Structural Audit of Sadhu Vaswani Pul using Institutionally Developed Displacement Sensors.

Mayuresh Raikwad, H.R. MagarPatil

Abstract— The main aim of this study is to conduct the structural audit of the Sadhu Vaswani Pul which is a Rail Over Bridge, situated in Koregaon Park, Pune and to establish the displacement sensors developed in the institution as a reliable test for structural auditing of the bridge decks. Traditional methods of auditing like the Rebound Hammer test and the Ultrasonic pulse velocity tests have been considered in this study. Very few methods are available for testing the deck displacement and this problem has been tackled here. The novelty of this research is that the institutionally developed displacement sensors are used for determining the deck displacement of the selected bridge. These sensors have not been used before and no on-site techniques are available to obtain the deck deflections under real-time loading. The displacement test on the decks was conducted. The critical decks which were determined during the Visual Inspections were tested by the displacement sensors. A two-axle truck of 18.5 tonnes was passed over the bridge deck and the displacement readings were recorded at the same time. The displacement reading thus obtained indicated the deflection of the deck under a uniform rolling load. The displacements obtained were then validated by the standards given in AASTHO-LFRD. After conducting the above tests, the overall condition of the bridge was determined and the critical sections which should be repaired were mentioned.

Keywords— Structural Audit; Bridge Audit; Bridge Assessment; Displacement sensors; Health Monitoring

I. INTRODUCTION

The bridge is a structure that carries road, path, railway, etc. across a river, road, or other obstacles. Many bridges in India were constructed by the British Empire which is used even today. Bridges are worked on all day every day. The continuous traffic over it exposes the bridges to deterioration as well as they are constantly exposed to the atmosphere. The load passing over the bridges also varies. It is heavily loaded when the traffic is high during peak hours and it has light loads passing over it during the night time. The continuous changes in loading also affect the deterioration of the bridge. The Structural audit of any structure takes place every three or five years depending upon the guidelines placed by the respective municipal corporation. Building auditing is being done for a long time but in recent years, bridge auditing has also gained importance. There is a difference between the structural composition of the bridge and the building, even if they are made of RCC.[1] Since there is a difference between these two structures, the method for auditing should thus also be different. Conventionally, the first step in auditing is the Visual Inspection. It is the most important step.

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After the Visual Inspection is done further tests are carried out depending on the results obtained. Rebound Hammer test and Ultrasonic pulse velocity tests are then carried on the critical sections selected after the Visual Inspection.[2] Further during the observation, it was found that certain decks showed exposed reinforcement and damage hence these decks were also chosen for the sensor test. The bridge undertaken for this study is the Sadhu Vaswani Pul located in Koregaon Park, Pune. This bridge has a span of 378.4mtrs and is a rail over bridge. The maximum height of the column was 6mtrs and each column set had a total of four columns together spaced equally. The bridge deck is of 450mm and the girder beam has a thickness of 900mm. The required permission for working on the bridge was obtained from the concerned authorities. According to the authorities, there were no plans for the bridge available. By using the sensors we get the displacement of the structure under various loading. An attempt was made to obtain the displacement of these critical decks under a constant loading to understand the individual behaviour of the deck. This checking is mostly done in ETABS where the model of the structure is made and then loading is applied, [3]whereas, in this paper instead of relying on the software, real-world experimentation is done.

II. AIM.

To carry out the structural audit of the RCC bridge and use Displacement sensors to check deck deflections under constant loadings.

III. OBJECTIVES

A. Carry out structural audit of a RCC bridge using Rebound hammer test and Ultrasonic pulse velocity test.
B. Use displacement sensors on the critical decks to obtain the deflection under a two axle truck load.
C. Suggest critical points of repair and comment on the overall condition of the selected bridge.

IV. VISUAL INSPECTION.

Visual inspection is the most important step in the process of Structural Auditing. This inspection allows us to check the structure in as it is condition, prepare drawings of the structure and determine if the structure is safe or not. If the structure is deemed not safe, then the critical sections are selected and further testing is done on these sections to get an in-depth understanding of the current condition of the structure.

