UCT JOURNAL OF RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY 2019(01)

Available online at http://journals.researchub.org

Investigating the vulnerability of Bridge by comparing the results of instrumentation and wavelet function

Muhammad Adnan Asif *

Deputy Director, Barani Institute of Sciences, Burewala JV of Arid University Rawalpindi, Pakistan

A R T I C L E I N F O

Article history:
Received 27 July. 2018
Accepted 06 Sept. 2018
Published 12 Dec. 2018

Keywords:
Vulnerability, Bridge, Wavelet Function, Crack.

A B S T R A C T

Many structural damages occurs due to breakdown of constituents. The onset of these fractures is usually accompanied by cracks, the spread of which poses a serious threat to their structures and behavior. Accordingly, the methods of diagnosis and detection of cracks have been the subject of much research to date. The existence of cracks changes the natural and mode frequency of seismic deformations, which analyzes these changes by identifying cracks. These methods are known as Structural Health Monitoring (SHM) techniques, which manage and evaluate the expected behavior and performance of structures over the life of the structure. There are various ways to evaluate and identify these changes, each of which has its strengths and weaknesses. These systems should be able to answer questions such as the location of damage and failure to structures. The modern methods of structural health monitoring are based on the dynamic properties of structures, most of which use modal analysis or Fourier series conversion. In the Fourier transform, information is given about the frequencies in a signal, while no information is recorded since a particular frequency occurs. To determine the location of a crack or any other damage of this kind, it is important to know when a particular frequency occurs that Fourier transform in this field is weak. A novel and efficient method of signal analysis, which has been welcomed by researchers in recent years, is called Wavelet Transform (WT) and has great ability to detect all kinds of discontinuities or inconsistencies, such as sudden loss of hardness, loss of performance, and failure. Bridges are one of the most important structural members, so this research will investigate an example of them, because of its historical importance, by the wavelet transform method.

1. INTRODUCTION

The origin of the breakdown and overall breakdown of the structure is the occurrence of cracks in the members of the structure. Sudden failure is one of the components of very costly and catastrophic structures in structures. Therefore, timely identification of cracks in structural components is essential before they can cause major structural problems. Bridges are one of the most important structural members. Also, failure to properly maintain important structures is the source of minor damage and consequently overall structural failure. Damages are a serious threat to the components of a structure and may result in many financial or life losses after the damage. The high structural losses in severe earthquakes indicate the necessity of investigations into the areas of failure detections in the initial steps and structural health. Also, by timely identification, minor structural damages can be remedied with less cost and less problems than general damages and without interruption in the use of structures [1].

Common applications of structural health assessment in bridges, dams and buildings are to calculate seismic vulnerability or aftershock failure. Also, other types of structures need to be evaluated after overloading, accidents, or when they endure intense environmental loads.

The mechanism of identifying the performance of structures has been considered in different ways from many years ago. Numerical methods, along with practical and laboratory methods, have always been the best option for defining the performance of structures in this field.

With the introduction of finite element methods into the analysis of important structures, the process of determining the performance of structures was greatly strengthened. These methods, along with improved numerical and equation methods, shorten the way to achieve the best behavioral pattern of structures. The methods of failure from long years were followed using equations, and in recent years, these methods have been mixed with finite element methods. Due to the importance of the Bridge structure, in this study, based to the information collected from field tests on the bridge, the finite element analysis is performed using ABAQUS software. Then, using damage detection algorithms by the wavelet function method, we investigate the magnitude and extent of damage created in the bridge under operational loads over the life span.

One way to overcome these limitations is to use general failure detection methods. The occurrence of damage to the structural members changes the physical characteristics of the structures. By the way, we know that structural responses and structural vibrations depend on physical properties. Therefore, changes in physical properties cause changes in the responses of the structure and its vibrations. For example, modal parameters (such as natural frequency, mode shape, etc.) are a function of the physical properties of the structure (hardness, damping, mass and boundary conditions). As such, changes in the rigidity or softness of the structure will cause changes in modal characteristics. This led to the development of new methods for troubleshooting structures called general methods. The general trend of

*Corresponding author: adnan.asif@baraniinstitute.edu.pk
DOI: https://doi.org/10.24200/jrset.vol7iss01pp28-34

these methods depends on comparing the responses of healthy structures with the responses of unhealthy structures and drawing conclusions based on their analysis.

