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Analysis of Box Girder Bridge with different Instrumentation Techniques

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ABSTRACT

Whenever structure is built, it is always aimed that it should withstand for minimum of 100 years or more than that. But due to some environmental, seismic or dynamic effects, the structure gets deteriorated soon which leads to the catastrophic failure of structure. There are many methods developed so far to detect the structural damage, such as visual inspection, non-destructive methods, such as rebound hammer, acoustic emission etc. but now more efficient and easy methods are developed which also are a type of non-destructive inspection which includes the use instrumentation the whole process is called Structural Health Monitoring(SHM). Instrumentation involves many sensors and other equipment's which are installed in the bridges and other structures at the time of construction only. In present study LokNayakSetu Bridge located in New Delhi has been considered for identification, estimation of present structural capacity and remaining life was performed at each stage. The bridge was extensive instrumented in 1997, which helps in continuous monitoring of the bridge.

1. Introduction

Strength and life of the structure are two basic aims with which any concrete structure is built. But due to loading, vibrations and environmental affects the strength and durability of the structure. To minimize these effects proper steps should be taken for better life of concrete structures. Using sensors and different techniques for evolution of structure is a quick assessment technique for the health monitoring of the structure without any physical damage. The present study will benefit the concern department of the bridge undertaken in maintenance of the structure. Now a day's continuous monitoring of structure has become one of the important task to ensure the safety of the public users mainly on the bridges. Varying environment condition, aging of material and the impact due to heavy loading on bridges cause deterioration that effect the strength of the bridge. Monitoring helps in providing necessary information to repair rehabilitate, limit the vehicular traffic, abandon or replace the existing bridge. Deflection of the bridge is one of the important factors which should be monitored at regular interval as its catastrophic failure may cause large damage to life as well as economy to reconstruct. In the present study S.H.M. of Lok Nayak Setuhas been done. The process of investigating and detecting the structural damage of existing bridges and buildings using different equipment's is termed as structural health monitoring (SHM). There are many methods developed so far to detect the structural damage, such as visual inspection, non-destructive methods, such as rebound hammer, acoustic emission etc. but now more efficient and easy methods are developed which also are a type of non- destructive inspection which includes the use instrumentation. A.C. Neves *et al.*,(2017) has presented a model-free damage detection approach based on machine learning techniques. Dhawan S.K. *et al.*,(2013) discussed about the recent advancement in SHM on EMI based techniques, using PZT patches and used ultrasonic vibration ranged between 0-400kHz frequency range to acquire the defect. This method is applied on the data which has been collected from the dynamic response of the structure and this method uses 3-D F.E.M. model to do numerical analysis of a railway bridge with very less friction to get its structural condition. In California method for real time remote monitoring of bridge deflections by testing feasibility of approach on two different highway bridges: a pre-stressed concrete box girder bridge in California and a concrete slab on steel girder bridge in Illinois K. helmi *et al*., (2015). This bridge is built over River Yamuna at I.T.O., New Delhi in the year 1996 and has been instrumented with many advanced sensors which help in knowing the various performance and stability factor easily. Goyal J.K in 2013 has explained the importance and necessity of bridges in the existing road network, and also the need of bridges scientific monitoring i.e. S.H.M. the author explained the structure of bridge information system which is under development at CSIR-CRRI and has also explained the different metrics such as acceleration, cracking, tilt, scour, corrosion, etc. Sensors are the new technology in this developing generation in the field of health monitoring which makes the work easier and efficient.

1.2 Brief About Lok Nayak Setu

LokNayakSetu is the first four lane single cell simply supported box girder bridge built in across River Yamuna at I.T.O., New Delhi as per the codal provision of the country to perform satisfactorily. This bridge has 13 spans of simply supported pre-stressed box girder (about 40m each) and 2 end spans of reinforced concrete of 20m each. It deck is about 16.3m wide single cell box girder and 14.5m wide 4-lane carriageway. LokNayakSetu since the day it was constructed with the aim to do instrumentation of the superstructure for long term monitoring of the performance of bridge through, measurement of several structural parameters such as strain, temperature gradient, deflection profile etc. from the construction stage itself (Sahu G.K. *et al*., 2014) The general arrangement of bridge is shown in Fig1.1 and cross section of box girder is shown in Fig1.2.

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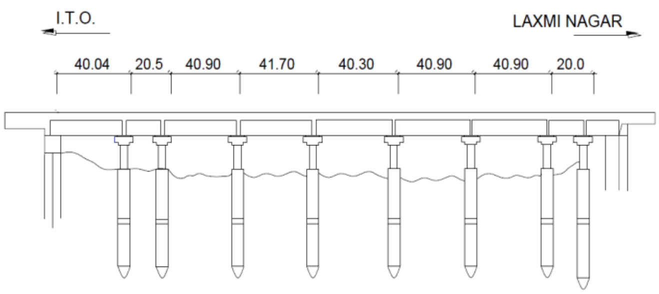

Fig1.1: General arrangement of LokNayakSetu, New Delhi

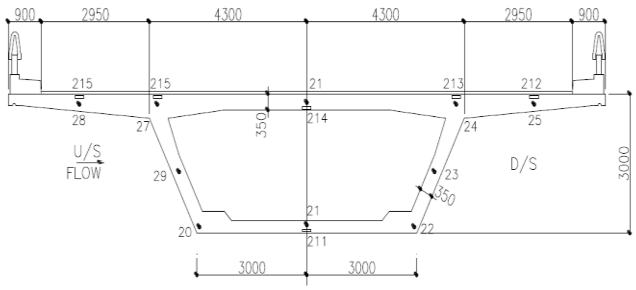

Fig1.2: Cross-section of box girder along with scheme of instrumentation for sensors

1.3 Objective of the Study

The main objectives of the study are:

- Defining the limits of the deflection and stress parameter of the LokNayakSetuby using the VW strain gauge and N3 precision level, installed on the bridge since the time of construction.
- Vibration analysis of LokNayakSetu, New Delhi.

1.4 Instrumentation Scheme

The instruments which are helpful in monitoring the various several parameters of the bridges such as deflection, tilting of pier, temperature of girder and strain produced in the girder shown in Table 1.1.

Table 1.1: Details of comprehensive instrumentation in box girder no. 3

No.	Parameters	Instrument/Sensors	Location	No. of Sensors installed
1.	Longitudinal Strain	V.W. Embedment strain gauges	Mid-span and quarter span sections	10x1=10 10x2=20 Total=30
2.	Transverse Stain	V.W. Embedment strain gauges	Mid-span and quarter span sections	18[6x3]
3.	Deflection Profile	N-3 Precision Level and benchmark plates	Uniformly spaced points on soffit slab along the girder axis	5

1.4.1 N3 Precision Level

In Lok Nayak Setu it has been used to monitor the deflection profile of the girders. It is done by fixing a benchmark point on the pier head by installing five stainless steel plates on the soffit slab in all girders to monitor their deflection.

Fig 1.3: Pictorial view of N3 precision level for deflection measurement

1.4.2 V.W. Strain Gauges

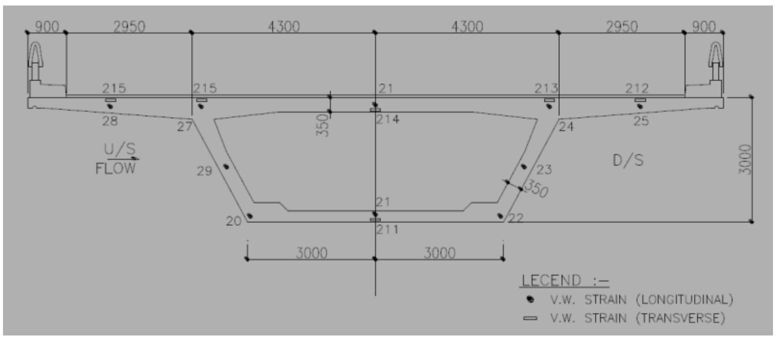

Fig 1.4: Positioning of strain gauges in box girder no. 3

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In Lok Nayak Setu a total of about 48 sensors are installed in 3 sections in box girder no. 3, each having 16 sensors. The strain gauges are installed longitudinally and transversally both which can be seen in Fig 1.4.

2. Methodology

The methodology followed for defining the limits is as follow:-

- Firstly, the basic of SHM and uses of all its instruments were studied using different-different manuals and some other sources, and also to know that how they are operated.
- The geometrical study of bridge was made.
- Study of the instrumentation scheme of box girder no. 3 was made.
- Analysis of the available readings of stress and deflection parameters to determine the limits.
- The diurnal and seasonal variation of the stresses and deformation will be studied.
- Coefficient of elasticity or "E" value will be calculated as per the concrete grade using IS 456:2000.
- The E value will be used for converting strain parameter to stress.
- Finally using all the data obtained. The limits of stresses and deformation will be carried out which will be applicable for all similar type of girders in Delhi zone.

