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DESIGN OF STORM WATER DRAINAGE SYSTEM FOR INDORE CITY

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ABSTRACT:

This project report presents a new approach, with the application of the stormwater drainage system made by making use of pervious concrete for recharging of the groundwater table. Pervious concrete is a new type of concrete with high porosity, which is usually used for flatwork applications to allow water to pass through it, and by that, it reduces the volume of direct water run-off from a site and increases the quality of stormwater. Due to the high flow rate of water through pervious concrete, rainfall can be captured and percolate into the ground, recharging groundwater, supporting sustainable construction, reducing stormwater runoff, and providing a solution for construction that is sensitive to environmental concerns.

This study examines the advantages of using such material to maximize stormwater, minimize flooding, improve water filtration, effective drainage during monsoon and improved efficiency of pavement in Indore by constructing a storm-water drainage system.

One of the major reasons for the deterioration of roads is rainwater. During rainfall, part of water flows on the ground surface and part of it percolates through soil mass until it reaches the groundwater below the water table. Due to the percolation of water in the pavement moisture content of soil increases which reduces the bearing capacity of the soil. Thus, the stability of the highway is reduced.

Therefore, in this project report, we have shown the complete hydraulic and hydrological analysis for the design of the stormwater drainage system and the advantages of using pervious concrete in it.

KEYWORDS: *Stormwater, drainage, pervious concrete, porosity, bearing capacity, hydrologic and hydraulic analysis, filtration and percolation*

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1. INTRODUCTION

Highway drainage is a necessary part of the highway design and its construction which removes the surplus water within the highway limits. Highway drainage consists of removing or controlling surface water and sub-surface water away from the road surface and the sub-grade supporting it. Part of the rainwater flows on the ground or road surface, while the other part percolates into the ground and reaches the groundwater table, raising its level.

About 100 million people across India are on the front lines of a nationwide water crisis. A total of 21 major cities are poised to run out of groundwater next year, according to a 2018 report by government-run think tank NITI Aayog.

Types of Highway Drainage

Basically, highway drainage is of two types:

a. Surface Drainage

b. Sub-surface Drainage

c. Cross Drainage

Surface Drainage: Removal and diversion of surface water from the roadway and adjoining land are termed as *surface drainage*. Surface drainage consists of the arrangements made for the quick and effective draining of water that collects on the pavement surface, shoulders, slopes of embankments and cuttings and adjoining land up to the right-of-way.

Sub-surface Drainage: Diversion or removal of excess soil-water from the sub-grade is termed as *sub-surface drainage*. The change in the moisture content of soil affects its bearing capacity of the soil. The increase in the moisture content of soil reduces its bearing capacity. Thus keeping this point in view, there should not occur any change in the moisture content of the sub-grade of the road.

Cross Drainage: Whenever highway crosses a river or stream, cross drainage works have to be provided. On highways usually, culverts and bridges are used as a cross waterway of about 6.0 m, and then the cross drainage structure is known as *a culvert*.

2. LITERATURE REVIEW

The stormwater drainage system comes under the category of the surface drainage system. The function of stormwater drainage systems is to collect minor design storm runoff and convey major design storm (flood) runoff to a discharge point. Stormwater drainage systems are of two types: *the minor system* and *the major system*.

Minor Systems: Minor systems are designed to carry runoff from a minor design storm event. Minor systems consist of curbs, gutters, inlets, pipe and other conduits, open channels, pumps, detention basins, water quality control systems, etc.

Major Systems: Major systems are designed to convey stormwater flow that exceeds the capacity of the minor system. This usually occurs during a major storm event. Major systems consist of overland flow routes such as streets, ditches, and swales. **[Iowa Department of Transportation]**

- **DESIGN OF SURFACE DRAINAGE SYSTEM:**

The design of surface drainage may be divided into two phases:

1. Hydrologic Analysis
2. Hydraulic Analysis

1. **Hydrologic Analysis:** The main objective of the hydrologic analysis is to estimate the maximum quantity of water expected to reach the element of drainage system under consideration. The remaining portion of water which flows over the surface is termed as *runoff*. The runoff and maximum rate of runoff for the area under consideration is determined using any of the accepted approaches.

2. Hydraulic Analysis: Once the run-off Q is determined next step is the hydraulic design of drains. The side drains and partially filled culverts are designed based on the principles of flow through open channels.