The general methods are studied by varying the vibrational parameters. It is believed that general and local methods should complement each other, depending on the structural conditions. The main issue in the methods of damage assessment based on the overall vibration is to find indicators that are sensitive to structural failure. Indicators including natural frequencies, mode shapes, mode shape curvature, softness matrix, stiffness matrix, etc. yielded successful results [3].

In general, failure detection methods include changes in mode shapes and frequencies, modal strain energy, changes in flexibility, frequency response function, and wavelet transform [2].

Wavelet analysis, one of the relatively new and exciting achievements of pure mathematics based on decades of research in harmonic analysis, has found important applications in many fields of science and engineering today and new possibilities have been provided for understanding its mathematical aspects as well as enhancing its applications.

The occurrence of cracks in structural members is the source of general failure and failure of the structure. The sudden breakdown of structural components in human life is very costly and catastrophic. Therefore, timely identification of cracks in structural components is essential before they can cause major structural problems [4].

It is made of cement and washed sand mortar and brick and there is no reinforcement in the building. In other words, the building is made of unarmed mortar.

Due to the importance of this historical structure, therefore, it is necessary to control the health of these structures. In the meantime, the issues of vibration that arise in bridges have always been discussed. In this research, we have tried to develop a new and efficient method to detect cracks in these types of structures.

First, the validation of finite element software is performed using field test results studied. Then, the linear and nonlinear analysis of the bridge structure is discussed.

We control displacement values and permissible and analytical stresses, and finally, using wavelet function numerical methods, identify damaged or vulnerable points of the bridge over its life span.

1.1. Investigating the results of a local bridge study

One of the most important goals of the country railway is to provide predictive maintenance, along with increasing existing infrastructure productivity, to meet existing demand from the rail network, which needs to be strengthened by evaluating its capacity in the event of deterioration or overburden caused by increased speed or axial load.

In this section, Bridge's health assessment based on optical inspection, material testing, theoretical modeling, static and dynamic loading test under the maximum permissible test survey, was put on the agenda. Then, using field results, the validation of the obtained model was performed. For this purpose, it is necessary to measure the behavior of the bridge under certain loads using field sensors in field experiments.

For instrumentation of the Bridge, a set of 16 sensors was used, and their location map is shown in Figure 1. The sensors used include LVDT and DCDT relay sensors, accelerometers, strain gauges and seismographs. Two GT26 locomotives and two grain freight wagons were used for loading the bridge.

DCDT displacement gauges were used to determine the vertical displacement of the middle and one-quarter middle openings of the bridge. The use of these sensors was due to restrictions on the use of conventional relay sensors, such as LVDT. To install this sensor, a point to connect the wire stretched from the sensor is needed. For this purpose, a concrete scaffold 18 meters below the bridge key was used.

Figure 1. A view of Bridge and the location of 25 positions designed for seismic station in deck area and bridge base. The location of the seismic stations is indicated by colored triangles. Station S1 is common to all 10 survey stages. Also, the S20 station is shared in the surveys of the eastern side of the Bridge Railway.

Based on the experimental design, the behavior of the bridge in two static and dynamic states is investigated. For this purpose, two GT26 locomotives and two freight wagons were used. The arrangement and load of the axels are as shown in Fig. 2.