The process involved for determining the range of stress and deflection parameter is shown in Fig 2.1

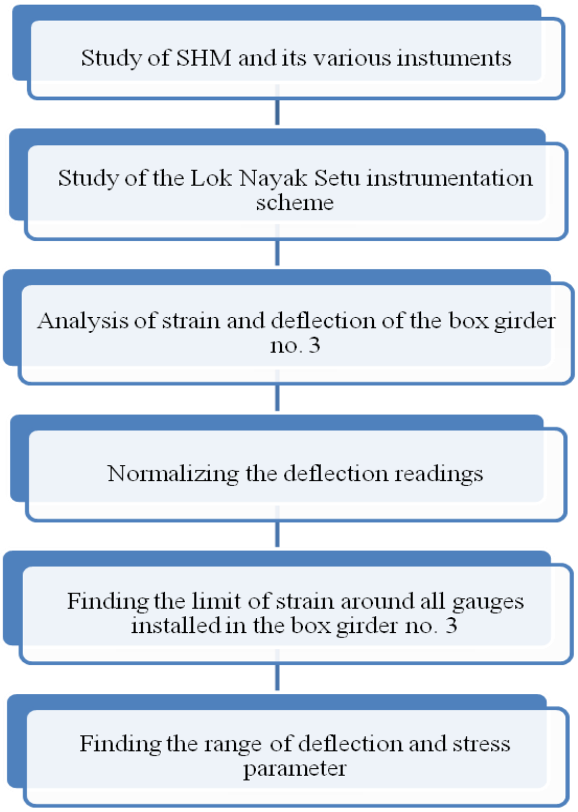

Fig 2.1: Step by step process involved for determining the limits

3. 3. Analysis and Results

3.1 Analysis of deflection parameter

An N-3 precision level was used to monitor the deflection profile of the girders. The deflection profile of each girder was monitored with respect to the bench mark point fixed at its pier head. Five stainless steel plates were installed on the soffit slab in all the girders to monitor their deflection profiles. The deflection profiles of the girders were monitored in the following stages to get the desired range.

- During peak summer, and
- During peak winter.

3.1.1 Peak Summer Study

To study the deflection profile of the of the girder no. 3(situated at mid span) the readings of the following year is taken when temperature has been very high in that year i.e. of the year 1999, 2000, 2001 and 2002. The deflection profile of the girder in mentioned year is shown in Figure 3.1 to 3.4 and the various observed readings are firstly normalized as their available some deflection over the pier because of bench mark available at some other point and deflection of girder measured with reference to its fixed ends which must be 0mm. Normalized deflection for all 4 years is given in Table 3.1 to 3.4

Table 3.1: Peak summer normalized defection in box girder no. 3 during the year 1999

Date	13/6	13/6	13/6	13/6	13/6	13/6	13/6	14/6
Distance(m)	500hrs	0700hrs	930hrs	1200hrs	1430hrs	1730hrs	2130hrs	0100hrs
B.M.	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
9	0	-0.34	-0.5	1.01	2.75	3.27	2.13	1
18	0	-0.49	-0.94	1.1	3.53	4.54	2.85	1.48
27	0	-0.3	-0.62	0.85	2.69	3.25	2.25	1.1
36	0	0	0	0	0	0	0	0

Table 3.2: Peak summer normalized defection in box girder no. 3 during the year 2000

Date	6/04	6/04	6/04	6/04	6/04	6/04	7/04	7/04	7/04
Distance(m)	0900hrs	1200hrs	1400hrs	1600hrs	1930hrs	2230hrs	0200hrs	0500hrs	0700hrs
P1(B.M)	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
9	0	1.04	2.08	2.1	0.36	-0.23	-0.75	-1.36	-1.28
18	0	1.32	2.94	3.15	0.55	-0.43	-0.75	-1.56	-1.71
27	0	1.22	2.18	2.25	0.49	-0.38	-0.73	-1.33	-1.17
36	0	0	0	0	0	0	0	0	0
P2 (42)	0	0	0	0	0	0	0	0	0

Table 3.3: Peak summer normalized defection in box girder no. 3 during the year 2001

Date	17/6	17/6	17/6	18/6		17/6	17/6	17/6	18/6
Distance(m)	0815hrs	1300hrs	1800hrs	0640hrs		0815hrs	1300hrs	1800hrs	0640hrs
P1(B.M.)	0	0	0	0		0	0	0	0
0	0	0	0	0		0	2.7	2.44	0.91
9	0	1.94	2.52	0.35		0	3.12	2.94	0.97
18	0	2.74	3.53	0.3		0	2.42	2.37	0.74
27	0	2.22	2.37	0.02		0	0	0	0
36	0	0	0	0		0	3.33	2.85	0.75
42	0	0	0	0		0	3.23	3.04	1.5

Table 3.4: Peak summer normalized defection in box girder no. 3 during the year 2002

Date	9/6	9/6	9/6	10/6		9/6	9/6	10/6
Distance(m)	0730hrs	1230hrs	1650hrs	0730hrs		0800hrs	1725hrs	0740hrs
B.M.	0	0	0	0		0	0	0
0	0	0	0	0		0	3.48	0.6
9	0	1.67	3.52	-0.34		0	4.79	1.01
18	0	2.42	4.88	-0.26		0	3.38	0.56
27	0	2.22	3.44	-0.26		0	0	0
36	0	0	0	0		0	3.62	0.96
42	0	0	0	0		0	6.01	0.63

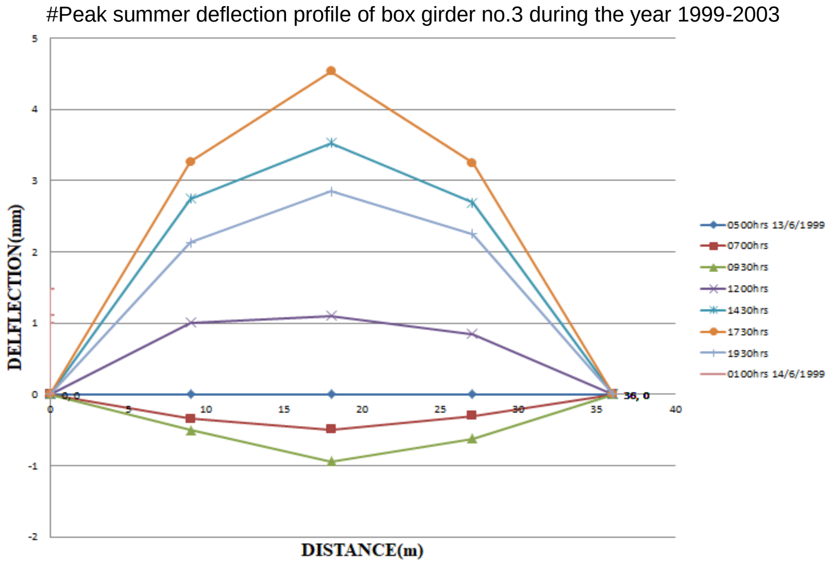

Fig3.1: Deflection Profile of Girder No. 3 During Peak Summer in the year 1999

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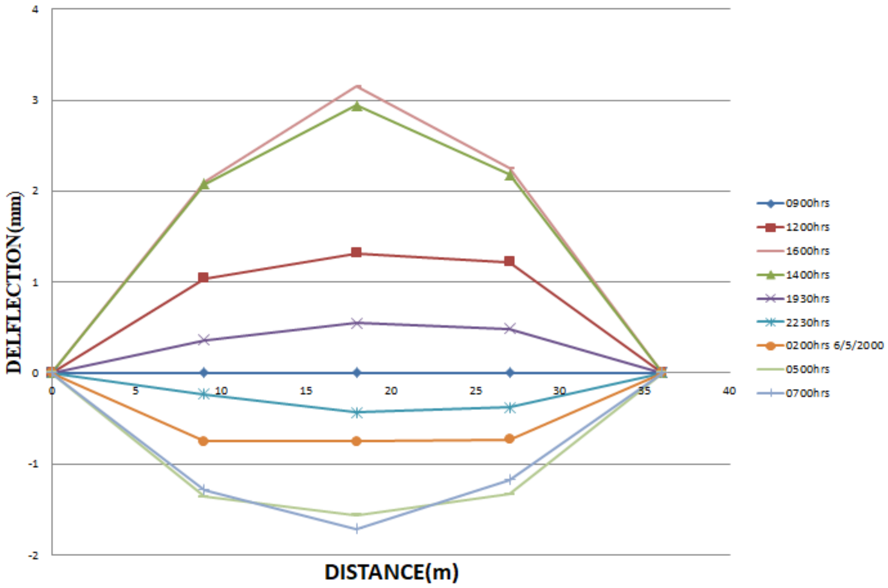

