Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University |
http://www.saujs.sakarya.edu.tr/en/

Title: Artic Determination of Dynamic Characteristics the Structure with ARX and ARMAX Estimation Methods

Authors: Hidayet UYAR, Elif AĞCAKOCA

Recieved: 2019-08-29 14:24:30

Accepted: 2020-02-24 09:15:55

Article Type: Research Article
Volume: 24
Issue: 3
Month: June
Year: 2020
Pages: 460-471

How to cite
Hidayet UYAR, Elif AĞCAKOCA; (2020), Artic Determination of Dynamic Characteristics the Structure with ARX and ARMAX Estimation Methods. Sakarya University Journal of Science, 24(3), 460-471, DOI: https://doi.org/10.16984/saufenbilder.612826
Access link
http://www.saujs.sakarya.edu.tr/en/issue/52472/612826

Sakarya University Journal of Science 24(3), 460-471, 2020

Artic Determination of Dynamic Characteristics the Structure with ARX and ARMAX Estimation Methods

Hidayet UYAR[1], Elif AĞCAKOCA[2*]

Abstract

In this study, the dynamic behavior of a single-span four-storey steel model structure is tried to determine by using 2 different methods. Connections between beams and columns are produced as rigid and the structure is connected to the shake table by a fixed support. In order to measure the forced vibration values applied to the model structure with the help of the shaking table, the smartphone was placed on the shaking table base and the top of the steel model structure and acceleration records were taken. After the records have been processed, structural algorithm is created using MATLAB autoregressive ARX and autoregressive moving average ARMAX models. Smartphone records from the shake table are defined as inputs and smartphone from the top of the structure are defined as outputs in MATLAB autoregressive ARX and autoregressive moving average ARMAX models. By doing this, structure's dynamic behavior is to be obtained by MATLAB autoregressive ARX and autoregressive moving average ARMAX models when only vibrating table acceleration record is inputted. Dynamic characteristics obtained by ARX and ARMAX were tried to be confirmed by finite element method using Sap2000 software. In order to determine the dynamic characteristics of the building, the earthquake records of Kobe, Sakarya, Loma-Priate and El-Centro were used as forced vibration. At the end of the study, dynamic properties obtained by numeric models (ARX and ARMAX) using input acceleration record are compared to the dynamic properties obtained by Sap2000 analysis. By doing this it was determined whether dynamic properties can be reliably obtained using autoregressive ARX and autoregressive moving average ARMAX models. Advantages and disadvantages of using this method to define structural behavior are discussed.

Keywords: Shaking table, ARX and ARMAX, Smartphone

---

[1] Sakarya University, Civil Engineeringt, Sakarya, Turkey. ORCID ID:0000 0002 8514 3398
[2] Sakarya University, Civil Engineeringt, Sakarya, Turkey. ORCID ID:0000 0001 8228 0592
[*] Corresponding Author: elifd@sakarya.edu.tr

1. INTRODUCTION

Since the beginning of the 20th century, steel started to be used for structure, one of the most basic needs of humans. Nowadays, structural steel is widely used especially in high rise building construction because of the development of the modern steel construction technics, high strength of the material and easiness of construction. High strength of the material used in the structure reduces the loss of life and property caused by natural disasters such as earthquakes. From structural aspect, in order to maximally decrease financial losses and casualties, it is important to evaluate and establish properties of the material under dynamic loading. The studies performed in structural dynamics field play important role in establishing dynamic properties of structures and designing earthquake resistant structures. In our country (Turkey) earthquake resistant design principles are specified in Turkey Building Earthquake Code (Türkiye Bina Deprem Yönetmeliği).

There are many methods for determining the dynamic behavior of structures numerically. However, the uncertainty of the boundary conditions of building elements, the material behavior can not be fully modeled and the earthquake movement varies with time. Therefore, it requires experimental studies to determine the structure behavior.

Since shaking table tests constitute a widespread experimental method, there are numerous studies on this topic in the literature. Durgun, successfully obtained the natural frequencies, mode shapes and peak displacements data of the undamaged structure model in the laboratory [1]. Özcelik, explores the change between parameters caused by the change of story stiffness of the model fixed to the electro-dynamic shaker and also the interaction between the model and the shaker [2]. Türker explores the effect of the P-Δ effects of different type of structure models on their periods [3]. Aydın observed improved behavior of models with mass tuned dumpers under harmonic excitation [4]. Birdal calibrated the results of structural analyses using results from different analytical methods for analysis [5]. Qui, the behavior of the steel structure connection points under the influence of earthquake was controlled with the help of shaking table [6]. With developing technologies, smart phones started to take their place in experimental studies. Among the studies within the literature that use smartphones, Yan Yu [7] showed that by using an application called Mobile-SHM smartphones can be used as a part of system for structural health monitoring. Also, Zhao et al [8] used 4 smartphones in dynamic experiment and they gave results which agreed with results acquired by other independent sensors. Mari [9] is attempting to prove the functionality of "ishake" smartphone system by performing field table shaking tests with 30 users. Qingkai [10] argues that smartphones can be used to detect traditional network earthquake data that they can be used to record earthquakes of magnitude of 5 from 10km or less of distance and filter them from non-earthquake motion. In addition, the effect of reinforced column-beam connections on modal parameters was investigated [11]. In addition, the effect of damage in the column-beam region on the dynamic behavior of the element was also investigated [12].

