Civil and Environmental Research www.iiste.org
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol 2, No.8, 2012

# PERFORMANCE STUDY OF FLEXIBLE PAVEMENTS ON NON EXPANSIVE SOILS

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**Abstract**

As part of infrastructure development huge investment is being made on expansion of National highways and important roads across the country. For improvement of Highways two types of Pavements are commonly used in India viz., Flexible Pavements (Bituminous) and rigid pavements (Concrete). Flexible pavements are widely used in this country from the considerations of economy The performance of Flexible pavements depends largely on properties of original ground on which the pavement rests, the quality of materials used in the construction of various layers of pavement and quality assurance as per relevant specifications. In general any road after construction is basically evaluated by the performance in terms of unevenness index and structural stability over a period of time. The evaluation of these two important parameters will facilitate the clear understanding of performance of various materials used in the construction and to undertake suitable rehabilitation measures if necessary.

**Keywords:** Expansive Soil, Flexible Pavement.

## 1. Introduction

Pavement evaluations are conducted to determine functional and structural conditions of a highway section either for purposes of routine monitoring or planned corrective action. Functional condition is primarily concerned with the ride quality or surface texture of a highway section. Structural condition is concerned with the structural capacity of the pavement as measured by deflection, layer thickness, and material properties. At the network level, routine evaluations can be used to develop performance models and prioritize maintenance or rehabilitation efforts and funding. At the project level, evaluations are more focused on establishing the root causes of existing distress in order to determine the best rehabilitation strategies.

Pavements respond to the various site characteristics like soil characteristics, heterogeneous traffic, climate, environmental conditions etc. in complex ways. Therefore, a pavement design should be done very carefully and in a scientific manner so that, the pavement serves its purpose with least maintenance during the expected design life. The pavement is subjected to many adverse environmental and traffic conditions. Therefore it is necessary that the road way is provided wi'

\th a suitably designed and constructed pavement structure

Two most important parameters that govern the pavement design are soil sub-grade and traffic loading. The Indian guidelines for the design of flexible pavements use soil sub-grade strength in terms of California Bearing Ratio (CBR) and traffic loading in terms of million standard axles (msa). The structural capacity of flexible pavements is attained by combined action of the different layers of the pavement. The load is directly applied on the wearing course and it gets dispersed with depth in the base, sub-base and sub-grade layers and then ultimately to the ground. Since the stress induced by traffic load is highest at the top, the quality of top and upper layer materials is better. The sub-grade layer is responsible for transferring the load from above layers to the ground. Flexible pavements are designed in such a way that the load transmitted to the sub-grade does not exceed its bearing capacity. Consequently, the thickness of layers would vary with CBR of soil and it would affect the cost of the pavement.

Standard procedures recommended in the respective I.S.Codes of practice (I.S.2720 (Part-V)-1985; I.S.2720 (Part-VI)-1972) are followed while finding the Index properties viz; Liquid Limit, Plastic Limit and Shrinkage Limit of the samples tried in this investigation.

As part of study, performance of flexible pavement on a live stretch of NH 16( Old NH5) from KM 799.999 to 901.753 (101.754 KM) is undertaken which was constructed by Gammon on BOT ( annuity basis)

To analyze the performance of flexible pavement six locations are selected where in the road is laid on the non-expansive soils but also the material used in the sub grade with varying degree of CBR values ranging from 10-14% The details of the locations are given below

Stretch 1: (S1) Km. 851.250 to Km. 852.250

Stretch 2: (S2) Km. 862.750 to Km. 863.750

Stretch 3: (S3) Km. 872.250 to Km. 873.250

Stretch 4: (S4) Km. 881.750 to Km. 882.750

Stretch 5: (S5) Km. 887.750 to Km. 888.750

Stretch 6: (S6) Km. 895.500 to Km. 896.500

## 2. LABORATORY EXPERIMENTATION

Laboratory experimentation is carried out on all original ground and borrow earth samples as per Indian Standard methods (IS: 2720-Part -1 to 28).

