Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2023) 3369-3378

ECCOMAS Proceedia

COMPDYN 2023
9th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Athens, Greece, 12-14 June 2023

EFFECTIVE TECHNIQUE FOR STRUCTURES DAMAGE DETECTION BASED ON THE STRUCTURAL FREQUENCY MAPS

Wael A. Altabey [1,2], Mohammad Noori [3,4,*], Zhishen Wu[1,*], Ahmad Silik[1], and Nabeel S. D. Farhan [5]

[1] International Institute for Urban Systems Engineering (IIUSE), Southeast University, Nanjing 210096, Jiangsu, China.
e-mail: wael.altabey@gmail.com; zsw@seu.edu.cn; silikth@gmail.com

[2] Department of Mechanical Engineering, Faculty of Engineering, Alexandria University, Alexandria (21544), Egypt.

e-mail: wael.altabey@gmail.com

[3] Department of Mechanical Engineering, California Polytechnic State University, San Luis Obispo, CA 93405, USA.

[4] Visiting Professor, School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK.

e-mail: mnoori@outlook.com

[5] School of Civil Engineering, Southeast University, Nanjing 210096, China.

e-mail: eng.nabeel.saeed@gmail.com

[*]Corresponding author: Mohammad Noori; Zhishen Wu

Abstract

This research studies a novel damage detection framework for beam structure systems using displacement sensors. First, a finite element model is established under the impact load. Based on this model, an accumulative damage model is introduced to model the beam damage, and the damage case is considered. Both static and transient displacement are collected from the beam sensors installing a long beam structure. A system transfer function (TF) is proposed and applied to the "open loop" beam system. Results show these approaches perform great promises when damage evolves in beam structure.

Keywords: Beam structure systems, Damage detection, Displacement, Open Loop System, Transfer Function, Frequency analysis.

ISSN:2623-3347
Peer-review under responsibility of the organizing committee of COMPDYN 2023.
doi: 10.7712/120123.10645.21865

1 INTRODUCTION

In recent years, the construction of beam structures has developed rapidly, and the health monitoring of beam structures has become a research hotspot at home and abroad. Reasonable configuration of sensors is the premise to ensure the quality of beam structure health monitoring, and it is very important to obtain accurate and real-time information on the health status of beam structures and realize the monitoring and evaluation of beam structures [1-12].

Nowadays, more and more use intelligent and digital means to automatically capture various structural safety-related data such as environmental temperature and humidity, expansion joint displacement, etc. through the beam and plate structural health monitoring system, identify and record the development of existing diseases in real time, Discover new diseases and report it, assist in decision-making and judgment, reduce maintenance costs, and improve monitoring efficiency and quality [13-26].

System's frequency response function using conventional valve closure signals was proposed to study the influence of various faults, friction and pipe wall viscoelasticity on this response function and were compared with the corresponding impacts in the time domain [27]. The applicability of the transient-based frequency-response function (FRF) method was investigated for detecting leaks in complex series pipelines [28]. Frequency response method requiring the measurement of pressure and discharge fluctuations at only one location was used as the potential to detect leaks in real-life pipe systems conveying different types of fluids [29]. An analytical simplification of the original system frequency response-based method was used to identify the key blockage parameters governing the frequency shifts and showed that the magnitude of the frequency shift increases with the severity of blockages and is related to the changes in characteristic impedance and wave propagation coefficient of pipeline (pipe diameter, thickness, and / or wave speed) imposed by the blockage [30].

This paper discuss a new damage detection strategy of beams structure in both static and transient sensing approaches using displacement sensors, the displacement as system inputs and outputs of transfer function system is proposed and applied to the "open loop" beam system. To the best of the author's knowledge, no work related to a new damage indicator based on "system control theory" has been conducted on beams structure. By applying static and dynamic load to the displacement sensor distributed on beam, damage area of the beam can be identified by detecting signal changes with an order of magnitude.

