	-	18

The untreated and NRL-treated compacted samples were subjected to air drying by keeping them open to atmospheric conditions. UCS tests were carried out after different periods of 0, 1, 2, 4, 7, 10 and 14 days. The daytime room temperature was found to vary between 30˚C to35˚C during the drying period. A couple of NRL-treated samples were kept for drying for 21 and 28 days to perceive the influence of further drying on their performance. In order to understand the effect of drying temperature, two sets of NRL-treated samples were dried under the controlled temperature of 25˚C and 50˚C for durations varying from 1 to 28 days and tested.

Unconfined Compressive Strength (UCS) Test. For comparative load-deformation studies of cohesive soils, the UCS test is widely accepted as it is quick, cheap and simple [21–23]. The UCS tests were carried out on all the samples as per IS: 2720 (Part 10) 1991 [24]. The tests were conducted with a strain rate of 1.25 mm/min, and the load applied on the sample was recorded at every 0.5 mm displacement.

3 Results and Discussions

2.3 Unconfined Compressive Strength

Fig. 3(a) shows the strength variation of untreated and NRL-treated soil with the drying period up to 14 days. It is well-known that compacted, unsaturated fine-grained soil strength is primarily controlled by suction [25–27]. Hence it is expected that the soil specimens will exhibit an increase in strength with drying due to the increase in suction. In untreated soil, it can be seen that after 4 days, the strength remains almost constant, whereas, in NRL-treated soil, the strength increases till 7 days and remains constant after that. It is worth noting that the increase in strength is slow in NRL-treated soil compared with untreated soil. Fig. 3(b) shows the strength development in NRL-treated soil when dried under different conditions. When dried at 25˚C, the slow rate of drying retards the development of suction and, thus, the strength of the soil. After 21 days, these samples also attain the strength of samples dried at room temperature. The samples dried at 50˚C show a different trend of strength development. Due to the fast drying rate, these samples achieved a very high strength within 2 days but lost the strength after that. This can be attributed to the softening and expansion of rubber content when subjected to high temperature for a long time, causing reduction in the number of inter-particle contacts, which is the most critical factor that influences cohesion [28].

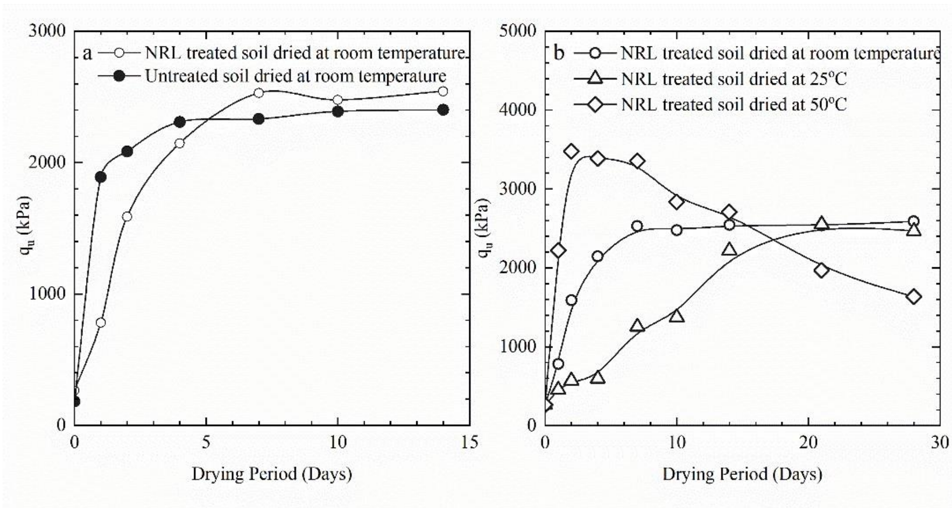

Fig. 3. Variation of strength with drying period (a) Untreated and NRL-treated soil at room temperature (b) NRL-treated soil under different conditions.

