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A Comparative Study of Different Soil Properties for Pavement Design of Various Locations

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Abstract. **Geotechnical engineers use predictive modelling in order to anticipate the behavior of geomaterials used in the highway infrastructure. For the purposes of determining the shear strength of subgrade material, and the stiffness modulus used in pavement design, GI & California Bearing Ratio (CBR) is applied to the subgrade. GI and CBR value can be directly assessed from laboratory tests such as Atterberg limit test & CBR test. Although a pavement's CBR value is a crucial design element, the test itself is time-consuming and tedious. In order to make a quick assessment of CBR, it is necessary to correlate CBR value with the soil properties that can be assessed immediately. In this study, soil samples have been collected from CIEM college campus at various depths. Furthermore, basic soil property tests along with CBR test, have been conducted in the laboratory. After getting the values of soil properties, pavement design procedure by GI and CBR method has been executed to get the pavement thickness. Further, a comparative study has been made for different locations around the world, having different soil properties, with regard to calculation of pavement thickness. This will lead to a clearer understanding of pavement thickness around the world.**

Keywords* — *CBR, Comparative Study, GI, Pavement Design, Pavement Thickness, Subgrade.

I. INTRODUCTION

Welcome Roads have been the cornerstone of transportation since the ancient Roman and Egyptian civilizations. In some 66000 BC, humans are believed to have created the first roads by modifying paths made by animals. In Iran, back in 4000 BC, the first roads were constructed of stone and paved.

The earliest evidence of road development in the Indian Subcontinent dates back to 2800 BC in the cities of Harappa and Mohenjo-Daro. One of the oldest roads is the G.T. Road.

According to a recommendation made by the Indian Road Development Committee of the government, the Indian Road Congress was formed in December 1934. of India.

Today, it is imperative to provide a better road network for the benefit of the entire nation. It is a challenging task but we have managed to do a great deal as a country, but it's not available everywhere as India is large and has a variety of terrain. The Pradhan Mantri Gram Sadak Yojona in India connects unconnected roads in plains and hills. In terms of direction, route, time and speed, road transportation can provide the best value in a country. The Govt of India is planning to increase the budget by 30% for the ministry of road transport to speed up the construction of 50 Km highway per day

A key role for geotechnical engineers should be in planning and designing infrastructure. Predictive modeling is an essential part of engineering that helps engineers make informed decisions. Geotechnical engineers must therefore be able to predict the behavior of geomaterials

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used in the highway infrastructure very quickly. A pavement's CBR value is a crucial design element. For the purposes of determining the shear strength of subgrade material, and the stiffness modulus used in pavement design, GI & California Bearing Ratio (CBR) is applied to the subgrade. GI Value can be directly assessed from laboratory tests such as Atterberg limit test & CBR value can be directly assessed by California Bearing Ratio test. However, the CBR test is time-consuming and tedious. In order to make a quick assessment of CBR, it is necessary to correlate CBR value with the soil properties that can be assessed immediately.

Pavement materials response to axle load imposed stress that is influenced by tyre pressure, temperature, and moisture, among others, whose individual and collective effects can be reduced through an effective structural design method. Most experts agree that highway pavements reflect the best modeling of a multilayered system, consisting of layers of varying materials (concrete, asphalt, granular base, sub-base and subgrade) resting on the natural subgrade.

Research in this area has been conducted by a variety of researchers. There are a number of studies, including [1], [2], [3] and [4] report that demonstrate the importance of the geotechnical character of soils and soil types for CBR values. Research has been conducted to develop effective correlations for predicting the California Bearing Ratio (CBR) from the index properties of soils. In 1962, [1] developed an approximate method to predict CBR value quickly. Based on Plasticity Index, He developed predictive models to predict CBR value. In 1970, [3] established that soil index properties and CBR value. Further [5], [6], [7], [8], [9], [10], [11], [12] and [13] has also stated different ways of pavement design, specially CBR method. BY the above literature review study, it has been observed that design of pavement plays an important role for road construction.

In this paper first of all soil has been collected from college campus CIEM i.e., in Tollygunge area of Kolkata, West Bengal, India at a depth of 1.5 m, 3.0 m & 4.5 m respectively [14]. After that basic soil property test (Atterberg limit test such as LL, PL, PI etc.) and along with CBR test has been done in the laboratory. After getting the values of soil properties, pavement design procedure by GI and CBR method has been executed to get the pavement thickness if campus’s soil has been used for pavement design.