[4] After Visual Inspection, many severe horizontal and vertical cracks were seen on the selected bridge and thus critical sections were selected for further non-destructive testing purposes. The following are the critical sections selected.

Figure 1:- Cracks in column number 6A due to satellite dishes.

West side :- Column number 3A, 3B, 3C, 3D, 4A, 4B, 4C, 4D, 9A, 9B, 9C and 9D.

East side :- Column number 1A, 1B, 1C, 1D, 1E, 1F, 5A, 5B, 5C, 5D, 6A, 6B, 6C and 6D.

Deck numbers :- Deck7, Deck8, Deck9, Deck 10, Deck 11 and Deck12.

Thus a total of 26 columns and 5 decks were selected as critical sections since most of the cracks and damages were seen on these locations. The selection of the critical section is mostly done based on the experience and not just the presence of cracks.

Also during the inspection, it was seen that human settlements were established below the deck on the West side. These settlements have been using the columns of the bridge as supporting elements and have erected housing structures below.

Decks with exposed reinforcements were seen at many places and also the staircases with totally open reinforcement were observed. The staircases were asked to be closed immediately as their condition was worse. Horizontal cracks were also observed on the decks and severe damage at the top of the column with structural cracks were also seen as shown in Figure 2.

The horizontal cracks spanned over the total length of the deck. The underside of the deck showed growth of algae which led to the assumption that water leakage and seepage were occurring thereby accelerating the corrosion process. The beam girders present below shows small cracks. The columns also shows many vertical cracks spanning over the entire length of the column, pointed out in Figure Number 3. This drilling was done without proper consideration of the damage to the column structure and the reinforcement that lies under as visible in Figure 1. While observing the above side of the deck it was noted that bitumen was just sprayed over the expansion joints as prevention for leakage of water but since the proper process was not adopted the leakage continued and thus the growth of algae was justified.

All these factors were taken into consideration while selecting the critical section. The plan drawing of the same bridge can be accessed from the " https://drive.google.com/file/d/1TSmm_MSFCXTP_Bm1LI2GrzFKOA6sKtVI/view?usp=sharing" link.

Figure 2. Exposed reinforcement on the underside of the staircase.

Figure 3. Structural cracks were seen on the columns

V. DISPLACEMENT METER TEST.

The main test in this study is the Displacement meter test. The whole setup comprises of three main components:

i) The displacement sensor.

ii) The recording instrument.

iii) The laptop for interpretation of result.

The whole experimental equipment was developed by Prof. Dr. H. R. MagarPatil in the Institutional laboratory. These sensors can measure the displacements occurring and the changes in real time. The sensitivity of the sensors is two places post the decimal point.

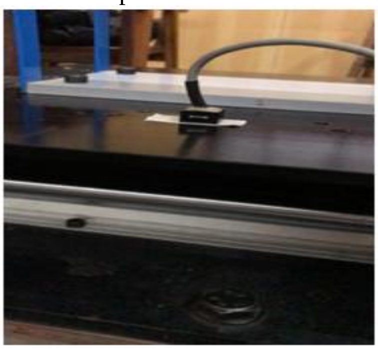

Figure 4. Sensor to be installed on the site.

Figure 5. Recording device with wires of sensors

The displacement sensors are the small black components shown in Figure 4. They have directions engraved on them which shows the dominant direction in which the readings will be recorded. The sensors can record acceleration, velocity and displacement in X, Y and Z direction. These sensors are installed on the mid-span of the deck platform and deflections readings are found out in Y direction when a load of a two-axle truck which is around 18.5 tonnes is passed over the deck..

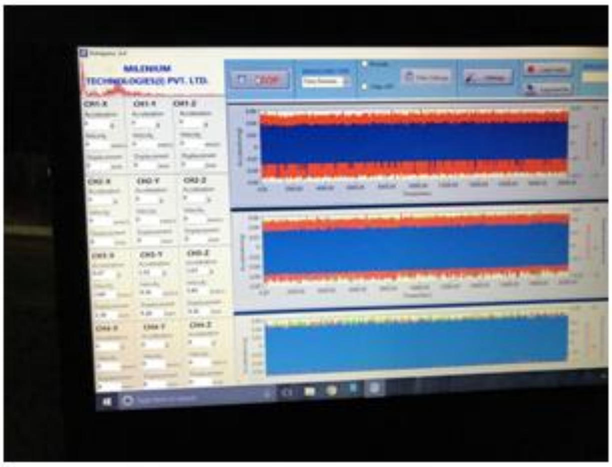

Figure 6. Laptop used with the application for readings.

