The Egyptian Int. J. of Eng. Sci. and Technology
Vol. 15 No. 1 (Jan. 2012)

EIJEST

ASSESSMENT OF SEISMIC PERFORMANCE OF MULTI-STORY REINFORCED CONCRETE STRUCTURES IN EGYPT*

Ashraf M. Elshihy, Yasser E. Ibrahim, Osman A. Shallan, Mohamed A. Selim**

Structural Eng. Dept., Zagazig University, Egypt

ABSTRACT

In this research, an assessment of seismic performance of multi-story reinforced concrete structures in Egypt is performed. Five structural models designed according to the Egyptian code of loads and practice are selected to investigate their seismic response under twelve ground motions using SeismoStruct software. In order to understand the overall response of selected structures natural periods and mode shapes are obtained from eigenvalue analysis using SeismoStruct software. Horizontal capacity of the selected structures is estimated through nonlinear static pushover analysis using SeismoStruct software, where the models subjected to static triangular load distributions at each floor. Incremental dynamic analysis curves are presented for each structural model. In this research, four damage limits are considered; fully operational (FO), operational (OP), life safe (LS), and near collapse (NC) damage limit, these limits are defined according to the interstory drift ratio with values of maximum permissible interstory drift ratio according to SEAOC vision 2000.

KEY WORDS: Seismic performance, damage limits, damage indices, Incremental analysis, performance based engineering, ground motion, pushover analysis.

ÉVALUATION DU RENDEMENT DE SISMIQUE MULTI-HISTOIRE STRUCTURES EN BÉTON ARMÉ EN EGYPTE

RÉSUMÉ

Dans cette recherche, une évaluation de la performance sismique des multi-étages en béton armé en Egypte est effectué. Cinq modèles structurels conçus selon le code égyptien de charges et la pratique sont sélectionnés pour étudier leur réponse sismique de moins de douze mouvements du sol en utilisant un logiciel SeismoStruct. Afin de comprendre la réponse globale des périodes de structures sélectionnées et modes propres sont obtenus à partir de l'analyse aux valeurs propres en utilisant le logiciel SeismoStruct. Capacité horizontale des structures sélectionnées est estimée par analyse pushover statique non linéaire utilisant le logiciel SeismoStruct, où les modèles soumis à la charge statique de distributions triangulaires à chaque étage. Incrémental courbes d'analyse dynamique sont présentés pour chaque modèle structurel. Dans cette recherche, quatre limites sont considérées comme des dommages; pleinement opérationnelle (FO), opérationnels (PO), la vie sans danger (LS), et quasi-effondrement de limiter les dommages (NC), ces limites sont définies en fonction du rapport de dérive interstory avec des valeurs de maximum de permise ratio de la dérive en fonction de interstory SEAOC la vision 2000.

MOTS CLÉS: Performance sismique, de limiter les dommages, les indices de dommages, l'analyse incrémentale, ingénierie de la performance basée, mouvements de terrain, analyse pushover.

* Received: 1/11/2011, Accepted: 18/12/2011 (Original Paper)
** Contact author (eng_selim@yahoo.com, +2 011 1566 4256)

1. INTRODUCTION

In our life there are many hazards; one of the most terrible ones is earthquakes. Not only the human life loss but also the huge damage of everything around man expresses the destructive potential of this phenomenon.

From this point of view, behavior of multi-story reinforced concrete structures in Egypt under the effect of seismic loads has often been a focus of consideration and investigation. Moreover, recent codes provide minimum provision for design and construction of structures to resist the motions with no clear definition of the expected performance and damage, which are important to estimate the potential life and economic losses under possible earthquakes [1]. Performance-based earthquake engineering judges the design, evaluation and construction of structures with a certain performance under different earthquakes satisfying the owner and users of such structures, in this field incremental dynamic analysis (IDA) is applied on a certain category of structures in order to investigate the response of this category under different earthquakes.

