# Use of Expanded Shale Amendment to Enhance Drainage Properties of Clays

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**ABSTRACT:**

Fine grained soils, in particular clays of high plasticity, are known to have very low values of hydraulic conductivity. Coarse aggregates have been used as a common fill material with fine grained soils for increasing the permeability of clayey soils. Expanded shale has recently been used as an amendment with clay soils to improve its drainage properties. However, limited effort has been made to quantify the effect of expanded shale on the hydraulic conductivity of clayey soils. Therefore, this paper presents the results of a series of laboratory fixed-wall permeameter tests conducted on naturally occurring clay deposits in the Austin, Texas area with different plasticity. The testing program comprised of clay samples with different quantities of expanded shale aggregates by volume, ranging between 0% and 50%, and compacted at two different compaction efforts (60% and 100% of the standard proctor compaction effort). The laboratory hydraulic conductivity of the amended Taylor clay compacted with 60% of the standard proctor effort increased by more than one order of magnitude with 20% expanded shale (by volume), more than two orders of magnitude with 30% expanded shale, and more than three orders of magnitude with 40% expanded shale. In addition to enhancing the drainage properties of the test specimen, the addition of expanded shale decreased the density of the clay samples which may benefit vegetation growth and root development. Another set of experiments conducted on Taylor Clay using limestone as amendment indicated similar effect on the hydraulic conductivity of the clay but led to increase in the density of the clay sample. The results discussed in this paper are being used in city of Austin to develop recommendations for increasing infiltration capacity of stormwater treatment systems by amending clayey soils with expanded shale material.

## INTRODUCTION

### Expanded Shale as Soil Amendment

The use of Expanded Shale as soil amendment is becoming more and more common to improve the physical properties of soils. Sloan et al. (2002) investigated the suitability of Expanded Shale amendments for clay soils. Specifically, they decided to study the effect of Expanded Shale on the growth of winter-grown pansies and summer-grown scaevola. They concluded that Expanded Shale amendment enhanced the growth of roots especially during periods of excessive rainfall (Figure

1). Also, they noticed large diameter Expanded Shale favored foliage quality and survival of scaevola. Out of a total of five tested amendments including small (0.039 to 0.118 inches) and large diameter (0.118 to 0.354 inches) Expanded Shale, quartz sand, sphagnum peat moss, and cottonseed hulls, large diameter Expanded Shale provided the best conditions for plants growth and roots development. Other researchers have also examined the benefits of Expanded Shale aggregates when used as soil conditioners. Ferguson (2005) describes Expanded Shale as porous and stable aggregates, the properties which allow expanded shale to be a favorite component of plant potting media. Nash et al. (1990) concluded that the growth of plants was enhanced in a medium amended with Expanded Shale and peat moss. Although the benefits of Expanded Shale on plant growth were well documented, there is lack of data in current literature on the effect of Expanded Shale on the hydraulic conductivity of fine grained soils.

**Figure 1: Comparison of plant growth in non-amended clay and clay amended with expanded shale (ESCI, 2002)**

The Expanded Shale, Clay, and Slate Institute (ESCSI, 2002) lists a series of properties that proves the suitability of Expanded Shale as soil amendment:

- Non-toxic, clean, and odorless ensuring a safe environment for plant and animal life.
- 100% inert and inorganic and will not react with other chemicals.
- Strong and durable thus maintaining its structure over time.
- Thermal insulator protecting the root system from weather fluctuations and severe conditions.
- Aerates the soil and decreases its density allowing better conditions for root development.
- Light in weight and sterile making it friendly to users.

**Geotechnical Applications of Expanded Shale**

Being a lightweight material with approximately half the density of regular fill materials, and having a relatively high friction angle, Expanded Shale aggregates present many advantages to geotechnical engineers and designers. Expanded Shale are often used as retaining walls backfill as they help reducing lateral forces, reducing loads on slopes and providing a free draining media. Those characteristics also allow the use of Expanded Shale in structural repair and rehabilitation.