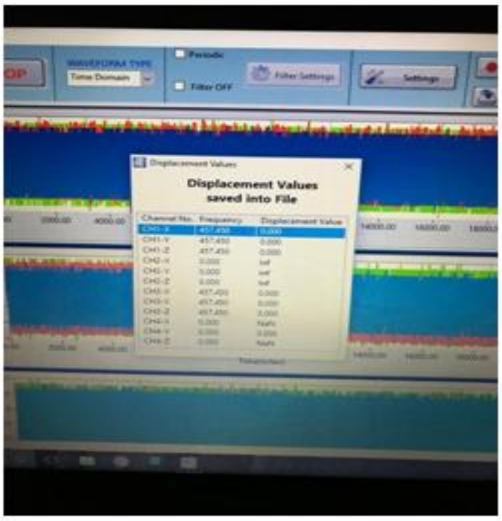

Figure 7. Zero Displacement shown when no load is passed.

The recording instrument is shown in Figure 5. This instrument works on electricity and has 4 channel openings in which the wire from the sensors is to be installed. There is one main opening in front of which a wire is connected to the computer. The recording device records the values and transfers it to the computer so that the user can read and interpret the displacement, velocity and acceleration values. The laptop displays the deflections, velocity and accelerations recorded by the sensor and shows them in real-time on the screen. Figure 6 shows the result screen obtained when the whole equipment is set up. Solely the displacement data were used for this study and were limited to Y direction alone. Though other readings were obtained main focus was on the displacement readings.

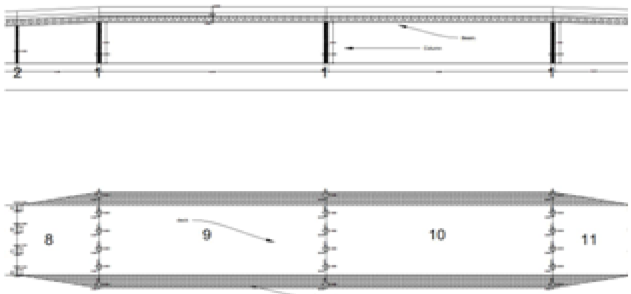

Figure 8. Central portion of the bridge with longest span deck.

Deck numbers 7, 8, 9, 10, 11 and 12 were selected for the sensors test. The sensors were installed at the mid-span of the deck and the whole setup was connected. When no load was passing on the deck, readings were taken so that a reference can be established. When no load was passing the computer showed zero reading as expected. Zero reading of displacement, acceleration and velocity were seen as visible from Figure 7. Once the setup was up and running, the two-axle truck was passed over the bridge and real-time deflection readings were recorded. The readings were shown only in the Channel in which the sensor was connected. Zero readings were shown in the other channels as no connections were made. The software named "KAMPANA" was used to read the recorded readings and to come to a conclusion. The sensors were placed on the ground. Double side tape was used so that sensors were held in position. The sensors were then connected to the recording device via the wires which were inserted in the Channel 1. The final wire or the USB wire from the recording device was then connected to the computer. Portable power supply was used to power the recording device on the bridge. Once the whole setup was done recording of the readings was initiated. This was done by running the "KAMPANA" application on the laptop to which the recording wires were connected. The vehicle was signalled to move over the selected bridge deck once the whole setup was ready. At the time of signalling the vehicle driver, the option of "record log" was clicked on. This option allowed us to record the ongoing displacements of the structure on which the sensors are placed, in real-time. Care was taken so that no other vehicle was passing on the selected deck.

This allowed us to interpret that as soon as the changes in the reading occurred it was only due to the load passing on the structure. The displacement readings obtained were then tabulated and are mentioned in the Results chapter.