Fig. 4 depicts the variation of soil strength with the sample's water content during the test. The strength of all the soil samples was found to have an exponential correlation with the water content during the test irrespective of the presence of NRL, except the NRL-treated sample, dried at 50˚C. This result infers that under normal temperature conditions, the influence of NRL on the strength of dry soil is practically nil. As mentioned earlier, the variation in behaviour of NRL-treated sample dried at 50˚C can be attributed to the expansion of rubber.

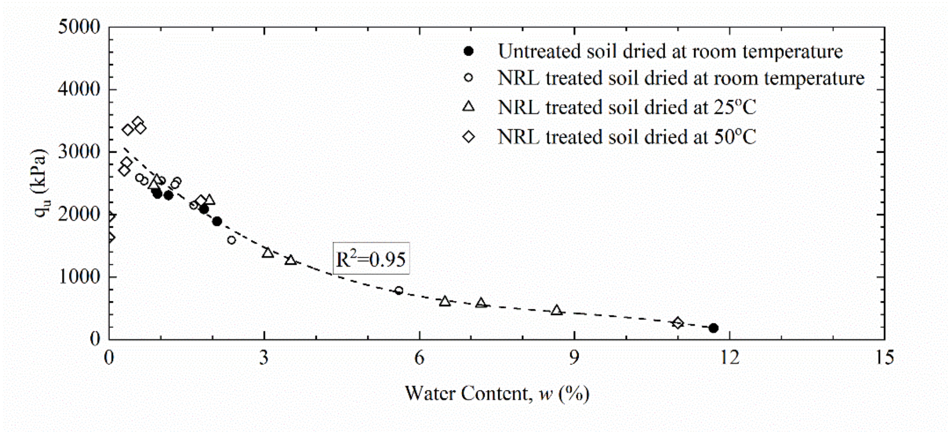

Fig. 4. Variation of UCS values with water content of sample during the test

2.4 Ductility Characteristics

In the present study, more emphasis is given to the ductility characteristics of the soils. Here, the term ductility indicates the ability of the material to deform without failure. Fig. 5(a) shows the stress-strain curves of untreated and NRL-treated samples dried at room temperature for various time durations. It can be seen that even though there is no considerable improvement in strength, the failure occurs at a higher strain in NRL-treated soil as compared to untreated soil. Fig. 5(b) shows the stress-strain curves of NRL-treated samples subjected to different drying conditions after 2 days and 28 days. It can be seen that the strain associated with peak stress is comparable in all these samples except the sample dried at 50˚C for 28 days, which shows a reduced strength and failed at a lower strain.

Deformability Index. For quantifying the improvement in ductility due to the NRL treatment, the parameter deformability index [29, 30] is used. The deformability index (I_D) can be calculated by using Equation 1.

$$I_D = \frac{\varepsilon_{treated}}{\varepsilon_{untreated}} \qquad (1)$$

Here $\varepsilon_{untreated}$ and $\varepsilon_{treated}$ indicate the strain associated with peak stress in untreated and NRL-treated soil samples. The values of the deformability index calculated for all the NRL-treated samples are plotted against the drying period in Fig. 6(a). It should be noted that the I_D values of most of the NRL-treated samples are nearly 2. It shows that NRL-treated soil can sustain double the strain than the untreated soil before failure, even in the dry state. In order to distinguish the influence of NRL in improving the ductility from that of the lubrication effect of sample moisture content, the failure strain was plotted against sample water content during the test in Fig. 6(b). Interestingly, it is evident that even at the same water content, NRL-treated samples are able to carry almost two times the strain taken by the untreated sample before failure.

