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INVESTIGATION OF EFFECT OF USING NANO COATING ON WOODEN SHEDS ON DYNAMIC PARAMETERS

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ABSTRACT

In this article, the dynamic parameters (frequencies, mode shapes, damping ratios) of the uncoated wooden shed and the coated by silicon dioxide are compared using the operational modal analysis method. Ambient excitation was provided from micro tremor ambient vibration data on ground level. Enhanced frequency domain decomposition (EFDD) was used for output. Very best correlation was found between mode shapes. Nano-SiO_2 gel applied to the entire outer surface of the red oak shed has an average of 14.54% difference in frequency values and 13.53% in damping ratios, proving that nanomaterials can be used to increase internal rigidity in wooden slabs. High adherence of silicon dioxide to wooden surfaces was observed as another important result of this study.

KEYWORDS: Operational modal analysis, nanomaterial, wooden, EFDD, SiO_2.

INTRODUCTION

Nanotechnology can produce products with many unique properties that can improve existing building materials: lighter and stronger structural composites, less maintenance coatings, more useful cement-based materials, products with better thermal insulation properties, etc. (Akbaş 2020). In addition, nanomaterials applied to the surfaces of structural elements of buildings can contribute to environmental cleaning and energy generation through photocatalytic reactions (Akbaş 2020). As many become interested in pursuing good health, environmental and protection in the use of wood products becomes increasingly critical (Jing et al. 2019). Thanks to nanotechnology, wood can be stronger, more durable and easier to place, steel can be made tougher, glass self-cleaning, and paints can be made more insulating and water-repellent (Tang et. al. 2018).

The reason for using silicon dioxide in the study is that its mechanical properties are as good as conventional materials (AFRP, BFRP, CFRP, GFRP, etc.) used in reinforcement (Arriaga et al. 2011, Motlagh et al. 2012, Prachasaree and Limkatanyu 2013, Glišović et al. 2016, Kisitotalla et al. 2017, Dave et al. 2018, Doubek et al. 2018). Nano-SiO_2 gel has large specific surface area and strong adsorption properties, which may help to prevent water-based fire retardant from running off (Zhongxi et al. 2020).

Operational modal analysis method is an up-to-date experimental method that is frequently used in determining the dynamic parameters of structures. The basic principle of the method is based on obtaining dynamic parameters such as frequency, mode shapes and damping ratios by processing the output data received from the structure. In addition, operational modal analysis is used to determine the damage levels of the existing structures, to check the validity of the assumptions made while constructing the finite element model, to update the initial numerical model of the existing structures according to the experimental data, to determine the dynamic characteristics of the structures by the experimental modal analysis method when the numerical model of the existing structures cannot be formed and to follow the structural health is widely used in the process (Alvin and Park 1994, Tseng et al. 1994, Aliev and Larin 1998, Ljung 1999, Lus et al. 2003, Roeck 2003).

It is necessary to estimate sensitivity of reaction of examined system to change of random or fuzzy parameters of a structure. Investigated measurement noise perturbation influences to the identified system modal and physical parameters. Estimated measurement noise border, for which identified system parameters are acceptable for validation of finite element model of examine system. System identification is realized by observer Kalman filter (Kalman 1960, Trifunac 1972, Ibrahim 1977, Juang 1994). In special case observer gain may be coincide with the Kalman gain. Stochastic state-space model of the structure is simulated by Monte-Carlo method. As a result of these theoretical and experimental studies, the importance of temperature change and humidity has emerged once again from the environmental factors affecting the odal parameters. The effects of temperature and humidity on modal parameters have been the subject of thorough examination in the last 15 years (Kasımzade and Tuhta 2017, Tuhta 2018, 2019).

It was observed that three types of definitions were used in the engineering structures: modal parameter identification; structural-modal parameter identification; control-model identification methods are used. In the frequency domain the identification is based on the singular value decomposition of the spectral density matrix and it is denoted frequency domain decomposition (FDD) and its further development enhanced frequency domain decomposition (EFDD). In the time domain there are three different implementations of the Stochastic Subspace Identification (SSI) technique: Unweighted principal component (UPC); Principal component (PC); Canonical variety analysis (CVA) is used for the modal updating of the structure (Sestieri and Ibrahim 1994, Balmes 1997, Bendat 1998, Marwala 2010).

