OVERLAY DESIGN AFTER BACK-CALCULATING k-VALUE WITH HFWD

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ABSTRACT

Determination of subgrade strength for rigid pavements, i.e. k-value, is an important factor for design of pavements. Various design manuals and practices suggest that the k-value should be determined by a plate bearing test at the natural subgrade. This value should be corrected for any stabilizing layer or other material laid over the subgrade (i.e., subbase course and base course) for pavement design purposes. This corrected k- value is thus used as an effective k-value by various designers. The Aerodrome Design Manual of ICAO suggests that plate bearing tests conducted on top of subbase courses can sometimes yield erroneous results, since the depth of influence beneath a 762 mm bearing plate is not as great as the depth of influence beneath a slab loaded with an aircraft landing gear assembly. In this instance a subbase layer can influence the response of a bearing plate more than the response of a loaded pavement. Some literature recommends an effective static k-value of one-half of the effective dynamic k-value, where the k-value back calculated by a falling-weight deflectomer (FWD) is considered as the dynamic k-value. In order to establish a relation between dynamic and static k-values in Indian conditions, plate load tests were conducted at many places at different airports on natural subgrade, on subsequent subbase and base course layers, and these were verified with designed k-values for individual layer. Further, the k-value achieved by heavy falling-weight deflectometer (HFWD) back-calculation after collection of deflection data on finished concrete pavement at the same locations was also compared. It was observed that in most of the cases the k-values calculated by HFWD readings were very close to the design k-value at the top of base course (underneath the concrete slab) as well as those worked out with plate load tests. Therefore, it is recommended that the k-values calculated by HFWD data can suitably be used as input for overlay design.

INTRODUCTION

The modulus of subgrade reaction, k, is a measure of the strength of the supporting soil/bed, which may be the subbase or the subgrade. Its value is given in kilograms per square centimeters per centimeter deflection or MN/m^3.

In general, soil strength depends upon density, moisture content and texture of the soil. Increase in density is usually accompanied by increase in strength, whereas increase in moisture content above a certain limit is usually accompanied by decrease in soil strength. However, moisture and density are interrelated. For this reason, the value of the modulus of subgrade reaction should be evaluated for the density and moisture content conditions expected to be approximated beneath the slab under service conditions [1].

Pavements constructed from designs based on careful and conservative selection of the k-value from actual plate load test results is not too sensitive to variations in the k-value [2] within the quantified observations made. But k-value is an important parameter in designing rigid pavements and influences pavement design thickness. When a new rigid pavement is designed, the k-value of the natural subgrade is determined and the same is improved to the desired level, normally between 100-130 MN/m^3, by theoretically providing one or more layers of standard materials or materials of known properties. While designing rigid overlays on the old rigid pavements, whose material properties for layers under the concrete slab are not available, results of sample testing of material extracted by core cutting are to be relied on. It may not be possible to cut many numbers of cores whereas the pavement may have any number of different sections and different layers may have different properties. It may also not be possible to measure k-value at the bottom of the concrete slab using static plate load tests as it would require cutting of the pavement at many places. Further, it is established that the k-value at the top of any layer other than the natural ground, if tested with the static method using a load plate may give erroneous results [2]. This is apparent from the test results shown in Table 1. The k-value can also be calculated by using deflection data with HFWD. This k-value is that at the bottom of the concrete slab, i.e. at the top of layer that supports the slab [3]. Values of k as per theoretical design, achieved with static plate load tests and calculated using HFWD were compared for many pavements at different airports in India. This paper presents the comparison between the above k values and study of the same to find suitability of k-values by HFWD for overlay designs.

Table 1.
Comparison of k-Values.

