Analysis of the effect of plastic waste strips on characteristics of fine-grained soils

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Abstract. Most of the developing countries like India are facing a severe crisis in solid waste management. Amongst all, plastic waste is considered to be more harmful because of its non-biodegradable nature and abundant usage. The current work deals with an engineering technique in order to eliminate this problem of plastic waste management, by using plastic waste as a potential reinforcing element in soils. This saves a lot of effort, intellect and money which would be otherwise invested to manage plastic waste from various sources. In this study, the effects of mixing low-density polyethylene (LDPE) strips on some of the physical properties of fine-grained soils are presented. These LDPE strips act like reinforcement for the soils and could be well used in the construction of embankments and roads. In the present analysis, unconfined compressive strength (UCS) test, proctor compaction test, bender-extender tests were conducted. Four different types of fine-grained soils (i.e., CH, CL, MH and ML) were taken and five different percentages by weight (i.e., 0%, 0.25%, 0.5%, 0.75%, and 1%) of LDPE strips were added to each of these soils. The optimum percentage of LDPE strips that results in maximum improvement of soil characteristics was evaluated. It was observed that the UCS value increases up to a certain percentage of plastic waste and then it starts decreasing. Poisson’s ratio was found to decreases with increase in plastic content and thus increasing the soil stiffness.

Keywords: LDPE, Unconfined compressive strength, Proctor compaction, Bender-Extender.

1 Introduction

Since last few decades, environmental degradation is taking place at an alarming rate due to various reasons including human activities like extreme usage of non-biodegradable materials and non-renewable resources. The disposal of non-biodegradable material is one of the most facing challenges in present day’s situation. These plastic wastes create a lot of problems like blockages in pipelines, water pollution, threat to the marine species, and release of toxic gases on burning etc. Some of the plastic materials are recyclable whereas some are not. The non-recyclable plastic wastes and the waste which are not cost effective in recycling can be used in construction industries quite effectively.

Some of the researches have used different types of plastic waste materials for improvement of various soil properties. Ilies et al. [1] used polyethylene waste material and binder for soil stabilization and then compared the results with that obtained from cement stabilization. Even though better results are obtained when cement is used, the usage of plastic waste is an eco-friendly technique and has a lower carbon footprint unlike cement. Choudhary et al. [2] have conducted studies on HDPE strips for the improvement of local sands. It was observed that the CBR and Secant modulus values increase with addition of the HDPE strips. Consoli et al. [3] have highlighted the benefits of utilizing randomly distributed polyethylene terephthalate fiber, obtained from recycling waste plastic bottles, alone or mixed with rapid hardening Portland cement to improve the engineering behaviour of uniform fine sand. Similarly, Sobhan and Mashnad [4] carried out an experimental investigation on soil-cement-fly ash mixture reinforced with recycled plastic strips that were collected from post consumer milk and water containers. It is found that the use of fiber reinforcement significantly increases the post peak load carrying capacity of the mix. In the present study, one time usable plastic which is generally manufactured for snack packaging is used for improving the strength characteristics of different soils.

2 Materials

2.1 Soil

In the present study, four different types of fine-grained soils were used due to the reason that fine-grained soils in general possess less strength as compared to the coarse-grained soils. An attempt has been made in this paper for improving the strength characteristics of fine-grained soils by using the plastic waste as soil reinforcing element. The soils were characterized in the laboratory for their basic geotechnical properties and the results obtained are summarized in Table 1. These soils are classified as CL, CH, ML and MH according to the unified soil classification system (USCS).

Table 1. Properties of soil used.

Property	CL	CH	ML	MH
Liquid limit (%)	34	59	49	65
Plastic limit (%)	23	30	40	44
Plasticity index (%)	11	29	9	21
75μ passing (%)	54	85	73	61
Maximum dry density (g/cc)	1.68	1.58	1.64	1.67
Optimum moisture content (%)	21	23	17	20
Specific gravity	2.53	2.54	2.61	2.62

Fig. 1 shows the position of the selected soils in the plasticity chart.

