EVALUATION OF MULTILAYERED COMPLEX AIRFIELD PAVEMENT WITH HFWD

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ABSTRACT

Normally airfield pavements are made either flexible or rigid when constructed. Over a period of time, some rigid pavements are overlaid with asphaltic concrete because such overlays can be done very fast as compared to rigid overlay and do not cause much traffic disruption. These pavements are put under category of composite pavements. However, some airfield pavements in India, built during Second World War era, were overlaid and strengthened to cater for heavier aircrafts using different layers of material. The materials used ranged from bricks laid flat, bricks on edge, lime concrete, asphaltic concrete, cement concrete etc. Behavior of such pavements varies from case to case basis depending on the different layers constituting the pavement. The PCN evaluation analysis of such pavements becomes complicated as the use of conventional methods and practices have certain limitations with respect to such complex structures. Attempt was made to solve the issue of evaluation of such complex pavements using HFWD. A complex pavement structure at Secondary runway at NSCBI airport, Kolkata was selected and tested for its in-situ strength in the year 2003. This runway pavement had four different cross-sectional structures along the length of the runway. One section of the runway has seven layers (subgrade to surface course): brick flat soling, Lime Concrete, HMA, Cement Concrete, brick flat soling, brick on edge and HMA, thereby making the pavement structure very complex for analysis. Deflection data was collected using HFWD and analyzed with various combinations of layers vis-à-vis individual layers considering their elastic properties to find out most realistic PCN. Overlay with HMA was designed for this pavement for its strengthening and the results were quite encouraging.

INTRODUCTION

Evaluation of Pavement Classification Number (PCN) of existing pavements is normally done either by reverse design method or with the help of nondestructive testing (NDT) equipment. Use of NDT equipment like Heavy Falling Weight Deflectometer (HFWD) has now become very common. Deflection data recorded through HFWD is processed in suitable software for calculating PCN. Evaluation of simply rigid or flexible pavements is very convenient with these methods. Evaluation of composite pavements needs special attention as thickness of each type of layer, i.e. rigid and flexible (normally asphaltic concrete), behave differently, but guidelines are available for the benefit of the evaluator to analyze such pavements. However, there exist some pavements that consist of many layers of different material. Evaluation of such pavements require a lot of engineering judgment and assumptions, particularly when one cannot cut many cores from an in-use runway and cannot get material properties from old records.

Runway 01L-19R at Netaji Subhas Chandra Bose International (NSCBI) Airport, Kolkata was built during the Second World War. This Runway is now used as the secondary runway. Dimensions of the the runway are 2399 x 45 m and it has four different sections along its length depending upon the structure of the pavement. The sections are (A) Chainage 0 to 240 m, (B) 240 to 852 m, (C) 852 to 1752 m and (D) 1752 to 2399 m. Structural details are shown in the longitudinal section in Figure 1. The details were compiled from available records, results of core cutting and soil investigation reports. It can be seen that section C, i.e. 900m length, was constructed first, extended at section B and section D subsequently, and further extended at Section A. The sections are plotted keeping the top level in a straight line and longitudinal slope/grading at top surface is avoided for convenience of understanding details, section-wise. It also appears that pavement at section A was built much earlier than sections B and D but was merged with the runway by providing additional layers of bricks and asphalt concrete (AC) to match the top level and increase strength to the desired value at a later date. The last resurfacing of the runway was done in the years 1990-91, with 7.5 cm BM, 5cm SDAC and 5cm DAC. Earlier records were not available.

The declared PCN for this runway was 45/F/C/W/T, as worked out by the reverse design method in the year 1991-92. The task was to ascertain the current PCN and suggest the overlay required for a target PCN of 70/F/C/W/T. This was the first job to be done in-house with a recently procured HFWD.