### 2.1 Properties of Original Ground Soil sample

Soil samples are collected from the original ground by digging trial pits at approximately 250 m intervals from each stretch and conducted the laboratory tests. The average test results for each stretch are shown in table: 1

Table: 1 Properties of Original Ground Soil sample

| Sl. No | Property | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| **1** | **Grain Size Distribution** | | | | | | |
| | Gravel (%) | 1 | 1 | 3 | 2 | 2 | 1 |
| | Sand (%) | 53 | 48 | 37 | 54 | 57 | 66 |
| | Silt and Clay ( %) | 46 | 51 | 60 | 44 | 41 | 33 |
| **2** | **Compaction Properties** | | | | | | |
| | Maximum Dry Density ( g/cc) | 1.85 | 1.77 | 1.86 | 1.85 | 1.85 | 1.925 |
| | O.M.C (%) | 9.00 | 7.37 | 8.68 | 9.78 | 7.95 | 8.25 |
| **3** | **Atterberg Limits** | | | | | | |
| | Liquid Limit (%) | 33 | 33 | 32 | 32 | 32 | 30 |
| | Plastic Limit (%) | 19 | 21 | 17 | 17 | 17 | 13 |
| | Plasticity Index (%) | 14 | 12 | 15 | 15 | 15 | 17 |
| **4** | **Free swell Index (%)** | **17** | **20** | **18** | **22** | **17** | **20** |
| | IS Classification | CL | CL | CL | CL | CL | CL |
| **5** | **Soaked CBR (Compacted to MDD at OMC) (%)** | **8.22** | **7.82** | **7.86** | **6.81** | **8.40** | **7.67** |

### 2.2 Properties of borrow earth samples used for subgrade

The borrow earth on which the road is formed at six stretches as explained above are tested in the laboratory to determine Grain size Analysis, Compaction properties, Atterberg Limits, Free Swell Index and CBR as per the relevant IS methods. The values of the same are shown in Table:2

Table :2 Properties of borrow earth used in the Stretch-1 to Stretch-6

| Sl. No | Property | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| **1** | **Grain Size Distribution** | | | | | | |
| | Gravel (%) | 1 | 3 | 1 | 1 | 4 | 5 |
| | Sand (%) | 75 | 76 | 60 | 59 | 77 | 76 |
| | Silt and Clay (%) | 24 | 21 | 39 | 40 | 19 | 19 |
| **2** | **Compaction Properties** | | | | | | |
| | Maximum Dry Density ( g/cc) | 1.9 | 2.0 | 1.9 | 1.9 | 2.0 | 1.9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | O.M.C (%) | 7.8 | 7.7 | 7.8 | 8.1 | 7.3 | 7.1 |
| 3 | **Atterberg Limits** | | | | | | |
| | Liquid Limit (%) | 33 | 29 | 35 | 35 | 28 | 26 |
| | Plastic Limit (%) | 16 | 15 | 17 | 18 | 14 | 14 |
| | Plasticity Index (%) | 17 | 14 | 18 | 17 | 14 | 12 |
| 4 | **Free swell Index (%)** | **10** | **10** | **10** | **10** | **10** | **10** |
| | IS Classification | CL | CL | CL | CL | CL | CL |
| 5 | **Soaked CBR (Compacted to MDD at OMC) (%)** | **11.1** | **12.1** | **10.8** | **10.6** | **12.9** | **13.7** |

## 3. FIELD STUDIES

The stretches were observed for 5 years by conducting two types of field tests viz., Benkle Man Beam Deflection (BBD) test to determine the characteristic deflection and Fifth wheel Bump Integrator test to determine the roughness index to assess the performance of the pavement during the period

### 3.1 Fifth wheel Bump Integrator Test

The Surface Unevenness of the road was determined by using the parameter Road Roughness Index. The surface unevenness affect the Vehicle speed, Comfort, Vehicle operating cost and hence it gives an indication to the road users as well as developer the likely impact on cost on surface evenness. Road Roughness Index is measured using 5th wheel Bump Integrator as shown in Fig:1, which falls in the category of roughness instrument called Response –type, Road Roughness Measuring system (RTRRM)