In this study, the EFFD method was used in the signal processing. The Enhanced Frequency Domain Decomposition technique is an extension to Frequency Domain Decomposition (FDD) technique. This technique is a simple technique that is extremely basic to use. In this technique, modes are easily picked locating the peaks in Singular Value Decomposition (SVD) plots calculated from the spectral density spectra of the responses. FDD technique is based on using a single frequency line from the Fast Fourier Transform analysis (FFT), the accuracy of the estimated natural frequency based on the FFT resolution and no modal damping is calculated. On the other hand, EFDD technique gives an advanced estimation of both the natural frequencies, the mode shapes and includes the damping ratios (Jacobsen et al. 2006). In EFDD technique, the single degree of freedom (SDOF) Power Spectral Density (PSD) function, identified about a peak of resonance, is taken back to the time domain using the Inverse Discrete Fourier Transform (IDFT). The natural frequency is acquired by defining the number of zero crossing as a function of time, and the damping by the logarithmic decrement of the correspondent single degree of freedom (SDOF) normalized auto correlation function Peeters (2000).

The aim of this study is to determine the effects of silicon dioxide usage on the dynamic parameters of the wooden sheds. For this purpose, the dynamic parameters (frequencies, mode shapes, damping ratios) of the wooden shed (red oak) and the dynamic parameters (frequencies, mode shapes, damping ratios) of the entire outer surface of the 80-micron thick silicon dioxide are compared using the operational modal analysis method.

MATERIAL AND METHODS

Description of wooden shed model

The wooden shed was produced from red oak slabs with a thickness of 20 mm with density 630 kg$\cdot$m^{-3} in the Ondokuz Mayıs University Civil Engineering Laboratory. Modulus of elasticity E = 11300 MPa was determined according to used materials property, Poisson ratio $\mu = 0.35$ was determined according to used materials property. The wooden shed model and dimensions is shown in Fig. 1.

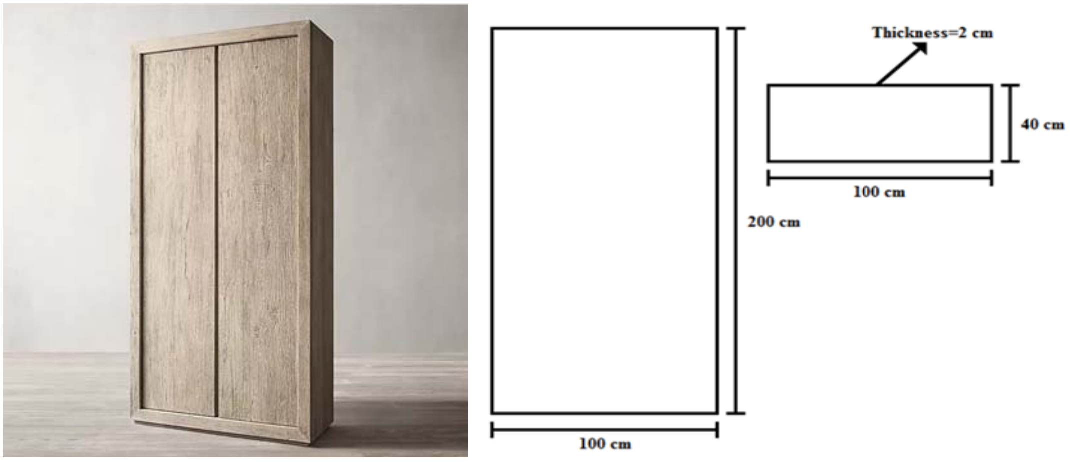

Fig. 1: Wooden shed model and dimensions.

