Rainwater & Storm Water Harvesting with Asphalt and Concrete Pavements

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Abstract – *Rainwater & storm water Harvesting being an essential need of the future, it can be achieved not only through roofs but also through concrete and asphalt roads, everyone focuses on creating pervious pavement and then letting that water seep into the ground to restore the Ground Water Level, but the main focus should be of using that water then and there itself, instead of allowing it to seep into the Ground, it should be cleaned, collected, and stored accordingly for future use. So here we conducted some test on pervious concrete to check it various technical parameters.*

The main purpose of this paper to show the techniques which should be installed beneath the pavement to purify, collect and store this rain harvested water, constantly bombarded on roads. How channels and pipelines need to be used in order to collect this water is mentioned below with Auto-Cad sketches shown further.

India has vast length of road, i.e., 6,215,797 kilometers, out of which rural road account for 4,535,511kms, district roads account for 632,154 kms, so out of total 100% the rural and district roads they make 83.14% of roads. With this being said, why are focusing on rural and district road, a question may arise in your mind? So, the reason why we are considering them is that these roads they have less traffic density as compared to NH, SH. This less traffic density is useful for us as the compressive strength of pervious pavement is less than that of the normal pavement, so use of these pavements is recommended on rural and district roads only.

*Tests sample were being taken on concrete block of 15*15*15* cm, they will be mentioned further in this paper.*
Although the method mentioned in this paper might be expensive at first, but the result on economy, water scarcity and environment are phenomenal, construction of such road will require highly skilled technicians and labors, nonetheless it will be all worth it.

Key Words: Rainwater & storm water harvesting, pervious pavement, ground water level, compressive strength, water scarcity, environment.

1.INTRODUCTION:

In this our primary focus is to harvest the rainwater, and also the storm water in the regions of high flood activity, these surfaces will make sure to absorb maximum amount of water, and once the underground tanks reach their maximum capacity it will be transferred to the next tank and further, so whatever the amount of water, it can be stored conveniently. With this being said, and the vast number of roads available with us in India, region which are drought prone can be supplied be abundant water supply due to this technique.

Secondary is the technique with which this water needs to store into these tanks, and what will be the purity of water, which is being stored? Well for this the road will first contain pervious layer of concrete or asphalt and then sub base to retain the water to the next stage where use of pipes can be done to supply the water without hampering the process of seepage of surface water. Water will first be purified at the source itself, i.e., right at the point of entry, where all the solid suspended materials will be filtered, (e.g., total suspended solids, metals, oils, and grease, as well as moderate removal for phosphorus, etc.), from using porous asphalt / concrete pavement, which consists of 10 to 20 % porosity. The second layer will be porous again to drain the water to pipes fitted beneath them, which will have porosity rate of 20 to 25 %, this layer will further purify the water of its remaining impurities, TSS (Total Suspended Solids) will all be taken care of, by this layer. By the time water reaches to the pipes it will be free from TSS, now with gradual slope this water can be collected into underground pits and tanks constructed for the purpose, and right before the water enters the tank, a secondary filter will purify the water, to remove majority of the TDS (Total Dissolved Solids), the principal constituents of TDS consist of calcium, magnesium, sodium, potassium, cations, and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions, these all constituents will be maintained at the standard rate in order to make the water free from pollution and suitable for further use. These tanks will be situated at every 10 km intervals, it may vary accordingly to the surface water conditions, flood prone zones, economy, and ease of installation at sites.

The use of these systems will surely help the locals use the water as and when needed, installing of these pavements is not restricted to only roads and pavements, individuals can implant this system in their home in open spaces, around gardens, parking spaces (private and public), lawns with pavers can be replaced with this. The connection of which can be united together to collect water in the pits, individuals can also demand for their own underground tanks to not rely on others for water supply during water shortages, this water being clean can be used to garden the plants, maintaining the ecological cycle and also the green lush places are possible at places with low rainfall, this will eventually impact the green cover available with us.

1.1 Pervious pavement:

Pervious pavement allow the surface water to seep into the ground, with more modification as stated, this water can be stored and further used accordingly, it has the potential to reduce the stagnant water onto the surface, resulting into less breeding of mosquitoes, also avoiding damage of the roads due to continuous exposure of road surface to water, clogging and water logging of open gutter will effectively be reduced, skidding on road surface causing accident will be prohibited, pervious pavement has more frictional surface having a grip onto the surface, making the vehicles have more control on the pavement. These pavements have tended to shown improved water quality, by reducing the temperature of the water, TDS and TSS pollutants is reduced significantly, also the heavy metals, polyaromatic, hydrocarbons and many other unnecessary nutrients are diminished. Pervious pavements have many advantages on conventional concrete and asphalt pavements.