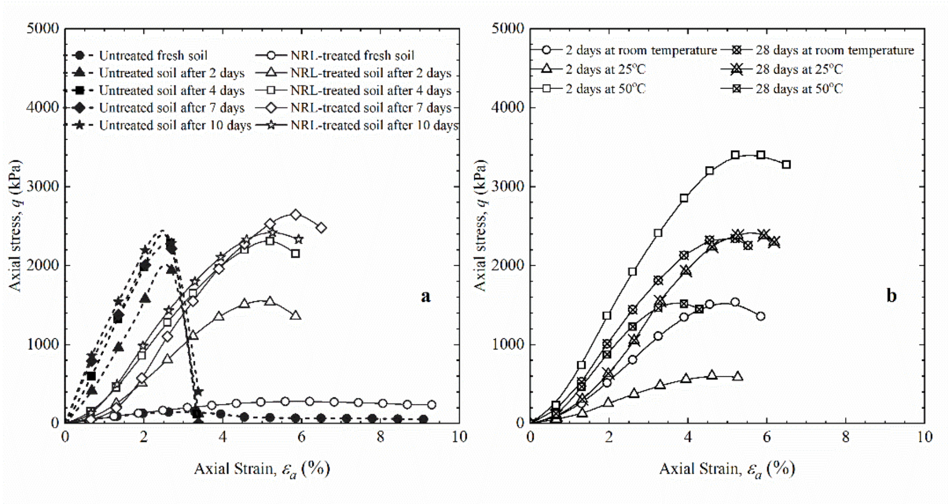

Fig. 5. (a) Stress-strain curves of untreated and NRL-treated soils dried at room temperature. (b) Stress-strain curves of NRL-treated soil dried under different conditions.

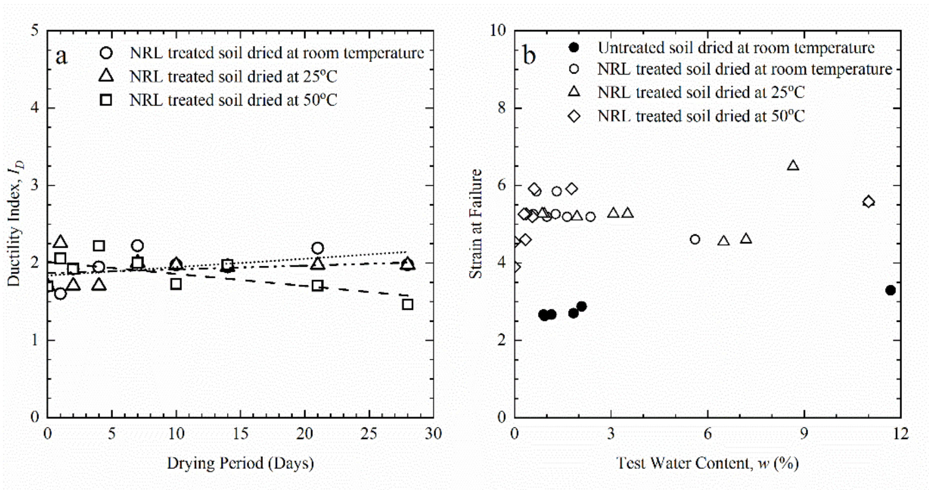

Fig. 6. (a) Deformability index of NRL-treated samples (b) Strain at failure versus test water content

Energy Absorption Capacity. The variation in soil's strength and strain capacity reflects in the parameter absorbed strain energy as it is calculated as the area under the stress-strain curve [9]. The strain energy absorbed by all the samples before failure are plotted against the drying period in Fig. 7(a) and against the water content during the test in Fig. 7(b). Irrespective of the comparable strength, the energy absorption capacity of NRL-treated soil samples was found to be higher than that of untreated soil. It was seen in section 3.1 that NRL-treated soil dried at 50˚C became weaker than the untreated soil after a period of 14 days. It is noteworthy that even these samples show an energy absorption capacity comparable to that of untreated soil samples. This represents the improved ductility acquired by the soil as a result of NRL treatment.