No.	Location	Layer	k-design[a]	k-static[a]	k-HFWD[a]
1	Delhi	Subbase top	120	125	85
2	Delhi	Subbase top	120	124	90
3	Delhi	Subbase top	120	124	100
4	Delhi	Subbase top	120	124	100
5	Delhi	Subbase top	120	125	90
6	Delhi	Subbase top	120	124	90
7	Delhi	Subbase top	120	124	80
8	Delhi	Subbase top	120	122	90
9	Delhi	Subbase top	120	121	90
10	Mumbai	NGL	16	16	-
11	Mumbai	Moorum Fill	66	80	-
12	Mumbai	GSBC	96	120	-
13	Mumbai	WMM	113	152	-
14	Mumbai	DRLC	120	160	100
15	Amritsar	NGL	40	40	-
16	Amritsar	CSL	90	140	-
17	Amritsar	DRLC	130	250	90

[a]k in $MN/m^2/m$

NGL:	Natural Ground Level
Moorum:	Fill material obtained from pits of weathered disintregated rocks. Contains silicious material and natural mixture of clay of calcarious origin.
GSBC:	Granular Subbase course
WMM:	Wet Mix Macadam
CSL:	Cement Stabilized Layer
DRLC:	Dry Rolled Lean Concrete
k-design:	Theoretical improved k-value at sub-grade/sub-base used for design of rigid pavement
k-static:	k-value obtained with static load plate
k-HFWD:	k-value back-calculated from deflection data collected with HFWD

STATIC METHOD

In the static method, The modulus of subgrade reaction k is generally determined by a plate loading test carried out in the field on the compacted soil at its natural moisture content. A plate of 76.2 cm diameter is generally employed in the test and the subgrade is subjected to pressures at a predetermined rate of speed. The value of the pressure generally used in the test is 0.7 kg/sq.cm. The modulus of subgrade reaction k can then be determined from the relationship:

$$k = \frac{P}{\Delta} \tag{1}$$

where:

P = pressure on the plate (kg/sq.cm), usually 0.7 kg/sq.cm, and

Δ = deflection of plate (cm), corresponding to the assigned pressure.

DYNAMIC (NDT) METHOD

The HFWD simulates the loading patterns of heavy aircraft and produces impulse loads up to 240 kN by falling of weight on the pavement surface. Deflection on the pavement surface caused by the impact of the load is recorded by a number of geo-sensors. Deflection data in the present study was collected with HFWD of KUAB make. KUAB software was used for all analysis and the software uses the so called AREA, developed at University of Illinois. For rigid pavements, the k-value is calculated using the D0 and AREA using methods prescribed in the AASHTO Guide for Design of Pavement Structures [xx]. The k-value so calculated is called the dynamic k-alue. For rigid pavements, this k-value is that at the top of subgrade or subbase course that supports the slab.

AASHTO Guide for Design of Pavement Structures [xx] suggests this k-value to be divided by 2 in order to get the effective static k-value. Some other papers/literature also suggest division of dynamic k value by 2 to 3 in order to get effective static k-value.

OBSERVATION

During collection of deflection data and PCN evaluation with HFWD at a number of airports in India, it was observed that k-values at the bottom of the slab calculated by software using AASHTO methods are generally less than the design k-values for most of the rigid and composite pavements. Some observations are given in Table 2.

Table 2.
Observations.