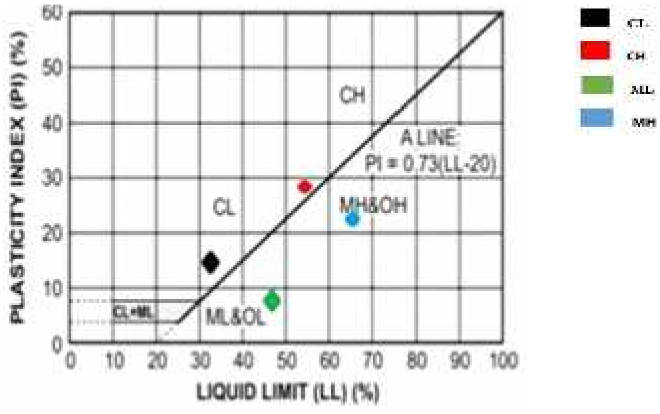


Fig. 1. Location of the used samples in soil plasticity chart

2.2 Plastic Waste

For the present study, plastic waste was collected from hostel areas of the Visvesvaraya National Institute of Technology, Nagpur. The selected plastic waste consists of packets used for snack packaging manufactured by the OMNIPLAST Pvt. Ltd. After collection, these wastes were cut into pieces (10 mm length × 10mm width) as shown in figure 2 and then the plastic strips were mixed with the soil. The percentage of plastic content in the mix was kept as 0, 0.25, 0.50, 0.75, and 1% by weight.

Fig. 2. Plastic waste strips used in present study

The mechanical properties of the plastic waste viz., tensile strength, elongation at break and Young's modulus are summarized in Table 2. In order to obtain these values, tensile strength test was conducted on the plastic strips as per the procedure presented in ASTM D638-14 (Standard Test Method for Tensile Properties of Plastics) by using the INSTRON Series IX automated material testing system. Using the computer interface, mechanical properties of the plastic strips were automatically obtained from the tests. The load displacement curve as obtained from the test is presented in Fig. 3.

Table 2. Properties of plastic waste.

Properties	Values
Tensile strength (MPa)	50.6
Elongation at break (%)	60.9
Young's modulus (MPa)	971.1

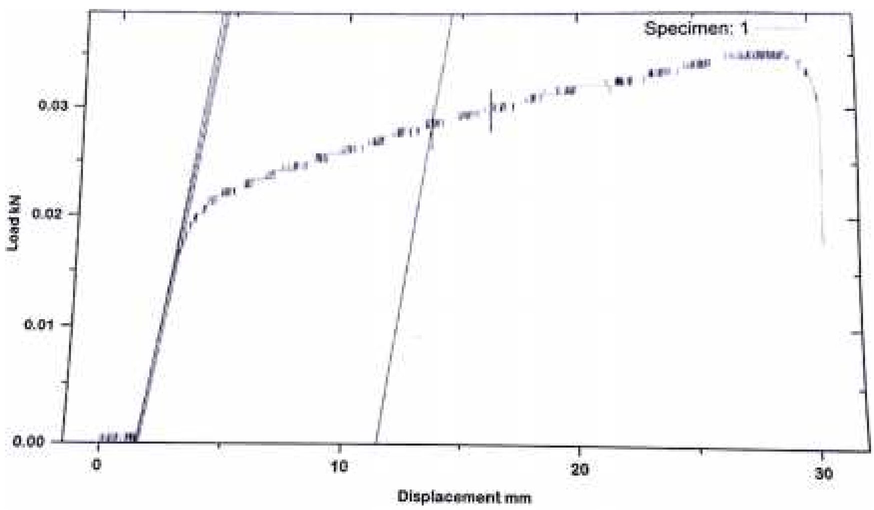


Fig. 3. Load settlement curve obtained from tensile strength test on the plastic strips

3 Experimental Investigations

As mentioned earlier, the plastic strips were mixed with the soils at five different percentages i.e., 0, 0.25, 0.5, 0.75, and 1% by dry weight of the soils. Then, proctor compaction tests were conducted to obtain the optimum moisture content (OMC) and maximum dry density (MDD) of the soils mixed with plastic strips.

