COMPARISON OF EFFECTIVE CBR VALUE BETWEEN JAPANESE FORMULA AND ELASTIC TWO LAYER THEORIES

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ABSTRACT

The upper 500 mm of soil, whether in embankment or in cutting, compacted to a higher density than that of the native soil below it is considered as the subgrade of pavement. In case the existing embankment soil is weak, it is a common practice to use borrow materials of suitable quality compacted to a thickness of 500 mm/ 300 mm less or more depending on the practices of the different countries. CBR of the subgrade is often used for design of pavements. IRC: 37-2012 recommended the effective CBR considering contribution of effect of road bed soil. This paper examines the issue of selecting an effective material property, CBR or modulus value, for the combination of embankment soil and subgrade layer. Elastic two layer theories have been adopted for evaluation of effective CBR using IITPAVE program. Variation in tire pressure from 0.56MPa to 0.8MPa is considered along with variation in axle type for analysis purpose. CBR Values are compared with CBR values obtained from Japanese Formula considering damaging effect of different axle configurations. It is found that at lower embankment CBR values Japanese formula gives conservative values. Equivalent CBR obtained from elastic two layer theories is found to be more realistic as it involves the consideration of infinite depth of the embankment soil which found to be missing in Japan Roads Association formula’s for effective CBR. It is observed that effective CBR decreases with decreasing subgrade thickness. Finally on the basis equal subgrade deflection equivalent CBR values for different types of embankment soil and the subgrade layers have been suggested in form of tables.

KEYWORDS

Subgrade, Embankment Soil, Effective CBR, Two Layer Theory, IITPAVE, Japanese Formula,

INTRODUCTION

Subgrade plays an important role in the performance of pavements. Its property is the main input to any type of pavement design procedure. The parameters commonly used to characterize the subgrade include CBR, resilient modulus, modulus of subgrade reaction etc. Although mechanistic design approaches require elastic (resilient) modulus of subgrade as input, a large number of the existing design procedures are based on CBR value of the subgrade. Even in the case of some mechanistic design methods, it is a common practice to estimate the modulus value of the subgrade from its CBR value using empirical relationships. In case the embankment soil is weak, borrow material of higher strength is used as subgrade and the CBR of this layer is usually taken as the design CBR for the design of pavements irrespective of the CBR of the embankment material below the 500 mm subgrade. This does not appear to be a sound practice since it is the composite strength of the subgrade and the embankment soil below it that should enter into the design rather than the strength of 500 mm thick subgrade alone. Japanese / Austroads method proposed effective CBR concept considering subgrade thickness of 500 mm and embankment thickness of 500 mm. Equivalent CBR can be determined using following equation:

$$CBR_{Equiavalent} = \left[\frac{\left[H_1 \times (CBR_1)^{(1/3)} + H_2 \times (CBR_2)^{(1/3)}\right]}{\left[H_1 + H_2\right]} \right]^3 \quad (1)$$

Where,
$CBR_{Equivalent}$= Effective CBR;
H_1 and H_2 are thicknesses of embankment and subgrade; and
CBR_1 and CBR_2 are CBR Values of embankment and subgrade.

This paper presents a method for computation of design (effective/equivalent) CBR of the subgrade for design of flexible pavements taking into account CBR values of subgrade as well as embankment materials based on elastic two layers theories. IIT Pave Software has been used and CBR values obtained using two layer theories are compared with Japanese formula taking damaging effect of different axles of vehicle.

LITERATURE REVIEW

Literature on effective CBR based on two layer theories is rare and limited documents are available. Basic concept of effective CBR was developed by Japan Roads Association. The same formula has been adopted by *Austroads (2010)* [1]. Equation for effective CBR is already presented in Equation 1.

In this paper, effective CBR has been determined based on two layer theories and compared with value obtained from equation 1.

Reddy et. al.2001 [2] developed a model for the determination of effective CBR based on single wheel load of 40 KN of single axle . Dual Tire of single axle has been replaced by equivalent single tire considering equivalent tire pressure.

LEAD FROM PAST STUDY

IRC:37-2012 [3] recommended effective CBR as shown in Fig. 5.1 of IRC:37-2012 considering maximum embankment CBR of 7 %. Major drawback of this model is only single axle with single tire has been considered and wheel load of 40 KN(single axle dual tire converted to single axle single tire) is considered for determination of effective subgrade. The same Code (IRC:37-2012) developed pavement design chart using single axle dual wheel i.e., wheel load of 20 KN in place of 40 KN. Therefore, two different models are used for evaluation effective subgrade CBR and finalization of pavement compositions. Tire pressure is considered 0.56 MPa. It is found that actual tire is in the range of 0.75-0.8 MPa.

