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ANN Model to Damage Detection of Steel Bridge Based on Signal Processing

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ABSTRACT: Measurement uncertainties were regarded in this study through the overview of Gaussian white noise and axle load error into the numerically modeled accelerations before using them to train the systems. The result was discovered to be noise delicate, as predictable, but the method appears strong and performs well within typical noise levels. Furthermore, since white noise is a broadband contribution, construction modes of vibration that are untruth within its necessary bandwidth can be recognized from the output measurements. In this study, two frames, an un-damaged and a damaged steel bridge beam, were modeled to evaluate damage detection methods by white noise excitation. In the damaged frame of a steel bridge, one of the beams of the steel deck was weakened by a decrease in the modulus of elasticity. These frames were analyzed under the comparable record of the Tabas earthquake, and the displacement responses and acceleration of the classes were extracted. The results of the signal analysis and processing showed that the best indicator for evaluating the difference between the dynamic properties of the two frames and the damage detection is the ANN, since any damage, along with significant energy absorption at a specified frequency, can be varied. Also, the natural frequency of both structural was obtained by noise excitation with the ANN algorithm.

Keywords: ANN, Genetic Algorithm (GA), Damage Detection, White Noise Excitation

1. Introduction

There are numerous vibration-based approaches for model updating in the literature. The elementary impression behind these works is that the modal parameters are occupations of the physical assets of the construction. A variation in the physical assets is related to changes in the modal assets, which may be noticed. Natural frequencies and mode shapes are frequently taken as the measured data to identify local damage. An inclusive appraisal has been given on the recognition, position, and description of structural damage via methods based on measured vibration response. Soft computing approaches such as fuzzy logic and neural networks have rewards over the old-style statistical approaches for predicting time series [1]. Soft computing approaches do not need to specify a model construction convent. It is more accessible to approximation complex classifications with these approaches than the simple linear statistical approaches because they are nonlinear [2]. Learning of the recent advances within Structural Health Monitoring (SHM) and damage detection was shown.

2. Research history

Concerning optimum sensor location (OSL), an essential part of any damage detection structures, reference shall be found to the research of Huang et al. [3] using GA, anywhere forthcoming algorithm usages some sensor kinds as contribution and standards about the anticipated amount correctness to bring the optimum amount of sensors and their place. A genetic algorithm (GA), enthused by the organic evolutionary procedure, is a universal optimization method that can be used to treasure a nearby optimum explanation to a problem with numerous resident answers. The genetic algorithm, first formal as an optimization technique by Holland [4], is a meta-heuristic optimization method for serious dimensional and nonlinear problems. Genetic programming (GP) [5], as an allowance of GA, was an artificial intelligence method in which the answers are network programs with tree-like structures and can be used to forecast the performance of engineering structures. The developed method can be effortlessly operated in applied conditions, noisy problems, and stochastic search methods based on the apparatus of natural assortment and natural genetics. Gene expression programming (GEP) [6] is a new postponement of GP, which changes network programs with different dimensions and forms programmed in linear chromosomes with a fixed length. Some technical exertions have been in plateful GEP physical and structural engineering responsibilities. The main benefit of the GEP-based method is its ability to make predictive calculations without assuming the previous form of the scientific association. The procedure was genuine, with an experimental study on a single-span steel structure as a case study. So, Li et al. [7] proposed a new structure enciphering and transformation particle group optimization algorithm technique. Consuming a numerical model of a three-span prestressed concrete cable-stayed bridge, this method was established to have increased merging rapidity and accuracy compared to the other state-of-the-art approaches (e.g., GA). Still, within the OSL theme, Yi et al. [8] upcoming new sensor location method in multi-dimensional space only promises optimization in a specific structural direction, which results in a useless optimization of the detection grid when retaining multi-axial sensors. So, numerical research was shown on a target structure model. Jin et al. [9] approach an extended screen-based artificial neural network (ANN) method for damage detection in a bridge under unembellished temperature variances. The time-lagged natural frequencies, time-lagged temperature, and period settings are chosen as the contributions for the neural network, which forecasts the natural frequency at the next time stage. There are numerous issued researches concerning the discovery of structural damage with the release of GEP. Still, most of the proposed approaches are based on an achieved information method, which needs information on the damage complaint of the structure to be obtainable. This postures an effort in the practical application of these methods because, as it is recognized, the information in damaged complaints does not typically exist. The technique obtainable in this paper contains an updated mode-free damage detection algorithm using Gene expression programming (GEP) by ANN Toolbox.