**Figure 2: Expanded shale used as retaining wall backfill (ECSI, 2013)**

Geotechnical applications of Expanded Shale are not limited to retaining walls and landscape fills. The high chemical stability coupled with the high permeability allows their use in some geoenvironmental applications such as landfills. Expanded Shale is becoming a well-known material in landfill drainage systems and leachate collection systems. Bowders et al. (1997) studied the suitability of Expanded Shale aggregates for leachate collection systems. They found that the hydraulic conductivity of Expanded Shale exceeded the specified minimum design value. Also, Bowders et al. (1997) did not notice any sign of mechanical deterioration of the lightweight aggregates upon immersion in actual landfill leachate. ESCSI (2008) describes Expanded Shale as the "Total Geotechnical Solution" and provides a list of advantages for designers, contractors, owners, and the environment. The advantages are summarized listed in Table 1.

**Table 1: Advantages of Expanded Shale in Geotechnical Applications**

| Designers | Contractors | Owners | Environment |
|---|---|---|---|
| Less weight | Quick delivery | Economical | Inert |
| Stable | Standard equipment | Reliable (permanent solution) | Non-toxic |
| Free draining | No formwork | Land use (allows land reclamation) | No maintenance |
| Abrasion resistant and durable | Not weather sensitive | | |

## MATERIALS USED

### Soils

For the purpose of this study, the selection of the soils was made in a way that best represents the Austin area. This was achieved by referring to the City of Austin, Texas Standard Specifications (2012). In those specifications, the City of Austin establishes a set of requirements that govern earthwork, electrical work, environmental enhancements, and many other types of services. In the subgrade and base construction specifications, soils are classified into three categories depending on their Plasticity Index (P.I.). The three types of soils are (1) Non-swelling Soils with P.I. less than 20, (2) Swelling Soils with P.I. between 20 and 35, and (3) Swelling Soils with P.I. greater than 35. This study involved sampling soils in each of the categories listed above as shown in Figure 3.

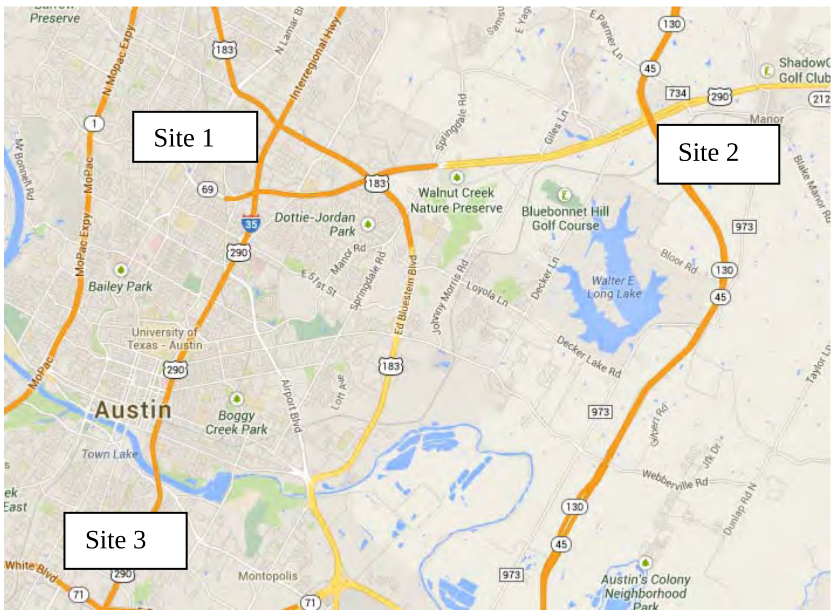



**Figure 3: Location of clays with different plasticity with Austin Area**

***Site 1: Clay with P.I. of 15***

The clay with P.I. of 15 was acquired from residential area in north Austin.

***Site 2: Clay with P.I. of 28***

The clay with P.I. of 28 consisted of Black Taylor clay samples obtained from a site located in Manor, Texas. The Black Taylor clay forms the upper weathered portion of the Taylor clay formation. Usually, the weathered Taylor, which as a dark grey color, extends until a depth of approximately 10 feet below ground surface.

