STORMWATER MANAGEMENT BY ADOPTING INFILTRATION TECHNIQUES OF PERVIOUS CONCRETE ON BROWN CLAY SOIL IN GVMC AREA OF VISAKHAPATNAM CITY

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Abstract:

The development of Smart cities in India, result Urbanization, Industrialization and increasing in infrastructure. Therefore, maximum Metro cities are getting covered with impermeable surfaces such as asphalt roads, concrete sidewalks, parking lots, building roofs, and areas of highly compacted soils. In India, groundwater table is decreasing at a faster rate due to reduction in groundwater recharge. These days, the vegetation cover is replaced by infrastructure hence the water gets less opportunity to infiltrate itself into the soil. Increase in urban storm water over the past few decades in Visakhapatnam city led to increase in pollution and runoff due to Urbanization. This directly leads to environmental issues such as erosion, pollution of rivers and lakes, decrease in groundwater table and flooding problems. One of the solutions to avoid these problems is to percolate natural water into the soil which can be done by Pervious concrete. Pervious Concrete is a type of porous pavement that can be used as an infiltration practice for storm water management contains little or no fine aggregates. Storm water management has become a concern for cities and municipalities due to increased urbanization of residential and commercial neighborhoods. Pervious concrete is one of the most effective and environmentally friendly solutions available as permeable pavement to control uncontrolled runoff, reduce pollution and replenish ground water. Pervious concrete is a mixture of coarse aggregate, Portland cement, water and admixtures. Lacking fines, this material has a void ratio that typically range from 15-25% allows to store and infiltrate storm water.

Important part of this research involves determining the infiltration rates through pervious concrete samples that are made with pure cement, cement partially replaced with fly ash and cement partially replaced with GGBS (Ground granulated blast furnace slag). Hardened concrete cubes were casted with these samples of materials. There was conducted a test for compressive strength on these hardened concrete cubes. The infiltration rate of pervious concrete samples was tested for concrete cast on different sub grades and was also tested without sub grade by the application of water at a constant rate to the concrete surface based on the test procedure as stipulated in ASTM1701/C 1701 M. Also, the properties of the sub grade were investigated to know the effect of the permeability of concrete.

As a part of this study the infiltration test was conducted mainly on Brown clay soil and Red Clay Soil in Visakhapatnam city. These soils cover an area of 35% in GVMC area of Visakhapatnam. These soils are smaller size particles have slow infiltration rates. These soils are mapped by using remote sensing and GIS techniques.

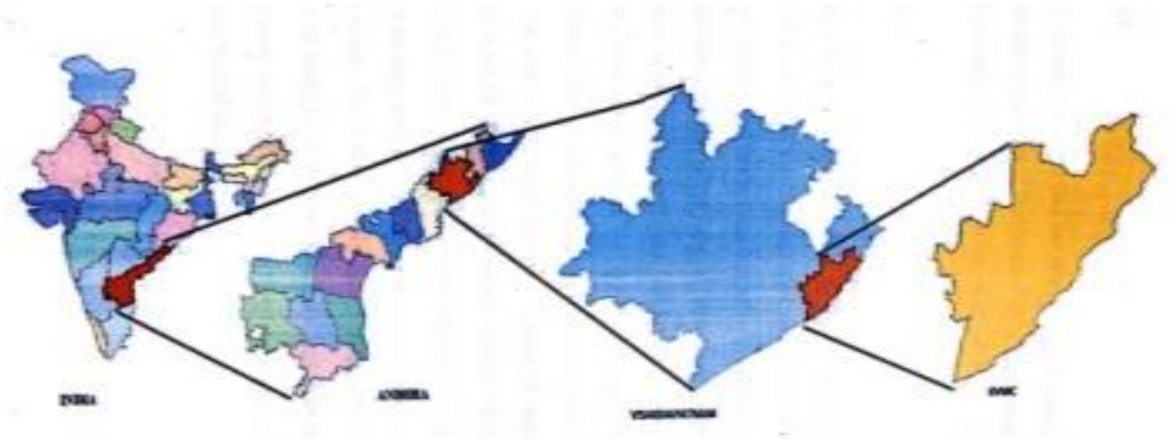
Keywords: Pervious Concrete, Flyash, GGBS, void ratio, Infiltration, ground water Recharge, Remote sensing and GIS Techniques.