3. ANN model

The ANN was developed and trained using the Neural Network Toolbox accessible in some software such as MATLAB. The special of complete construction has essential consequences concerning how well the system will make the forecasts. The ANN algorithm's superiority concluded other procedures in runtime and exercise, and challenging errors were established by applying the genetic algorithm (GA). In GEP, entities are programmed as linear threads of fixed size, as shown in Fig. 1, which are advanced as non-linear objects with different dimensions and shapes. These objects are known as expression trees (ETs). Typically, entities are composed of only one chromosome, which, in turn, can have one or more genetic factors separated into head and conclusion portions. ETs are the appearance of a chromosome and experience the collection process, directed by their suitability value, to generate new entities. The structural organization of the GEP genes is better understood in terms of open reading frames (ORFs). In GEP, there are two tongues: the linguistic of the genes and the linguistic of the ETs. In GEP, cheers to the modest rules that control the structure of ETs and their connections, it is likely to conclude the phenotype assumed the arrangement of a gene directly and iniquity versa [10]. Figure 2 illustrates the essential stages of GEP. The procedure commences by randomly generating the chromosomes that form the initial population. Next, these chromosomes are expressed, and each individual's fitness is assessed by evaluating a set of fitness cases (known as the selection environment). Using a roulette wheel sampling approach, individuals are then chosen based on their fitness levels (their performance in that particular environment) to reproduce with alterations, resulting in offspring with new traits. This modification of the population is accomplished by applying one or more genetic operators to selected chromosomes, such as crossover, mutation, and rotation. The resulting new individuals are then subjected to the same developmental process, which involves genome expression, exposure to the selection environment, and reproduction with modification. This entire process is repeated for a set number of generations or until a satisfactory solution is obtained.

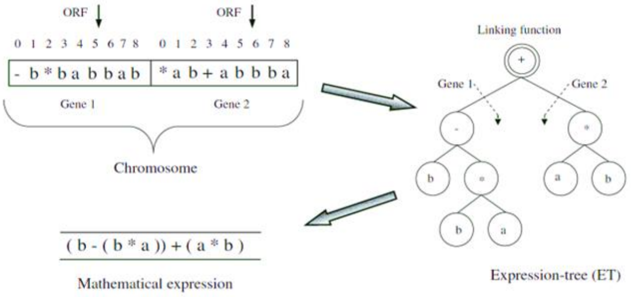


Fig.1 Chromosome with 2 genes and its decryption [8]

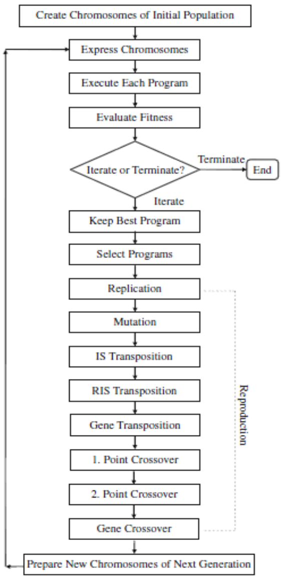


Fig. 2 Flowchart of a GEP [8].

This comprehensible fluent symbolization is named the Karva linguistic. For sample, a scientific appearance [a×(b+c)]-[√(a-c)] can be signified by a two-gene chromosome or an ET, as shown in Fig. 3. This character displays how two genes are programmed as a linear thread and how it is expressed as an ET [10].