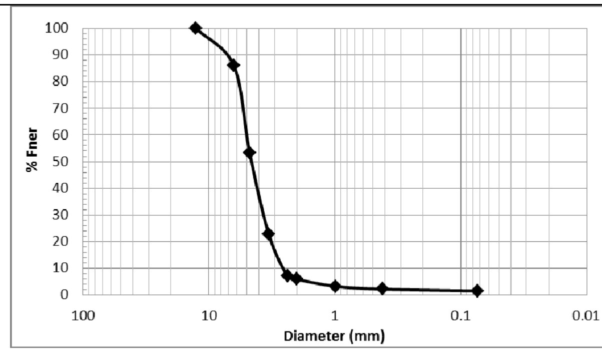
***Site 3: Clay with P.I. of 48***

The clay with P.I. of 48 was sampled near Austin airport.

## Expanded Shale

The Expanded Shale aggregates used in this study were provided by the Expanded Shale & Clay group at Texas Industries, Inc. (TXI). As specified by the producer, the dry specific gravity of the Expanded Shale is approximately 1.40 while the saturated surface dry specific gravity is approximately 1.80. The grain size distribution of the Expanded Shale is shown in Figure 4.

(a)




(b)

**Figure 4: Expanded Shale Lightweight Aggregate**

## HYDRAULIC CONDUCTIVITY TESTS

This section describes equipment used, sample preparation method and testing procedure used to conduct hydraulic conductivity tests. Hydraulic conductivity tests were conducted on the selected soils with quantities of Expanded Shale varying between 0% and 50% by volume and compacted with two efforts (standard and reduced Proctor). A set of hydraulic conductivity tests is conducted on the clay with P.I. of 28 amended with crushed limestone having the same grain size distribution as the Expanded Shale. The purpose of these tests was to compare the effect of both aggregates on the hydraulic conductivity of the clay.

## Equipment Used

The tests were conducted using rigid-wall permeameters as it allowed direct compaction of the samples in the mold. This ensured the maintenance of the samples' structure which tends to collapse upon extrusion, especially for high aggregate quantities and lower compactive efforts as used in this study. Also, rigid-wall permeameters are characterized by the simplicity of equipment and ease of testing compacted specimen directly in the compaction mold (Boynton and Daniel, 1984). Moreover, the results of Boynton and Daniel's investigation on the effect of permeameters type on the hydraulic conductivity indicates slight difference between flexible-wall and rigid wall permeameters, especially for swelling clays. For that reason, rigid wall permeameters are used in this study.

The compaction-mold permeameter used had a diameter of 10 cm (4.0 inches) and a height of 11.5 cm (4.5 inches) which was compatible with the standard Proctor compaction mold. The top and bottom caps of the permeameter had O-ring grooves which allowed for a tight seal to prevent any outward leakage. Four tie rods were used to join the top and the bottom cap and allowed for tightening the seal after placing the specimen in the permeameter. Figure 5 shows a schematic of the compaction-mold permeameter. For simplicity of data collection, and to better represent conditions in the field, hydraulic conductivity tests were performed while maintaining a constant head throughout the permeation process.

