System Identification of RC Building Using N4SID

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***Abstract*—In recent years, surveys of earthquake and earthquake effects have an important place in civil engineering field. Earth on structures have been severely damaged by the earthquake. Thus, there has been loss of life and property. This has particularly affected countries located on active fault lines. For all these reasons, pre- and post-earthquake measures have been developed. Attention has been paid to taking earthquake effect into consideration in rebuilding structures. However, there are no measures other than demolition or retrofit options for existing buildings.System identification methods have emerged in order to determine the earthquake performance of the buildings.In this paper, a new structural identification tool is proposed to identify the modal properties of structures.At last, after collecting modal responses from the available sensors, the mode shape vector for each of the decomposed modes in the system is identified from all obtained modal response data. System identification of RC building was performed. Matrices A, B, C, D, K were omitted. All these works have been done by using N4SID. N4SID stands for numerical algorithms for system identification. With the numerical algorithms found, the mathematical model of the system is extracted. The mathematical model of the system determines the performance of the system. Results demonstrated that N4SID system identification method is efficient in identifying modal data of the structures.**

***Keywords*—System identification, N4SID, RC building, Earthquake performance, Numerical algorithms**

I. INTRODUCTION

Most of structures located in regions prone to earthquake hazards suffer from various types of destructioncaused by seismic loads. Under such earthquake occurring, the parts (especially the columns) of building structuressuffer damage. Looking on the other side, especially considering the performance of such buildings under seismicoccurrence, there is a great need to strengthen the columns even without changing their building masses; this clearlyshows that there is a need to investigate the connection between technical repairing or strengthening procedures andthe column capacity. In this understanding, more researches are being conducted to get required performance ofstructures under seismic loading, by means of looking at different point of view and directions [2], [12],[13],[14].

In recent years, one of the reasons for increasing the importance of observing the health of the building civil engineering, scientific research circles; Which damage can be identified first? How long is the usable life of the building? to develop methods to answer questions such as. These studies are increasing. This issue is given importance due to factors such as the health of the structure against natural and artificial influences and its economic longevity. In all construction systems, damage starts at the material level. As the damage in the system increases, it reaches a value defined as deterioration. Civil engineering structures are exposed to a variety of natural and artificial effects throughout their lifetime. These effects are the forces that can affect the dynamic characteristics of the structure and thus the service life.[15]

Stable adaptive controller designs have been one of the most important research topics in recent years as they can produce effective solutions against time-varying system parameters and disturbing effects in the desired system output monitoring problem.[14]

System identification (SI) is a modeling process for an unknown system based on a set of input outputs andis used in various engineering fields. (Sirca and Adeli, 2012)[6]. Subspace system identification is introduced as apowerful black-box system identification tool for structures. The application of the method for supporting excitedstructures is emphasized in particular. The black- box state- space models derived from the identification ofsubspace systems are used to estimate the modal properties (i.e. modal damping, modal frequency and mode shapes)of the structures [7],[13],[14].

System identification methods are used to determine the modal parameters of the system. These dynamic parameters in structural engineering, bridges, buildings and so on. it helps to understand the dynamic behavior of other structures. Modal system identification is used to check the reliability of structural structure under sudden and dynamic loads such as earthquake, storm and explosion.[15].

Choosing the right model grade is an important step in system identification. If the degree of the model is too high, unreal modes will be able to produce results. Modal parameters may not be obtained when the model degree is selected too small.[15].

Based on the information to be obtained from the examination of the characteristics of the data at the determination stage, the appropriate ones are selected from the general models. In other words, the inputs and outputs received from the system are examined and the model which is suitable for the system examined is investigated. Once the appropriate model is decided temporarily, the order of determination of the order of this selected model is reached.[15].

Depending on the input and output sizes of these systems, In order to obtain a behavioral model, it is necessary to determine and measure the magnitudes affecting the structures.Model identification, system-related, based on physical laws based on the preliminary information and the size of the system (introduction magnitude or input signal) from the system's response to these magnitudes (output magnitude or output signal) It is exploited. Physical laws are defined by differential or algebraic equations. In this way model, not only the relationship between the input and output sizes, but also by determining the model structure are expressed.On the other hand, the lack of any preliminary information about the system or the system is too complex. In case of having, identification methods (such as parametric definition) are used in determining the model of the system. In this case, the model is obtained by using input and output sizes. This technique can be applied by making some preliminary assumptions regarding the choice of system grade, input and output sizes.[15].