VI. REBOUND HAMMER TEST.

Rebound hammer test was carried out on the columns which were claimed to be critical. The columns selected for testing were column numbers 1A, 1B, 1C, 1D, 1E, 1F, 5A, 5B, 5C, 5D, 6A, 6B, 6C and 6D from the East side and column numbers 3A, 3B, 3C, 3D, 4A, 4B, 4C, 4D, 9A, 9B, 9C and 9D from the West side of the bridge. These can be seen in Figure 9.

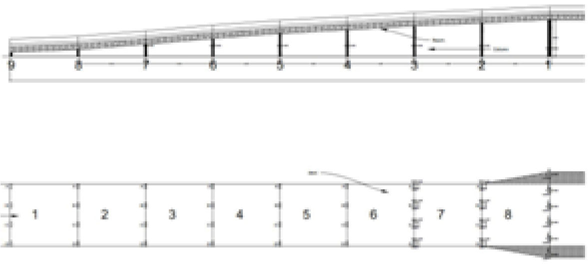

Figure 9. Plan of the bridge on West Side.

The rebound hammer readings were taken at the height of 1meter from the bottom of the column and also at the middle height of the column. For this study, a total of twenty-one readings were taken at the mentioned positions.[5] Then the average of these readings was taken and further the corresponding compressive strength of the column was found using the Compressive strength vs Rebound Number graph.

The rebound numbers obtained on the site are as follows,

TABLE I. BOTTOM HEIGHT REBOUND NUMBER OF COLUMNS 1,5 AND 6.

PIER NUMBER	SUB NUMBER	BOTTOM REBOUND NO.			AVERAGE NO.
1	A	35.36	35.34	34.5	35.06666667
	B	34	34	34.35	34.11666667
	C	34	32	31	32.33333333
	D	30	31	31	30.66666667
	E	28	36	29	31
	F	30	36	30	32
5	A	20	21	25	22
	B	21	22	22	21.66666667
	C	21	26	20	22.33333333
	D	20	22	20	20.66666667
6	A	20	23	20	21
	B	22	21	18	20.33333333
	C	19	22	20	20.33333333
	D	22	20	20	20.66666667

Out of the twenty-one readings taken at each location, only six readings were considered (as per IS 13322 Part 2) and the averages of theses six readings were further undertaken. The readings taken are more or less similar to the maximum rebound number obtained and thus to remove the unwanted deviation this procedure was undertaken.[5] Readings on each face of the columns were taken, meaning all the four faces of the column were duly tested and only then these rebound hammer indices were interpreted and noted above in Table number I to Table number IV. The critical sections were determined during the Visual Inspection of the bridge which was done in the presence of Prof. Dr. H.R. MagarPatil.

TABLE II. MIDDLE HEIGHT REBOUND NUMBER OF COLUMNS 1,5 AND 6.

PIER NUMBER	SUB NUMBER	MID REBOUND NO.			AVERAGE NO.
1	A	44	41	44	43
	B	44	41	44	43
	C	41	38	45	41.33333333
	D	44	42	42	42.66666667
	E	44	46	45	45
	F	42	44	44	43.33333333
5	A	20	18	18	18.66666667
	B	20	25	24	23
	C	18	23	21	20.66666667
	D	20	24	19	21
6	A	21	19	20	20
	B	21	20	20	20.33333333
	C	21	24	24	23
	D	20	21	22	21

TABLE III. BOTTOM HEIGHT REBOUND NUMBER OF COLUMNS 3,4 AND 9.

