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Experimental Evaluation of the Infiltration Capacity of Urban Soils Using a Lab-Scale Model

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ABSTRACT. *Due to urbanized developments and excessive compaction from construction activities the in-situ infiltration capacity of urban soils has decreased. As a result, soil tends to behave more like a brick rather than a sponge to absorb water, resulting in poor drainage properties which lead to surface ponding, depleted underground water resources and eventually urban flooding. To counter this issue an infiltration-based system i.e., Drywell can be useful to facilitate the process of infiltration. In-situ infiltration capacity for sandy silt (ML) and lean clay (CL) was determined using single-ring infiltrometer test on site. A series of permeability tests at varied moisture content (N.M.C (Natural Moisture Content), OMC (Optimum Moisture Content), dry & wet side of OMC (Optimum Moisture Content) and from 0-50%) compacted at various compactive efforts was performed to make up a total 26 moisture-density scenarios. Full-scale Drywell test was performed to determine the infiltration performance of tested soils against varied initial moisture content and dry unit weight. The results showed increased infiltration capacity when compared to the in-situ infiltration capacities as determined in field. Linear regression revealed that the parameter of initial moisture content had a correlation of ($R^2 = 0.53$) and ($R^2 = 0.50$) for ML and CL respectively with infiltration capacity, dry unit weight for ML (Sandy Silt) and CL (Lean Clay) had a correlation of ($R^2 = 0.74$) and ($R^2 = 0.64$) with infiltration capacity.*

Keywords: Infiltration Capacity, Urban Soils, Drywell, Initial Moisture Content & Dry Unit Weight.

1. INTRODUCTION

Excessive developments in Lahore have reduced the infiltration capacity of the native soils which is caused by over-compaction, the soils being predominantly of two types including sandy silt (ML) and lean clay (CL). Previous studies indicate that the infiltration rates in sands are influenced more by compaction than the moisture content while clays are affected by both factors, un-compacted sands have the highest potential for infiltration [1]. Compaction in these urban soils leads to reduced infiltration capacity which causes excessive stormwater runoff which leads to urban flooding. Studies reported that the infiltration rates determined in undisturbed wooden lots had a high average infiltration rate in a range of 377 to 634 mm/hr. The Infiltration rates determined after development were reduced by 80% as determined in the front yard and by 99% in the backyard [2]. To counter this Drywell can be used is a subsurface storage facility that receives and temporarily stores runoff from storm water. Drywell used to facilitate the process of infiltration and reduced localized flooding [3]. An experimental approach has been used in which a lab-scale tank and a soil column are used to simulate different real-world infiltration scenarios. This study also determined the influence of different initial water contents from heavy precipitation and drought on soil moisture distribution, water infiltration and different soil types [4]. A modeling study for soil infiltration rate for VLSI (Vertical Line Source Irrigation) used different soil types at varied initial moisture content by testing on physical model of VLSI (vertical Line Source Irrigation) [5]. A comparison is made between Drywells and Infiltration Basins by testing the infiltration capacity and water retention both systems for stratified soil layers. The results of this study indicated that Dry wells were cheaper and easier to maintain [6].

A Previous study reported the infiltration rate of leaky well infiltration systems which are like Drywell. The results of the in-situ infiltration rates showed that the use of gravel in leaky well had the highest volumetric capacity and infiltration rate [7]. The infiltration-based systems like Drywell can get have issue of clogging with time which can be reduced. Studies showed that urban gardening could prove useful in improving the physical properties of the soil and make infiltration rates more rapid [8]. There is presently no guidance on the design and use of drywells for Lahore city and many areas of Pakistan. To address this problem this current study was devised which included field investigations, laboratory experimentation and physical modeling.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The sites selected for this study were housing schemes of Jubilee Town LDA, Lahore and Mohlanwal Scheme, LDA, Lahore. Both sites have a history of over-irrigation prior to development which causes the surface crusting that with time is going to become hard pan.

Fig -1: (a) Jubilee Town, LDA, Lahore, (b) Mohlanwal Scheme, LDA, Lahore

2.2 Experimental Setup

Single-ring infiltrometer test performed consisted of circular cylinder of height feet 6 inches and diameter 1 ft-10 in. driven into the ground as shown in Figure-3. The Physical model of Drywell for full-scale Drywell infiltration test consisted of a plastic drum of height 3ft. and a diameter of 1 ft-10 in. to confine the soil sample; other components include a mild steel mesh, filter of height 3 ft. and diameter 1ft- 9 in. to contain the coarse gravel. The last component of the physical model was a PVC perforated pipe of height 1 m and diameter 6 inches as illustrated in Figure-4 (a) and shown in Figure-4 (b).

