Geotechnical Engineering Journal of SEAGS & AGSSEA

https://ph01.tci-thaijo.org/index.php/seags_agssea_journal

Effect of Solid Waste on Swell–Shrink Behaviour of Clay with Intermediate Plasticity

Hasan M. Rangwala [1], Apurvkumar Prajapati [2]
[1,2]Civil Engineering Department, Nirma University, Ahmedabad, Gujarat, India
E-mail: hasan.rangwala@nirmauni.ac.in[1], 20ftphde50@nirmauni.ac.in[2]

ABSTRACT: Structures in various regions of the world with expansive soils are affected by the poor engineering properties of these soils. The soil experiences swelling and shrinkage problems, and thus, the structure is encountered to get settled or uplifted. This has a significant impact on the infrastructure development of such regions. It has always been a difficult task for engineers to design and build civil engineering structures on such soils. For local earthwork construction, mechanically stabilized clays combined with sand are employed. Expansive soil can cause extremely high lateral pressures on the back of a retaining wall, and in this situation, expansive soils are often avoided despite their availability as they can seriously damage the retaining wall structures due to the lateral swelling pressure in addition to the earth pressures. In order to overcome the poor engineering properties of these soils, the reduction of swelling and shrinkage has been recommended. For this, the soil can be effectively modified and made suitable for use as backfill. Additionally, the lateral swelling pressure can also be determined experimentally; however, this has not been incorporated into the current study. This study is an attempt to implement comprehensive experimental research into the possibilities of employing solid waste to improve the engineering properties of clay with intermediate plasticity (CI). In this study, solid waste is used in different proportions with CI to determine its influence on swelling and shrinkage. The analysis shows that the replacement of CI with solid waste results in a significant reduction of swelling and shrinkage. The study envisages providing an optimized quantity of solid waste, which shows an improvement in swell-shrink characteristics.

KEYWORDS: Clay, Swelling, Shrinkage, and Solid Waste.

7. INTRODUCTION

The infrastructure is significantly harmed or distressed when built on or in expansive soils, which is well acknowledged by the scientific community (Chen, 1988; Pedarla et al., 2011). One approach is to combine or replace the expansive soil with non-expansive soil, but this method is considered damaging to the ecosystem and does not address the underlying issue of clay swelling. It can also be quite expensive and labour-intensive. So, the primary method for handling these problematic soils is stabilization using the appropriate additive(s). The beneficial effects and efficacy of the many additives that have developed over the past few decades have been established by earlier studies (Phanikumar & Sharma, 2004; Punthutaecha et al., 2006; Lamara et al., 2006; Cokca et al., 2009; Cokca, 2001; Al-Rawas et al., 2022; Srinivas & Raju, 2010; Gueddouda et al., 2011; Jones et al., 2012). Several additives have been used for a while to stabilise these soils effectively.. These additives may be roughly divided into different categories.

Among all different categories, Solid waste can have a substantial influence on the swell-shrink behaviour of clay with intermediate plasticity (Soltani et al., 2019; Reddy et al., 2015). Swell is the volume increase that occurs when clay absorbs water, whereas shrink is the decrease in volume when clay dries out. When solid waste is present in the clay, it can modify the geotechnical characteristics and behaviour of the clay. Organic particles, debris, or construction debris can all introduce voids or channels inside the clay. These voids can function as water drainage paths, potentially speeding up the drying process.

To optimize the engineering properties of problematic soils for backfill applications, a crucial aspect is the reduction of swelling and shrinkage. These soil behaviours, characterized by volume changes due to moisture fluctuations, can compromise the stability and functionality of backfilled areas. By implementing measures to minimize swelling and shrinkage, such as moisture control or the addition of stabilizing agents, the soils can be effectively modified and made suitable for use as backfill. In various situations, the utilization of alternative materials such as quarry dust, fly ash, kiln dust, stone dust, granite sawdust, GGBS, lime kiln dust, marble dust, and similar options appears to be a promising approach. These materials are not only highly cost-effective but also readily available in large quantities, making them viable substitutes for traditional construction materials (Cokca et al., 2009; Cokca et al., 2001; Al-Rawas et al., 2022; Bhuvaneshwari et al., 2005).