There is a need for study considering single wheel of 32.5 KN with tire pressure of 0.8 MPa for single axle with single tire and 40 KN for single axle dual tire.

OBJECTIVE AND SCOPE OF STUDY

Based on present need, the scope of the present work has been identified as:

- Determination effective CBR considering subgrade CBR and subgrade thickness of 500 mm.
- Variation of Subgrade thickness from 200 mm to 500 mm /1000 mm.
- Variation of Embankment and Subgrade CBR from 5 to 30 %

- Variation of Poisson Ratio from 0.3 to 0.4.
- Variation of Tire pressure from 0.56 MPa to 0.8 MPa
- Effect of weak subgrade over strong embankment material

RESSILENT MODULUS OF SUBGRADE

AASHTO (1993) [4] guideline also recommended the use of Eq.2 in the absence of repeated load tri-axial test data.

$Mr=10\times CBR$ for $CBR \leq 5$ 2a
$Mr=17.6\times CBR^{0.64}$ for $CBR > 5$ 2b

These two equations are used to determine E value of embankment and subgrade.

PROPOSED METHODOLOGY FOR DETERMINATION OF EFFECTIVE CBR

It is clear that if the compacted subgrade is laid over a weak soil, it is necessary to evaluate the composite strength of the subgrade or the effective CBR of the subgrade for pavement design. In this investigation, an attempt has been made to determine the equivalent subgrade CBR values for the combination of natural soil bed and borrow material. Subgrade surface deflection under the action of wheel load computed using layered elastic theory has been used as the parameter to assess the equivalence. CBR has been determined based on several variations as mentioned in proposed methodology. The loading arrangement considered is a single wheel load of magnitude 32.5 KN acting over circular contact area at pressure varying from 0.56 to 0.8 MPa for single axle with single wheel load. Single wheel load will be 20 KN, 18.5 and 18.7 KN for single axle dual tire, tandem axle and tridem axle with dual wheel.

Two layers and the equivalent subgrade systems with loading under consideration are shown in Figure.1.

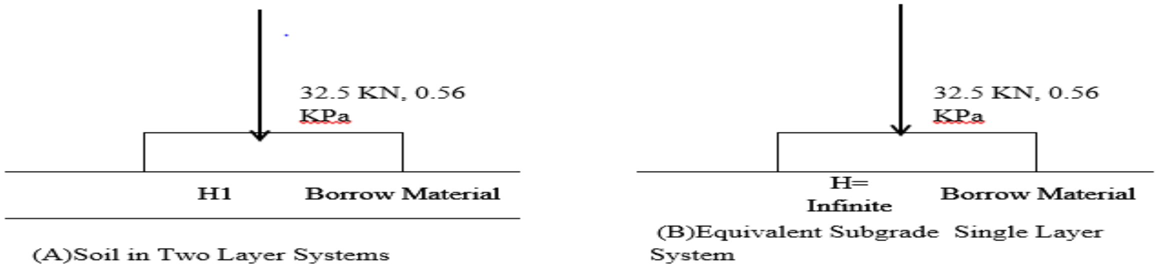

FIGURE 1 Two Layer and Equivalent Subgrade Systems

The basic strain stress equations for three dimensional theories are presented below:

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_r + \sigma_t)] \qquad 2a$$

$$\varepsilon_r = \frac{1}{E}[\sigma_r - \mu(\sigma_t + \sigma_z)] \qquad 2b$$

$$\varepsilon_t = \frac{1}{E}[\sigma_t - \mu(\sigma_r + \sigma_z)] \qquad 2c$$

When a load is applied over a single circular loaded area, the most critical stress, strain and deflection occur under the center of the circular area on the axis of symmetry, where $\tau_{rz} = 0, \sigma_r = \sigma_t$,so $\sigma_r and \sigma_t$ are the principal stresses.