In engineering structures, three types of identification are used: modal identification of parameters; structural-modal identification of parameters; control model identification methods. In the frequency domain the identification is based on the unique value decomposition of the spectral density matrix and it is denoted Frequency Domain Decomposition (FDD) and its further development Enhanced Frequency Domain Decomposition (EFDD) [1].

In the time domain there are three different implementations of the Stochastic Subspace Identification (SSI) technique: Unweight Principal Component (UPC); Principal component (PC); Canonical Variety Analysis (CVA) are used [1].

System İdentification with Classical Identification and Subspace Identification are given fig 1.

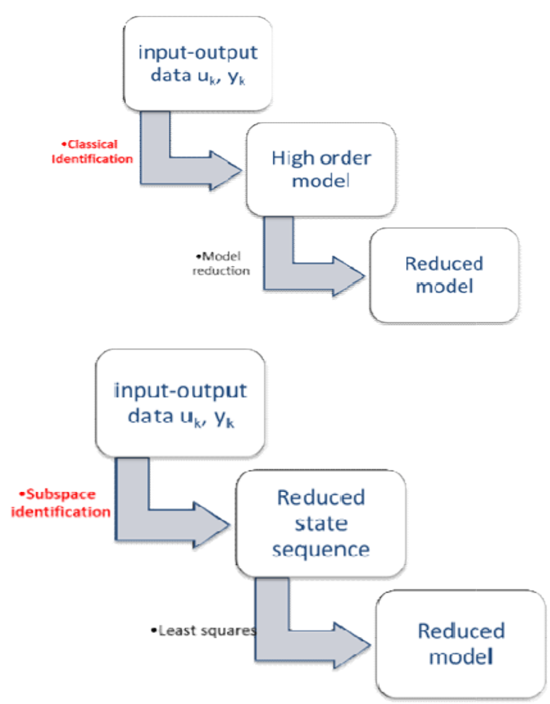


Fig. 1 System İdentification with Classical Identification and Subspace Identification

When a reduced order model is required, one first identifies a high order model in some classical approaches (on the right) and then applies a model reduction technique to obtain a low order model. The left side shows the subspace identification approach: first we obtain a "reduced" status sequence, after which a low order model can be identified directly. (Overschee and Moor, 1996).[9],[12].

In this paper, the problem of multiple degrees of free structural systems without a limited number of elements was investigated. As known for similar type systems the system matrices [m], [c], [k] may be built only by FEM and the equation of motion for a finite-dimensional linear-dynamic system a set of n2 second-order differential equations are arranged as

$[m]\{\ddot{u}(t)\} + [c]\{\dot{u}(t)\} + [k]\{u(t)\} = [d]\{f_{\oplus}\,(t)\}$(1a)

Here the direct stiffness method was used for implementation in the finite element method and appropriately was build system mass, damping and stiffness matrices ($[m]$; $[c]$; $[k]$). For example, The FEM implementing system stiffness matrix [k] is shown as follows by the direct stiffness method:

$[\bar{k}_r] -> [\bar{\bar{k}}_r] = [C_r][\bar{k}_r][C_r]^T -> [\bar{\bar{k}}_{r+}] = [\tau_r]^T[\bar{\bar{k}}_r][\tau_r] ->$
$[k.] = \sum_{r=1}^{r.}[\bar{\bar{k}}_{r+}] -> a.b.c. -> [k]$
(1b)

where, $[\bar{k}r]$ is the element stiffness matrix in local coordinate system (c.s.) for *r*-th finite element, $[\bar{\bar{k}}r]$ is the element stiffness matrix in global coordinate system for *r*-th finite element,

$[Cr]$ is the coordinate transformation matrix from local to global c.s. for *r*-th finite element,

$[\tau_r]$ is the topology matrix for *r*-th finite element, *a.b.c.* is abbreviation "mean after application of boundary conditions", $r_*$is a number of identical finite elements examined system,

$[k]$ is the stiffness matrix of the in examined system in global c.s. The main relationships of the FEM are based on the Lagrange principle of variation.