IDA is a recently-developed computer-intensive method that gives a clear vision about the performance of a certain type of structures under seismic excitations with wide range of intensities [2].

Moreover (IDA) curve is a superior tool, by which the engineer and the owner can select a certain level of performance of the designed structure under seismic loads, in the Egyptian code of loads and practice performance levels of structures is not considerable in spite of its importance in predicting and controlling the damage of the structures under earthquakes [3].

In this research, four damage limits are considered; fully operational (FO), operational (OP), life safe (LS), and near collapse (NC) damage limit, these limits are defined according to the interstory drift ratio, the suggested values of maximum permissible interstory drift ratio according to SEAOC vision 2000 [4] is listed in Table 1.

In this research the IDA will be carried out on multi-story reinforced residential concrete buildings in Egypt designed according to the Egyptian code.

$$\delta_{max}\,\% = \frac{\Delta_{max}}{H} \times 100$$

where Δ_{max} is the maximum interstory drift and H is the floor height.

Table 1: Maximum permissible interstory drift ratio

Limit State	δ_{max} %
FO	0.2
OP	0.5
LS	1.5
NC	2.5

2. STRUCTURAL MODELING

The structural analysis software package SeismoStruct was chosen to perform the structural modeling of the different structures [5]. This is a finite element software package that can be used to investigate the large displacement behavior of structures under static or dynamic loading taking various forms of nonlinearity into account.

Both geometric and material nonlinearity can be incorporated into a finite element model in SeismoStruct.

2.1. Geometric Nonlinearity

Geometric nonlinearity of a model due to large deformations is taken into account by employing a co-rotational formulation with element displacements and the resulting internal forces defined by the movement of a local chord system. As shown in Fig. 1; this local system consists of six basic degrees of freedom, five rotational , $\Theta_{2(A)}$ $\Theta_{3(A)}$, $\Theta_{2(B)}$, $\Theta_{3(B)}$, $\Theta_{(T)}$) and $\Theta_{2(A)}$ a $\Theta_{3(A)}$, $\Theta_{2(B)}$, $\Theta_{3(B)}$, $\Theta_{(T)}$ translational one named (Δ).

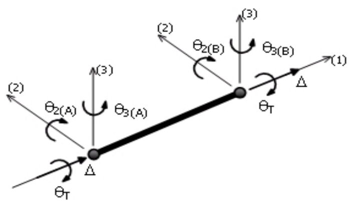


Fig. 1: Local degrees of freedom

The resulting element internal forces, Fig. 2, and element stiffness matrix are directly transformed into the global system of coordinates, allowing large geometric nonlinearity to be accounted for.

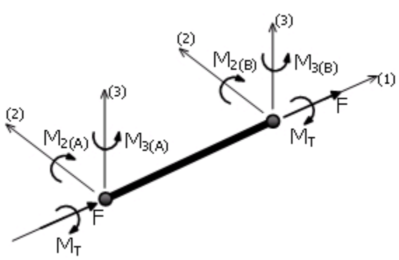


Fig. 2: Element internal forces

A constant axial strain shape function is assumed over the length of an element and therefore its application is only fully valid to model geometric nonlinearity of relatively short members. For this reason SeismoStruct propose that at least three to four elements should be used per member. Another important assumption to be taken into account is that shear strains are not modeled across an element cross section and therefore a Bernoulli flexure-only beam formulation is employed, as opposed to a Timoshenko flexure-shear beam model.

2.2. Material Inelasticity

Material inelasticity across an element section and length is taken into account by employing a fiber element approach. This enables the accurate representation of structural damage distribution.