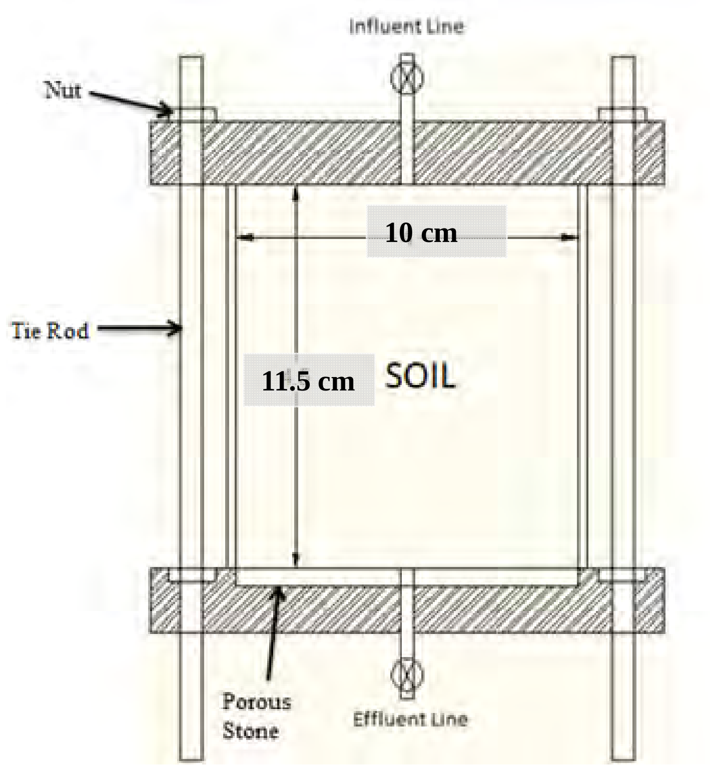



**Figure 5: Schematic of the compaction-mold permeameter**

## Sample Preparation

Clay samples were directly compacted in the rigid-wall permeameter before starting the hydraulic conductivity tests. The clay was spread in wide pans to let it air-dry and then passed through the 4.75 mm (No. 4) sieve to remove any larger size particles. The clay sample was then mechanically crushed, and water was added and mixed thoroughly to form a batch of pulverized clay. The samples were prepared such that the targeted water content was between 2 and 5 percent dry of the optimum moisture content based on the standard and reduced Proctor test. For amended clay samples, a certain percentage of amendment (containing expanded shale or lime), by weight, was added and manually mixed with the clay. The amended clay was then compacted in the fixed wall cell. Figure 6 shows the crushed clay before and after amending it with Expanded Shale.

**Figure 6: Clay before and after mixing expanded shale**

The compaction process was performed using two different compactive efforts. The standard Proctor effort involved compacting the soils in three lifts, using a 2.5 kg hammer, and 25 blows per lift (bpl). The second effort was the reduced Proctor which involved applying 15 bpl instead of 25 bpl. After carefully removing the top cap, the extra 12 mm of sample was trimmed using a sharp edge metal plate. The net weight and volume of the compacted sample was then obtained.

## Testing Procedure

After compaction, the fixed wall cell was mounted on the permeameter where a fully saturated porous stone and filter paper were placed in the bottom of the apparatus. Vacuum grease was applied on the top cap before placing the four tie rods and closing the permeameter. The inflow outlet was then linked to the T-section connection which was connected to the Mariotte bottle. The tip of the inner tube of the Mariotte device was placed at an appropriate height to obtain the desired hydraulic gradient, which ranged between 5 for highly amended samples to 15 for non-amended samples. The reason for applying higher gradients for samples that are expected to have very low hydraulic conductivity was to reduce testing time.

Once all the parts were connected, the drainage valve of the T-section was opened to completely drain the inner tube of the Mariotte device. The drainage valve was used to lower the water level until it was leveled with the first reading mark of the graduated burette. At this stage, the permeation process was initiated. The inflow valve was opened to allow the water to flow into the permeameter while air bubbles appeared from the tip of the inner tube. The outflow was also collected and measured using a graduated cylinder. Once the inflow and outflow volumes were within 10% of one another, the permeation time was determined using a stopwatch. The hydraulic conductivity was calculated based on the volume of inflow and the recorded time. The tests were stopped once the hydraulic conductivity reached a relatively steady value.

## RESULTS

### Hydraulic Conductivity of Non-Amended Clays

The effect of compaction effort (standard and reduced proctor energy) on the hydraulic conductivity of the non-amended clayey soils is shown in Figure 7. The hydraulic conductivity of three soils used in this study was about four times greater for the specimens compacted using reduced proctor effort to that compacted using standard proctor effort irrespective of the plasticity index. For a plasticity index of 15, the hydraulic conductivity was an order of magnitude greater than the clay with a plasticity index of 28. The difference was less significant between the clay with a plasticity index of 28 and the clay with plasticity index of 48 where the hydraulic conductivity decreased by a factor of 2.