PIER NUMBER	SUB NUMBER	BOTTOM REBOUND NO.			AVERAGE NO.
9	A	52	56	48	52
	B	47	54	47	49.33333333
	C	47	46	43	45.33333333
	D	45	44	45	44.66666667
4	A	45	45	43	44.33333333
	B	42	48	42	44
	C	43	43	40	42
	D	42	47	42	43.66666667
3	A	42	47	43	44
	B	42	42	43	42.33333333
	C	47	45	49	47
	D	35	38	34	35.66666667

TABLE IV. MIDDLE HEIGHT REBOUND NUMBER OF COLUMNS3,4 AND 9

PIER NUMBER	SUB NUMBER	MID REBOUND NO.			AVERAGE NO.
9	A	46	56	52	51.33333333
	B	52	48	50	50
	C	48	47	40	45
	D	44	50	46	46.66666667
4	A	45	50	44	46.33333333
	B	41	41	44	42
	C	45	45	42	44
	D	45	54	47	48.66666667
3	A	38	45	41	41.33333333
	B	40	39	40	39.66666667
	C	45	43	44	44
	D	38	38	36	37.33333333

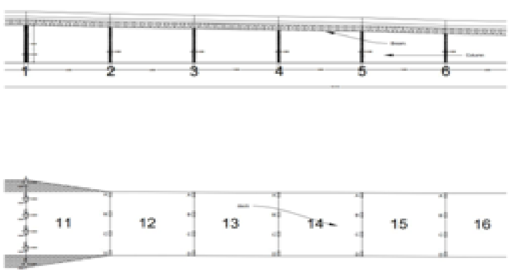

FIGURE 10. EAST SIDE PLAN OF CRITICAL SECTIONS

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Once all the rebound indices were noted down from the site, the Rebound number Vs Compressive strength graph was used to convert the obtained rebound number into relative compressive strength. The readings of all the faces are averaged and the final rebound numbers are mentioned in the Result chapter along with their compressive strength.

VII. ULTRASONIC PULSE VELOCITY TEST.

Next, the Ultrasonic Pulse Velocity was carried out. The columns selected for testing were column numbers 1A, 1B, 1C, 1D, 1E, 1F, 5A, 5B, 5C, 5D, 6A, 6B, 6C and 6D from the East side and column numbers 3A, 3B, 3C, 3D, 4A, 4B, 4C, 4D, 9A, 9B, 9C and 9D from the West side. Similar to the rebound hammer test, a total of twenty-one readings were taken at the bottom height and the middle height and later their averages were used. The average velocity obtained in km/sec was then compared with the quality table given in the IS 13322. This table gives distinct differentiation between the qualities of the columns depending upon the velocities obtained. The procedure undertaken for the Rebound hammer test is adopted here. The piers of the bridge were made smooth with the help of a grinder stone. The transducers were covered with petroleum jelly before taking the readings to avoid the fluctuations in the obtained readings due to the presence of the air gap. The readings obtained from the tests are tabulated below. Readings were taken on each face of the columns and care was taken to avoid the reinforcement cover area for testing.[6] Table number V reports the velocity of the pulse obtained when column numbers 3,4 and 9 of the West side of the bridge were tested. Table number VI reports the velocities of the columns on the East side. A combined approach of Rebound number and Ultrasonic Pulse Velocity was undertaken. If the quality of the structure is good and if it gives a good corresponding compressive strength, then the structural element can be determined to be safe. If the quality is medium then the correlation should be done with uttermost care and lastly, if the quality is doubtful or poor then no correlations should be made and proper repair techniques should be enacted upon.[7] The Rebound Hammer and Ultrasonic Pulse Velocity tests were done according to the guidelines presented in IS 13322 Part 2.

TABLE V. UPV VELOCITY OF COLUMN NUMBER 3, 4 AND 9 OF WEST SIDE.

WEST SIDE						
SR. NO.	PIER NO.	COLUMN NO.	TIME(microseconds)		VELOCITY	
			L=770	L=320	L=770	L=320
1	9	A	230	105	3.347826	3.047619
		B	250	75	3.08	4.266667
		C	210	85	3.666667	3.764706
		D	265	90	2.90566	3.555556
2	4	A	190	96	4.052632	3.333333
		B	200	100	3.85	3.2
		C	226	89	3.40708	3.595506
		D	235	105	3.276596	3.047619
3	3	A	210	78	3.666667	4.102564
		B	223	86	3.452915	3.72093
		C	256	95	3.007813	3.368421
		D	206	96	3.737864	3.333333

TABLE VI. UPV VELOCITY OF COLUMN NUMBER 1, 5 AND 6 OF EAST SIDE.