Further a comparative study has been made for different locations around the world with different soil properties for calculating the thickness of the pavement and for that CBR value has been obtained with the help of an empirical formula given by [12], for better understanding of pavement thickness around the world using GI and CBR method.

II. Methodology and Experimental Program

In accordance with IRC recommendations, GI & California Bearing ratio (CBR) Method is used for the design of flexible Pavements. For that, liquid limit (LL), plastic limit (PL), plasticity index (PI) and California Bearing Ratio (CBR) plays an important role.

A. Design of Pavement Thickness by GI (Group Index) Method

For finding the GI value of campus’s Soil (CIEM i.e., in Tollygunge area of Kolkata, West Bengal, India) has been collected at a depth of 1.5 m, 3.0 m & 4.5 m respectively and is shown in Fig.1. The detailed calculation for depth 1.5 m has been shown and same procedure has been followed for other two depths.

Figure 1 - Soil sample collected at 1.5 m depth

The Liquid and Plastic limits (Atterberg limits) of soil indicate when a change in physical properties occur as a result of changes in water content and physical behavior of soil can be observed. Atterberg limits can be used as a guide for estimating the engineering properties of fine-grained soils. The property of plasticity is the ability of a material to undergo deformation without experiencing noticeable elastic recovery and without crumbling or cracking. An important characteristic of clay-rich soils is their plasticity. Atterberg Limit Test for finding Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) value has been executed. The details of these tests have been shown below in Table.1, Chart.1 and Table.2.

Table1 - Atterberg Limit

SL No	Determination No	01	02	03	04
01	No. of Blows	12	18	27	30
02	Container No.	1	2	3	4
03	Wt. of Container (W_1)	10	10	10	10

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04	Wt. of Container + Wet Soil (W_2)	23.1	22	20.5	20
05	Wt. of Container + Dry Soil (W_3)	18	17.784	17.5488	17.5
06	Loss of Moisture (gm)	5.1	4.216	2.9512	2.5
07	Wt. of Dry Soil (gm)	8	7.784	7.5488	7.5
08	Moisture Content %	63.8	54.2	39.1	33.3

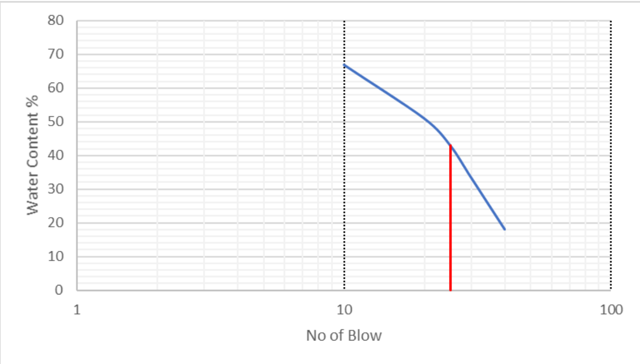

Chart 1 - Liquid Limit Chart

Table - 2 Determination of Plastic Limit

SL No	Determination No	01	02
1	Container no.	1	2
2	Wt. of Container (gm)	15	17
3	Wt. of Container + Wet Soil (gm)	22.031	21.8998
4	Wt. of Container + Dry Soil (gm)	20.81	21.05
5	Water Content %	21.02	20.98
6	Avg. Water Content %	21	

By the above Chart -1 and Table – 2, LL, PL and PI value for depth 1.5 m comes as 43% ,21% and 22% respectively and for other depths the values are given in Table – 3.

Table – 3. LL – PL & PI Value for Various Depths

SITE – CIEM Campus Tollygunj, Kolkata, India			
Depth (in mtr)	LL	PL	PI
3.0	41	22	19
4.5	40	22	18

By the value of LL, PI and with the help of Plasticity Chart Soil Classification has been done and is shown in Chart 2(Plasticity Chart)