DESIGN STEPS:

Simplified steps for the design of longitudinal drains of a road to drain off the surface water are given below:

i. The frequency of return period such as 10 years, 25 years, etc. is decided based on finances available and desired margin of safety, for the design of the drainage system.

ii. The values of coefficients of run-off C_1, C_2, C_3, etc. from drainage areas A_1, A_2, A_3, etc. are found and the weighted value of C is computed.

iii. Inlet time T_1 for the flow of storm water from the farthest point in the drainage area to the drain inlet along the steepest path of flow is estimated from the distance, slope of the ground and type of the cover.

iv. Time of flow along the longitudinal drain T_2 is determined for the estimated length of the longitudinal drain L upto the nearest cross drainage or a water course, and for the allowable velocity of flow V in the drain i.e., $T_2 = \frac{L}{V}$.

v. The total time T for inlet flow and flow along the drain is taken as the time of concentration or the design value of rainfall duration, $T = T_1 + T_2$.

vi. From the rainfall intensity-duration curves, the rainfall intensity i is found in mm/s corresponding to duration T and frequency of return period.

vii. The total area of drainage A_d is found in units of 1000 m^2.

viii. The run-off quantity Q is computed = CiA_d.

ix. The cross-sectional area of flow A of the drain is calculated = Q/V, where V is the allowable speed of flow in the drain.

x. The required depth of flow in the drain is calculated for a convenient bottom width and side slope of the drain. The actual depth of the open channel drain may be increased slightly to give a free board. The hydraulic mean radius of flow R is determined.

xi. The required longitudinal slope S of the drain is calculated using Manning's formula adopting suitable value of roughness coefficient n.**[S.K. Khanna and C.E.G. Justo (2011)]**

- **What is Pervious Concrete?**

Pervious concrete is a mixture of cement, water, and coarse aggregate, and little to no sand. It also frequently contains chemical admixtures. Pervious concrete creates a very porous medium that allows water to drain to the underlying soils. By allowing rain events to penetrate the paved surface to the underlying soils, the first flush of the paved surface is contained on site. The natural infiltration of the area remains unchanged so the water can recharge the water table.

Pervious concrete has been used in some areas of the country for decades. However, recent interest in sustainable development and recognition of pervious pavements by the United States Environmental Protection Agency (EPA) as a best management practice for stormwater management has heightened interest in its use.

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3. HYDROLOGICAL ANALYSIS

- **RAINFALL DATA**

The following data are obtained from the **Meteorological Department of India** and **Madhya Pradesh Water Resources Department**.The data collected is of the past 30 years from 1988 to 2018.

The data collected is from rain gauge station established at College of Agriculture, Indore (M.P.).

MONTHLY RAINFALL DATA: All data in millimeter.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1988	0.0	0.0	0.0	2.53	9.65	82.27	309.28	318.24	225.05	90.5	1.27	0.0
1989	0.0	0.0	15.5	0.0	12.0	193.1	93.4	193.9	150.7	0.0	0.0	5.7
1990	0.0	11.3	0.0	0.0	42.1	119.0	256.5	420.9	172.1	43.5	4.7	22.8
1991	0.0	0.0	0.0	0.0	0.0	208.2	416.8	110.5	7.7	0.0	1.4	0.0
1992	0.0	0.0	0.0	0.0	0.0	57.6	155.5	198.4	88.5	55.0	0.0	0.0
1993	0.0	0.0	0.6	0.0	6.3	134.3	394.4	277.0	201.4	46.7	0.0	1.8
1994	31.0	2.8	0.0	0.0	5.5	315.4	314.8	470.4	302.6	2.4	0.5	0.0
1995	11.7	0.0	2.8	2.35	0.75	145.28	385.5	224.4	121.3	51.5	0.0	0.0
1996	9.8	0.0	2.0	1.4	9.3	54.7	676.9	269.0	227.9	79.82	0.8	0.0
1997	2.0	0.0	0.0	8.8	0.0	191.45	480.13	351.4	50.06	21.7	45.9	10.1
1998	23.2	2.7	0.8	0.7	22.1	138.5	202.8	181.6	366.5	24.8	5.8	0.0
1999	2.2	57.8	0.0	0.0	14.6	246.8	173.0	91.1	244.1	72.4	0.0	0.0
2000	0.0	2.0	0.0	0.0	47.4	111.3	149.9	165.1	9.0	3.0	0.0	0.0
2001	5.0	0.0	6.3	5.0	28.5	329.7	187.6	97.8	71.8	54.6	0.0	0.0
2002	0.0	23.2	6.6	7.0	0.0	124.4	49.2	289.2	154.6	21.4	3.4	0.0
2003	1.2	13.6	0.0	0.0	15.2	107.7	349.3	137.2	350.3	0.0	0.2	0.0
2004	0.8	0.0	0.0	0.0	31.0	101.2	188.1	410.1	78.8	24.4	12.4	0.0
2005	0.2	0.0	6.0	0.0	1.2	71.4	178.4	249.0	234.2	0.0	0.0	0.0
2006	0.0	0.0	39.2	0.0	44.5	40.8	350.4	429.7	244.4	13.4	13	0.0