EAST SIDE						
SR. NO.	PIER NO.	COLUMN NO.	TIME(microseconds)		VELOCITY	
			L=770	L=320	L=770	L=320
1	5	A	200	124.3	3.85	2.574417
		B	265	111.4	2.90566	2.872531
		C	286	110.6	2.692308	2.893309
		D	245	95	3.142857	3.368421
2	6	A	260	115	2.961538	2.782609
		B	275	130	2.8	2.461538
		C	250	125.3	3.08	2.553871
		D	280	140.5	2.75	2.27758
3	1	A	210	88	3.666667	3.636364
		B	207	69	3.719807	4.637681
		C	225	78	3.422222	4.102564
		D	230	75	3.347826	4.266667
		E	215	96	3.581395	3.333333
		F	206	83	3.737864	3.855422

VIII.RESULTS.

According to AASTHO-IFRD section on deck displacement, the maximum displacement of the deck is given by [8]

$$\Delta = L/800$$

For bridges without sidewalks and,

$$\Delta = L/1000$$

For bridges with sidewalks.

Where L= span of the bridge.

During Visual Inspection it was found that the bridge does have a sidewalk and thus L/1000 is to be used. Also during observations, it was noted that vibrations could be felt when heavy vehicles were passed over the bridge decks. Because of the vibrations noticed these decks were considered, as it is not structurally safe to have vibrations when loads are passing because it will lead to further deterioration and unwanted damage to the critical areas of the structure. Table number VII below gives the displacement readings of the deck numbers 7, 8, 9, 10, 11 and 12 which were selected for testing.

$$\Delta = L/1000$$

Where,

L = Span of the bridge.

$$\Delta = 378.4/1000$$

$$= 0.3784 \text{ meters.}$$

$$= 1.24 \text{ feet.}$$

Thus the displacements obtained should be less than 0.3784 meters or 378mm or 1.24 feet.

TABLE VII. RECORDED DISPLACEMENTS USING SENSORS.

Serial Number	Deck Number	Recorded Displacement(mm)
1.	7	9.28
2.	8	11.55
3.	9	35.62

4.	10	37.33
5.	11	19.67
6.	12	15.73

Thus from the above Table number VII, it is clear that the maximum value of displacement is 37.33mm or 0.12 feet. Since this value and all the other values of displacement in the Y direction are way less than the expected limit according to AASTHO-IFRD, it can be concluded that the decks are safe. The bridge was 25 years old and thus the minimum deflections suggest that the severe damages to the decks have not occurred. The bridge did not have any bearings present below the decks and the vibrations felt can be a result from the absence of bearings. Thus proper deck treatment or replacement and installation of bearings should be conducted to avoid further damage. The vibrations might lead to an increase in spacing between the expansion joints, causing an improper transfer of load to the columns, seepage of water to the internal portions leading to corrosion and thus causing serious problems which will be economically challenging and time-consuming. The positive results obtained from the test help to establish the fact that this method can be used on the site for deck displacements. Thus this method can be used for auditing the bridge decks or the other components of the bridge where the deflections or displacements occur. The compressive strength of the selected columns is mentioned in the Table number VIII and Table number IX. These indices are the average of the six readings taken beforehand. From the Rebound number vs Compressive strength graph, the compressive strengths of the columns are found and tabulated. The column Number 1 on the East side is the column with the maximum height of 6meters.

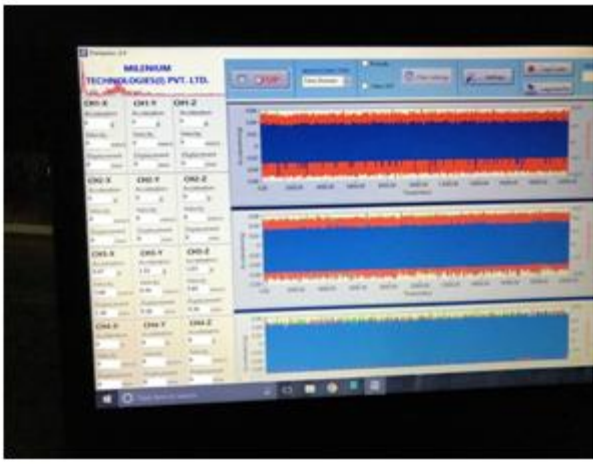

FIGURE 11 . DISPLACEMENT READINGS FOR DECK NUMBER 7.