In the method used in this study, structural dynamic properties of a model steel structure are determined by autoregresive ARX and autoregresive moving average ARMAX models. Autoregresive moving average ARMAX models are known as Box-Jenkins model "time series prodiction" method in statistics and is applied to time series with equal time increments. In ARMAX model is used to understand and predict next increment values in a time series of X(t) form. While creating ARMAX model, model is established in 2 stages. Firstly, autoregresive AR part, then the moving average parts (MA) are created. In ARMAX Model, p and q indeces is defined as autoregresive and moving average part degrees respectively and model is shown as ARMA (p,q).

2. EXPERIMENTAL SETUP

The shaking table used in the study is 1x1m size. It has 1250kN load capacity and is shown in Figure 1. The table is designed to have maximum movement capacity of 92.5mm, maximum horizontal force capacity of 2500N, maximum acceleration capacity of 2g and maximum velocity of 500mm/s. Thanks to load control algorithm table can reproduce the motion of many different earthquake records such as Kobe (1995), Sakarya (1999), etc.

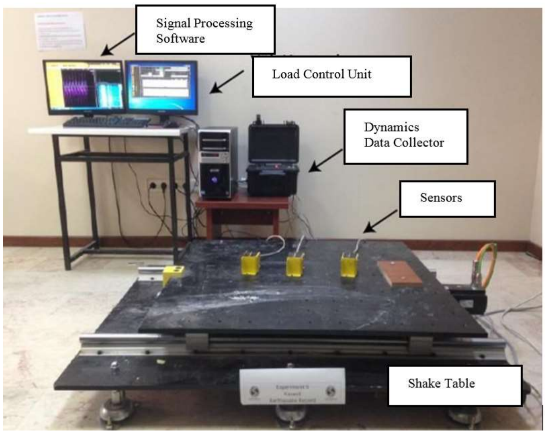


Figure 1.Experiment setup [13]

Experiment setup is comprised of shaking table, smart phone and dynamic data receiver device as well as other units such as laptop computer. Within experiment study, 4 story steel model structure is built on shaking table. Total weights of columns and slabs are 3.76kg and 40.76kg respectively and their geometric features are presented in Table 1.

Table 1. Model structure size

	Number	Top-Length (mm)	Dimensions (mm)
Column	4	1200	50x2
Floor	4	360x360	10

The model structure was parts used in experiment were produced in an industrial factory as shown in Figure 2. All structure elements were brought and assembled on shaking table Figure 3.

Figure 2. Preparation of model structure

In order to provide rigid connection between elements they were connected by bolts and nuts on floor levels where nuts were substantially fastened. In order to extract data from the model, smartphones was placed on top floor (on top of shaking table).

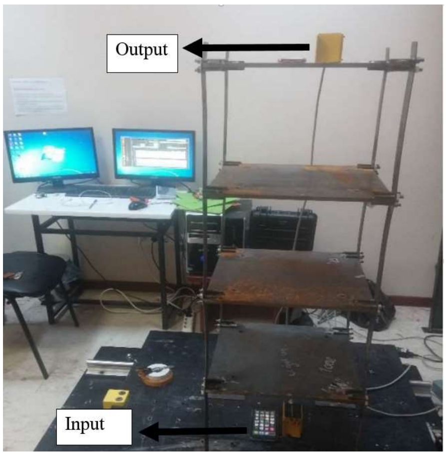


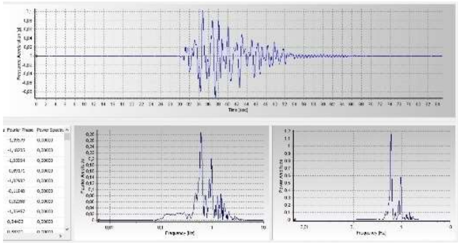
Figure 3. Steel building model, shaking table, computer system, smart phone