A substantial amount of construction and demolition waste (C&DW) produced by India is approximately 4.11 lakh tonnes each day. However, the current capacity for recycling this waste is only around 6,500 tonnes daily, accounting for approximately 1.6% of the total waste generated (CSE, 2020). C&DW constitutes a substantial portion of municipal solid waste. Unfortunately, illegal dumping of C&DW on vacant fields and paths is becoming more prevalent in many areas. To address this issue and promote sustainable waste management, there is a need to intensify efforts in sorting, processing, and reusing C&DW. By doing so, not only can illegal dumping be reduced, but the establishment of more C&DW recycling plants can also be encouraged. C&DW is commonly employed as a substitute material for concrete production, road pavement, backfill material, and the manufacturing of bricks and blocks. (Kourmpanis et al., 2008; Ossa et al., 2016; Prajapati & Rangwala, 2022; Prajapati & Rangwala, 2023).

The oedometer swell tests are commonly utilized to Identify soils prone to swelling and to estimate the extent of potential swelling. These tests are favoured due to their operational simplicity and the widespread availability of consolidometers (Kassiff & Ben-Shalom, 1971). However, there is typically a significant disparity between the predicted heave using factors derived from swell tests and the actual heave observed in field conditions. Comparative analysis of both the field and the lab datahas shown that the laboratory results are often overvalued in-situ heave (Gizienski & Lee, 1965; Richards, 1967;

https://doi.org/10.14456/seagj.2025.5 Published on 18 September 2025

Johnson & Snethen, 1979). As a result, some scientists have recommended using a lateral restriction or correction factor to convert possible volume change to projected vertical heave. (Johnson & Snethen, 1979; Dhowian et al., 1990). In contrast, it was demonstrated by a previous study that the swelling is likely to escalate as the number of cycles increases for wetting and drying conditions, provided that the samples are permitted to experience full shrinkage when moisture content is equal to or lower than the shrinkage limit (Osipov et al., 1987).

The purpose of this study is to conduct extensive experimental research to examine the feasibility of utilizing C&DW to enhance the properties of CI. By analysing the effects of C&DW and their varying proportions, this study targets to provide valuable perceptions into the practical application and effectiveness of utilizing C&DW for improving the swelling characteristics and shrinkage characteristics of CI. The results of this study will aid in the advancement of eco-friendly and sustainable approaches to improve the swell-shrink characteristics of clay soils.

2. METHODOLOGY

2.1 Materials

Soil samples were obtained from an excavation site in Chekhla Village, Sanand Taluka, Ahmedabad, Gujarat, India for this study. The soil, readily accessible in the local area, had a natural moisture content of 22.05%. Various properties of the soil were examined, including particle size distribution, specific gravity, compaction characteristics, and swell-shrink behaviour.

The C&DW employed for this study was obtained from Ahmedabad Enviro Projects Pvt. Ltd. located in Piplaj, Ahmedabad, Gujarat, India. The C&DW underwent processing in crushing plants, where it was crushed, reduced in size, and sorted into various particle sizes. The C&DW employed in this research encompassed particles within the size range of 4.75 mm to 75 microns. The C&DW was analysed for particle size distribution, specific gravity, and compaction characteristics.

2.2 Materials characterization

The grain size distribution of both the soil and C&DW materials was classified following Indian standards IS:2720 – IV (1983) and IS:1498 (1970), respectively. To ascertain the specific gravity of the materials, the pycnometer technique was employed in accordance with the guidelines specified by IS: 2720 – III (1980). Likewise, the light compaction tests, which are also known as Standard Proctor tests, were conducted, as per IS:2720–- VII (1980), to assess the compaction parameters of mixes with different mix mixtures of C&DW and soil. The optimum dosage of C&DW was utilized using the findings of the compaction tests. The swelling test was conducted on both the soil and the soil with the optimum dosage of C&DW, following IS:2720–- XLI (1977). The shrinkage behaviour of these two sample types was analysed.

2.3 Material properties

The grain size distribution curve of soil, depicted in Figure 1, was constructed following the methodology outlined in IS:2720-IV (1983). The liquid and plastic limits were determined in accordance with the guidelines provided by IS:2720-V (1985), while the shrinkage limit was assessed using the procedures specified in IS:2720-VI (1972). Table 1 presents the index properties, including specific gravity, percentage of fines, and consistency limits. Based on the information provided in Table 1, the soil has a CI (clay with intermediate compressibility) classification according to the IS classification.