2.3 Physical Properties

To determine the physical properties of the materials experiments were conducted in accordance with ASTM (American Standards for Testing Materials) in Geotechnical Engineering Laboratory at University of Engineering and Technology, Lahore. Specific gravity was conducted using as per ASTM D-854. Bulk dry density was conducted in field by performing field density test using a core cutter as per ASTM D-2937. A falling-head permeability test was performed as per ASTM D-5084. Constant-head permeability test was conducted in accordance with ASTM D-2434. Particle size distribution was done as per ASTM D-422 and classified according to USCS (Unified Soil Classification System). Particle size distribution is presented in Figure-2.

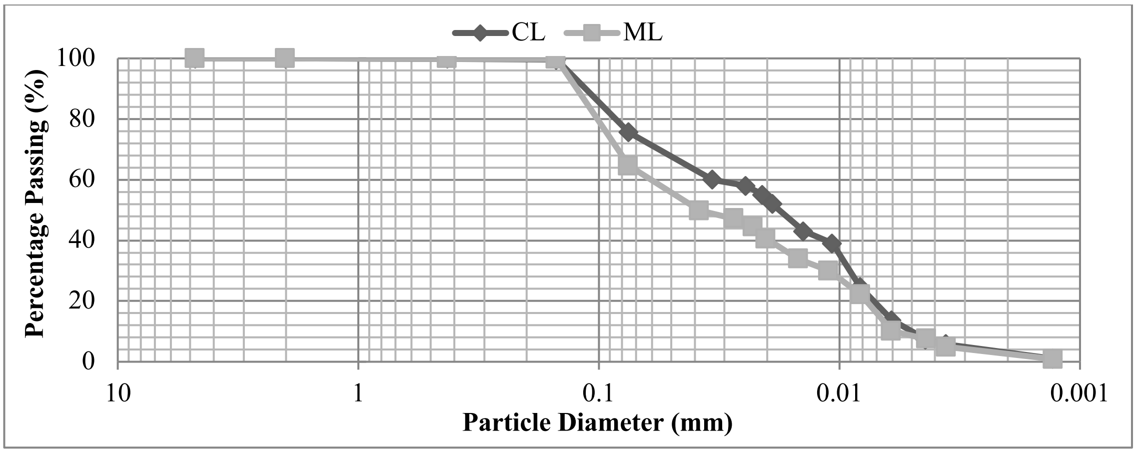

Fig-2: Particle Size Distribution of Tested Materials

Table -1: Physical Properties of Materials Used in The Study

Soil	**Specific Gravity**	**Dry Bulk Density (g/cc)**	**Moisture Content (%)**	**Saturated Hydraulic Conductivity (cm/s)**
ML (Sandy Silt)	2.67	1.72	12.83	1.80E-5
CL (Lean Clay)	2.78	1.90	17.70	4.00E-6

2.4 Infiltration Test and Analysis

Single-ring infiltrometer test was performed as per ASTM D-5126. For silty sand and lean clay, the test under falling-head conditions was performed for 1 hour 20 minutes on site for 3 inches of head of water against which infiltration was measured.

Fig-3: Single-Ring Infiltrometer Test

2.5 Full-Scale Drywell Infiltration Test

A full-scale drywell test was conducted against 26 different moisture-density scenarios. For ML and CL, the test was performed at falling-head condition for duration of 3 hours. The samples were compacted at 13 moisture-density scenarios. Each Infiltration rate for fine-grained soils was measured against a head drop of 3 feet after during the interval of testing. The breakdown of scenarios is as follow:

Table-2: Breakdown of Moisture-Density Scenarios-(ML+CL)

Initial Moisture Content	N.M.C	Moisture Content on the dry/ wet side of OMC	OMC (Optimum Moisture Content	Moisture content from 0-50% with an increment of 10%
Compacted at Dry Unit Weight	Field Density	Density on dry/wet side of OMC	Maximum Dry Density (Standard and Modified Proctor Test)	Maximum Tested Density
Total	1x1	2x2	2x1	6x1 = 13 TOTAL