Advantages:

1) Storm water management,
2) Rain water harvesting,
3) Purify the water and collect it for further use,
4) Avoid potholes on road,
5) Improve the road conditions,
6) Muddy surface causing skidding is avoided,
7) Increased control over road of the vehicles in rainy season,
8) Stagnant water covers on road is avoided, improving the ecological conditions and human health
9) Use of stored water as and when required with outlet systems,
10) With nozzles provided above the ground connecting it to the fire hydrants, this water can be used to fire fighters to diffuse fire,
11) DO (Dissolved Oxygen) of the water is increased due to continuous hammering of water on the surface.

Types of Pervious Pavement:

1) Pervious Concrete pavement,
2) Pervious Asphalt pavement,
3) Pervious Paving surface with interlocks,
4) Concrete grid pavers,
5) Plastic reinforcement grid pavers.

1) Pervious Concrete pavement:

Pervious concrete also known as permeable concrete pavement is more useful and long-lasting pavement in comparison to asphalt pavement, the reason being the concrete has better life compared to asphalt, now a days initiative is taken to make most the highways of concrete, so instead of focusing on asphalt more pervious concrete is what we must be focusing on, tests were done on pervious concrete in this research paper, the observation table for the same are mentioned further in the paper.

It is key element in harvesting rainwater, and also the storm water can be well managed with it, it mostly contains no sand or minute fine particle in the mortar, it is constituting of cement, coarse aggregate, water, and some time admixtures. In comparison to asphalt it is more porous, is has porosity of about 15 to 25 %. Also, with the use of 20 to 30 % fly ash, the economy can be greatly achieved, making it more ecofriendly by replacing the concrete required to construct this pavement, also the tons of fly ash generated is used responsibly, having an environment friendly environment. Temperatures while placing the concrete plays a vital role in this pavement, if the paste gets too thin, it will settle at the bottom blocking the porosity of the pavement, and if the paste gets too thick, problems of surface wear off and raveling can be inevitable. So, placing the concrete at right time is the key in this. About 12 to 30 liters of water can pass through an area of 0.09 SqM. Per minute.

Vital elements to be considered are as follows:

1) temperature, (Ideal placement temperature is: 4 to 23 degrees Celsius)
2) humidity, (recommended high humidity.)
3) wind, (wind speed is **α** to the drying rate of the concreteα)
4) surface area being exposed to the surface.

Another important factor is that, the aggregates used should be coated with thin paste of the concrete, and the mix should be non-sticky, free from lumps, and also not to dry. The result obtained after this is pervious interconnected small gravels forming the permeable porous pavement, as this pavement is filled with the voids, it is economical as it saves 15 to 20 % of cement, as a result it also makes it less heavy, the density is less than that of the conventional one, it is an average of 1700 kg/m^3 or 1.7 g/m^3. As the use of small aggregate and fines is avoided here, the placing of the pavement requires additional attention, as the paste is harsh, non-workable, the slump is also very low. (Slump: it is the measure of consistency of the concrete, the ease with which the concrete flows). The applications of these concrete are still limited to use in places of low-density traffic, parking areas, gardens, paving blocks, etc. the limited compressive strength of the concrete makes is use limited, nonetheless if made more researches it can be the best alternative to conventional pavements. These concrete lowers the temperatures of water as well as surrounding areas too, it allows swift passage of wind through it, thereby increasing the quality of air, lowering its temperature, black color of the road absorbs more heat which increases the surrounding temperatures by 4 degrees, the concrete pavement is not black, as a result heat island effect is reduced. The compressive strength lies from 3 to 27 MPa.

2) Pervious asphalt pavement:

Permeable asphalt also known as permeable asphalt or porous or popcorn asphalt. This pervious asphalt is made up of the standard hot mix asphalt with fine grade aggregate and sometimes sand on availability. These fine aggregate and sand are mixed together with asphalt or bitumen-based binder coarse. Base coarse formed with this bitumen binder coarse, acts as the first layer, and sub base is also needed to support this bed. The construction cost of this pavement is economical if constructed with right equipment and skilled labor. With aggregates of 3 to 4 mm size, substantial air voids can be formed. The bitumen binder acts as a connector in these aggregates, so without having to worry about the raveling problem caused to removal of fine aggregates, these asphalt pavements can be constructed.

The common problems that are noticed in the formation of these pavements is moving of the binder material into the pore spaces available and settling at the bottom due to gravity, causing the main motive of the pavement to die. In order to incorporate with this problem placing of this pavement needs to be done at ideal conditions. Also use of various admixtures can turn out effective to increase the setting time of the pavement to avoid settling of the pavement. Hun-Dorris, 2005 & NCDENR, 2007; have been proved to be useful admixtures to deal with the problem.