The grain size distribution curve for the C&DW was obtained using the procedure specified in IS:2720–- IV (1983). Figure 1 depicts the grain size distribution curve. Table 2 presents various properties of the C&DW, including specific gravity. Based on the grading characteristics provided in Table 2, the C&DW was classified as SP (Poorly graded sand) according to the IS classification.

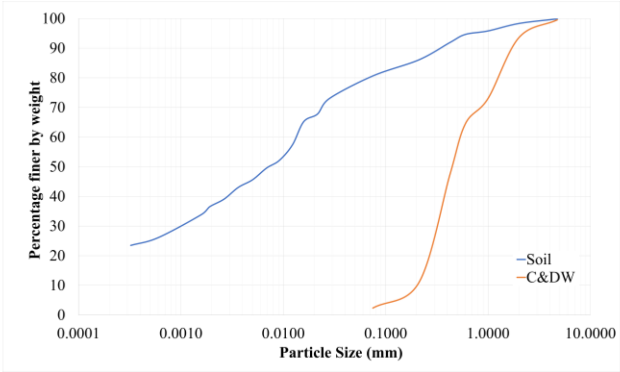

Figure 1 Particle size distribution curve of soil and construction and demolition waste

Table 1 Soil properties

Property	Obtained Value
Specific Gravity	2.66
% Finer	80.65 %
Liquid Limit	41 %
Plastic Limit	18 %
Shrinkage Limit	11 %
IS Classification	CI

Table 2 C&DW properties

Property	Values Obtained
Specific Gravity	2.51
Percentage Finer	2.33 %
Cu	3.10
Cc	0.83
IS Classification	SP

3. RESULTS AND DISCUSSIONS

The study conducted various experiments, examining and comparing the findings for various combinations of both materials, i.e., soil and C&DW, to determine the optimum dosage of C&DW for reducing soil swelling and shrinking behaviour. The investigation involved conducting laboratory tests, including specific gravity, analysis for grain size distribution, consistency limits, and standard proctor tests. These tests were performed to gather data and evaluate the effects of different C&DW and soil mixtures on the desired soil properties.

3.1 Compaction test

The compaction test was conducted to identify the optimum dosage of C&DW that could be advised for the most favourable mix among all the mixtures. The Standard Proctor test, which follows the guidelines of IS 2720–- VII (1980), was performed to determine the optimum moisture content (OMC) and maximum dry density (MDD). This test aimed to establish the desired compaction characteristics, aiding in determining the appropriate quantity of C&DW to be utilized.

Table 3 Mix proportion

Soil + C&DW	Mix proportion
100% + 0%	1:0
80% + 20%	4:1
75% + 25%	3:1
70% + 30%	7:3
65% + 35%	13:7
50% + 50%	1:1

The OMC and MDD were determined experimentally through compaction tests performed on various proportions of C&DW and soil mixtures, as indicated in Table 3. The evaluation of OMC values for various C&DW and soil proportions is presented in Figure 2. It was observed that increasing the quantity of C&DW in place of soil decreased in the OMC value, with the OMC remaining relatively constant after samples containing 30% C&DW. The results indicate that the OMC value for the virgin soil was 16.93%, while the soil mixed with 30% C&DW exhibited an OMC value of 14.83%. Figure 3 illustrates the comparison of MDD values for all the C&DW and soil proportions. The findings demonstrate that as the proportion of C&DW increased, the MDD value also increased, reaching a maximum value of 1.85 gm/cm^3 for the sample containing 30% C&DW, after which the MDD value decreased. Based on the compaction characteristics observed across all mixtures, it was determined that the optimum dosage of C&DW is 30%. This dosage was selected to assess the swelling and shrinkage behaviour of the soil.

