International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)

ISSN: 2456-236X

Vol. 04 Issue 01 | 2019

Multi Input - Multi Output System Identification of Concrete Pavement Using N4SID

Sertaç TUHTA[1], Furkan GÜNDAY[2]

[1, 2] *Department of Civil Engineering, Ondokuz Mayis University, Turkey*

ABSTRACT

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. To demonstrate the efficiency of the algorithm, a series of numerical, and laboratory studies were evaluated. In this study, concrete pavement was used. In this study, Multi input- multi output (MIMO) system identification method was used. The modal properties of the concrete pavement were computed using analytical approach for a comparison with the experimental modal frequencies. Fit to estimation data is %98.69. Results demonstrated that N4SID multi input-multi output (MIMO) system identification method is efficient and accurate in identifying modal data of the concrete pavements and other pavements.

Keyword: ***MIMO, N4SID, System Identification, Numerical Algorithms, Concrete Pavements***

1. INTRODUCTION

Most of structures located in regions prone to earthquake hazards suffer from various types of destruction caused by seismic loads. Under such earthquake occurring, the parts (especially the columns) of building structures suffer damage. Looking on the other side, especially considering the performance of such buildings under seismic occurrence, there is a great need to strengthen the columns even without changing their building masses; this clearly shows that there is a need to investigate the connection between technical repairing or strengthening procedures and the column capacity. In this understanding, 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 [2].

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. (Sirca and Adeli, 2012). Subspace system identification is introduced as a powerful black-box system identification tool for structures. The application of the method for supporting excited structures is emphasized in particular. The black- box state- space models derived from the identification of subspace systems are used to estimate the modal properties (i.e. modal damping, modal frequency and mode shapes) of the structures [10].

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) is used [1].