2 BEAM MODELING

2.1 Beam Description

Consider a beam subjected to an impact force, as shown in Fig.1 as an example, the beam length is $20m$, $E = 210\ GPa$, $\rho = 7850\ kg/m^3$, $A = 1m^2$, $I = 0.083m^4$. An impact exciting force of $1000\ N$ is applied at the midpoint of the beam. Fig. 2 introduced the force-time relation. Various sensors were installed on the longitudinal direction of the beam at total of 20 orders element, 21 nodes, as shown in Fig.1 the sensors positions ate each node. Use ANSYS performs a transient analysis, simulating damage with stiffness drop at each element. The suitable finite elements were selected, i.e. for simulating structural characteristics is used BEAM3 element with material model EX 210000, PRXY: 0.3, and DENS: 7.85e-6. The displacement of the 21 nodes before and after the damage under the action of the exciting force is shown in Fig. 3.

Fig. 4 shows the acceleration responses of Impact excitation measured from the various sensors installed on the longitudinal direction of the beam. The acceleration responses change due to the structural damage. So, the time history acceleration responses are sensitive to structural damage and can be used as a damage indicator. Fig.5 shows the energy variations strength or shows at which frequencies variations are strong and at which frequencies variations are weak. Any changes in the PSD can be used as indicator of damage. Also it can be used to reduce the effect of noise in the signal and also can be used to trace the damage through the curvature of the power spectrum energy. Fig. 6 shows 1st, 2nd and 3rd frequency of the intact pipeline. Table 1 lists all the values of frequency orders for different damage case (D0 & D1).

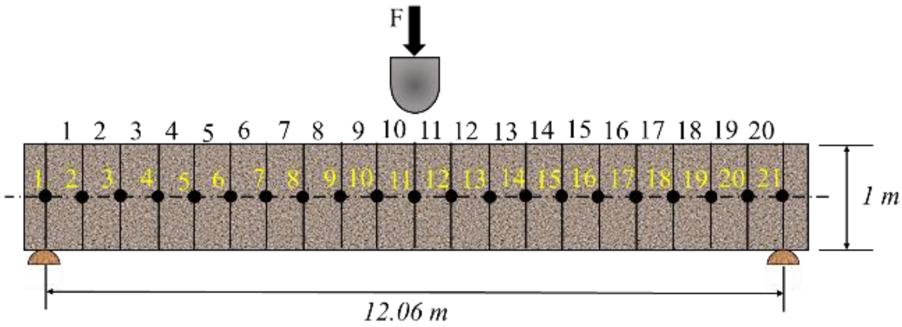


Figure 1: General View of beam.

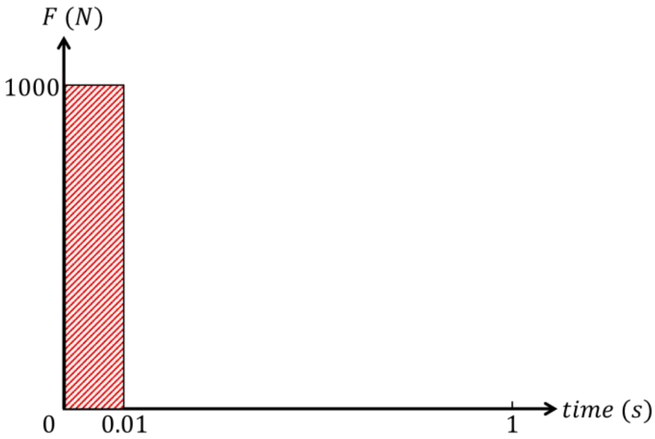


Figure 2: Impact Excitation.