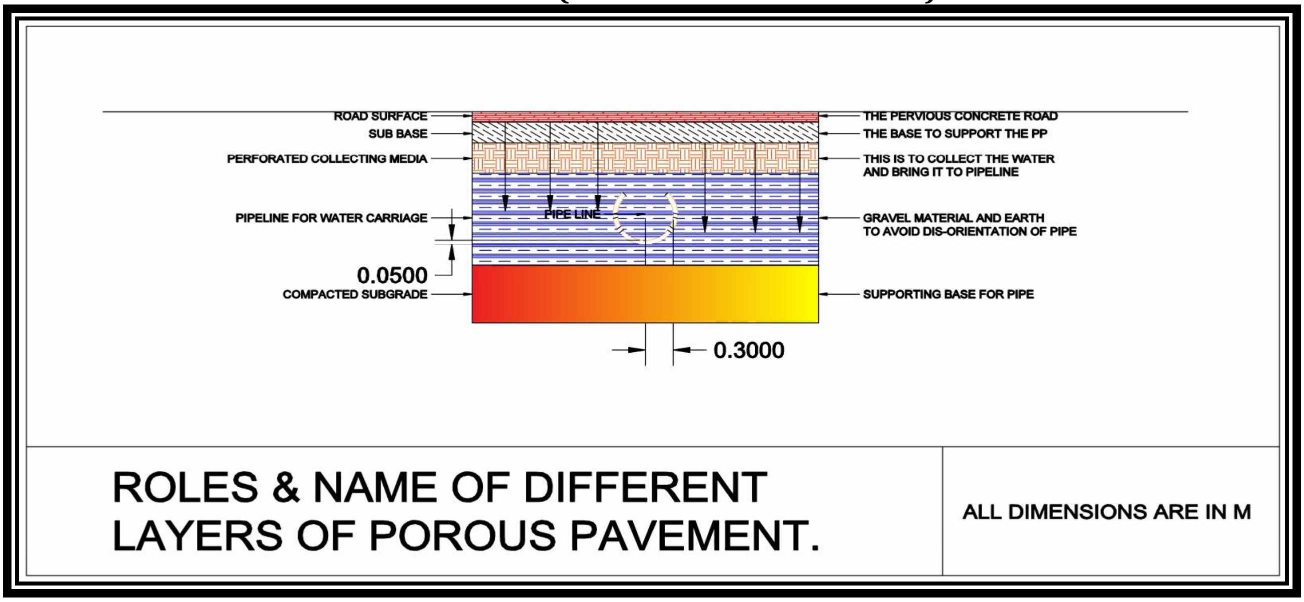
Thickness of the pavement is very important issue as where this pavement is being placed matters the most, with this being said, generally 8 to 19 cm thickness is preferred, although depending on bedding conditions and use of the road, this thickness should be varied accordingly.

Different Polymers are also used to incorporate strength by increasing the bonding strength of the mix, at the same time avoiding settling of the binder. This pavement being a good solution to conventional pavements, this can used to collect and store storm water, and also be used for various personal activities and also for public welfare. By implanting this technique on the roads, two goals of locomotion and water storage are achieved simultaneously. Government doesn't have to invest funds for any other schemes which involves formation of huge lakes artificially to provide water, purchasing of land and formation of ponds which involves maintenance, this can initially be time consuming be can be fruitful for the upcoming decades with enormous benefits economically, and ecologically. This system can be used in municipal green infrastructures and also low impact development plans. This asphalt proves to me more useful and beneficial than conventional asphalt, having more friction on rainy days and wet roads make is more sustainable, and can bring revolution if used everywhere.

3) Pervious Paving surface with interlocks,
4) Concrete grid pavers,
5) Plastic reinforcement grid pavers.

These pavements cannot be used on roads, and we are going to discuss about rain water harvesting on roads, so will not go into details for these three.

1.2 SETUP STRUCTURE STRATEGY FOR RWH (RAINWATER HARVESTING)

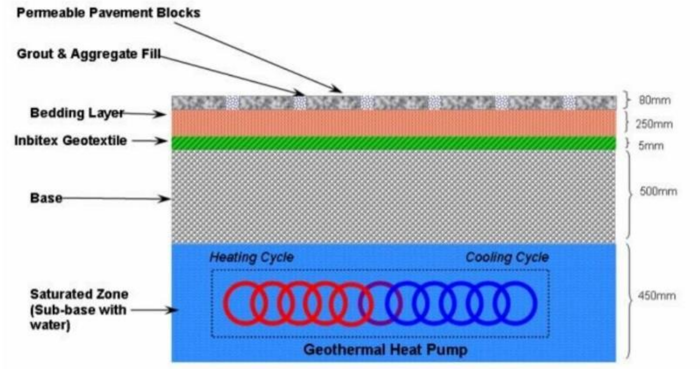


The image above shows the cross section of the PRP 8(Pervious Road Pavement). Right side shows the function of these layers.