The average compressive strength obtained for the same is around 45mPa. Other columns that were selected as critical sections have shown lower rebound indices implying lesser compressive strength.

This is due to non-uniformity in the material used during construction or the fact that proper construction practices might have not been implemented. Also, human settlements were seen below the bridge on the West side and since the columns of the bridge were used as supporting structures for the roofs built, the additional eccentric load was imposed on the columns. At several places, dish antennas were installed on the columns by drilling the antennas inside the column without taking into account the reinforcement damage and thus further loss of strength of the column can be noted.

TABLE VIII. MIDDLE AND BOTTOM REBOUND NUMBER AND COMPRESSIVE STRENGTH OF THE CRITICAL COLUMNS 1,5 AND 6.

Pier Number	Sub number	Bottom Average Number	Middle Average Number	Bottom Compressive strength	Middle Compressive Strength
9	A	52	51.33333333	63.157	62.00633333
	B	49.33333333	50	58.55433333	59.705
	C	45.33333333	45	51.65033333	51.075
	D	44.66666667	46.66666667	50.49966667	53.95166667
4	A	44.33333333	46.33333333	49.92433333	53.37633333
	B	44	42	49.349	45.897
	C	42	44	45.897	49.349
	D	43.66666667	48.66666667	48.77366667	57.40366667
3	A	44	41.33333333	49.349	44.74633333
	B	42.33333333	39.66666667	46.47233333	41.86966667
	C	47	44	54.527	49.349
	D	35.66666667	37.33333333	34.96566667	37.84233333

The velocities obtained while testing are then compared with the velocities table given in IS 13322 part 2 and the corresponding quality of each column is mentioned in the Table number X and Table number XI.

TABLE IX. MIDDLE AND BOTTOM REBOUND NUMBER AND COMPRESSIVE STRENGTH OF THE CRITICAL COLUMNS 3,4 AND 9.

Pier Number	Sub number	Bottom Average Number	Middle Average Number	Bottom Compressive strength	Middle Compressive Strength
1	A	35.06666667	43	33.93006667	47.623
	B	34.11666667	43	32.29036667	47.623
	C	32.33333333	41.33333333	29.21233333	44.74633333
	D	30.66666667	42.66666667	26.33566667	47.04766667
	E	31	45	26.911	51.075
	F	32	43.33333333	28.637	48.19833333
5	A	22	18.66666667	11.377	5.623666667
	B	21.66666667	23	10.80166667	13.103
	C	22.33333333	20.66666667	11.95233333	9.075666667
	D	20.66666667	21	9.075666667	9.651
6	A	21	20	9.651	7.925
	B	20.33333333	20.33333333	8.500333333	8.500333333
	C	20.33333333	23	8.500333333	13.103
	D	20.66666667	21	9.075666667	9.651

TABLE X. QUALITY OF THE COLUMNS 1,5 AND 6 DETERMINED AS PER PULSE VELOCITY TEST.

EAST SIDE						
SR. NO.	PIER NO.	COLUMN NO.	TIME(microseconds)		REMARKS	
			L=770	L=320	L=770	L=320
1	5	A	200	124.3	GOOD	DOUBTFULL
		B	265	111.4	DOUBTFULL	DOUBTFULL
		C	286	110.6	DOUBTFULL	DOUBTFULL
		D	245	95	MEDIUM	GOOD
2	6	A	260	115	DOUBTFULL	DOUBTFULL
		B	275	130	DOUBTFULL	DOUBTFULL
		C	250	125.3	MEDIUM	DOUBTFULL
		D	280	140.5	DOUBTFULL	DOUBTFULL
3	1	A	210	88	GOOD	GOOD
		B	207	69	GOOD	GOOD
		C	225	78	MEDIUM	GOOD
		D	230	75	MEDIUM	GOOD
		E	215	96	GOOD	MEDIUM
		F	206	83	GOOD	MEDIUM

TABLE XI. QUALITY OF THE COLUMNS 3, 4 AND 9 DETERMINED AS PER THE PULSE VELOCITY RESULTS.