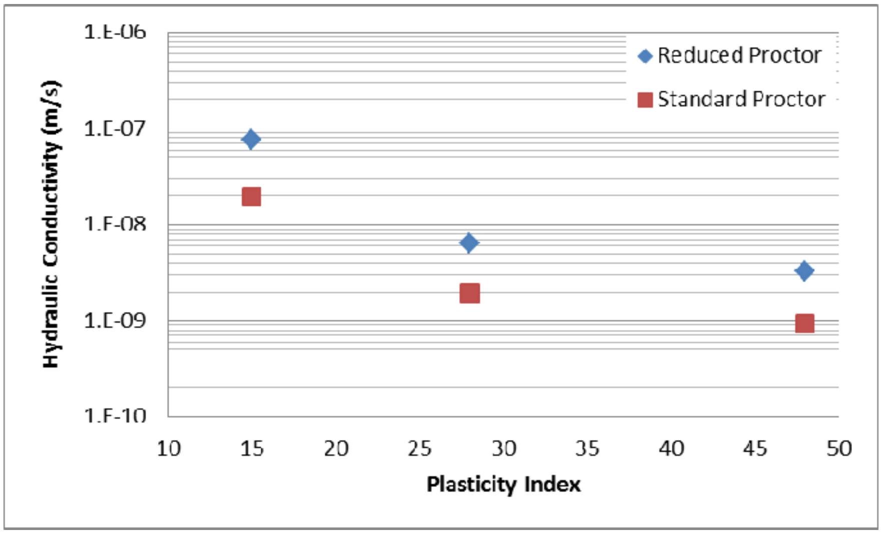



**Figure 7: Variation of hydraulic conductivity with plasticity index for non-amended clayey soils**

### Comparing the Hydraulic Conductivity of Amended and Non-amended Clays

The hydraulic conductivity curves of the three soils amended using various quantities of shale for standard and reduced proctor effort are plotted in Figures 8 and 9. A general increase in hydraulic conductivity with increase in expanded shale quantity was observed for all three soils. The hydraulic conductivity of the amended samples was higher than the non-amended samples for values of shale exceeding 10% to 20% by volume of clay for both compaction efforts. As observed in non-amended soils, the amended soils with higher plasticity index had lower hydraulic conductivities for same amount of shale.

For amended clay specimen with 25-30% of shale by volume, an increase in hydraulic conductivity of amended clay specimen upto three orders of magnitude was observed when compared with non-amended clay specimen independent of the compaction effort. At about 50% Expanded Shale by volume of clay, the hydraulic conductivity of the three soils converged to a value around $1\times10^{-5}$ m/s.