2007	3.8	6.8	0.0	0.0	46.2	153.6	313.8	197.2	200.8	0.0	0.0	0.0
2008	0.0	0.0	0.0	0.0	0.0	132.0	158.4	181.2	101.0	16.0	7.2	2.0
2009	28.6	0.0	3.6	0.0	43.7	109.5	419.3	124.8	142.8	64.8	124.0	34.2
2010	7.0	4.0	0.0	0.0	13.4	183.2	165.3	354.9	170.2	1.4	99.4	0.0
2011	0.0	0.0	0.0	0.0	8.4	105.6	480.0	772.0	202.7	16.2	0.0	0.0
2012	0.0	0.0	0.0	0.0	83.7	34.4	490.0	239.1	174.7	0.0	0.0	0.0
2013	0.0	17.94	5.25	30.4	0.0	372.45	616.4	367.7	136.2	107.6	0.0	2.2
2014	55.6	41.6	0.0	0.0	24.2	11.0	375.6	155.6	174.2	31.4	0.0	12.8
2015	60.6	0.0	8.8	4.4	0.0	237.5	557.5	317.3	61.8	4.5	0.0	0.0
2016	0.0	0.0	0.0	0.0	30.9	215.7	459.5	342.9	44.7	17.1	0.0	0.0
2017	58.2	126.2	39.9	2.7	54.4	74.0	54.1	63.9	125.8	36.4	194.1	50.7
2018	0.0	0.0	0.1	3.4	0.6	176.6	257.6	227.5	142.7	3.4	0.0	0.0

MAXIMUM RAINFALL IN A YEAR EVER RECORDED:

DATE	RAINFALL IN 24 HRS. IN MM
19-07-1988	106.17
01-09-1989	101.2
23-08-1990	128.5
30-07-1991	96.0
29-07-1992	63.0
18-08-1993	97.6
05-07-1994	149.0
25-07-1995	128.7
28-07-1996	206.7
26-07-1997	241.0
23-09-1998	105.0
14-09-1999	98.0

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18-06-2001	130.0
01-09-2002	63.8
28-07-2003	98.0
23-08-2004	99.4
01-08-2005	181.0
08-08-2006	84.2
09-07-2007	110.8
26-08-2008	82.4
23-07-2009	108.0
07-08-2010	106.0
24-08-2011	156.2
29-07-2012	161.0
04-07-2013	234.4
24-07-2014	88.4
05-08-2015	230.1
11-07-2016	174.8
28-08-2017	87.2
26-07-2018	92.5

From the above data maximum, rainfall intensity in one day from 1988-2018 is found to be **241.0 mm**which was recorded on 26-07-1997. So, let us convert this value into mm/hr we get **10.042 mm/hr**.

The time of entry and time of flow was found to be 57.24 minutes and 23.51 minutes. Therefore, time of concentration (T_c) = 57.24 + 23.51 = 80.75 minutes

- **Catchment Area and Surface Run-off Coefficients**

1. For unpaved or ordinary earth, area covered = 0.08km^2
2. For buildings and paved roads, area covered = 0.2062 km^2
3. For heavy vegetation or grass, area covered = 0.1838 km^2

Total catchment area=0.47 km^2

Surface run-off coefficient for unpaved or ordinary earth = 0.165

Surface run-off coefficient for buildings and paved roads = 0.85

Surface run-off coefficient for heavy vegetation or grass = 0.42

Therefore, C_1=0.165, C_2=0.850, C_3=0.425, A_1 = 0.08, A_2 = 0.2062 and A_3 = 0.1838

Hence, the weighted value of run-off coefficient will be:

$$C = \frac{A_1C_1 + A_2C_2 + A_3C_3}{A_1 + A_2 + A_3}$$

$$C = \frac{(0.08 \times 0.165) + (0.2062 \times 0.850) + (0.1838 \times 0.425)}{0.08 + 0.2062 + 0.1838} = 0.567$$

Therefore, the runoff coefficient(C) =0.567

- **CALCULATION OF PEAK FLOW(Q)**

From the formula below;

$$Q = CiA_d$$

where, Q = run-off, m^3/s

C = run-off coefficient, expressed as a ratio of run-off to rate ofrainfall

i = intensity of rainfall, mm/s

A_d = drainage area in 1000 m^2

where, C=0.567

I= 10.042mm/hr = 2.789×10^{-6} m/s

A= 0.47 km^2 = 0.47×10^6 m^2

Therefore,

$$Q = 0.567 \times 2.789 \times 10^{-6} \times 0.47 \times 10^6 = 0.743 \text{ m}^3/\text{sec}$$

