Exerting Modal Incremental Dynamic Analysis (MIDA) in Surveying Seismic Behavior of Structures Equipped by Self-Centering Viscoelastic Damper

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SUMMARY:
One of the most recent methods for estimating behavior of structures is MIDA technique. Although this method presents the approximate results, high accuracy, fastness and inexpensive procedure made this manner to an efficient method. Indeed, this method has been presented to be exerted instead of exact IDA method which is too complicated and prolix. Up to now, no one has used this method for structures with additional damping. In the MIDA manner, there is no dynamic analysis of whole structure. Therefore, it could be interpreted that this method cannot be used for structures with additional damping. In this article, it is intended to represent an approach to use MIDA method for structures, which damped by additional damping. The results show appropriate accuracy of proposed technique in applying MIDA method for structures with additional damping. Results show SCVDs make structure's behavior better.

Keywords: IDA analysis, Modal Incremental Dynamic Analysis, SCVDs damper

1. INTRODUCTION

Predicting the actual behavior of structures under the earthquake excitation is one of the major purposes of structure and earthquake engineers. When a severe earthquake takes place, most of the structures pass the elastic limit to the nonlinear area. Therefore, linear analyses could not present the accurate behavior of structures. On the other hand, static analyses (linear and nonlinear) are associated with large approximation because these manners equate the earthquake excitation with a static load with a constant height wise distribution and restricted to single-mode response. This equated load, causes uneconomic design. Consequently, it seems that nonlinear time history analysis could present the most real seismic demand of structures. The advantage of incremental techniques (such as pushover method) over the time history analysis is considering a wide range of lateral load amounts from zero to instability load. Therefore, researches have been seeking a method having both mentioned advantages simultaneously; real dynamic behavior of structure and different scaled levels of earthquake record. Consequently the IDA (Incremental Dynamic Analysis) method was developed. This procedure is considered to be the most accurate method for determining the seismic demand of structures. It seems that the IDA method declared by Bertero, (Bertero 1977) at first time. After that (Nassar and Krawinkler 1991), (Bazzurro and Cornell 1994), (Luco, Wong et al. 1992), (SS and GG 2000), (Dubina D 2000), (Psycharis, Papastamatiou et al. 2000), (Gupta B 2000), (Yun SY 2001), (Vamvatsikos and Allin Cornell 2002), (Aschheim M 2007), (ManderB, RajeshP et al. 2007) have researched about the IDA method.

As mentioned above, the IDA technique is the most accurate solution for determining the seismic behavior of structures and its outcomes are exact. However, this method is so rigorous because in order to produce each IDA curve lots of time history analysis is needed to be done. Therefore, it is not economic in addition to taking a long time to perform the IDA procedure. As a result, an approximate method which is capable of producing the IDA curve has been invented, namely the MPA-based IDA

or MIDA (Modal Incremental Dynamic Analysis) method. Besides being fast and inexpensive, the errors and difference between the IDA and the MIDA outcomes is negligible.
The first approximate method for reducing the computational effort of IDA devised by (Vamvatsikos and Cornell 2005), who are developers of IDA method. Afterwardss, Mofid, Zarfam and Fard proposed the approximate MIDA method,2005(Mofid, Zarfam et al. 2005) and compared the MIDA and IDA results. They concluded acceptable accuracy of MIDA method. Han and Chopra presented MPA-based IDA method, which is similar to the MIDA procedure (Han and Chopra 2006).
As mentioned earlier none of the forenamed researchers have exerted the MIDA method for structures with additional damping. Applying static analysis in the procedure of MIDA technique might make one think that the effect of additional damping does not contribute in MIDA method. In this essay, a novel idea will be presented which develops the MIDA technique for structures with additional damping. The rest of this paper is structured as follows. Section two reviwes the procedure of the MIDA method for ordinary structures, section three represents the proposed idea for exerting the MIDA method on structures with additional damping, section four describes SCVDs, section five and six represent used model and records, section seven exerts proposed idea on structures which equipped by SCVDs and finally section eight shows results.