The equation of motion (1) are transformed to the state-space former of first order equations-i.e., a continuous-time state-space model of the system are evaluated as

$\{\dot{z}(t)\} = [A_c]\{z(t)\} + [B_c]\{f_{\oplus}\,(t)\}$(2a)

$$[A_c] = \begin{bmatrix} [0] & [I] \\ -[m]^{-1}[k] & -[m]^{-1}[c] \end{bmatrix} \quad (2b)$$

$$[B_c] = \begin{bmatrix} [0] \\ [m]^{-1}[d] \end{bmatrix} \quad (2c)$$

$$\{z(t)\} = \begin{bmatrix} u(t) \\ \dot{u}(t) \end{bmatrix} \quad (2d)$$

If the response of the dynamic system is measured by the m_1 output quantities in the output vector $\{y(t)\}$using sensors (such as accelerometers, velocity, displacements, etc.,), for system model represented by the equations (2), appropriate measurement-output equation become as

$\{y(t)\} = [C_a]\{\ddot{u}\} + [C_v]\{\dot{u}\} + [C_d]\{u\} = [C]\{z(t)\} + [D]\{f_{\oplus}\ (t)\}$(3a)

$[C] = \left[[C_d] - [C_a][m]^{-1}[k],\ [C_v] - [C_a][m]^{-1}[c]\right]$(3b)

$[D] = [C_a][m]^{-1}[d]$ (3c)

Where $\{u\}$is the vector of displacement; $[Ac]$, is an n_1 ($n1 = 2n_2$; n_2 is the number of independed coordinates) by n_1 state matrix ; $[d]$ is an n_2 by r_1 input infuence matrix, characterizing the locations and type of known inputs $\{f_{\oplus}(t)\}$; $[Ca]$; $[Cv]$; $[Cd]$ are output influence matrices for acceleration, velocity, displacement for using sensors (such as accelerometers, tachometers, strain gages, etc.,) respectively; $[C]$ is an $m_1\ x\ n_1$ output influence matrix for the state vector $\{z\}$and displacement only; $[D]$ is an $m_1\ x\ r_1$ direct transmission matrix; r_1 is the number of inputs; m_1 is the number of outputs.

In the output - only modal analysis environment, the main assumption is that input force $\{F\ (t)\} = [d]\left\{f_{\oplus}(t)\right\}$comes from white noise or time impulse excitation. Under this hypothesis discrete-time stochastic state {space model may be written as:

$\{z_{k+1}\} = [A]\{z_k\} + [B]\{f_{\oplus k}\} + \{w_k\}$(4)

$\{y_k\} = [C]\{z_k\} + [D]\{f_{\oplus k}\} + \{v_k\}$
(5)

where $\{z_k\} = \{z(k\Delta t)\}$is the discrete-time state vector; is the process noise due to disturbance and modeling imperfections;$\{v_k\}$is the measurement noise due to sensors' inaccuracies; $\{w_k\}, \{v_k\}$vectors are non-measurable, but assumed that they are white noise with zero mean.

If this white noise assumption is violated, in other words if the input contains also some dominant frequency components in addition to white noise, these frequency components cannot be separated from the eigen frequencies of the system and they will appear as eigenvalues of the system matrix $[A]$.

In the real structures, exited by ambient vibration, the input $\{f_{\oplus}\ (t)\}, \left\{f_{\oplus k}\right\}$ remains unmeasured and therefore it disappears from the equations (2)-(5) respectively. Then to take into consideration this fact, the input is implicitly modeled by the noise terms $\{\underline{w}_k\}\{\underline{v}_k\}$, which are indirectly contain no measurable input from ambient vibration and mentioned relation became as:

$\{z_{k+1}\} = [A]\{z_k\} + \left\{\underline{w}_k\right\}$ (6)

$\{y_k\} = [C]\{z_k\} + \left\{\underline{v}_k\right\}$ (7)

II. DESCRİPTİON OF RC BUİLDİNG

The building is 27.5 m in height from the ground level.The building consists of 11 floors.The parking levels are located beneath ground level with a depth of 2.75 m. The first and second storey heights are 3 m and 2.5 m appropriately. Storey slab between these two stories are not. The upper eight stories are 2.75 m in height. The residential floors on levels three through ten are 12.75 m x 29.4 m = 374.85 m^2 in area. Construction of the building began in the fall of 2003 and was completed (retrofitted) during the winter of 2005. Storey slab type mainly (~97%) are ribbed floor (~3% plate floor). Picture and a typical floor plan of the building are shown in (Fig.2 a, b).