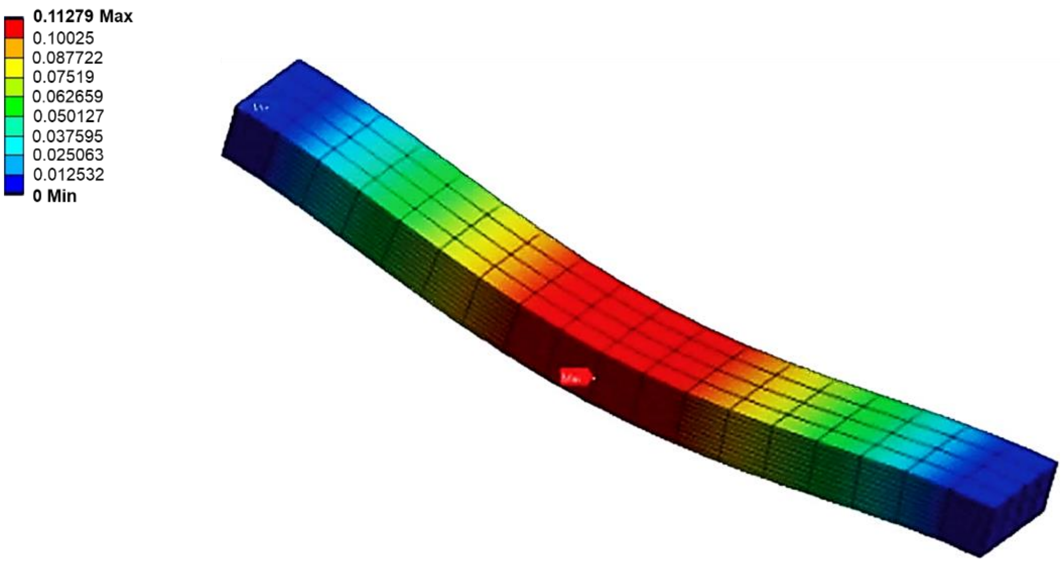


Figure 3: Displacement of a beam.

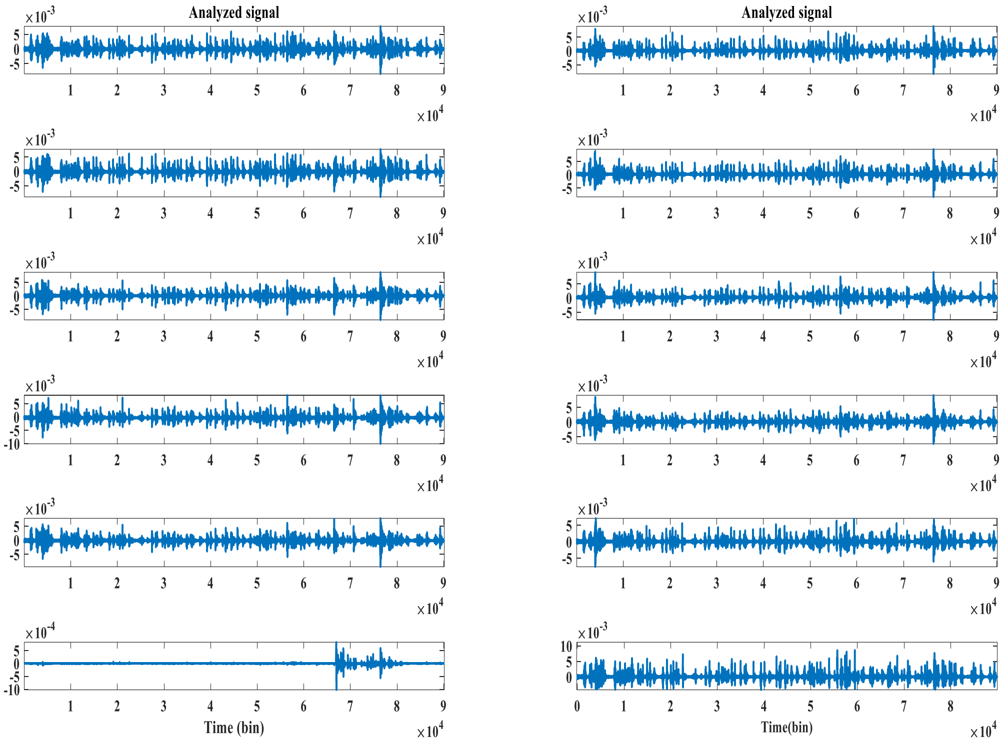


Figure 4: The acceleration of impact excitation.