2. REWIEV OF THE MIDA METHOD FOR ORDINARY STRUCTURES (STRUCTURES WITH NO ADDITIONAL DAMPING)

As mentioned above, this method has been exerted by several researchers. Generally, all users of this technique proposed the same procedure or flowchart. In summary, the procedure is consisted of following steps:

- Determine the mode shape of nth mode.
- Construct the pushover curves of MDOF (Multi degree of freedom) structure under lateral loading pattern related to nth mode.
- Convert the pushover curve of MDOF structure to the behavior of SDOF structure for the nth mode by use of Eqn. 2.1., Eqn. 2.2. and Eqn. 2.3.

$$(F_{yi})_{SDF} = \frac{(F_{yi})_{MDF}}{(\frac{L}{M})_i} \qquad (1.2)$$

$$(D_{yi})_{SDF} = \frac{(D_{yri})_{MDF}}{(\frac{L}{M})_i \, \phi_{ri}} \qquad (2.2)$$

$$\alpha_{SDF} = \alpha_{MDF} \qquad (2.3)$$

- Apply scaled level of each record to SDOF structure and compute the maximum displacement.
- Calculate maximum displacement of the MDOF structure for each mode, by use of Eqn. 2.4.

$$(MaxDispl)_{MDF} = (\frac{L}{M})_i \, .\phi_{ri} \, .(MaxDispl)_{SDF} \qquad (٢.۴)$$

- Push the MDOF structure to the maximum displacement and calculate damage index.
- Repeat above steps for the next mode until achieving proper accuracy.
- Combine the damage indexes for several first modes.
- Apply this procedure for different scales of records from zero to instability.

With respect to above algorithm there is no need to analyze the MDOF structure by using of nonlinear dynamic analysis, however the SDOF structure analyzed based on nonlinear dynamic analysis.

3. THE MIDA METHOD FOR STRUCTURES WITH ADDITIONAL DAMPING

As it figured above, in the procedure of MIDA method, the MDOF structure is analyzed by using of nonlinear static analysis. Therefore, dynamic analysis of MDOF structures is not used in the mentioned method so it might be misinterpreted that the effect of additional damping is not considered in the MIDA technique. As a result, no one has exploited the MIDA method for structures with addition damping. In this paper, a novel idea is presented and it is intended to replace the additional damping of MDOF structure with inherent damping of SDOF structure. Considering this idea, additional damping is converted to the equal inherent damping, in other words, there is no additional damping and instead of that equal inherent damping is added to the real inherent damping of structure. Now the structure is an ordinary structure with no additional damping but with inherent damping which is more than the inherent damping of common structures so the ordinary MIDA procedure could be used to analyze that. It should be noted that by using of this idea the effect of additional damping appears on the target displacement of SDOF structure. Target displacement of MDOF structure is related to the target displacement of SDOF structure, so decreasing in the target displacement of SDOF causes decreasing in the target displacement of MDOF structure.
In this article, first, SCVDs will be described and will be designed for a sample structure. Afterwards a general method for estimating equal inherent damping of SDOF structure for any kind of additional damping will be presented and sample structure which is equipped by SCVDs will be analyzed by using of this method.
Considering that the IDA method is an exact technique, a proper judgment for determining the accuracy of the MIDA could be surveying the difference between the IDA graph and the graph which has produced by the MIDA.

4. SELF CENTERING VISCOELASTIC DAMPER (SCVDs)

SCVDs devised by (Karavasilis, Blakeborough et al. 2011). SCVDs is attained from series combination of viscoelastic (VE) dampers and self-centering (SC) device. Figure 4.1. shows the SCVDs model. The behavior of VE part is represented by generalized Maxwell which is combination of springs and dashpots. SC part consists of a pretensioning elastic tendon and a friction-based part.