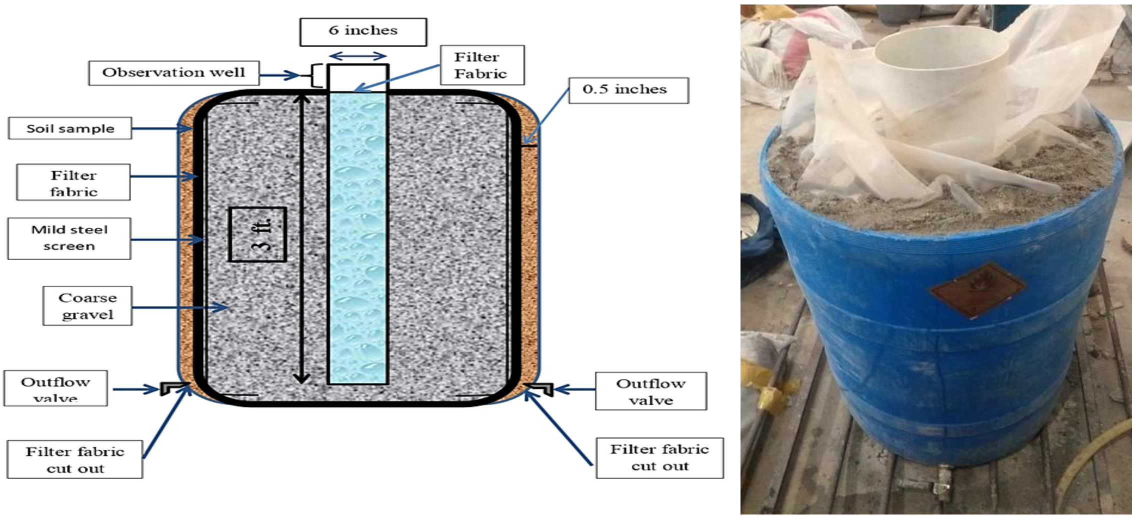

Figure 4: (a) Illustration of Drywell Physical Model, (b) Photograph of Physical Model

3.RESULTS AND DISCUSSIONS

3.1 In-situ Infiltration Testing

Results of single ring infiltrometer ML and CL have infiltration rates of 0.3 and 0.2 in/hr. that put them in the permeability class of moderately slow soils [9]. It is recommended that then in-situ soil where Drywell is to be installed have a minimum infiltration rate of 0.2 inches/hr. [10]. The results of single ring infiltrometer testing are as follow:

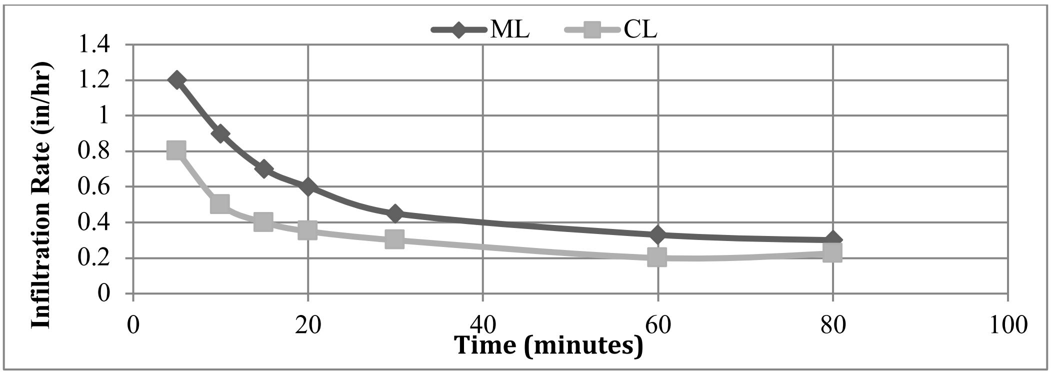

Fig-5: Infiltration Rates from Single-Ring Infiltrometer

3.2 Infiltration Capacity Results Full-Scale Drywell Test

Testing was conducted in the physical model for each sample at varied initial moisture content and dry unit weight. For ML testing was done for an initial moisture content range of 0-50% and unit weight range of 1.62-1.80 g/cc the average initial infiltration rate increased by 1.9 times and the average infiltration capacity increased by 2 times as determined on site The correlation between infiltration capacity with soil moisture and dry unit weight is shown as follow in Figure-6 & Figure-7.