The fiber modeling approach incorporated in the inelastic beam-column elements used by SeismoStruct consists of modeling the material inelasticity by dividing a section in various fibers. Each fiber in the section can be assigned a nonlinear uniaxial stress-strain response with the sectional stress-strain response of the member obtained by integrating the nonlinear behavior of the individual fibers. This subdivision of an element into fiber elements with different material nonlinearity is shown in Fig. 3

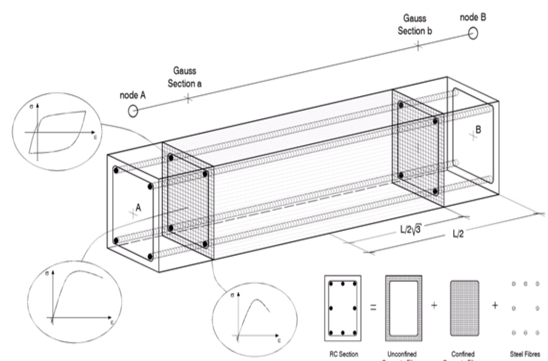


Fig. 3: SeismoStruct element modeling

2.3. Material Properties

Properties were prescribed for three main groups of material types: reinforcement steel, unconfined concrete, as well as confined concrete. The properties of confined concrete are highly dependent on the reinforcement detail of a section and for this reason different material properties were prescribed for the confined concrete of different sections.

2.4. Reinforcement Steel

SeismoStruct provides various material types with predefined response patterns.

A bilinear model including strain hardening was chosen to model reinforcement steel fibres, Parameters that are required to define the stress-strain characteristics of the steel model are summarized in Table 2.

Table 2: Reinforcement steel material properties

Property	Value
Modulus of elasticity (kpa)	2.1E+8
Yield strength (kpa)	350000
Strain hardening parameter	0.005
Specific weight (kN/m³)	78

2.5. Concrete Properties

As mentioned before, there are two types of concrete provided in SeismoStruct software;" confined and unconfined". Properties of the two types are summarized in Table 3 and Table 4 respectively.

Table 3: Confined concrete material properties

Property	Value
Compressive strength (kpa)	25000
Tensile strength (kpa)	0
Strain at peak stress (m/m)	0.002
Confinement factor	1.1
Specific weight (kN/m³)	25

Table 4: Unconfined concrete material properties

Property	Value
Compressive strength (kpa)	25000
Tensile strength (kpa)	0
Strain at peak stress (m/m)	0.002
Confinement factor	1.001
Specific weight (kN/m³)	25

2.6. Sections and Element Classes

Reinforced concrete sections were defined for column, shear wall and beam sections as well as slab sections.

Due to negative bending moments in the concrete slab at slab-column connections tension reinforcement is placed in the top layer of the slab at these locations. Between these slab-column connections, bottom tensile reinforcement is placed in the slab to resist positive bending moments resulting from gravity loads, so double layers of reinforcement were used according to Egyptian code.

“SeismoStruct” provides the user with various types of sections that can be used to model different structural elements. Table 5 shows the section types that were chosen for the various sections [6].

The coordinates and diameters of reinforcement bars are defined for each section according to the reinforcement layout of the relevant section.

3. SELECTED STRUCTURES

Five existing residential reinforced concrete structures in Egypt were selected to be studied in this paper in order to evaluate IDA curves using SeismoStruct program, Table6 summarize the characteristics of these structures. Flat slabs are used in these structures with columns and shear walls as supporting elements.

Table 5: Section types

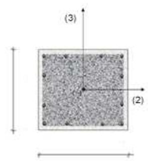
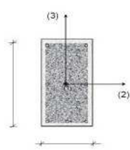
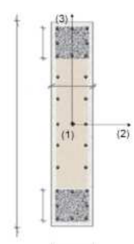
section	Section type	layout
Columns	Reinforced concrete rectangular section (rcrs).	
Slab	Reinforced concrete asymmetric rectangular section (rcars)	
Shear walls	Reinforced concrete flexural wall section(rcfws)	

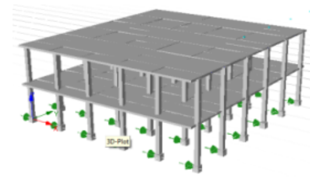
Table 6: Structures characteristics summary

Model label	No. levels
1	2
2	4
3	6
4	8
5	10

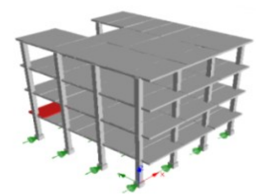
For all models, story height is 3 meters while spacing between columns in both X and Y directions is 4 meters.