In the case of coated wooden shed, the following studies are made on it to check and examine the efficiency of using SiO_2 coating: entire outer surface of the 80 μm thick of wooden shed are coated with multi-layer SiO_2 coating. SiO_2 coating and its components YKS is product of YKS Corporation. The properties of the slab coated with SiO_2 are: E = 7.5E10 N$\cdot$m^{-2}, Poisson ratio $\mu = 0.17$, mass per unit volume $\rho = 22000$ N$\cdot$m^{-3}, thickness = 0.00008 m. The entire outer surface of the wooden shed is covered of silicon dioxide. Approximately amount of

180 g of paint is used in 1 m^2. The surface is expected to dry during each application approximately 1 hour of curing in order to prepare a surface for application of silicon dioxide. After these setups, ambient vibration tests are followed by curing to obtain experimental dynamic characteristics similar to previously used properties in order to obtain comparative measurements.

Operational modal analysis of wooden shed

In this study, the operational modal analysis method was used to obtain the modal parameters. Three accelerometers are used to measure ambient vibrations. One of them is always assigned as the reference sensor located at the bottom of shear wall. The acceleration record was measured in two data sets. For the two data sets, 2 and 3 accelerometers were used, respectively. Accelerometers were calibrated and used, thus preventing possible measurement errors. 100 min were recorded for each data set. Selected measurement points and directions are shown in the figure. Ambient stimulation was achieved using microtremor data recorded at ground level. Matlab software and Artemis modal pro software were used to obtain modal parameters. First setup and second setup are given in Fig. 2.

Fig. 2: First setup and second setup for OMA.

RESULTS AND DISCUSSION

Ambient excitation data from the recorded micro tremor data on ground level is given in Fig. 3. Singular values of spectral density matrices of wooden shed are given in Fig. 4.

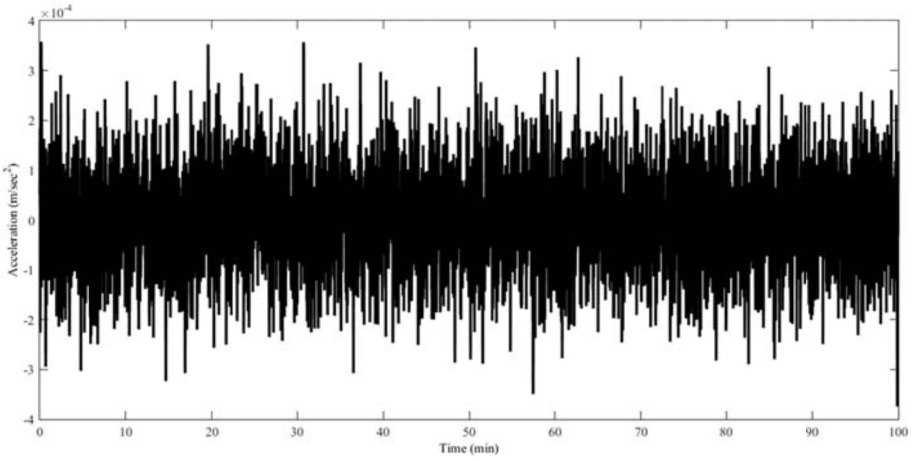

Fig. 3: Ambient excitation data from the recorded micro tremor data on ground level.

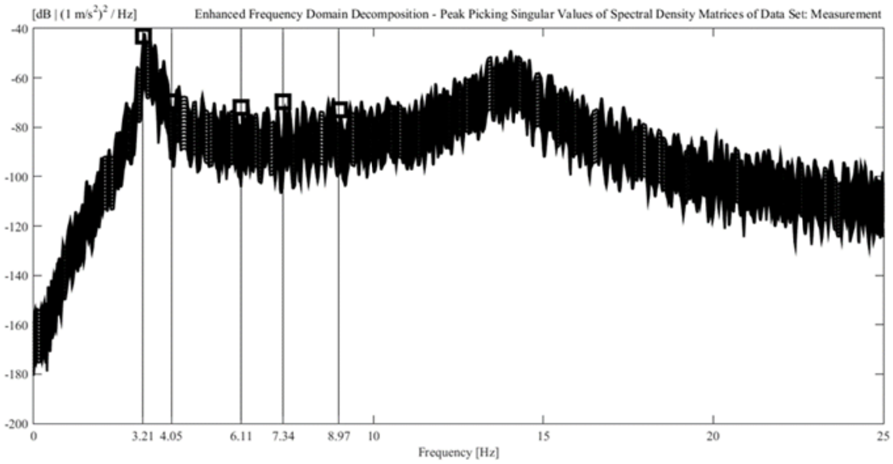

Fig. 4: Singular values of spectral density matrices of wooden shed model.