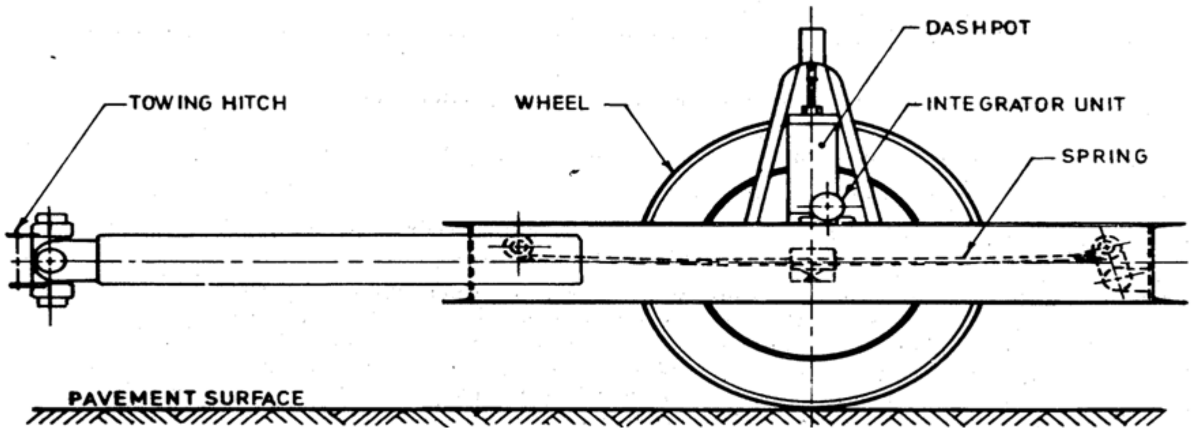


**Fig :1 5th Wheel Bump Integrator**


**Fig:2 Bump Integrator test in field**

The above machine basically relies on capturing the dynamic response of a mechanical system (e.g a vehicle) moving along a wheel path to the road profile at a uniform speed of 32 Kmph besides maintaining the standard pneumatic tyre wheel inflated to the pressure of 5.6 Kg/ sqcm. The cumulative response (typically the sum of upward and downward movements of the axle with the chassis) is then related to the roughness characterizing that profile. Fig:2 shows the fifth wheel bump integrator connected to the vehicle just before test drive.

The road roughness (unevenness Index) value was calculated for the test run as shown below:

UI : (10*B*R)/ W mm/Km

Where

UI: Unevenness Index, mm/km

B: Calibrated Bump Integrator readings from field, mm/km

R: No of revolutions of test wheel, rev

W: No of wheel revolutions from field, rev

The following table:3 gives the guidelines of acceptable criteria of road roughness value (Table - 3 of IRC: SP-16: 2004):

| Sl. No | Type of Surface | Condition of the Road | | |
|---|---|---|---|---|
| | | Good | Average | Poor |
| 1 | Surface dressing | < 3500 | 3500 – 4500 | >4500 |
| 2 | Open Graded pre mix carpet | < 3000 | 3000 - 4000 | >4000 |
| 3 | Mix seal surface | < 3000 | 3000 - 4000 | >4000 |
| 4 | Semi dense bituminous macadam | < 2500 | 2500 - 3500 | >3500 |
| 5 | Bituminous concrete | <2000 | 2000 - 3000 | >3000 |
| 6 | Cement Concrete | <2200 | 2200 - 3000 | >3000 |

Table: 4 The Results obtained after normalizing at these selected stretches are shown in the table below

| Period | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|

| | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | | **1525** | | **1653** | | **1662** | | **1708** | | **1468** | | **1712** |
| **2006** | **1852** | **2099** | **1852** | **1995** | **1775** | **2041** | **1802** | **1972** | **1876** | **1984** | **1793** | **2145** |
| **2007** | **2225** | **2122** | **2237** | **2087** | **2078** | **2262** | **2109** | **2118** | **1754** | **1938** | **2134** | **2018** |
| **2008** | **2087** | **2110** | **2145** | **2145** | **2097** | **2161** | **2041** | **2141** | **1995** | **2168** | **2087** | **2248** |
| **2009** | **1673** | **1772** | **2437** | **2469** | **2234** | **2298** | **2099** | **2158** | **2110** | **2192** | **2133** | **2210** |
| **2010** | **1598** | | **1561** | | **1468** | | **1340** | | **1401** | | **1549** | |

### 3.2 Benkelman Beam Deflection Test

The other key determining factor for the evaluation of the pavement is the structural deflection using the Benkelman Beam Deflection Method in accordance with IRC: 81This method involves the determination of the rebound deflection under static load of the rear axle to a standard Truck as the performance of the flexible pavement is closely related to the elastic deflection of pavement under the wheel loads. The deflection measurement is to be taken based on the **static** load deflection test procedure – CGRA Method (Annexure – 1 of IRC: 81 –1997)

Fig: 3 shows the setup of BBD test. The values determined are shown in table:5.