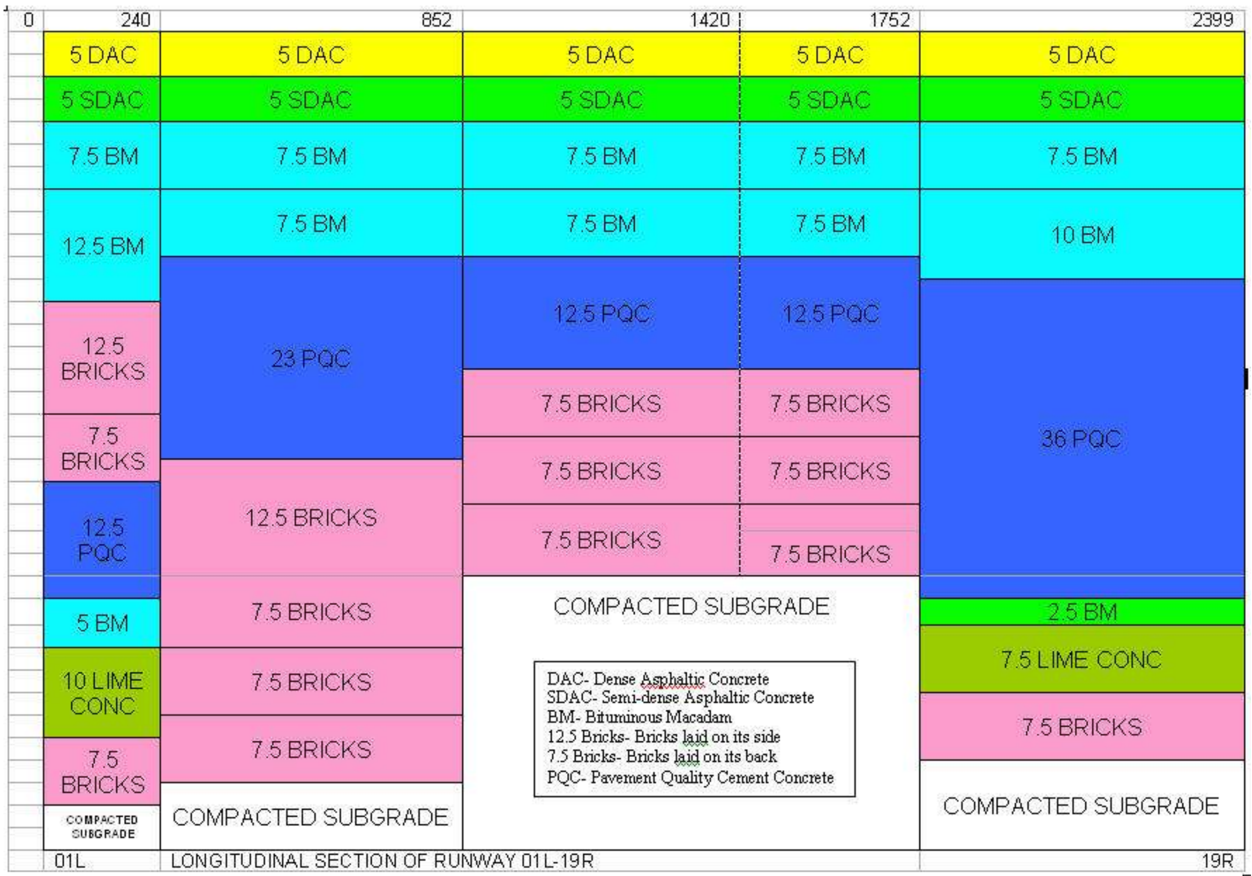

Figure 1. Cross-Sectional Details.

COLLECTION OF DATA

The meteorological/soil data were as follows:

- Max Temperature 40° C
- Average day Temperature 35° C
- Intensity of Rainfall 5cm/hr

- Average Rainfall | 130cm
- Ground Water Table | 1.5 to 2m in dry season and 60 to 90cm in monsoon
- Soil Type | Clayey Silt 1 to 8 m depth
- Surface Drainage | Good
- CBR | 5%
- k-value | 41MN/m3

Deflection Data

Reflection cracks were not visible on the pavement surface. The joint pattern of the concrete pavement was also not known. Therefore, efforts were made to record many readings at and around the centre line at four different locations to ascertain if there was any indication of joints in concrete affecting the deflection bowl. Nothing of that sort was observed. The deflection pattern was consistent and all sections showed behavior of the pavement as that of a composite pavement, asphalt overlay over rigid pavement. However, in order to avoid readings very close to longitudinal joints of concrete underneath, it was decided to record deflections at the following offsets:

(a) 1m from Centre Line

(b) 5m from Centre Line

(c) 8m from Centre Line

(d) 10m from Centre Line

(e) 17.5m from Centre Line

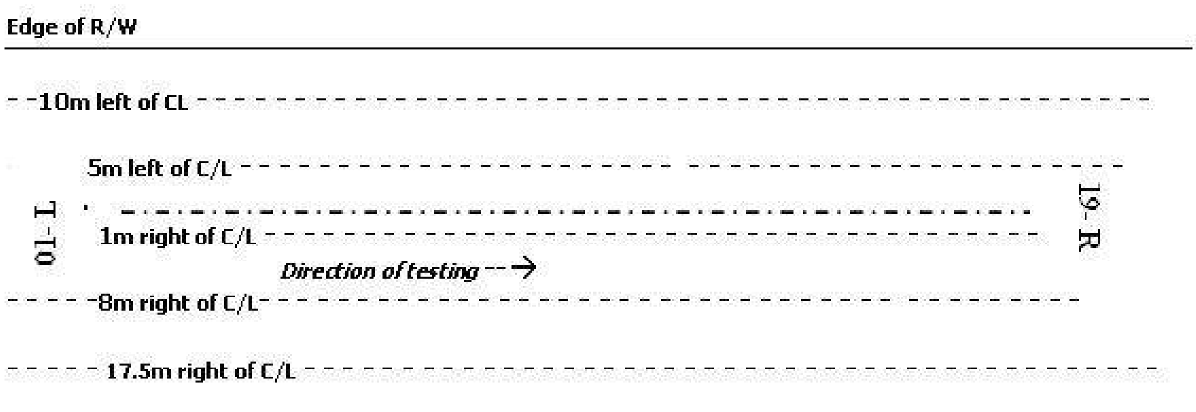

Figure 2. Testing Layout.

Deflection data was recorded on 18th and 19th August 2003. This is the monsoon period in this region but there were no rains during these two days. Air temperature varied from 33° to 38° C and pavement temperature from 38° to 60° C.

The HFWD used is van-mounted and capable of generating a load up to 240 kN. It is equipped with 9 sensors, one at the centre of the load plate, seven at one side and one at other side, as shown in Figure 3. A 30 cm diameter four-part split load plate was used. The sequence of load was set as 6, 6, 6, 3 and 1. The numeral "6" denotes an impact load of 200 kN, "3" a load of 75kN and "1" a load of 40kN. This load sequence was selected because at a test point, the first impact allows the split load plate to settle on the ground according to the surface profile. When the first load is higher than or equal to subsequent loads, the load transfer during subsequent impacts is uniform. If the first impact is lighter than the subsequent impacts, there are chances that load transfer in the second or third impact will not be uniform, as the load plate is not seated close to the surface profile, hence deflections recorded may be less. Until the plate is properly seated, deflection readings are likely to reduce in subsequent impacts even if same load is applied. In this case, the highest load selected for recording of deflection data was 200 kN (load 6). Deflections at first impact were not recorded. Subsequent deflections were recorded. The second and third impacts were also kept as 200 kN so that consistency in deflections can be ensured.

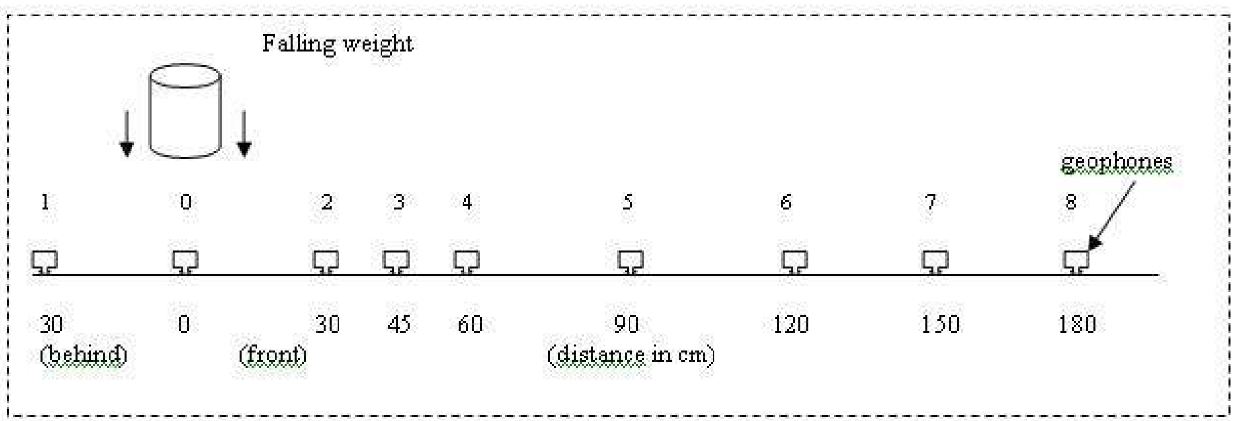

Figure 3. Sensor Placement.