The layers are as follows:

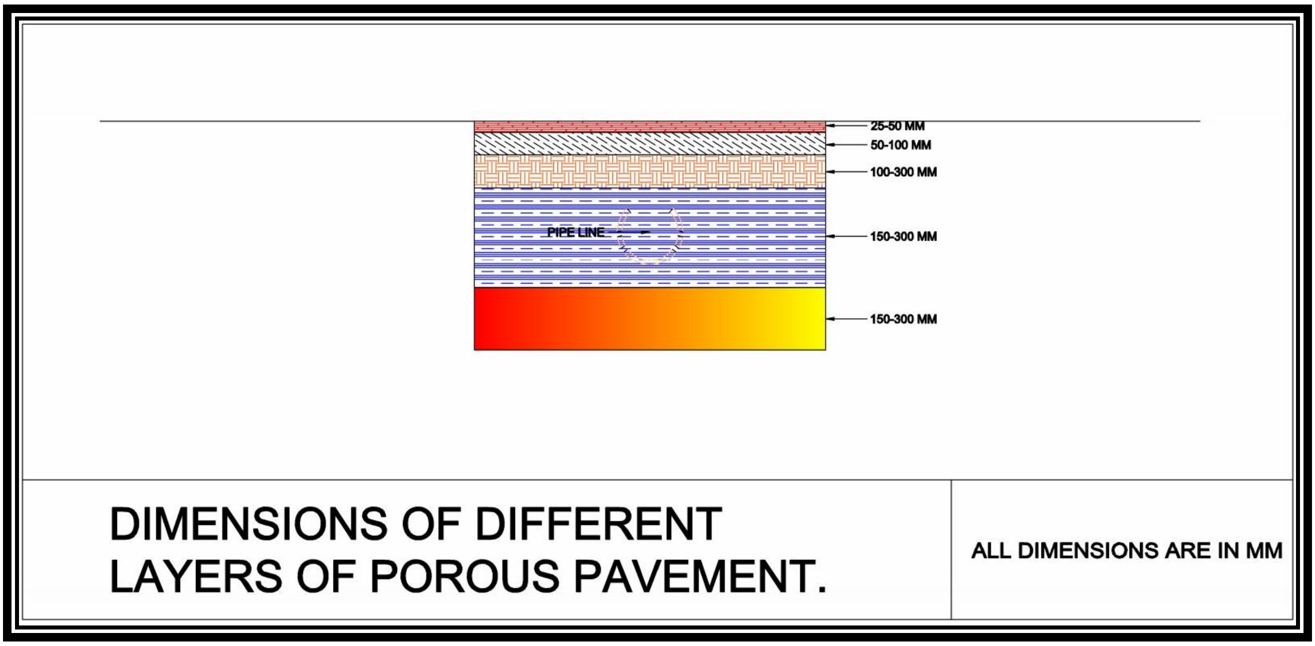
1) Road surface,
2) Sub base,
3) Perforated media consisting of binder course and base course,
4) Pipeline for water locomotion, + gravel media and earth,
5) Compacted subgrade.

1) **Road surface:** As mentioned earlier, this layer is the porous bitumen or concrete layer. The primary use to filter all kinds of TSS from the water.
2) **Sub base:** This layer will make sure to remove any leftovers from the water, help reducing its temperature, also the water quality can be enriched by adding stones which replenish minerals by locating them at distant places in this layer. Rain may contain 5-day biochemical oxygen demand (1–2 mg/l), sulphate (0.56–14.40 mg/l), chloride (0.2–5.2 mg/l), ammonia (0.1–2.0 mg/l), nitrate (0.l–7.4 mg/l), and total phosphate (0.01–0.19 mg/l), copper (1–355 mg/l) and zinc (5–235 mg/l) [these are the figures according to the study at NCDENR, 2005]. So, with this data at hand, essential minerals can be added to the water, to make it fit for use. Also, by inserting DO meters and sensors in the collection tanks, one can identify what the water in a particular area constitutes of. Permeable concrete has the highest heavy metal removal rate (96.5% average) followed by block paving with brick substrate infill (92.9% average). No significant differences between the narrow infiltration pores and the wide pores were observed (63.1% and 78.6% average removal rates, respectively). When set over a 4 cm crushed basalt or brick substrate roadbed and a 40 cm limestone base course, average pollution removal rates for all pavements and substructures were very high, ranging from 96 to 99.8 percent. Permeable pavements can operate as efficient hydrocarbon traps and powerful in-situ bioreactors. Research showed that suspended solids and lead can be reduced by PPS up to 64% and 79%, respectively. Filtration through a specific adsorbent organic medium can remove about 95% of dissolved copper and zinc. Permeable pavements can reduce hydrocarbon contamination by 98.7%. So based on these parameters, suitable installations can be made in this layer to get rid of desired contaminants we want.