Fig3.2: Deflection Profile of Girder No. 3 During Peak Summer in the year 2000

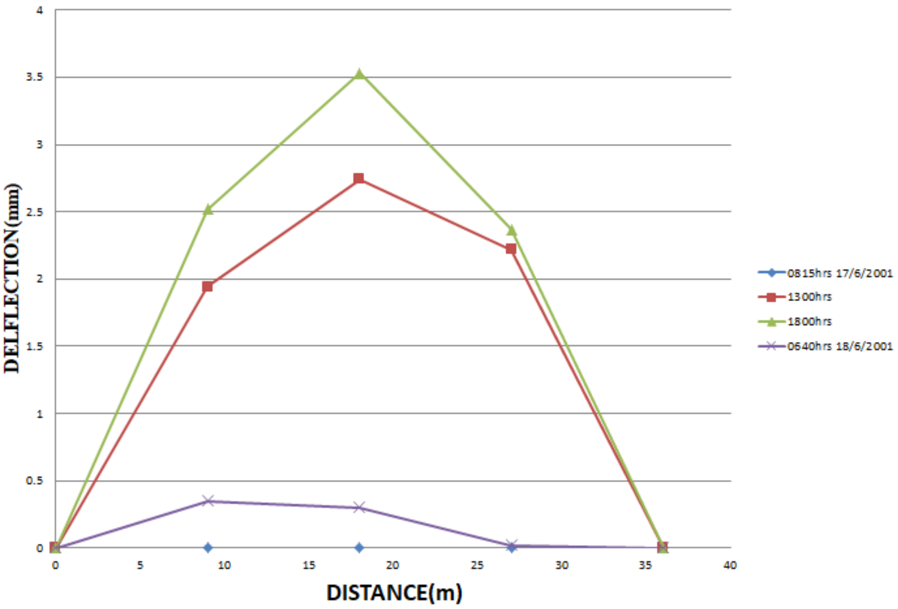

Fig3.3: Deflection Profile of Girder No. 3 During Peak Summer in the year 2001

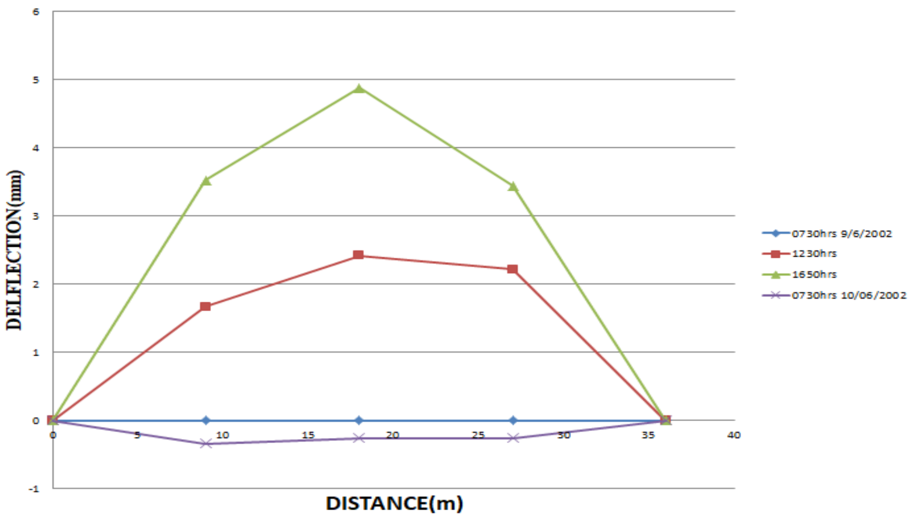

Fig3.4: Deflection Profile of Girder No. 3 During Peak Summer in the year 2002

#Maximum and minimum value of the deflection during peak summer during year1999-2003

Table 3.5: Maximum normalized deflection during peak summer on box girder no. 3 during the year 1999-2003

			MAXIUM			
Year	**1999-2000**	**2000-1**	**2001-2**		**2002-3**	
Distance			**TOP**	**SOFFIT**	**TOP**	**SOFFIT**
B.M.	0	0	0	0	0	0
0	0.4	0.33	0.24	2.7	0.98	3.48
9	3.81	2.24	2.1	3.2	4.01	4.79
18	4.54	3.15	2.74	2.7	4.88	4.02
27	3.33	2.45	2.38	0.7	3.72	2.46
36	0.18	0.41	0.33	3.3	0.56	3.62
42	-----	0.55	0	3.24	0	6.01

Table 3.6: Minimum normalized deflection during peak summer on box girder no. 3 during the year 1999-2003

			MINIMUM			
Year	**1999-2000**	**2000-1**	**2001-2**		**2002-3**	
Distance			TOP	SOFFIT	TOP	SOFFIT
B.M.	0	0	0	0	0	0
0	-0.53	-0.21	0	0	-0.34	0
9	-0.76	-1.47	0	0	-0.51	0
18	-0.94	-1.71	0	0	-0.26	0
27	-0.83	-1.33	0	0	-0.47	0
36	-0.54	-1.15	0	0	-0.42	0
42	------	-0.81	-0.07	0	-0.66	0

3.1.2 Peak Winter Study

To study the deflection profile of the of the girder no. 3(situated at mid span) the readings of the following year is taken when temperature is very low in that year i.e. of the year 2000, 2001, 2002 and 2003. The deflection profile of the girder in mentioned year can be seen fromFig4.5 to 4.8 and the normalized readings from obtained readings are shown in Table 4.7 to 4.10:

#Readings:

Table 3.7: Peak winter normalized defection in box girder no. 3 during the year 2000

Date	**9th Jan**	**9th Jan**	**9th Jan**	**9th Jan**	**10th Jan**	**10th Jan**
Distance(m)	**0900hrs**	**1500hrs**	**1900hrs**	**0000hrs2**	**0500hrs**	**0700hrs**
B.M.	0	0	0	0	0	0
0	0	0	0	0	0	0
9	0	0.37	0.23	-0.05	-0.42	-0.34
18	0	0.47	0.36	-0.1	-0.64	-0.73
27	0	0.41	0.2	-0.1	-0.48	-0.57
36	0	0	0	0	0	0

Table 3.8: Peak winter normalized defection in box girder no. 3 during the year 2001

Date	**7th Jan**	**7th Jan**	**7th Jan**	**8th Jan**	**8th Jan**
Distance(m)	0800hrs	1500hrs	2100hrs	0000hrs2	0500hrs
B.M.	0	0	0	0	0
0	0	0	0	0	0
9	0	2.07	1.52	1.16	0.3
18	0	2.51	1.79	1.24	0.35
27	0	2.07	1.63	1	0.3
36	0	0	0	0	0
42	0	0	0	0	0

Table 3.9: Peak winter normalized defection in box girder no. 3 during the year 2002

Date	**20th Jan**	**20th Jan**	**21th Jan**	**20th Jan**	**20th Jan**	**21th Jan**
Distance(m)	0830hrs	1630hrs	0650hrs	0900hrs	1700hrs	0700hrs
B.M.	0	0	0	0	0	0
0	0	0	0	0	2.04	0.35
9	0	2.78	0.3	0	2.88	0.97
18	0	3.88	0.5	0	1.87	0.36
27	0	2.85	0.29	0	-0.41	0
36	0	0	0	0	2.69	0.89
42	0	0	0	0	3.14	1.08

Table 3.10: Peak winter normalized defection in box girder no. 3 during the year 2003

Date	19th Jan	19th Jan	19th Jan	20th Jan		19th Jan	19th Jan	19th Jan	20th Jan
Distance(m)	0830hrs	1500hrs	1715hrs	0630hrs		0915hrs	1530hrs	1740hrs	0700hrs
B.M.	0	0	0	0		0	0	0	0
0	0	0	0	0		0	1.24	1.44	0.86
9	0	1.44	1.56	0.59		0	1.4	1.46	0.49
18	0	2.06	2.12	0.88		0	1.14	1.14	0.63
27	0	1.47	1.74	0.78		0	0	0	0
36	0	0	0	0		0	1.54	1.33	0.53
42	0	0	0	0		0	1.38	1.36	0.48

#Deflection profile of the girder no. 3 during peak winter in the years 1999-2003