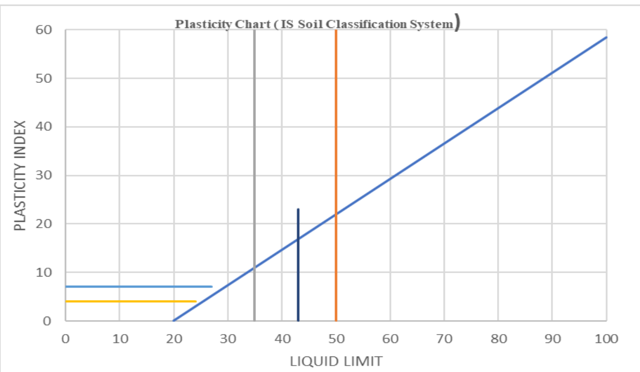

Chart 2 - Plasticity Chart

For depth 1.5 m LL = 43 and PL = 21, Thus PI = 22 [14] Again, PI by A-Line formula = .73(LL-20) = 16.79, So, 21 >16.79 % which implies soil category is Clay and PI value is 23, so it implies Intermediate Plasticity. i.e., CI, similar result has been obtained for 3.0 m and 4.5 m respectively.

Calculation of GI Value:
Sieve analysis:
Mass of soil taken =500 gm
Mass of soil passing through 0.075 mm sieve = 355 gm

$$\% \text{ Finer} = \frac{\text{Mass of Soil Passing Through 75 mm seive}}{\text{Mass of total Soil Taken}} \text{ X } 100$$

$$= \frac{355}{500} \text{X} 100$$

$$= 71\%$$

$$F = 71$$

GI = 0.2a + 0.005ac + 0.01bd

Where,

a = percentage of material passing through IS 200(75 µ) sieve more than 35 and less than 75

b = percentage of material passing through IS 200(75µ) sieve more than 15 and less than 55

c = liquid limit more than 40 and less than 60

d = plastic limit more than 10 and less than 30

We have,

LL = 43
PL 21
PI = LL-PL = 22
a = F – 35, i.e., 36 (40 is considered as ≯40)
b = F – 15, i.e., 56; 40 (40 is considered as ≯40)
c = LL – 40, i.e., 3 (20 is considered as ≯20)
d = PI -10, i.e., 12 (20 is considered as ≯20)
GI = 0.2a + 0.005ac + 0.01bd
= 0.2*22 + 0.005*22*16+0.01*42*4
= 13.9

For Depth 3.0 m and 4.5 m the GI value has been obtained as 15.1 and 14.6 respectively.

Calculation of Pavement Thickness by GI Value

The graph of Design Chart by Group Index Value for finding thickness of pavement has been given in Chart.3

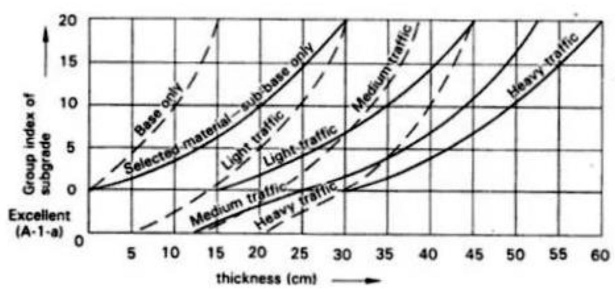

Chart - 3 Design Chart by Group Index Value

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Thus, from the above chart by assuming medium traffic the desired Thickness of pavement obtained is 38.4 cm at 1.5m depth and for 3.0m, 4.5m depth the desired pavement thickness obtained is 84.68 cm and 83.84 cm respectively

B. Calculation for CBR value

The soil which is collected at 1.5 m, 3.0 m and 4.5 m from college campus i.e., CI has been used to perform CBR test and to obtained CBR value. Details of the CBR value estimation has been shown in Fig.2, & Chart.4