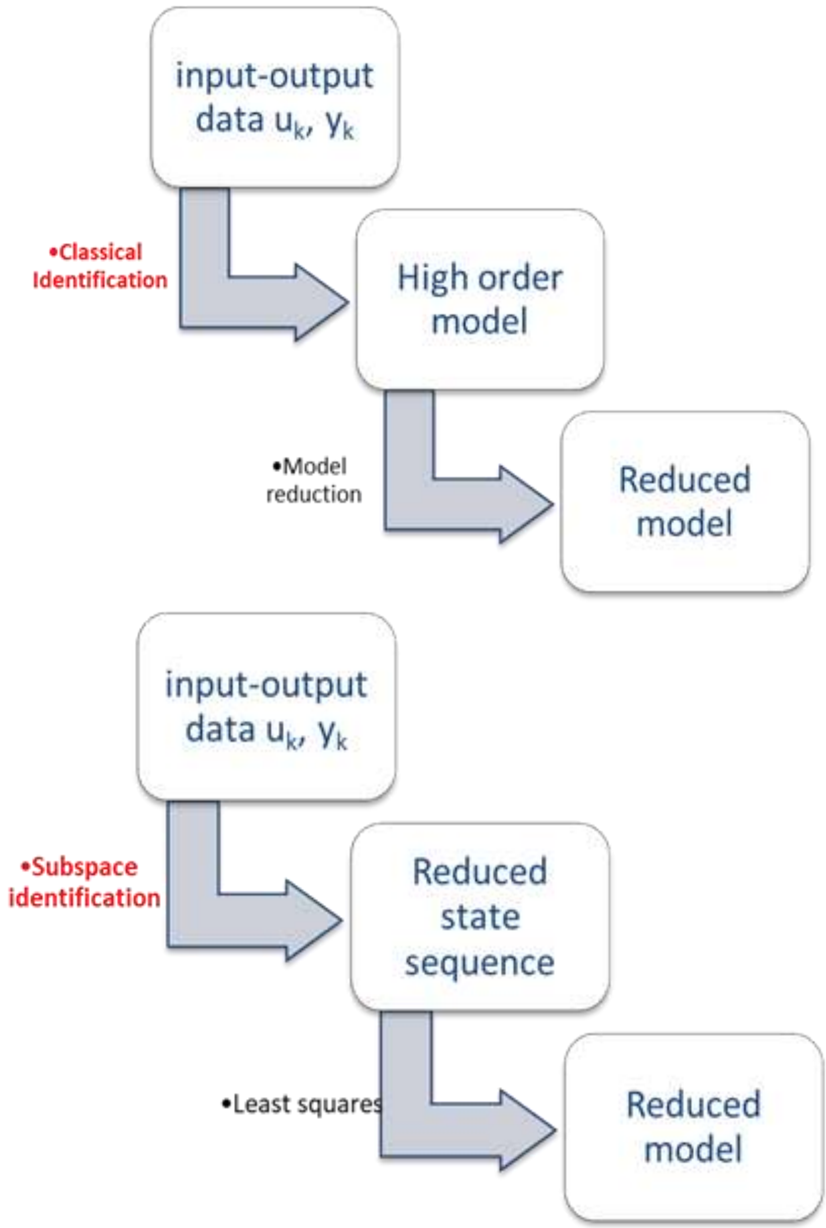

Fig-1: System İdentification Aims to Create İnput - Output Data State Space Models

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).

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

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

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:

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

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

$$\{\dot{z}(t)\} = [A_c]\{z(t)\} + [B_c]\{f_\oplus (t)\} \quad \text{(Eq. 2a)}$$

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

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

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

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

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

$$[C] = [\,[C_d] - [C_a][m]^{-1}[k], \qquad [C_v] - [C_a][m]^{-1}[c]\,] \quad \text{(Eq. 3b)}$$

$$[D] = [C_a][m]^{-1}[d] \quad \text{(Eq. 3c)}$$

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 $\{F\ (t)\} = [d]\,\{f_\oplus(t)\}$ comes from white noise or time impulse excitation. Under this hypothesis discrete-time stochastic state {space model may be written as:

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

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

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 $\{f_\oplus (t)\}, \{f_{\oplus k}\}$ 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:

$$\{z_{k+1}\} = [A]\{z_k\} + \{\underline{w}_k\} \quad \text{(Eq. 6)}$$

$$\{y_k\} = [C]\{z_k\} + \{\underline{v}_k\} \quad \text{(Eq. 7)}$$

2. DESCRIPTION OF CONCRETE PAVEMENT

Total area of concrete pavement are 2 m x 2 m = 4 m^2 in area. Concrete C20 f_{ck}=20 MPa are respectively used. The pavement thickness is 0.15 m. Concrete pavement and measurements are shown in figure 2 and figure 3.

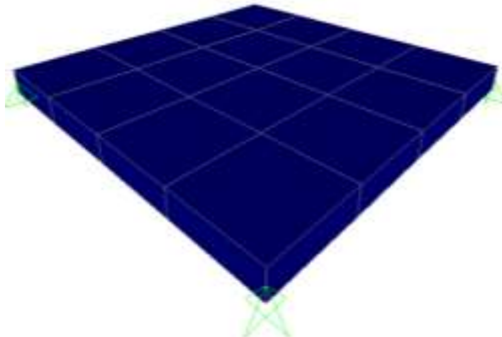

Fig-2: Concrete Pavement Model

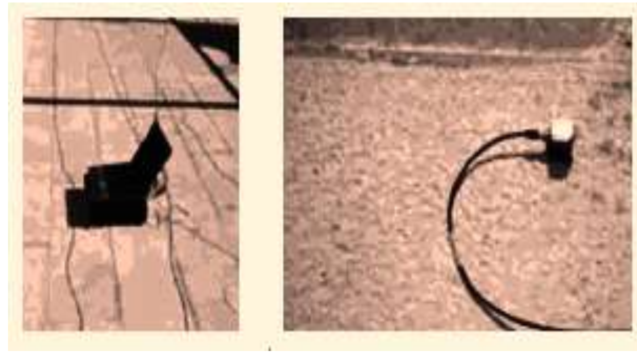

Fig-3: Concrete Pavement Measurement

3. N4SID RESULTS

If After analyzing the data in MATLAP using N4SID with multi input – multi output (MIMO) method the following results are summaries in figures 4- 15.