**Fig: 3 Benkelman Beam Deflection Test.**

The characteristic deflection based on the above readings is shown below.
Characteristic Deflection (Dc) = $\bar{x} + 2\sigma$ mm

Dc = Characteristic Deflection, mm

$\bar{x}$ = Mean Deflection, mm

σ = Standard Deviation, mm

The permissible criteria for the characteristics deflection for this project are given below:

Desirable condition : up to 0.50mm

Acceptable condition : up to 0.80mm

Table:5 The Results obtained after carrying out the Benkelman beam deflection tests.

| Period | S1 | | S2 | | S3 | | S4 | | S5 | | S6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon | Before Monsoon | After Monsoon |
| 2005 | | 0.479 | | 0.331 | | 0.320 | | 0.268 | | 0.265 | | 0.224 |
| 2006 | 0.482 | 0.509 | 0.412 | 0.446 | 0.382 | 0.425 | 0.341 | 0.412 | 0.336 | 0.395 | 0.302 | 0.389 |
| 2007 | 0.552 | 0.577 | 0.484 | 0.508 | 0.464 | 0.501 | 0.484 | 0.536 | 0.452 | 0.522 | 0.452 | 0.511 |
| 2008 | 0.591 | 0.621 | 0.552 | 0.608 | 0.552 | 0.606 | 0.568 | 0.607 | 0.568 | 0.611 | 0.554 | 0.602 |
| 2009 | 0.600 | 0.532 | 0.510 | 0.463 | 0.520 | 0.460 | 0.535 | 0.471 | 0.551 | 0.493 | 0.532 | 0.475 |

## 4. Discussion of test results

The results obtained from the lab and field is summarized in respect of stretch, year and parameter which are shown and discussed in the subsequent sections.

### 4.1 Laboratory Results

#### 4.1.1 Original Ground Samples:

The summarized lab test results on Original Ground and Subgrade material on the stretches chosen for non-expansive soils are hereby shown in table:6 and the curves of the same are plotted as shown in Fig:4

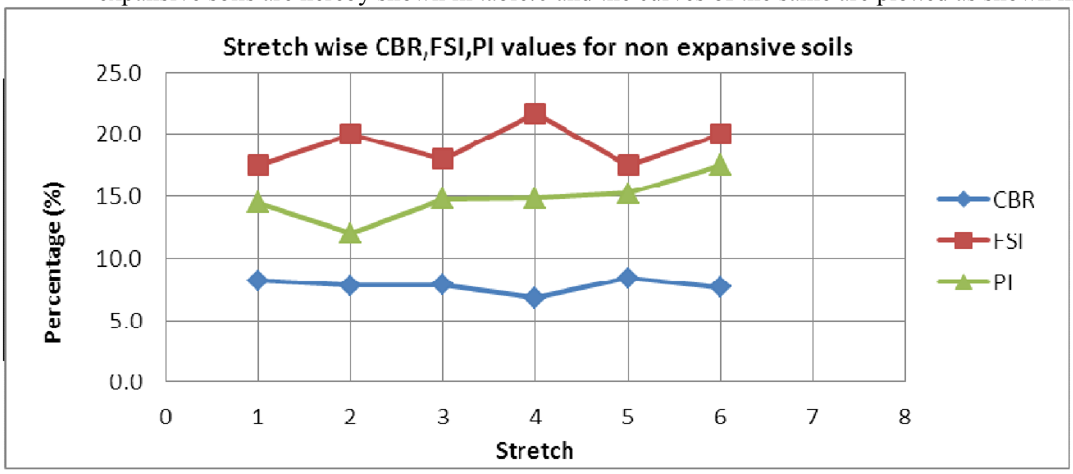


**Fig:4 CBR,FSI & PI plots for different stretches.**

### 4.1.2 Borrow Earth Samples

The summarized lab test results on borrow earth material on the stretches chosen for non-expansive soils are hereby shown in table:7 and the curves of the same are plotted as shown in Fig:5