3. NUMERICAL ANALYSIS

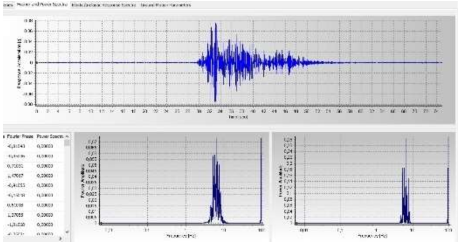
At present, it is not possible to determine the dynamic behavior of existing structures under forced vibration. That’s why many studies start with smaller scaled model in order to determine real-size structure dynamic properties. There are many methods used to determine dynamic behavior of model structures. In this study, model structure is assembled on shaking table, forced by existing earthquake record and goal is to develop structural algorithm using system identification method. Steel structure model dynamic properties are obtained through the established structural algorithm. Thus, by placing sensors it will be possible to develop algorithm for dynamic characteristic definition of structures with various properties such as suspended bridges, high rise buildings, television towers etc., for structural health monitoring and for detection of damage [14]. In definition techniques, most commonly, it requires an excitation (input) and response (output) measurements to fully determine the dynamic behavior of a model.

In experimental study, the acceleration values is recorded on top of the shaking table (input) and on top of the model (output). These input-output values are created using sensitive receptors within smartphones placed on top of the shaking table (base of the model) and on top of the model.

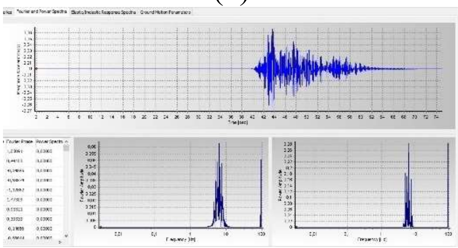
These unprocessed input-output values are studied using FFT (Fast Fourier Transform) within Seismo program. FFT analyses of smartphone input values are presented in Figure 4.



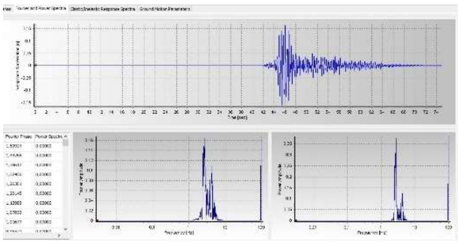
(a)



(b)



(c)



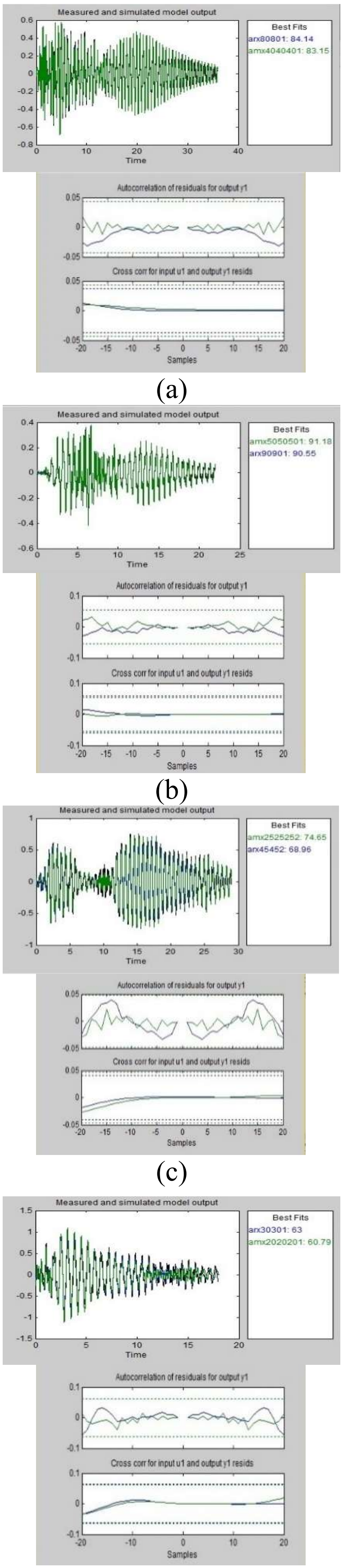
(d)

Figure 4. Fast Fourier Transform of earthquake (a) Kobe, (b) Sakarya, (c) El-Centro, (d)Loma Priate

MATLAB System Identification Toolbox is an application written to establish mathematical models of dynamic systems using measured input-output data. This application allows creation and use of dynamic system models of structures that are complex and not easy to model. It is possible to use input-output data in time or frequency domain in order to define continuous time, incremental time, process models and case space models. Also it contains technics such as algorithms for hidden online parameter prediction, most likeliness and prediction error method and subspace system definition. Toolbox also supports data modeling prediction for time series [15]. It is possible to create mathematical models of smartphone acceleration data whose FFT analyses are performed in Siesmo Signal by choosing proper modeling within system identification method.