The first five mode shapes extracted from experimental modal analyses are given in Fig. 5. Natural frequencies and modal damping ratio acquired from all measurement setups with operational modal analyses are given in Tab. 1. When all measurements are examined, it can be seen that a best accordance is found between experimental mode shapes. In addition, when both setup sets are experimentally identified modal parameters are checked with each other, it can be seen that there is a best agreement between the mode shapes in the operational modal analyses.

Fig. 5: The first five mode shapes respectively.

Tab. 1: Operational modal analysis result at the wooden shed model.

Mode number	1	2	3	4	5
Frequency (Hz)	3.21	4.05	6.11	7.34	8.97
Modal damping ratio (ξ)	1.34	1.18	0.91	1.02	0.84

Operational modal analysis of coated wooden shed model

Care is taken to ensure that the measurements are the same as those made in the wooden shed model. SVSDM are shown in Fig. 6. The first five mode shapes extracted from experimental modal analyses are given in Fig. 7.

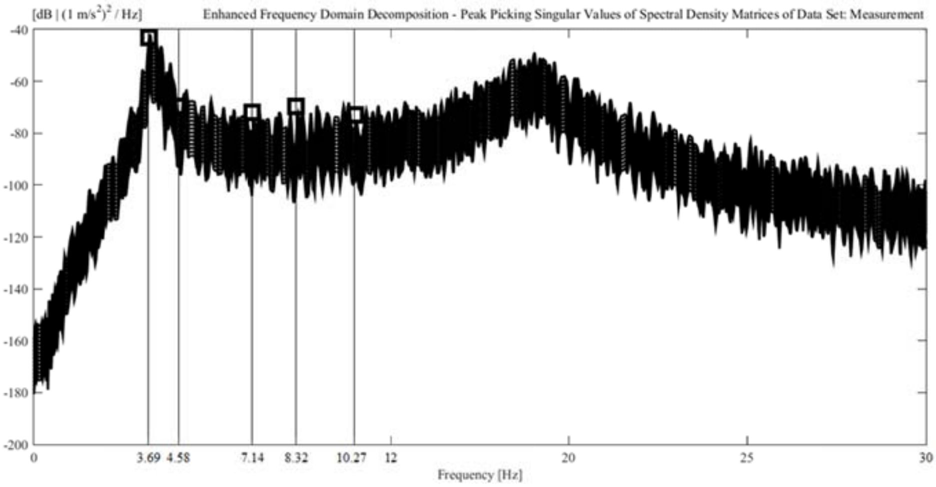

Fig. 6: Singular values of spectral density matrices of coated wooden shed model.

Fig. 7: The first five mode shapes respectively.

It is clear that using silicon dioxide seems to be very effective for strengthening wooden members along with increasing stiffness; this research aims to determine how SiO_2 implementation affects structural response of wooden shed by changing of dynamic characteristics. Natural frequencies and modal damping ratio acquired from all measurement setups with operational modal analyses are given in Tab. 2.

Tab. 2: Operational modal analysis result at the coated wooden shed model.

Mode number	1	2	3	4	5
Frequency (Hz)	3.69	4.58	7.14	8.32	10.27
Modal damping ratio (ξ)	1.07	0.98	0.82	0.93	0.74

Comparison of existing and coated wooden shed models frequency results are given in Tab. 3. Where E is the existing wooden shed model and C is coated shed model. Comparison of Existing and Coated Shed Damping Ratio Results are given Tab. 4. Where E is the existing wooden shed model and C is coated shed model.

Tab. 3: Comparison of existing and coated wooden shed model frequency results.

Mode number	1	2	3	4	5
Frequency (Hz)-E	3.21	4.05	6.11	7.34	8.97
Frequency (Hz)-C	3.69	4.58	7.14	8.32	10.27
Difference (%)	14.95	13.08	16.85	13.35	14.49

Tab. 4: Comparison of existing and coated shed damping ratio results.