ANALYSIS OF DEFLECTION DATA

Normalized deflection charts for deflection values recorded at 1 m, 5 m, 8 m and 10 m offsets from the centre line are placed at Figures 4, 5 and 6. The Impulse Stiffness Modulus (ISM) chart is placed at Figure 7.

It can be seen from these charts that the deflection at D0 is significantly higher than those at a distance from the centre of the load plate. It is also observed that at some places, deflection at D2 is very close to or slightly less than that at D3. The reason for excessive deflection at D0 is compaction of AC under heavy load. Under load, when there is a rigid base underneath, the AC gets compacted and the sensor records the deflection as actual deflection plus settlement of AC surface. The reason for less deflection at D2 is that D2 is just 15 cm away from the edge of the

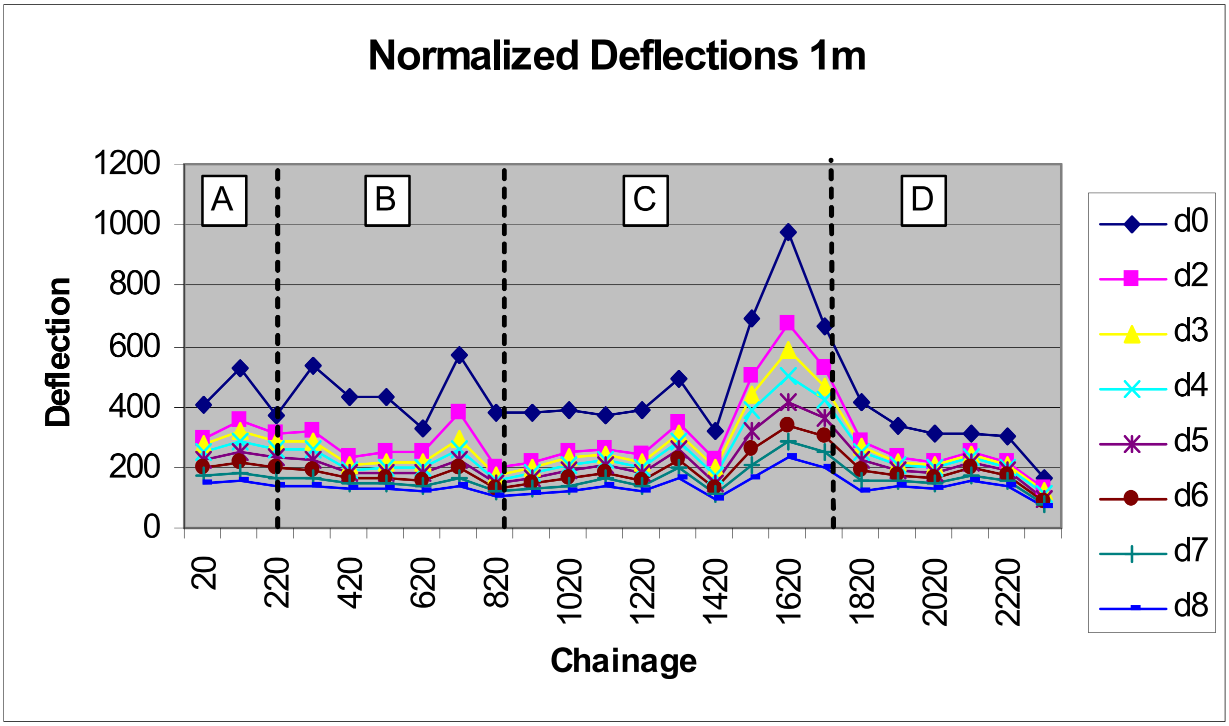

Figure 4. Normalized Deflection Chart, 1 m from Centerline.