No.	Airport	Area	Type	T	FS	k-HFWD[a]	k-design[a]
1	Amritsar	Runway	R	430	4.5	86	130
2	Delhi	Taxi	R	430	4.5	85	120
3		Taxi	R	430	4.5	90	120
4		Taxi	R	430	4.5	100	120
5		Taxi	R	430	4.5	100	120
6		Taxi	R	430	4.5	90	120
7		Taxi	R	430	4.5	90	120
8		Taxi	R	430	4.5	80	120
9		Taxi	R	430	4.5	90	120
10		Taxi	R	430	4.5	90	120
11		Taxi	C	460	2.6	130	120
12		Runway	C	630	2.8	100	120
13	Goa	Apron	R	530	3.0	510	136
14		Apron	R	530	3.0	330	136
15		Apron	R	530	3.0	134	136
16		Apron	R	450	3.0	190	136
17		Apron	R	450	3.0	120	136
18		Taxi	R	450	3.0	125	136
19	Mumbai	Taxi	C	470	2.1	130	120
20		Taxi	C	270	2.1	100	120
21		Taxi	C	500	2.1	130	120
22		Taxi	C	470	2.1	120	120
23		Taxi	R	450	3.4	120	120
24		Taxi	R	430	3.4	100	120
25		Apron	R	380	3.4	110	120
26		Apron	R	470	3.4	120	120
27		Apron	R	380	3.4	100	120
28		Apron	R	400	3.4	157	120
29		Apron	R	400	3.4	70	120
30		Apron 2	R	380	3.4	76	120
31		Apron	R	380	4.5	89	120
32		Apron 2	R	400	4.5	87	120
33	Surat	Apron	R	375	3.4	43	60
34	Kolkata	Apron	R	300	3.4	90	110
35		Taxi	R	450	3.4	120	130
36		Runway	C	380	3.4	85	100
37		Runway	C	400	3.0	74	80
38		Runway	C	300	3.0	85	100
39		Taxi	R	460	3.0	90	110
40		Taxi	R	400	3.0	73	100
41		Taxi	R	450	3.0	120	130
42		Taxi	C	460	3.0	100	130

[a]k value in MN/m3

In Table 2:

R:	Rigid
C:	Composite
T:	Thickness of rigid layer, in mm
FS:	Flexural strength, in MPa
k-design:	Theoretical improved k value at sub-grade/sub-base used for design of rigid pavement
k-static:	k-value obtained with static load plate
k-HFWD:	k-value back-calculated from deflection data collected with HFWD

For the observations in Table 2:

- The above results are extracted from actual test data of some airports. This study was not planned or conceptualized while collecting the deflection data.

- The data presented in this paper is the result of 200 kN impulse load. At many locations, impulse loads of 150 kN, 100 kN, 75 kN, 50 kN and 40 kN were also applied but readings with lower loads were not recorded at all the locations. Readings at lower loads were recorded to observe behavior of upper layers only. Therefore, k-HFWD with lower loads are not used for this study. However, it is worth mentioning here that considering slab thickness more than 375 mm in all cases, lower loads would not reflect the true picture of the subgrade condition.

- The k-HFWD values are 1st quartile values of an array of data (k-values) for each pavement. Readings collected on a particular pavement vary from 50 to 250. In all more than 5000 readings were collected at the airports/pavements considered for this study.

- Quartile and median k-HFWD values were found to be very close, generally within 10% variation in pavements that showed no surface distresses and in the locations where the soil properties are near similar.

- Large differences in quartile and median k-values were observed in pavements that show some kind of distresses or damages on visual inspection. The difference was also large in rocky terrain, e.g., Goa Airport. The difference was even more than 100% in some areas.

- Depth of hard strata, where consistency in calculated value of k was observed, was 5 m or more.

ANALYSIS OF DATA

The k-HFWD and design k values are compared graphically in Figures 1-7, for different values of concrete slab thickness and modulus of elasticity.

