Subspace based identification of structural parameters of the base isolation level

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ABSTRACT

One of the common methods in controlling the seismic response of structures is the use of seismic isolators. Base isolations reduce the base shear as well as the relative displacement of the floors by increasing the period of the structure. Typically, extreme deformation of the base isolation level occurs due to severe environmental factors, which can lead to damage to the base isolations; As a result, there is a possibility of permanent deformation in the base isolation and also the collision of the structure with adjacent buildings. Therefore, to prevent damage to buildings equipped with base isolations due to severe ground motions, it is important to identify damage at the base isolations. In this study, assuming the linear behavior of the main structure, a proposed subspace-based method for identifying the stiffness of the base isolation with a limited number of sensors is presented. For this purpose, using the compression technique, the structure equipped with a separator with a large number of degrees of freedom (DOFs) is transformed into a two DOF structure; So that the stiffness associated with the first DOF in the reduced system corresponds to the stiffness of the Base isolation level in the original structure. Then, using the identified Markov parameters of the system, the reduced structural stiffness is identified. Numerical examples are used to evaluate and compare the performance of the proposed method. The results show that even in the presence of noises in the measured responses, the proposed method detects the amount of damage at the base isolation level with acceptable accuracy.

Keywords: base isolation, damage identification, subspace technique, passive control, structural health monitoring

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1. Introduction

One of the acceptable strategies to ensure the promotion of safety and long-term performance of the structure is the use of control equipment to reduce the dynamic response of the structure under the impact of severe earthquakes [1-4]. A new approach to seismic design is moving towards reducing demand as an alternative to increasing capacity, and one way to achieve this is to use flexible devices at foundation levels to prevent the transfer of seismic energy to the structure [5]. By increasing the period of the structure, the base isolation reduces both the base shear and the relative displacement of the floors [6]. Large deformations caused by severe environmental factors such as earthquakes and winds at the base isolation level can lead to damage to them. Damage to the base isolation will significantly increase the rigid displacement of the structure; as a result, there is a possibility of residual deformation in the base isolation level as well as the collision of the structure with adjacent buildings [7]. Therefore, early detection of structural damage before it causes irreparable damage is essential. In this article, we try to identify a small part of the structure that includes the level of the base isolation. For this purpose, it is only necessary to measure and record dynamic responses in a limited number of related DOFs. This reduces the amount of measurement data and equipment required and, consequently, the time required for system identification calculations. As a result, it will save a lot of cost and time. Numerous damage identification methods have been [8]. Damage detection methods in large structures will always have several problems with increasing the number of DOFs and uncertain parameters [9-11]. One of the methods to overcome this problem is the substructure method [12]. In this research, a new substructure-based method for identifying the stiffness of the base isolation level in a structure equipped with an base isolation with a limited number of sensors is presented. In the proposed method, a structure with several DOFs equipped with a base isolation is transformed into a two-DOFs structure using the compression technique. The stiffness corresponding to the first DOF in the reduced mathematical model of the structure is equal to the stiffness of the base isolation level in the original structure. Here, the damage detection algorithm based on the identified system Markov parameters (DDA/ISMP) [8] is used to identify the structural parameters of the reduced model.

2. Compression of the structure equipped with a base isolation

Figure (1) shows a n floor building equipped with a base isolation. x_i where $i = b, 1, 2, 3, \cdots, n$ represents the displacement of the i-th story relative to the base isolation level. m_i, c_i and k_i are the mechanical properties of the *i*-th story of the structure, indicating the mass, damping and stiffness, respectively. In order to identify the system, it is assumed that excitations f_b, f_n are applied to the structure by two actuators installed in the base isolation level and the roof floor, respectively. Also, the dynamic response of the structure under the effect of input excitation is measured only in two DOFs, including the level of the base isolation and the roof floor by sensors installed in these DOFs. Let's, define the following parameters:

$$
\begin{array}{ll}
\boldsymbol{\Delta} = [1 \quad \mathbf{O}] & \boldsymbol{\Omega} = [\mathbf{O}^T \quad \mathrm{I}] \\
\boldsymbol{\varphi}_\mathbf{s} = \boldsymbol{\Omega}\tilde{\boldsymbol{\varphi}}_\mathbf{1} & \mathrm{m} = 6\boldsymbol{\varphi}_\mathbf{s}{}^T \mathbf{m}_\mathbf{s}\mathbf{L} \\
c_r = \boldsymbol{\varphi}_\mathbf{s}{}^T \mathbf{c}_\mathbf{s}\boldsymbol{\varphi}_\mathbf{s} & f_{r1} = \boldsymbol{\Delta}\boldsymbol{\Gamma}\mathbf{B}_\mathbf{u}\mathbf{f} \\
k_r = \boldsymbol{\varphi}_\mathbf{s}{}^T \mathbf{k}_\mathbf{s}\boldsymbol{\varphi}_\mathbf{s} & f_{r2} = \boldsymbol{\varphi}_\mathbf{s}{}^T \boldsymbol{\Omega}\boldsymbol{\Gamma}\mathbf{B}_\mathbf{u}\mathbf{f} \\
m_{r2} = \boldsymbol{\varphi}_\mathbf{s}{}^T \mathbf{m}_\mathbf{s}\boldsymbol{\varphi}_\mathbf{s} - \frac{m}{3} & m_{r1} = m_b + \mathbf{L}^\mathbf{T}\mathbf{m}_\mathbf{s}\mathbf{L} - \frac{m}{3}
\end{array} \tag{1}
$$