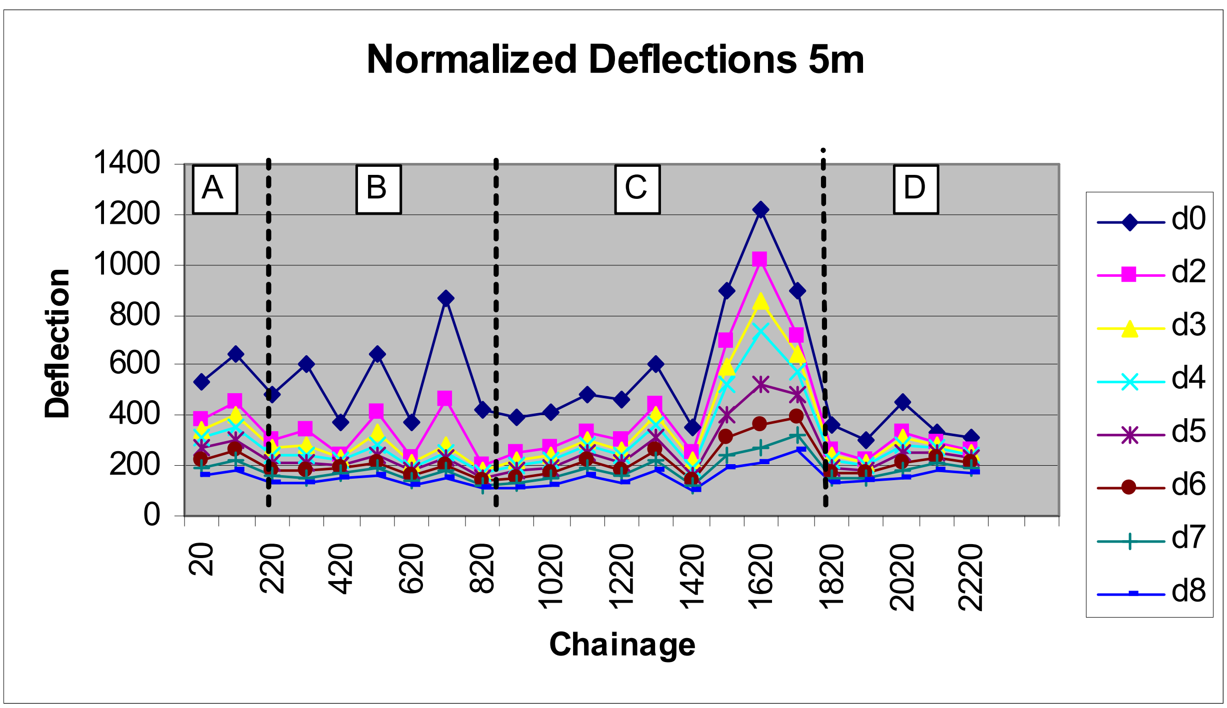

Figure 5. Normalized Deflection Chart, 5 m from Centerline.

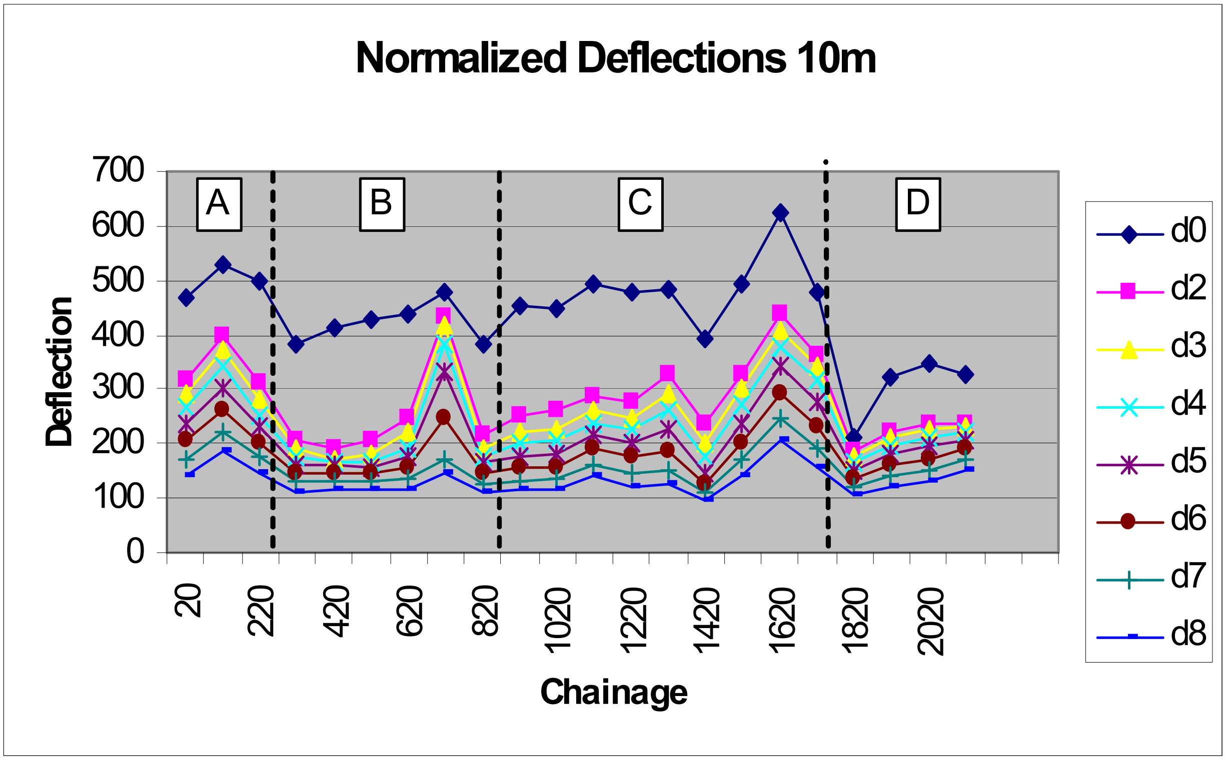

Figure 6. Normalized Deflection Chart, 10 m from Centerline.

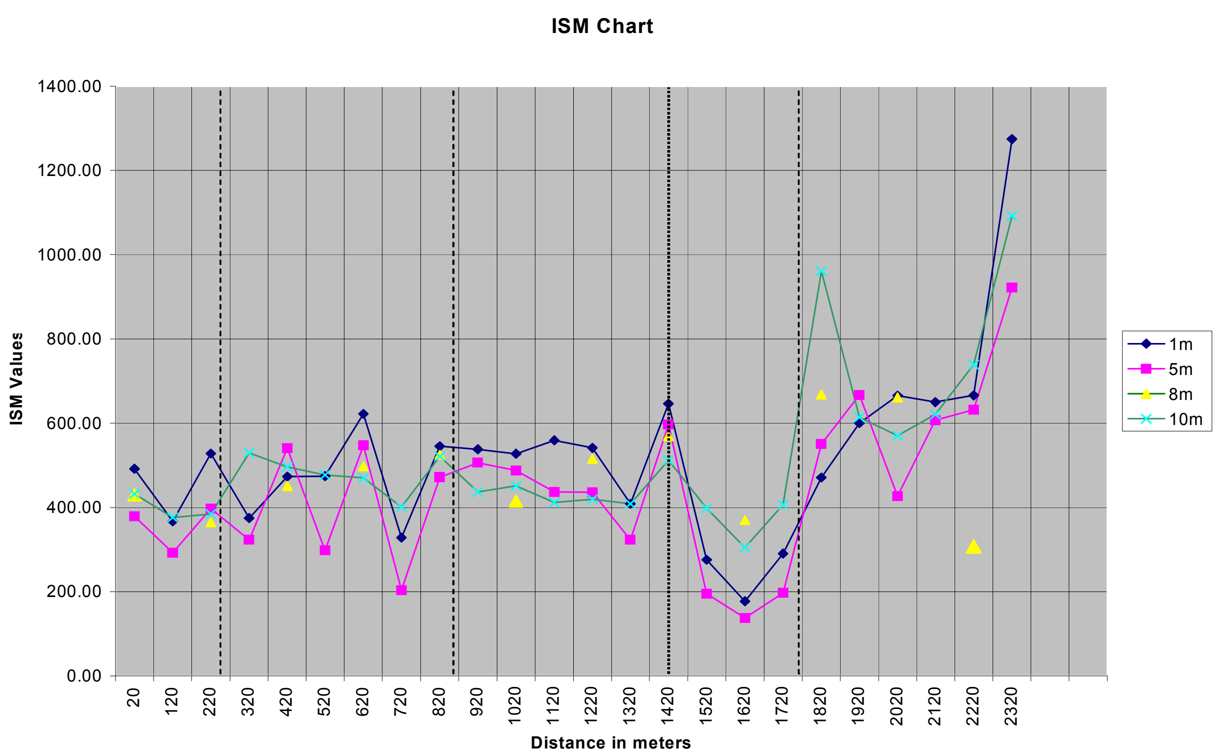

Figure 7. ISM Chart.