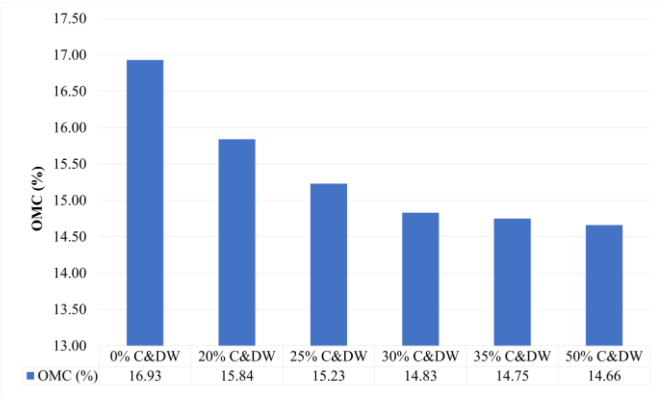

Figure 2 Comparison of OMC value for various mixes

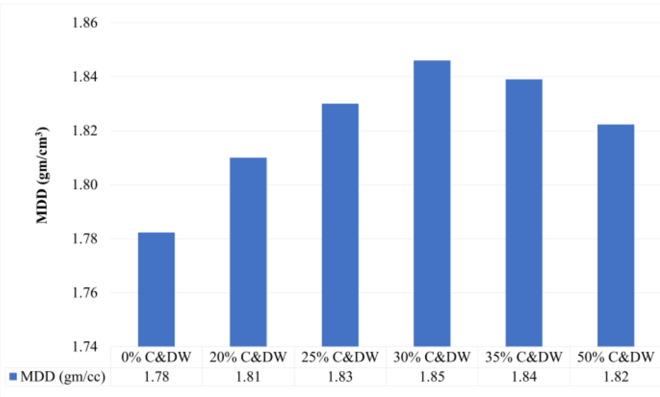

Figure 3 Comparison of MDD value for various mixes

3.2 Swell measurements

The degree of swelling observed in oedometer tests is impacted by the specific testing procedure used, particularly regarding the soaking conditions. Various methods and approaches have been employed to assess and anticipate the expansion of expansive soils in oedometer tests, such as the“"free swell”"“"constant volume swell”" and“"swell overburde”" methods. Among these, the swell overburden method stands out due to its ability to replicate real field conditions, making it a more representative approach for characterizing soil swelling behaviour.

The free swell index (FSI) is a fundamental parameter used in geotechnical engineering to evaluate the swelling potential of soil. It measures the volumetric expansion of a soil sample when it is freely exposed to water. In the context of this study, the FSI values for two different samples were determined: one for the virgin soil and the other for the soil mixed with 30% C&DW. The FSI value for the virgin soil was 36.36%, indicating a significant potential for volumetric expansion. On the other hand, the soil with 30% C&DW exhibited a lower FSI value of 20.00%, suggesting a reduced swelling potential compared to the virgin soil. The lower FSI value for the soil mixed with C&DW suggests that using C&DW as an additive can be beneficial in mitigating the adverse effects of soil swelling.

To assess the accuracy and dependability of the oedometer testing equipment and procedure for measuring swelling pressure, the constant volume swell method was employed. All samples were compacted at the MDD and OMC. Two sets of oedometer swell tests, namely OSPT-1 and OSPT-2, were conducted specifically for the virgin soil and soil mixed with 30% C&DW, respectively. Additionally, another set of swell tests known as CVSPT-1 and CVSPT-2 were performed using the constant volume swell method.

To perform the swell pressure test, the soil specimen with a diameter of 60 mm was appropriately prepared, and it was transferred to a consolidometer. The sample was carefully positioned onto a porous stone, and another porous stone was placed on the sample. The expansion of the specimen was continuously monitored until there were very minor changes, indicating the completion of the test. At this point, the water content of the specimen was determined. This testing facility was also helpful in knowing about the swell pressure of samples.

An in-depth investigation into the swelling potential of the soil was conducted through two sets of oedometer swell tests, namely OSPT-1 and OSPT-2, which were performed on virgin soil and soil with 30% C&DW, which is illustrated in Figure 4. As illustrated in Figure 4, firstly, samples must be free from expansion, then initially a lower stress of 10 kPa was applied to reduce height, which was expanded by saturation condition, and it is denoted with a first red line. Then, the stress was gradually increased, i.e., 20 kPa, 40 kPa, 50 kPa, and 60 kPa, and the height reduction was recorded. All the increased stress is denoted with the red lines in Figure 4.