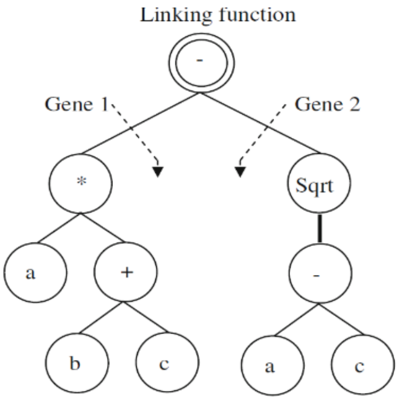


Fig. 3 Sample of a GEP expression tree [8].

4. Finite Element Model and Model Assessment

In this section, numerical simulation is modeling. The laboratory analysis response consists of 30 lateral-displacement loading cycles, while the numerical analysis response comprises a lateral-displacement loading cycle. The numerical analysis cycle has obtained the coverage of the laboratory analysis cycles. The following figure compares the cyclic response of the numerical simulation with that of the laboratory cycles. The connection response is the force-displacement relation. As can be seen, the numerical simulation cyclic response is in good agreement with that of the laboratory cycles. There is an excellent agreement, both in the pre-compression phase, post-compression phase, and compression phase, whether positive or negative. The best model was chosen on the basis of a multi objective strategy as below:

i. The simplicity of the model, although this was not a predominant factor.
ii. The best fitness value of the model on the training dataset.
iii. The best fitness value of the model on the testing dataset.

The first objective was controlled by the user through the parameter settings (e.g., the number of genes or head size which determines the upper limit for the size of the programs encoded in the gene).

5. The deformation and stress distribution

The following figure shows a simulated sample in the Abaqus software. Given that to generate simple connection numerical simulations, the exact dimensions and sizes of components, materials, interactions, and finite element grids are considered to create numerical connectivity simulations, it can be claimed that the numerical analysis results of the sample Simple connection cases are also highly accurate and reliable.

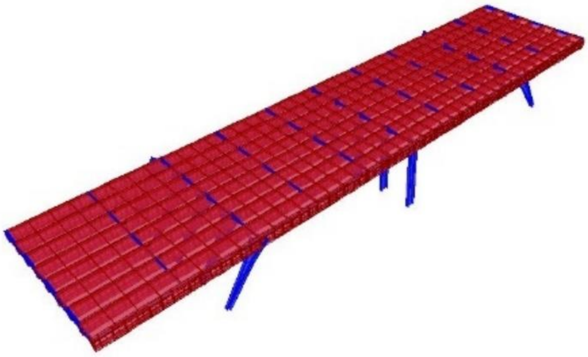


Fig. 4 Finite Element Steel Bridge Modeling

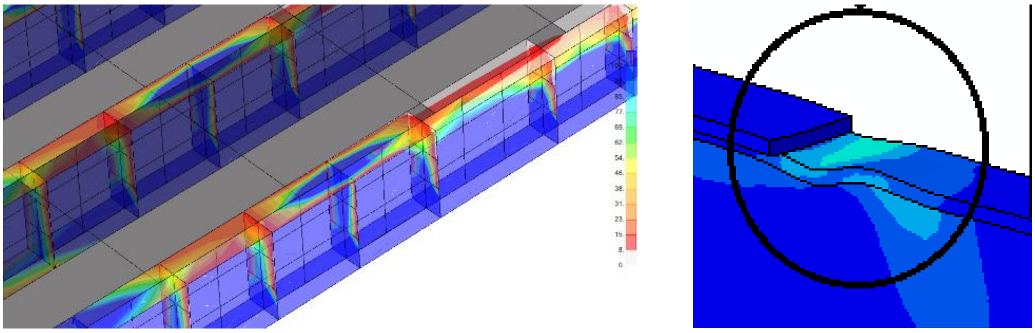


Fig. 5 Beam Local Buckling Analyze

Therefore, a simplified model of this frame is created in OPENSEES software, in which the beams and columns are connected by a torsion spring and a short spring. As stated earlier, two damaged and un-damaged beams must be simulated to capture the response under input stimulation and identify the damage's place and extent. For this purpose, the elastic modulus of the target beam was reduced to 0.1E to cause damage, reducing the lateral stiffness of the target frame. In the un-damaged frame (A), the elastic modulus of all beams is considered to be E. This strategy can be implemented in three ways:

1- Reduce the stiffness of the first beams to One-tenth of the stiffness of the second & third lateral beams (frame B)

2- Reduce the stiffness of the second beams to One-tenth of the stiffness of the 1st & third lateral beams (frame C)

3. Reduce the stiffness of the third beams to One-tenth of the stiffness of the 1st & second lateral beams (frame D)

Each of these strategies has been applied separately, and the frame response has been extracted under the scale of the Tabas earthquake. The earthquake was also applied to the un-damaged beam, with all beams having an elastic modulus E (un-damaged frame). Finally, the acceleration and displacement response was extracted by OPENSEES software.

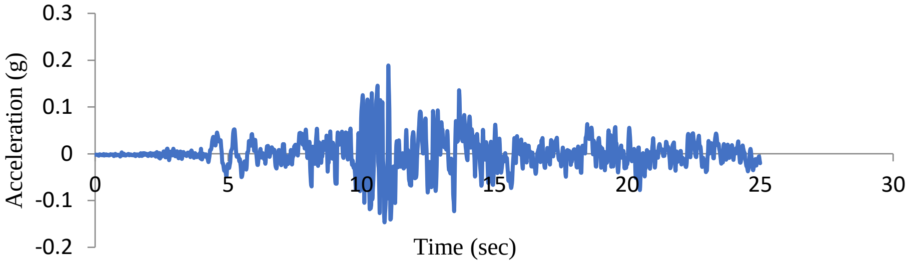
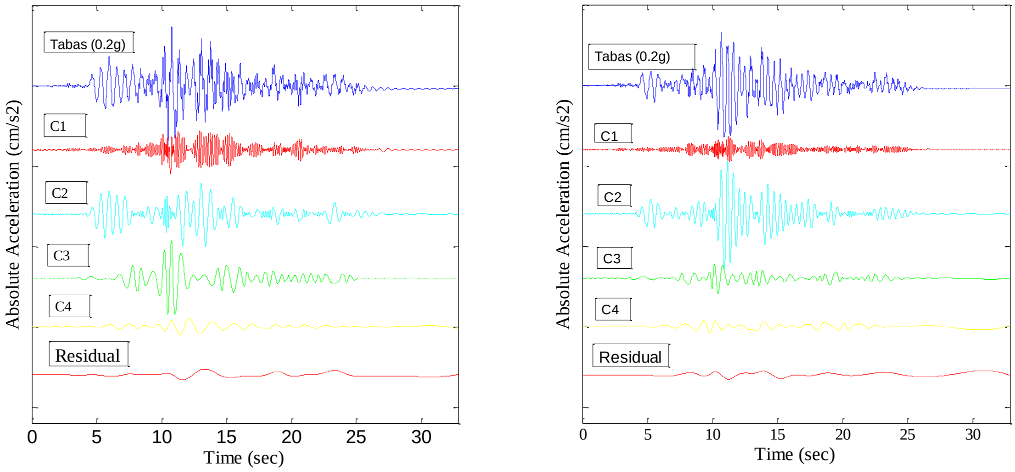


Fig. 6 TABAS earthquake accelerometer



A. The damaged frame response (Frame C)

B. The non-damaged frame response (Frame A)

Fig. 7 Comparison of natural frequency Modes: Accelerated Response of Second beam, un-damaged Frame (Frame A), and Damaged Frame (Frame C)