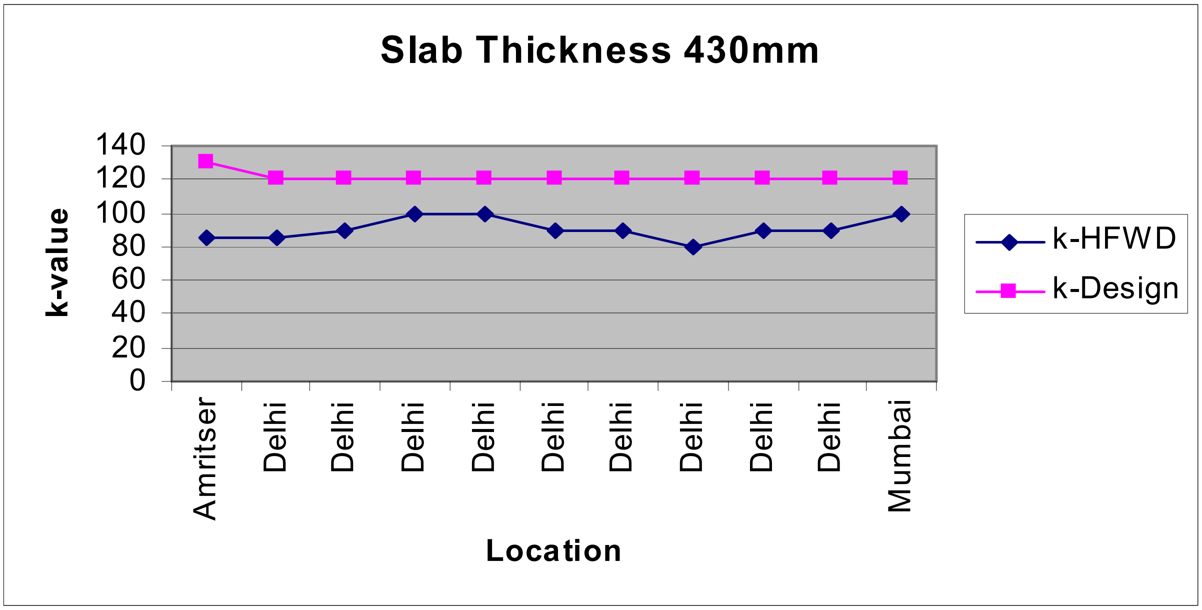

Figure1. k-Values for 430 mm Thick Slab.

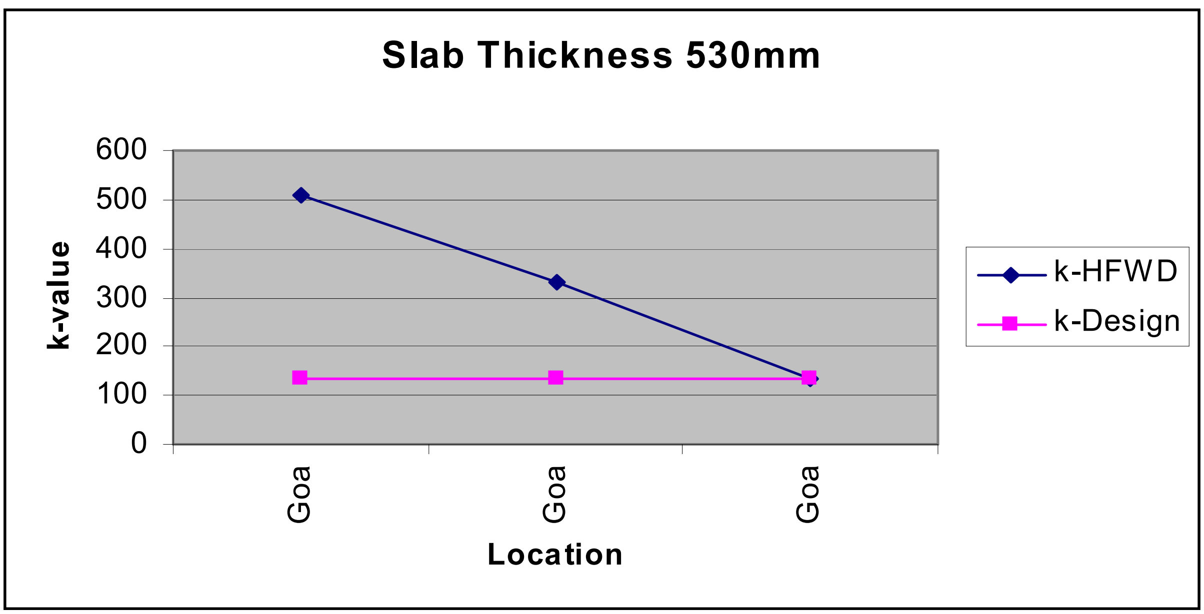

Figure 2. k-Values for 530 mm Thick Slab.