All structures are designed according to the Egyptian code [7]. Analyses are performed using SAP 2000 program. All columns' bases are modeled as fixed supports.

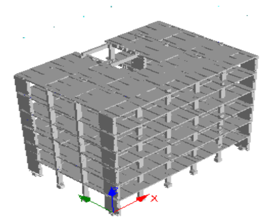
Fig. 4 shows the selected structures as they were modeled in SeismoStruct software. Fig. 5 shows the typical plan of structure No.3 as an example.



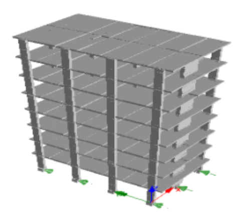
3D model of structure No.1



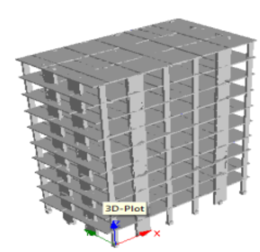
3D model of structure No.2



3D model of structure No.3



3D model of structure No.4



3D model of structure No.5

Fig. 4: 3D SeismoStruct models of selected structure No. 5

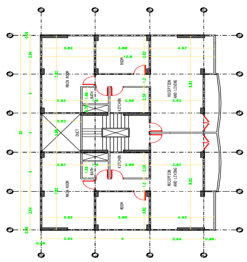


Fig. 5: Typical plan of structure No.3

3.1. Natural Periods and Mode Shapes

In order to understand the overall response of selected structures natural periods and mode shapes are obtained from eigenvalue analysis using SeismoStruct software, Table 7 summaries the time periods of selected structures.

Table 7: Time periods and mode shapes of selected structures

Model	Mode No.	Period (sec)	Individual Mode	Freq. rad/sec	
			Ux %	Uy %	
NO.1	1	1.551	0.00	82.48	4.05
	2	0.839	90.71	0.00	7.49
NO.2	1	0.630	83.00	0.00	9.98
	2	0.545	0.00	84.70	11.52
NO.3	1	0.790	81.50	0.00	7.95
	2	0.282	0.00	63.86	22.23
NO.4	1	0.930	71.03	0.00	6.76
	2	0.492	0.00	80.79	12.77
NO.5	1	1.263	0.00	75.49	4.97
	2	1.022	77.64	0.00	6.15

Fig. 6 shows the mode shapes of structure No.1 in both X and Y directions as an example.

4. STATIC PUSHOVER ANALYSIS

This type of analysis is performed In order to estimate the horizontal capacity of the selected structures. Models are subjected to nonlinear static pushover analysis using SeismoStruct software. Static triangular load distributions are applied to models at each floor then the top roof displacements versus total base shear or load factor is introduced in a chart named Pushover curve [8].

In SeismoStruct program the applied incremental load P is kept proportional to the pattern of nominal loads initially defined by the user then the load factor is automatically increased by the program until a user -defined limit, or numerical failure, is reached.

In this research the user-defined limit is the near collapse limit state at which the interstory drift equals 2.5% of the total building height. The numerical failure occurs when the convergence couldn't be obtained by the program.

Figs. 7 and 8 show the loading directions in SeismoStruct and the pushover curves respectively. The two curves are identical as the model is squared.

5- IDA

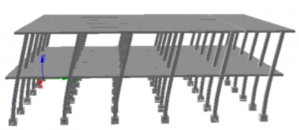
IDA curve gives a relationship between the maximum interstory drift ratio and the intensity of the ground motion. IDA gives better understanding of how the response of a structural system changes with the increase of the intensity of the ground motion [9]. Also, it gives an estimate of the overall structural capacity and its relationship with the structural demand. Moreover, IDA is considered the first step towards developing the fragility curves, which are used in the seismic risk analysis (Ibrahim and Mustafa M. El-Shami [10]).