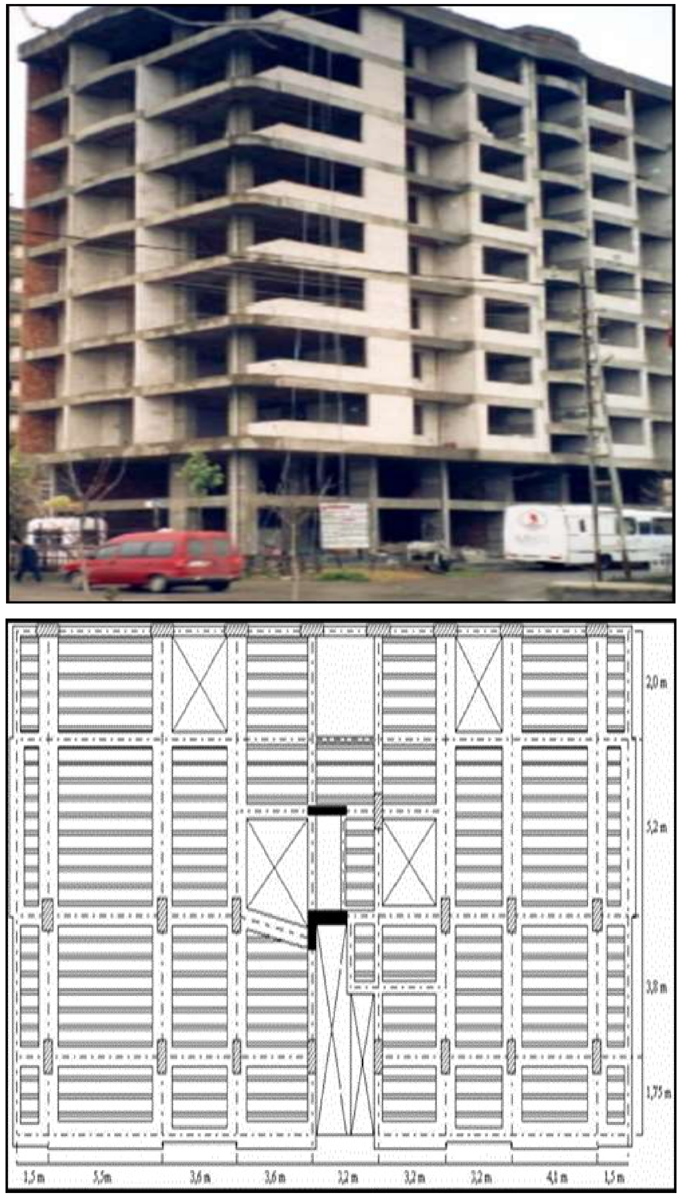
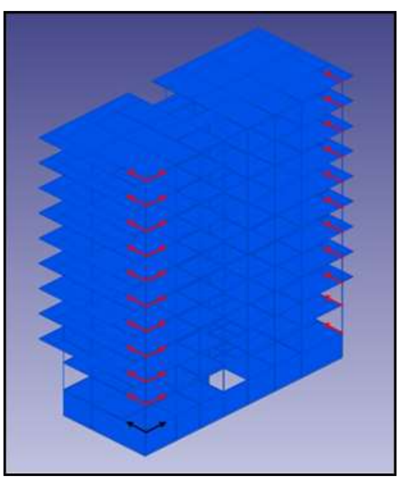


Fig. 2a, b Picture and a typical floor plan of the building

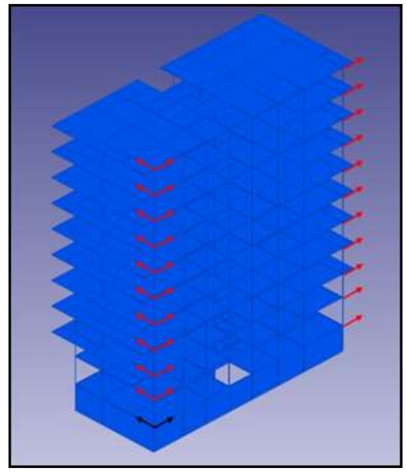
The floor slabs are 0.3 m thick (6.25 kN/m^2) and the plate floor are 0.1m thick (2 kN/m^2). Walls are 0.15 m thick (2 kN/m^2). In testing study of the building structure elements have not plastered. Specified concrete strengths in unit MPa for all of the building are summarized as: Column level (1-2)-