The load applied from tire to pavement is similar to a flexible plate with a radius, and uniform tire pressure, p. The stress beneath the center of the plate can be determined from the following equations as presented below.

$$\sigma z = q\left[1 - \frac{z^3}{(a^2+z^2)^{1.5}}\right]$$

$$\sigma r = \frac{q}{2}\left[1 + 2\nu - \frac{2(1+\nu)z}{(a^2+z^2)^{0.5}} + \frac{z^3}{(a^2+z^2)^{1.5}}\right]$$

The vertical deflection ‘ω’ can be determined from

$$\omega = \frac{(1+\nu)qa}{E}\left\{\frac{a}{(a^2+z^2)^{0.5}} + \frac{1-2\nu}{a}\left[(a^2+z^2)^{0.5} - z\right]\right\}$$

On the surface of half-space, i.e. z = 0, above equation can be deduced as

$$\omega = \frac{2(1-\nu^2)qa}{E}$$

Formula for Equivalent CBR as presented in Equation1 has been used to determine CBR Value and presented in Table 1.

CBR is also determined based on two layer theories using IIT Pave Software. Summarized results obtained from two layer theories are presented in Table 2 for single axle single tire configuration.

TABLE 1 Effective CBR Value Based on Japanese Formula

Subgrade CBR (%)	**Effective CBR for Different Embankment CBR (%)**							
	5	7	10	12	15	20	25	30
5	5.00	5.94	7.21	8.00	9.10	10.83	12.44	13.97
7	5.94	7.00	8.41	9.28	10.50	12.39	14.15	15.81
10	7.21	8.41	10.00	10.97	12.33	14.43	16.37	18.21
12	8.00	9.28	10.97	12.00	13.44	15.66	17.71	19.65
15	9.10	10.50	12.33	13.44	15.00	17.38	19.58	21.64
20	10.83	12.39	14.43	15.66	17.38	20.00	22.41	24.66
25	12.44	14.15	16.37	17.71	19.58	22.41	25.00	27.42
30	13.97	15.81	18.21	19.65	21.64	24.66	27.42	30.00

TABLE 2 Equivalents CBR for Embankment CBR 5% and Different Subgrade CBR

Subgrade CBR	**Single Axle with Single Tire**		
	0.56 Mpa	**0.7 Mpa**	**0.8 Mpa**
5	5	5	5
7	6.6	6.6	6.7
10	8.7	8.9	8.9
12	10.0	10.2	10.3
15	11.9	12.1	12.3
20	14.6	15.1	15.3
25	17.1	17.8	18.1
30	19.4	20.2	20.7

Surface Deflection considering subgrade thickness of 500 mm has been calculated for Embankment CBR Value of 7% and presented in Fig. 2. Similar figure/graphs can be plotted for other embankment CBR Values.

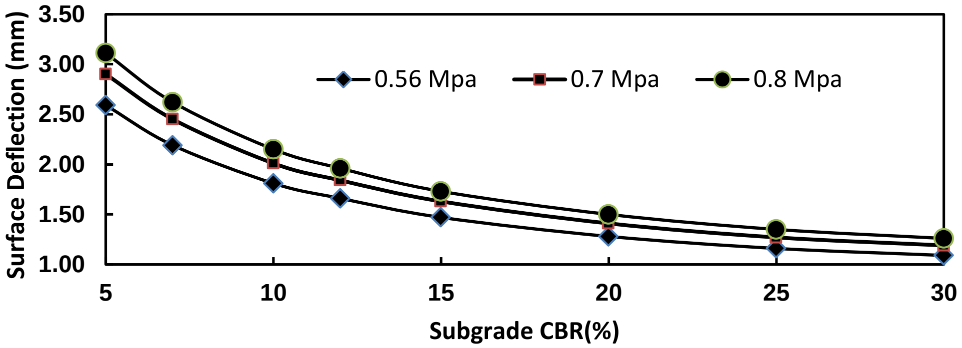

FIGURE 2 Surface Deflection for Embankment CBR 7% with Different Tire Pressures for Front Wheel damage for wheel Load of 32500N for Subgrade Thickness of 500 mm

SINGLE AXLE DUAL TIRE

Model 1- Equivalent Single Axle Radius (ESAL)

In place of equal contact radius or equal pressure, *Ioannides and Khazanovich (1993)* [5] proposed the use of an equivalent contact radius to determine the load equivalency and called Equivalent Single Axle Radius (ESAL). The basic concept is to determine a single tire load with an equivalent radius that would lead to the same response if the loaded by the same total load as the dual tire assembly. Following equivalent radius equation is proposed *Haung (2012)* [6].

$$a_{eq} = a[1 + 0.241683 \times \frac{s}{a}] \qquad (2)$$

Where,

aeq= Equivalent tire radius;

A= Contact radius of each of the dual tire; and

S= Center to center spacing between the dual.