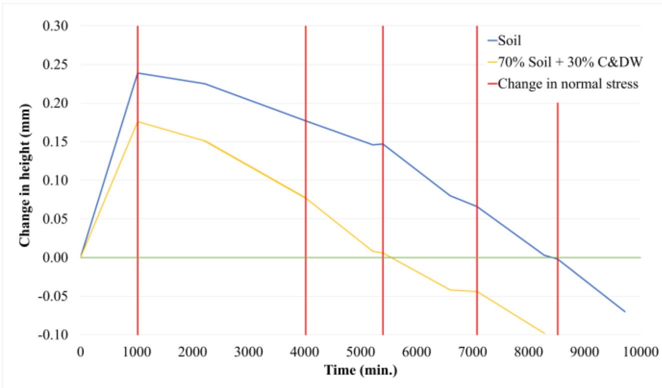

Figure 4 Variation in height with respect to time in oedometer swell pressure tests

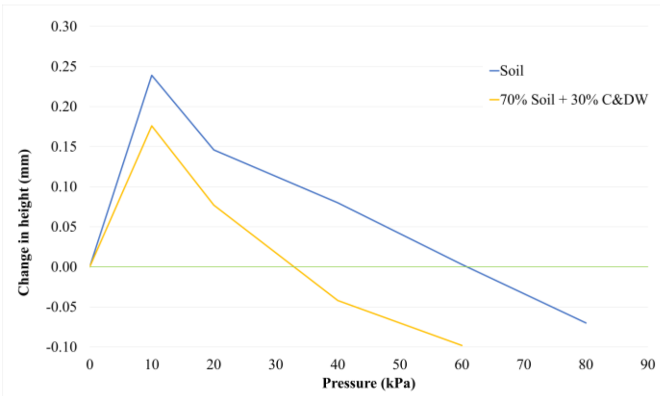

Figure 5 Variation in height with respect to the pressure in oedometer swell pressure tests

Figure 5 illustrates the compaction behaviour of both soil samples subjected to varying pressures and the swell pressure can be determined by the oedometer swell pressure tests. The figure unveils a discernible negative correlation between pressure and height, indicating that as pressure increases, the soil samples undergo compression, resulting in a reduction in height. Notably, the virgin soil sample exhibits the most pronounced decrease in height, with 70% soil mixed with 30% C&DW closely following. This observation suggests that the incorporation of C&DW into the soil mixture enhances its resistance to compaction, potentially due to the altered particle arrangement and interlocking mechanisms facilitated by the presence of C&DW.

The constant volume swell pressure test is employed to assess how soils behave when they undergo swelling under restricted conditions. During this test, a soil sample is placed within an oedometer mould, which confines its lateral expansion, ensuring a constant volume. The specimen is then saturated with water, and the resulting pressure caused by swelling is measured. This test yields essential insights into the soi''s capacity to expand and generate pressure when confined, offering valuable information about its swelling characteristics.

A set of swell tests denoted by CVSPT-1 and CVSPT-2 were performed using the constant volume swell method. CVSPT-1 and CVSPT-2 samples were made of virgin soil and soil with 30% C&DW respectively. Swell pressure results from the constant volume method are illustrated in Figure 6.

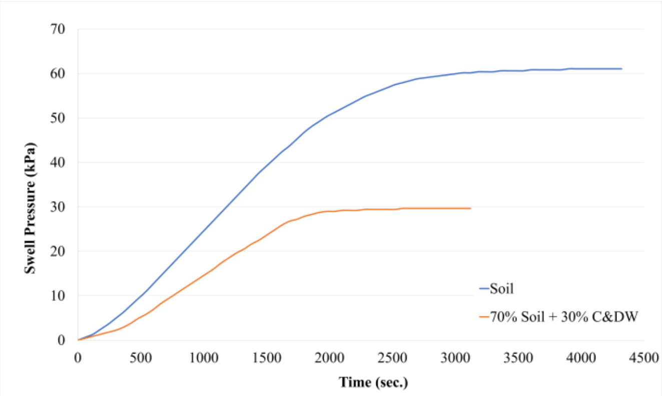

Figure 6 Time swell relationship for constant volume swell pressure tests

From both types of methods, oedometer swell pressure tests and constant volume swell pressure tests, it is observed that the swell pressure potential for virgin soil and soil with 30% C&DW gets identical values. The value of swell pressure for OSPT-1 is nearly 60kPa and for OSPT-2, it is between 20 kPa to 40 kPa. Similarly, the value of swell pressure for CVSPT-1 is 60.83 kPa, whereas for CVSPT-2, it is 32.63 kPa. The values of swell pressure from both tests are identical.