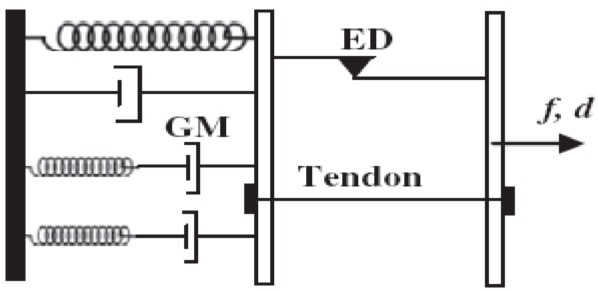


Figure 4.1. SCVDs Model

Under small amplitudes of deformation the SC part is inactive and SCVDs acts as a VE damper. Under large amplitudes of deformation the SC part is activated and SCVDs behaves as a hysteretic damper. Indeed, the VE part acts as an energy dissipating device and the SC part eliminates the residual drifts and inelastic deformations.

5. USED MODEL

In this study, a five story steel frame structure is considered as prototype. The frame consists of three bays with four meter length for each bay and the height of each story is three meter. For each story a SCVDs has designed. SCVDs supported by braces in the middle bay. The steel frame and dampers modeled in OpenSees (S, F et al. 2006) software. The prototype includes six models which are one model with no SCVDs and five models with five different amount of additional damping. Damping of SCVDs represents by the proportion of the stiffness of viscoelastic part of SCVDs to the stiffness of structure $K(ve)/K(st)$. In this essay in order to achieving a comprehensive comparison, the amount of $K(ve)/K(st)$ is considered to be 0, 0.2, 0.5, 0.8, 1 and 10. For each amount of damping, structures analyzed by using of the IDA and the MIDA methods under the excitation of thirty records.

6. USED RECORDS

The IDA and MIDA analysis has been done for each of six sample structures. Both IDA and MIDA have been done for thirty records.

Table 5.1. Used Records

No	Record	Station	Soil	PGA	Duration
1	Imperial Valley 1979	Chihuahua	C,D	0.254	40
2	Imperial Valley 1979	Chihuahua	C,D	0.27	40
3	Northridge 1994	Hollywood Storage	C,D	0.231	40
4	San Fernando 1971	Lake Hughes #1	_,C	0.145	30
5	San Fernando 1971	Hollywood Stor Lot	C,D	0.21	28
6	Super Stition Hills 1987	Wildlife Liquefaction Arrey	_,D	0.134	29.805
7	Super Stition Hills 1987	Wildlife Liquefaction Arrey	_,D	0.134	29.805
8	Super Stition Hills 1987	Salton Sea Wildlife Refuge	D,D	0.119	21.89
9	Super Stition Hills 1987	Plaster City	C,D	0.186	22.23
10	Super Stition Hills 1987	Calipatria Fire Station	C,D	0.247	22.11
11	Landers 1992	Barstow	B,D	0.135	40
12	Cape Mendocino 1992	Rio Dell Overpass	C,B	0.385	36
13	Cape Mendocino 1992	Rio Dell Overpass	C,B	0.549	36
14	Coalinga 1983	Parkfield - Fault Zone 3	_,D	0.164	40
15	Whittier Narrows 1987	Beverly Hills	B,C	0.126	37.4
16	Northridge, 1994	LA, Baldwin Hills	B,B	0.239	40
17	Imperial Valley, 1979	El Centro Array #12	C,D	0.143	39
18	Loma Prieta, 1989	Anderson Dam Downstream	B,D	0.24	39.6
19	Loma Prieta, 1989	Anderson Dam Downstream	B,D	0.244	39.6
20	Loma Prieta, 1989	Agnews State Hospital	C,D	0.159	40
21	Loma Prieta, 1989	Anderson Dam Downstream	B,D	0.244	39.6
22	Loma Prieta, 1989	Coyote Lake Dam Downstream	B,D	0.179	40
23	Imperial Valley, 1979	Cucapah	C,D	0.309	40
24	Loma Prieta, 1989	Sunnyvale Colton Ave	C,D	0.207	39.25
25	Imperial Valley, 1979	El Centro Array #13	C,D	0.117	39.5
26	Imperial Valley, 1979	Westmoreland Fire Station	C,D	0.074	40
27	Loma Prieta, 1989	Sunnyvale Colton Ave	C,D	0.209	39.25
28	Imperial Valley, 1979	El Centro Array #13	C,D	0.139	39.5
29	Imperial Valley, 1979	Westmoreland Fire Station	C,D	0.11	40
30	Loma Prieta, 1989	Hollister Diff. Array	–,D	0.269	39.65