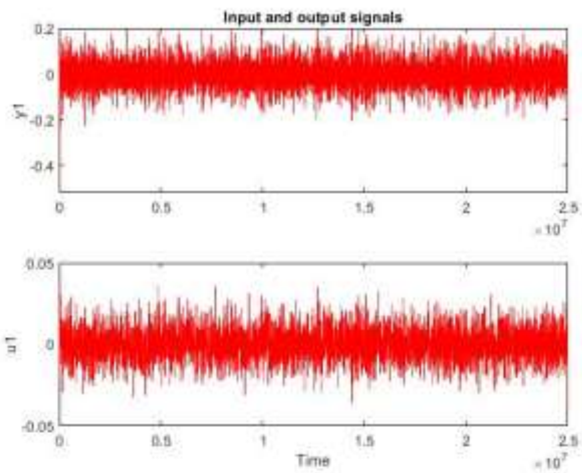

Fig-4: İnput and Output Signals u1->y1

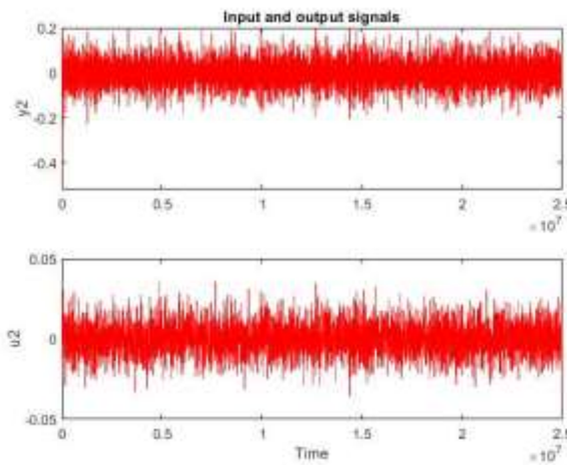

Fig-5: İnput and Output Signals u2->y2

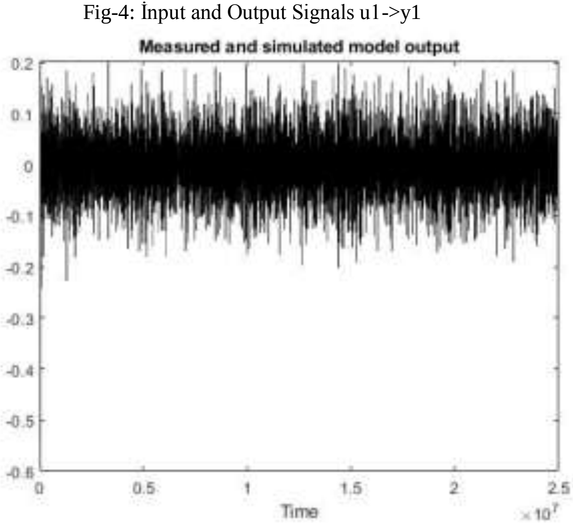

Fig-6: Model Output y1

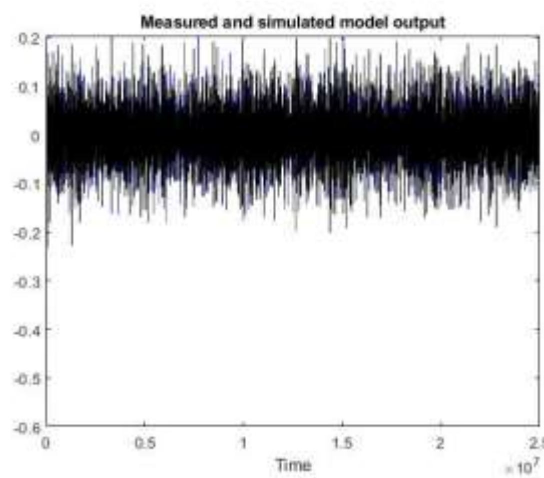

Fig-7: Model Output y2

Fit to estimation data is %98.69. A, B, C, D and K matrices are given below;

A=

0.008354969	-0.019794599	0.002451	-0.00348
0.983430773	0.177332637	0.006953	-0.01023
0.011888539	-0.036881852	0.685432	0.41415
-0.003015394	0.022425175	0.18818	0.415822

B=

0.713561248	0.713561248
-0.011652957	-0.011652957
0.081206774	0.081206774
0.013617411	0.013617411

C=

3.76359244804666	-1.40103720241517	0.00456	0.007424
3.76359244804666	-1.40103720241517	0.00456	0.007424