Twelve earthquakes accelerograms were used in this study, these earthquake records were applied on the five selected buildings. These records were applied to the models in two directions (East-West and North-

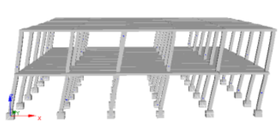
South directions); Table 8 summarizes the selected earthquakes.

Table 8: Details of ground motions [11]

No	Ground motion	t(sec)	Country	PGA
1	El Centro	50	San Diego	0.35 g
2	Northridge	60	Arleta and Nordhoff Fire	0.60 g
3	Parkfield	30	Cholame, Shan-	0.24 g
4	49 OLY	40	USA	0.28 g
5	Kern	55	Taft Lincoln School Tunnel, USA	0.16 g
6	Loma Prieta	40	Corralitos recording sta-	0.28 g
7	San Fer-nando	60	8244 Orion Blvd., USA	0.28 g
8	Kobe	50	Takatori	0.35 g
9	Chi-Chi longt	37	Unknown, Taiwan	0.36g
10	Friulli	20	Unknown, Italy	0.48 g
11	Hollister	15	City Hall, USA	0.12 g
12	Sakaria	20	TURKEY	0.63 g

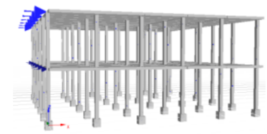


Y1 , T1 = 1.552 sec

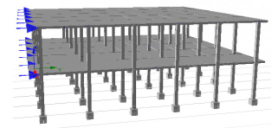


b) X1 , T3 = 0.839 sec

Fig 6: Mode shapes of structure No. 1

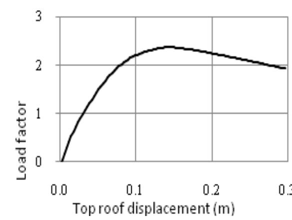


a) X-direction

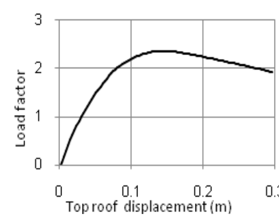


Y-direction

Fig. 7: Loading distribution on each floor of structure No.1, as an example.



X-direction



Y-direction

Fig. 8: Pushover curves for structure No.1, as an example.

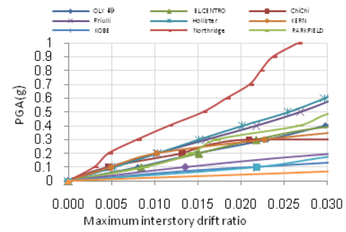
IDA curves show wide range of behavior with large variation from record to another, that is obvious in Figs. 9 and 10 show different structural behaviors (softening, hardening and resurrection) respectively, In Fig. 10-(a) structure No.5 shows softening structural behavior under Loma Prieta earthquake, while some hardening was noticed in other cases, such as the behavior of structure No.2 structure under Kern earthquake as shown in Fig. 10-(b). Another behavior, called structural resurrection, was observed in some cases, such as the response of structure No.5

under Parkfield earthquake, as shown in Fig. 10-(c). The structure encountered global instability at PGA of around 0.64 g, while it was resurrected at PGA of 0.78 g. Although the structure performed well again at higher PGA up to 0.95g, for safety the structural failure is considered at 0.64 g, which is the earliest structural instability.

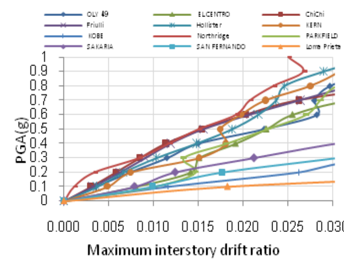
According to IDA curves obtained in this research, the increase of number of floors the better seismic performance under different earthquakes.