Total axle load 80 KN. Dual tire load=40 KN and load on each tire=20 KN. Tire pressure=0.56 MPa.

Radius of single tire = $[20000/\{(22/7)/0.56\}]^{0.5}$=106.6 mm

Equivalent Tire radius = 106.6×[1+0.241683×310/106.6=181.8 mm.

Final pressure = 40000/ $(3.1414*181.8^2)$=0.386 MPa

This load will produce lesser deflection and yields lesser CBR than that of the case of single axle with single tire. Therefore, the effect of single axle dual tire is not considered for the determination of effective CBR. However, this has been checked and presented in Table 3.

Model 2-Equal Contact Pressure Concept

It is assumed dual tire will be considered as single tire with same pressure and same area.

2P/2A=2P/A’ i.e., A’=2A.

Equivalent radius=$2^{0.5}$×a=1.414×a=106.6*2 $^{0.5}$=150.8 mm.

CBR and damaging aspect are determined using these two models for dual tire axle load case and presented in Table 3.

TABLE 3 A Effective CBR for Single Axle Dual Tire Case

Embankment CBR	Subgrade CBR	Single Axle Dual Tire		Single Axle Single Tire
		Model 1	Model 2	
10	15	13.57	13.78	13.89
15	20	18.67	18.87	18.97

TABLE 3 B Compressive Strain for Single Axle Dual Tire Case

Embankment CBR	Subgrade CBR	Single Axle Dual Tire		Single Axle Single Tire
		Model 1	Model 2	
10	15	0.1022E-02	0.1503E-02	0.1512E-02
15	20	0.8624E-03	0.1263E-02	0.1268E-02

Effective CBR for different embankment and Subgrade CBR Values is presented in Table 4

TABLE 4 A CBR Based on Two Layer Theories for Different CBR and Tire Pressures

Subgrade CBR(%)	Embankment CBR 7 %			Embankment CBR 10 %			Embankment CBR 12 %			Embankment CBR 15 %		
	0.56 Mpa	0.7 Mpa	0.8 Mpa	0.56 Mpa	0.7 Mpa	0.8 Mpa	0.56 Mpa	0.7 Mpa	0.8 Mpa	0.56 Mpa	0.7 Mpa	0.8 Mpa
5	5.0	5.0	5.0	5.3	5.2	5.2	5.4	7.0	5.3	5.5	5.4	5.4
7	6.5	6.5	6.5	6.9	6.9	6.8	7.1	9.6	7.0	7.3	7.2	7.2
10	8.8	8.9	8.9	9.4	9.4	9.4	9.7	11.1	9.6	10.1	9.9	9.8
12	10.1	10.2	10.3	10.9	10.8	10.9	11.2	13.6	11.1	11.5	11.5	11.5
15	12.2	12.3	12.5	13.0	13.2	13.3	13.6	17.1	13.7	14.0	14.2	14.1
20	15.1	15.4	15.6	16.5	16.7	16.8	17.1	10.7	17.4	17.8	18.0	18.0
25	17.6	18.2	18.4	19.4	19.9	20.0	20.3	22.7	20.7	21.2	21.5	21.5
30	19.4	20.1	20.5	21.5	21.8	22.1	22.2	25.3	23.0	23.7	23.8	24.3

TABLE 4 B CBR Based on Two Layer Theories for Different CBR and Tire Pressures

Equivalent CBR									
Subgrade CBR(%)	Embankment CBR 20%			Embankment CBR 25%			Embankment CBR30 %		
	0.56 Mpa	0.7 Mpa	0.8 Mpa	0.56 Mpa	0.7 Mpa	0.8 Mpa	0.56 Mpa	0.7 Mpa	0.8 Mpa
5	5.69	5.59	5.53	5.80	5.69	5.62	5.88	5.72	5.69
7	7.51	7.44	7.33	7.69	7.54	7.53	7.82	7.65	7.58
10	10.34	10.27	10.26	10.73	10.45	10.43	10.86	10.63	10.60
12	12.03	11.85	11.93	12.58	12.30	12.25	12.69	12.42	12.36
15	14.73	14.77	14.66	15.41	15.10	15.11	15.46	15.43	15.27
20	18.85	18.86	18.81	19.21	19.35	19.49	19.96	19.60	19.73
25	22.54	20.94	22.67	23.09	23.41	23.29	24.04	23.75	23.93
30	24.85	25.21	25.30	26.16	26.40	26.04	26.62	29.08	27.62

Different axle load surveys were carried out in India and abroad, it is found that truck vehicle tire pressure is in the range of 110-120 PSI which is close to 0.8 MPa. Therefore, CBR at 0.8 MPa has been considered for pavement design from practical consideration. Finally recommended CBR for subgrade thickness of 500 mm is presented in Table 5. Lower thickness of subgrade is also required for medium, low traffic volume and village road. Similar table of effective CBR at 0.80 MPa tire pressure for different thicknesses of subgrade i.e. 400mm, 300mm and 200mm are presented in Table 6.