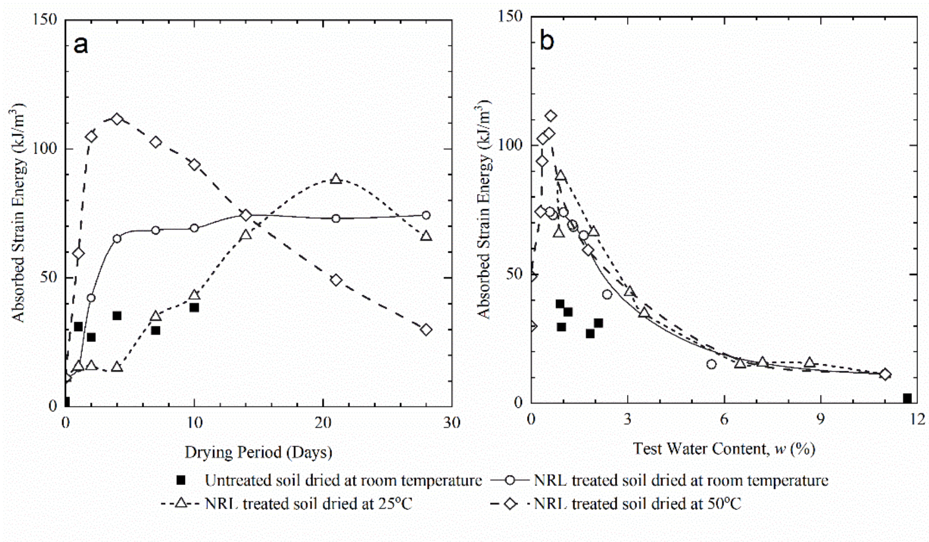

Fig. 7. Strain energy absorbed by the samples before failure plotted against (a) drying period and (b) water content during the test

Post-failure Behaviour. To get an insight into the post-failure behaviour of dry soil, an untreated soil sample and an NRL-treated soil sample were subjected to the UCS test to a higher value of post-failure strain. Samples dried for 14 days were chosen for this test. Fig. 8 shows the stress-strain curves obtained from the tests. The stress-strain curve of untreated soil shows a pure brittle behaviour indicated by a substantial post-failure strength loss. Whereas, in NRL-treated soil, nearly 22% of the peak strength was preserved after the rupture. From the peak strength q_p and residual strength q_r, the brittleness index I_B [31], a parameter to quantify the soil brittleness, can be calculated using Equation 2.

$$I_B = \frac{q_p - q_r}{q_p} \tag{2}$$

A higher value of I_B (≈1) indicates brittle failure, and a lower value indicates ductile failure. The brittleness index of dried untreated soil sample calculated from Fig. 8 is 0.99, while that of dried NRL-treated soil sample is only 0.78. This result manifests the potential of NRL treatment in reducing the soil brittleness induced by post-compaction moisture reduction.

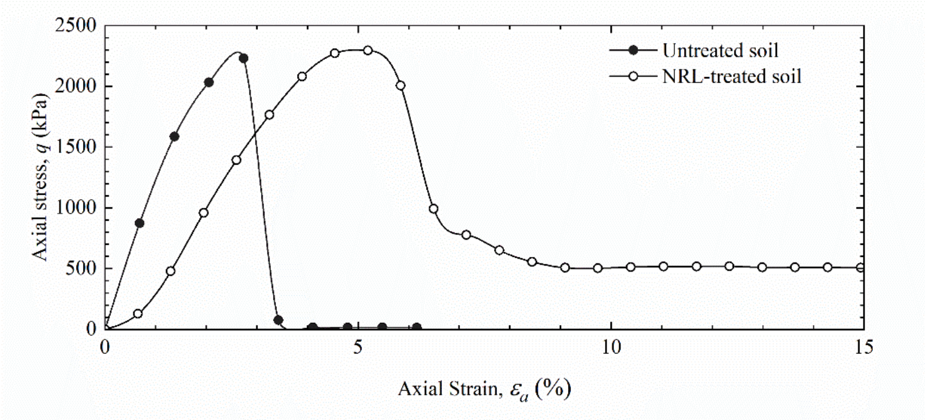

Fig. 8. Stress-strain curves showing post-failure behaviour of soil samples

3 Conclusion

In the present study, the effect of NRL-treatment on load-deformation characteristics of soil samples subjected to post-compaction drying was investigated. Untreated and NRL-treated soil samples were prepared and dried for different periods, and UCS tests were carried out. The following conclusions were drawn from the experimental study.