3.1. ARX and ARMAX

Engineering structures consist of infinite dimensional parameter systems. Autoregressive ARX and autoregressive moving averages ARMAX models in Matlab System Diagnostics can be expressed as discrete time models. It creates finite dimensional systems in the analysis of discrete time complex systems, thus offering a practical approach to infinite dimensional systems. When creating a model, the determination of modal parameters is expressed as simple eigenvalues. The most important issue here is the selection of the previously unknown model type (ARX, ARMAX…).



(a)

(b)

(c)

(d)

Figure 5. Smartphone input-output recording and compliance ratio (a)Kobe,(b) Sakarya,(c)El-Centro,(d)Loma Priate

The choice of model type often determines the results and the number of modal parameters. In practice, further analysis may be required to determine the model due to noise and discretization errors. In this study, using MATLAB, System Identification, autoregressive ARX and autoregressive moving averages ARMAX models were produced and their advantages and disadvantages in terms of structure recognition technique were investigated

Autoregressive and Autoregressive Moving Averages Models

When a time series (X_t) is given, the ARMA model is used to understand and even predict the values of the series in future periods. The model consists of two parts. One of these is the autoregressive part AR and the other is the moving averages part. ARMA Model is generally shown as ARMA (p,q) model, where p is the degree of autoregressive part and q is the degree of moving average part.

Autoregressive Ar(p), Model Autoregressive Ar(p)

Ar (p) is p. defines an autoregressive model. The Ar (p) model is shown in (1).

$$X_t : c + \sum_{i:1}^{p} \theta_i X_{t-i} + \varepsilon_t \qquad (1)[16]$$

Moving Averages Method, Ma (q) Model

Ma(q), q. A moving averages model of degrees is shown in (2)

$$X_t : \varepsilon_t + \sum_{i:1}^{q} \theta_i \varepsilon_{t-i} \qquad (2)[16]$$

$\theta_1, \ldots, \theta_q$ are the parameters of the model ε_t, ε_{t-1},... are the error terms of the model. It is understood that in the "moving averages" model, the value of a time series variable at a given time point (value of X_t) q is the predominance of the errors made at each of the previous time points.

Autoregressive Moving Averages, ARMA (p, q), Model

This model is a combination of Ar(p) and Ma(q) models and is shown in (3). An ARMAX model can be seen as an effective model, where all aspects of the AR, ARX and ARMA models are included. ARMAX creates a generalized mathematical description of the nonlinear dynamical system with stochastic noise and integrates the variation of input parameters into the system model [17]. The main advantage of ARMAX model is that, it inherently mitigates for signals with noise from various sources, providing unbiased parameter estimates.

$$X_t\colon \sum_{i:1}^{p} \theta_i\, x_{t-i} + \sum_{i:1}^{q} \theta_i\, \varepsilon_{t-i} \qquad (3)[14]$$

In the experiment, the input-output of the records that we receive from the smartphone and sensor placed on the building with the shaking table are defined. Baseline correction and filtering procedures were applied to the obtained data. After baseline zero line correction and filtering, the synchronization of the graph was checked by plotting the data in the same graph as input and output. Figure 5 show that the data of the inputs and outputs are synchronized. ARX and ARMAX are a special function of AR and ARMA.

In this study, after checking the input-output matching and synchronization of the data defined on the shaking table, forced vibration intervals obtained from FFT analysis were used. The algorithm has been developed with the help of ARX and ARMAX models in the System Diagnostics section of MATLAB. The input-output values given to the Matlab program are re-created by installing ARX and ARMAX models in the program. Matlab program uses mathematical prediction to generate input-output. Then, it expresses the difference between the predicted data and the experimental data as residues. It was also checked whether there was a cross-correlation between the input-residue and whether the results remained in the safe zone and whether they passed the whiteness and independence tests. Whiteness test; shows that there is no input-residue relationship and the prediction remains within a certain confidence interval. Independence test; checks whether the input-output data is connected to the residue. Figures 5 illustrate that the graph remains within the area indicated by dashed lines; ıt shows that there is no correlation between input-residue. The polynomial coefficients (n) in the mathematical model were increased and maximum fit ratios of the model were tried to be obtained. In addition to increasing coefficient (n) in the formed polynomial, whiteness and independence test remain within the determined limits, this shows the accuracy of the study [17].

4. FINITE ELEMENT MODELLING

In order to obtain the dynamic characteristics of the steel model structure, the finite element program SAP2000 was used. The materials used in the experiment are St 235 steel, yield strength is 235 MPa. Modulus of elasticity 2.1 GPa, slabs arc designed as a rigid diaphragm. The frequency values obtained at the from the finite element model are f_1:1.3204, f_2:3.8039, f_3:5.8332, f_4:7.1601(Figure 6.)