Introduction:

Due to rapid urbanization most of the places are covered with impermeable surfaces like cement concrete. This has a major impact on ground water table [1]. Pervious concrete pavement is an innovative solution to minimize this issue. Pervious concrete (also called porous concrete, permeable concrete, no fines concrete and porous pavement) is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. Pervious concrete is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. Pervious concrete is traditionally used in parking areas, areas with light traffic, residential streets, pedestrian walkways, and greenhouses. It is an important application for sustainable construction and is one of many low impact development techniques used by builders to protect water quality. Pervious concrete was first used in the 1800s in Europe as pavement surfacing and load bearing walls. Cost efficiency was the main motive due to a decreased amount of cement. It became popular again in the 1920s for two store homes in Scotland and England. It became increasingly viable in Europe after WWII due to the scarcity of cement. It did not become as popular in the US until the 1970s. In India it became popular in 2000. The proper utilization of pervious concrete is a recognized Best Management Practice by the U.S. Environmental Protection Agency (EPA) for providing first flush pollution control and storm water management.

Study Area

The study area of GVMC is lies between 17˚32'-17˚54' northern latitude and 83˚5' - 83 ˚25' eastern longitude with an area of 598 km^2. The area is located in and around the Visakhapatnam city in Visakhapatnam district of Andhra Pradesh. GVMC is divided in to six zones and further divided into 72 municipal wards. The city is bounded in the North by the Kailasa hill, in the south by Yarada hill and the west by the Narava hill while the eastern side of the city is Bay of Bengal.



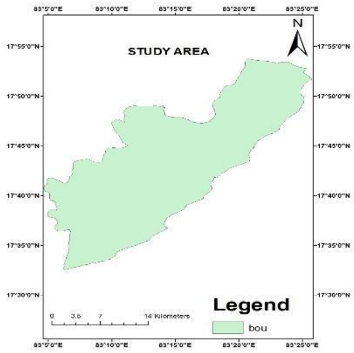


Fig.1. Study area – Location map GVMC, Visakhapatnam

DATA USED

The details of the different data used in this study is given below

- Survey of India toposheets — 65 0/1, 65 0/2 & 0/3, 65 0/5, 65 0/6, scale 1:50,000.
- Sentinel 2A and ASTER DEM data was used.
- Code books of Civil Engineering, ASTM C1701
- Reference maps of various data
- Field data

SOFTWARE USED

- ARC GIS 10.3

METHODOLOGY:

An integrated approach of Remote Sensing and GIS for evaluation of land use and land cover, hydro geomorphology, geology, soil and slope, groundwater table map followed by determination of surface water infiltration on newly developed pervious concrete surface in different soil types of Visakhapatnam and surrounding areas. Methods followed in the study comprise field-work, laboratory work, remote sensing and GIS work following the standard scientific procedures.

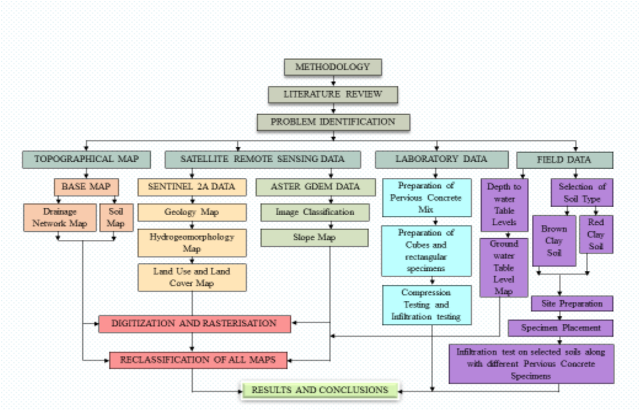


Fig 1.2 Methodology

Drainage network map:

Drainage network map helps to know the patterns formed by streams, rivers and lakes in a particular drainage basin. A drainage basin is the topographic region from which stream receives runoff, through flow and groundwater flow.

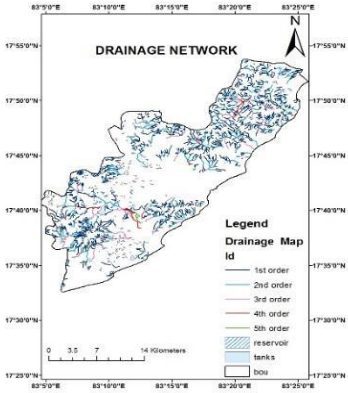


Fig 1.3 Drainage network map

Geology map:

Geology map of this study area helps to know rock formation and ground water occurrences.

