UNIVERSITI PUTRA MALAYSIA

EVALUATION OF IDEALIZED CAPACITY CURVE GENERATION FOR REINFORCED CONCRETE FRAMED-STRUCTURES SUBJECTED TO SEISMIC LOADING

MEHRDAD SEIFI

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By

MEHRDAD SEIFI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

September 2008

DEDICATION

Dedicated to my parents and my brother owing to their precious support during my studies

EVALUATION OF IDEALIZED CAPACITY CURVE GENERATION FOR REINFORCED CONCRETE-FRAMED STRUCTURES SUBJECTED TO SEISMIC LOADING

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September 2008

Chairman : Associate Professor Jamaloddin Noorzaei, PhD

Faculty : Engineering

The designing of R/C framed structures subjected to seismic excitation generally is performed by linear elastic method, while current trend of the codes of practice is moving toward increasing emphasis on evaluating the structures using nonlinear static pushover (NSP) approaches. Recently, several NSP approaches, with varying degree of vigor and success have been proposed. In this study, initially a comparative study has been made among different nonlinear static methods for adopting the most suitable method of extracting the capacity curve of R/C framed structures. Then, a program was developed to overcome the difficulties of graphical iterative procedure of idealization proposed by FEMA-356.

Subsequently, the comparative tool which is a combination of the superior NSP method detected and the developed program was used to investigate the effects of significant structural variables on idealized parameters of capacity curves of population of R/C framed structures. Eventually, the applicability of replacing the time-consuming NSP procedure by ANN for deriving the capacity curve was tested. The outcomes demonstrated the outperformance of interstorey-based scaling adaptive pushover in

addition to high precision of the developed program. Furthermore, the distinct effects of each one of the considered structural variables on idealized parameters were unveiled. Finally, an acceptable performance of ANN as an alternative to NSP procedure was observed.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENILAIAN DALAM PENGHASILAN KAPASITI LENGKUNGAN DIIDEALKAN UNTUK STRUKTUR KONKRIT-BERSANGGA DIDEDAHKAN KEPADA GELOMBANG

Oleh

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Pengerusi: **Professor Madya Jamaloddin Noorzaei, Ph.D.**

Fakulti: **Kejuruteraan**

Rekaan struktur konkrit bersangga berdasarkan rangsanagn gempa biasanya terbentuk daripada kaedah *linear elastic method* , sementara itu pendekatan sekarang mengenai kod proktis sentiasa meningkat kehadapan dengan menekankan pengukuran struktur menggunakan kaedah *nonlinear static pushover (NSP).* Terbaru, beberapa kaedah NSP dengan pelbagai sudut vigor telah mencapai kejayaan. Dalam kajian ini , biasanya kajian perbandingan telah dibuat dikalangan kaedah 'non linear static method' yang berbeza untuk memilih kaedah yang paling sesuai dalam meningkatkan kapasiti lengkuk struktur konkrit bersangga. Seterusnya program telah dibina untuk mengatasi masalah *graphical interactive procedure* yang dicadangkan oleh FEMA-356.

Selepas itu , alat perbandingan yang mengandungi kombinasi kaedah NSP telah dikesan dan program tersebut telah digunakan untuk menyiasat kesan perubahan pada struktur berdasarkan populasi parameter lengkung keupayaan struktur konkrit bersangga. Kesudahannya, keterapan perubahan prosedur pengukuran masa NSP daripada

ANN untuk mengukur kapasiti lengkungan telah diuji. Keputusan yang ditunjukkan daripada keupayaan program inter storey based scaling pushover yang dibina mempunyai ketepatan yang tinggi. Sebagai tambahan, kesan berlainan pada pelbagai struktur pada parameter dapat dilihat. Akhir sekali, keupayaan ANN sebagai alternative pada prosedur NSP diiktiraf atau diterimapakai.

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Allah, the dominion of the heavens and the earth belongs to him. No son has he be gotten nor has he a partner in his dominion. It is he who created all things and ordered them in due proportions (Holly Quran 25:2).

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I certify that an Examination Committee met on 14 July 2008 to conduct the final examination of Mehrdad Seifi on his Master of Science thesis entitled "Evaluation of Idealized Capacity Curve Generation for Reinforced Concrete-Framed Structures Subjected to Seismic Loading" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the student be awarded the Master of Science.