This figure shows the actual placing of in site concrete pavement, currently in practice today.

3) **Perforated media + binder course + base course:** This third layer actually collects all the water received form the above layer and collects it to make sure it reaches into the pipe which can then be collaborated into to collection tank.
4) **Pipeline for water locomotion, + gravel media and earth:** This layer consists of V shaped structure it, which converges onto the mouth of the pipe, which connects to the secondary filter, (if needed) which ends up in the collection tank.
5) **Compacted subgrade:** The main reason of this layer is to support the above system, which applies a lot of pressure on ground, so even distribution of this is necessary, which is taken care of by this layer, depending on the type of the road, and water catchment and rainfall index, this layer needs to be varied. Also, if the system has leakage, this layer will make sure to distribute the water into the ground, with water sensitive sensors fitted at interval of 1 km, whether the system comprises of leakage or not will be detected.



This figure shows what should the dimensions of these layers vary from, by defining low limit and high limit.

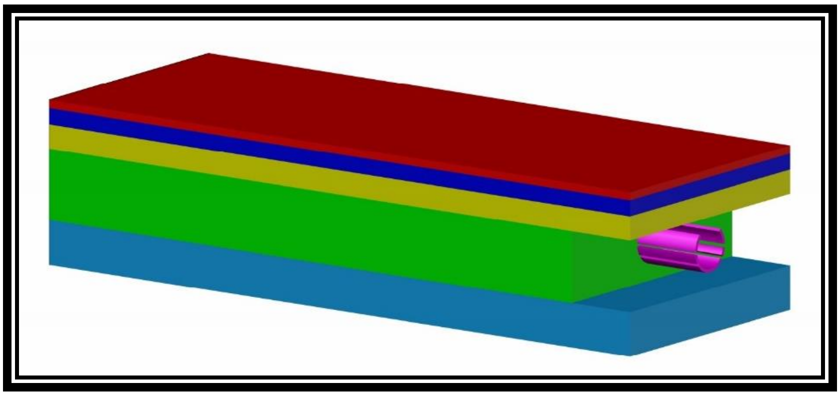


Figure 1

This section shows how the composition of layers should be done with pipe in purple colour, this pic is not comprised of V-shaped collector installed right above the collection pipe as shown in the next figure in cyan colour. The pipe below the road consists of 0.3 m radius and is 0.05 m thick concrete pipe with overflow values, shown in the figure with open spaces. An 0.32 m radius pipe is then fitted at the end this pipe to fuse it to the collection tank, shown in figure with red colour, this tank dimensions can vary accordingly, and also a man hole provision is advised with screens for safety purpose. The tank is 1 m in diameter and 2 m in height, with its only 0.25 m concrete reinforced cover lid right above the surface for accessibility. Pumps can then be fitted or connections to the individuals residing in that area can be provided for further use.

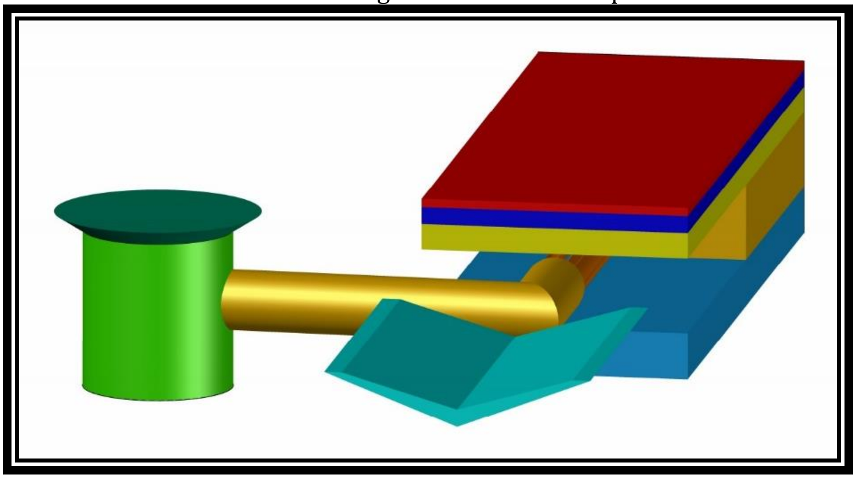


Figure 2

Figure 2: showing V- shaped collector how will it be responsible, and
Figure 3: showing how the system should look.

