NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal
ISSN No: 2581 - 4230
VOLUME 7, ISSUE 5, May. -2021

NONLINEAR SYSTEM IDENTIFICATION OF WPC TERRACE WALL WITH HAMMERSTEIN-WIENER MODEL USING AMBIENT VIBRATION

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ABSTRACT:

Today, many advances in engineering field have been and are being made. Especially the predictions of the strengths and behavior of the models designed against external factors are of great importance. Elimination of negative effects and necessary updates on the model or in other words, strengthening works play the biggest role in the design stages. In addition to all these, the dynamically influenced situations of existing structures should be revealed. New methods have been developed for this and similar reasons. System identification is one of these methods. System identification is simply the estimation of the mathematical model of the building from the input and output vibration data obtained through the structures. Thanks to the predicted mathematical model, the reactions of the building to dynamic effects can be predicted. The aim of this study is to reveal the mathematical model of the WPC terrace wall with the nonlinear system identification method. Finally, nonlinear system identification of the WPC terrace wall results demonstrated that fit to estimation data was nearly 100 % and it can be concluded that Hammerstein–Wiener system identification method is efficient and accurate in identifying mathematical model of the WPC terrace wall.

Keywords: System Identification, Ambient Vibration, WPC Terrace Walls, Dynamic Effects, Mathematical Model.

INTRODUCTION :

It is known to affect civil engineering structures negatively from dynamic effects. Most of structures located in regions prone to earthquake hazards suffer from various types of destruction caused by seismic loads [1]. There are many studies that take this into account. In the regions of seismic hazards, structures are expected to have vibrations due to seismic loads [2]. In civil engineering field, currently there are many varieties of structural and architectural structures. Such structures can be managed to resist to both static and dynamic loads effectively [3]. More work should be done to clarify the performance of structures under seismic loads [4]. More researches are being conducted to get required performance of structures under seismic loading, by means of looking at different point of view and directions [5]. In recent years, in the world and our country, the determination of the effect of vibrations on structures and structural behavior has become very important [6].

As the name suggests, WPC products are composite products obtained by extruding milled wood powder (wood chips) and various polymers. By combining the natural and pleasant looking form of WPC material wood with the durable and long-lasting structure of plastic; Beyond the usual elegance, it has also been developed to produce durable and reliable products that require much less maintenance than wood. In order to obtain the wood powder used in the WPC material, no trees are also cut, but wood sawdust, which is the production residue obtained from forest products and similar sectors, is used. Together with the plastics it contains, wood-plastic composite products are produced from 100% recyclable materials. Therefore, it is environmentally friendly. Wood-Plastic Composite products show high resistance to abrasion, rot, insect infestations such as pier worms and bedbugs. Thanks to its superior homogeneous structure gained as a result of the extrusion process, it does not absorb water and prevents the wood molecules in its composition from being damaged. It can be shaped and cut. All kinds of assembly and forming tools used in wood products can be used with WPC material. All kinds of wooden products used outdoors need constant periodic maintenance and their service life is very limited. There are maintenance costs that are repeated at least once a year, such as varnish, paint, and sandpaper. Environmental factors such as severe climatic conditions, sunlight and moisture create damage that will make maintenance inadequate after a few years and make product change mandatory, especially in places where visuality is highlighted. In short, WPC materials have been developed in order to eliminate these weaknesses of wood.

System identification (SI) is a modeling process for an unknown system based on a set of input outputs and is used in various engineering fields [8], [9], [10], [11], [12], [13]. Nowadays, researchers use genetic algorithm, artificial neural networks [14-15], fuzzy logic [16-17], etc. This more detailed system topology can improve the performance of the model by defining a true nonlinear system, both actuator nonlinear and sensor nonlinear [18-19]. they moved the works in different directions. In the studies, the use of traditional tools and equipment has been replaced by more advanced technological materials. Some studies have also shown that the H-W system can approach almost all higher order nonlinear systems relatively well [20-21]. The block structured class allows the separation of the linear dynamic part and the nonlinear static part into different subsystems (Hammerstein, Wiener, Hammerstein - Wiener, etc.) that can be interconnected in a different order [22]. The more general model of this class is the Hammerstein-Wiener (HW) model, which consists of three subsystems in which a linear block is embedded between two non-linear subsystems [23].