Figure 2 – California Bearing Ratio Test

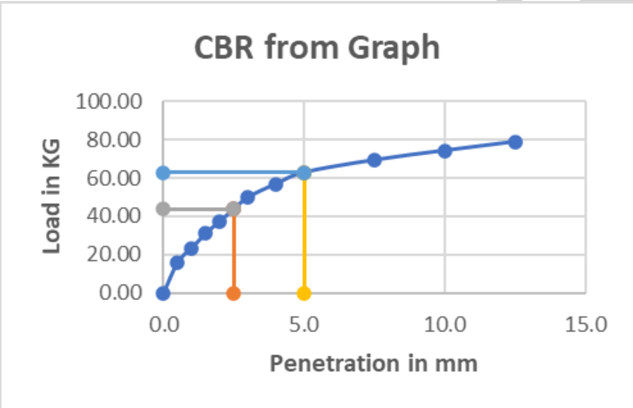

Chart.4 CBR From Graph

In Chart 4, the load penetration values of CBR test of the sample at depth 1.5 m has been shown.
In the proving ring 100 division of the load dial represent 190 Kg load in the calibration chart. So, 1 division in the proving ring is equal to 1.9 Kg.
.So, from the chart 4 it has been observed that
Penetration value of 2.5 mm = 43.7 division = 43.7 x 1.9= 83.03 Kg
Penetration value of 5 mm = 63.00 division = 63.00 x 1.9= 119.7 Kg
So,
$(CBR)_{2.5} = \frac{83.03}{1370} x100 = 6.06$
$(CBR)_5 = \frac{119.7}{2055} x100 = 5.82$
So, $(CBR)_{2.5} > (CBR)_5$
Therefore, the required CBR value is 6.06. For Depth 3.0 m and 4.5 m the CBR value has been obtained as 6.68 and 7.10 respectively.

Calculation of Pavement Thickness by CBR Value

Design Thickness of pavement by CBR $T = \sqrt{\left(\frac{1.75P}{CBR}\right) - \frac{P}{\pi p}}$

P = 8000 KG (IRC:37-2018, page no 70) [39]
p = 8 Kg/cm^2 (IRC:37-2018, Page 70)
where, P = wheel load in KG
p = Contact Pressure or Tier Pressure

$$T = \sqrt{\left(\frac{1 \cdot 75P}{CBR}\right) - \frac{P}{\pi p}}$$

$$T = \sqrt{\frac{1.75 \times 8000}{6.06} - \frac{8000}{\pi \times 8}}$$

= 44.6 cm
= 446 mm

So, the thickness of the pavement for 1.5 m depth, comes as 44.6 cm. for further classification of the thickness of the pavement for CBR 6% (plate 2) to be followed and is given in figure 3.

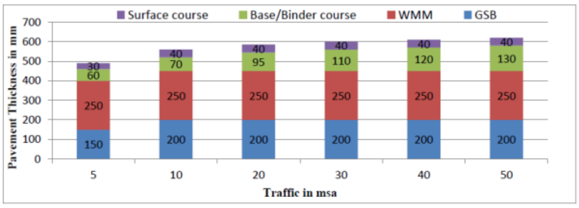

Fig. 3 - Catalogue for pavement with bituminous surface course with granular base and sub-base - Effective CBR 6% (Plate-2)

For Depth 3.0 m and 4.5 m the thickness of pavement has been obtained as 42.18 cm and 40.67 cm respectively.

III. COMPARATIVE ANALYSES

In this section a comparative study of CBR and GI values for finding pavement thicknesses of different location has been executed. For that LL and PL value has been collected for 30 Samples of 28 different locations by Vigorous Literature review and with the help of empirical formula given by [12], CBR value has been analyzed except for Sample 2 [14], Sample 3 [14] and Sample 5 [14].

A. Comparative Analysis of GI value for finding pavement thickness of different locations:

Different GI value has been analyzed from different part of the world and pavement thickness has been calculated to analyze the variation of pavement thickness with different soil properties for different locations. The details of the analysis have been tabulated in Table 4.

B. Comparative Analysis of CBR value for finding pavement thickness of different locations:

Different CBR value has been analyzed from different part of the world and pavement thickness has been calculated to

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analyze the variation of pavement thickness with different soil properties for different locations. The details of the analysis have been tabulated in Table 5.

Ultimately a full comparative analysis of pavement thicknesses by GI & CBR method has been depicted in chart.5.

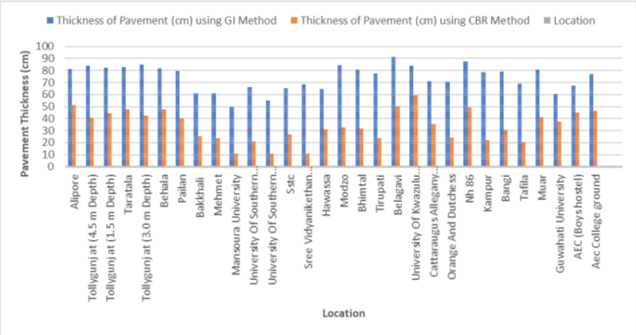

Chart – 5 Comparative Analysis of Pavement Thickness of different locations

IV. CONCLUSION

Samples of soil with different parameters are collected from around the world to conduct a predictive analysis for design of pavement for road construction and it can be concluded that the thickness of pavement varies with change of GI & CBR value. Economically where less thickness means savings. The CBR method gives better estimations of material to be used in different course of road. CBR value gives separate values of thickness of wearing course and sub base course where as Group Index provide thickness of Base course and sub base course. From the Chart.5 it can be clearly concluded that soil parameters in certain locations like Egypt [16], USA [25] and Australia [17] etc. are of far better excellence than of India hence calculated pavement thickness of Indian locations are on higher side along with higher economy.