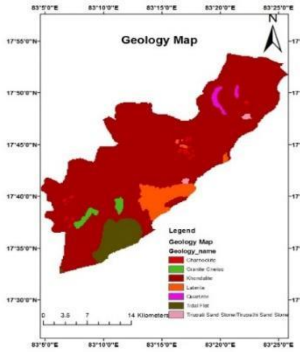


Fig 1.4 Geology map

Hydro geomorphology map:

Hydro geomorphology classes like moderately and shallow weathered Pedi plain are Considered suitable because they have good water recharging capability.

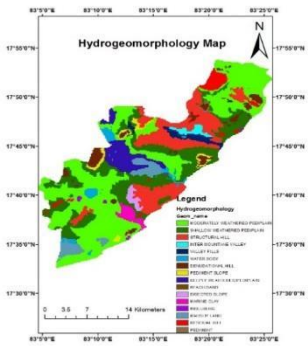


Fig 1.5 Hydro geomorphology map

Land use and land cover map:

Land use and land cover classes like road and built-up land are suitable. Pervious concrete pavements can be used as footpaths along the major roads in the study and as roads where there is no heavy traffic load. Also, a pervious concrete pavement as open parking lot for light weight vehicles is a possibility.

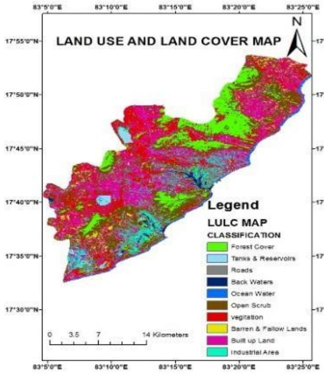


Fig 1.6 Land use and land cover map

Soil map:

Soil map of this study area helps to know the area covered by different types of soils and also to know the permeability and infiltration characteristics through these soil media.

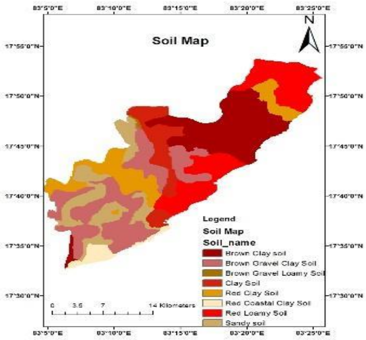


Fig 1.7 Soil map

Slope map:

Slope is the important parameter in this study area to know the major runoff from the areas. In this study area of gvmc, gentle slope and moderately gentle slope are most suitable for surface water infiltration.

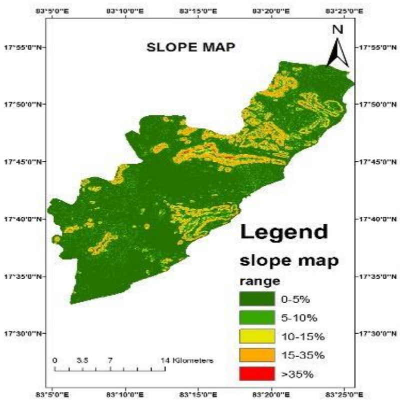


Fig 1.8 Slope map

Groundwater table map:

Groundwater table level data is collected from MDC app. There are chances of surface overflow of groundwater if the groundwater table is close the surface, so the locations with deep level of groundwater table are chosen.

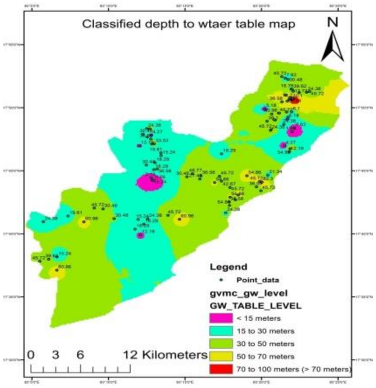


Fig 1.9 Groundwater table map

ASTM C1701: Infiltration Test for Pervious Concrete

ASTM C1701 is the standard infiltration test for pervious concrete. We recommend that an infiltration test be performed at least annually in multiple locations to identify where and when maintenance might be needed. The test consists of four main components: Installing the infiltration ring, pre-wetting the concrete, testing the concrete and calculating the results.