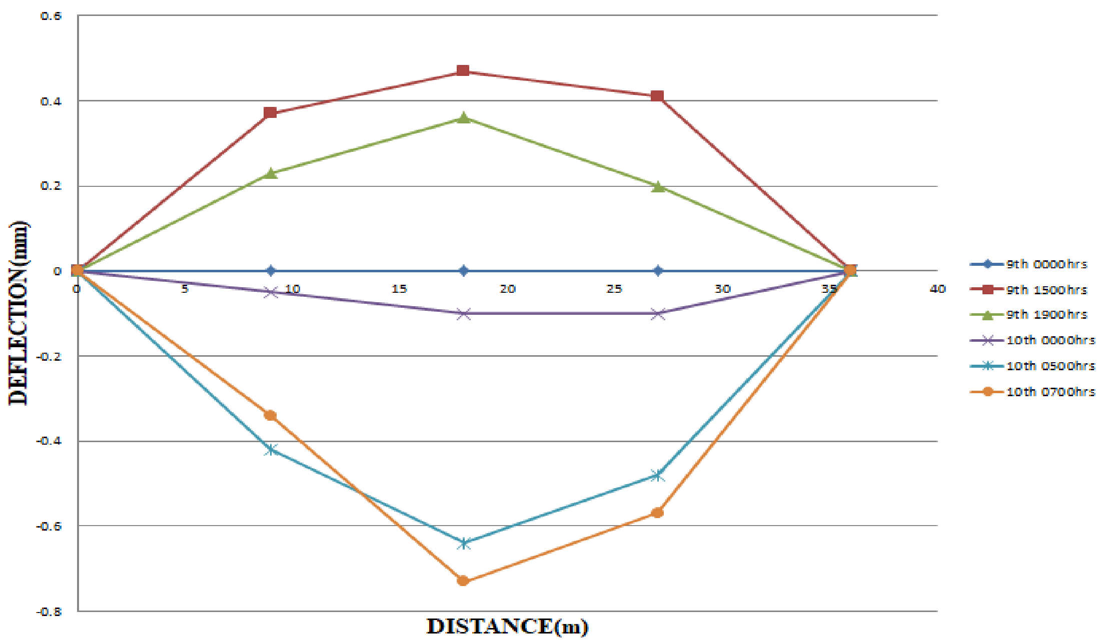

Fig3.5: Deflection profile of girder no. 3 during peak winter in the year 2000

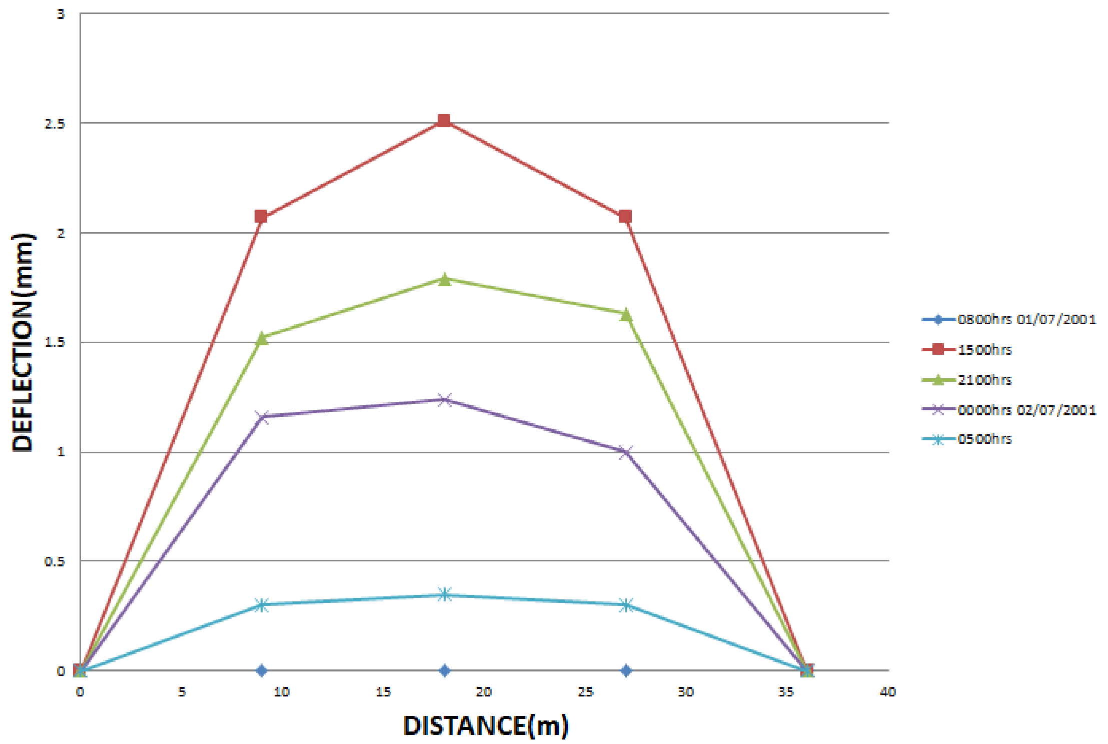

Fig3.6: Deflection profile of girder no. 3 during peak winter in the year 2001

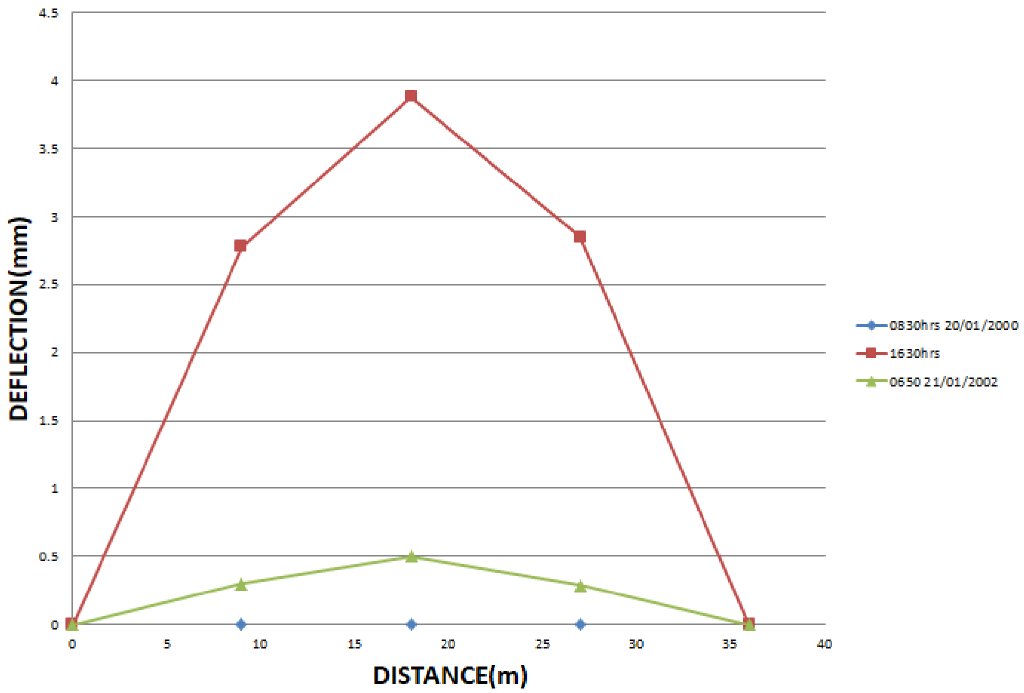

Fig3.7: Deflection profile of girder no. 3 during peak winter in the year 2002

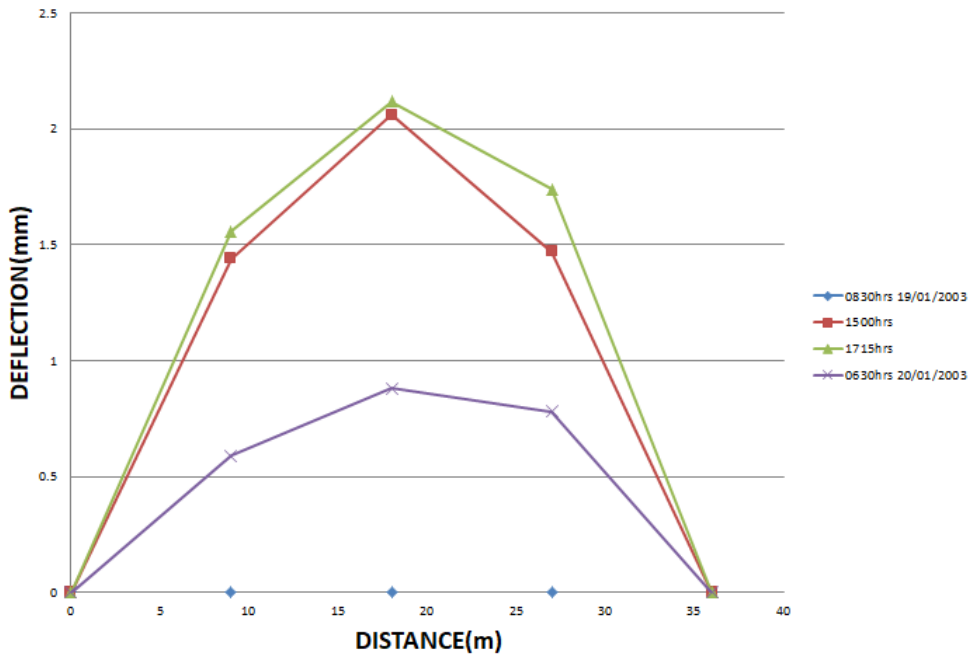

Fig3.8: Deflection profile of girder no. 3 during peak winter in the year 2003

#Maximum and minimum value of the deflection during peak Winter during year 1999-2003

Table 3.11: Maximum normalized deflection during peak winter on box girder no. 3 during the year 1999-2003

			MAXIMUM			
Year	**1999-2000**	**2000-1**	**2001-2**		**2002-3**	
Distance			**TOP**	**SOFFIT**	**TOP**	**SOFFIT**
B.M.	0	0	0	0	0	0
0	0.13	0.16	0.4	2.04	0.4	1.44
9	0.43	2.1	3.94	2.88	1.71	1.46
18	0.47	2.5	3.88	1.87	2.12	0.76
27	0.58	2	3.11	1.56	2.02	0
36	0.34	0.4	0.52	2.69	0.7	1.54
42		0.12	0.29	3.14	0.67	1.38

Table 3.12: Minimum normalized deflection during peak winter on box girder no. 3 during the year 1999-2003

			MINIMUM			
Year	**1999-2000**	**2000-1**	**2001-2**		**2002-3**	
DISTANCE			TOP	SOFFIT	TOP	SOFFIT
B.M.	0	0	0	0	0	0
0	-0.1	0	0	0	0	0
9	-0.7	0	0	0	0	0
18	-0.7	0	0	0	0	0
27	-0.48	0	0	-0.41	0	-0.76
36	-0.1	-0.1	0	0	0	0
42		-0.12	-0.35	0	0	0

4. Results

4.1 Result of monitoring deflection:

After analyzing the various readings during peak summer and peak winter in the year 1999-2003, it is concluded that the maximum and minimum deflection is at the center of the girder no. 3 i.e. 18m from the pier. Since in the girder no. 3 the maximum and minimum deflection is at center only, a graph is generated using normalized deflection observation readings in the various years which are shown in Fig 4.1 of peak summer changes and in Fig 4.2 for peak winter changes in profile.

