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Estimation of Median Incremental Dynamic Analysis Curve Using Ranking of Strong Motion Records

A. Yazdani^{1*}, H. Baharmast², S. Razmyan³

1- Associate Professor, Department of Engineering, University of Kurdistan

2- M.Sc. Student, Department of Engineering, University of Kurdistan

3- Assistant Professor, Department of Mathematics, Firoozkuh Branch of Islamic Azad University

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ABSTRACT

Incremental dynamic analysis (IDA) is a parametric analysis method that is used in estimation of structural performance by subjecting the structural model to multiple suitably scaled ground motion records, each scaled to multiple levels of intensity, thus produce several curves of response parameterized by intensity level. Recognizing that IDA of practical structures is computationally demanding, an approximate procedure based on the reduction of the number of ground motions is developed. A methodology based on data envelopment analysis, mathematical programming that can handle large numbers of variables and relations is proposed to reduce the number of ground motions needed for the production of a reliable median incremental dynamic analysis curve. These curves computed by the exact and approximate procedures for two different 4- and 8-storey buildings and one set of ground motions is presented. The results demonstrate that the approximate procedure which uses a limited number of input ground motions has the error less than about 5%.

KEYWORDS:

Incremental Dynamic Analysis, Data Envelopment Analysis, Ranking

* Corresponding Author, Email: a.yazdani@uok.ac.ir

1- Introduction

Incremental dynamic analysis (IDA) is a parametric analysis method that estimates seismic demand and capacity by subjecting the structural model to multiple suitably scaled ground motion records, each scaled to multiple levels of intensity, thus produce several curves of response parameterized by intensity level [1]. A series of nonlinear dynamical analyses under a suite of ground motion records is a computer-intensive procedure. Therefore, there is a great need for a simple procedure that carries the advantages of IDA while using nonlinear dynamical analyses. In an approximate method, a single degree of freedom (SDOF) system is defined to approximate the static pushover (SPO) curve for the multiple degree of freedom (MDOF) structure to reduce the computational effort required for IDA to estimate the seismic demand for the structure [2-4].

The standard deviation in the estimation of the median provides a measurement of the uncertainty in the median caused by the limited number of ground motion records. The standard deviation of the median values of the IDA curve can be reduced by increasing the number of records. Although the dispersion in the seismic response is an important result, it is often more important to quantify the median response, e.g., the median IDA curve. Data envelopment analysis (DEA) [5] is widely applied to the performance analysis of many decisional entities. The main objective of the DEA models is the evaluation of the overall efficiencies of the decision making units (DMUs) by a scalar measure with a value between zero and one that converts a set of inputs into a set of outputs. Combining various inputs and outputs into one value, such as the ratio of aggregated outputs to aggregated inputs, will allow to evaluate and rank the performance of DMUs by their corresponding single measures. With the proposed ranking methodology, an attempt has been made to reduce the number of ground motion records required to predict the median IDA curve. The procedure based on this ranking methodology is illustrated by example computations for 4 and 8 storey building using the exact and approximate procedures for ensembles of ground motion records.

2- Data envelopment analysis

Data envelopment analysis (DEA) is widely applied to the performance analysis of many decisional entities in different fields, such as

economics, business and engineering. DEA utilizes techniques like mathematical programming that can handle large numbers of variables and relationships (constraints) which relaxes the requirements that are often encountered when one is limited to choosing only a few inputs and outputs. In DEA, the organization under study is called a DMU [5]. The use of DEA to provide an overall assessment of the performances of all efficient DMUs and rank them has become an interesting topic. The ranking is based on a measurement of the efficiency of the DMU. The efficiency is calculated by a scalar measure with a value between zero (the worst) and one (the best) through a linear programming (LP) model, and the weights assigned to each linear aggregation are the results of the corresponding LP. Different ranking methods have been developed that use several classification criteria and are not entirely mutually exclusive [6]. For n DMUs with the input $X=(x_{ij}) \in R^{m \times n}$ and the output $Y=(y_{ij}) \in R^{s \times n}$, the production possibility set P is defined as follows:

$$P = \{(x, y) | x \geq X \lambda, y \leq Y \lambda, \lambda \geq 0\} \tag{1}$$

where λ is a non-negative vector in R^n . In an effort to estimate the efficiency of k^{th} -DMU, the following linear program can be formulated:

$$Min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^m s_i^- / x_{io}}{1 - \frac{1}{s} \sum_{r=1}^s s_r^+ / y_{ro}} \tag{2}$$

where ρ is a positive index that it is equal to or smaller than unity ($0 < \rho \leq 1$) and s is the number of outputs. Given the data, the efficiency of each DMU is measured; hence, n optimizations is needed, one for each DMU _{j} ($j=1, \dots, n$) to be evaluated.

3- Methodology

IDA requires both creation of a MDOF mathematical model that can be used for the simulation of the realistic seismic response of the structure and selection of a suite of ground motion records to represent an earthquake scenario. Consequently, IDA is powerful tool, but in most design cases it is complex and time-consuming. The aim of this study is to decrease the number of ground motion records needed for the prediction of a median IDA curve of the MDOF system. The main steps of the methodology are present in Fig. 1 and can be describe as follow:

1) Create simple mathematical model e.g. SDOF system. This model should be a good representative of the linear and non-linear characteristic MDOF

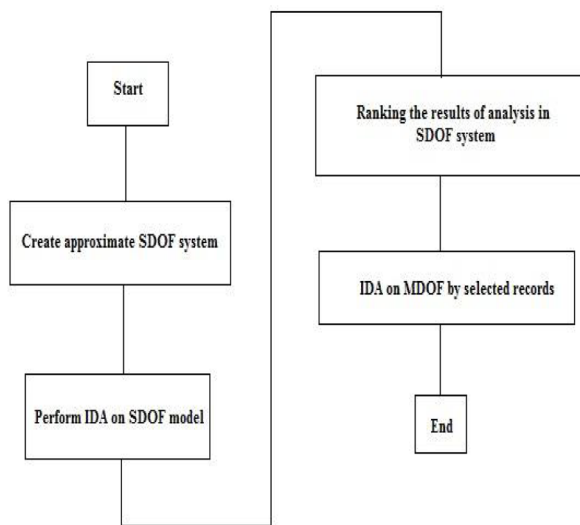


Fig. 1. Framework reduction ground motion for IDA

model.

2) Performing IDA analysis on the SDOF system

3) In the next step, data envelopment analysis is applied to arrange the ground motion records. The measures of efficiency of the different ground motions are calculated by a scalar measure between zero and one.

4) According to step 3, the results will be ranked. Based on the ranked records, a limited number of ground motion records are considered.

5) In the final step, a single-record IDA curve for the MDOF model is computed for a limited number of ground motion records from the preceding list.

4- Conclusions

Incremental dynamic analysis is one of base in performance-based earthquake engineering concepts. Estimating the seismic demands on a structure by an approximate method leads to a highly efficient procedure and the proposed approach offers a significant reduction of computational effort. The approximation procedure based on the reduction of the number of ground motions is accurate over the entire range of interstory drift and roof drift ratios,

even close to collapse. In the proposed methodology, the response of a SDOF model is used to rank the ground motion set based on data envelopment analysis (DEA). The accuracy of the method depends on the number of selected records. For the ground motion set the accuracy of the approximate procedure for the four selected ground motions is satisfactory. The error in the prediction of the median IDA curve up to collapse, in terms of the interstory drift and roof displacement ratio, is less than 5%.

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