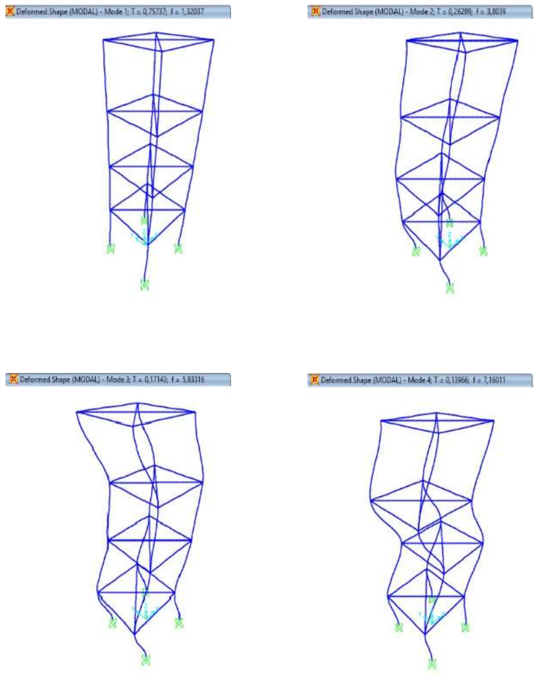


Figure 6. Modal Analysis

5. DISCUSSIONS

In order for the selected model types to give correct results, the input-outputs must be in a certain harmony. In this study, were conducted on the forced vibrations of Kobe, Sakarya, Loma-Priate and El-Centro earthquakes.

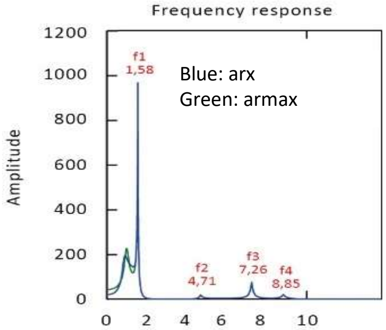


Figure 7. Kobe forced vibration smartphone recording

Table 2. Kobe earthquake data

Kobe earthquake	ARX	ARMAX	Finite Element (Sap 2000)
1th period	1.58	1.58	1.3204
2th period	4.71	4.71	3.8039
3th period	7.26	7.26	5.8332
4th period	8.89	8.89	7.1601
Best Fits (Matlab)	84.14	83.15	-
Difference between (Sap2000)%	19	19	-

When examining the 1st period values, comparison of the results for forced vibration of the Kobe earthquake smartphone recording is show (Figure 7) and (Table 2). The first mode of the finite element module f_1:1.3204. In the ARX model, f_1:1.58. In the ARMAX model, f_1: 1.58. Matlab's input and outputs are compatible with the ARX model defined in Matlab 84%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 83%. Considering the Matlab model agreement, it is seen that there is 19% difference when the frequency values obtained in ARX and ARMAX are compared with the finite element frequency values obtained using experimental data.

When examining the 2nd period values, if we compare the results for forced vibration of Kobe earthquake smartphone recording; The second mode of the finite element module f_2: 3.8039. In the ARX model, f_2:4.71. In the ARMAX model, f_2:4.71. Matlab's input and outputs are compatible with the ARX model defined in Matlab 84%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 83%. Considering the Matlab model agreement, it is seen that there is 23.82% difference when the frequency value obtained in ARX and ARMAX is compared with the finite element frequency values obtained by using experimental data.

When examining the 3rd period values, if we compare the results for forced vibration of Kobe earthquake smartphone recording; The third mode of the finite element module f_3: 5.8332. In the ARX model, f_3:7.26. In the ARMAX model, f_3:7.26. Matlab's input and outputs are compatible with the ARX model defined in Matlab 84%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 83%. Considering the Matlab model agreement, it is seen that there is a 24.46% difference when the frequency values obtained in ARX and ARMAX are compared with the finite element frequency values obtained by using experimental data.

When examining the 4th period values, comparing the results for forced vibration of Kobe earthquake smartphone recording; The thourd mode of the finite element module f_4: 7.1601. In the ARX model, f_4:8.89. In the ARMAX model, f_4: 8.89. Matlab's input and outputs are compatible with the ARX model defined in Matlab 84%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 83%. Considering the Matlab model agreement, it is seen that there is a difference of 24.16% when the frequency values obtained in ARX and ARMAX are compared with the finite element frequency values obtained using experimental data.