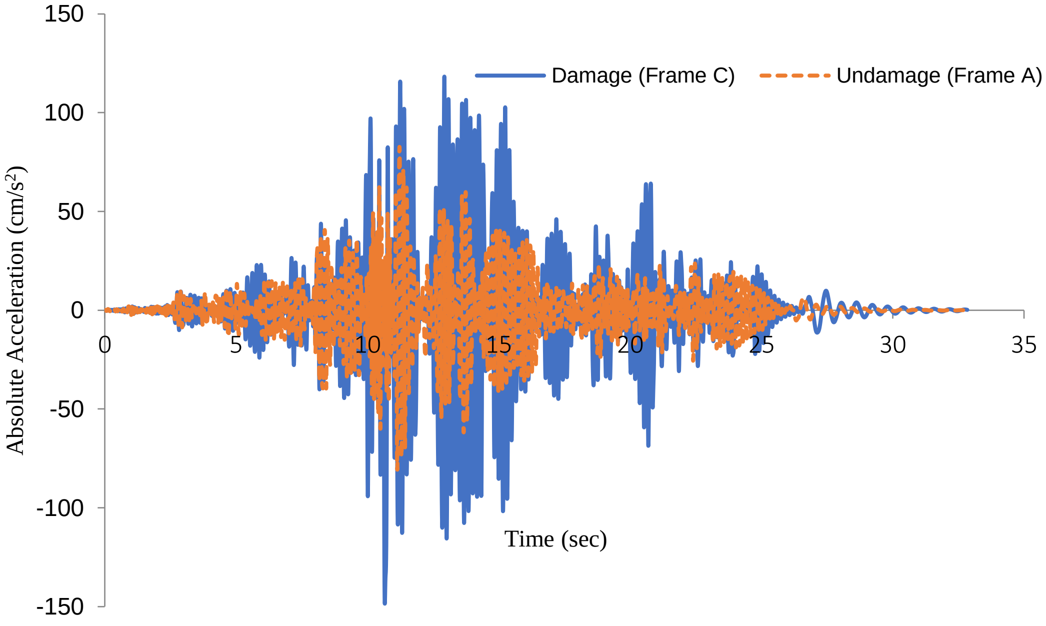


Fig. 8 Comparison of first natural frequency Modes: Accelerated Response of un-damaged Frame (Frame A) and Damaged Frame (Frame C)

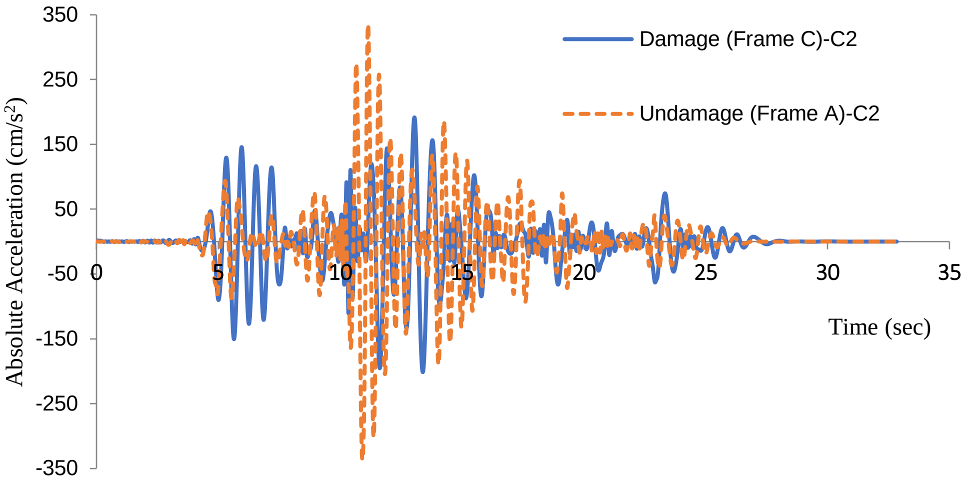


Fig. 9 Comparison of second natural frequency Modes: Accelerated Response of un-damaged Frame (A) and Damaged Frame (C)