Engineers produce various solutions against dynamic effects. [24-26] Nowadays, it is often used to combine two materials to reduce the negative properties of two materials [27]. The production of composite materials is an example of engineering solutions. However, the theoretical flawlessness of newly created composite materials does not mean that they are flawless in practice [28-29]. Besides the decorative use of WPC terrace walls, the usability of WPC terrace walls as a building element against dynamic factors in some designs is considered in some designs. The responses of designs using composite materials to dynamic effects under ambient vibrations are extremely important. For this reason, it is necessary to examine the designs using composite materials with the system identification method.

The purpose of this study is to using ambient vibration successfully obtain the A, B, C, D and K matrix of the WPC terrace wall model and provide system identification. Thus, it is thought that the responses of the design model created against dynamic effects will be evaluated more reliably.

MATERIAL AND METHOD:

A. Description of WPC terrace wall:

The terrace wall is manufactured using only WPC composite. The geometric dimensions of the WPC terrace wall are 200 cm in width and 200 cm in length. The thickness of the WPC terrace wall is 5 cm. WPC terrace wall's modulus of elasticity is 2 Gpa. Poisson rate is 0.35. Unit volume weight 10 Kn/m3. The WPC terrace wall is not an anchor to the floor. It exists in free form. The WPC terrace wall is given fig. 1.

Fig. 1. WPC terrace wall

B. Hammerstein-Wiener model:

Hammerstein-Wiener models describe dynamic systems using one or two static nonlinear blocks in series with a linear block. The linear block is a discrete transfer function that represents the dynamic component of the model. This block diagram represents the structure of Hammerstein-Wiener model in fig. 2:

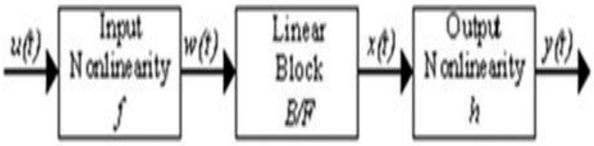

Fig. 2. Block diagram of Hammerstein-Wiener model

Where, f is a nonlinear function that transforms input data u(t) as w(t)=f(u(t)).

w(t), an internal variable, is the output of the Input Nonlinearity block and has the same dimension as u(t).

B/F is a linear transfer function that transforms w(t) as x(t)= B/Fw(t).

x(t), an internal variable, is the output of the Linear block and has the same dimension as y(t).

B and F are similar to polynomials in a linear Output-Error model

For ny outputs and nu inputs, the linear block is a transfer function matrix containing entries:

$$\frac{B_{i,j}(q)}{F_{i,j}(q)}$$

where j = 1,2,...,ny and i = 1,2,...,nu.

h is a nonlinear function that maps the output of the linear block x(t) to the system output y(t) as y(t) = h(x(t)).

Because facts on the input port of the linear block, this function is called the input nonlinearity. Similarly, because facts on the output port of the linear block, this function is called the output nonlinearity. If your system contains several inputs and outputs, you must define the functions f and h for each input and output signal. You do not have to include both the input and the output nonlinearity in the model structure. When a model contains only the input nonlinearity f, it is called a Hammerstein model. Similarly, when the model contains only the output nonlinearity h, it is called a Wiener model. The software computes the Hammerstein-Wiener model output y in three stages:

1.Compute w(t) = f(u(t)) from the input data.

w(t) is an input to the linear transfer function B/F.

The input nonlinearity is a static (memory less) function, where the value of the output a given time t depends only on the input value at time t.

You can configure the input nonlinearity as a sigmoid network, wavelet network, saturation, dead zone, piecewise linear function, one-dimensional polynomial, or a custom network. You can also remove the input nonlinearity.

2. Compute the output of the linear block using w(t) and initial conditions:

x(t) = (B/F)w(t).

You can configure the linear block by specifying the orders of numerator B and denominator F.

3. Compute the model output by transforming the output of the linear block x(t) using the nonlinear function h as

y(t)= h(x(t)).

Similar to the input nonlinearity, the output nonlinearity is a static function. You can configure the output nonlinearity in the same way as the input nonlinearity. You can also remove the output nonlinearity, such that y(t) = x(t).

In the explanation of this method, the studies of the authors in the past were also used.