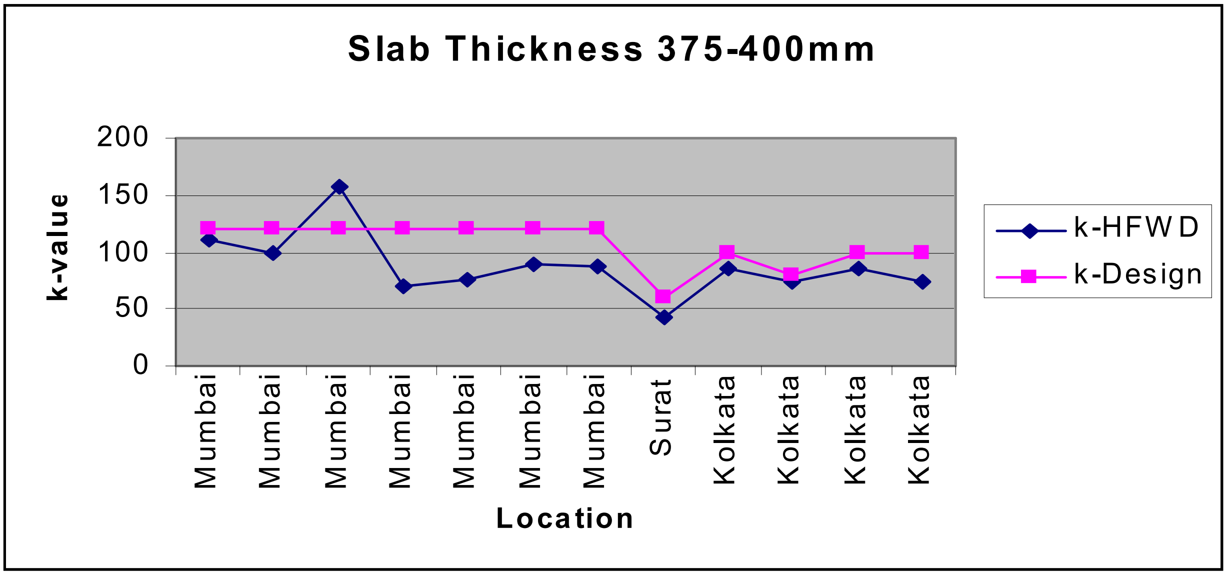

Figure 3. k-Values for 375-400 mm Thick Slab.