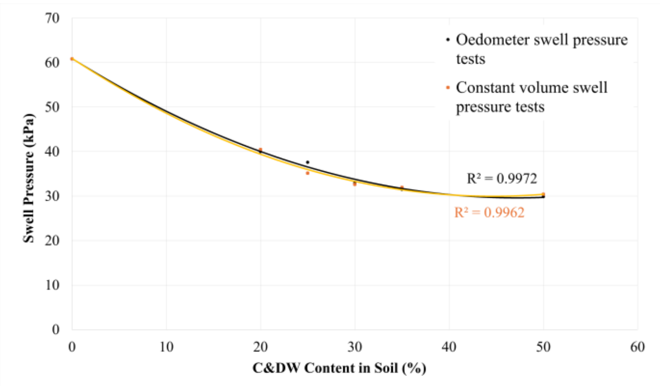

Figure 7 Relationship between C&DW content and swell pressure of Soil

In Figure 7, the swell pressure of the soil is illustrated, as measured through both oedometer testing and constant volume swell pressure testing, across varying levels of Construction and Demolition Waste (C&DW) content. The R^2 values presented on the graph serve as coefficients of determination, serving as statistical indicators of the degree to which the data points align with a regression line. Notably, both R^2 values depicted in the figure approximate 1.0, suggesting a robust correlation between the C&DW content within the soil and its respective swell pressure. This graphical representation highlights a conspicuous decrease in swell pressure as the percentage of C&DW content within the soil increases. Remarkably, this reduction demonstrates consistency up to a critical threshold of 30% soil replacement with C&DW. Beyond this threshold, the swell pressure of the soil reaches a point of stabilization, exhibiting minimal variation.

3.3 Shrink measurements

Following the accomplishment of the swell pressure tests, the surrounding water was removed, and the consolidation mould was disassembled while keeping the sample inside the consolidation sampler. The sample was then allowed to dry and undergo shrinkage. To achieve "full shrinkage," the samples were dried in an oven at 50°C until they reached or fell below their shrinkage limit. The time for the samples to reach their shrinkage limit was approximately assessed by periodically weighing the specimens over 36 hours and calculating their water contents. The results, presented in Figure 8 as water content versus time for both samples, demonstrate that as the samples dried, they underwent shrinkage in vertical direction and horizontal direction, reaching a water content equivalent to or lower than the shrinkage limit. Therefore, achieving unidirectional shrinkage in these specimens proved to be challenging.

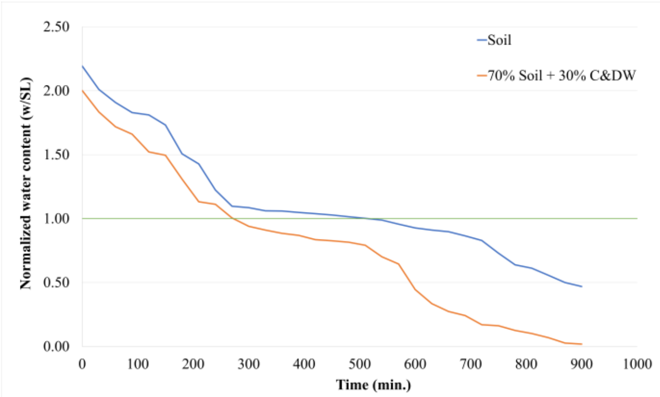

Figure 8 Variation in moisture content during the full shrinkage process

In the shrinkage process, moisture content was reduced with respect to time. The magnitude of shrinkage was most significant during the initial phase and gradually diminished in the subsequent stages. From the results, soil can be fully shrunk within 510 minutes after starting the shrinkage at controlled temperatures of 50°C in the oven. Meanwhile, soil with 30% C&DW can shrink within 270 minutes after shrinkage is started.

4. CONCLUSIONS

An effort has been made to suggest the optimum dosage of C&DW that can be substituted in the soil to mitigate the swell-shrink behaviour. The key findings are outlined as follows.

The results obtained from both the oedometer swell pressure tests and constant volume swell pressure tests indicate that the swell pressure potential is comparable for virgin soil and soil containing 30% C&DW.

The swell pressure of the virgin soil remains consistent at 60.83 kPa across both tests, while the soil containing 30% C&DW exhibits a swell pressure of 32.95 kPa from the oedometer swell pressure test and 32.63 kPa from the constant volume swell pressure tests. Considering the swell pressure as 32.95 kPa for the soil containing 30% C&DW, this value is nearly 45.84% lower than virgin soil. Notably, the value of swell pressure potential obtained from both types of tests is consistent with each other, reinforcing the reliability of the findings.