Table:7 Borrow earth for Subgrade average values of CBR, FSI and PI for Stretch-1 to Stretch-6

| Stretch | CBR | FSI | PI |
|---|---|---|---|
| S1 | 11.1 | 10.0 | 17.0 |
| S2 | 12.1 | 10.0 | 14.0 |
| S3 | 10.8 | 10.0 | 18.0 |
| S4 | 10.6 | 10.0 | 17.0 |
| S5 | 12.9 | 10.0 | 14.0 |
| S6 | 13.7 | 10.0 | 12.0 |

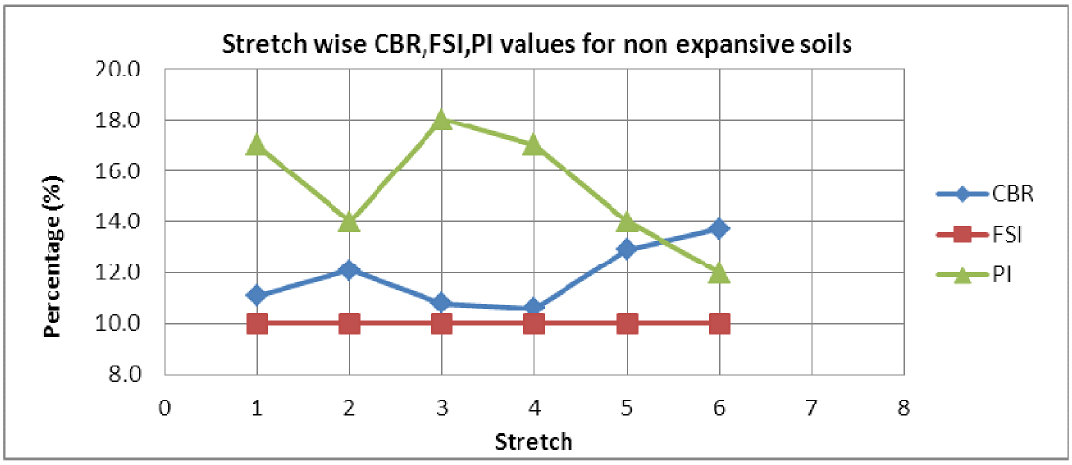


**Fig:5 CBR, FSI and PI plots for different stretches for borrow earth.**

## 4.2 Field Test Results

### 4.2.1 Roughness Index

The field test result in respect of Roughness Index are summarized and shown in table:8&9 and plots are shown in Fig:6&7

Table: 8 Average values of Roughness Index during the 5 years period for Stretch-1 to Stretch-6

| Stretch | Roughness Index (mm/km) | |
|---|---|---|
| | Before Monsoon | After Monsoon |
| S1 | 1649 | 1750 |
| S2 | 1688 | 1769 |
| S3 | 1706 | 1797 |
| S4 | 1726 | 1822 |
| S5 | 1754 | 1893 |
| S6 | 1851 | 1955 |

Civil and Environmental Research
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol.2, No.8, 2012


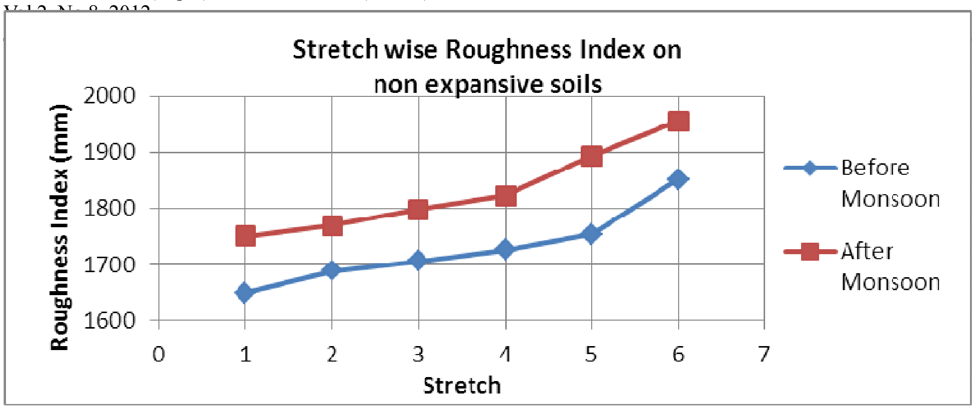


Fig.6 Trend of Roughness performance for Stretch-1 to Stretch-6

Table: 9 Year wise Roughness Index up to 5years period

| Year | Before Monsoon | After Monsoon |
|---|---|---|
| 2006 | 1570 | 1677 |
| 2007 | 1713 | 1815 |
| 2008 | 1843 | 1933 |
| 2009 | 1968 | 2062 |
| 2010 | 2133 | 2283 |