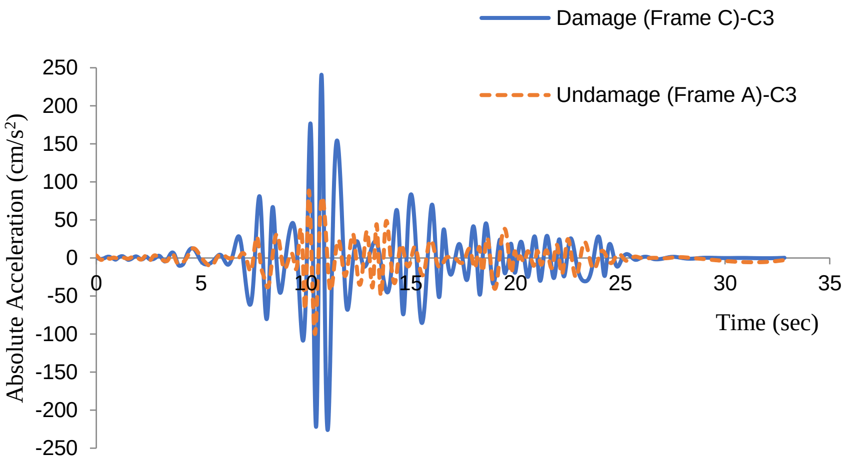


Fig. 10 Comparison of third natural frequency Modes: Accelerated Response of un-damaged Frame (Frame A) and Damaged Frame (Frame C)

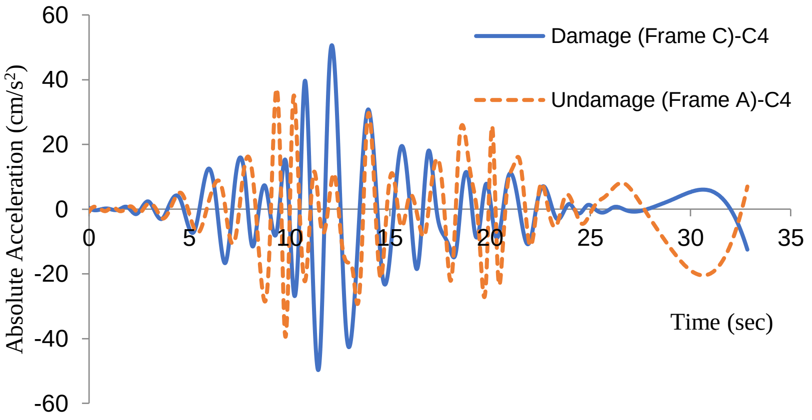


Fig. 11 Comparison of fourth natural frequency Modes: Accelerated Response of un-damaged Frame (Frame A) and Damaged Frame (Frame C)

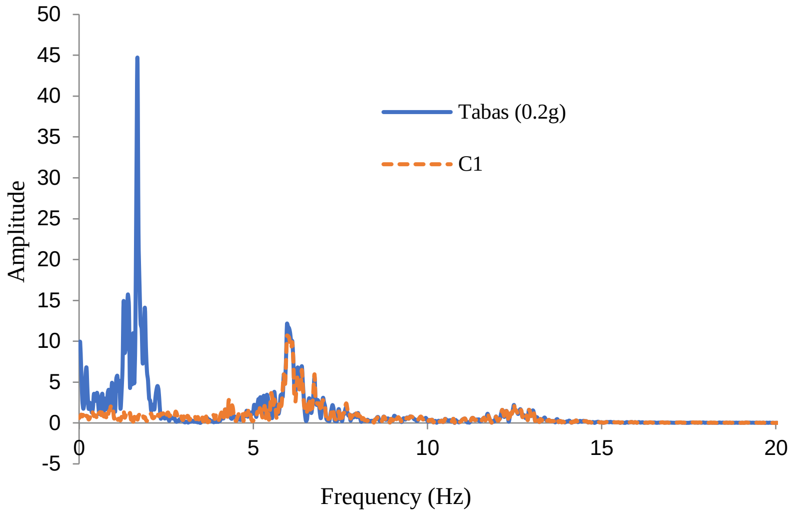


Fig 12. Comparison of first Mode (C1) Fourier Spectrum with Fourier Spectrum Accelerated Damage Response Frame