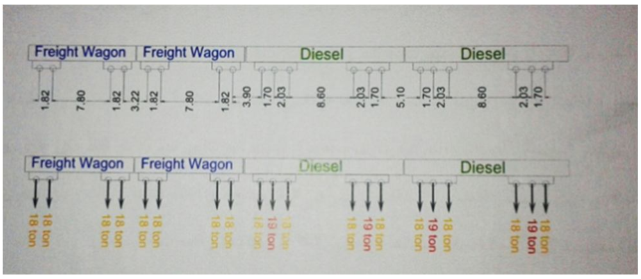

Figure 2. The arrangements of the location of axles of diesels and wagons and their axial loads

Table 1. The specifications of freight locomotives and wagons at loading

Vehicle	The number of axles	Full weight (tons)	Distance between the center of two bogies (m)	Distance between the axles of two bogies (m)	Tampon to tampon distance (m)
Locomotive	6	110.97	12.5	2.02-	21.1

GT26				1.69	
Grain transport unit	4	76	9.86	1.8	15.06

1.2. Static loading

In the static tests, when passing the train from Dowgal to (south to north), freight wagons were first passed, and diesels were then passed over the bridge. On the route to Dowgal (north to south), diesels first and then wagon crossed the line. Table 2 shows the specifications of the tests performed. In these tests, the train was passed across the bridge uniformly and at the lowest possible speed (about 3 km / h) and the sensor information was recorded.

Table 2. The specifications of static tests

Test number	Direction of movement	Passing train arrangement	Speed (km / h)
1	Dowgal to bridge (South to North)	Wagon-Wagon-Diesel-Diesel	2.8
2	Dowgal to bridge (South to North)	Wagon-Wagon-Diesel-Diesel	3.5
3	bridge to Dowgal (North-South)	Diesel-Diesel-Wagon-Wagon	3.5
4	bridge to Dowgal (North-South)	Wagon-Wagon-Diesel-Diesel	3.9

1.3. Dynamic loading

In dynamic loading, the test train with the arrangement expressed at different speeds was crossed over two lanes and the structural response to this loading was picked up by the installed sensors. Almost all tests had a survey frequency of 1 khz and a digital low pass filter was used. It should be noted that the results for freight and passenger trains were also surveyed and using their installed strain gauge output, their axial velocity and load were calculated. The specifications of the tests are shown in Tables 3 to 5.

Table 3. Dynamic test specifications (train direction from Dowgal to bridge)

Test number	Type of fleet	Passing train arrangement	Speed (km / h)
1	Test train (2 diesel + 2 wagon)	Wagon-Wagon-Diesel-Diesel	46.2
2		Diesel-Diesel-Wagon-Wagon	47.6
3		Wagon-Wagon-Diesel-Diesel	48.3
4		Wagon-Wagon-Diesel-Diesel	49.1
5		Wagon-Wagon-Diesel-Diesel	50.2
6		Wagon-Wagon-Diesel-Diesel	50.3
7		Diesel-Diesel-Wagon-Wagon	50.7
8		Wagon-Wagon-Diesel-Diesel	57.3
9		Wagon-Wagon-Diesel-Diesel	61.7

Table 4. Dynamic test specifications (train direction from bridge to Dowgal)

Test number	Type of fleet	Passing train arrangement	Speed (km / h)
1	Test train (2 diesel + 2 wagon)	Diesel-Diesel-Wagon-Wagon	35.2
2		Wagon-Wagon-Diesel-Diesel	42.9
3		Diesel-Diesel-Wagon-Wagon	50.8
4		Diesel-Diesel-Wagon-Wagon	51.9
5		Wagon-Wagon-Diesel-Diesel	52.1
6		Diesel-Diesel-Wagon-Wagon	52.3
7			52.8
8		Diesel-Diesel-Wagon-Wagon	53.9
9		Diesel-Diesel-Wagon-Wagon	54.1

Table 5. Dynamic test specifications of passing trains

Test number	Type of fleet	Direction of movement	Passing train arrangement	Speed (km / h)
1	Freight	Dowgal-bridge	Diesel-Diesel-Wagons	38
2		bridge - Dowgal	Diesel-Diesel-Wagons	43
3	Passenger	Dowgal-Veresk	Diesel-Wagons	56

2. RESULTS FROM FIELD EXPERIMENTS

By examining the data collected from the experiment, the rate of block seam openings, acceleration on the bridge main arch and vertical bridge deformation were calculated and presented. The results show that the gap between the blocks was very small and reached only 0.02 mm at the maximum passing time. Also, the acceleration on the bridge is very small and at the state passing of test train with 60 km / h, its total square root reaches 0.32 gal. The results of change sensors of DCDT placemeter show that the average vertical bridge deformation in the static test is 1.6 mm in the middle of the opening. The results of DCDT installed in the middle and one-quarter of openings up to a maximum speed of 60 km / h indicate that the vertical displacement of the bridge is not dependent on the speed and direction of the test train.