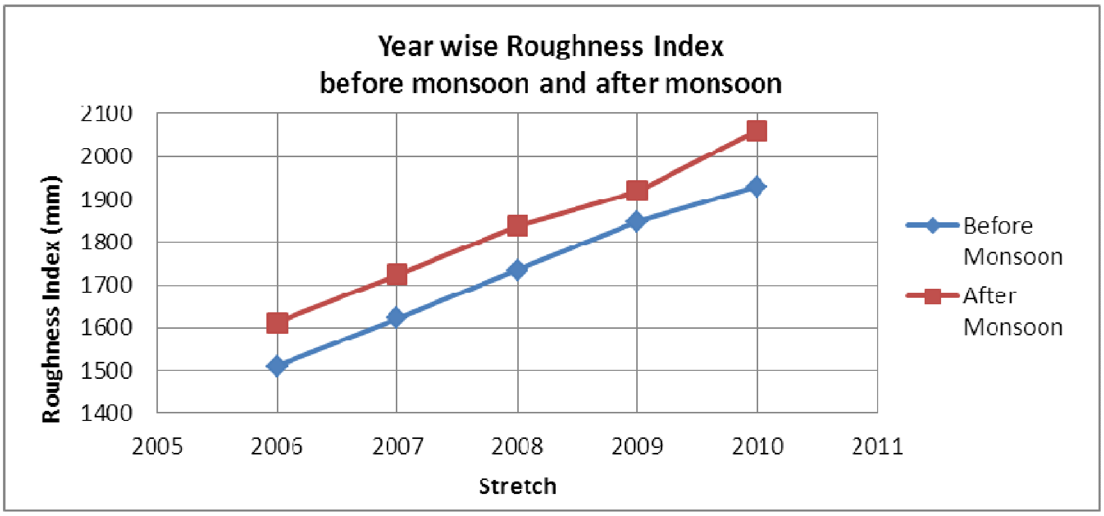


**Fig: 7 Trend of Roughness Index over period of 5 years.**

From the above tables and plots, it can be seen that Roughness index of the pavement increases with time and also Rough ness index is more after monsoon season when compared with the before monsoon season due to volumetric changes in Subgrade soil

Table:10 Variation of Roughness Index in 2006 & 2010(before and after Monsoon) for Stretch-1 to Stretch-6

| Stretch | Roughness Index (mm/km) | | | |
|---|---|---|---|---|
| | 2006 (Before Monsoon) | 2006 (After Monsoon) | 2010 (Before Monsoon) | 2010 (After Monsoon) |
| S1 | 1450 | 1525 | 1820 | 1990 |
| S2 | 1510 | 1575 | 1860 | 1970 |
| S3 | 1500 | 1612 | 1880 | 2000 |
| S4 | 1490 | 1650 | 1910 | 2010 |
| S5 | 1460 | 1600 | 2020 | 2190 |
| S6 | 1650 | 1710 | 2085 | 2210 |