To install the infiltration ring, first clean the surface. The infiltration ring must meet certain size requirements and be marked with two lines on the interior to correctly perform the test. The ring is then placed on the cleaned surface and secured in place with plumber's putty. Once secure, pre-wet the concrete and infiltration ring with 3.6 Kgs of water maintaining the head of water between the two marks on the interior of the ring. Begin timing as soon as the water hits the pervious concrete surface. When water is no longer present of the surface, record the elapsed time of the pre-wetting. The time elapsed determines the amount of water to be used in the actual test. The test shall be started with in 2 min after the completion of the prewetting stage is less than 30s, then use a total of 18 kg of water. If the elapsed time in the prewetting stage is greater than or equal to 30s, then use a total of 3.6 kg of water. In most cases, 18 Kgs of water will be required for the test. Record the weight. Within 2 minutes, add the proper amount of water to the ring. As with the pre-wetting stage, we will begin timing when the water impacts the pervious concrete surface and maintain the water head between the two lines marked on the infiltration ring. Again, when water is no longer present of the surface, record the elapsed time of the test.

With all of our data points collected, we then perform the infiltration calculation using the mass of the water, the diameter of the infiltration ring and time of the test. With that information we have our final infiltration rate.

Infiltration Calculation:

$\mathbf{I = KM/D^2(T)}$

I = Infiltration rate in mm/h

M= Mass of infiltrated water in Kgs

D = Inside diameter of infiltration ring in mm
T = Time required for measured amount of water to infiltrate the concrete in sec
K = 4583666000 (constant)

RESULTS:

SUITABILITY MAP PREPARATION:

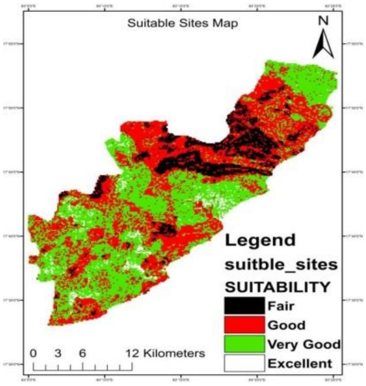


Fig 2.1 Suitability map for laying of Previous Concrete in GVMC area

The final output map has produced only four classes by the end of overlay analysis because of the raster calculation explained in illustration section above. The scale values of the output are seen in the attribute table of the map in the "Value" column. The attribute table is shown below in Table the pictorial representation of areas covered under different suitability sites is shown above.

Rowid	VALUE	COUNT	SUITABILITY	AREA_SQKM
0	2	3043	Fair	71.123703
1	3	10062	Good	235.178015
2	4	10852	Very Good	253.642597
3	5	713	Excellent	16.66487

Table.: Attribute table of suitable sites map

CLASSIFICATION	AREA_SQKM
Forest Cover	78.90792
Tanks & Reservoirs	10.50894
Roads	**64.95332**
Back Waters	7.265568
Ocean Water	8.918387
Open Scrub	137.7145
Vegetation	87.26638
Barren & Fallow Lands	21.09563
Built up Land	**146.9233**
Industrial Area	**35.22686**
Total	**598.7808**

COMPRESSIVE STRENGTH VALUES:

Concrete 28 days Compressive Strength Results (all values in N/mm^2)

Table:1 Compressive Strength Values for Pervious Concrete Cubes tested in CTM

S. No.	Cubes with Pure Cement			Cubes with Cement + Fly ash			Cubes with Cement + GGBS		
	Trail 1	Trail 2	Trail 3	Trail 1	Trail 2	Trail 3	Trail 1	Trail 2	Trail 3
1	23.12	22.75	22.93	22.47	21.81	22.72	23.79	22.37	23.08
2	**Avg = 22.93**			**Avg = 22.33**			**Avg = 23.08**		

Compressive strength results of all the combinations of Pervious Concrete samples have achieved moreover same results 22 N/mm^2 to 23 N/mm$^{2.}$