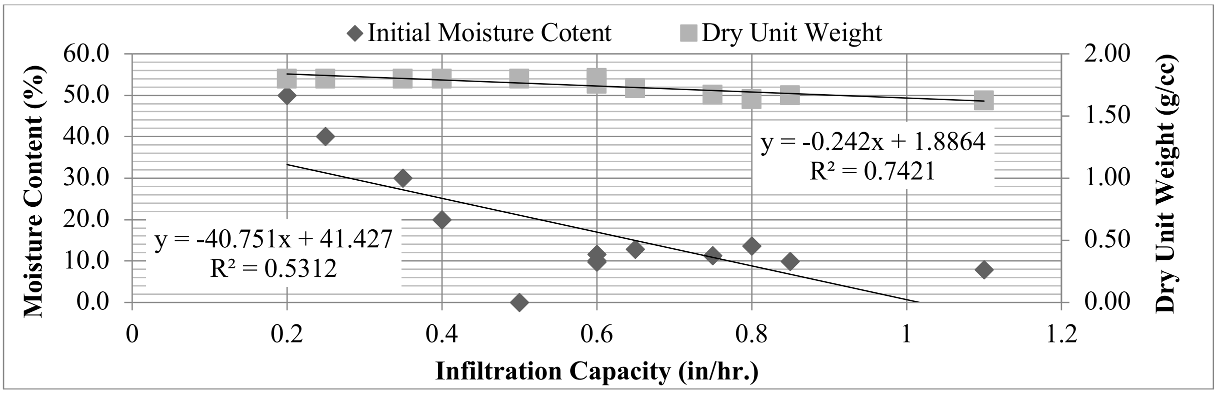

Fig-6: Infiltration Capacity in Drywell Model w.r.t Moisture Content & Dry Unit Weight-ML

For CL tested for an initial moisture content range of 0-50% and unit weight range of 1.8-2 g/cc the average initial infiltration rate and the average infiltration capacity both increased by 2.25 times as determined in the field.

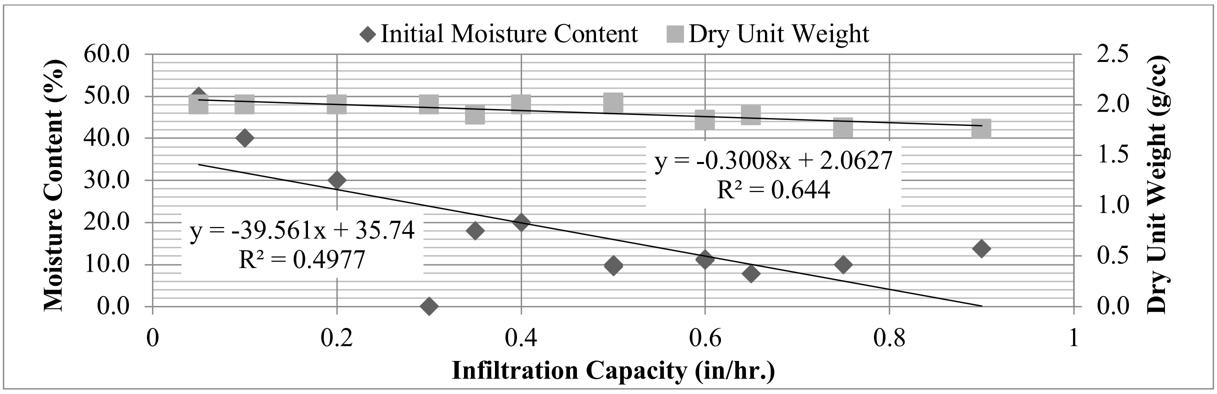

Fig-7: Infiltration Capacity in Drywell Model w.r.t Moisture Content & Dry Unit Weight-CL

The initial moisture content had a correlation of ($R^2 = 0.53$) and ($R^2 = 0.50$) for ML and CL respectively with infiltration capacity. The parameter of dry unit weight had a better influence on the infiltration capacity on ML and CL which had a correlation of ($R^2 = 0.74$) and ($R^2 = 0.64$).

4.CONCLUSION

This research has evaluated the infiltration capacity in field and with Drywell in laboratory. The results of the in-situ infiltration testing revealed that the in-situ soils have moderately slow infiltration capacities. Infiltration testing was done on all the soil samples in the physical model. Following the steps in this research the infiltration capacity in the field can be determined prior to Drywell installation. The results presented in this paper can be used to formulate guidelines for infiltration systems design and to estimate the infiltration capacities of Drywell against geotechnical parameters like compaction, moisture content and saturated hydraulic conductivity. Parameters can be predicted prior to Drywell installation like the cumulative infiltration depth and outflow rates.

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