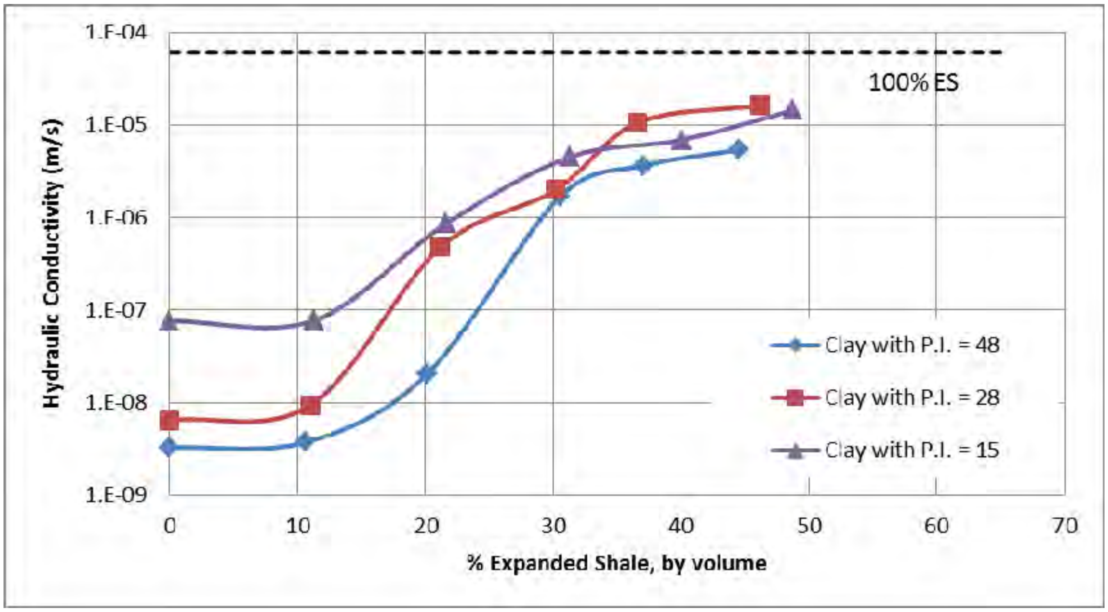



**Figure 8: Effect of expanded shale amendment on hydraulic conductivity of clays for reduced proctor effort**

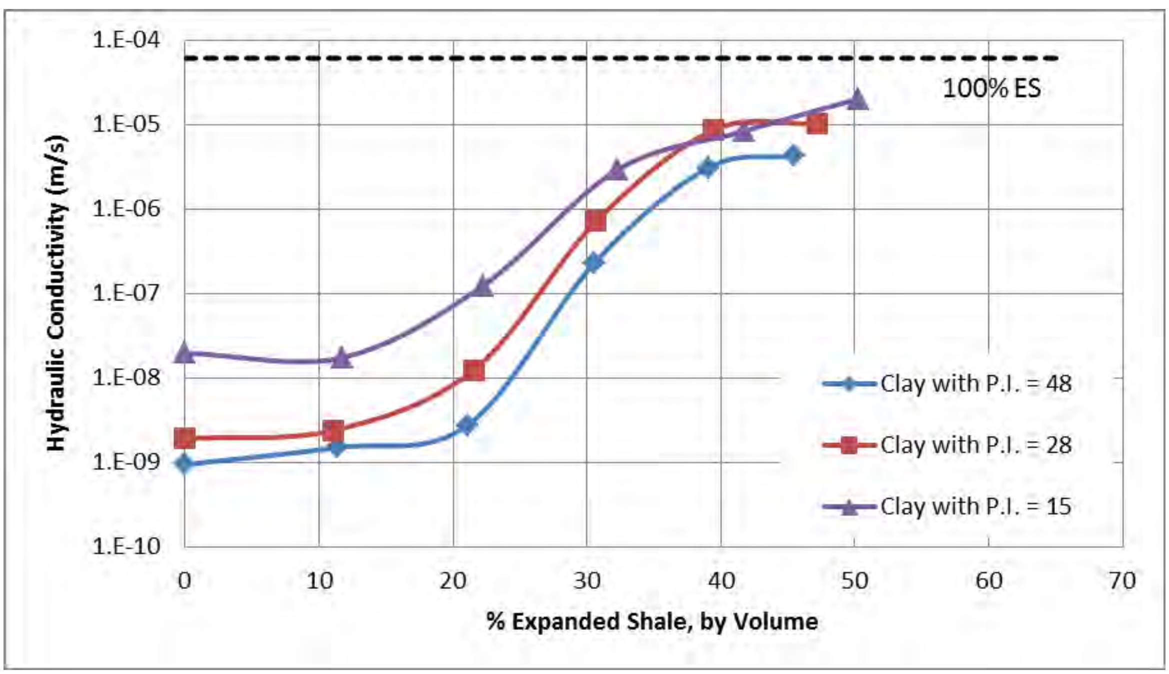



**Figure 9: Effect of expanded shale amendment on hydraulic conductivity of clays for reduced proctor effort**

**Comparing the Hydraulic Conductivity of Shale and Lime Amended Clays**

As part of this study, tests were conducted to compare the effect on hydraulic conductivity of clays when crushed limestone was used instead of expanded shale. Figure 10 shows the variation of hydraulic conductivity with varying percentages of expanded shale and crushed limestone amendment for clay with PI of 28 compacted using the reduced proctor effort. Based on the test results, it was observed that the clays amended with expanded shale on an average had higher hydraulic conductivity than those amended with crushed limestone for same volume of amendment. This may be attributed to the internal porosity of expanded shale as some of the air pockets in expanded shale are connected allowing for additional flow of water through them.