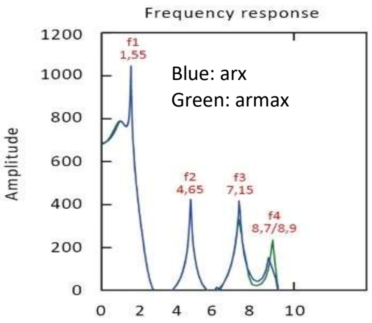


Figure 8. Sakarya forced vibration smartphone recording

Table 3. Sakarya earthquake data

Sakarya earthquake	ARX	ARMAX	Finite Element (Sap 2000)
1th period	1.55	1.55	1.3204
2th period	4.65	4.65	3.8039
3th period	7.15	7.15	5.8332
4th period	8.7	8.9	7.1601
Best Fits (Matlab)	91.18	90.55	-
Difference between (Sap2000)%	17	17	-

When examining the 1st period values, if we compare the results for forced vibration of Sakarya earthquake smartphone recording (Figure 8) and (Table 3). The first mode f_1:1.3204 emerges in the Sap2000 software. In the ARX model, f_1:1.55. In the ARMAX model, f_1:1.55. Matlab's input and outputs are compatible with the ARX model defined in Matlab 91%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 90.6%. Considering the Matlab model agreement, it is seen that there is a 17% difference between the frequency values obtained in ARX and ARMAX and finite element frequency values obtained using experimental data.

When examining the 2nd period values, if we compare the results for forced vibration of Sakarya earthquake smartphone recording; The second mode f_2:3.8039 emerges in the Sap2000 software. In the ARX model, f_2:4.65. In the ARMAX model, f_2:4.65. Matlab's input and outputs are compatible with the ARX model defined in Matlab 91%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 90.6%. Considering the Matlab model agreement, it is seen that there is a 22% difference between the frequency value obtained from ARX and the finite element frequency values obtained by using experimental data.

When examining the 3rd period values, if we compare the results for forced vibration of Sakarya earthquake smartphone recording; In the Sap2000 software, the third mode is f_3:5.8332. In the ARX model, f_3:7.15. In the ARMAX model, f_3:7.15. Matlab's input and outputs are compatible with the ARX model defined in Matlab 91%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 90.6%. Considering the Matlab model agreement, it is seen that there is a 23% difference between the frequency values obtained in ARX and ARMAA and the finite element frequency values obtained using experimental data.

When examining the 4th period values, if we compare the results for forced vibration of Sakarya earthquake smartphone recording; The fourth mode f_4:7.1601 emerges in the Sap2000 software. In the ARX model, f_4:8.7. In the ARMAX model, f_4:8.9. Matlab's input and outputs are compatible with the ARX model defined in Matlab 91%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 90.6%. Considering the Matlab model agreement, it is seen that there is a 22% difference between the frequency values obtained in ARX and ARMAX and finite element frequency values obtained using experimental data.

When examining the 1st period values, comparing the results for forced vibration of the El-Centro smartphone recording (Figure 9) and (Table 4). The first mode f_1:1.3204 is displayed in the Sap2000finished software. In the ARX model, f_1:1.56. In the ARMAX model, f_1:1.56. Matlab's input and outputs are compatible with the ARX model defined in Matlab 74.65%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 68.96%. Considering the Matlab model agreement, it is seen that there is approximately the same 18% difference between the frequency values obtained in ARX and

ARMAX and finite element frequency values obtained using experimental data.

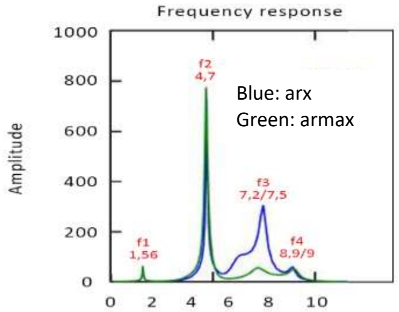


Figure 9. El-Centro forced vibration smartphone recording

Table 4. El-Centro earthquake data

El-Centro earthquake	ARX	ARMAX	Finite Elemant (Sap 2000)
1th period	1.56	1.56	1.3204
2th period	4.7	4.7	3.8039
3th period	7.2	7.15	5.8332
4th period	8.9	9	7.1601
Best Fits (Matlab)	74.65	68.96	-
Difference between (Sap2000)%	18	18	-

When examining the 2nd period values, if we compare the results for forced vibration of El-Centro earthquake smartphone registration; The second mode f_2:3.8039 emerges in the Sap2000 software. In the ARX model, f_2:4.7. In the ARMAX model, f_2:4.7. Matlab's input and outputs are compatible with the ARX model defined in Matlab 74.65%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 68.96%. Considering Matlab model agreement, it is seen that there is a 23% difference when the frequency value obtained in ARX and ARMAX is compared with the finite element frequency values obtained using experimental data.