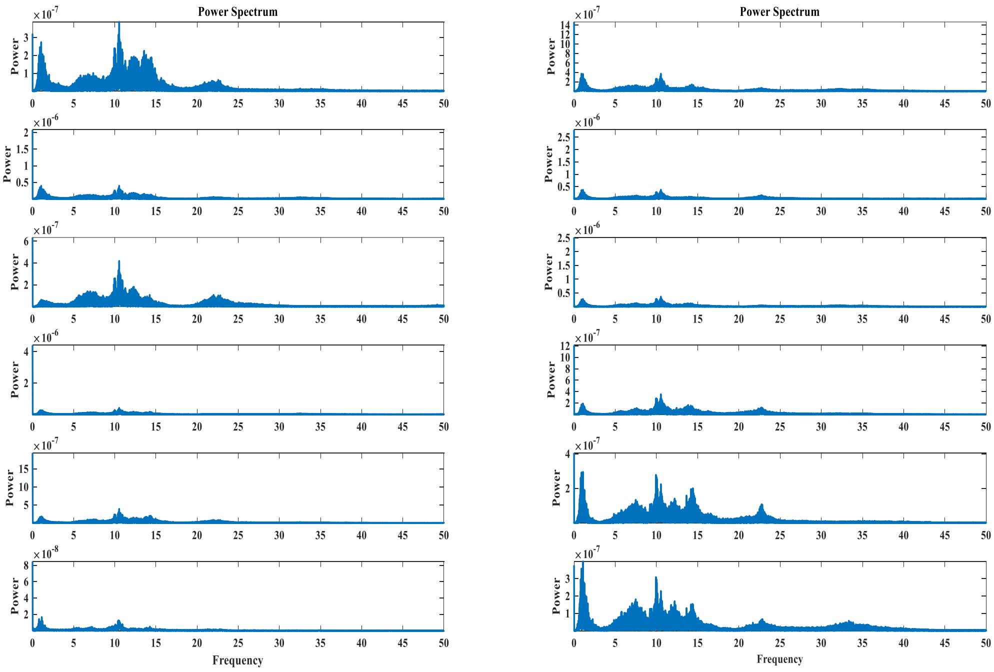


Figure 5: The Power spectral density.

Table 1: Structural frequency.

Frequency Order	D0 (Hz)	D1 (Hz)
1st order (Lateral Bending)	233.55	232.85
2nd order (Vertical Bending)	315.62	312.67
3rd order (shear)	824.38	822.90

3 RESULTS AND DISSECTIONS

3.1 Acceleration Responses Analysis in the Frequency Domain

Considering the uncertainties of modeling, the typical fitting curves (average values) of acceleration variation response are selected (Equation 2) to describe the output of the structure field system excited by impact input, where the Cubic, Quadratic, Linear, and Constant terms of the fitting equation are 0.0287, -0.0016, 0.0063, 0.0005, respectively.

$$X(t) = 0.0287t^3 - 0.0016t^2 + 0.0063\text{t} + 0.0005 \quad (1)$$

The differential equation can represent herein:

$$a_0 x_o^{(n)}(t) + a_1 x_o^{(n-1)}(t) + \cdots + a_{n-1} x_o^{(1)}(t) + a_n x_o(t) = b_0 x_i^{(m)}(t) + b_1 x_i^{(m-1)}(t) + \cdots + b_{m-1} x_i^{(1)}(t) + b_m x_i(t), n \geq m \quad (2)$$

Where x_o is the system output, x_i is the system input.

$$\text{G(s)} = \frac{\text{X}_\text{o}(\text{s})}{\text{X}_\text{i}(\text{s})} = \frac{\text{b}_0\text{s}^\text{m}+\text{b}_1\text{s}^{\text{m}-1}+\cdots+\text{b}_{\text{m}-1}\text{s}+\text{b}_\text{m}}{\text{a}_0\text{s}^\text{n}+\text{a}_1\text{s}^{\text{n}-1}+\cdots+\text{a}_{\text{n}-1}\text{s}+\text{a}_\text{n}} \quad (3)$$

System input can be expressed as:

$$\text{X}_\text{i}(\text{s}) = \frac{2232\pi}{\text{s}^2+35642\pi^2} \quad (4)$$

System output can be expressed as:

$$\text{X}_\text{o}(\text{s}) = \frac{213}{854\text{s}^4} - \frac{1}{2232\text{s}^3} \quad (5)$$