Therefore, quantity of peak flow/discharge (Q) = 0.743m^3/s

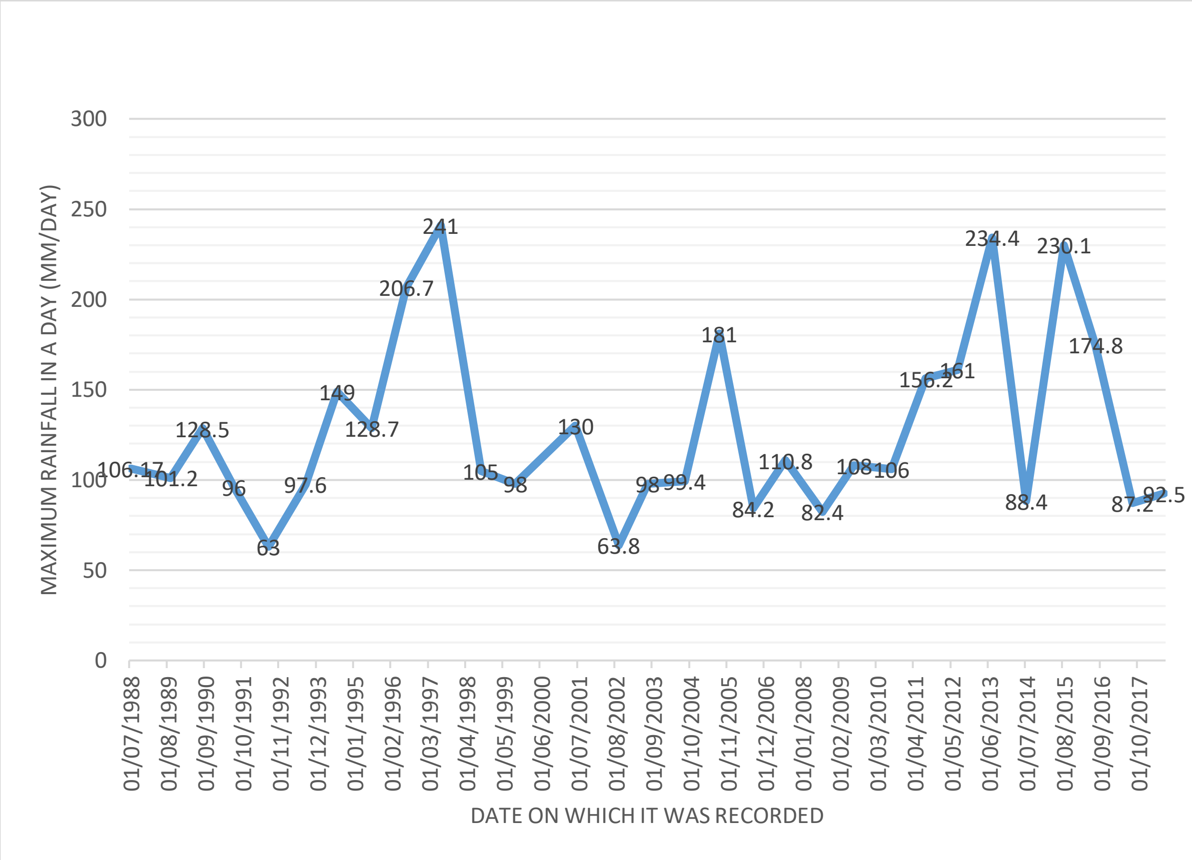

Fig. 1 Rainfall Intensity Duration Curve (30- year frequency)

4. HYDRAULIC ANALYSIS

- **Velocity of Flow in Drain**

To prevent sedimentation and vegetative growth, the *minimum average flow velocity* shall not be less than 0.3 m/s.

The *maximum average flow velocity* shall not exceed 4 m/s. flow velocities above 2 m/s, drains shall be provided with a 1.2 m high handrail fence, or covered with solid or grated covers for the entire length of the drain for public safety.

Hence, in this project, we'll consider the velocity of flow to be 0.6 m/s (=V).

- **Design of Drain**

1. Calculation of cross-sectional area

Consider the *rectangular section* for the storm water drain.