2.1. Modal test

To investigate the frequency response of the rail on the Bridge and to find the dominant response frequency of the rail, a modal test was performed on the line. For this test, a shaker and four accelerometers were used. The accelerometers used were mounted on the rails on the traverse, the rails located between the two traverses and the bridge body. The line excitation power was applied as sweep sine in a specified range to the line by shaker and the line response was recorded by accelerometers. In addition, momentary stimulation (impact load) was used to determine the pin-pin mode.

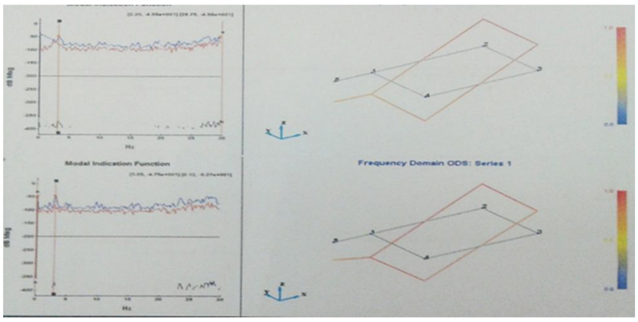

Figure 3. Oscillating shape obtained from two different tests at 3.3 Hz

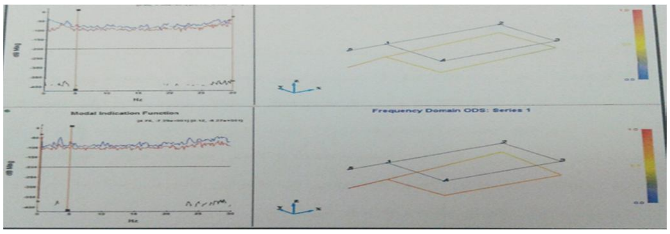

Figure 4. The oscillating shape obtained from two different tests at a frequency of 5 Hz

2.2. Vertical deformation in the middle of the opening

The results obtained from the sensor mounted in the center of the opening indicates that the deformation at this point begins with a slight elevation in some cases before the first axis arrives. Then, on reaching the first axis, the main arch moves downwards and returns to its original location after passing the train and removing the load. Figures 5 and 6 illustrate the repeatability of experiments in two directions. As shown in Fig. 7, if the diesel is the leading one, there is no noticeable change in the vertical displacement of the bridge when the wagon passes under pressure. And as the train exits, the deformation gradually declines and becomes zero. Figure 8 shows the maximum displacement parameter for all tests and dynamic tests. As can be seen, in these tests there is no logical relationship between the vertical displacement of the bridge in the middle of the opening and the train speed.

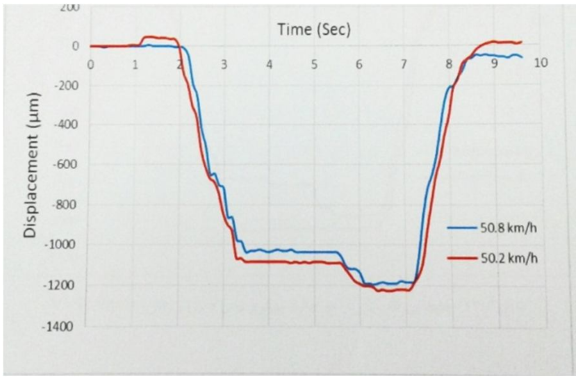

Figure 5. Vertical displacement of the bridge in the middle of the opening with the wagon leading