In order to determine the unconfined compressive strength (UCS) of the reinforced soils (i.e., soil-plastic mix), soil specimens of size 5cm diameter × 10cm length were prepared in the laboratory. However, before conducting the UCS tests, bender-extender tests were conducted on these prepared specimens. For this purpose, small grooves were made on top and bottom of the soil specimens (as shown in figure 4a. The bender-extender system consists of a piezo-ceramic transmitter which is fixed to a triaxial pedestal and a receiver fixed to a top acrylic plate as shown in figure 4b. A schematic representation of the test setup is also shown in figure 5. The piezo-ceramic transmitter generates shear or compression wave which transmits through the soil specimen and is captured by the receiver. If the piezo-ceramic element generates and captures shear wave, then it is known as a bender element. On the other hand, if the piezo-ceramic element generates and captures compression wave, then it is known as an extender element. The generation of shear or compression wave was facilitated by a master control unit and the waveforms were analyzed with the help of GDS bender element system software. Then the travel time was determined by using peak-to-peak method as shown in figure 6. Knowing the length of wave propagation (i.e. tip-to-tip distance between the transmitter and the receiver, L_{tt}) and the travel time (i.e. time lag between the I/P and O/P waves, t), the shear and compression wave velocities (V_s and V_p, respectively) were calculated using equation 1.

$$V = L_{tt}/t \tag{1}$$

where, V is either V_s or V_p depending upon whether bender or extender elements have been used.

(a) **(b)**

Fig. 4. (a) Soil samples used for the bender/extender testing (b) Bender/Extender test.

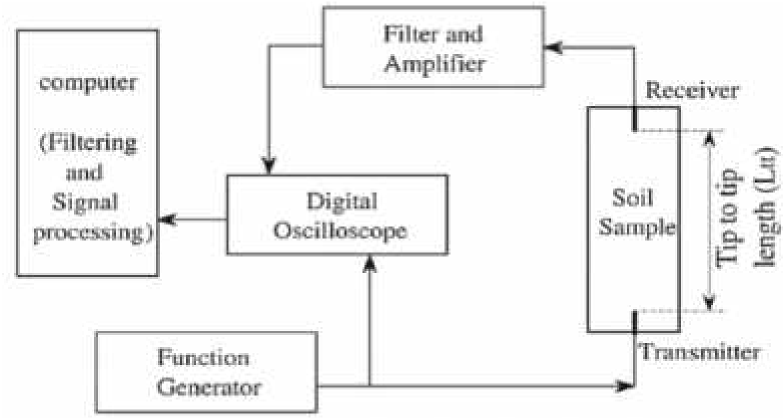


Fig. 5. Schematic representation of bender/extender test setup

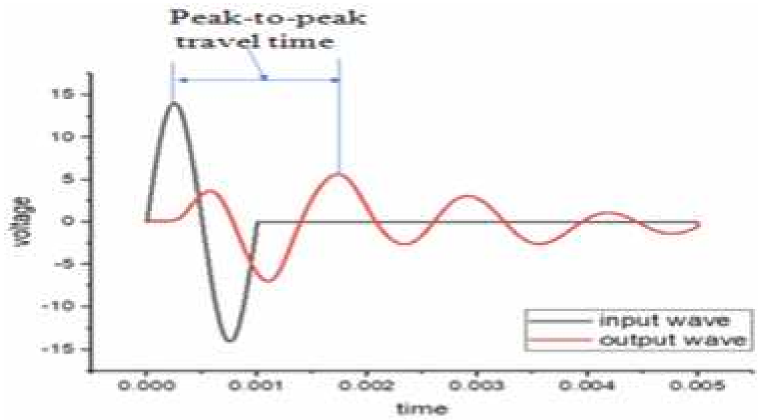


Fig. 6. Determination of peak-to-peak travel time

Further, the Poisson's ratio (v) was determined by using equation 2.

$$v = \frac{0.5r^2 - 1}{r^2 - 1} \tag{2}$$

where, r is the ratio between V_p and V_s.

The Unconfined compressive strength (UCS) test was conducted on all the samples used for the bender-extender test. It is worth mentioning that the bender-extender test is non-destructive in nature and hence, the same samples after bender-extender test can be used for other tests like UCS. The test setup used to conduct the UCS test is presented in figure 7.

Fig. 7. Test setup used for the UCS test

4 Results and Discussion

4.1 Compaction Characteristics

The variation in maximum dry density (MDD) and optimum moisture content (OMC) of different soils with addition of different percentage of the plastic strips are presented in figure 8 and figure 9, respectively.