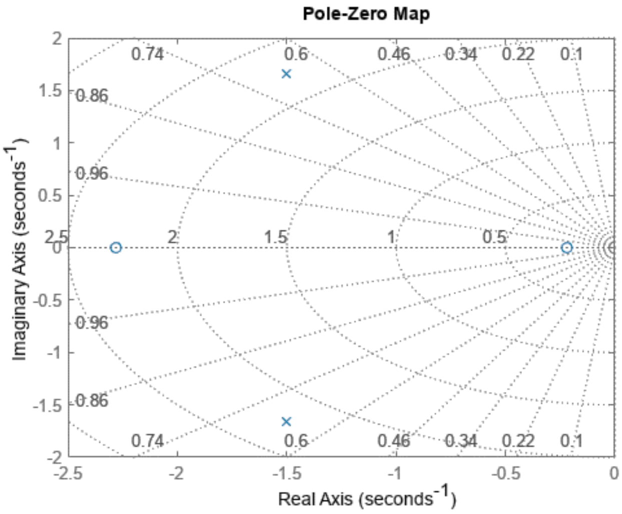
System TF can be expressed as follows according to the presented damage case (D1).

$$\text{G}_1(\text{s}) = \frac{(\text{s}^2+35642\pi^2)(854\text{s}-11160)}{2.5\text{E}9\pi\text{s}^4} \quad (6)$$

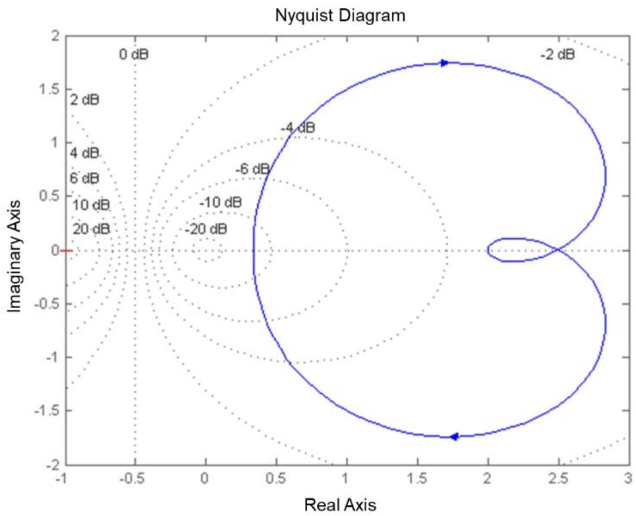
3.2 Frequency Domain Analysis Methods

The beam system subjected to different conditions of damage features when excited by a impact signal input. Let us regard it as a "control system" with an input excitation and an output measurement sensors. When considering the system as an open loop control system, this means that no feedback from output to the system, the main control on the system is from input only. The frequency domain analysis methods (Zero-Pole, Nyquist, Bode, Nichols) are applied to measure the dynamic response characteristics of the system regarding damage using Simulink software.

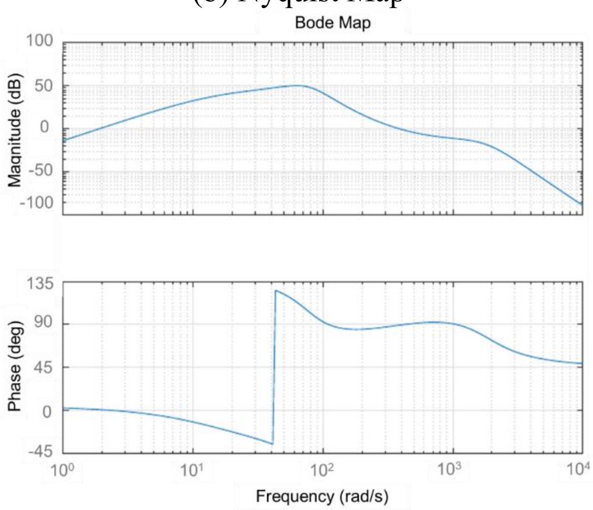
The Zero-Pole Point Map analysis for the presented damage case is plotted in Fig. 5(a). For the presented damage we can see that the Zero point of system TF (0.4) moves towards zero when the damage range increases. The Nyquist map analysis for the presented damage case is plotted in Fig. 5(b). As shown in the Figure, for the presented damage we can see the variation of the endpoint trajectory of the vector $G(j\omega) = A(\omega)e^{j\varphi(\omega)}$ (Where shows $A(\omega_i)$ appears the vector magnitude $G(j\omega_i)$ when the frequency equals ω_i, and The case of polar coordinates is $\varphi(\omega)$) when frequency ω changes from $0 \rightarrow \infty$. The Nyquist diagram shows in the non-overlapped part the system frequency of G is -13.3. The system frequency decreases as the damage range increases. The Bode map analysis for the presented damage case is plotted in Fig. 5(c). As shown in the Figure, for the presented damage we can see the frequency of the excitation signal is 100π. In detail, when damage occurs the absolute value of magnitude increases over 40dB, and the corresponding phase changes more than 165°. The Nichols map for the presented damage case is plotted in Fig. 5(d). As shown in the Figure, for the presented damage phase reaches about 180, accordingly G change at the inflection point with Gain 20 at the frequency is 100π.