Mode number	1	2	3	4	5
Modal damping ratio (ξ) - E	1.34	1.18	0.91	1.02	0.84
Modal damping ratio (ξ) - C	1.07	0.98	0.82	0.93	0.74
Difference (%)	20.14	16.94	9.89	8.82	11.90

CONCLUSIONS

In this research, the conducted were both operational modal analysis of existing wooden shed and silicon dioxide coated wooden shed. Comparing the result of study, the followings are noticed: *(1)* From the ambient vibration test, the first five natural frequencies are attained experimentally, which range between 3 and 11 Hz. *(2)* When comparing the existing and coated wooden shed results, it is clearly seen that there is very best agreement between mode shapes. *(3)* It has been determined that there is an average of 14.54% difference between the frequency values of the existing wooden shed and the silicon dioxide coated wooden shed. *(4)* It has been determined that there is an average of 13.53% difference between the damping ratios of the existing wooden shed and the silicon dioxide coated wooden shed. *(5)* Silicon dioxide applied to the entire outer surface (80 micron thick) of the wooden shed has an average of 14.54% difference in frequency values (Tab. 3) and 13.53% in damping ratios (Tab. 4), proving that nanomaterials can be used to increase rigidity in wooden sheds, in other words, for reinforcement. *(6)* The fact that no negative chemical reaction was observed between wood and silicon dioxide during the examination revealed that such nano-coatings can be used in wooden structures. *(7)* Another important result determined in the study is that it has been observed that the adherence of silicon dioxide and similar nanomaterials mentioned in the introduction to wooden shed surfaces is at the highest level.

REFERENCES

1. Akbaş, Ş.D., 2020: Modal analysis of viscoelastic nanorods under an axially harmonic load. Advances in Nano Research 8(4): 277-282.
2. Aliev, F.A., Larin, V.B., 1998: Optimization of linear control systems. Analytical Methods and Computational Algorithms. Florida, CRC Press, 279 pp.
3. Alvin, K.F., Park, K.C., 1994: Second-order structural identification procedure via state-space-based system identification. AIAA Journal 32(2): 397-406.
4. ANSI S2.47-1990, 1990: Vibration of buildings. Guidelines for the measurement of vibrations and evaluation of their effects on buildings.
5. Arriaga, F., Íñiguez-Gonzáles, G., Esteban, M., 2011: Bonding shear strength in timber and GFRP glued with epoxy adhesives. Wood Research 56(3): 297-310.
6. Balmes, E., 1997: New results on the identification of normal modes from experimental complex modes. Mechanical Systems and Signal Processing 11(2): 229-243.
7. Bendat, J.S., 1998: Nonlinear systems techniques and applications. USA, Wiley, 488 pp.