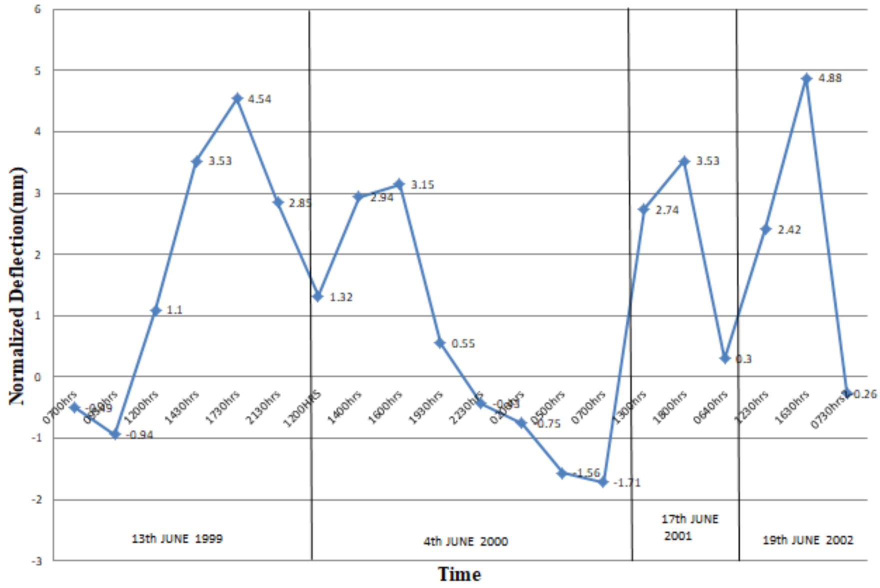

Fig 4.1: Deflection profile of center of the girder no. 3 during summer in various years

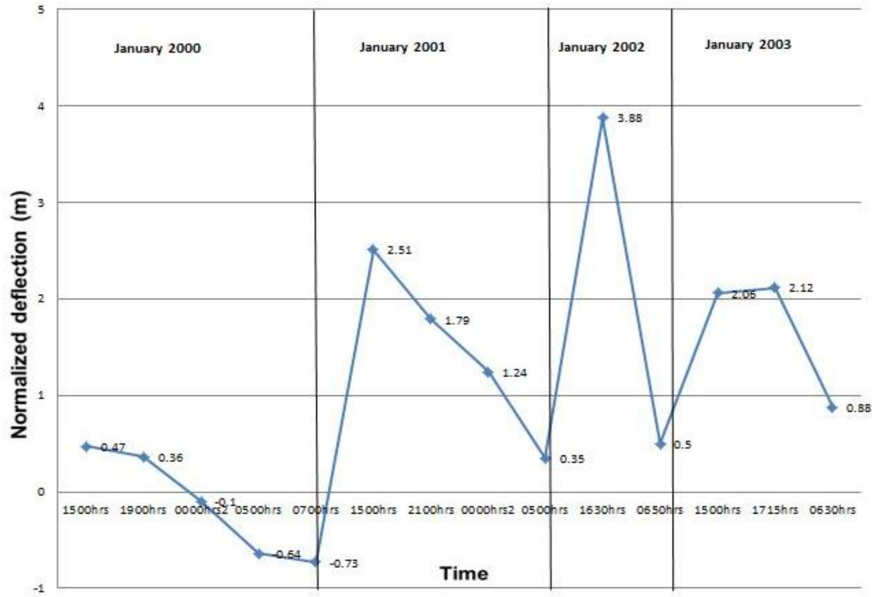

Fig 4.2: Deflection profile of center of the girder no. 3 during winter in various years

4.1.1 Interpretation:

With the help of graphs in Fig 4.9 and 4.10, range of the deflection i.e. 4.88mm during compression and 1.71 during tension is identified. This range will be helpful for all surveyors or engineers to identify that the girder needs to be retrofitted or not i.e. if the deflection is inside the given range the girder is okay and if it exceeds the range a brief analysis of the girder would be made or retrofitting work should made. The range can be used for similar type of girders in Delhi zone. Using the initial or reference R.L. of the center of the girder i.e. 101.2906m.The limits obtained for the deflection is RL 101.2955m – RL 101.2889m.

4.2 Results Of Monitoring Strain Parameters

Out of that data the maximum and minimum strain which is produced in that particular year is taken for each and every working gauge since 1999 during peak winter as well as in peak summer and hence graphs are obtained for different-different gauges which are shown from Fig 4.3 to Fig 4.18

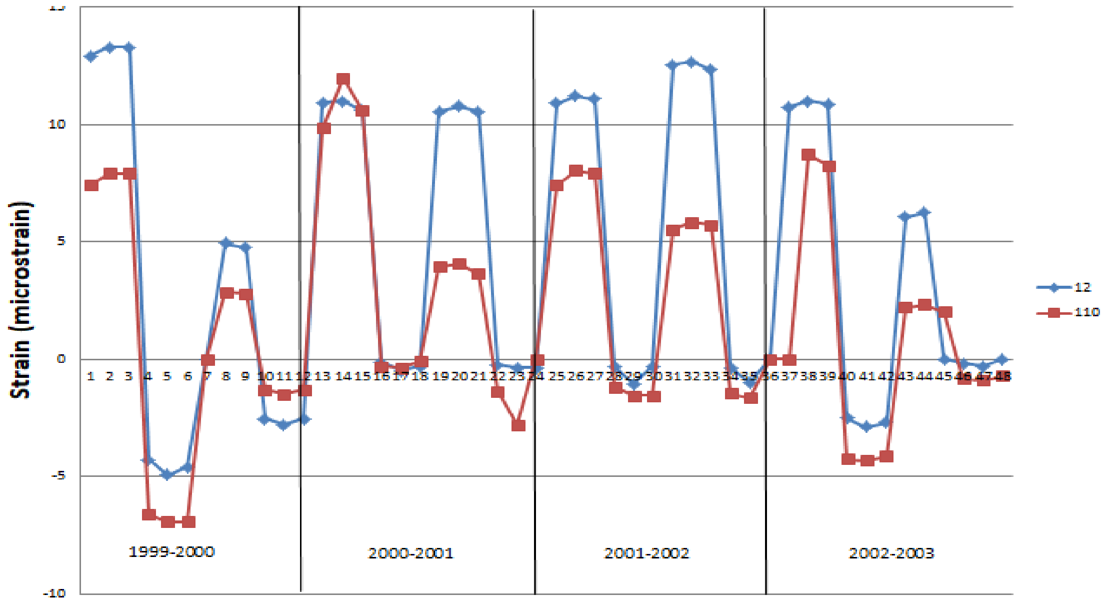

Fig 4.3 Strain variation during 1999-2003 at the soffit slab atsection 1 of girder no.3

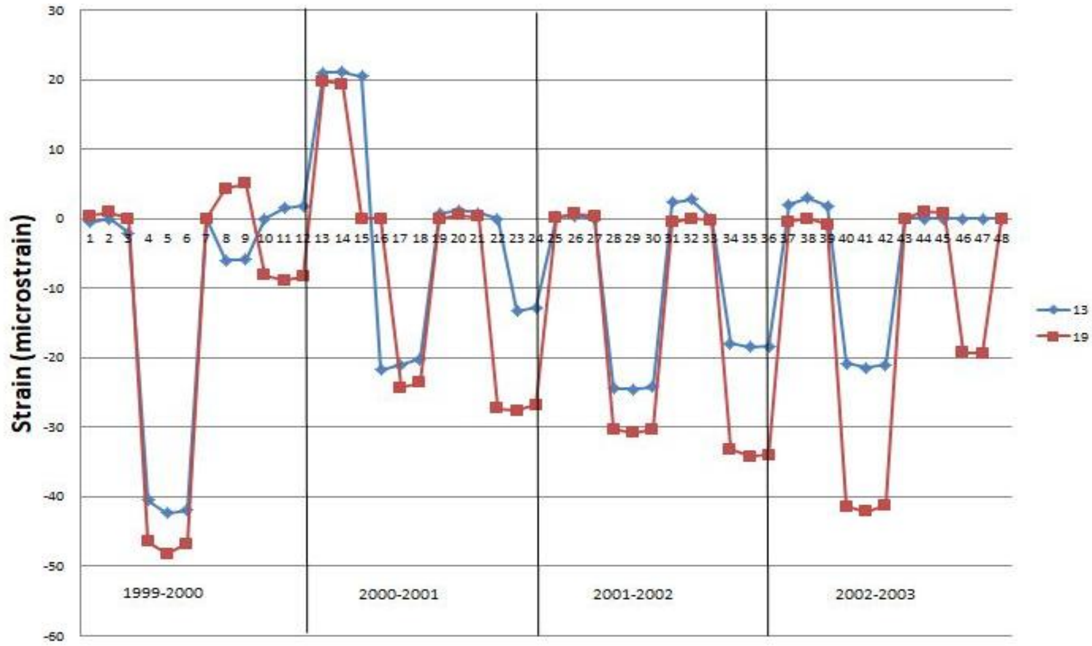

Fig 4.4: Strain variation during 1999-2003 at the centre of webs at section 1 of girder no. 3