Fig 2.2 Compression testing machine

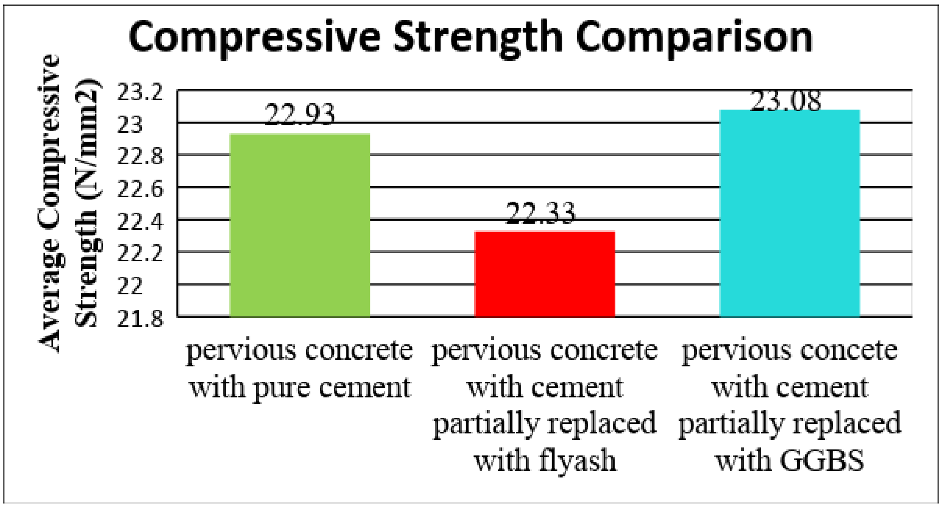


Fig 2.3 Average Compressive Strength Values for different Pervious concrete Samples

INFILTRATION RATE: LABORATORY TESTING

From ASTM C1701 code book, a formula is used to find the infiltration rate of water passing through the pervious concrete to sub grade soils.

Fig 2.4 Laboratory Core Test

$I = KM/D^2 \times T$
I - Infiltration Rate in mm/h
K - Constant Value (4583666000)
M- Mass of infiltrated Water in Kgs
D- Inside diameter of the infiltration ring in mm and
T- Time required for measured amount of water to infiltrate the concrete in sec

Values of Cement:

Trail-1
$I = KM/D^2 \times t$
$I = 4583666000 \times 18/ (300)^2 \times (32) = 28.647 \times 10^3$ mm/h
Trail-2
$I = KM/D^2 \times t$
$I = 4583666000 \times 18/ (300)^2 \times (29) = 31.611 \times 10^3$ mm/h
Trail-3
$I=KM/D^2 \times t$
$I = 4583666000 \times 18/ (300)^2 \times (30) = 30.557 \times 10^3$ mm/h

Average Value I= (28.65+ 31.61 + 30.55)/3 = **30.27×10^3 mm/h**

Values of Fly ash:
Trail-1
$I=KM/D^2 \times t$
$I =4583666000 \times 18/ (300)^2 \times (38) = 24.124 \times 10^3$ mm/h
Trail-2
$I=KM/D^2 \times t$
$I =4583666000 \times 18/ (300)^2 \times (41) =22.36 \times 10^3$ mm/h
Trail-3

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (42) = 21.826 \times 10^3$ mm/h

Average Value I= (24.12+22.36+21.82)/3 = **22.77×10^3 mm/h**

Values of GGBS:

Trail-1

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (60) = 15.278 \times 10^3$ mm/h

Trail-2

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (58) = 15.805 \times 10^3$ mm/h

Trail-3

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (59) = 15.537 \times 10^3$ mm/h

Average Value I= (15.27 + 15.80 + 15.53) / 3 = **15.54×10^3 mm/h**

LABORATORY INFILTRATION TEST RESULTS:

Table:2 Laboratory Infiltration test results for different pervious concrete Samples

S. No	Description	Average Infiltration rates for different Samples(mm/h)
1	Pervious concrete with Pure Cement	30.25×10^3
2	Pervious concrete (Cement Partially replaced with Fly ash)	22.77×10^3
3	Pervious concrete (Cement Partially replaced with GGBS)	15.54×10^3