8. Brincker, R., Zhang, L., Andersen, P., 2000: Modal identification from ambient responses using frequency domain decomposition. Proceedings of the 18th International Modal Analysis Conference (IMAC), Pp 625-630, San Antonio, Texas, USA.
9. Dave, M., Pandya, T., Stoddard, D., Street, J., Blake, C., Ly, P., 2018: Dynamic and damping properties of novel bio-composites using the hammer excitation vibration technique. Wood Research 63(2): 215-226.
10. Doubek, S., Borůvka, V., Zeidler, A., Reinprecht, L., 2018: Effect of the passive chemical modification of wood with silicon dioxide (silica) on its properties and inhibition of moulds. Wood Research 63(4): 599-616.
11. Glišović, I., Stevanović, B., Todorović, M., Stevanović, T., 2016: Glulam beams externally reinforced with CFRP plates. Wood Research 61(1): 141-154.
12. Günday, F., 2018: GFRP retrofitting effect on the dynamic characteristics of model steel structure using SSI. International Journal of Advance Engineering and Research Development 5(4): 1160-1173.
13. Günday, F., 2018: OMA of RC industrial building retrofitted with CFRP using SSI. International Journal of Advance Engineering and Research Development 5(5): 759-771.
14. Ibrahim, S.R., 1977: Random decrement technique for modal identification of structures. Journal of Spacecraft and Rockets 14(11): 696-700.
15. Jacobsen, N.J., Andersen, P., Brincker., R., 2006: Using enhanced frequency domain decomposition as a robust technique to harmonic excitation in operational modal analysis. International Conference on Noise and Vibration Engineering (ISMA), Leuven, Belgium.
16. Jing, Q., Jinpeng, L., Zhenyu, W., Lijie, Q., Yu, D., Songlin, Y., Zhengbin, H., 2019: Effects of wax and dimethyl silicone oil mixed impregnation on dimensional stability of two hardwoods. Wood Research 64(1): 165-176.
17. Juang, J.N., 1994: Applied system identification. New Jersey, Prentice Hall, 394 pp.
18. Kalman, R.E., 1960: A new approach to linear filtering and prediction problems, Journal of Basic Engineering 82(1): 35-45.
19. Kasimzade, A.A., Tuhta, S, 2017: Application of OMA on the bench-scale earthquake simulator using micro tremor data. Structural Engineering and Mechanics 61(2): 267-274.
20. Kasimzade, A.A., Tuhta, S, 2017: OMA of model steel structure retrofitted with CFRP using earthquake simulator. Earthquakes and Structures 12(6): 689-697.
21. Kisitotalla, P., Atchounga, P.K., Mtopi, B., 2017: Kalman filtering of gauges noise on the creep behavior of *Entandrophragma cylindricum* (Sapelli) under a constant stress. Wood Research 62(3): 341-352.
22. Ljung, L., 1999: System identification: Theory for the user. New Jersey, Prentice Hall, 640 pp.
23. Lus, H., De Angelis, M., Betti, R., Longman, R.W., 2003: Constructing second-order models of mechanical systems from identified state space realizations. Part I: Theoretical discussions. Journal of Engineering Mechanics 129(5): 477-488.
24. Marwala, T., 2010: Finite element model updating using computational intelligence techniques: Applications to Structural Dynamics. USA, Springer Science-Business Media, 250 pp.

25. Motlagh, B., Gholipour Y., Ebrahimi G., 2012: Experimental investigation on mechanical properties of old wood members reinforced with FRP composite. Wood Research 57(2): 285-296.
26. Peeters, B., 2000: System identification and damage detection in civil engineering. PhD. dissertation, Katholieke Universiteit Leuven, Leuven, Belgium, 238 pp.
27. Prachasaree, W., Limkatanyu., S., 2013: Performance evaluation of FR Preinforced para wood glued laminated beams. Wood Research 58(2): 251-264
28. Roeck, G.D., 2003: The state of the art of damage detection by vibration monitoring: the SIMCES experience. Journal of Structural Control 10(2): 127-134.
29. Sestieri, A., Ibrahim, S.R., 1994: Analysis of errors and approximations in the use of modal coordinates. Journal of Sound and Vibration 177(2): 145-157.
30. Tang, Z., Yu, L., Zhang, Y., Zhu, L., Ma, X., 2018: Effects of nano-SiO_2/polyethylene glycol on the dimensional stability modified ACQ treated southern pine. Wood Research 63(5): 763-770.
31. Trifunac, M.D., 1972: Comparisons between ambient and forced vibration experiments. Earthquake Engineering and Structural Dynamics 1(2): 133-150.
32. Tseng, D.H., Longman, R.W., Juang, J.N., 1994: Identification of the structure of the damping matrix in second order mechanical systems. Spaceflight Mechanics 167-190.
33. Tuhta, S., 2018: GFRP retrofitting effect on the dynamic characteristics of model steel structure. Steel and Composite Structures 28(2): 223-231.
34. Tuhta, S., 2019: OMA of model chimney using bench-scale earthquake simulator. Earthquakes and Structures 16(3): 321-327.
35. Zhongxi, Z., Chungui, D., Huilong, Y., Xiaoling, Y., Qiuli, H., 2020: Promotion effect of nano-SiO_2 on hygroscopicity, leaching resistance and thermal stability of bamboo strips treated by nitrogen-phosphorus-boron fire retardants. Wood Research 65(5): 693-704.

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