Table 4-Various Pavement Thicknesses by GI method for different locations:

S/N	MATERIAL NAME	COUNTRY	SAMPLE SITE	CITY	LL	PL	PI	% FINER	Group Index	Thickness of Pavement (cm)	
1	S 1	India	Alipore [14]	Kolkata	43	21	22	92.00	13.0	45.9	35.2
2	S 2	India	Tollygunge at 4.5 m Depth [14]	Kolkata	40	22	18	73.00	14.6	47.18	36.66
3	S 3	India	Tollygunge at 1.5 m Depth [14]	Kolkata	43	21	22	71.00	13.9	46.2	36.07
4	S 4	India	Taratala [14]	Kolkata	45	20	25	71.00	13.7	46.6	35.9
5	S 5	India	Tollygunge at 3.0 m Depth [14]	Kolkata	41	22	19	74.00	15.1	47.6	37.084
6	S 6	India	Behala [14]	Kolkata	42	22	20	89.00	13.2	46.06	35.48
7	S 7	India	Pailan [14]	Kolkata	36	22	14	92	12.0	45.1	34.48
8	S 8	India	Bakkhali [14]	West Bengal	24	14	10	57.00	4.3	32.82	28.012
9	S 9	Turkey	Mehmet [15]	Mehmet	27.6	17.1	10.5	49.00	4.3	32.82	28.012
10	S 10	Egypt	Mansoura University [16]	Mansoura	23.9	18	5.94	31.00	0.8	24.42	25.072
11	S 11	Australia	University Of Southern Queensland [17]	Norman Street East Brisbane	32	23	9	47.00	6.1	36.48	29.524
12	S 12	Australia	University Of Southern Queensland [17]	Settler Way	25	20	5	37.00	2.5	28.5	26.5
13	S 13	India	Sstc [18]	Bhilai	24	14.3	9.72	65.00	5.7	35.76	29.188
14	S 14	India	Sree Vidyanikethan Engineering College [19]	Tirupari	23.7	20.5	3.18	57.00	7.0	38.1	30.28
15	S 15	Ethiopia.	Hawassa [20]	Hawassa	44	25	19	42.00	5.6	35.58	29.104
16	S 16	Ethiopia.	Modzo [20]	Modzo	46	31	15	59.00	14.8	47.34	36.82
17	S 17	India	Bhimtal [21]	Uttarakhand	27.8	17.9	9.91	85	12.5	45.5	34.9
18	S 18	India	Tirupati [22]	Ap	23	17	5.96	85	10.7	44.06	33.388

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19	S 19	India	Belagavi [23]	Karnataka	50	26.9	23.1	85	24.3		
20	S 20	South Africa	University Of Kwazulu Nala College of Agri Campus [24]	Natal	62.5	30.8	31.7	85.00	14.6	47.18	36.664
21	S 21	Usa	Cattaraugus Allegany State Park, Dam Site [25]	New York	24.6	12.6	12	85.00	8.0	39.9	31.12
22	S 22	Usa	Orange And Dutchess [25]	New York	20.1	13.9	6.2	85.00	7.8	39.54	30.952
23	S 23	India	Nh 86 [26]	Bhopal	41	19	22	85.00	16.6	39.54	30.952
24	S 24	Malaysia	Kampur [27]	Kampur	39.8	31.2	8.6	52.50	11.4	44.62	33.976
25	S 25	Malaysia	Bangi [28]	Bangi	43.8	28.2	15.6	55.00	11.7	44.86	34.228
26	S 26	Jordan	Tafila [29]	Tafila	31.7	23.6	8.1	49.80	7.1	38.28	30.364
27	S 27	Malaysia	Muar [30]	Johor	64.8	36.6	28.2	47.30	12.6	45.58	34.984
28	S 28	India	Guwahati University [31]	Guwahati	38	14.6	23.4	48.50	4.1	32.34	27.844
29	S 29	India	AEC (Boy's hostel) [31]	Guwahati	46	16.2	29.8	53.20	6.6	37.38	29.944
30	S 30	India	Aec College ground [31]	Guwahati	59	25	34	49.6	9.497	43.86	32.988