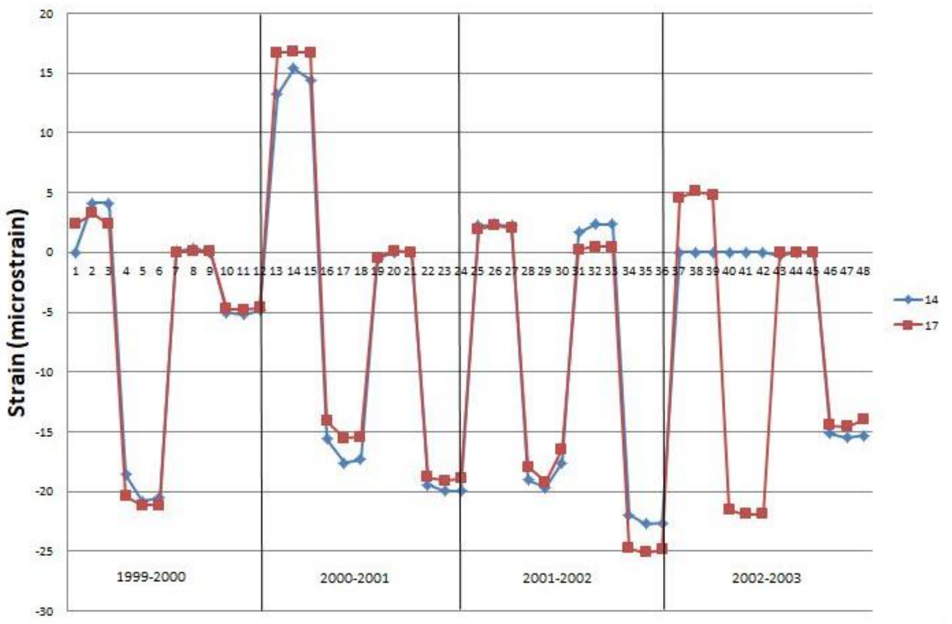

Fig 4.5: Strain variation during 1999-2003 at the junction of webs & deck slab at section 1 of girder no. 3

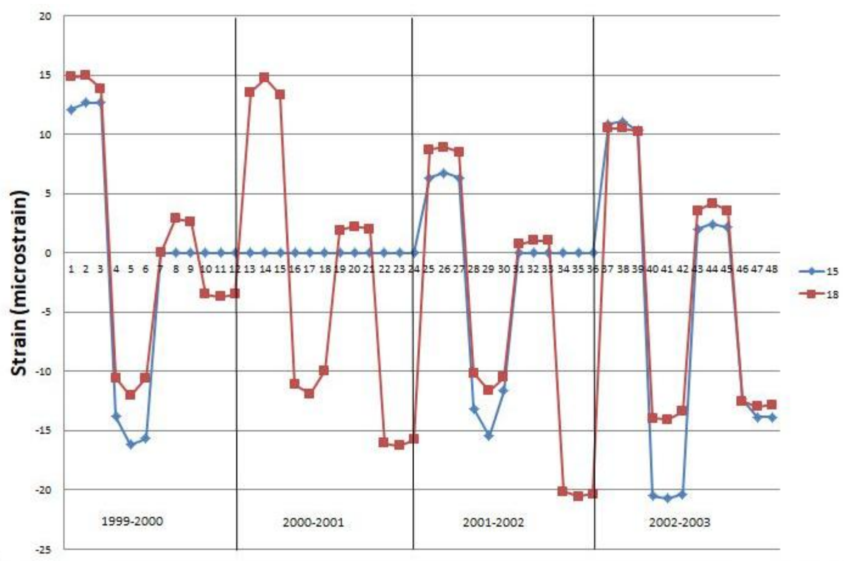

Fig 4.6: Strain variation during 1999-2003 at the cantilever of deck slab at section 1 of girder no. 3

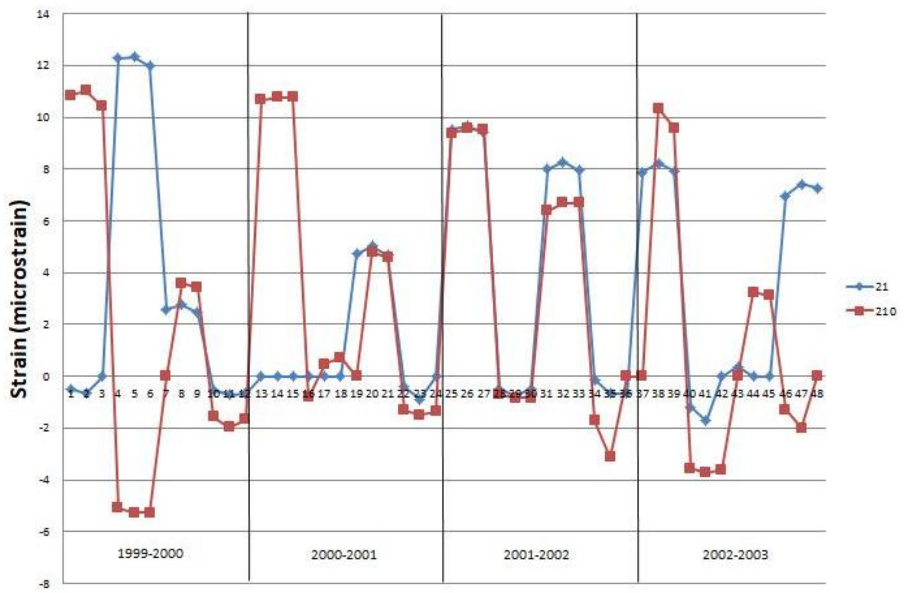

Fig 4.7: Strain variation during 1999-2003 at the soffit slab at mid span of girder no.3

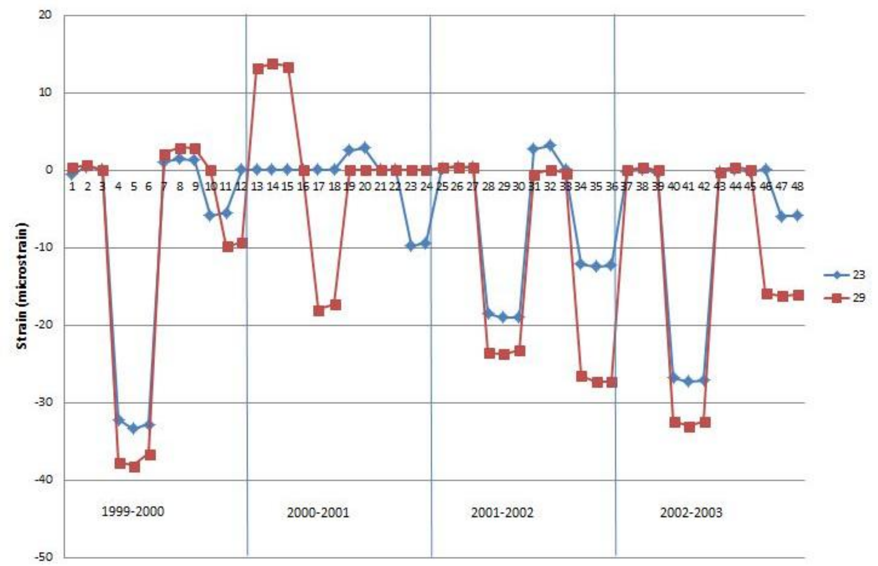

Fig 4.8: Strain variation during 1999-2003 at the center of web at mid span of girder no. 3

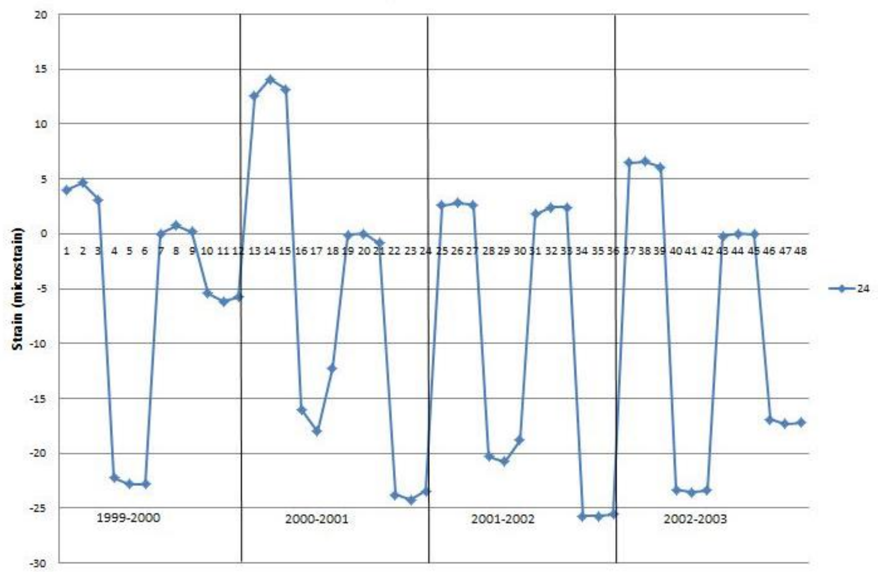

Fig 4.9:Strain variation during 1999-2003 at the junction of web and deck slab at mid span of girder no. 3

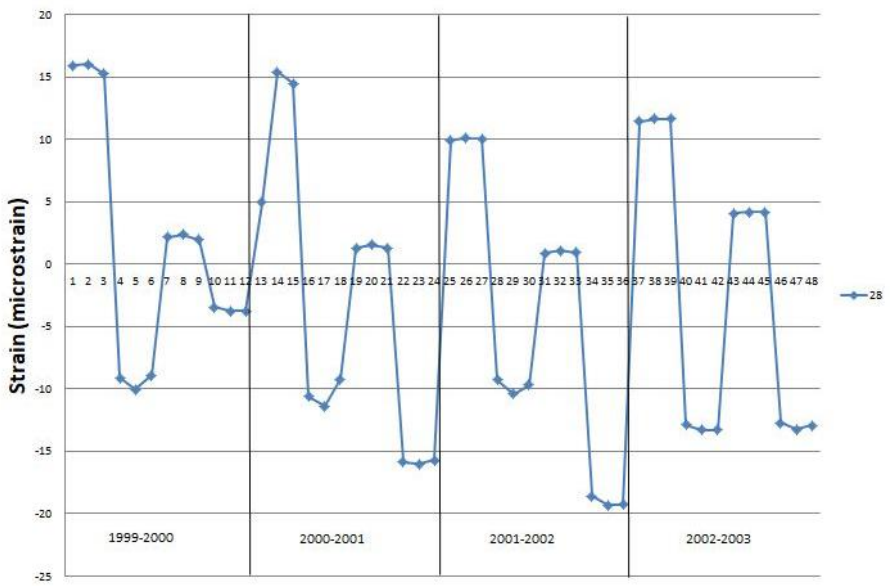

Fig 4.10: Strain variation during 1999-2003 at the cantilever portion of the deck slab at mid span of girder no. 3