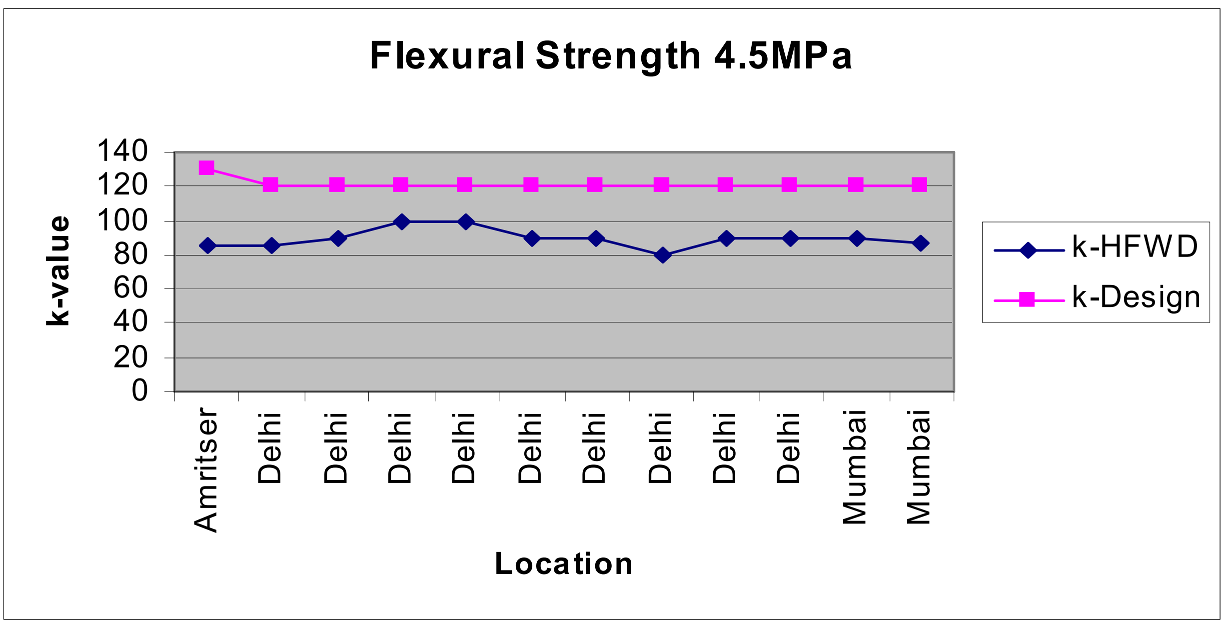

Figure 4. k-Values for 4.5MPa FS.

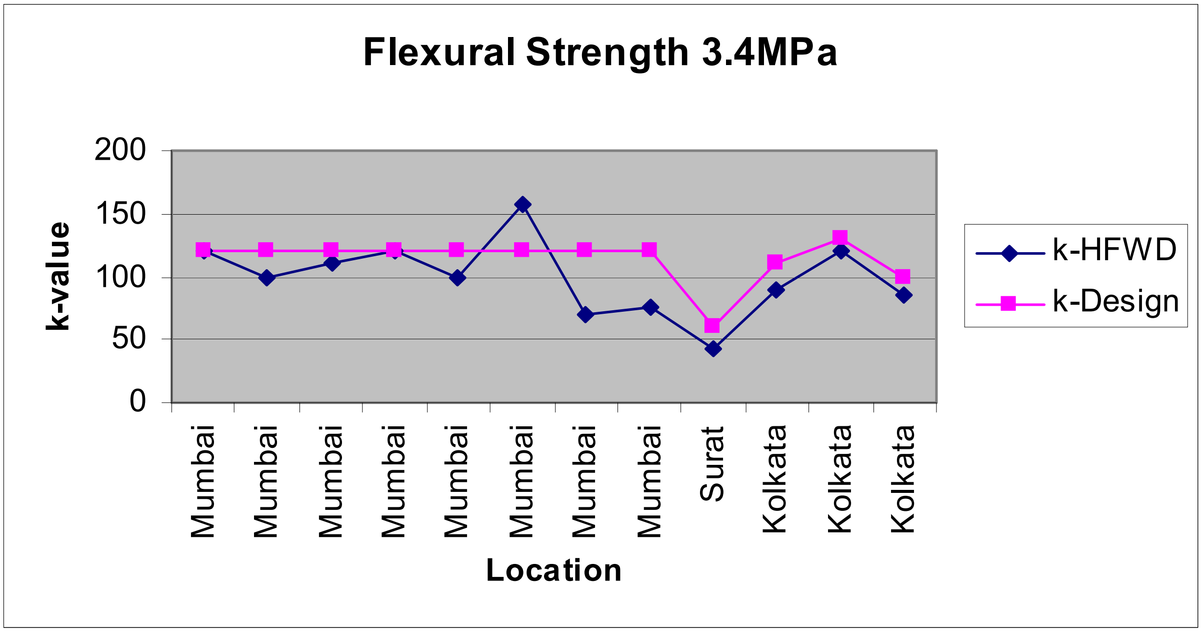

Figure 5. k-Values for 3.4 MPa FS.