For all structures, In order to better assess the structural performance of these structures under different ground motions, four performance levels were considered. The vertical gridlines on each curve at maximum interstory drift ratio of 0.002, 0.005, 0.15 and 0.025 represent performance level of fully operational, operational, life safe, and near collapse respectively.

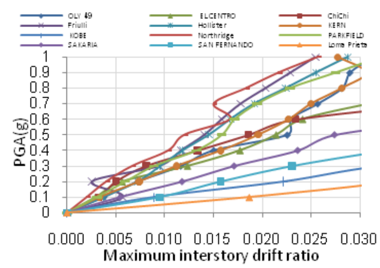
Structures are not fully operational under all records for PGA higher than 0.07g, 0.16g, 0.12g, 0.11g, and 0.12g, for structure No.1, 2, 3, 4, and 5 respectively, Also Structures are not operational under all records for PGA higher than 0.21g, 0.24g, 0.25g, 0.24g, and 0.33g, for structure No.1, 2, 3, 4, and 5, respectively. While life is not safe in all structures under all records for PGA higher than 0.48g, 0.51g, 0.56g, 0.71g, and 0.78g, for structure No.1, 2, 3, 4, and 5 respectively, Moreover all structural elements suffer severe damage and near to total collapse under all records for PGA higher than 0.94g, 0.84g, 0.98g, 1.2g, and 1.42g, for structure No.1, 2, 3, 4, and 5 respectively.



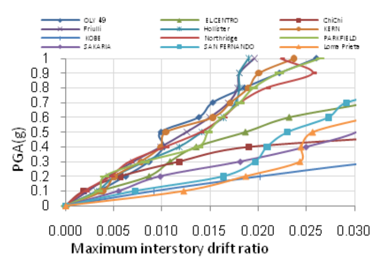
a) IDA curves for structure No.1



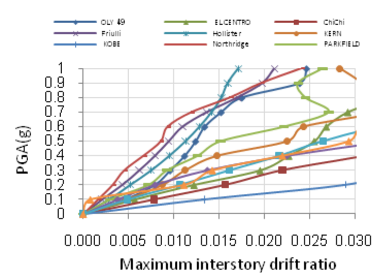
b) IDA curves for structure No.2



c) IDA curves for structure No.3

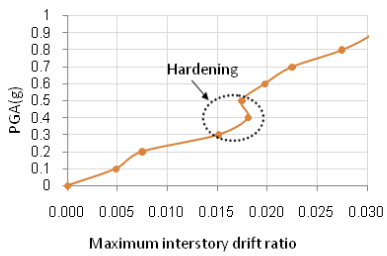


d) IDA curves for structure No.4

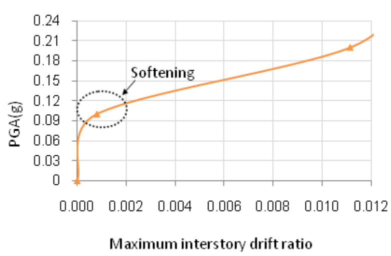


e) IDA curves for structure No.5

Fig. 9: IDA for structures 1, 2, 3, 4 and 5



a) Structural hardening (structure No.2 under Kern earthquake)



b) Structural softening (structure No.5 under Loma Prieta earthquake)

c) Structural resurrection (structure No.5 under Parkfield earthquake)

Fig. 10: Different structural behavior obtained in IDA curves

For all ground motions, structures reached fully operational limit for PGA less than 0.1g, 0.1g , 0.1g, 0.02g, and 0.02g for structure No.1, 2, 3, 4, and 5, respectively, also structures reached operational limit for PGA less than 0.02g, 0.03g , 0.03g, 0.04g, and 0.05g for structure No.1, 2, 3, 4, and 5, respectively, while structures reached life safe limit for PGA less than 0.04g, 0.08g , 0.09g, 0.13g, and 0.11g for structure No.1, 2, 3, 4, and 5, moreover structures reached near collapse limit for PGA less than 0.06g, 0.11g , 0.13g, 0.23g, and 0.25g for structure No.1, 2, 3, 4, and 5 respectively.IDA curves for structure No.5.