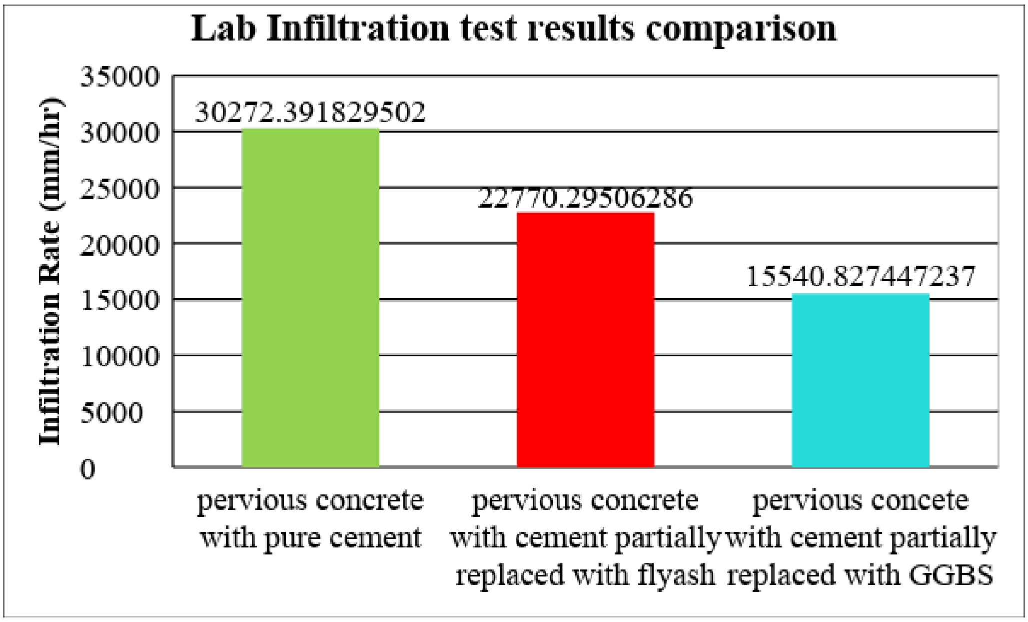


Fig 2.5 Average Laboratory Infiltration rate values for different Pervious Concrete Samples

INFILTRATION RATE ON BROWN CLAY SOIL:

Field Testing Calculations:

Fig 2.6 Infiltration rate Testing of Pervious Concrete Samples on Brown clay soil.

From ASTM C1701 code book, a formula is used to find the infiltration rate of water passing through the pervious concrete to sub grade soils.

$$\mathbf{I=KM/D^2 \times T}$$

I - Infiltration Rate in mm/h

K - Constant Value (4583666000)

M- Mass of infiltrated Water in Kgs

D- Inside diameter of the infiltration ring in mm and

T- Time required for measured amount of water to infiltrate the concrete in sec

Values of Cement:

Trail-1

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (64) = 14.32 \times 10^3$ mm/h

Trail-2

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (68) = 13.48 \times 10^3$ mm/h

Trail-3

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (74) = 12.39 \times 10^3$ mm/h

Average value $I = [(14.32 + 13.48 + 12.39)/3] \times 10^3$ mm/h = **13.40×10^3 mm/h**

Values of Fly ash:

Trail-1

$I = KM/D^2 \times t$

$I = 4583666000 \times 18/ (300)^2 \times (58) = 15.81 \times 10^3$ mm/h

Trail-2

$I = KM/D^2 \times t$

$I = 4583666000 \times 18 / (300)^2 \times (63) = 14.55 \times 10^3$ mm/h

Trail- 3

$I = KM/D^2 \times t$

$I = 4583666000 \times 18 / (300)^2 \times (68) = 13.48 \times 10^3$ mm/h

Average Value $I = [(15.81 + 14.55 + 13.48) / 3] \times 10^3$ mm/h = **14.61 ×10³ mm/h**

<u>Values of GGBS</u>:

Trail-1

$I = KM/D^2 \times t$

$I = 4583666000 \times 18 / (300)^2 \times (85) = 10.79 \times 10^3$ mm/h

Trail-2

$I = KM/D^2 \times t$

$I = 4583666000 \times 18 / (300)^2 \times (94) = 9.75 \times 10^3$ mm/h

Trail-3

$I = KM/D^2 \times t$

$I = 4583666000 \times 18 / (300)^2 \times (98) = 9.35 \times 10^3$ mm/h

Average Value $I = [(10.79 + 9.75 + 9.35)/3] \times 10^3$ mm/h = **9.96 ×10³ mm/h**

FIELD INFILTRATION TEST RESULTS

Table:3 Field Infiltration test results for different pervious concrete Samples on Brown clay soil

S. No	Description	Average Infiltration rates for different Samples(mm/h)
1	Pervious concrete with Pure Cement	13.40×10^3
2	Pervious concrete Cement Partially replaced with Fly ash	14.61×10^3
3	Pervious concrete Cement Partially replaced with GGBS	9.96×10^3