10.108; (3-5)-8.036; (6-8)-4.936; (9-10)-2.457; Slab and beams 2.7 and 9.155; Footings 5.677. Building has A1 (Torsional Irregularity) and B2 (Interstorey Stiffness Irregularity-Soft Storey) types of irregularities. A1-The case where Torsional Irregularity Factor η_{bi}, which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum storey drift at any storey to the average storey drift at the same storey in the same direction, is greater than $1.2[\eta_{\mathrm{bi}} = (\Delta_i)_{\mathrm{max}}/(\Delta_i)_{\mathrm{ort}}>1.2]$. B2-The case where in each of the two orthogonal earthquake directions, Stiffness Irregularity Factor η_{ki}, which is defined as the ratio of the average storey drift at any storey to the average storey drift at the storey immediately above, is greater than $1.5[\eta_{\mathrm{ki}} = (\Delta_i)_{\mathrm{ort}}/(\Delta_{\mathrm{i+1}})_{\mathrm{ort}}>1.5]$. Concrete C20 ($f_{\mathrm{ck}}$=20MPa) and steel S420$\left(f_{\mathrm{yk}} = 420\mathrm{MPa}\right)$ are respectively used. Foundation type of the building is both direction continuous footing and 0.4 m thickness slabs (plates). The building was designed accordance with Turkish reinforced concrete design standard TS-500 and design loads for buildings TS-498.

Ambient vibrations are obtained by taking the micro-vibration data through the seismometer. Three-axis accelerometers were used for measurements. ambient vibration measurements of x and y directions were taken into account. Details of the ambient vibration measurements are given in figure 4. The ones located in the first floor are allocated as reference sensors. Two accelerometers are used for reference. The reference accelerometers used are indicated in Figure 3.a, b on black. Two data sets were used to measure the response (Fig. 3 a, b). For the two data sets that were used 3 and 5 degrees of freedom were recorded respectively (Fig. 3 a, b). Every data set (Fig. 3 a, b) was measured at 100 min. The points and directions in which all these measurements are made are shown in detail on Fig. 3a, b



a) First setup



b) Second setup

Fig. 3 Accelerometers location of building in the 3D view

Fig. 4 Ambient vibration record from the traffic load with seismometer on ground level

III. N4SID RESULT

If After analyzing the data in MATLAP using N4SID method the following results are summaries in figures 5- 12.

They were examined respectively;

- İnput and Output Signal
- Model Output
- Fit to Estimation Data
- Transient Response
- Frequency Function
- Poles and Zeros
- Noise Spectrum
- Model Residual Analysis
- A, B, C, D and K matrices