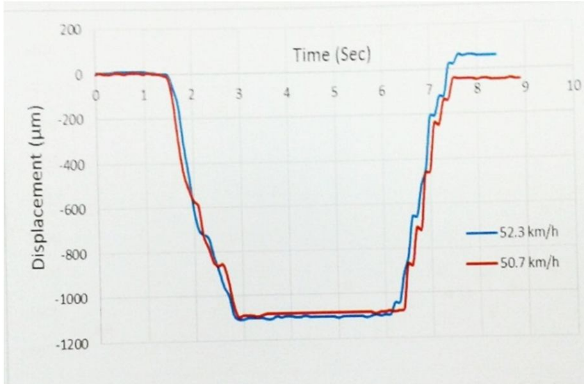

Figure 6. Vertical displacement of the bridge in the middle of the opening with diesel leading

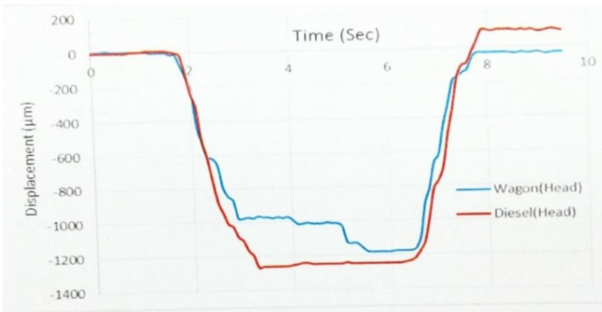

Figure 7. Vertical bridge displacement in the diesel and wagon leading

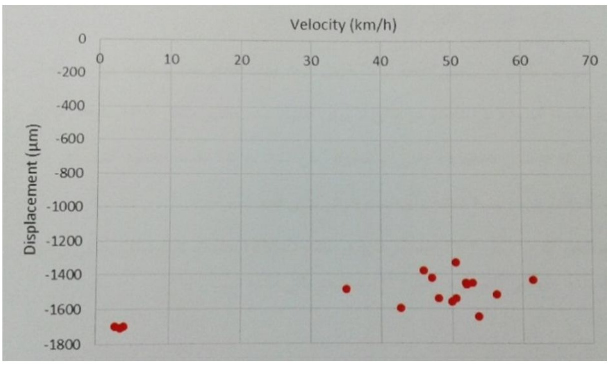

Figure 8. Maximum vertical displacement in the middle of the opening at different speeds (all tests)

2.3. Vertical deformation in one quarter of the opening

The results of the DCDT mounted at one quarter of the opening indicate that the vertical displacement of the bridge at one quarter of the openings is a constant value and it's not dependent on the speed or direction of the train. The results show that at this point, the bridge displacement is as a continuous rise and fall that, due to the train moving from the south of the bridge, first raise and then fall occurs, and if the train arrives from the north of the bridge, the opposite happens. Figure 9 shows the vertical displacement of the bridge at one quarter of the main opening for the train to travel in either direction.

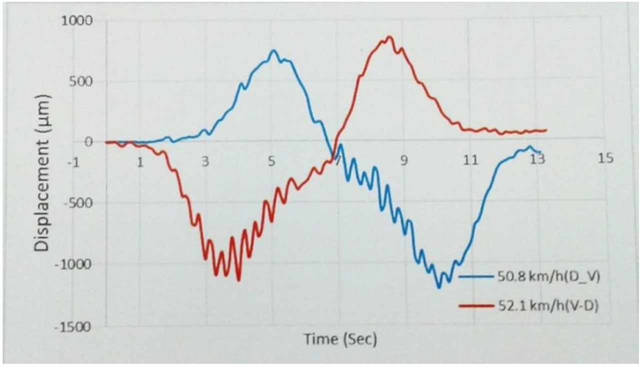

Figure 9. Vertical displacement of the bridge at one quarter of the main opening to move the train in both directions

2.4. The results of the analysis with wavelet function:

In the results section of the analysis using the wavelet function, the values of the bridge displacement under the discussed loads are shown. The following figure shows the vertical bridge displacement values in the middle of the opening with wagon and diesel leading.