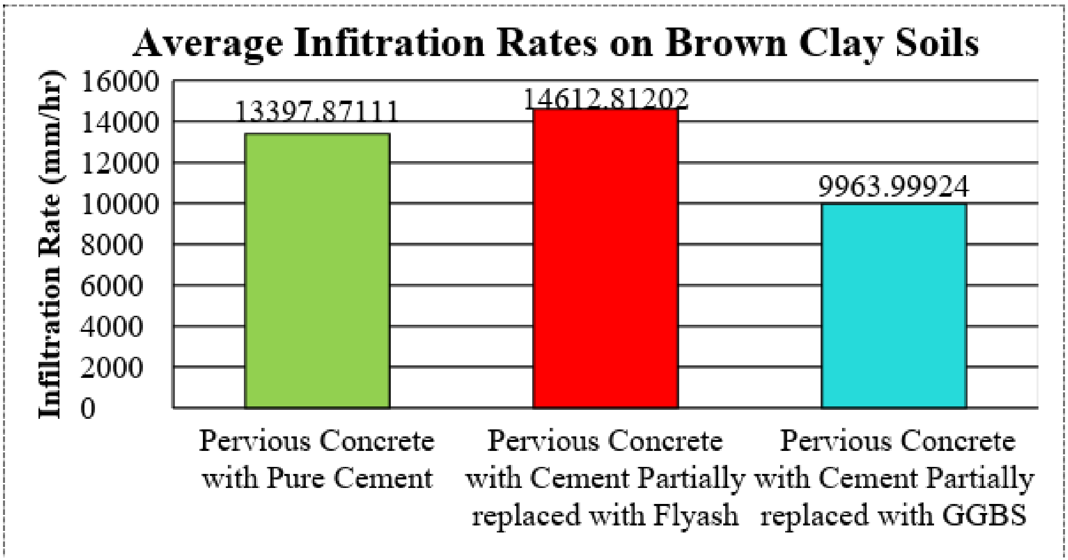


Fig 2.7 Average Field Infiltration rate values for different Pervious Concrete specimen on Brown clay soil

CONCLUSIONS:

From the Results of experimental approach:

- The population of the Visakhapatnam city is more than 4 million. Fast industrialization in the region, with increase in population caused major issues in water supply administration in the city and its surrounding zones.
- The concretization of the surface range in the city is genuinely influencing the groundwater energize as the vast majority of the water is running off into the ocean.
- The pervious concrete and subsoil system display infiltration rates of nearly the same magnitude as the subsoil in the locations where the pervious concrete infiltration rate is higher than that of the subsoil.
- Proper mix design and placement techniques will be presented in detailed specifications at the completion of this project. This field test may also be applied to soils with lower infiltration rates as seen in the case of Site.
- Different types of materials like Cement, fly ash, and GGBS are used in pervious concrete to find the infiltration rate of water through these samples.
- From the Results of experimental approach: Cement and Cement+ Fly ash pervious concrete has more infiltration rate in both sub-grade and non-sub-grade soils. The pure OPC and OPC +Fly ash can be recommended for the use of pervious concrete over the subgrade soil. As both the cement and Fly ash are of fineness materials and more fines are in Fly ash passing through 45 microns. Also, in commercials point of view, the combination of OPC+ Fly ash gives us more saving than choosing the pure Ordinary Portland cement (OPC)
- We can adopt the usage of pervious concrete with the combination of OPC + Fly ash, as this is an Environmental Eco-friendly product by minimizing the CO_2 emission into Environment and also the compressive strength results of all the combinations of Pervious Concrete samples has achieved moreover same results 22 N/mm^2 to 23 N/mm^2
- The simple test set-ups used in this study are suitable to determine the water permeability and infiltration rates for pervious concrete in the Visakhapatnam area.
- The compression test results showed that the increase in the comprssion strength of concrete sample as the curing period increases.

- Use of flyash reduces the amount of cement content as well as heat of hydration in a concrete mix. Thus , the construction work with flyash concrete becomes environmentally safe and economical.
- The Replacement of Cement by GGBS not only increases the compressive strength but also reduces the cement content which eventually leads to the decrease in emission of co_2.
- The tests are carried out based on ASTM C1701 code, which is suitable to determine the water permeability and infiltration rates of pervious concrete on different soils in the GVMC area.
- Nearly 247.10 Sq Km of the GVMC area is under Concretization in 598.7808 Sq Km. In Brief decision Built up Land is 146.9233 Sq Km, Industrial Area is 35.22686 Sq Km and Roads has covered 64.95332 Sq Km.

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