- Development of strength of a compacted sample after drying is mainly controlled by matric suction. The presence of NRL does not cause considerable improvement in strength. When dried at a higher temperature, the presence of rubber resulted in softening of soil.
- In NRL-treated samples, failure occurred at a higher strain level, nearly double that in untreated samples. This indicates that NRL improved the ductility of soil, and hence NRL treatment can help to avoid brittleness-induced failure of dry soil structures to some extent.
- The energy absorption capacity was found to be much more in NRL-treated soil, indicating improved ductility of dry NRL-treated soil.

References

1. Dhar, S., Hussain, M.: The strength behaviour of lime-stabilised plastic fibre-reinforced clayey soil. Road Mater. Pavement Des. 20, 1757–1778 (2019). https://doi.org/10.1080/14680629.2018.1468803.
2. Ashmawy, A.K., Bourdeau, P.L.: Response of a woven and a nonwoven geotextile to monotonic and cyclic simple tension. Geosynth. Int. 3, 493–515 (1996). https://doi.org/10.1680/gein.3.0072.
3. Azadegan, O., Li, J., Hadi Jafari, S., Ren, G.: Geogrid reinforced lime cement-treated granular soils. In: Applied Mechanics and Materials. pp. 1090–1094 (2013). https://doi.org/10.4028/www.scientific.net/AMM.330.1090.

4. Jahandari, S., Mojtahedi, S.F., Zivari, F., Jafari, M., Mahmoudi, M.R., Shokrgozar, A., Kharazmi, S., Vosough Hosseini, B., Rezvani, S., Jalalifar, H.: The impact of long-term curing period on the mechanical features of lime-geogrid treated soils. Geomech. Geoengin. 00, 1–13 (2020). https://doi.org/10.1080/17486025.2020.1739753.
5. Watanabe, K., Nakajima, S., Fujii, K., Matsuura, K.: ScienceDirect Development of geosynthetic-reinforced soil embankment resistant to severe earthquakes and prolonged overflows due to tsunamis. Soils Found. 60, 1371–1386 (2020). https://doi.org/10.1016/j.sandf.2020.08.006.
6. Gray, D.H., Ohashi, H.: Mechanics of fiber reinforcement in sand. J. Geotech. Eng. 109, (1983). https://doi.org/10.1061/(ASCE)0733-9410(1983)109:3(335).
7. Maher, M.H., Ho, Y.C.: Mechanical properties of kaolinite/fiber soil composite. J. Geotech. Eng. 120, 1381–1393 (1994). https://doi.org/10.1061/(ASCE)0733-9410(1994)120:8(1381).
8. Consoli, N.C., Vendruscolo, M.A., Prietto, P.D.M.: Behavior of Plate Load Tests on Soil Layers Improved with Cement and Fiber. J. Geotech. Geoenvironmental Eng. 129, 96–101 (2003). https://doi.org/10.1061/(asce)1090-0241(2003)129:1(96).
9. Yadav, J.S., Garg, A., Tiwari, S.K.: Strength and ductility behaviour of rubberised cemented clayey soil. Proc. Inst. Civ. Eng. - Gr. Improv. 1–38 (2019). https://doi.org/10.1680/jgrim.19.00017.
10. Edil, T., Bosscher, P.: Engineering Properties of Tire Chips and Soil Mixtures. Geotech. Test. J. 17, 453 (1994). https://doi.org/10.1520/gtj10306j.
11. Rao, G.V., Dutta, R.K.: Compressibility and strength behaviour of sand-tyre chip mixtures. Geotech. Geol. Eng. 24, 711–724 (2006). https://doi.org/10.1007/s10706-004-4006-x.
12. Mashiri, M.S., Vinod, J.S., Sheikh, M.N., Tsang, H.H.: Shear strength and dilatancy behaviour of sand-tyre chip mixtures. Soils Found. 55, 517–528 (2015). https://doi.org/10.1016/j.sandf.2015.04.004.
13. Kong, D., Deng, M., Liu, Y., Wang, X.: The environmental study on consolidated undrained triaxial compression tests on lightweight soil mixed with rubber chips of scrap tires. Ekoloji. 27, 1503–1510 (2018).
14. Edil, T.B.: A review of environmental impacts and environmental applications of shredded scrap tires. In: Proceedings of the International Workshop on Scrap Tire Derived Geomaterials - Opportunities and Challenges, IW-TDGM 2007 (2008).
15. Banasiak, L., Chiaro, G., Palermo, A., Granello, G.: Recycling of end-of-life tyres in civil engineering applications: environmental implications. In: WasteMINZ 2019 Conference. p. 15 (2019).
16. Mohajerani, A., Burnett, L., Smith, J. V., Markovski, S., Rodwell, G., Rahman, M.T., Kurmus, H., Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., Maghool, F.: Recycling waste rubber tyres in construction materials and associated environmental considerations: A review, (2020). https://doi.org/10.1016/j.resconrec.2020.104679.
17. Veena, U., James, N.: Natural Rubber Latex for Improving Ductility Characteristics of Soil: A Preliminary Experimental Investigation. Geotech. Geol. Eng. (2022). https://doi.org/10.1007/s10706-022-02162-1.
18. IS:1498: Classification and identification of soils for general engineering purposes. Bureau of Indian Standards, New Delhi (2007).
19. IS:2720 -Part 7: Methods of test for soils, Determination of water content dry density relation using light compaction. Bureau of Indian Standards, New Delhi (1980).
20. Stark, T.D.: Postconstruction evaluation of fill compaction. J. Leg. Aff. Disput. Resolut. Eng. Constr. 12, 04520030 (2020). https://doi.org/10.1061/(ASCE)LA.1943-4170.0000415