load plate. Under impact, the AC around the load plate moves in an upward direction, causing a reduction in deflection.

Typical deflection bowls are given at Figure 8 and 9. The deflection bowls clearly indicate the pavement structure to be a composite one. Deflection readings from Sensor D4 to D8 are almost in a straight line indicating a rigid structure and those from D0 to D3 indicate a flexible structure.

The difference between D0 and D2 is less at 1 m and 5 m offsets as compared to 8 m and 10m. This stretch got compacted under regular loads of operating aircraft main gears and therefore, compaction under the FWD load was not that high.

Deflection readings at chainage 720 and 1620 m show excessive deflection at all sensor positions and at all offsets. This could be because of some local problem like excavation for cable/pipe laying and refilling the trench. Similarly, deflections at chainage 2320 are too low. At other locations, the deflection pattern is normal.

The Impulse Stiffness Modulus (ISM) calculated for each point, as shown in Figure- 6, indicates high ISM at points of low deflection values and vice versa.

In section C, deflection readings as well as ISM values show a different trend between chainage 1420 and 1752 m even when the structural section between 852 and 1752 (900m) is the same. The same section can be accepted logically also as during those days the runway length was normally 3000ft or 900m. However, there could be a possibility of taking up the construction in two phases and difference in construction material properties has caused different structural behavior to applied load. A weak subgrade in the later section can also not be ruled out. Segregation of this section, accordingly, was kept in mind.

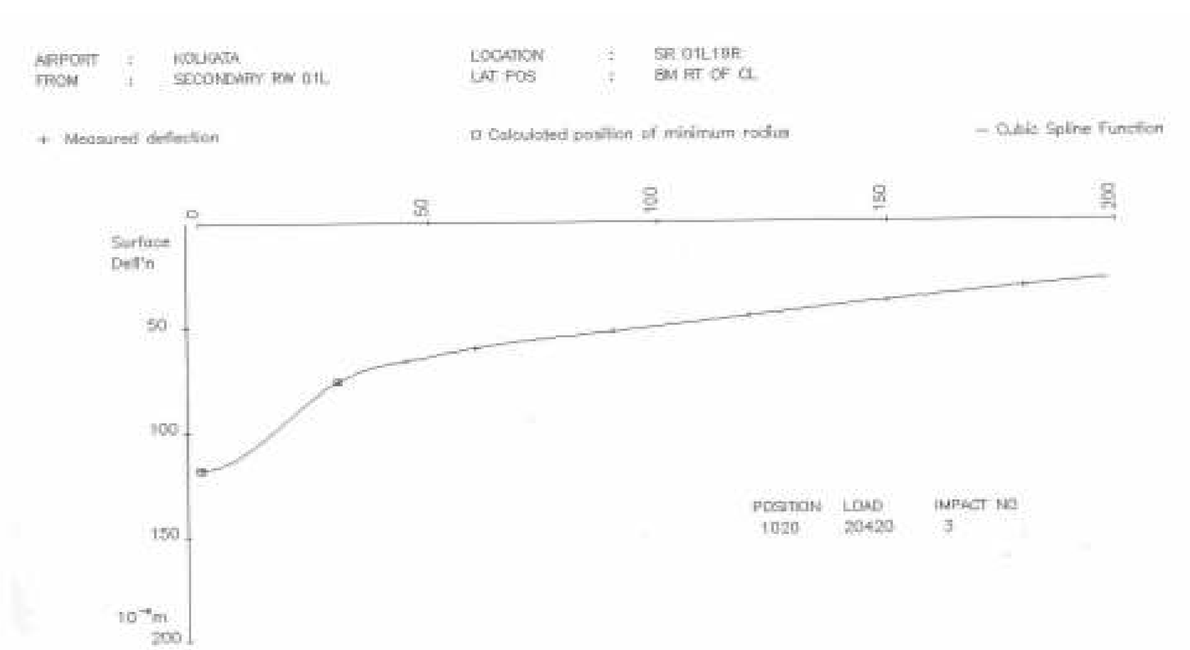

Figure 8. Deflection Bowl 1.