7. Proposed technique for exerting MIDA on structures equipped by SCVDs

As mentioned earlier, in order to exert MIDA on structures which damped by dampers, the most important point is converting additional damping to equal inherent damping. In this article lots of analyses have been done to determine the effect of record and its scale on the equal inherent damping. A useful achieved result could be interpreted as "the record and its scale factor don't affect the amount of equal damping significantly". This result is so useful and it can be easily used to determine the equal inherent damping for any kind of additional damping. After determining the equal inherent damping, the procedure is similar to the procedure of ordinary MIDA which mentioned at part two. Consequently, the main point is determining the equal damping.

As mentioned above the amount of equal inherent damping doesn't dependent on the record and its scale. Therefore, by using of the following algorithm the amount of equal inherent damping could be determined.

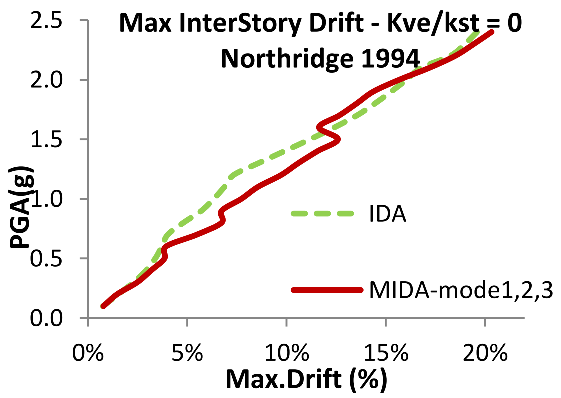
- Exert time history analysis on the structure under an optional record and scale factor.
- Analyze the structure based on MIDA method under the selected record and scale factor with an assumed inherent damping.
- Change the assumed inherent damping and perform an iterate process until the outcome ofMIDA analyses equals to the result of IDA analysis. The equal inherent damping which makes the IDA and MIDA same, is the proper equal inherent damping.

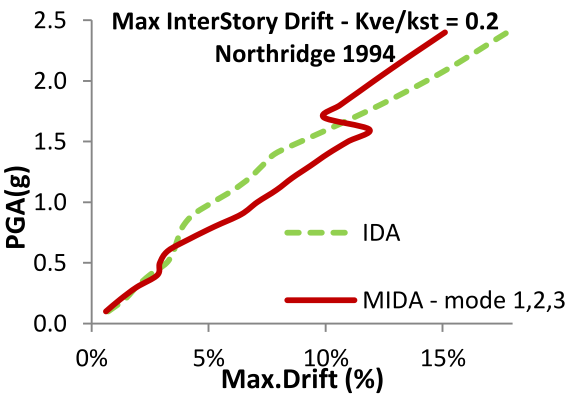
As the algorithm shows, the equal inherent damping is determined by using of one analysis only. Knowing the equal inherent damping, the MIDA method could be done using the algorithm which presented at part two.

It should be noted that by selecting another record or scale, the equal inherent damping might change slightly, although lots of performed analyses show that this change is negligible and don't affect the results.

8. Analyze results

The IDA and MIDA analyses have been exerted for each of six structures under the records listed in table 5.1. As a sample, the outcomes of MIDA and IDA method demonstrated in figure 7.1. for San Imperial Valley 1979 earthquake and for various amounts of viscoelastic damping. The MIDA analyses have been done by using of proposed idea.