The results indicate that the soil takes 510 minutes to fully shrink, whereas the soil with C&DW achieves the same level of shrinkage in just 270 minutes, highlighting the significant reduction in shrinkage time with the addition of C&DW.

The study provides compelling evidence that incorporating C&DW in the soil successfully mitigates both swelling and shrinkage. The findings suggest that the C&DW utilized in this research holds promise for enhancing the performance of CI-type soils. These results encourage further exploration and utilization of C&DW as a valuable solution for improving soil behaviour and overall performance.

The addition of C&DW in the soil significantly improves the swell characteristics. However, the swell pressure of the reinforced soil can still affect the infrastructure like pavement, low-rise buildings, etc. Future research shall explore the possibility of reducing swelling by further reinforcing the soil with combination of more reinforcing additives.

5. ACKNOWLEDGMENTS

The authors express their gratitude to Nirma University for providing invaluable facilities and infrastructure support during this research.

6. REFERENCES

Al-Rawas, A. A., Taha, R., Nelson, J. D., Beit Al-Shab, T., Al-siyabi, H., (2002). "A Comparative Evaluation of Various Additives used in the Stabilisation of Expansive Soil." *Geotech Test JASTM,* 25(2):199–209

Bhuvaneshwari, S., Robinson, R. G., Gandhi, S. R., (2005). "Stabilisation of Expansive Soil Using Fly Ash." *Fly Ash Utilisation Programme, TIFAC-DST, New Delhi, VIII,* pp 5.1–5.10.

Centre for Science and Environment (CSE) (2020). "India Manages to Recover and Recycle only about 1 percent of its Construction and Demolition (C&D) Waste." *Centre for Science and Environment*, https://www.cseindia.org/india-manages-to- recover-and-recycleonly-about-1-per-cent-of-itsconstruction- and- demolition-10326.

Chen, F.H., (1988). "Foundation on Expansive Soil: Developments in Geotechnical Engineering, Vol 54." *Elsevier Publishing Co, Amsterdam*.

Cokca, E., Yazic, E. V., Ozaydi, E. V. (2009). "Stabilisation of Expansive Clays Using Granulasted Blast Furnace Slag (GBFS) and GBFS Cement." *Geotech Geol Eng*, 27:489–499

Cokca, E. (2001). "Use of Class C Fly Ashes for the Stabilisation of an Expansive Soil." *J Geotech Geoenviron Eng*, 127:568–573

Dhowian, A. W., Erol, A. O., Youssef, A., (1990). "Evaluation of Expansive Soils and Foundation Methodology in the Kingdom of Saudi Arabia." *Final Report, King Abdulaziz City for Science and Technology, KACST,* AT-5-88.

Gizienski, S. F., Lee, L. J., (1965). "Comparison of Laboratory Swell Tests to Small Scale Field Tests, Engineering Effects of Moisture Changes in Soils." *Concluding Proceedings, International Res. and Engrg. International on Expansive Clay Soils, Texas A&M Press, Texas*, pp. 108-119.

Gueddouda, M.K., Goual, I., Lamara, M., Smaida, A., Mekarta, B. (2011). "Chemical Stabilisation of Expansive Clays from Algeria." *Glob J Res Eng,* 11(5):1–8

IS 2720-part IV (1983). "Methods of Test for Soils: Grain Size Analysis." *Bureau of Indian Standards, New Delhi, India.*

IS 1498 (1970). "Classification and Identification of Soils for General Engineering Purposes." *Bureau of Indian Standards, New Delhi, India*.

IS 2720-part III (1980). Sec 1: "Methods of Test for Soils: Determination of Specific Gravity Section 1 Fine Grained Soils." *Bureau of Indian Standards, New Delhi, India*.

IS 2720-part VII (1980). "Methods of Test for Soils: Determination of Water Content-dry Density Relation Using Light Compaction" Bureau of Indian Standards, New Delhi, India.

IS 2720-part XLI (1977). "Methods of Test for Soils: Measurement of Swelling Pressure of Soils." *Bureau of Indian Standards, New Delhi, India.*

IS 2720-part V (1985). "Methods of Test for Soils: Determination of Liquid and Plastic Limit." *Bureau of Indian Standards, New Delhi, India.*

IS 2720-part VI (1972). "Methods of Test for Soils: Determination of Shrinkage Factors." *Bureau of Indian Standards, New Delhi, India*.