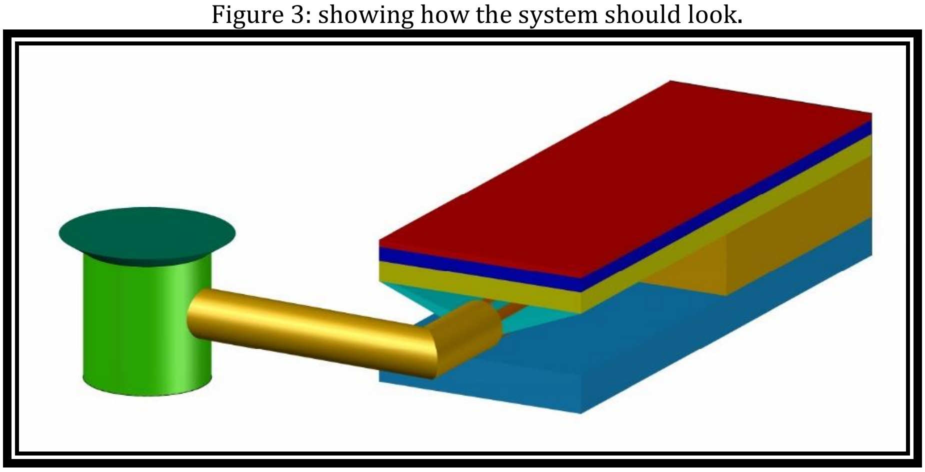


Figure 3

2.1 EXPERIMENTAL VALUES

I. Observations of experiments on pervious concrete are as follows:

1. Cement (53 Grade ULTRATECH Cement):
   - ➢ Specific gravity: 3.02
   - ➢ Fineness of cement: 3.15
   - ➢ Consistency: 35%
   - ➢ Initial setting time: 120min.

2. Coarse Aggregate:
   - ➢ Specific gravity: 3.00
   - ➢ Bulk density: 1.50

3. Fine Aggregate:
   - ➢ Specific gravity: 2.63
   - ➢ Fineness modulus: 2.5

A. Compressive strength:

1. FOR Uniform -20 mm:

Days	W/C Ratio	C:A	Comp. Strength (N/mm2)
3	0.31	1:4.32	04.16
7	0.31	1:4.32	10.68
28	0.31	1:4.32	15.72

2. FOR Non-Uniform – 10+20 mm (30/70):

Days	W/C Ratio	C:A	Comp. Strength (N/mm2)
3	0.31	1:4.32	06.76
7	0.31	1:4.32	13.46
28	0.31	1:4.32	19.28

B. Flexural Strength:

1. FOR Uniform – 20 mm:

Days	W/C Ratio	C:A	Flexural Strength (N/mm2)
7	0.31	1:4.32	0.14
28	0.31	1:4.32	1.60

2. FOR Non-Uniform – 10+20 mm (30/70):

Days	W/C Ratio	C:A	Flexural Strength (N/mm2)
7	0.31	1:4.32	0.16
28	0.31	1:4.32	2.10

C. Permeability:

Composition	W/C Ratio	C:A	Coefficient of Permeability (Cm/Sec)
Uniform	0.31	1:4.32	1.66
Non- Uniform	0.31	1:4.32	0.88

(Note: 30/70 mentioned in the observation table is the ratio with which the aggregates are used in the mix.)

II. Observations of experiment on pervious asphalt are as follows:

1. Perks of pervious asphalt are as follows:

- Specific Gravity: 0.882,
- Ductility: 3.5cm,
- Penetration Value: 30-50 mm,
- Stripping value: 1.72%.

2. Properties of coarse aggregate:

Impact value:

- Passing through 16mm & retained on 12.5mm: 5.1%,
- Passing through 12.5mm & retained on 10mm: 10.52 %,

According to IS-2386 (Part IV) Aggregate impact value shall not exceed 45% for aggregate used in base course& intermediate course and 30% for wearing surfaces.

Crushing value:

- Passing through 16mm & retained on 12.5mm: 15.47 %,
- Passing through 12.5mm & retained on 10mm: 17.79 %,

According to IS-2386 (Part IV) Aggregate crushing value shall not exceed 45% for aggregate used in base course& intermediate course and 30% for wearing surfaces.

Abrasion value:

- Passing through 16mm & retained on 12.5mm: 3.48 %,
- Passing through 12mm & retained on 10mm: 4.24 %.

Abrasion value of aggregate for pavement is up to 20%. Hence above samples should be useful for road surfacing.

3. Properties of gravel:

- Passing through 50mm& retained on 40mm (Impact value): 1.96%,
- Passing through 50mm& retained on 40mm (Crushing Value): 11.59%,
- Passing through 50mm & retained on 40mm (Abrasion value): 1.44%,
- Specific gravity: 3.167,
- Water Absorption: 2.183%.

4. Properties of soil:

- Water Content: 12.98%,
- Specific gravity: 2.34,
- Type of sand: medium,
- Coefficient of permeability: 0.0219cm/s.

5. Mix design of sample for top layer:

The 9 samples are made with using combinations of 10mm aggregate and grit. The samples are casted in PVC pipe with constant diameter and thickness.