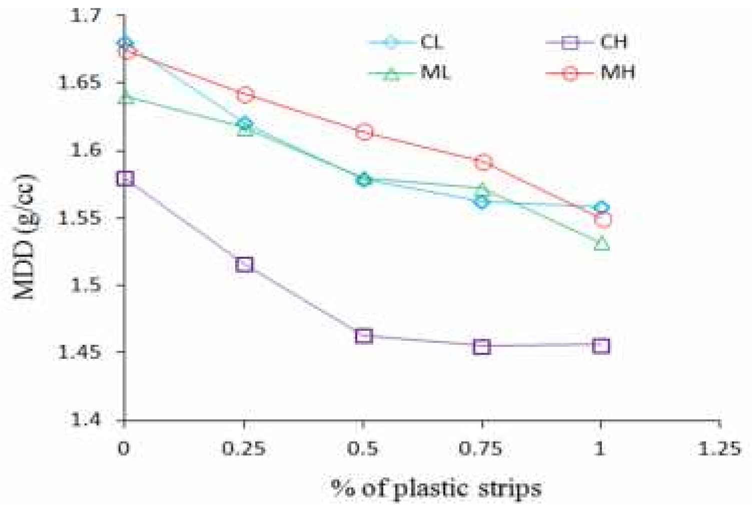


Fig. 8. Variation of MDD with % plastic strips

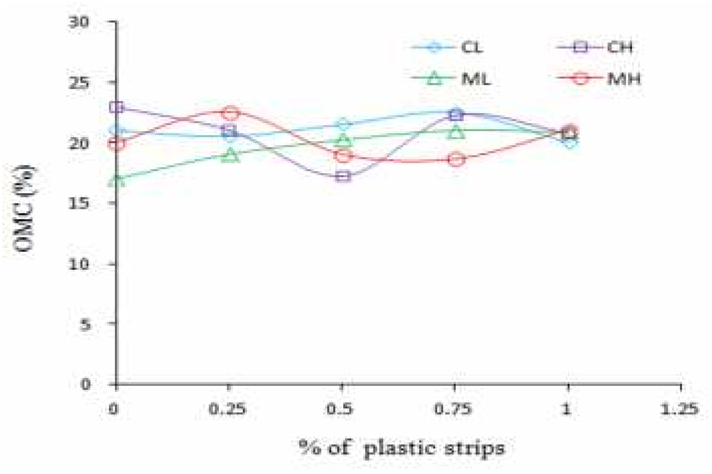


Fig. 9. Variation of OMC with % plastic strips

From figure 8, it can be observed that the MDD decreases with increase in plastic content in all types of soils. This is due to fact that the density of plastic strips is less as compared to that of the soil. No clear trends were obtained between OMC and % of plastic strips as can be seen from figure 9. The plastic strips added to soil results in a more dispersed and disturbed structure of the mixture. Hence, based upon the inter-voids created in the soil plastic mixture, it is expected that within the small range of plastic strip added, a clear trend could not be obtained for OMC.

4.2 Unconfined Compressive Strength

The variation of UCS with % of plastic strips added in different types of soils is presented in figure 10. For the sake of completeness, all the stress-strain curves obtained from the UCS tests are also presented in figure 11.

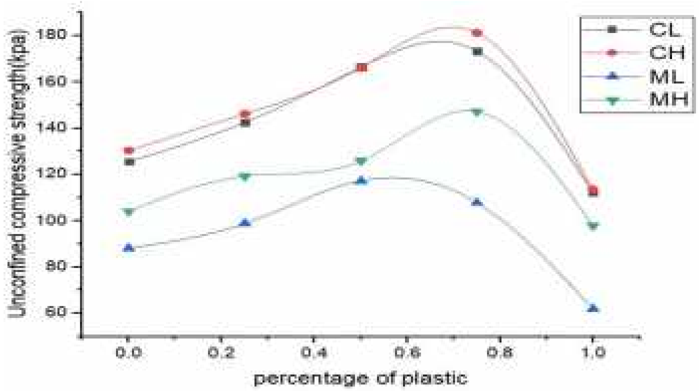
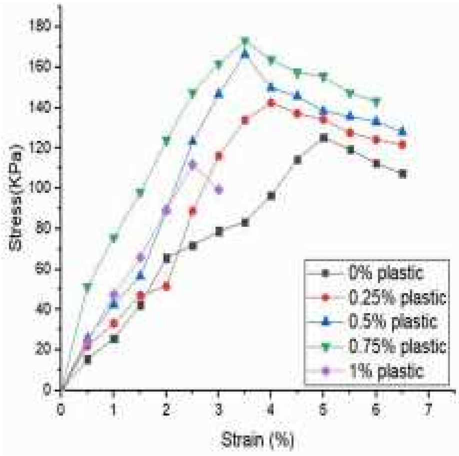
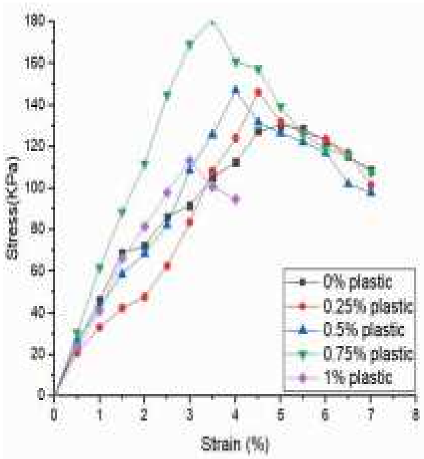