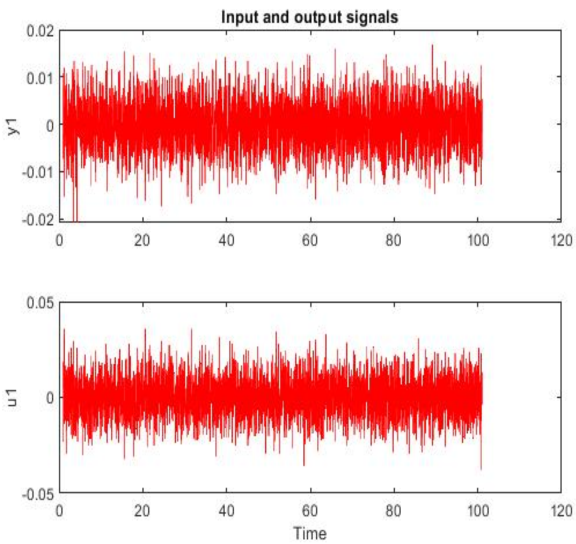


Fig. 5İnput and Output Signals u1->y1

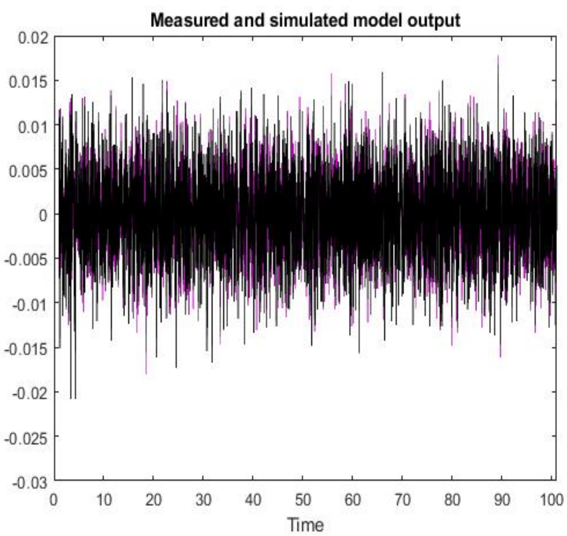


Fig. 6Model Output

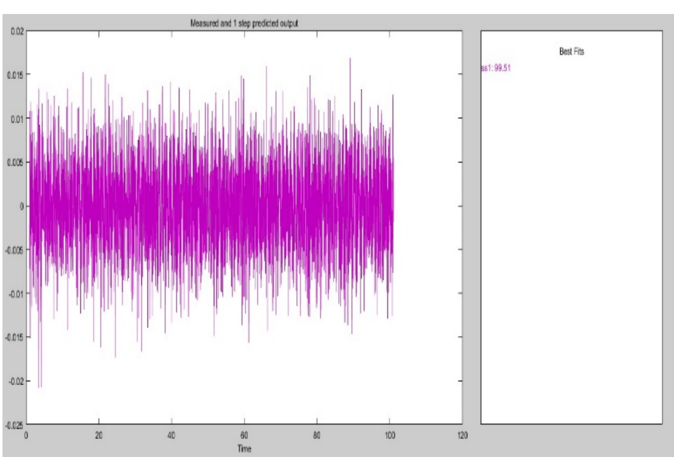


Fig. 7 Fit to Estimation Data %99.51

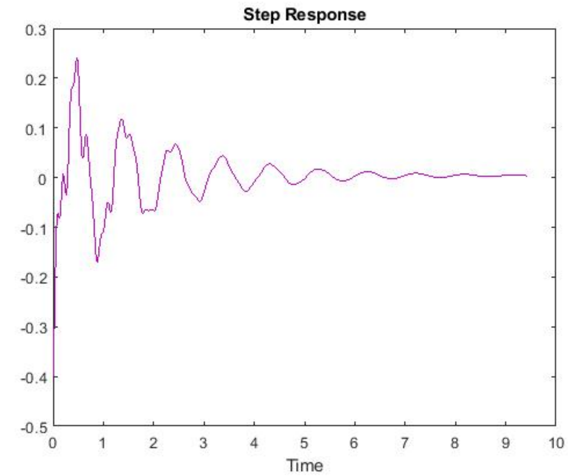


Fig. 8 Transient Response

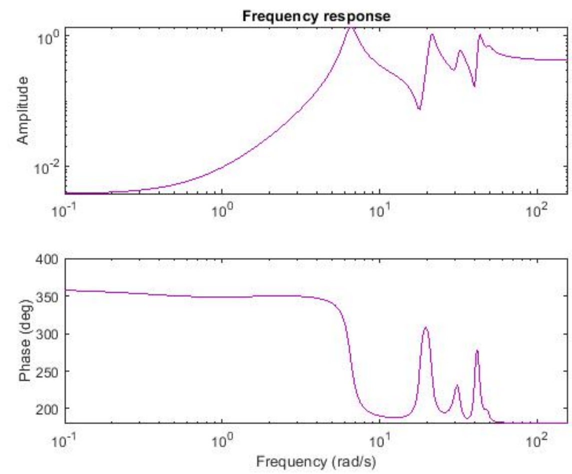


Fig. 9 Frequency Response

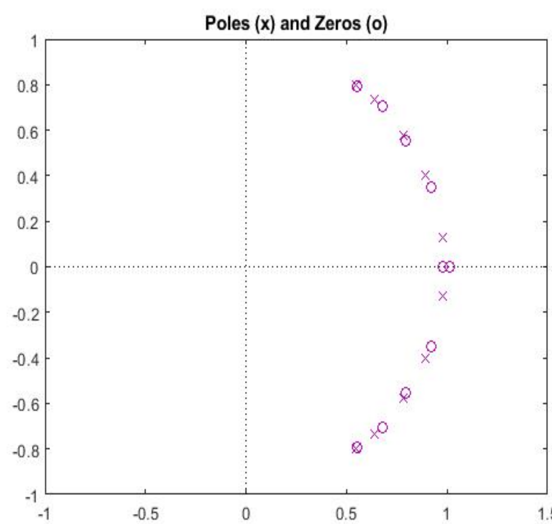


Fig. 10 Poles and Zeros

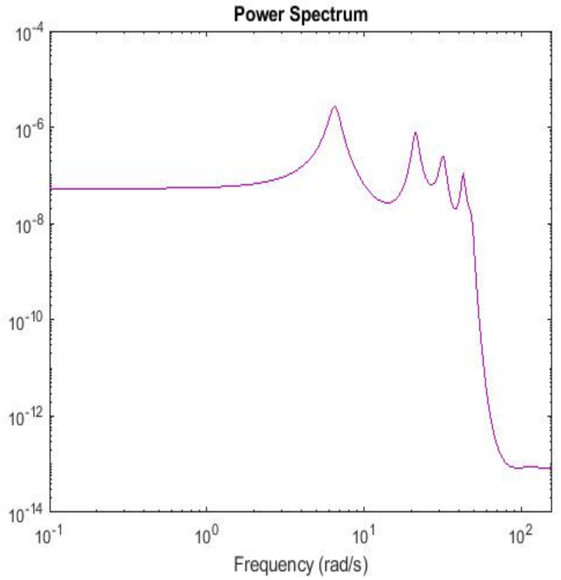


Fig. 11 Noise Spectrum

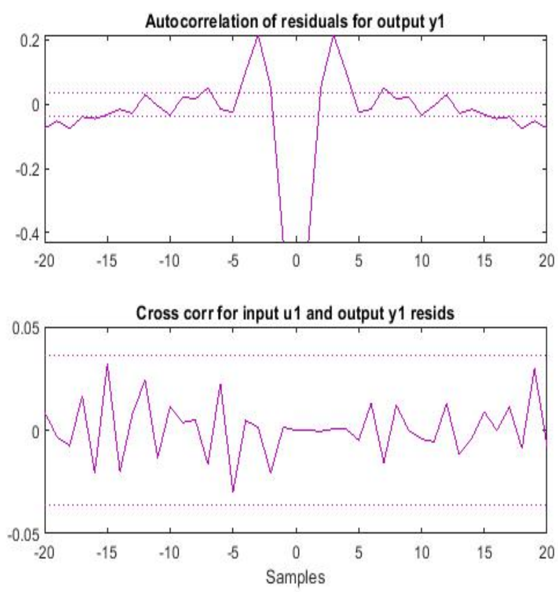


Fig. 12Model Residual Analysis

The matrices A, B, C, D and K were obtained as follows;

A=

$$\begin{bmatrix} 0.829 & -0.511 & 0.135 & -0.049 & -0.009 & 0.013 & 0.000 & 0.005 & 0.010 & 0.006 \\ 0.524 & 0.575 & -0.432 & 0.070 & -0.018 & -0.024 & 0.000 & -0.012 & -0.018 & -0.011 \\ 0.156 & 0.499 & 0.777 & -0.326 & 0.019 & 0.097 & 0.001 & 0.058 & 0.051 & 0.033 \\ 0.048 & 0.066 & 0.327 & 0.777 & -0.373 & -0.153 & 0.010 & 0.050 & -0.335 & -0.118 \\ -0.006 & -0.044 & 0.068 & 0.326 & 0.661 & 0.519 & 0.024 & 0.419 & -0.158 & 0.033 \\ 0.017 & 0.072 & -0.091 & 0.085 & -0.380 & 0.806 & 0.035 & -0.362 & 0.095 & 0.076 \\ 0.002 & 0.016 & -0.043 & -0.047 & -0.104 & -0.014 & 0.965 & 0.223 & -0.005 & 0.028 \\ 0.006 & 0.051 & -0.157 & -0.175 & -0.396 & 0.126 & -0.254 & 0.797 & -0.217 & 0.077 \\ 0.002 & -0.005 & 0.028 & 0.237 & -0.123 & -0.081 & -0.044 & 0.209 & 0.678 & 0.543 \\ 0.002 & 0.009 & -0.005 & -0.053 & 0.072 & -0.068 & 0.019 & -0.173 & -0.546 & 0.817 \end{bmatrix}$$

$$B=\begin{bmatrix} -0.248 \\ 0.625 \\ 0.007 \\ 0.025 \\ 0.186 \\ -0.269 \\ -0.098 \\ -0.285 \\ 0.052 \\ -0.034 \end{bmatrix}$$