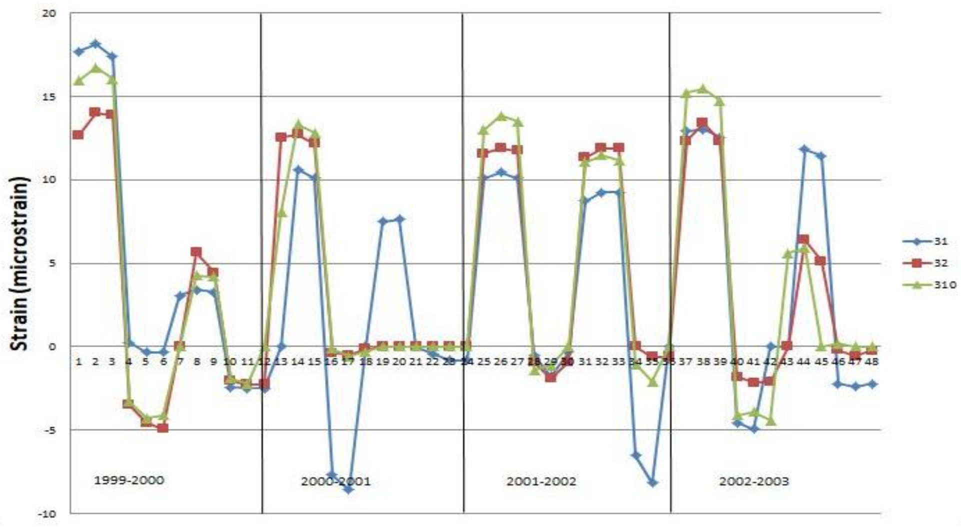

Fig 4.11: Strain variation during 1999-2003 at the soffit slab at section 3 of girder no. 3

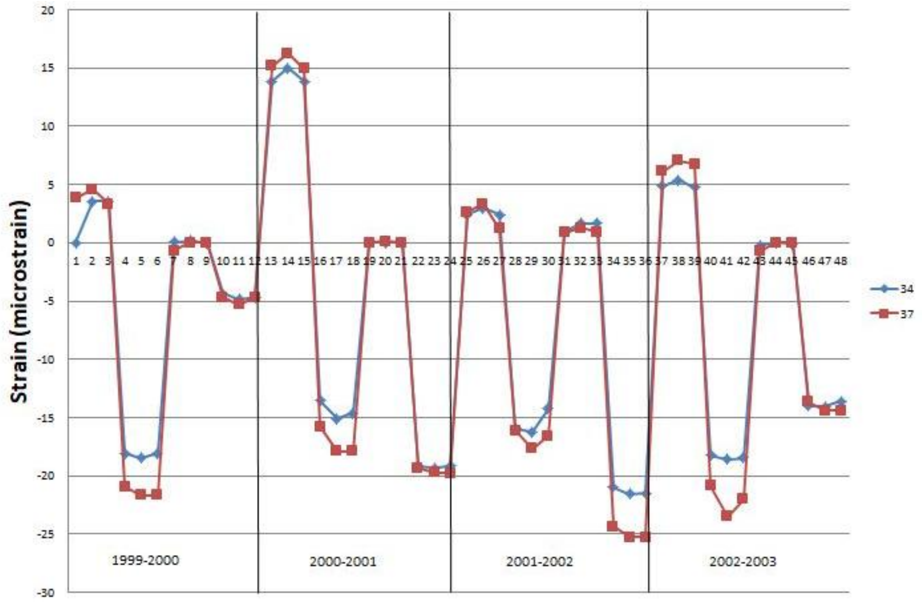

Fig 4.12: Strain variation during 1999-2003 at the junction of webs & deck slab at section 3 of girder no. 3

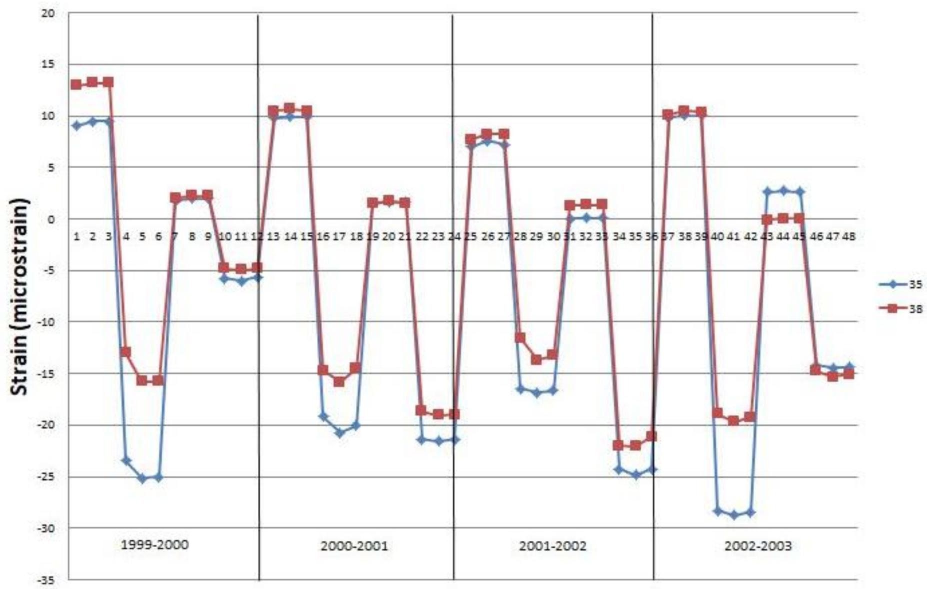

Fig 4.13: Strain variation during 1999-2003 at the cantilever portion at section 3 of girder no. 3

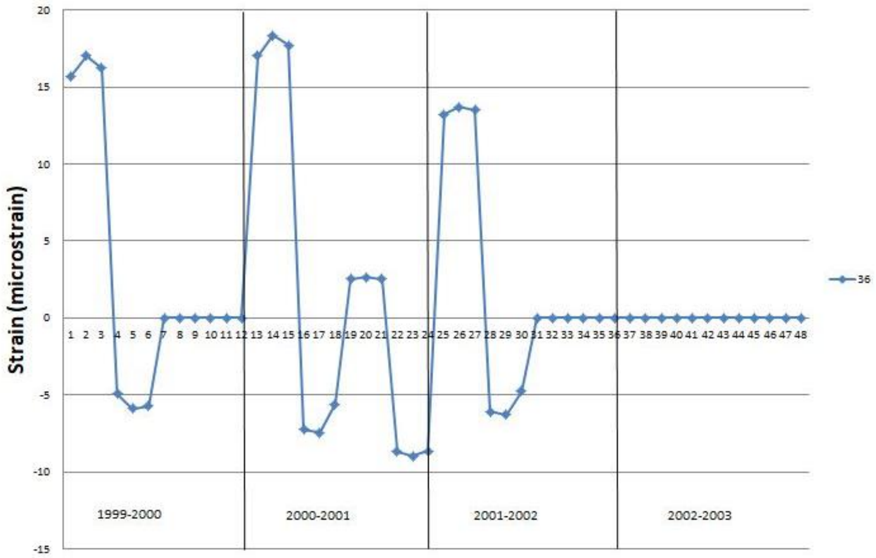

Fig 4.14: Strain variation during 1999-2003 at the centre of deck slab at section 3 of girder no. 3

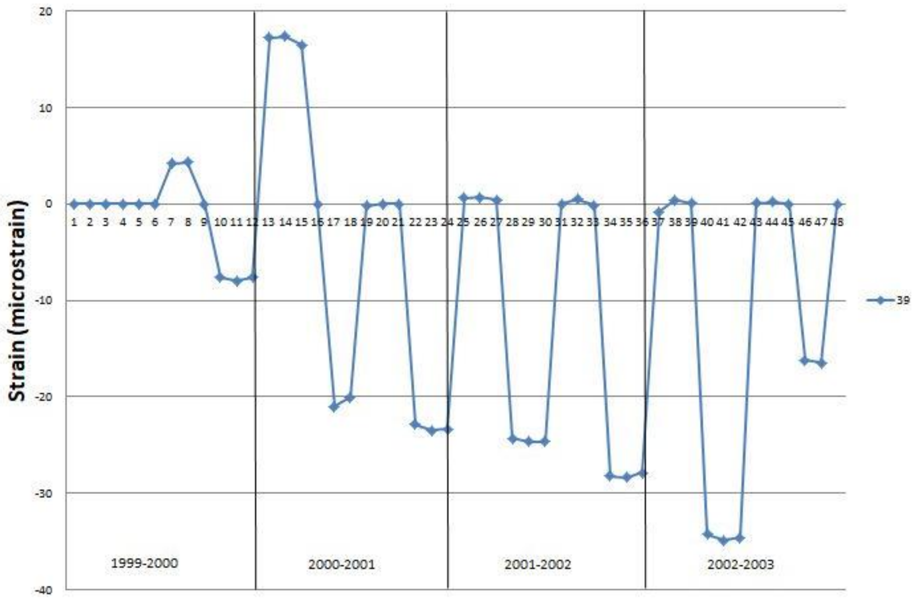

Fig 4.15: Strain variation during 1999-2003 in the centre of up-stream web at section 3 of girder no. 3