D=

-1.4888	-1.4888
0	0

K=

0	0
0	0
0	0
0	0

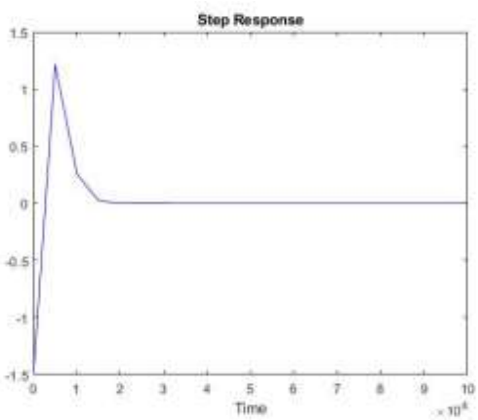

Fig-8: Step Response u1 > y1

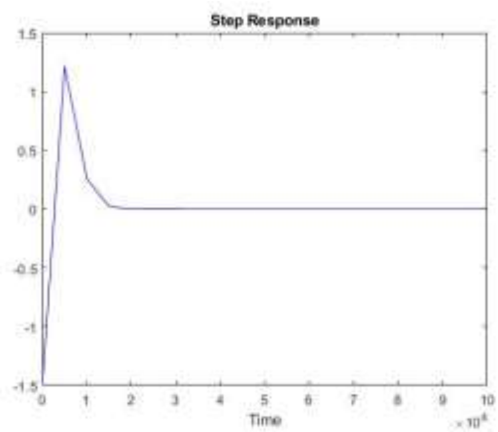

Fig-9: Step Response u2 > y1

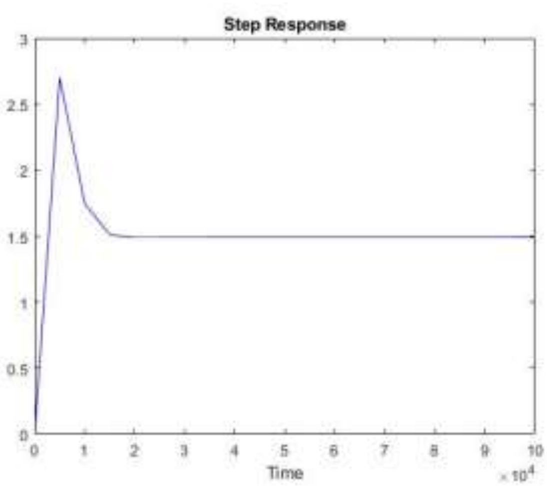

Fig-10: Step Response u2 > y2

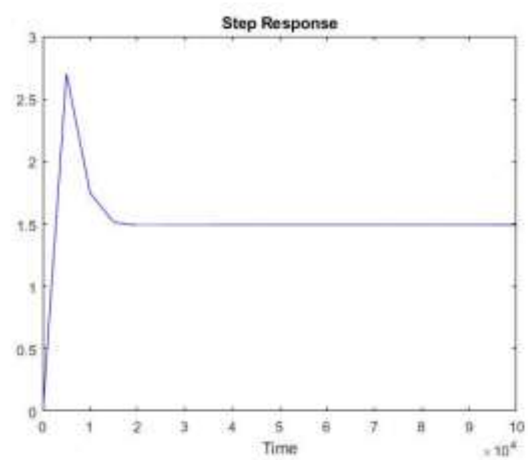

Fig-11: Step Response u1 > y2

International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)
ISSN: 2456-236X
Vol. 04 Issue 01 | 2019