21. Budhu, M.: Soil mechanics and foundations. Wiley, (2020).
22. Park, S.S.: Unconfined compressive strength and ductility of fiber-reinforced cemented sand. Constr. Build. Mater. 25, 1134–1138 (2011). https://doi.org/10.1016/j.conbuildmat.2010.07.017.
23. Nagaraj, H.B.: Influence of gradation and proportion of sand on stress-strain behavior of clay-sand mixtures. Int. J. Geo-Engineering. (2016). https://doi.org/10.1186/s40703-016-0033-8.
24. IS:2720 -Part 10: Methods of test for soils, Determination of unconfined compressive strength. Bureau of Indian Standards, New Delhi (1991).
25. Bishop, A.W., Alpan, I., Blight, G.H., Donald, I.B.: Factors controlling the strength of partly saturated cohesive soils. In: Proceedings of the ASCE Research Conference on Shear Strength of Cohesive Soils. pp. 503–532 (1960).
26. Bishop, A.W., Blight, G.E.: Some aspects of effective stress in saturated and partly saturated soils. Geotechnique. 13, (1963). https://doi.org/10.1680/geot.1963.13.3.177.
27. Fredlund, D.G., Morgenstern, N.R., Widger, R.A.: The shear strength of unsaturated soils. Can. Geotech. J. 15, 313–321 (1978). https://doi.org/10.1139/t78-029.
28. Mitchell, J.K.: Shearing resistance of soils as a rate process. J. Soil Mech. Found. Div. 90, 29–61 (1964). https://doi.org/https://doi.org/10.1061/JSFEAQ.0000593.
29. Eskisar, T.: Influence of Cement Treatment on Unconfined Compressive Strength and Compressibility of Lean Clay with Medium Plasticity. Arab. J. Sci. Eng. 40, 763–772 (2015). https://doi.org/10.1007/s13369-015-1579-z.
30. Bekhiti, M., Trouzine, H., Rabehi, M.: Influence of waste tire rubber fibers on swelling behavior, unconfined compressive strength and ductility of cement stabilized bentonite clay soil. Constr. Build. Mater. 208, 304–313 (2019). https://doi.org/10.1016/j.conbuildmat.2019.03.011.
31. Bishop, A.W.: The influence of progressive failure on the choice of the method of stability analysis. Geotechnique. 21, 168–172 (1971). https://doi.org/10.1680/geot.1971.21.2.168.