Concerning the above relation, the domain and frequency of natural functions can be represented in a 3D graph with time. The domain can be added to the 2D time-frequency diagram in the form of color plots. This spectrum can be represented as a frequency-time function of the natural modes in a graph. This spectrum is called the image plot of the ANN transform. This spectrum for the two un-damaged frames (A) and the damaged frame (C) is shown in figure 13.

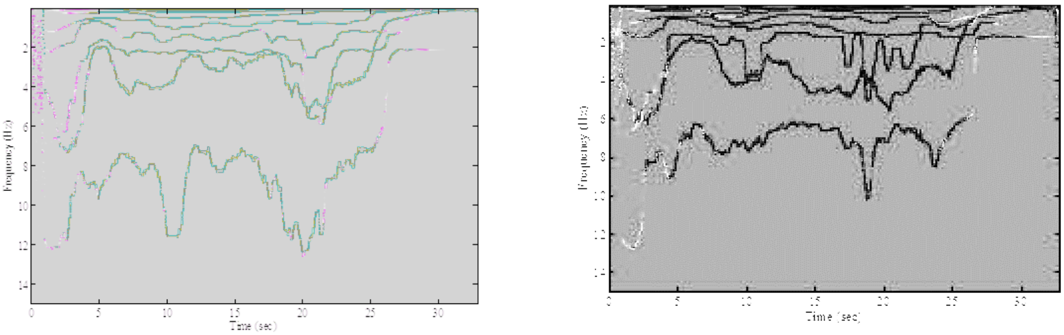


Fig.13 Comparison of the 2D time-frequency diagram of the un-damaged frame (A) and the damaged frame (C)

To extract the shape of the natural modes of the frame, it uses the recorded acceleration response of the classes, so that the acceleration response of all the classes is first extracted by input stimulation. The intrinsic modes of acceleration response of each class are then extracted by the modal analysis function method.

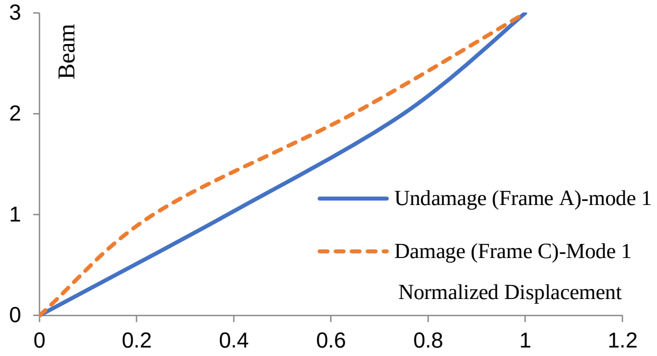


Fig.14 Comparison of first Mode Shape of the un-damaged frame (Frame A) and Damaged Frame (Frame C)

6. Model Validity

To examine how close, the predicted values were to the compressive strength steel fiber concrete, for indices, mean absolute error (MAE), mean absolute percentage error (MAPE), root mean square error (RMSE), and absolute fraction of variance (R2) were employed to evaluate the performance of models which are defined as follows:

$$RMSE = \sqrt{\frac{\sum(output - t\,arg\,e\,t)^2}{n}}$$

$$MAE = \frac{\sum abs(output - t\,arg\,e\,t)}{n}$$

$$MAPE = \frac{\sum((abs(output - t\,arg\,e\,t)/abs(t\,arg\,e\,t))}{n} \times 100$$

$$R^2 = 1 - \frac{\sum(output - t\,arg\,e\,t)^2}{\sum(output)^2}$$

The main reason for defining other statistical parameters was that the R-value alone is not an appropriate indicator of prediction accuracy of a model. This is because R will not change significantly by shifting the output values of a model equally. The statistical parameters of the final GEP model are given in Table 1.