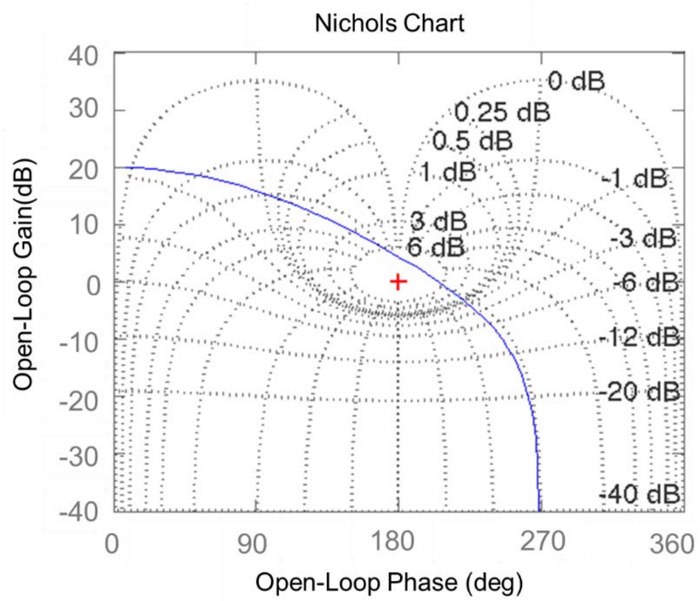
(a) Pole-Zero Map



(b) Nyquist Map



(c) Bode Map



(d) Nichols Map

Figure 6: The frequency domain analysis methods for steel beam.

4 CONCLUSIONS

This paper established a FEM of steel beam damage system from the impact load, by extracting the measurements of sensors and loaded with impact signal. Results show that the signal magnitude will suddenly and sensitively change when the damage starts. The beam system TF and the frequency domain are established and applied to reflect damage evolution through plotting the zero-pole points map, Nyquist Map, Bode Map, and Nichols Map. The most motivating conclusion in this work is that, instead of using the vibration signals of the responses of the structural system, the variation of the frequency is used to observe the time and displacement characteristics variation of the system due to structural damage.

REFERENCES

[1] R. Ghiasi, M. Noori, W.A. Altabey, T. Wang, Z. Wu, Structural Damage Detection under Uncertain Parameters using Non-Probabilistic Meta-Model and interval mathematics, Lifeline 2022: Advancing Lifeline Engineering for Community Resilience, ASCE Library, 2022, 670-679. https://doi.org/10.1061/9780784484449.061.

[2] R. Ghiasi, M. Noori, W.A. Altabey, T. Wang, Z. Wu, Uncertainty Handling in Structural Damage Detection using Non-Probabilistic Meta-Model and interval mathematics, International Conference on Structural Health Monitoring of Intelligent Infrastructure: Transferring Research into Practice, SHMII 2021, Volume 2021-June, 819–824, 2021.

[3] Z. Li, D. Feng, M. Noori, D. Basu, W. A. Altabey, Dynamic response analysis of Euler–Bernoulli beam on spatially random transversely isotropic viscoelastic soil. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(5), 1037-1052, 2022, https://doi.org/10.1177/14644207211067442.