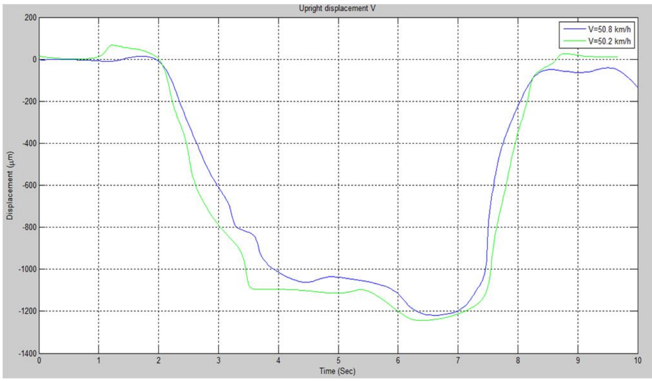

Figure 10. The comparison of vertical bridge displacement values in the middle of the opening with the wagon leading for the two states of v = 50.8km / h and v = 50.2km / h

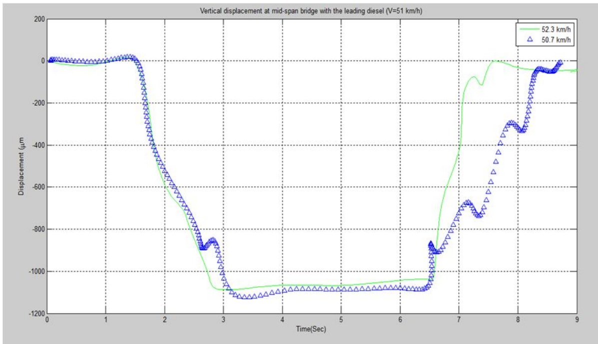

Figure 11. The comparison of vertical bridge displacement values in the middle of the opening with diesel leading for the two states of v = 52.3km / h and v = 50.7km / h

The vertical bridge displacement values in the first quarter of the main opening with the wagon and diesel leading in both directions are shown in Figures 11 and 12. Also shown in Fig. 13 are the maximum values of vertical bridge displacement in the middle of the opening at different loading speeds in all tests.

Figure 11: Vertical bridge displacement values in one quarter of the main opening shaft with diesel leading for v = 50.8km / h

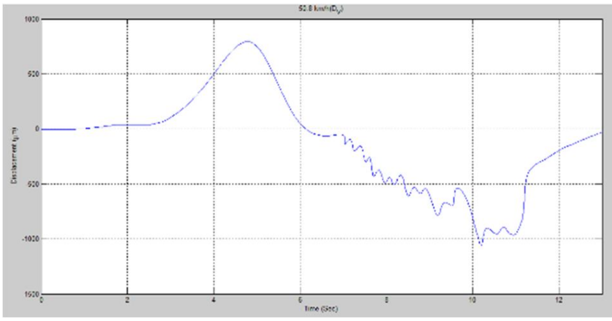

Fig. 12. Vertical bridge displacement values in one quarter of main opening with carriage leading for v = 52.1km / h

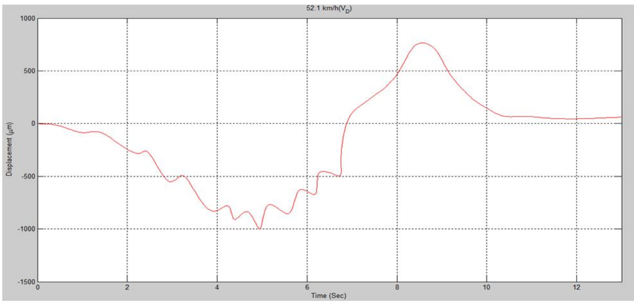

Figure 13. The maximum values of vertical bridge displacement in the middle of opening at different loading speeds

2.5. The comparison of the results of the analysis by wavelet function with the results of Dr. Ataee's health monitoring using instrumentation:

In this section, we compare the results of wavelet analysis with the results of Dr. Ataee's health monitoring using instrumentation in the field survey. After comparing and analyzing the results, it is concluded that the modeling of the bridge with the wavelet function software is reasonably close to reality, and it can be used to use and extract other items not covered in field tests.