Therefore, the *cross-sectional area* of the drain will be obtained from the formula given below:

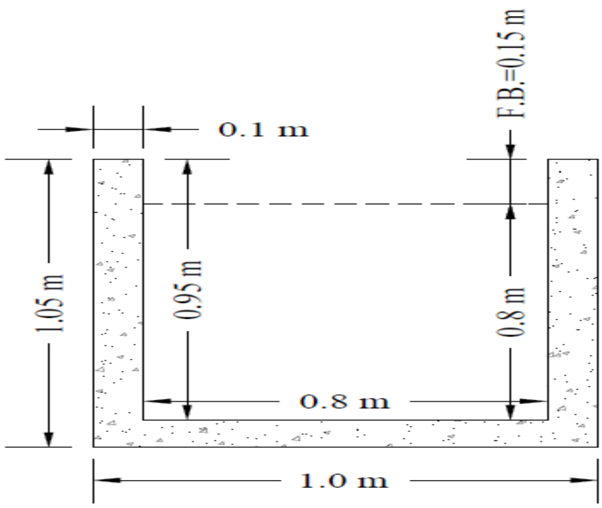

Fig. 2 Proposed cross-section

$$A = Q/V$$

where, A = cross-sectional area of the drain

Q = peak discharge into the drain = 0.743 m^3/s

V = velocity of flow in the drain = 0.6 m/s

Therefore, $A = \frac{0.743}{0.6} = 1.268\ m^2$

Hence, the required cross-sectional area for drain is 1.238m^2.

Provide drain on each side of the pavement. Hence, the area of one drain = $\frac{1.238}{2} = 0.619\ m^2$

Now, we know that, area of rectangle = b × h

Let us assume:

Bottom width (b) = 0.8 m

Therefore, h = $\frac{0.619}{0.8} = 0.77\ m \approx 0.80\ m$

Take free board to be 0.15 m.

Hence, total depth of drain (H) = 0.80 + 0.15 = 0.95 m

Therefore, area provided = $A_{provided} = 0.8 \times 0.95 = 0.76m^2$

2. Calculation of wetted perimeter and hydraulic radius

We are considering drain to be running partially full i.e., $3/4^{th}$ of the cross-section.

Wetted perimeter (P) = 0.71 + 0.80 + 0.71 = 2.22 m

Now hydraulic radius (R) = A/P

$R = \frac{0.76}{2.22} = 0.342$ m

3. Calculation of longitudinal slope

Longitudinal slope can be found using Manning's formula:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where, V = velocity of flow = 0.6 m/s

R = hydraulic radius = A/P = 0.342

S = longitudinal slope

n = Manning's roughness coefficient = 0.013 (for well finished concrete)

Therefore, substituting values in the formula we get,

$$0.6 = \frac{1}{0.013} 0.342^{\frac{2}{3}} S^{\frac{1}{2}}$$

S = 1 in 256

Hence, the longitudinal slope for the drain is found to be, S = 1 in 256

- **RESULTS**

1. Width of the cross-section = 0.8 m
2. Depth of the cross-section = 0.95 m (including free board)
3. Velocity of flow in the drain = 0.6 m/s
4. Amount of discharge that will be flowing in the drain = 0.743 m^3/s
5. Longitudinal slope of the drain = 1 in 256

5. FUTURE SCOPE OF THE PROJECT

a. **Effective drainage during monsoon:** a. During the monsoon, we observe waterlogged on the roads at many places in the cities because of insufficient drainage capacities, especially in India, due of which people face many problems due to the waterlogging, in fact, many people even face serious injuries too. Since we designed the stormwater drainage which will help solve the problems of waterlogging by draining off the excess water from the road.

b. **Recharges the ground water table:** The stormwater drainage will be constructed using the pervious concrete at its base which will help in raising the falling groundwater table of the city and help in combating the water crisis. The pervious concrete will allow the water to percolate into the earth and lets the excess water drained out.

c. **Helpful in heavy rainfall:** During the heavy rainfall if there occurs the condition of flooding, then this stormwater drainage system will become very useful to reduce the chances of flooding into the city.

d. **Sustainable construction:** Since in this stormwater drainage system as pervious concrete is being used, therefore, use of pervious concrete leads in the development/creation of sustainable construction because it is neither harming the environment and nor future of upcoming generations.

6. CONCLUSION

By the help of this project work, we provided a possible solution to combat against the water crisis, in other words, a possible solution which can be used to raise the falling groundwater table in the country. It may not be the best solution available but it is one of the solutions available to us to think upon.

In this project, we designed the complete stormwater drainage system of the selected area of the city, which if executed it will result in god drainage during the monsoon and eliminate the problems of waterlogging, poor drainage. Also, it will increase the life of the pavements in the city. Since the pervious concrete is being used which will help in raising the groundwater table.

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