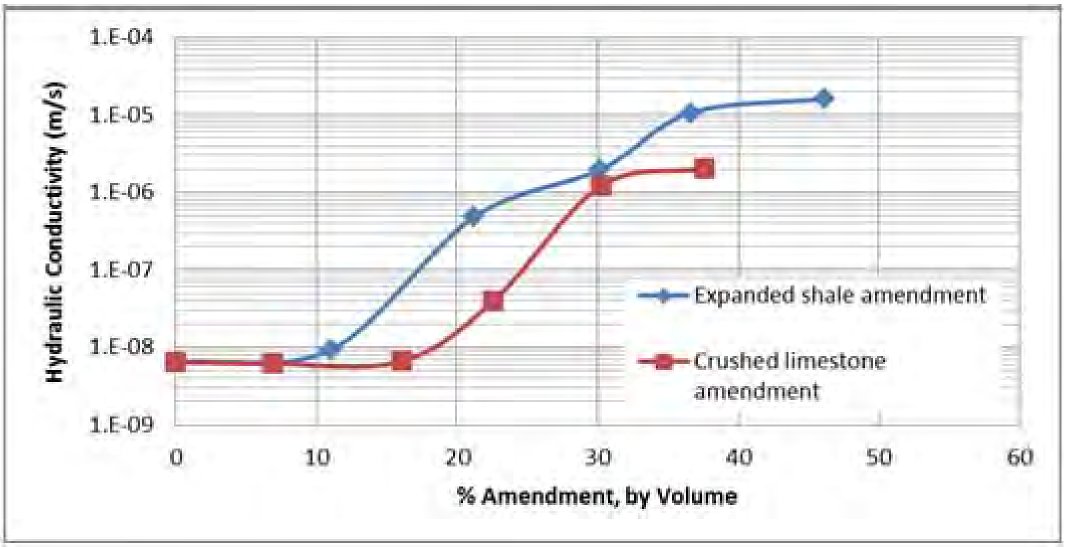



**Figure 10: Effect of expanded shale and crushed limestone amendment on hydraulic conductivity of clay with P.I. of 28**

## SUMMARY AND CONCLUSIONS

This paper presented the effect of expanded shale lightweight aggregates on the hydraulic drainage properties of clays. The constant head fixed-wall hydraulic conductivity tests were performed on three clays retrieved from the Austin area. The main conclusions of the study are:

(1) The hydraulic conductivity of the amended samples is higher than the non-amended samples for percentages of expanded shale exceeding 25% by volume of clay, independent of the compaction effort used and plasticity index of the soil.

(2) For soils amended using more than 35% by volume of expanded shale the maximum hydraulic conductivity was $1 \times 10^{-5}$ m/s.

(3) For clays amended using similar quantities of expanded shale and lime stone aggregates, an order of magnitude higher hydraulic conductivity can be obtained for expanded shale amended clays as compared to crushed limestone amended clays.

From this study, it was concluded that expanded shale lightweight aggregates can significantly increase the hydraulic conductivity of clays which may benefit plant growth and reduce stormwater flux in poorly draining soils. The tests conducted as part of this research were limited to small-scale laboratory tests which revealed the general patterns expected when adding expanded shale amendment to clayey soils. However, more research is needed to quantify those effects on a larger scale by conducting in-situ field tests. Moreover, a cost/benefit type of analysis may also be important to compare the applicability of expanded shale on large scale projects.

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