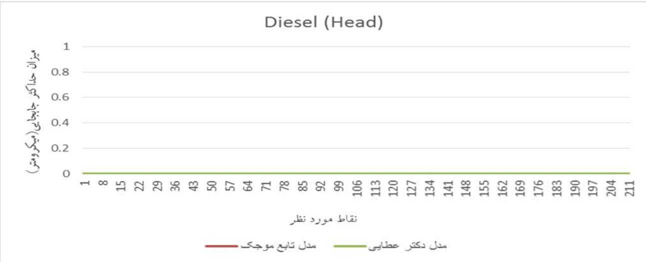

Figure 14. The comparison of the maximum orthogonal values of different points in the middle of the opening with diesel leading (V = 52.8 km / h)

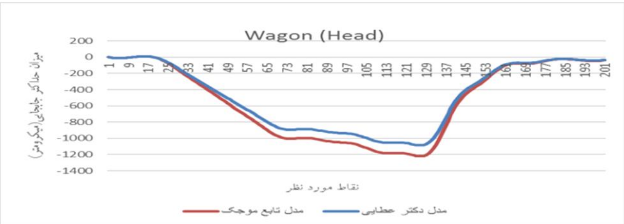

Figure 15. The comparison of the maximum displacement values of the different bridge points in the middle of the opening with the wagon leading (V = 52.1 km / h)

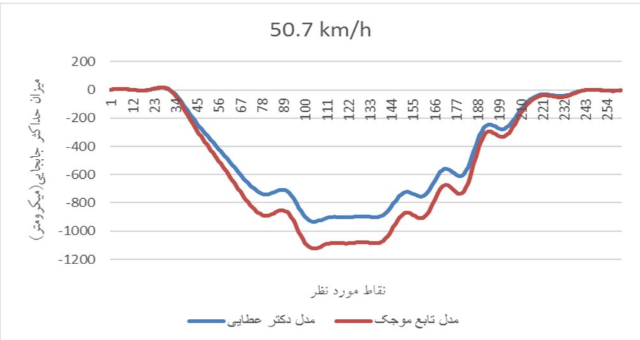

Figure 16. The comparison of the maximum displacement values of different bridge points in the middle of the opening with diesel leading (V = 50.7 km / h)

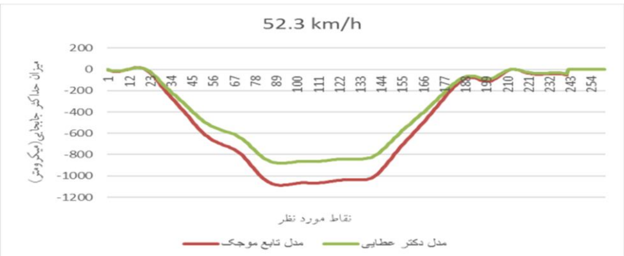

Figure 17. The comparison of the maximum displacement values of different bridge points in the middle of the opening with diesel leading (V = 52.3 km / h)

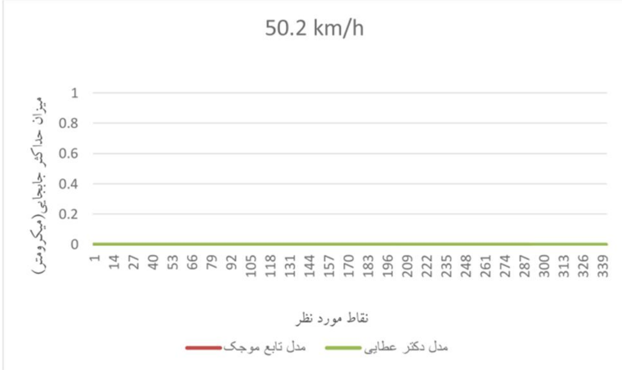

Figure 18. The comparison of the maximum displacement values of different bridge points in the middle of the opening with the wagon leading (V = 50.2 km / h)

Figure 19. The comparison of the maximum displacement values of the different bridge points in the middle of the opening with the wagon leading (V = 50.8 km / h)