in which, $\mathbf{m}_\mathbf{s} \in \mathbb{R}^{n\times n}$, $\mathbf{c}_\mathbf{s} \in \mathbb{R}^{n\times n}$ and $\mathbf{k}_\mathbf{s} \in \mathbb{R}^{n\times n}$ are the mechanical properties of the structure with fixed support. The location of the inputs in the primary structure is presented by $\mathbf{B}_\mathbf{u} \in \mathbb{R}^{(n+1)\times r}$. The external force vector $\mathbf{f} \in \mathbb{R}^r$ is used to simulate the environmental excitation in the primary structure. The parameter $\tilde{\boldsymbol{\varphi}}_\mathbf{1} \in \mathbb{R}^{(n+1)}$ is the first identified modeshape of the primary structure. The matrices $\mathrm{I} \in \mathbb{R}^{n\times n}$, $\mathbf{O} \in \mathbb{R}^{1\times n}$ and $\mathbf{L} \in \mathbb{R}^n$ are the unit matrix, zero matrix and unit vector. The parameter $\boldsymbol{\Gamma} \in \mathbb{R}^{(n+1)\times(n+1)}$ indicates the interaction matrix. The motion equation of the compacted structure is obtained as follows:

$$\mathbf{m_0}\ddot{\mathbf{x}} + \mathbf{c_0}\dot{\mathbf{x}} + \mathbf{k_0}\mathbf{x} = \mathbf{f_r} \tag{2}$$

$$
\begin{array}{l}
\mathbf{x} = \begin{Bmatrix} x_b \\ x_n \end{Bmatrix}, \quad \mathbf{m_0} = \begin{bmatrix} \frac{m}{3} + m_{r1} & \frac{m}{6} \\ \frac{m}{6} & \frac{m}{3} + m_{r2} \end{bmatrix} \\
\mathbf{c_0} = \begin{bmatrix} c_b & 0 \\ 0 & c_r \end{bmatrix}, \quad \mathbf{k_0} = \begin{bmatrix} k_b & 0 \\ 0 & k_r \end{bmatrix}, \quad \mathbf{f_r} = \begin{Bmatrix} f_{r1} \\ f_{r2} \end{Bmatrix}
\end{array} \tag{3}
$$

In fact, Equation (2) represents the equation of motion of a reduced two DOFs system in which the vector $\mathbf{x} \in \mathbb{R}^2$ is the displacement of the system, respectively. Also, $\mathbf{m_0} \in \mathbb{R}^{2\times 2}$, $\mathbf{c_0} \in \mathbb{R}^{2\times 2}$ and $\mathbf{k_0} \in \mathbb{R}^{2\times 2}$ are mass, damping and stiffness of the two DOFs system, respectively. Finally, the mechanical properties of the reduced structure is estimated using the DDA/ISMP method.

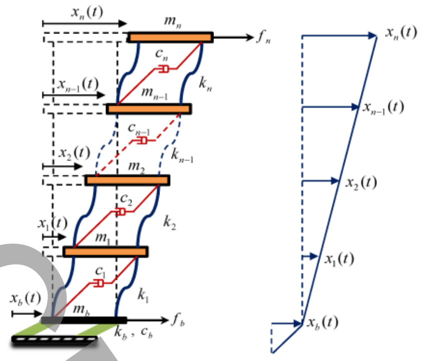

Figure 1. Shear model of *n* degree freedom structure equipped with base isolation.

3. Numerical example

In this paper, in order to evaluate the performance of the proposed method in identifying the occurred damage in the isolation layer, two structures of five [13] and eight [14] stories equipped with base isolation is applied. In order to evaluate the accuracy of the proposed method, the amount of error in identifying base isolation stiffness in three noise intensities of 0%, 3% and 5% has been estimated. The error value in the identification of the eight-story structure is 0.81%, 2.28% and 4.44% and for the five-story structure is equal to 1.02%, 4.23% and 7.74%. Also, the correlation between the responses of the primary and reduced systems in the two structures of eight and five stories is 83.82% and 97.73%, respectively. The results show that the percentage of error in the absence of noise is less than 2% and the identification precision error decreases under the high noise intensity level; however, the error rate is less than 10%.

4. Conclusions

In this paper, a substructure identification method is proposed to identify the stiffness of the isolation level in structures equipped with the base isolation. The results showed that the proposed method, using a smaller number of sensors, detects the amount of stiffness in the level of the base isolation with appropriate accuracy even in the presence of high noise intensity. Moreover, due to the reduction in the number of data, the time required to identify the structure in the compressed case is approximately half of the original structure; this shows the efficiency and effectiveness of the proposed method in terms of cost and time.

5. References

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