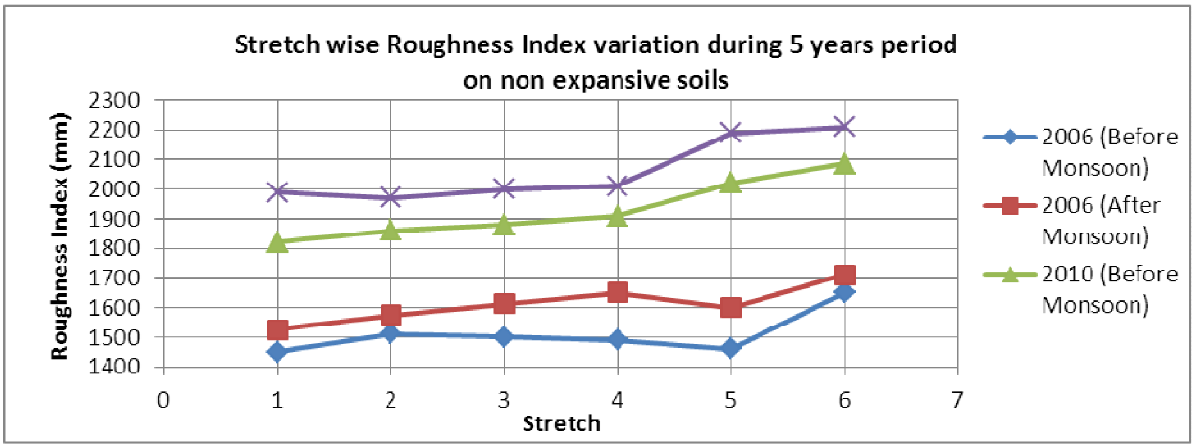


**Fig: 8 Trend of Roughness index at the beginning and at the end before monsoon and after monsoon.**

The trend line shows the increase of Roughness index with age and also increase of roughness index after Monsoon

### 4.2.2 Benkelman Beam deflection Test

The values obtained from the field at various locations are summarized and shown in table:11&12 and the plots are shown in Fig:9&10

Table:11 Average values of Deflection during the 5 years period for Stretch-1 to Stretch-6

| Stretch | Deflection (mm) | |
|---|---|---|
| | Before Monsoon | After Monsoon |
| S1 | 0.471 | 0.507 |
| S2 | 0.532 | 0.578 |
| S3 | 0.53 | 0.587 |
| S4 | 0.525 | 0.583 |
| S5 | 0.521 | 0.568 |
| S6 | 0.511 | 0.551 |

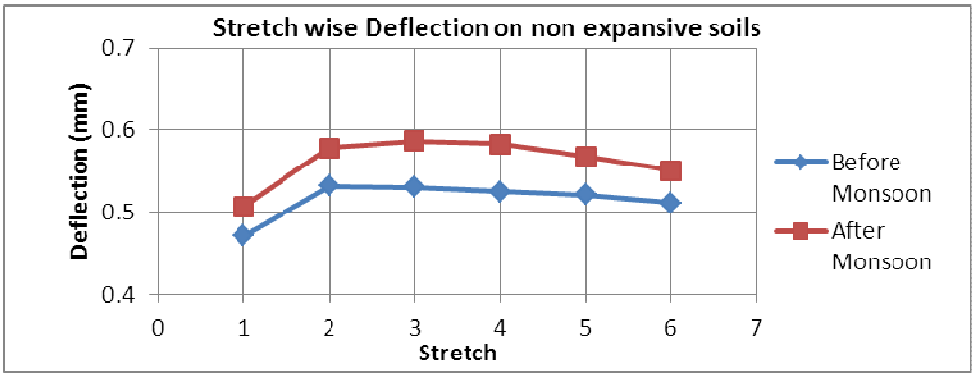


Fig.9 shows the trend of Deflection performance for Stretch-1 to Stretch-6

Table: 12 Average values of Deflection during the 5 years period (before Monsoon &After Monsoon)

| Year | Before Monsoon | After Monsoon |
|---|---|---|
| 2006 | 0.366 | 0.389 |
| 2007 | 0.414 | 0.458 |
| 2008 | 0.488 | 0.544 |
| 2009 | 0.594 | 0.659 |
| 2010 | 0.713 | 0.762 |

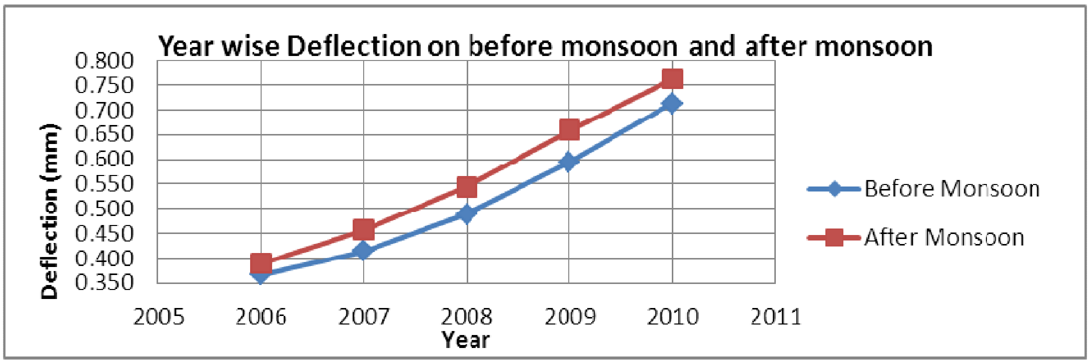


**Fig: 10 Trend of Deflection values over a period of 5 years.**

The above plots shows the increase of Deflection with age and also increase in Monsoon season