Table 5- Various Pavement Thicknesses by CBR method for different locations:

S.NO	MATERIAL NAME	COUNTRY	SAMPLE SITE	CITY	LL	PL	PI	% FINER	CBR	T (cm)
1.	S 1	India	Alipore [14]	Kolkata	43.00	21.00	22.00	0.92	4.77	51.17
2.	S 2	India	Tollygunge at 4.5 m Depth [14]	Kolkata	40.00	22.00	18.00	0.73	7.10	40.67
3.	S 3	India	Tollygunge at 1.5 m Depth [14]	Kolkata	43.00	21.00	22.00	0.71	6.06	44.62
4.	S 4	India	Taratala [14]	Kolkata	45.00	20.00	25.00	0.71	5.39	47.75
5.	S 5	India	Tollygunge at 3.0 m Depth [14]	Kolkata	41.00	22.00	19.00	0.74	6.68	42.18
6.	S 6	India	Behala [14]	Kolkata	42.00	22.00	20.00	0.89	5.37	47.82
7.	S 7	India	Pailan [14]	Kolkata	36.00	22.00	14.00	0.92	7.23	40.23
8.	S 8	India	Bakkhali [14]	West Bengal	24.00	14.00	10.00	0.57	14.56	25.35
9.	S 9	Turkey	Mehmet [15]	Mehmet	27.60	17.11	10.49	0.49	15.82	23.81
10.	S 10	Egypt	Mansoura University [16]	Mansoura	23.94	18.00	5.94	0.31	32.04	10.88
11.	S 11	Australia	University Of Southern Queensland [17]	Norman Street East Brisbane	32.00	23.00	9.00	0.47	18.38	21.05
12.	S 12	Australia	University Of Southern Queensland [17]	Settler Way	25.00	20.00	5.00	0.37	31.96	10.94
13.	S 13	India	Sstc [18]	Bhilai	24.00	14.28	9.72	0.65	13.39	26.96
14.	S 14	India	Sree Vidyanikethan Engineering College [19]	Tirupari	23.68	20.50	3.18	0.57	32.33	10.70

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15.	S 15	Ethiopia.	Hawassa [20]	Hawassa	44.00	25.00	19.00	0.42	11.01	30.86
16.	S 16	Ethiopia.	Modzo [20]	Modzo	46.00	31.00	15.00	0.59	10.08	32.72
17.	S 17	India	Bhimtal [21]	Uttarakhand	27.80	17.89	9.91	0.85	10.52	31.83
18.	S 18	India	Tirupati [22]	Ap	23.00	17.04	5.96	0.85	16.00	23.59
19.	S 19	India	Belagavi [23]	Karnataka	50.00	26.92	23.08	0.85	4.91	50.34
20.	S 20	South Africa	University Of Kwazulu Nala College of Agri Campus [24]	Natal	62.47	30.78	31.69	0.85	3.64	59.40
21.	S 21	Usa	Cattaraugus Allegany State Park, Dam Site [25]	New York	24.60	12.60	12.00	0.85	8.90	35.42
22.	S 22	Usa	Orange And Dutchess [25]	New York	20.10	13.90	6.20	0.85	15.51	24.17
23.	S 23	India	Nh 86 [26]	Bhopal	41.00	19.00	22.00	0.85	5.13	49.09
24.	S 24	Malaysia	Kampur [27]	Kampur	39.80	31.20	8.60	0.53	17.50	21.95
25.	S 25	Bangladesh	Bangi [28]	Bangi	43.80	28.20	15.60	0.50	11.27	30.40
26.	S 26	Jordan	Tafila [29]	Tafila	31.70	23.60	8.10	0.50	19.05	20.40
27.	S 27	Malaysia	Muar [30]	Johor	64.80	36.60	28.20	0.48	6.98	41.09
28.	S 28	India	Guwahati University [31]	Guwahati	38.00	14.60	23.40	0.48	8.14	37.43
29.	S 29	India	AEC [31]	Guwahati	46.00	16.20	29.80	0.53	5.98	44.97
30.	S 30	India	AEC College ground [31]	Guwahati	59.00	25.00	34.00	0.50	5.65	46.47

NOTE: CBR= $\frac{75}{(1+0.728)XwPI}$ and T= $\sqrt{\frac{1.75}{CBR}-\frac{P}{\pi \cdot p}}$

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