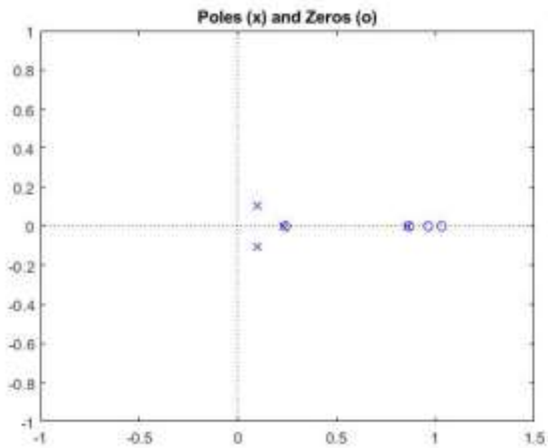

Fig-12: Poles and Zeros u1 > y1

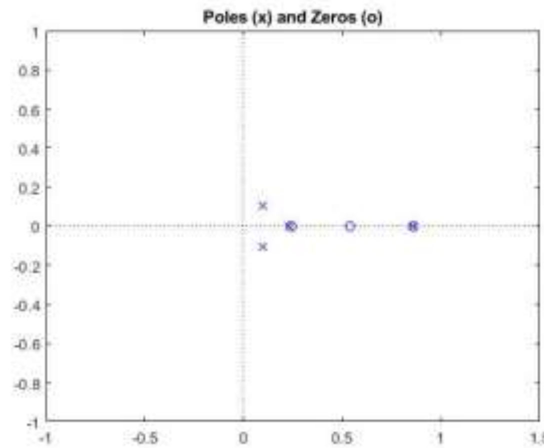

Fig-13: Poles and Zeros u2 > y2

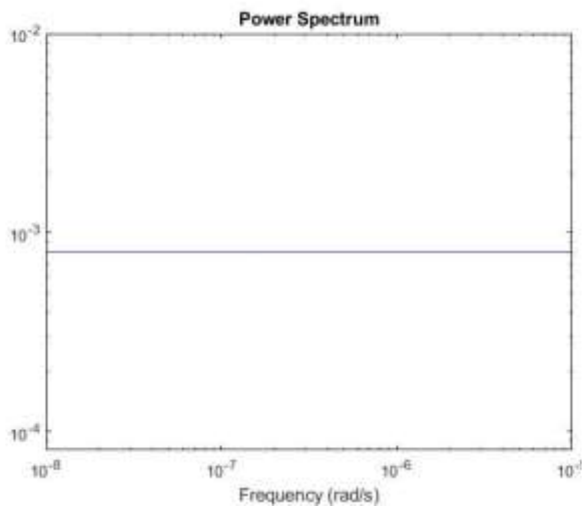

Fig-14: Noise Spectrum y1

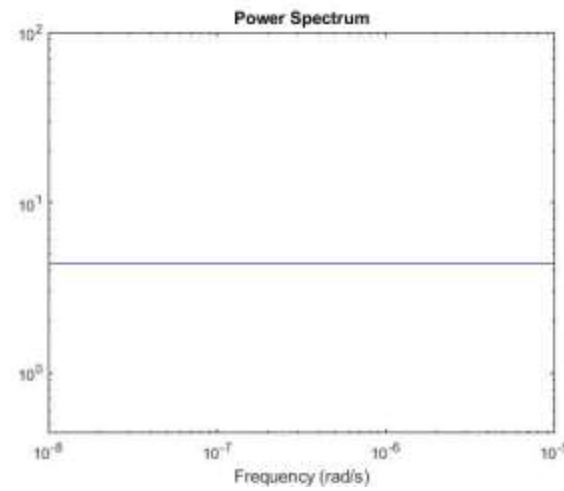

Fig-15: Noise Spectrum y2

4. CONCLUSIONS

In this paper reviews the theoretical principles of subspace system identification as applied to the problem of estimating black-box state-space models of support-excited structures (e.g., structures exposed to earthquakes). The work distinguishes itself from past studies by providing readers with a powerful geometric interpretation of subspace operations that relates directly to theoretical structural dynamics.

To validate the performance of subspace system identification, a series of experiments are conducted on a concrete pavement exposed to moderate seismic ground motions; structural response data is used off-line to estimate black-box state-space models. Ground motions and structural response measurements are used by the subspace system identification method to derive a complete multi input – multi output state-space model of the concrete pavement system. The modal parameters of the concrete pavement are extracted from the estimated multi input – multi output state-space model. With the use of only structural response data, output-only state-space models of the system are also estimated by subspace system identification.

In this paper, a new structural identification tool is proposed to identify the modal properties of concrete pavements. Results demonstrated that fit to estimation data was %98.69 and it can be concluded that N4SID multi input – multi output (MIMO) system identification method is efficient and accurate in identifying modal data of concrete pavements.

5. 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] M. Ziada, S. Tuhta, E. H. Gençbay, F. Günday, And Y. Tammam, “Analysis of Tunnel Form Building Retrofitted with CFRP using Finite Element Method,” International Journal of Trend in Scientific Research and Development, pp. 0–0, Feb. 2019.

[6] 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.

[7] S. Tuhta, I. Alamerı, And F. Günday, “Numerical Algorithms N4sıd For System Identification Of Buildings,” International Journal Of Advanced Research İn Engineering Technology Science, Vol. 1, No. 6, Pp. 0–0, Jan. 2019.

[8] Kasimzade, A.A.(2018), Yapı Dinamiği: Deprem Mühendisliği Teori ve Uygulamaları Ankara, Nobel Yayınevi, Üçüncü Baskı p.527

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

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

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

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

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

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