Table 13 Variation of Roughness Index in 2006&2010 for Stretch-1 to Stretch-6

| Stretch | Deflection (mm) | | | |
|---|---|---|---|---|
| | 2006 (Before Monsoon) | 2006 (After Monsoon) | 2010 (Before Monsoon) | 2010 (After Monsoon) |
| S1 | 0.352 | 0.385 | 0.650 | 0.675 |
| S2 | 0.375 | 0.415 | 0.720 | 0.758 |
| S3 | 0.354 | 0.375 | 0.740 | 0.788 |
| S4 | 0.365 | 0.375 | 0.725 | 0.815 |
| S5 | 0.375 | 0.385 | 0.725 | 0.788 |
| S6 | 0.375 | 0.398 | 0.715 | 0.745 |

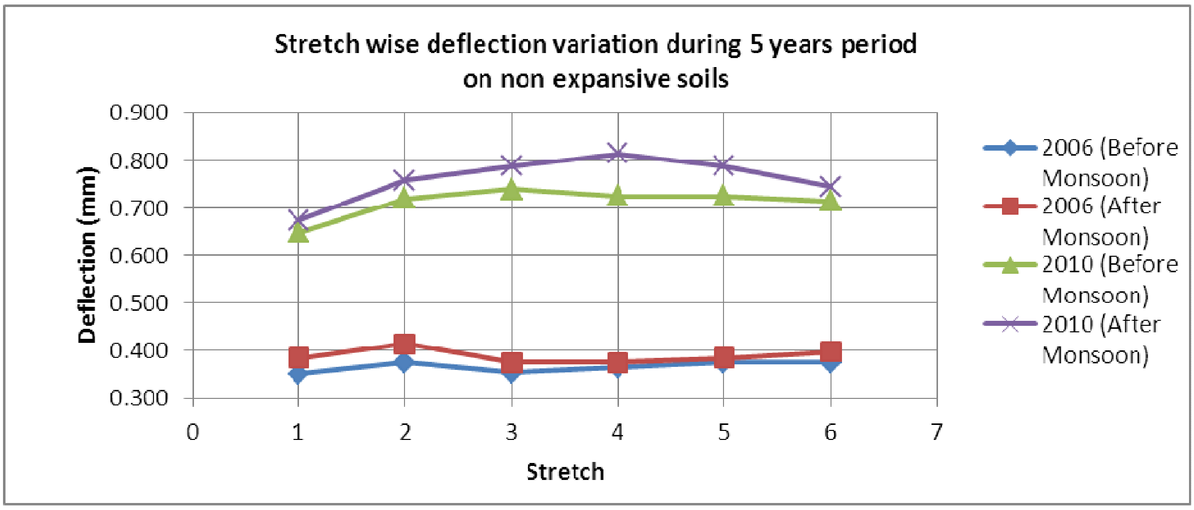


**Fig: 11Trend of deflections before monsoon and after monsoon at the beginning and at the end of the period.**

The above plot reflects the increase in deflection of pavement with age and also increase of deflection after Monsoon season

## 5. Conclusions

The following conclusions can be drawn based on the laboratory and field results made in this investigation

1. The nature of existing ground and the Quality of materials used in the Subgrade plays a very important role in the riding quality and structural stability of the pavements
2. The CBR value of ground and Borrow earth used for subgrade is the key factor which will influence the roughness index and deflection of pavements. More the CBR valve less the above and vice versa.
3. The Roughness index and deflection of pavement increases due to aging of pavement
4. The values of Roughness index and Deflection generally higher after monsoon season due to volumetric changes in the soil
5. The increase in Roughness index after monsoon is observed from 6 to 7% and the increase in Deflection is observed from 8to 9%
6. The rate of increase of Roughness index is observed from 9-10% with age and rate of increase of Deflection is observed from 14-20%

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