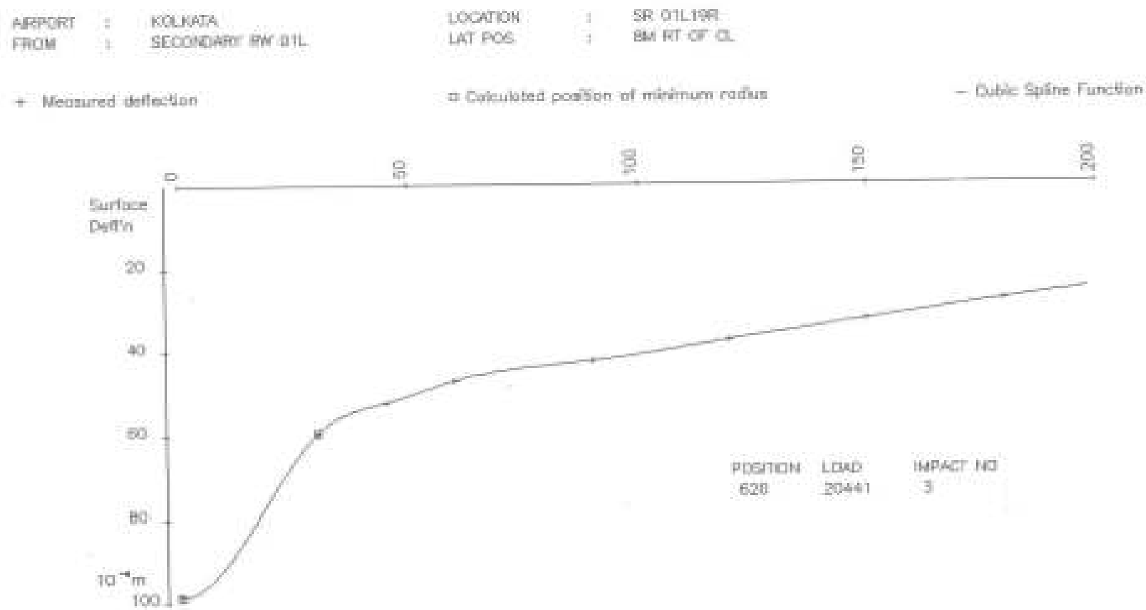

Figure 9. Deflection Bowl 2.

CONDITION SURVEY

The runway was thoroughly inspected across the length and breadth. Even after 13 years of continuous use, the runway surface did not show any signs of structural deformities. Oxidation of asphalt and scanty small pot holes were observed.

CALCULATION OF PCN

Deflection bowls in all the four sections clearly indicate behavior of the pavement as that of a composite pavement, i.e. a rigid structure overlaid with flexible material. As there was no indication of change in deflection pattern even up to 180 cm distance (D8 position) from the centre of the load plate, it further confirmed presence of rigid layer that still behaved structurally rigid. Looking at section A , where the 12.5 cm thick cement concrete was overlaid with 20 cm brick layers and 30 cm AC, one could have doubted the structural behavior. But the deflection bowl was exactly the same as shown in figures 8 and 9. Deflection bowls were similar for all loads, i.e. 200 kN, 75 kN and 40 kN. This left no other option but to analyze all the four sections of the pavement as composite.

Sections B and C had layers of bricks underneath Cement Concrete layer, acting as a base course. But Section A had one 7.5 cm thick brick layer, 10c m thick Lime Concrete (LC) and 5cm thick AC below the Cement Concrete (CC) layer of 12.5 cm thickness. Similarly, at Section D, a 7.5 cm thick brick layer, 7.5 cm thick LC and 2.5cm thick AC was laid under a 36 cm thick PQC. It was interesting to know the k-value at the bottom of CC layer in section A and D.

Bricks in this region have a compressive strength of 100kg/cm^2. The CBR is about 5% and the modulus of subgrade reaction k = 41 MN/m^3. As the concrete was laid long back, its flexural strength was considered as 2.7 MPa and Emod as 20000 N/mm^2. Considering the pavement temperature to be between 40 to 60° C most of the time throughout the year, Emod for AC is considered as 2800 N/mm^2.

Section A

Efforts were made to analyze section A with software for flexible pavement. The 7-layered section was converted into 5 layers with different combinations as the software could take a maximum of 5 layers. After iterations, all results show very high E-modulus of AC layers- even up to 20000 N/mm^2. Because of the rigid layer underneath, deflections in AC layer were less and did not match the theoretical values. Therefore, it was decided to analyze the pavement as a composite one.

Deflection readings in section A from D4 to D8 were compared with deflection readings at other rigid pavements at the same airport. These readings were found to be quite similar to those where 40 cm thick cement concrete was laid during the same period. Some sample readings are given in Table 1.

Table 1.
Deflection Reading Comparision.

Similar Old Pavement					Section A of Runway				
Deflection Readings, m x 10^{-6}					Deflection Readings, m x 10^{-6}				
d4	d5	d6	d7	d8	d4	d5	d6	d7	d8
253	226	197	169	142	243	219	191	163	134
296	259	222	190	160	239	217	191	162	136
266	247	216	188	157	268	240	211	187	158
267	240	213	185	156	257	236	209	190	157

Equivalent concrete thickness in section A was computed in the following manner:

(a) Equivalent CC thickness (based on the formula $E_1 \times t_1^3 = E_2 \times t_2^3$ - Westergaard's equation)

For top 30 cm AC $= \sqrt[3]{2800/20000} \times 30 = 15.60$ cm (A)

(b) Brick on edge + flat bricks = 20 cm
Brick compressive strength = 10 N/mm^2
Brick flexural strength $= 0.7 \times \sqrt{10} = 2.21$ N/mm^2
E-modulus $= 5000 \times \sqrt{10} = 15811$ N/mm^2

The above formula for working out the E-modulus holds well for cement concrete. Considering that the bricks were tightly packed and gaps were filled with sand, and assuming that about 50% of the bricks would have broken into two or more pieces during compaction of upper layers, a factor of safety of 2.5 was applied.

E-mod (brick layer) = 15811/2.5 = 6324 N/mm^2
Equivalent CC thickness
for 20 cm thick brick layer $= \sqrt[3]{6324/20000} \times 30 = 13.60\,\text{cm}$ (B)

(c) Cement concrete = 12.5 cm (C)

Total equivalent thickness of concrete (A+B+C) = 41.70 cm

Considering assumptions made in (b) and the deflection data comparison above, the concrete equivalent thickness was rounded off to 40 cm.

Section B

(a) Equivalent CC thickness
for top 25 cm AC $= \sqrt[3]{2800/20000} \times 25 = 13.00\,\text{cm}$ (A)

(b) Cement concrete = 23 cm (B)

Total equivalent thickness of concrete (A+B) = 36.00 cm

Section C

(b) Equivalent CC thickness
for top 25 cm AC $= \sqrt[3]{2800/20000} \times 25 = 13.00\,\text{cm}$ (A)

(b) Cement concrete = 12.5 cm (B)

Total equivalent thickness of concrete (A+B) = 25.5 cm (say 25 cm)

Section D

(c) Equivalent CC thickness
for top 27.5 cm AC $= \sqrt[3]{2800/20000} \times 27.5 = 14.30\,\text{cm}$ (A)

(b) Cement concrete = 36 cm (B)

Total equivalent thickness of concrete (A+B) = 50.30 cm (say 50 cm)

The above data was processed in the KUAB software for composite pavements and the quartile PCN values and back-calculated k values at the bottom of the CC layer are given in Table 2.

Table 2.
PCN and Back-calculated k-Values.