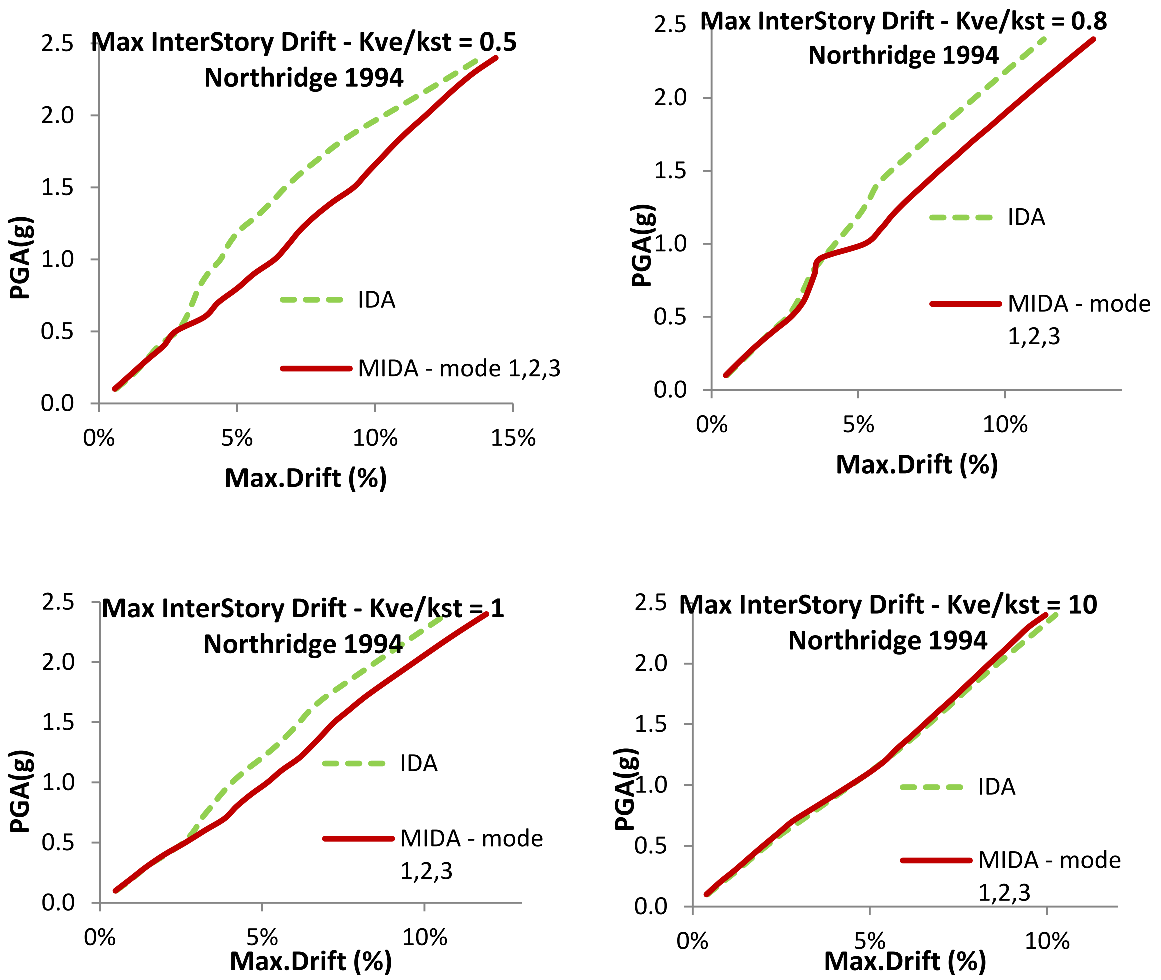


Figure 8.1. Comparing the IDA and MIDA method results for Northridge earthquake

9. Conclusion

In this essay, an idea proposed for exerting MIDA method on structures with additional damping. By using of this idea additional damping converts to the equal inherent damping. Therefore, the MIDA analysis could be done just like as ordinary MIDA procedure for structures which have no additional damping.

Following results can be concluded from this investigation.

- Proposed idea for exploiting MIDA method on the structures equipped by SCVDs is accurate enough to use.
- The accuracy of MIDA method for structures equipped with additional damping is more than the ordinary structures. In other word, the accordance of MIDA and IDA curves for damped structures is more than the ordinary structures.
- Increasing the additional damping causes increasing the accuracy of proposed method. Indeed, increasing the additional damping causes more accordance between IDA and MIDA curves.
- Exploited record and also its scale don't affect the equal inherent damping. In other word, the proposed method is not sensitive to the record and its scale.

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