TABLE 5 Effective Design CBR for Different Embankment CBR for 500 mm Subgrade

Borrow Subgrade CBR (%)	EMB 5	EMB 7	EMB 10	EMB 12	EMB 15	EMB 20	EMB 25	EMB 30
5	5.12	5.35	5.59	5.70	5.82	5.97	6.07	6.14
7	6.67	7.01	7.37	7.53	7.73	7.95	8.11	8.23
10	8.93	9.46	10.01	10.29	10.59	10.96	11.22	11.42
12	10.33	10.98	11.69	12.02	12.41	12.87	13.21	13.46
15	12.30	13.15	14.06	14.51	15.03	15.65	16.10	16.43
20	15.33	16.50	17.78	18.40	19.12	20.02	20.68	21.18
25	18.12	19.59	21.23	22.04	22.99	24.18	25.03	25.72
30	20.70	22.48	24.48	25.46	26.67	28.11	29.21	30.05

TABLE 6A Effective Design CBR for Different Embankment CBR for 400 mm Subgrade

Borrow Subgrade CBR (%)	EMB 5	EMB 7	EMB 10	EMB 12	EMB 15	EMB 20	EMB 25	EMB 30
5	5.12	5.41	5.71	5.85	6.01	6.21	6.34	6.44
7	6.59	7.01	7.46	7.68	7.92	8.21	8.42	8.58
10	8.69	9.33	10.01	10.35	10.74	11.21	11.55	11.80
12	9.98	10.76	11.61	12.02	12.51	13.10	13.53	13.86
15	11.76	12.75	13.84	14.38	15.03	15.80	16.38	16.81
20	14.45	15.80	17.28	18.04	18.92	20.02	20.83	21.48
25	16.89	18.55	20.45	21.39	22.54	23.98	25.03	25.87
30	19.12	21.10	23.36	24.55	25.94	27.69	29.03	30.05

TABLE 6B Effective Design CBR for Different Embankment CBR for 300 mm Subgrade

Borrow Subgrade CBR (%)	EMB 5	EMB 7	EMB 10	EMB 12	EMB 15	EMB 20	EMB 25	EMB 30
5	5.12	5.51	5.92	6.12	6.35	6.63	6.83	6.98
7	6.46	7.01	8.37	8.71	9.12	9.60	8.96	9.19
10	8.33	9.13	10.01	10.46	10.98	11.64	12.10	12.48
12	9.44	10.40	11.48	12.02	12.67	13.48	14.07	14.52
15	10.96	12.15	13.50	14.20	15.03	16.07	16.85	17.46

Borrow Subgrade CBR (%)	EMB 5	EMB 7	EMB 10	EMB 12	EMB 15	EMB 20	EMB 25	EMB 30
20	13.19	14.74	16.54	17.48	18.59	20.02	21.12	21.98
25	15.17	17.05	19.26	20.42	21.84	23.65	25.03	26.13
30	16.94	19.12	21.73	23.11	24.82	26.99	28.67	30.05

TABLE 6 C Effective Design CBR for Different Embankment CBR for 200 mm Subgrade

Borrow Subgrade CBR (%)	EMB 5	EMB 7	EMB 10	EMB 12	EMB 15	EMB 20	EMB 25	EMB 30
5	5.12	5.70	6.35	6.68	7.07	7.55	7.91	8.19
7	6.24	7.01	7.91	8.37	8.93	9.62	10.14	10.55
10	7.71	8.76	10.01	10.67	11.48	12.50	13.29	13.91
12	8.55	9.78	11.24	12.02	12.98	14.23	15.17	15.95
15	9.66	11.12	12.90	13.84	15.03	16.58	17.78	18.74
20	11.24	13.04	15.26	16.47	18.00	20.02	21.64	22.96
25	12.59	14.69	17.32	18.77	20.60	23.05	25.03	26.67
30	13.78	16.14	19.12	20.78	22.90	25.80	28.11	30.05

DISCUSSION

From Table 1, it is found that CBR value increases with increasing value of subgrade CBR and maximum CBR archived when embankment CBR is equal to subgrade CBR.