3. DISCUSSION AND CONCLUSION

According to the analyses performed on the bridge using instrumentation analysis and sensitivity analysis by the wavelet function model, the results are as follows:

1. Comparing the results obtained from the wavelet function analysis and the results of field surveys and sensors installed for vertical bridge deformation in the middle of the opening and comparing Figures 5 to 10, the results are physically consistent, and, as previously stated and expected, the deformations obtained from the wavelet function analysis, as the train passes, are accompanied by a small lift and then downward movement that returns to its original location as the load exits.
2. Concerning the vertical deformations of the bridge at one quarter of the openings, the results again are physically consistent by comparing Fig. 6 with Fig. 11, and being a diesel or wagon leading does not make a significant difference to the vertical bridge movement.
3. Regarding the maximum vertical displacement of the bridge in the middle of the opening at different velocities resulted from the comparison of Figures 8 and 13, while confirming the results of field tests, in some places up to 15% difference in the displacement rate can be seen.
4. By comparing the analysis obtained from the wavelet function and the results of the installed sensors for the vertical deformation of the bridge at one quarter of the main opening for the train movement of both modes in

Figures 9, 11 and 12, physical behavior adaptation is reaffirmed.

5. By comparing the analysis obtained from Fig. 14 (comparing the maximum orthogonal values of different points in the middle of the opening with diesel leading (V = 52.8 km / h)), the maximum difference of the results of the wavelet function results with the results of field tests is 11%. (0/03/11%)

6. By comparing the analysis obtained from Fig. 15 (the comparison of the maximum vertical displacement values of different bridge points in the middle of the mouth with the wagon leading (V = 52.1 km / h)), the maximum difference between the results of the wavelet function and the results of field tests is 11%.

7. By comparing the analysis obtained from Fig. 16 (comparing the maximum vertical displacement values of different bridge points in the middle of the opening with diesel leading (V = 50.7 km / h)), the maximum difference between the results of wavelet function results and the results of field tests is 17%.

8. By comparing the analysis obtained from Fig. 17 (comparing the maximum vertical displacement values of different bridge points in the middle of the opening with diesel leading (V = 52.3 km / h)), the maximum difference between the results of the wavelet function and the results of the field tests is 19%.

9. By comparing the analysis obtained from Fig. 18 (comparing the maximum vertical displacement values of different bridge points in the middle of the opening with the wagon leading (V = 50.2 km / h)), the maximum difference between the results of the wavelet function with the results of field tests is about 11%. (10.98%)

10. By comparing the analysis obtained from Fig. 19 (comparing the maximum vertical displacement values of different bridge points in the middle of the opening with the wagon leading (V = 50.8 km / h)), the maximum difference between the results of the wavelet function and the results of field tests is about 14%.

Based on the results of Bridge's analysis, the following research models are suggested:

1. The investigation of bridge repair and reinforcement methods such as the use of FRP
2. The investigation of the performance of Bridge behavior under earthquakes near and far from the fault
3. Investigating the impact of progressive failure effect on Bridge.
4. Investigating the use of different dampers to help improve the behavior of the bridge under current operating loads

REFERENCES

[1] Kheradmand, Samira, Salajeghe, Eesa, The determination of bending plates by wavelet method and its intensity, MSc thesis, Kerman Shahid Bahonar University, 2011

[2] Li, X.Y. Law, S.S (2010). Adaptive Tikhonov Regularization for Damage Detection Based on Online Updating. Mechanical Systems and Signal Processing, Vol. 24 (6), 1646–1664

[3] Naseralavi, S.S. Salajeghe, J. Salajeghe, E. Fadaee, M.J.(2010). An Improved Genetic Algorithm Using Sensitivity Analysis and Micro-search for Damage Detection. Asian J. Civil Eng. Vol. 11 (6), 717–740

[4] Naseralavi, S.S. Fadaee, M.J. Salajeghe, J. (2011). Subset Solving Algorithm: A Novel Sensitivity-Based Method for Damage Detection of Structures. Applied Mathematical Modelling. Vol. 35. 2232–2252