[4] Z. Li, M. Noori, D. Basu, E. Taciroglu, Z. Wu, W.A. Altabey, Dynamic analysis of soil structure interaction shear model for beams on transversely isotropic viscoelastic soil,

Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(5), 999-1019, 2022, https://doi.org/10.1177/14644207211067437.

[5] M. Ghabdian, B. B. A. Seyed, M. Noori, W. A. Altabey, Reliability of reinforced concrete beams in serviceability limit state via microprestress-solidification theory, a structural health monitoring strategy, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(5), 1077-1093, 2022, https://doi.org/10.1177/14644207211069035.

[6] B. B. A. Seyed, M. Ghabdian, M. Noori, W. A. Altabey, Simultaneous Effect of Temperature, Shrinkage, and Self-Weight Creep on RC Beams: A Case Study, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(5), 1020-1036, 2022, https://doi.org/10.1177/14644207211067440.

[7] R. Arash, S. B. B. Aval, M. Noori, V. Sarhosis, W. Zhishen, A. Nikkhoo, W. A. Altabey, A simplified beam model for the numerical analysis of masonry arch bridges –A case study of the Veresk railway bridge, Structures, 45, 1253-1266, 2022, https://doi.org/10.1016/j.istruc.2022.09.087.

[8] M. Noori, W.A. Altabey, Hysteresis in Engineering Systems. Appl. Sci. 2022, 12, 9428. https://doi.org/10.3390/app12199428

[9] A. Silik, W. Hong, J. Li, M. Mao, M. Noori, W. A. Altabey, Develop a Health Monitoring Technique for Analysis a Big Data of Bridges, Lecture Notes in Civil Engineering, 292, 59–78, 2023, https://doi.org/10.1007/978-981-19-5783-3_5.

[10] A. Silik, M. Noori, W.A. Altabey, D. Ji, R. Ghiasi, A New Denoising Technique via Wavelet Analysis of Structural Vibration Response for Structural Health Monitoring Applications, Lifeline 2022: Advancing Lifeline Engineering for Community Resilience, ASCE Library, 2022, 691–706. https://doi.org/10.1061/9780784484449.063.

[11] W. A. Altabey, Z. Wu, M. Noori, H. Fathnejat, Structural Health Monitoring of Composite Pipelines Utilizing Fiber Optic Sensors and an AI-Based Algorithm—A Comprehensive Numerical Study. Sensors, 23, 3887, 2023, https://doi.org/10.3390/s23083887.

[12] P. Mohebian, B. B. A. Seyed, M. Noori, N. Lu, W. A. Altabey, Visible Particle Series Search Algorithm and Its Application in Structural Damage Identification, Sensors, 22(3), 1275, 2022, https://doi.org/10.3390/s22031275.

[13] X. Yanliang, Z. Chuanyue, S. Gongzuo, J. Ye, Q. Yujin, M. Xueshun, X. Jingtao, M. Noori, W. A. Altabey, Research of pavement crack detection system based on image processing, Proc. SPIE 12590, Third International Conference on Computer Vision and Information Technology (CVIT 2022), 1259007, 2023; https://doi.org/10.1117/12.2669715.

[14] W.A. Altabey, M. Noori, Z. Wu, M. A. Al-Moghazy, S. A. Kouritem, Studying Acoustic Behavior of BFRP Laminated Composite in Dual-Chamber Muffler Application Using Deep Learning Algorithm, Materials, 15(22), 807, 2022, https://doi.org/10.3390/ma15228071.

[15] W.A. Altabey, S. A. Kouritem, M. I. Abouheaf, N. Nahas, Research in Image Processing for Pipeline Crack Detection Applications, IEEE conference, 2nd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME-2022), Maldives, 16-18 November 2022. https://doi.org/10.1109/ICECCME55909.2022.9988417.

[16] W.A. Altabey, The Damage Identification in Laminated Composite Plate under Fatigue Load through Wavelet Packet Energy Curvature Difference Method. Composites Part C: Open Access, 9, 100304, 2022, https://doi.org/10.1016/j.jcomc.2022.100304.