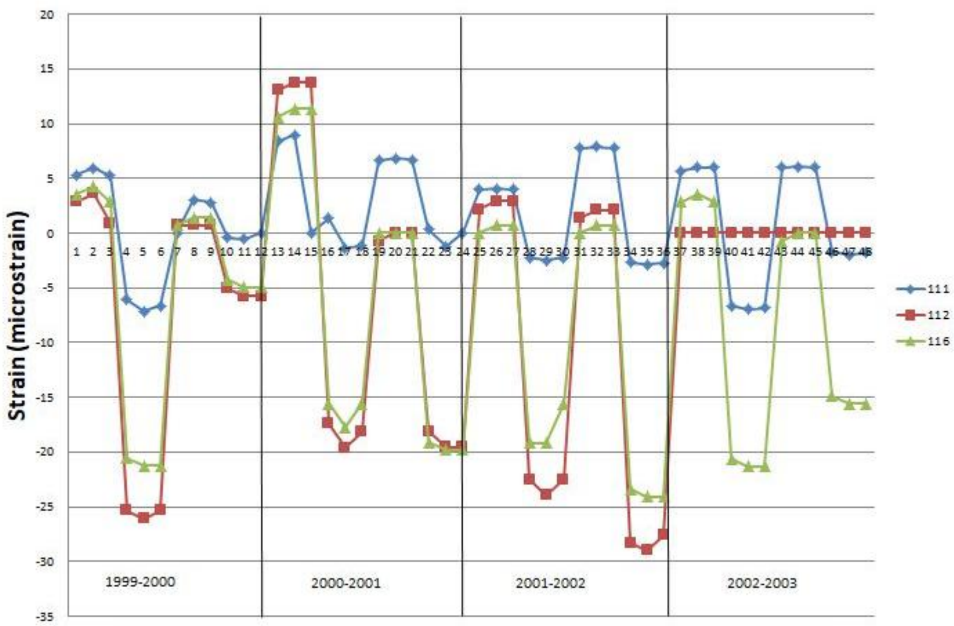

Fig 4.16: Transverse strain variation during 1999-2003 at section 1 of girder no. 3

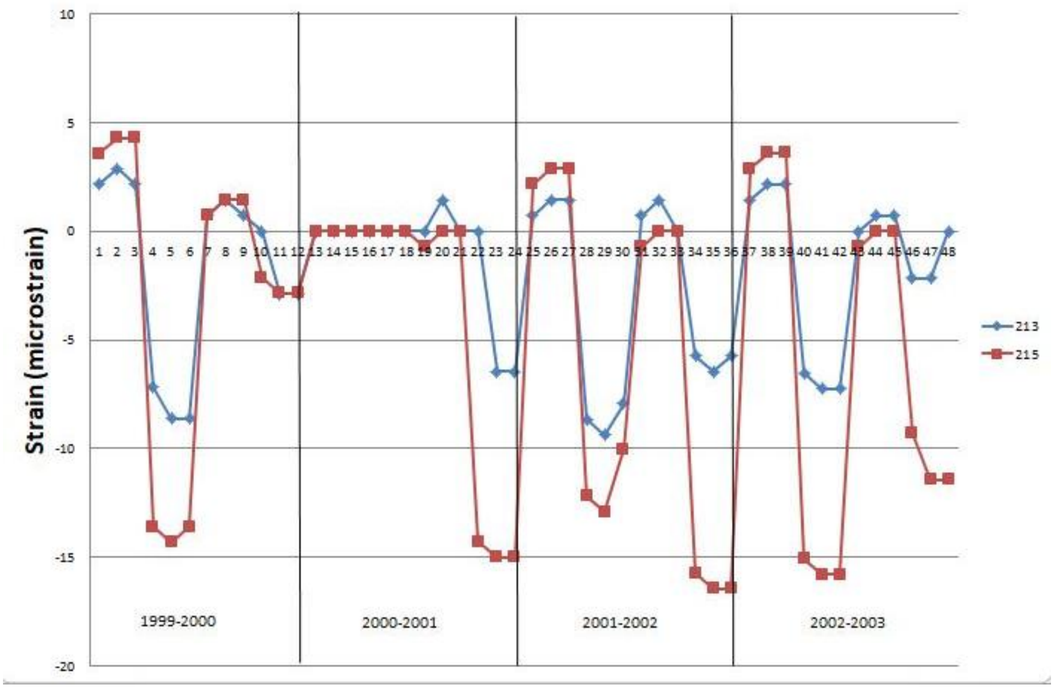

Fig 4.17: Transverse strain variation during 1999-2003 at the junction of web & deck slab of girder no. 3

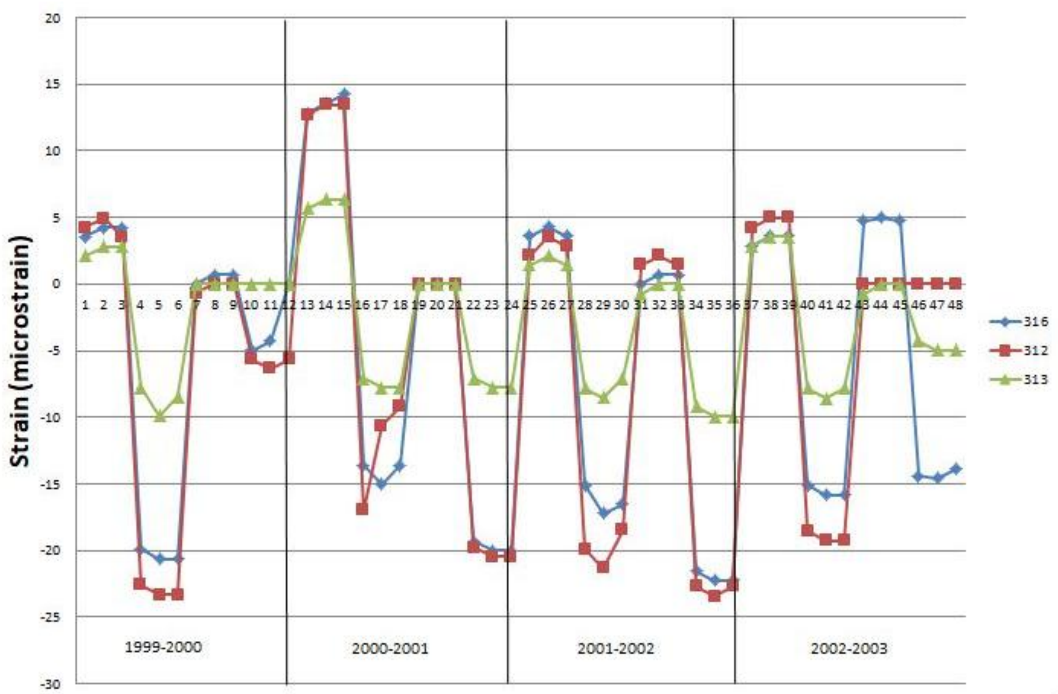

Fig 4.18: Strain variation during 1999-2003 at the deck slab at section3 of girder no. 3

4.2.1 Interpretation

By analyzing all the obtained graphs in Fig 4.11 to 4.26 it is seen that with respect to 1997 cumulative reading the maximum compression is near gauge no. 13 i.e. 21.09 micro-strain and maximum tension has been occurred near the gauge no. 19 i.e. 48.24 micro-strain an both of the gauges are located near center of web of section no. 1 in box girder no. 3.

5. Conclusion

The conclusions drawn from this study are divided in the section:

Deflection Parameter

A limit of the deflection has been derived using the case study of LokNayakSetu which will be applicable for all the similar type of box-girders in Delhi and its nearby zone where seismic and environmental effect is almost similar. The limit/range of deflection is the maximum permissible limit of the girder's deflection in the upward and downward direction below the reference line, due to the contraction and expansion of the girder with change in temperature. The range obtained after this case study is (-)1.77mm – (+)4.88mm. Where negative sign indicates deflection in downward direction and positive sign indicates deflection in upward direction. This limit will help in recognizing that weather the bridge with similar construction specification and environmental condition needs retrofitting or not. This may also help in identifying the damage occurred in girder which can also leads to catastrophic failure also. It is also concluded that the maximum deflection has occurred at the center of the girder only weather there may be contraction or expansion. This is due to distance from the supporting edge i.e. pier.

Stress Parameter

Stress plays an important role in the bridge service life. It leads all other physical parameters. LokNayakSetu is embedded with a number of vibrating wire strain gauges at the time of construction in different parts inside the girder which has made the study to derive the compressive and tensile limit inside the girder easier. As stress is directly proportional to strain, with proportionality constant E i.e. elasticity coefficient. This limit/range will be helpful in future for all similar type of girders that weather the stress which the girder is bearing is safe or not. The compression and expansion which is occurring due to stress is safe so that there may not cause any catastrophic failure of the bridge which may cause the loss of property and life also. If the stress obtained at the time of inspection in M40 grade box girder of length 36m is beyond the limit, it will helpful in alerting the inspector to make a brief inspection or to do retrofitting process of that girder. The limits of stress obtained after conducting the analysis of results obtained from the case study of LokNayakSetu are as follows:

- For compression 15.88N/mm^2, and
- For tension 3.34N/mm^2.

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