From Table 2, it is observed that CBR increases with increasing tire pressure. Maximum CBR is found at tire pressure of 0.8 MPa.

From Fig. 2, it is noticed that surface deflection decreases with increasing subgrade CBR values of borrow materials. Deflection is higher for higher tire pressure and CBR with higher tire pressure is also higher value. Flexible pavement thicknesses are determined considering tire pressure is one of the most important inputs. It varies from country to country. It is adopted 560 KPa in India and 700 KPa in Australia. From field study, it is found that tire pressure is 110 PSI for front axle and 120 PSI for rear axle. Therefore, tire pressure of 0.80 MPa is considered for adaptation of CBR.

From Table 3, it is found that damaging effect of single axle with single tire (Generally front axle) is more critical and single axle dual tire is lesser critical and therefore, single axle with single tire shall be considered for evaluation effective CBR.

From Table 4, it is noticed that effective CBR depends on embankment and subgrade CBR Values and effective CBR mainly depends on Subgrade CBR. From Table 4, it is found that effective CBR is close to subgrade CBR value. For subgrade CBR 5, effective CBR varies from 5.1 to 5.7 % whereas embankment CBR varies from 7 to 30. From this variation, it may be concluded that embankment CBR should be less than or equal to subgrade CBR and it will not exceed subgrade CBR Value for optimizing benefit.

Table 5 presents effective CBR value which may be useful for design of pavement. This Table is developed considering subgrade thickness is equal to 500 mm. Similar Tables for 400,300 and 200 mm subgrade thicknesses have been developed and presented in Table 6. Table 1 is compared with the results of Japanese Formula as presented in Table 1 and it is found the proposed method gives slightly more CBR. For embankment CBR 15 to 30 %, CBR from two layer theory gives conservative value. . For embankment CBR 5 to 10 and 12 to 15 %, CBR from Japanese Formula gives conservative value. From Table 5, it is also found that effective CBR is 20.7 % for embankment and subgrade CBR 12 and 25 % respectively whereas effective CBR is 12.6 % for embankment and subgrade CBR 25 and 12 %. Effective CBR is 17.7% for both cases as obtained from Japanese Formula. This case is found when subgrade is proposed over rocky natural ground /embankment. It may be concluded that major effect of effective subgrade CBR depends on the value borrow subgrade CBR. Therefore, subgrade CBR should be superior quality to improve the strength of pavement foundation. From Tables 5 and 6, it is found that CBR increases with the increasing value of subgrade thickness .Therefore; adequate subgrade thickness shall be provided to strengthen the life of the pavement.

Effective CBR is calculated varying Poisson Ratio from 0.3 to 0.4 and no significance different is found from the analysis. Therefore, adaptation of Poisson ratio 0.35 is found to be ok for the analysis.

It is generally found while comparing, CBR obtained from Japanese Formula and Two Layers Theories, effective CBR from Japanese Formula shows conservative value. This is due to consideration of embankment thickness. Embankment thickness is considered 500 mm while two layer theories consider the thickness of infinite depth and achieve higher effective CBR Value. Therefore, CBR obtained from two layer theories may be adopted for design of pavement.

CONCLUSIONS

This paper presents the comparison of effective CBR based on Japanese Formula and effective CBR obtained using two layer theories. Based on the findings of results, following conclusions may be drawn:

- From Japanese Formula, CBR value increases with increasing value of subgrade CBR and maximum CBR archived when embankment CBR is equal to subgrade CBR.
- It is observed that CBR increases with increasing tire pressure.
- CBR obtained from front axle wheel load analysis may be considered for pavement design
- It is observed that effective CBR decreases with decreasing subgrade thickness. Therefore, higher subgrade thickness is better than that of lower subgrade thickness for same subgrade CBR.
- Tables 5 and 6 may be adopted for pavement design and Fig 1 of IRC:37-2012 may be replaced by these Tables.
- Subgrade CBR should be always greater than or equal to embankment CBR.
- Effective CBR is not depended on feasible range of Poisson Ratio of materials.
- Japanese Equation recommended lower CBR due to consideration 500 mm subgrade and 500 mm embankment whereas two layers theories give higher value due the consideration of higher thickness of infinite depth.

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