Section	A	B	C	D
PCN	75	79	50	87
k-value, $kg/cm^2/cm$	8.95	10.3	8.0	8.4

In view of the observations above under “Analysis of Deflection Data,” PCN values in section C were segregated for chainage 852 to 1420 and 1420 to 1752m as section C1 and C2. It was observed that the PCN in section C2 was generally less than that in section C1. Revised quartile PCN values are given in Table 3.

Table 3.
PCN and Back-calculated k-Values.

Section	A	B	C1	C2	D
PCN	75	79	56	36	87
k-value, $kg/cm^2/cm$	8.95	10.3	10.3	5.5	8.4

OVERLAY DESIGN

It was suggested by the Operations Department that presently B-747-200 series aircraft use this runway at 3-4 movements per week. Other aircraft that frequently use this runway include A-310-300 and B-767-200. Therefore, B-747-200 was considered as the critical aircraft. For C category subgrade, the PCN requirement for this aircraft was 70.

The software supplied by KUAB calculates overlay thickness for target PCN with the assumption that the new concrete will have the same modulus as the old one. The software provides overlay requirement at each point of test. For AC overlay on a pavement that has an existing AC overlay over CC base, same thickness conversion factor has to be applied that was used while working out PCN. Sections A , B and D already have PCNs higher than the target PCN. The overlay requirement in Sections C-1 and C-2 shown by the software was 4.5 and 11.5 cm, respectively. Therefore, the overlay thickness for AC was worked out as

(a) Section C-1 9cm, making total AC thickness 34cm

(b) Section C-2 23cm, making total AC thickness 48cm.

Now, there was a question, how to verify these overlays suggested by the software? Key elements were noted:

- CBR = 5%.
- k-value in Section C-1 = 10.3 and in Section C-2 = 5.5 (at the bottom of CC layer)

Interestingly, C-1 and C-2 have the same material layers and appear to have been constructed in the same period. But there is a strong evidence in the form of k-values at the bottom of CC layer that suggests that something was wrong with the three layers of bricks underneath the concrete pavement in Section C-2, and that is why the k value increased only by 1.4% in this section, against an increase of 5.2% in Section C-1. This could be either because of low original subgrade strength in Section C-2 or poor quality bricks used in this area. Since the original subgrade strength is considered the same for the whole runway, the effective equivalent thickness of brick layers that would have modified the k-value were worked out using Chart 4.13 of the Aerodrome Design Manual, Part 3 [1].

(c) Effective equivalent thickness of 22.5 cm thick brick layer in Section C-1 = 59 cm

(d) Effective equivalent thickness of 22.5 cm thick brick layer in Section C-2 = 23 cm

(e) Although the projected annual movements of the critical aircraft B-747-200 were about 210 per annum, considering growth rate of air traffic in India, annual movements of 1200 of critical aircraft are considered.

(f) With overlay thickness given by KUAB software, overall AC thickness in Section C-1 is 34 cm and 48 cm in Section C-2.

In these sections, the thickness of the AC overlay is more than that of CC base of 12.5 cm. Therefore, requirement of further overlay was verified by using the design method for flexible pavement and treating the existing rigid pavement as a high quality subbase/ base material.

The design chart of the US Army Corps of Engineers for Model B-747-200 was used.

(a) Total pavement thickness required for CBR 5%, 345000,kg weight on the main landing gear and 1200 annual departures was calculated as 118cm.

(b) Combined thickness of Bituminous Surface Course plus Base Course for CBR 20% is 42cm.

(c) Thickness of Sub-base, therefore, is 118-42 = 76 cm.

(d) Thickness of Base-course, keeping minimum surface course as 10 cm is 42-10 = 32 cm.

(e) Minimum Base course thickness for CBR 5 % from Chart 4.45 is calculated as 34 cm.

(f) Using Chart 4.13 of the Aerodrome Design Manual (ADM), Volume 3 [1], an effective equivalent thickness of brick layers that would have modified the k-value was worked out. For Section C-1, the k value was increased from 4.1 to 10.3 and effective equivalent thickness of brick layers is worked out as 59 cm. The same in Section C-2 for increase in k value from 4.1 to 5.5 is 23 cm.

(g) Balance layers on top of brick layers are considered to have same properties. Equivalency factors as per Table 4.9 and 4.10 of ADM Part 3 were adopted for these layers and are given in Table 4 below:

Table 4.
Equivalency Factors.

Material Type	Subbase Course	Base Course	Surface Course
Cement Concrete	2.0	1.5	-
Asphaltic Concrete	2.0	1.35	1.25
Bricks	1.0	0.75	-

(h) Based on the above data/calculations, existing pavement thickness plus suggested overlays in both sections are divided in the following manner (Table 5):

Table 5.
Layer Courses.

Layer	Course	Section C-1	Layer	Course	Section C-2
Asphalt Conc.	Surface	8 cm	Asphalt Conc.	Surface	8 cm
Asphalt Conc.	Base	26 cm	Asphalt Conc.	Base	26 cm
Cement Conc.	Base	4 cm	Asphalt Conc.	Subbase	14 cm
Cement Conc.	Subbase	8.5 cm	Cement Conc.	Subbase	12.5 cm
Bricks	Subbase	22.5 cm	Bricks	Subbase	22.5 cm

(i) Design requirements for Flexible pavement are summarized below:

AC Surface Course = 10cm
Base Course = 34cm
Sub-base Course = 76cm

Against the above design requirement, new overlaid pavement will have the following section as given in Figure 10:

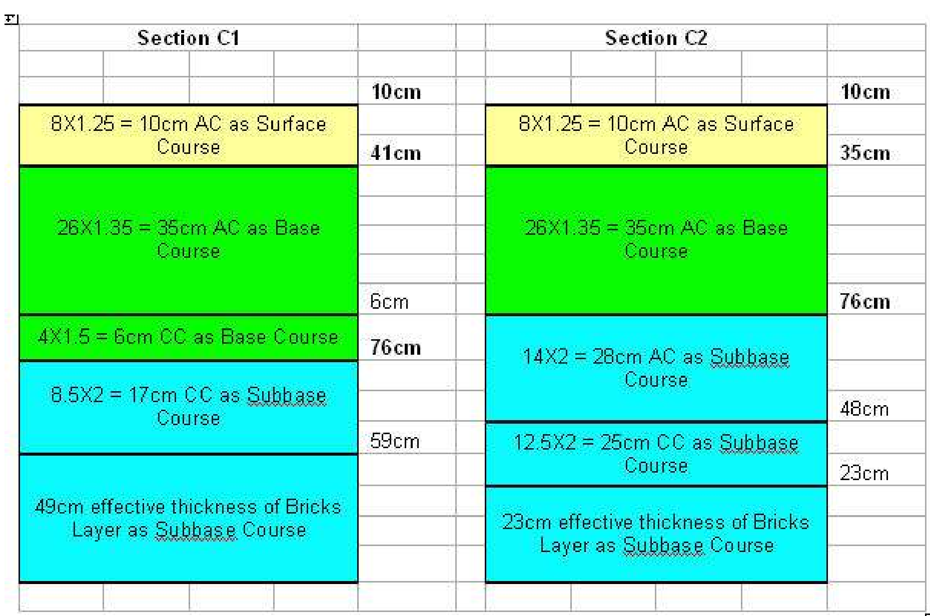

Figure 10. New Overlaid Pavement – Section C

In order to verify PCNs worked out with HFWD for Sections A, B and C, a similar exercise was done for these sections. Results are shown in Figure 11.

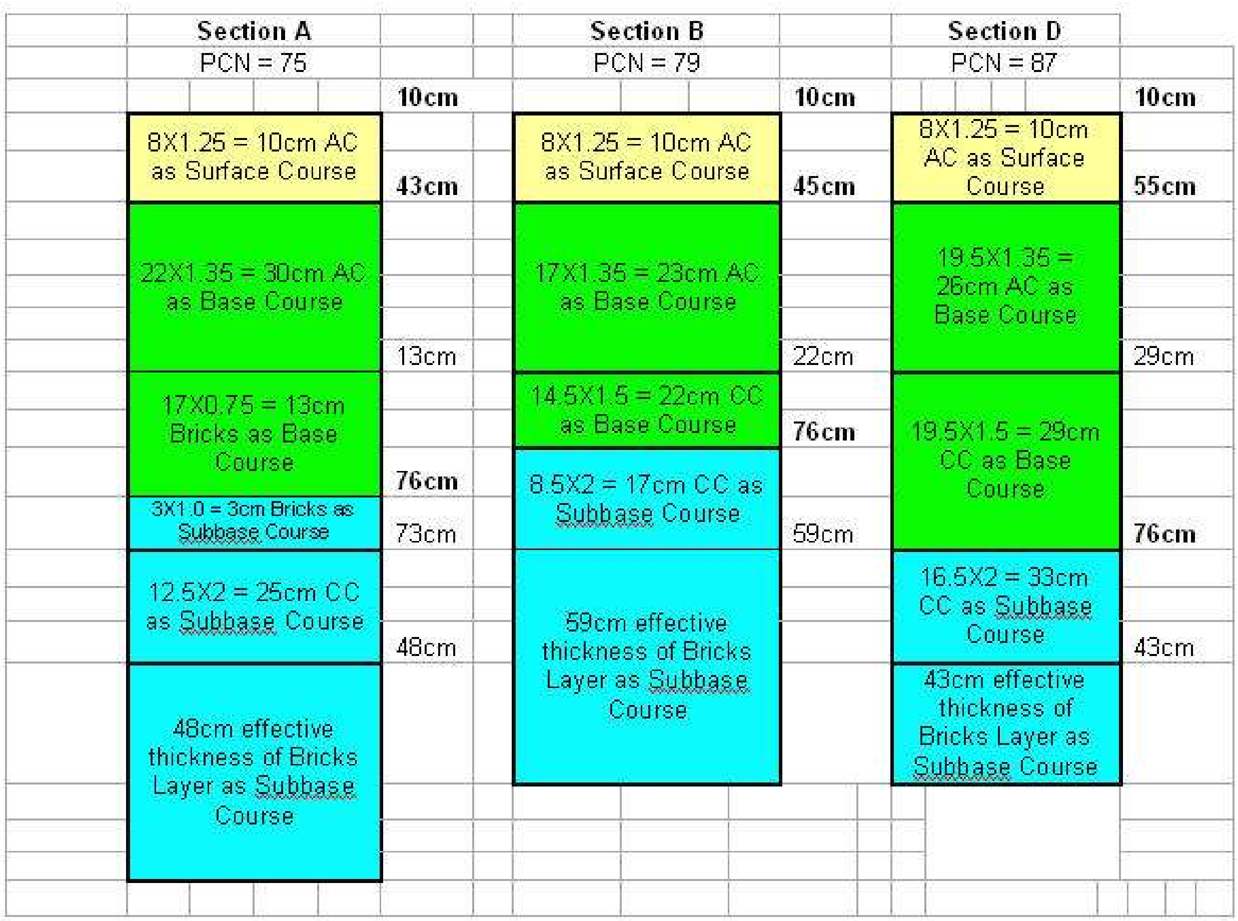

Figure 11. New Overlaid Pavement – Sections A, B and D.

It can be noticed that by keeping equivalent thickness of subbase course and surface course same in all sections, base course thickness in Sections A, B and D are 43, 45 and 55 cm respectively and calculated PCNs are 75, 79 and 87. The relationship with equivalent thickness and PCNs in all the five sections is proportional and therefore, the PCNs calculated with HFWD and overlay suggested are justified. The above results support assumptions for material properties, wherever applied. Overlay work has recently been started and is likely to be completed by March 2007.

CONCLUSION

HFWD deflection data can be used to work out PCNs of multilayered complex airfield pavements. A close look at the deflection data, deflection pattern and data analysis with various permutations and combinations along with engineering judgment allow the evaluator to estimate properties of materials used in individual layers and its effective thickness. It is essential to know the behavior of a pavement section before selecting a suitable method to analyze the deflection data for layer properties and subsequent PCN evaluation. Deflection bowls provide reasonable information on pavement behavior. In the case of rigid pavements overlaid with AC, AC overlay design is possible with software, and the same methodology can be used with proper engineering judgment and some cross-checks for multilayered complex pavements also. The above study proves the same.

REFERENCES

1. International Civil Aviation Organization (ICAO), *Aerodrome Design Manual, Part 3 - Pavements*, 2nd ed., 1983 (reprinted June 2003).