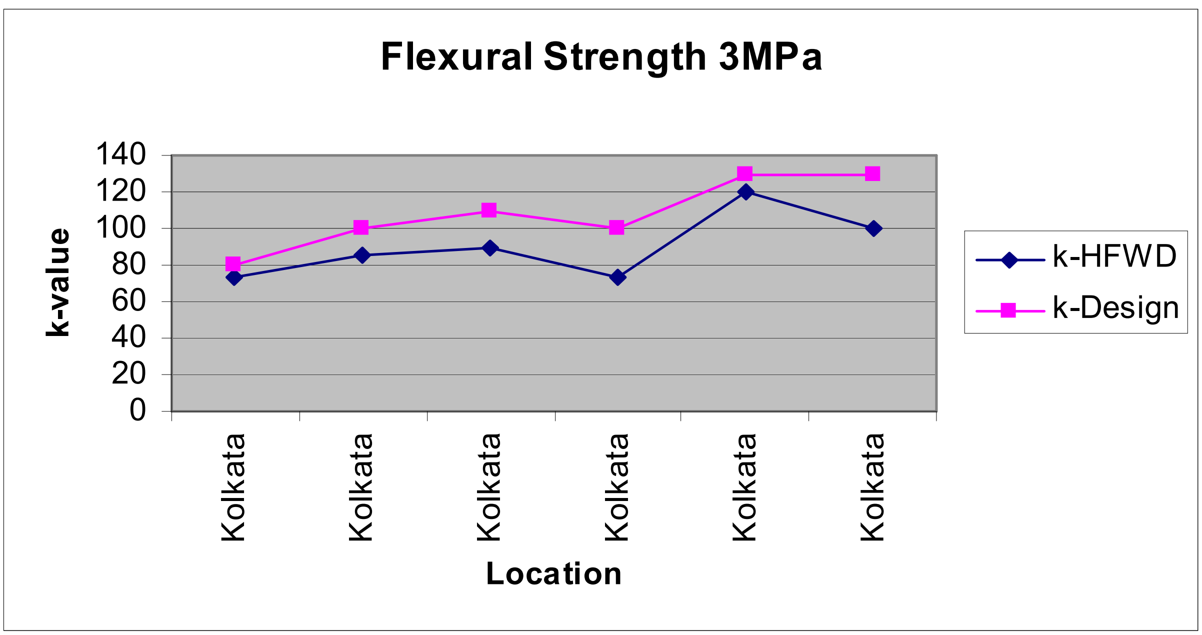

Figure 6. k-Values for 3 MPa FS.

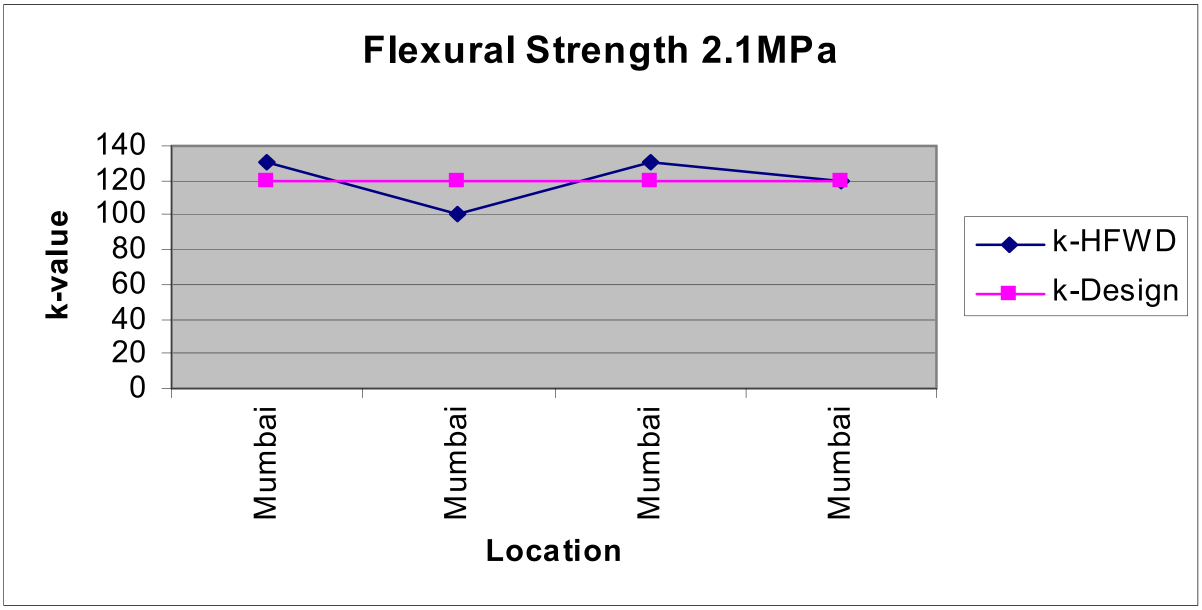

Figure 7. k-Values for 2.1 MPa FS.