RESULTS AND DISCUSSION:

System Identification Toolbox is used in the study. System Identification Toolbox™ provides MATLAB® functions, Simulink® blocks, and an app for constructing mathematical models of dynamic systems from measured input-output data. It lets you create and use models of dynamic systems not easily modeled from first principles or specifications. You can use time-domain and frequency-domain input-output data to identify continuous-time and discrete-time transfer functions, process models, and state-space models. The toolbox also provides algorithms for embedded online parameter estimation [19], [20], [30].

Measurements were made in an open environment to make more use of ambient vibrations. Two 3-axis accelerometers were placed on the WPC terrace wall. Accelerometers were placed on the upper right and lower left corners of the WPC terrace wall using strong tapes in a fixed manner. Placement of the accelerometers is given in fig. 3.

Fig. 3. Placement of the accelerometers

Factors that will adversely affect the measurement in the environment where the measurement will be made have been removed from the environment. Thus, mishaps during the data collection period were avoided.

After analyzing the data in MATLAB using System Identification Toolbox the following results are summaries in Figures (4- 12).

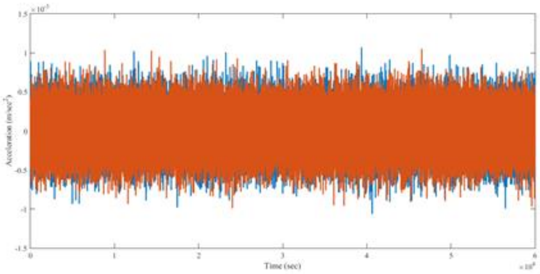

Fig. 4. İnput signals

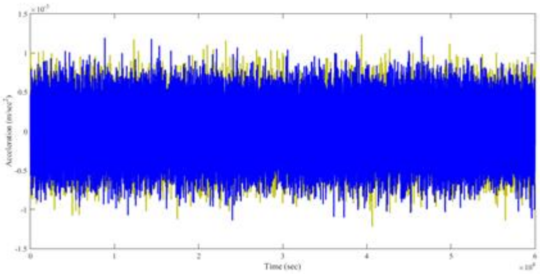

Fig. 5. Output signals

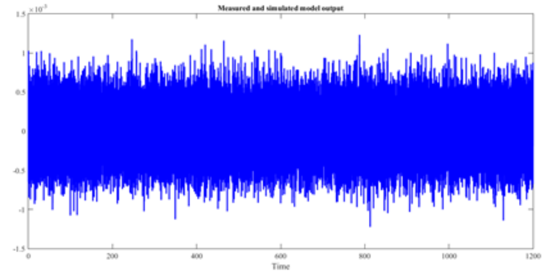

Fig. 6. Model Output (Fit to estimation data 100 %)