Johnson, L. D., Snethen, D. R., (1979). "Prediction of Potential Heave of Swelling Soils." *Geotechnical Testing Journal, ASTM, Vol. 1, No. 3,* pp. 117-124.

Jones, C.J.F.P., Lamont-Black, J., Hall, J.A., (2012)., "Stabilisation of a Railway Embankment Using Electrokinetic Geosynthesis." *Eng Geol Spec Publ,* 26:125–139

Kassiff, G. and Ben-Shalom, A., (1971). "Apparatus for Measuring Swell Potential Under Controlled Moisture Intake." *Journal of Materials, JMLSA,* 6, 1, pp. 3-15.

Kourmpanis, B., Papadopoulos, A., Moustakas, K., Stylianou, M., Haralambous, K. J., Loiz-idou, M., (2008). "Preliminary Study for the Management of Construction and Demolition Waste." *Waste Manag Res*, 26(3). 267-275, http://doi.org/10.1177/0734242X07083344.

Lamara, M., Gueddouda, M. K., Benabed, B., (2006). "Physical and Chemical Stabilisation of Expansive Soil." *Revue Francaise De Geotechnique*, 115:25–35.

Osipov, V.I, Bik, N.N., Rumjantseva, N.A., (1987). "Cyclic Swelling of Clays." *Appl. Clay Sci.,* 2(7): 363-374.

Ossa, A., García, J. L., Botero, E., (2016). "Use of Recycled Construction and Demolition Waste (CDW) Aggregates a Sustainable Alternative for the Pavement Construction Industry." *Journal of Cleaner Production*, (135). http://doi.org/10.1016/j.jclepro.2016.06.088.

Pedarla, A., Chittoori, B., Puppala, A. J., (2011). "Influence of Mineralogy and Plasticity Index on Stabilisation Effectiveness of Expansive Clays." *J Transp Res Board,* 2212:91–99

Phanikumar, B. R., Sharma, R. S. (2004). "Effect of Fly Ash on Engineering Properties of Expansive Soil." *J Geotech Geoenviron Eng*, 130(7):764–767

Prajapati, A., Rangwala, H., (2022). "Utilization of Recycled Construction and Demolition Waste in Backfill Soil." *Int. J. of Geosynth. and Ground Eng*, 8, 67. https://doi.org/10.1007/s40891-022-00410-1.

Prajapati, A.R., Rangwala, H.M. (2023). "Numerical Analysis of a Rigid Wall Retaining Soil Reinforced with C&D Waste." *In: Shrikhande, M., Agarwal, P., Kumar, P.C.A. (eds) Proceedings of 17th Symposium on Earthquake Engineering (Vol. 3). SEE 2022. Lecture Notes in Civil Engineering, Vol 331. Springer, Singapore*. https://doi.org/10.1007/978-981-99-1579-8_46

Punthutaecha, K., Puppala, A. J., Vanapalli, S. K., Inyang, H., (2006). "Volume Change Behaviors of Expansive Soils Stabilized with Recycled Ashes and Fibers." *J Mater Civ Eng*, 18(2):295–306

Reddy, N.G., Tahasildar, J. & Rao, B.H., (2015). "Evaluating the Influence of Additives on Swelling Characteristics of Expansive Soils." *Int. J. of Geosynth. and Ground Eng.* 1, 7. https://doi.org/10.1007/s40891-015-0010-x

Richards, B. G., (1967). "Moisture Flow and Equilibria in Unsaturated Soils for Shallow Foundations." *Permeability and Capillarity of Soils, STP 417, ASTM, Philadelphia, PA*, pp. 4-34.

Srinivas, M., Raju, G.V.R.P., (2010). "Effect of Strong Chemicals on the Swell Properties of an Expansive Clay." *In: Proceedings of IGC- 2010: GEOtrendz, IIT Bombay*, pp 613–616. 16–18 Dec

Soltani, A., Deng, A., Taheri, A., Mirzababaei, M., Vanapalli, S. K., (2019). "Swell–Shrink Behavior of Rubberized Expansive Clays during Alternate Wetting and Drying. Minerals." 9, 4. https://doi.org/10.3390/min9040224