It is observed from these graphs that:

- Barring a few locations at Goa and Mumbai, the k-HFWD is less than k-design.
- The locations where k-HFWD is more than k-design have hard rock as subgrade. This is so because for design purposes, the k-value is restricted to 136 MN/m^3 and in rocky terrain it is generally more than this value. But in pavements where hard strata underneath pavement are deep or non existent, k-HFWD is less than k-design.
- No significant difference in the k-HFWD to k-design ratio was observed when the values in rigid and composite pavements were compared. This implies that the k-value back-calculated by using HFWD deflection data for composite pavements can also be relied upon, considering the fact that for composite pavements, equivalent cement concrete thicknesses in lieu of asphaltic concrete were used for calculations.
- Values of k-HFWD as percentage of k-design for different parameters are worked out. Median and average k-HFWD as percentage of k-design are given in Table 3.
- Serial no. 2 contains readings mainly at Goa Airport, which has hard rocks as subgrade. Therefore, these data are not being considered for further analysis.
- The higher the thickness of the concrete slab, the lower the value of k-HFWD. At 430 mm slab thickness, the median k-HFWD is 25% below the design k.
- At 375-400 mm slab thickness, k-HFWD increases to around 80% of k-design.
- The higher the flexural strength, the lower the k-HFWD.

- The relation between slab thickness, flexural strength, k-theoretical and k-HFWD is expressed as, "k-HFWD decreases with an increase in slab thickness and flexural strength of concrete."

- In view of the above findings, the modulus of subgrade reaction k, calculated using deflection data with the help of HFWD (k-HFWD) can suitably be used for overlay design on old rigid pavements. The designer may enhance the k-HFWD up to 25% considering the physical condition of the pavement, the thickness of the existing slab and the flexural strength of the existing concrete.

Table 3.
k-HFWD as a Percentage of k-Design.

		k-HFWD (% of k-design)	
No.	Parameter	Average	Median
1	430 mm thick slab	69.7	75
2	530 mm thick slab	238.7	242.6
3	375-400 mm thick slab	81.8	78.8
4	Concrete flexural strength 4.5 MPa	74.3	75
5	Concrete flexural strength 3.4 MPa	86.8	84.2
6	Concrete flexural strength 3.0 MPa	83.6	83.4
7	Concrete flexural strength 2.1 MPa	100	104.2

CONCLUSION

The static k-value using the plate load test on different layers of subbase courses may not be consistent and may sometimes be erroneous. While designing overlays on existing rigid pavements for achieving higher strength, k-values at the bottom of concrete slabs can be back-calculated using HFWD deflection data at many locations. The back-calculated k-values (k-HFWD) can be used safely for overlay design. The value of k-HFWD, for pavements of 300 mm or greater thickness, is generally less than the theoretical or design k-value at the bottom of the concrete slab. The value of k-HFWD decreases with an increase in slab thickness, and also with an increase in the flexural strength of concrete. The above concept is true only when hard strata under the natural ground are more than 5 m deep. Under similar conditions, the designer may use the k-HFWD value, as it is or with some enhancement, depending upon the physical condition of the pavement, the slab thickness and the flexural strength.

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REFERENCES

1. Sargious, M., *Pavements and Surfacings for Highways and Airports*, New York, Halsted Press, 1975.
2. International Civil Aviation Organization (ICAO), *Aerodrome Design Manual, Part 3 - Pavements*, 2nd ed., 1983 (reprinted June 2003).
3. KUAB, Pavement Evaluation Software Manual, KUAB Konsult & Utveckling AB, Sweden.