C=

$$[-0.201\ 0.048\ -0.029\ 0.008\ -0.002\ -0.002\ 0.000\ -0.001\ -0.002\ -0.001]$$

$$D= [-0.400]$$

$$K=\begin{bmatrix} -5.603 \\ 9.892 \\ -31.382 \\ 109.013 \\ -20.517 \\ -47.340 \\ -8.714 \\ 2.916 \\ -200.266 \\ -25.830 \end{bmatrix}$$

IV. CONCLUSIONS

In this paper, System identification of an RC building was successfully realized and system matrices were putforward. Thus, mathematical model was created at % 99.51.

- A, B, C, D and K matrices of the system were obtained.
- Input and output signals were obtained.
- Transient Response in other words step response values were obtained.
- Frequency Function was obtained and values were calculated.
- Poles and Zeros were obtained.
- Noise Spectrum was obtained.
- Model Residual Analysiswere conducted.

Numerical algorithms of the system have been obtained successfully using model input and model output.

In the light of all this information, the system's reactions to dynamic effects can be calculated by defining the system.

REFERENCES

[1]. A. A. Kasimzade and S. Tuhta, Stochastic parametric system identification approach for validation of finite element models: industrial Applications, TWMS Jour. Pure Appl. Math., V.3, N.1, 2012, pp.41-61.

[2]. Tuhta.S., Gunday F., Aydin H., Dynamic Analysis of Model Steel Structures Retrofitted with GFRP Composites under Microtremor Vibration International Journal of Trend in Scientific Research and Development (IJTSRD)Volume: 3 | Issue: 2 | Jan-Feb 2019

[3]. Tuhta.S., Abrar O., Gunday F., Experimental Study on Behavior of Bench-Scale Steel Structure Retrofitted with CFRP Composites under Ambient Vibration, European Journal of Engineering

Research and Science, 2019

[4]. Tuhta.S., "OMA of model chimney using Bench Scale earthquake simulator," Earthquakes and Structures, vol. 16, no. 3, pp. 321–327, Mar. 2019.

[5]. A. Kasımzade Et Al., "A Comparative Study On Effectiveness Of Using Horasan Mortar As A Pure Friction Sliding Interface Material," European Journal Of Engineering Research And Science, Pp. 0–0, Feb. 2019.

[6]. G.F. Sirca Jr., H. Adeli, System identification in structural engineering, Scientia Iranica A (2012) 19 (6), 1355–1364.

[7]. J. Kim, System Identification of Civil Engineering Structures through Wireless Structural Monitoring and Subspace System Identification Methods, PhD thesis, University of Michigan, 2011.

[8]. MATLAB and Statistics Toolbox Release 2018b, the Math Works, Inc., Natick, Massachusetts, United States.

[9]. P. V. Overschee and B. D. Moor, Subspace identification for linear systems theory-implementation – applications, Kluwer academic publishers Boston, London, Dordrecht, 1996.

[10]. Gunday.F., "OMA of RC Industrial Building Retrofitted with CFRP using SSI" International Journal of Advance Engineering and Research Development , 2018

[11]. Gunday.F., "GFRP Retrofitting Effect on the Dynamic Characteristics of Model Steel Structure Using SSI" International Journal of Advance Engineering and Research Development , 2018

[12]. Tuhta, S., & Günday, F. (2019). Multi Input Multi Output System Identification of Concrete Pavement Using N4SID. International Journal of Interdisciplinary Innovative Research Development, 4(1),

[13]. Tuhta, S., Alameri, I., & Günday, F. (2019). Numerical Algorithms N4SID for System Identification of Buildings. International Journal of Advanced Research in Engineering Technology Science, 1(6)

[14]. Tuhta, S., Günday, F., Aydin, H., & Alalou, M. (2019). MIMO System Identification of MachineFoundation Using N4SID. International Journal of Interdisciplinary Innovative Research Development

[15]. Tuhta, S., & Günday, F. (2019). Mimo System İdentification of İndustrial Building Using N4sid with Ambient Vibration. International Journal of Innovations in Engineering Research and Technology,