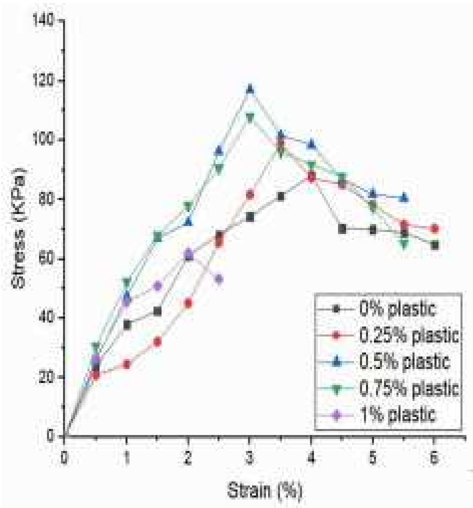
Fig. 10. Variation of UCS with % of plastic strips



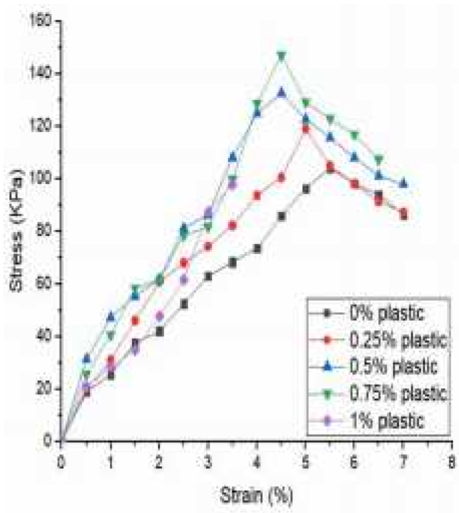
(a)



(b)



(c)



(d)

Fig. 11. Stress-strain curves obtained from UCS tests for (a) CL (b) CH (c) ML (d) MH soils

Based upon the results as shown in figure 10, the optimum UCS value was obtained at about 0.75% of plastic strips in all the soils. With addition of plastic strips more than 0.75%, the UCS value started decreasing. This might be again attributed to the more disturbed structure of the soil samples at higher plastic content. Further, the percentage increase in the UCS value at 0.75% plastic content was calculated and it was found to be almost similar (varying between 33 to 41%) for all the soils. The strain value corresponding to failure stress was found to decrease with increase in plastic content as shown in figure 11. Hence, it is quite useful to reinforce the soils with addition of plastic waste where soil deformation is an issue. However, at higher plastic content, the soil becomes more brittle as can be seen from figure 11 at 1% plastic. This is due to the fact that at higher plastic content the bonding between soil solids decreases.

4.3 Wave Velocities and Poisson's ratio

The results obtained from bender-extender test are presented in Table 3. The V_s, V_p and v values were determined as per the procedure presented in section 3.

Table 3. Wave velocities and Poisson's ratio results

Soil type	Percentage plastic	V_p (m/s)	V_s (m/s)	Poisson's ratio, ν
CL	0	325	86	0.4620
	0.25	352	94	0.4614
	0.5	282	88	0.4459
	0.75	281	94	0.4375
	1	264	84	0.4425
CH	0	249	92	0.4358
	0.25	223	77	0.4321
	0.5	184	71	0.4258
	0.75	192	68	0.4264
	1	169	63	0.4104
ML	0	235	70	0.4503
	0.25	163	63	0.4115
	0.5	163	64	0.4082
	0.75	169	64	0.4162
	1	124	53	0.3862
MH	0	235	79	0.4346
	0.25	223	77	0.4321
	0.5	202	69	0.4328
	0.75	176	71	0.4007
	1	146	63	0.3847

Further, as presented in figure 12, the Poisson's ratio value was found to decrease with increase in the plastic content. The decrease in v value is about 4 to 6% and 11 to 14% in clayey and silty soils respectively. With decrease in v value, the soil stiffness increases. This increase in soil stiffness is another reason that at higher plastic content, the soils become more brittle.