When examining the 3rd period values, compare the results for forced vibration of the El-Centro earthquake smartphone registration; In the Sap2000 software, the third mode is f_3:5.8332. In the ARX model, f_3:7.2. In the ARMAX model, f_3:7.15. Matlab's input and outputs are compatible with the ARX model defined in Matlab 74.65%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 68.96%. Considering the Matlab model agreement, when the frequency value obtained from the ARX and the finite element frequency values are compared by using experimental data, it is seen that there is 23% difference in ARMAX and 23% difference in ARMAX.

When examining the 4th period values, if we compare the results for forced vibration of the El-Centro earthquake smartphone registration; The fourth mode f_4:7.1601 emerges in the Sap 2000 software. In the ARX model, f_4:8.9. In the ARMAX model, f_4:9.0 Matlab's input and outputs are compatible with the ARX model defined in Matlab 74.65%, Matlab's input and outputs are compatible with the ARMAX model defined in Matlab 68.96%. Considering Matlab model agreement, it is seen that there is a 24% difference between the frequency values obtained in ARX and ARMAX and finite element frequency values obtained by using experimental data.

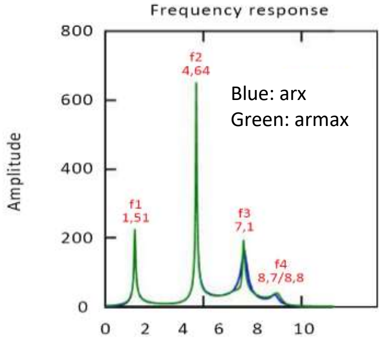


Figure10. Loma-Priate forced vibration smartphone recording

When examining the 1st period values, if we compare the results for forced vibration of Loma-priate smartphone recording (Figure 10) and (Table 5). The first mode f_1:1.3204 emerges in the Sap2000 software. In the ARX model, f_1:1.51. In the ARMAX model, f_1:1.51. The compatibility of the inputs and outputs given to Matlab with the ARX model defined in Matlab is 63%, and the compatibility of the inputs and outputs given to Matlab with the ARMAX model defined in Matlab is 60.79%. Considering Matlab model agreement, it is seen that there is a 14% difference when the frequency value obtained in ARX and ARMAX is compared with the finite element frequency values obtained by using experimental data.

Table 5. Loma-Priate eartquake

Loma-Priate earthquake	**ARX**	**ARMAX**	**Finite Elemant (Sap 2000)**
1th period	1.51	1.51	1.3204
2th period	4.64	4.64	3.8039
3th period	7.1	7.1	5.8332
4th period	8.7	8.8	7.1601
Best Fits (Matlab)	63	60.79	-
Difference between (Sap2000)%	14	14	-

When examining the 2nd period values, Loma-Priate earthquake smartphone recording forced vibration compared to the results; The second mode f_2:3.8039 emerges in the Sap2000 software. In the ARX model, f_2:4.64. In the ARMAX model, f_2:4.64. The compatibility of the inputs and outputs given to Matlab with the ARX model defined in Matlab is 63%, and the compatibility of the inputs and outputs given to Matlab with the ARMAX model defined in Matlab is 60.79%. Considering the Matlab model agreement, it is seen that there is a 22% difference between the frequency values obtained in ARX and ARMAX and finite element frequency values obtained using experimental data.

When examining the 3rd period values, if we compare the results for forced vibration of Loma-priate earthquake smartphone registration; In the Sap2000 software, the third mode is f_3:5.8332. In the ARX model, f_3:7.1. In the ARMAX model, f_3:7.1. The compatibility of the inputs and outputs given to Matlab with the ARX model defined in Matlab is 63%, and the compatibility of the inputs and outputs given to Matlab with the ARMAX model defined in Matlab is 60.79%. Considering the Matlab model agreement, it is seen that there is a 22% difference between the frequency values obtained in ARX and ARMAX and the finite element frequency values obtained using experimental data.

When examining the 4th period values, Loma-Priate earthquake smartphone recording forced comparison of the results for vibration; The fourth mode f_4:7.1601 emerges in the Sap 2000 software. In the ARX model, f_4:8.7. In the ARMAX model, f_4:8.8. The compatibility of the inputs and outputs given to Matlab with the ARX model defined in Matlab is 63%, and the compatibility of the inputs and outputs given to Matlab with the ARMAX model defined in Matlab is 60.79%. Considering the Matlab model agreement, it is seen that there is a 23% difference between the frequency values obtained in ARX and ARMAX and finite element frequency values obtained using experimental data.