WEST SIDE						
SR. NO.	PIER NO.	COLUMN NO.	TIME(microseconds)		REMARKS	
			L=770	L=320	L=770	L=320
1	9	A	230	105	MEDIUM	MEDIUM
		B	250	75	MEDIUM	GOOD
		C	210	85	GOOD	GOOD
		D	265	90	DOUBTFULL	GOOD
2	4	A	190	96	GOOD	MEDIUM
		B	200	100	GOOD	MEDIUM
		C	226	89	MEDIUM	GOOD
		D	235	105	MEDIUM	MEDIUM
3	3	A	210	78	GOOD	GOOD
		B	223	86	MEDIUM	GOOD
		C	256	95	MEDIUM	GOOD
		D	206	96	GOOD	MEDIUM

Columns showing low velocity are proof that homogeneity of the material is not present, the presence of internal cracks or loss in continuity of the member. Testing was done on all the faces of each selected column and thus readings for each side have been noted. It has been seen that the columns have shown good results when the distance of transmission was 770 mm and doubtful results are seen only in the columns where even the rebound indices obtained where less.Thus co-relation between the two tests was used to determine the final quality of the bridge element. Thus from the results in Table numbers VIII to Table number XI, we can conclude that column numbers 3,4 and 9 have shown great compressive strengths and the quality of the structure obtained from the pulse velocity is also in the range of GOOD to MEDIUM. This confirms that the conditions of the columns are good and only surface treatments are required. However, the rebound indices and the compressive strength of the column number 1,5 and 6 show abrupt results. The compressive strength of column numbers 5A, 5B, 5C, 5D, 6A, 6B, 6C and 6D are very less. This implies that the surface hardness and the strengths are reduced. The same columns when tested for pulse velocity tests have resulted in BAD quality. This confirms that the columns have internal damages, cracks and have lost homogeneity. Moreover, out of the columns on the west side, many columns had chunks of concrete removed and cover to the reinforcement was absent. Not only these damages but the settlements below the bridge should be shifted so that additional eccentric load on the columns is reduced and proper maintenance and repair work of the columns can be done. Thus the combined approach helps us to understand the actual condition of the column and also helps verify the results by considering these two tests.

IX. CONCLUSION.

The above results help us to conclude that the bridge is in Okay condition. The test results were quite positive and thus if proper repairing techniques are applied on to the highlighted critical columns and decks then the service life of the bridge can be increased manifold as the bridge is situated in one of the densely populated areas. The main aim of this study was to apply the displacement sensors for the auditing of the bridge. From the positive results obtained we can conclude that the test can be used in the real world on the site. The whole setup is very concise and thus if a continuous supply of electricity is managed then these devices can be installed on the bridge for full time. By installing them full time the engineer can obtain real-time data of the bridge behaviour at any time of the day. Real-time data available at any given point is precious and this is possible through this method. Thus this method can be included in the structural health monitoring of the bridges and deck. Rather than obtaining this data once every three or five years when the auditing of the bridge is done, the whole displacement, velocity and acceleration data can be read at any given point. Instead of installing this setup on every bridge, engineers can install them at the high priority bridges or the bridges which are nearing to the end of their life span. This way the critical bridges can be kept under observation and thus help to avoid severe damages to the bridge and also human life. In this way, the main aim of auditing, which is avoiding the damage of structure and saving human life, can be achieved. Further development can be done in this method to make it more precise and modifications can be made to use the velocity and acceleration data obtained from the sensors. The placement of the sensors for this study was done on the top side of the deck. Further, if the sensors are installed on the underside of the deck or the beam girders then more accurate results may be obtained. Also if developments are made so that the data recorded by the sensors can be interpreted in the office instead of on-site then the full-time gathering of the data will become possible through the office and thus physical work can be reduced. Accessing the data remotely can be made possible with this equipment, saving the traveling cost and physical efforts.

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