Table 1 The statistical parameters of the best GEP model

Data sets	RMSE	MAE	MAPE (%)	R-value
Training data	5.26	3.75	10.73	0.98
Testing data	4.90	3.73	11.65	0.98

If a model gives R>0.8, a strong correlation exists between the predicted and measured values. In all cases, the error values (e.g., RMSE and MAE) are at the minimum. Therefore, the model can be judged as very good.

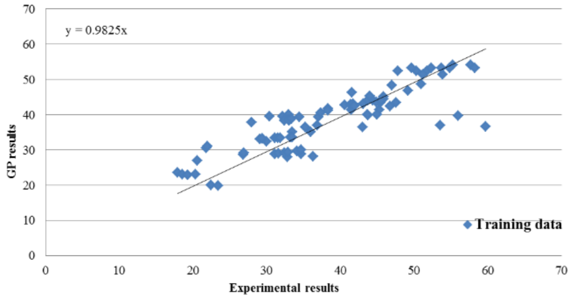


Fig.15 Comparison of experimental results with the predicted results for training set

7. Conclusion

In this study, two frames as un-damaged and a damaged beam of steel bridge were modeled to evaluate damage detection methods. In the damaged frame, one of the beams was weakened by a decrease in the modulus of elasticity. These frames were analyzed under the comparable record of the Tabas earthquake and the displacement responses and acceleration of the classes were extracted. Because of the importance of road communication, bridge was one of the most important principal constructions under development in any country that has many research backgrounds. Checking the condition of bridges before the operation and during operation is important to ensure the proper performance of the bridge according to the design in different periods. Besides, transportation development in many cases, requires the use of an existing route for heavy loads as well as higher speeds. Therefore, it is necessary to study the behavior of the bridge during its lifetime and to consider the necessary arrangements for its maintenance and repair. Detecting breakdowns in early stages in structural systems during their service life has involved the attention of many scientists in recent decades and has been the subject of many research articles in the fields of civil, mechanical, and aerospace engineering. Therefore, the present article presents a methodology for performing bridge health monitoring in order to reach the location and severity of the damage, determining the service life-prediction of the bridge. For this purpose, the accessibility cable bridge of Tehran Milad Tower on Sheikh Fazlollah Nouri highway will be investigated, and numerical simulations will be performed, the types of sensors required as well as the sensor layout architecture and the service life-prediction of the bridge will be evaluated.

The results of the signal analysis and processing showed that the best indicator for evaluating the difference between the dynamic properties of the two frames and the damage detection is the ANN, since any damage, along with significant energy absorption at a specified frequency, can be varied. Frequency of structural modulus obtained. Also, the ANN is much more accurate than single-dimensional transforms such as Fourier transforms because it can calculate the instantaneous frequency, since, in one-dimensional transforms, one of the later answers disappears, making it difficult to evaluate the dynamic properties of the system. Also, the empirical decomposition method used in the ANN is well able to separate the output signal into the natural frequency modes, which are equivalent to the natural modes of the frame. It is much easier and more accurate to compare the response of two frames using the natural modes to compare the overall response of two frames. Because the damage is associated with high-frequency components of the response, therefore, by distinguishing the structural response to natural modes with a specified frequency range, the presence or absence of damage can be identified by using natural modes of high-frequency response. Natural frequency analysis can determine the shape of the natural modes of the structure by responding to the classes because the natural modes of the response correspond to the natural modes of the structure with reasonable accuracy. The results showed that with the event of damage to the structure, the natural frequency of the structure decreases, the period increases, the hardness decreases, the mode governing the response of the structure to the shear mode increases and the contribution of higher modes to the overall response of the structure increases.

8. References

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