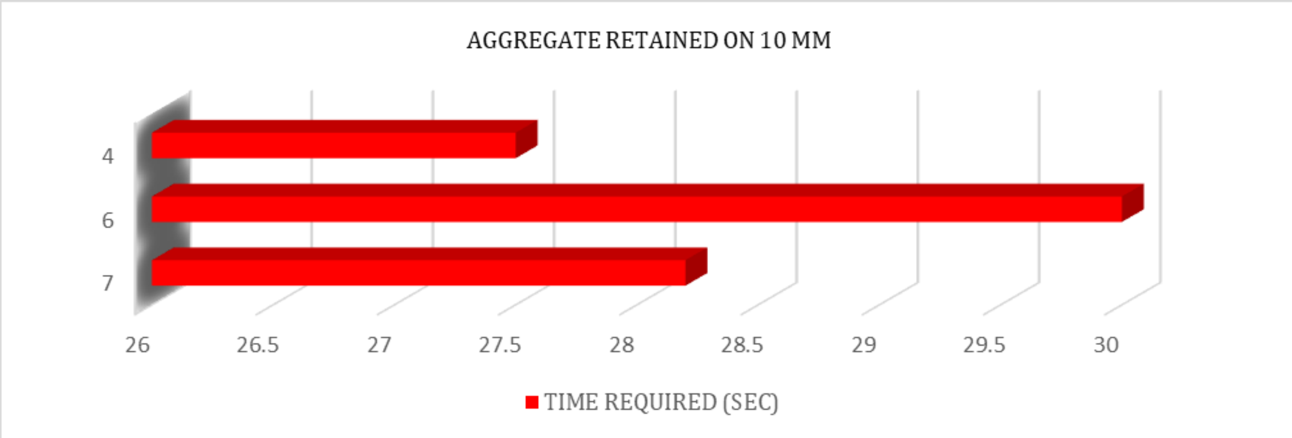
Sample	Weight of aggregate (gm)	Percent of Porous Asphalt added (%)	Weight of Porous Asphalt (gm)
Aggregate retained On 10mm	960	7	67.2
	960	6	57.6
	960	4	38.4
Grit	913	7	63.91
	913	6	54.78
	913	4	36.52
Retained on 10mm+Grit	965	7	67.55
	965	6	57.9
	965	4	38.6

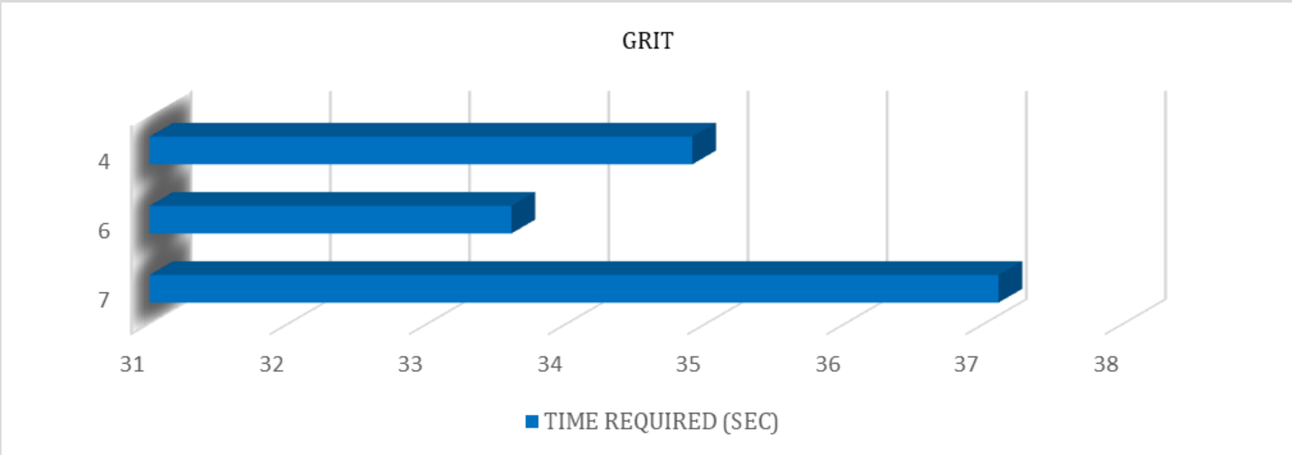
The samples are made with the combination, 3 samples are made with only 10mm retain aggregate size, 3 samples are made with only grit, and other 3 samples are made with combination of these two.