[17] W. A. Altabey, M. Noori, Z. Wu, M. A. Al-Moghazy, S. A. Kouritem, A deep-learning approach for predicting water absorption in composite pipes by extracting the material's dielectric features, Engineering Applications of Artificial Intelligence,121, 105963, 2023, https://doi.org/10.1016/j.engappai.2023.105963.

[18] A. Silik, M. Noori, W. A. Altabey, R. Ghiasi, Z. Wu, J. Dang, Evaluation of analytic wavelet parameters effet for data analyses in civil structural heath monitoring, International Conference on Structural Health Monitoring of Intelligent Infrastructure: Transferring Research into Practice, SHMII 2021, Volume 2021-June, 813–818, 2021.

[19] W.A. Altabey, S. A. Kouritem, M. I. Abouheaf, N. Nahas, A Deep Learning-Based Approach for Pipeline Cracks Monitoring, IEEE conference, 2nd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME-2022), Maldives, 16-18 November 2022, https://doi.org/10.1109/ICECCME55909.2022.9987998.

[20] H. Weixing, W. Ju, G. Dangui, W. Xiaodong, S. Gongzuo, X. Yan-liang, Z. Chuanyue, M. Noori, W.A. Altabey, Artificial intelligence Technique for Pavement Diseases Identification, ACM Digital Library, Proceedings of the 4th International Conference on Intelligent Science and Technology (ICIST '22), August 2022, 66–72, https://doi.org/10.1145/3568923.3570515.

[21] W. Hong, M. Noori, H. Jiang, Y. Liu, W. A. Altabey, Machine Vision-Based Structural Diagnosis Application, Lecture Notes in Civil Engineering, 292, 79–88, 2023, https://doi.org/10.1007/978-981-19-5783-3_6.

[22] A. Silik; M. Noori, R. Ghiasi; T. Wang; S. Kuok; N. S. D. Farhan; J. Dang; Z. Wu, W. A. Altabey, Dynamic wavelet neural network model for damage features extraction and patterns recognition, Civil Structural Health Monitoring, 2023, https://doi.org/10.1007/s13349-023-00683-8.

[23] T. Wang, H. Li, M. Noori, R. Ghiasi, S. Kuok, W. A. Altabey, Seismic response prediction of structures based on Runge-Kutta recurrent neural network with prior knowledge, Engineering Structures, 279, 115576, 2023, https://doi.org/10.1016/j.engstruct.2022.115576.

[24] H. Fathnejat, B. Ahmadi-Nedushan, S. Hosseininejad, M.Noori, W.A. Altabey, A data-driven structural damage identification approach using deep convolutional-attention-recurrent neural architecture under temperature variations, Engineering Structures, 276, 115311, 2023, https://doi.org/10.1016/j.engstruct.2022.115311.

[25] W.A. Altabey, M. Noori, Artificial-Intelligence-Based Methods for Structural Health Monitoring, Appl. Sci. 2022, 12(24), 12726. https://doi.org/10.3390/app122412726.

[26] Z. Li, M. Noori, C. Wan, B. Yu, B. Wang, W.A. Altabey, A Deep Learning-Based Approach for the Identification of a Multi-Parameter BWBN Model. Appl. Sci. 2022, 12, 9440. https://doi.org/10.3390/app12199440.

[27] P. J. Lee, H. Duan, M. S. Ghidaoui, B. Karney, Frequency domain analysis of pipe fluid transient behavior, Journal of Hydraulic Research, 51(6), 609-622, 2013.

[28] H. Duan , P. J. Lee , M. Ghidaoui, Y. Tung, Leak detection in complex series pipelines by using the system frequenc M. S. Ghidaoui y response method, Hydraulic Research, 49 (2), 213-221, 2011.

[29] W. Mpesha; S. L. Gassman; M. H. Chaudhry, Leak Detection in pipes by frequency response method, Hydraulic Engineering, 127 (2), 127-134, 2001.

[30] H. Duan; P. J. Lee; A. Kashima; J. Lu; M. S. Ghidaoui; Y. Tung, Extended Blockage Detection in Pipes Using the System Frequency Response, Analytical Analysis and Experimental Verification, Hydraulic Engineering, 139 (7), 2013.