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Date: 11 September 2008

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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MEHRDAD SEIFI

Date: 22 September 2008

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LIST OF ABREVIATIONS

α	Learning rate on neural network, a positive constant less than unity
αK_e	Post-yield stiffness of structure
β	Momentum term in neural network
Γ_j	Modal participation factor of the j th mode
$\Delta\lambda_0$	Initial step increment in load factor of adaptive pushover
$\delta_k(P)$	Error gradient
Δ_M	Storey drift ratio in j th floor
ΔP	load increment vector in adaptive pushover
Δ_W	Difference of displacement of two consecutive floors
Δw_{jk}	Weight corrections" related to output layer of a neural network
ε_c	Strain at peak stress for concrete
θ_j	Threshold on neuron j
λ	Load factor of adaptive pushover
μ	Strain hardening parameter of steel
ξ	Damping ratio
ϕ	Size of applied reinforcement
ϕ_j	Modal shape
a_1 & a_2	Transition curve shape calibrating coefficients of steel
a_3 & a_4	Isotropic hardening calibrating coefficients of steel

D_{ij}	i th storey displacement due to j th mode
E_s	Modulus of elasticity of steel
f_c	Compressive strength of concrete
f_i	Storey safety
f_t	Tensile Strength of concrete (or) Total reduction factor
F_i	Proportion of load of each storey
F_t	Whiplash effect
F_y	Yielding strength of reinforcement
$\overline{F}$	Normalized scaling vector in adaptive pushover
$\overline{F_i}$	Calculation of relative values of story forces
h_i	Height of i th floor above the base.
I_g	Gross moment of inertia
k_e	Confinement factor of concrete
K_e	Effective lateral stiffness of structure
P_0	Nominal counterpart of load vector in force based adaptive pushover
R_o	Transition curve initial shape parameter of steel
$S_a(j)$	Spectral amplification of the j th mode
T_1	Fundamental natural vibration period of structure in second
V_b	Base shear of structure
w_i	Weight of the i th floor

$V_{intersect}$	Base shear at the intersection point between idealized and main curve
V_{max}	Maximum base shear among all coordinates in capacity curve
V_y	Effective yield strength of structure
w_{ij}	Preliminary weight of input i for neuron j
$X_{intersect}$	Displacement at the intersection point between idealized and main curve
$x_{i,s}$	Standardized variable value for p th model
x_{max}	Maximum value of the specific variable among all models
x_{min}	Minimum value of the specific variable among all models

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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December 2007

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Under different circumstances various approaches starting from simplistic linear static to the accurate but cumbersome, time-consuming nonlinear time-history procedure are applicable for analysis of buildings. Performance-based design engineering (PBDE) as one of the major domains in earthquake engineering, is concerned with performance evaluation of structures under seismic excitation. Nonlinear static pushover (NSP) as main product of PBDE is compromise of simplicity and accuracy has been legitimatized and found its way into codes such as Federal Emergency Management Agency (FEMA), Eurocode… One of the momentous outcomes of this method is capacity curve, declares the relating between base shear force and lateral displacement of control node.

The conventional pushover method applying in real-life engineering relies on incremental pushing the structure with constant distribution of lateral load that is not exempt of error. Several methods have been proposed to overcome its deficiencies by the researchers. By criticizing them adaptive pushover analysis (APA) that considers all deficits of conventional method seems to be more logic. Although, various

techniques have been suggested for pushover analysis, there is solidarity for bilinearization and extraction of idealized parameters based on iterative graphical method of FEMA. Moreover, parallel to evolution of pushover analysis procedure they become more rigorous. Consequently, applications of artificial neural network (ANN) as an alternative for solving PBDE problems have been noted recently. This study focused on R/C regular 2D frames by extensive comparative study among five alternatives of conventional and adaptive pushover, codifying a program to overcome deficiencies of graphical iterative bilinearization method, study on effect of structural variables on idealized parameters and just testing this issue that whether it is applicable to use ANN as replacement of pushover for idealization.

Along the line of study, preliminary static analyze, designing and detailing, finite element modeling including physical and material modeling as close as possible to practical structure have been done for 30 case studies. Then, procedure of loading a case study by five various conventional and adaptive pushover procedure and also incremental dynamic analysis (IDA) as reference were implemented and an comprehensive comparative study procedure in aspects of capacity curve and interstorey drift evaluation has been made. Developing a program for accurate bilinearization and overcoming the deficiency of graphical iterative procedure of FEMA was the next stage. Achieving a comparative tool as combination of best NSP method and the developed program results in extensive course of actions for application of this tool for 30 created different models. Eventually, feed forward back propagation method process as a prevalent type of ANN have been studied for testing its applicability for replacing outstanding NSP method of deriving capacity curve.