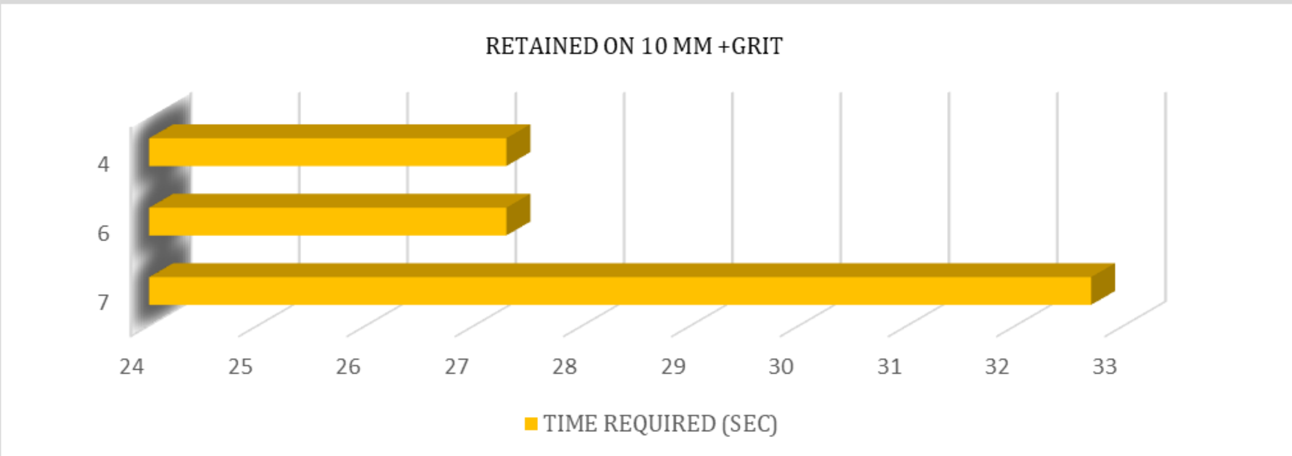
6. Determination of time for passage of water:

The 9 samples are made, after casting determine the time, for passing the same amount of water from each sample. The time required for passing the water through each sample is given below in the table.

Sample	Percent of Porous Asphalt added (%)	Time required for pass the same amount of water in (sec)
Aggregate retained On 10mm	7	28.2
	6	30
	4	27.5
Grit	7	37.1
	6	33.6
	4	34.9
Retained on 10mm+Grit	7	32.7
	6	32.1
	4	27.3







From above table and graphs it is observed that, the sample made with 10mm size aggregate with grit give better and controlled performance instead of only 10mm size or only grit models. We chose 6% asphalt content + 10mmsize with grit sample mix for the final model for the top wearing course.

2.2 COST

Several factors influence the overall cost of pervious concrete:

1. Material availability and transport - The ease of obtaining construction materials and the time and distance for delivery.

2. Site conditions - Accessibility by construction equipment, slope, and existing buildings and uses.

3. Sub grade - Sub grade soils such as clay may result in additional base material needed for structural support or added storm water storage volume.

4. Storm water management requirements - The level of control required for the volume, rate, or quality of storm water discharges will impact the volume of treatment needed.

5. Project size - Larger pervious concrete areas tend to have lower per square foot costs due to construction efficiencies.

Costs vary with site activities and access, pervious concrete depth, drainage, curbing and under drains (if used), labor rates, contractor expertise, and competition. The cost of the pervious concrete material ranges from 100 rupees to 350 rupees per square foot. The material cost of pervious concrete can drop significantly once a market has opened and producers have made initial capacity investments. Eliminating or reducing the use of admixtures, which are a significant cost in construction, can also lower installation costs.

2.3 Results:

- Pervious concrete made from coarse aggregate size 10mm has compressive strength of 48.89kg/cm^2 and 20mm aggregate has 35.56kg/cm^2.
- Pervious concrete made from coarse aggregate size 20mm had compressive strength value of 74% compared to that of 10mm.
- The aggregate/cement ratio of 10:1 produced pervious concrete of higher co-efficient of permeability of 3.14 x 10^{3}cm/sec and 3.65 x 10^{3}cm/sec for aggregate size 10mm and 20mm respectively.

3. CONCLUSIONS:

- Use of pervious pavement is definitely going to bring changes in the environment temperature, air quality, frictional grip of the road surface.
- The smaller the size of coarse aggregate should be able to produce a higher compressive strength and at the same time produce a higher permeability rate.
- The mixtures with higher aggregate/cement ratio 8:1 and 10:1 is considered to be useful for a pavement that requires low compressive strength and high permeability rate.
- Finally, further study should be conducted on the pervious concrete pavement produced with these material proportions to meet the condition of increased abrasion and compressive stresses due to high vehicular loading and traffic volumes.
- Flood prone zones can never be flooded with this system, and it helps to maintain the road hygiene by avoiding formation of mud.
- With water being seeped down, formation of potholes is diminished also breeding of mosquitoes is avoided.

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