6. CONCLUSIONS

ARX and ARMA's algorithm can be solved in a very short time with Matlab. Although ARMAX and ARX algorithms contain many coefficients, they are preferred in engineering studies because they can be calculated quickly and easily. ARMAX and ARX, one of the mathematical prediction models, have started to be used in structural identification with the developing technology. In this study, 4-storey model structure acceleration data were obtained by using smartphone recorder using 4 different earthquake data. In the determination of the dynamic characteristics of the structure, ARX and ARMAX algorithm is used. The two results were very close. In the four earthquake data used in the study, ARX and ARMAX rigging gave approximately the same values. When the ARX and ARMAX result, were compared with the finite element model result, the best estimation was achieved at Loma Priate with 14% prediction error at the 1st frequency value. The worst estimate was obtained Kobe with a 65% difference. Using only input data, the dynamic characteristics of the structure can be predicted with the help of the algorithm used. Due to noise and other residues, no exact match can be achieved between the data predicted or estimated by Matlab and the results of the experiment.

7. REFERENCES

[1] T. Baran, et al. “Deney ve Eğitim Amaçlı, Mekanik Tek Eksenli Bir Sarsma Tablasının İmalatı ve Performansının Araştırılması” , Altıncı Ulusal Deprem Mühendisliği Konferansı, 605-616, 2007.

[2] Ö. Özçelik, İ.S.Mısır, U. Yücel, “Model bir yapının hasar tanımlaması ve Model-Sarsıcı etkileşiminin azaltılması için kullanılan offline iterasyon tekniği”, 2. Türkiye Deprem Mühendisligi ve Sismoloji Konferansı, 2013.

[3] H. Türker, C. Mertayak, H.Çolak, “Peryot hesaplanmasında P-Δ etkisi: Sarsma tablası deneyi”, 1. Türkiye Deprem Mühendisligi ve Sismoloji Konferansı, 2011.

[4] E. Aydın, B. Öztürk, M. Gökdemir, H. Çetin, “Sarkaç tipi ayarlı kütle sönümleyicilerin harmonik etkiler altındaki davranışı: Deneysel bir çalışma”, 3. Türkiye Deprem Mühendisligi ve Sismoloji Konferansı, 2015.

[5] F. Birdal, F. Altun, A.K. Tanrıkulu, “Sarsma tablası deney sonuçlarına göre dinamik karakteristikleri belirlenmiş ölçekli betonarme bir yapının nonlineer dinamik ve statik analizlerinin karşılaştırılması”, 8. Ulusal Deprem Mühendisliği Konferansı, 2015.

[6] J. Goggins, B.M. Broderick, A.Y. Elghazouli, S. Salawdeh, A. Hunt, P. Mongabure, “Shake table testing of concentrically braced steel structures with realistic connection details subjected to earthquakes”, In Structures, vol. 13, pp. 102-118, 2018.

[7] Y. Yan, Z. Xuefeng, H. Ruicong, Q. Jiping, “Design and Initial Validation of External Sensors Board of Smart Phones for Mobile Structural Health Monitoring System”, In Proceedings of the 7th International Conference on Structural Health Monitoring of Intelligent Infrastructure, 2015.

[8] X. Zhao, K. Ri, R. Han, Y. Yu, M. Li, J. Ou, “Experimental research on quick structural health monitoring technique for bridges using smartphone” , Advances in Materials Science and Engineering, 2016.

[9] E. Mari, D. Shideh, R. Jack, D. B. Jonathan, B. Alexandre, G. Steven, “I-Shake:Mobile Phones as Seismic Sensors User Study Findings”, Proceedings of the 10th International Conference on Mobile and Ubiquitous Multimedia, 2011.

[10] K. Qingkai, M. A. Richard, S. Louis, K. Young-Woo, “My Shake: A smartphone seismic network for earthquake early warning and beyond”, 2016.

[11] Nasery, Mohammad Manzoor, et al. "Damage effect on experimental modal parameters of haunch strengthened concrete-encased composite column–beam connections", International Journal of Damage Mechanics, 2019.

[12] Hüsem, Metin, et al. "Experimental evaluation of damage effect on dynamic characteristics of concrete encased composite column-beam connections." Engineering Failure Analysis 91, 2018.

[13] H. S. Küyük, Z. D. Yaman, “Eşik Seviyesine Bağlı Protatip bir Deprem Erken Uyari Sistemi Geliştirilmesi”, 8. Ulusal Deprem Mühendisliği Konferansı, 2015.

[14] H. S. Ulusoy, Q. Maria, J. F. Paul, “System identification of a building from multiple seismic records”, 2010.

[15] https://www.mathworks.com/products/sysid.html Erişim Tarihi: 14.05.2019.

[16] Ü. M. Kahraman, “Çok değişkenli eşiksel otoregresif modeller üzerine bir çalışma,” Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, Doktora Tezi, 2012.

[17] M. Ay Ali, Y.Wang, “Structural damage identification based on self-fitting ARMAX

model and multi-sensor data fusion”, Struct. Health Monit, vol. 13(4), pp. 445–460, 2014.