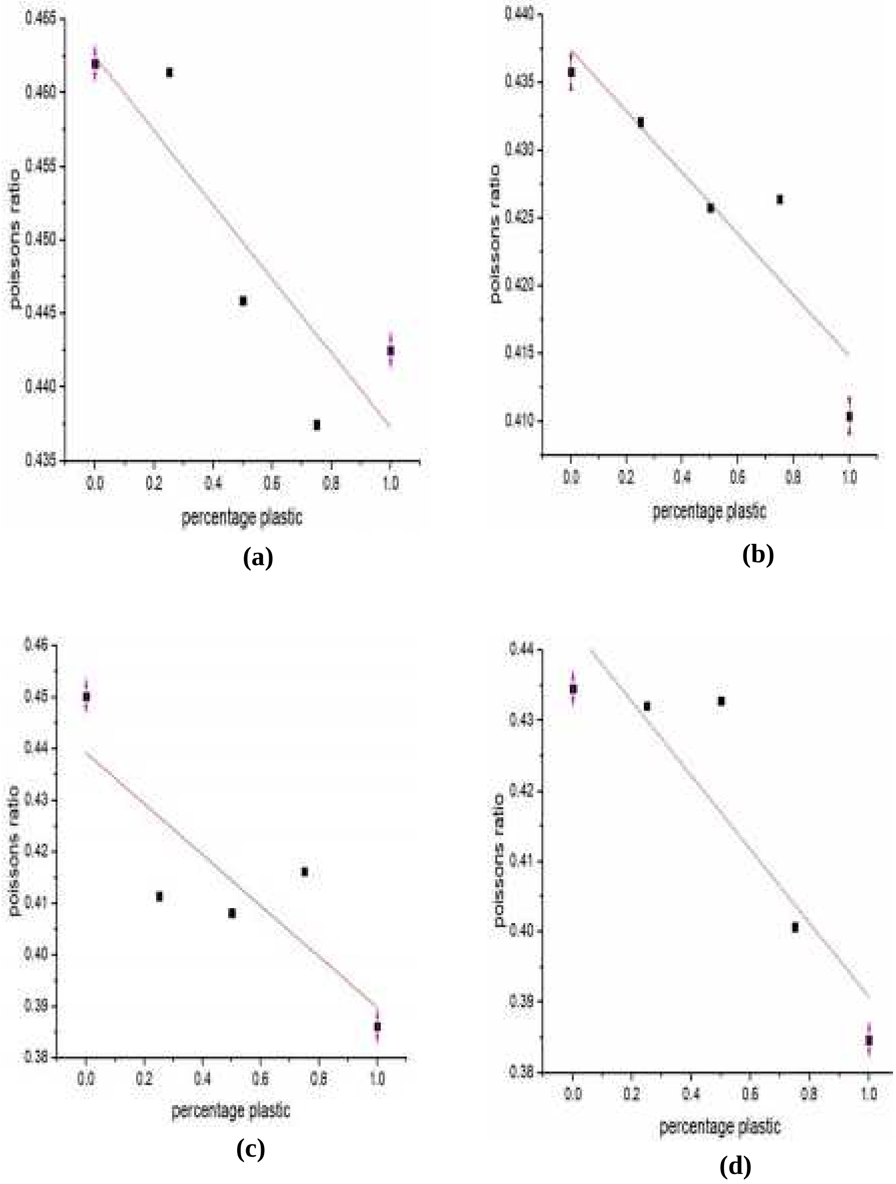


Fig. 12. Variation of Poisson’s ratio with plastic content for (a) CL (b) CH (c) ML (d) MH soils

5 Conclusions

The following conclusions can be derived from the present study.

- The MDD value was found to decrease with increase in plastic content.
- The UCS value was found to increase with increase in plastic content up to a certain percentage and then it starts decreasing.
- Soil brittleness increases with increase in plastic content.
- The percentage increase in the UCS value was found to be almost similar for all types of soils.
- The Poisson's ratio decreases with increases in plastic content and thus there is an increase in soil stiffness.

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