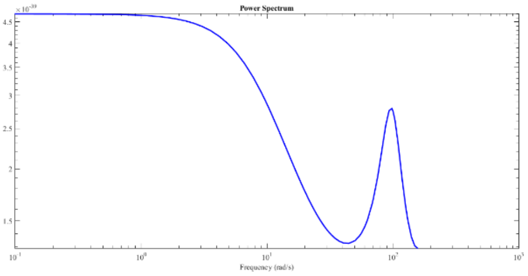

Fig. 7. Power spectrum graphics

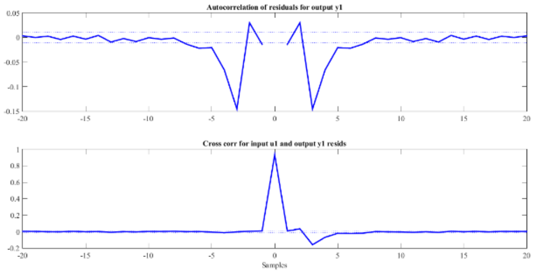

Fig. 8. Autocorrelation of residuals for output graphics

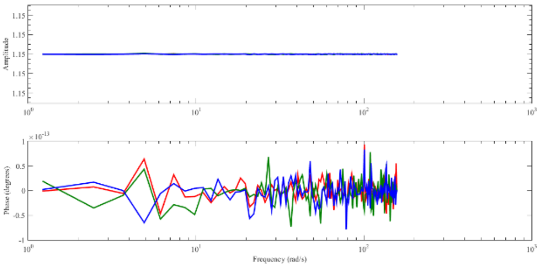

Fig. 9. Frequency function graphics

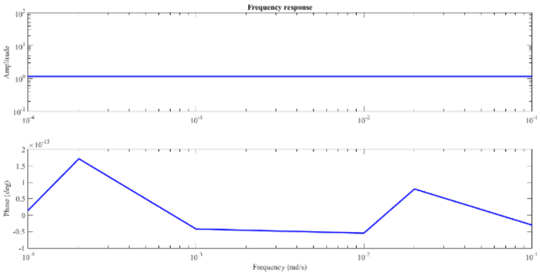

Fig. 10. Frequency response graphics

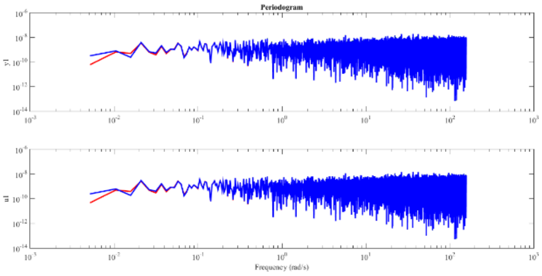

Fig. 11. Periodogram

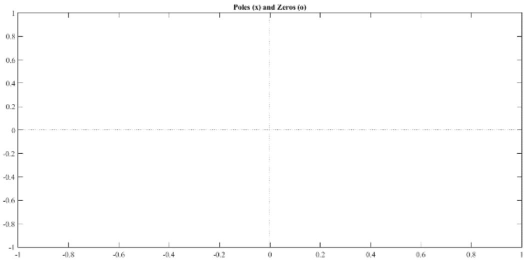

Fig. 12. Poles and zeros graphics

A, B, C, D, and K are state-space matrices. u(t) is the input, y(t) is the output, e(t) is the disturbance, and x(t) is the vector of nx states. All entries of A, B, C, and K are free estimable parameters by default. For dynamic systems, D is fixed to zero by default, meaning that the system has no feed through. For static systems (nx = 0), D is an estimable parameter by default [9], [33], [34].

Discrete-time identified state-space model:

x(t+Ts) = A x(t) + B u(t) + K e(t)

y(t) = C x(t) + D u(t) + e(t)

A, B, C, D and K Matrices obtained with MATLAB as a result of the analysis of the WPC terrace wall;

Matrix of A;

$$\begin{bmatrix} -0.003 & 0.758 & 0.216 & 0.805 \\ 0.159 & -0.062 & -0.830 & 1.262 \\ -0.176 & 0.305 & 0.175 & -0.016 \\ 0.344 & -0.069 & -0.323 & 0.052 \end{bmatrix}$$

Matrix of B;

$$\begin{bmatrix} -8.865e-20 \\ -1.785e-16 \\ 1.030e-17 \\ -2.576e-19 \end{bmatrix}$$

Matrix of C;

$$\begin{bmatrix} -8.865e-20 & -1.785e-16 & 1.030e-17 & -2.576e-19 \end{bmatrix}$$

Matrix of D;

$$[1.15]$$

Matrix of K;

$$\begin{bmatrix} 3.21451643080778e+15 \\ -2.29021063673858e+15 \\ -892679924874944 \\ 4.02907132422540e+15 \end{bmatrix}$$

CONCLUSIONS:

In the light of all this study;

- The WPC terrace wall input signals
- The WPC terrace wall output signals
- The WPC terrace wall model output
- The WPC terrace wall power spectrum
- The WPC terrace wall autocorrelation of residuals for output
- The WPC terrace wall frequency function
- The WPC terrace wall frequency response
- The WPC terrace wall periodogram
- The WPC terrace wall poles and zeros graphics
- The WPC terrace wall A, B, C, D, K state- space matrices have been successfully obtained.

The mathematical model of the structure is extracted from the estimated input–output state-space model. The system identification of a structure produced with composite material has been successfully created. Nonlinear system identification of the WPC terrace wall results demonstrated that fit to estimation data was nearly 100 % and it can be concluded that Hammerstein–Wiener model is efficient and accurate in identifying system identification of

WPC terrace wall. Successful system identification can be made using Ambient vibration. Hammerstein–Wiener Models using with Nonlinear system identification tool is proposed to identify the identification of composite structures.

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