6. CONCLUSIONS

Five structural 3D models 2, 4, 6, 8, and 10-story reinforced concrete structures were selected to represent mid-rise residential flat-slab buildings located in Egypt. The structures were designed according to the Egyptian code of practice for loads and earthquakes in structural work for seismicity zone 3. The structures were subjected to twelve real records of historic earthquakes. These records were scaled incrementally to investigate the elastic, inelastic behavior and the dynamic instability of the structures under the chosen earthquakes with different intensities [11]. IDA curves with four main performance limits (fully operational, operational, life safe, and near collapse) are shown for each structure under different selected ground motions. According to the results obtained, the following observations, conclusions and recommend-dations were obtained:

IDA curves showed wide range of behavior with large variation from record to another. Some cases showed softening structural response, however others showed hardening structural response. Another behavior, called structural resurrection, was observed in some cases.

For relatively short structures, such as structure No.1 and 2, the performance under ground motions was not satisfactory. The Fully operational limit was obtained at low values of PGA values, the 2-story and 4 -story structures had a fully operational limit at PGA values less than 0.1g and under all ground motions, which is a small value from the structural and economical point of view. Moreover, structure No.1 and 2 reached other damage limits at lower values than the other structures.

Generally, the response of structure No.3 (6-story), No.4 (8-story), and No.5 (10-story), showed better performance under the majority of earthquakes.

More ductile behavior is recommended for structures designed according to the Egyptian code of practice for loads and earthquakes in structural work in order to have better performance under earthquakes. Important structures constructed recently in Egypt, such as malls, financial and entertainment centers should be designed to have both fully operational and operational limits at relatively higher maximum interstory drift ratio in order to minimize the economic losses after earthquakes.

REFERENCES

1. Y. E. Ibrahim. “Performance limits of mid-rise moment-resisting framed structures in low-seismicity areas” 11th Arab Structural Engineering Conference (11th ASEC) 25-27 October, 2009, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.
2. Dimitrios Vamvatsikos and C.Allin Cornell. ” Incremental dynamic analysis” Journal of Earthquake Engineering and Structural Dynamics, Vol. 31 (3), 2002, 491-514
3. Matthew E. Bowers," Seismic fragility curves for typical highway bridge in Charleston, SC considering soil-structure interaction and liquefaction effects", the Graduate School of Clemson University, 2007.
4. SEAOC, Vision 2000 Performance Based Seismic Engineering of Buildings, San Francisco, April 1995.
5. SEISMOSOFT, SeismoStruct Ver. 5.0.4 - A computer program for static and dynamic nonlinear analysis of framed structures, (2010): SeismoSoft, Earthquake Engineering Software Solutions, Italy,(www.seismosoft.co).
6. Johann Eduard van der Merwe, " Rocking shear wall foundations in regions of moderate seismicity", University of Stellenbosch, (2009).
7. The Egyptian Code of practice and design for loads and Earthquakes in structural work (2008).
8. Mary Beth D. Hueste, Jong-Wha Bai, “Seismic retrofit of a reinforced concrete flat-slab structure: Part II — seismic fragility analysis”, Engineering Structures (2006), doi: 10.1016/j. engstruct. 2006.07.022.
9. Kratzig, W.B., Meyer, I.F. and Meskouris, K., 1989, " Damage evolution in reinforced concrete members under cyclic loading", Proc. of the 5th International conference on Structural safety Reliability (ICOSSAR89), San Francisco, CA. , USA., II, 759-802.
10. Yasser E. Ibrahim and Mostafa M. El-Shami, 2011. Seismic fragility curves for mid-rise reinforced concrete frames in Kingdom of Saudi Arabia. The IES Journal Part A: Civil & Structural Engineering, Vol. 4, Issue 4, pp. 213-223.
11. PEER Strong Motion Database. University of California, Berkeley. Available from URL: http://peer.berkeley.edu/smcat/search.htm.