ENG Transactions

Journal homepage: http://www.engtransactions.com

ENG Transactions, vol. 3, pp. 1-9, August 2022
ID: ENGT-2208102112805

Research Article

A Comparison of Different Linear and Non-linear Structural Analysis Methods

Hasan Dilek *, Ali Sadeghpour

Civil Engineering Department, European University of Lefke, Lefke, Mersin 10, N. Cyprus, Turkey

Keywords

Structural, Analysis, Modellings, Static, Dynamic, Pushover.

Abstract

The research compares the structural analyses discussed by mathematical modeling with those addressed by structural approaches. It discusses Eigenvalue Analysis, Static Pushover Analysis, Static Adaptive Pushover Analysis, Static Time-History Analysis, Dynamic Time-History Analysis, Incremental Dynamic Analysis (IDA), Response Spectrum Analysis (RSA), and Buckling Analysis. Structural limitations, brief or extensive information about the structure, as well as the result of the output approach, have a major impact on the selection of the structural analysis method. In this research, by examining each analytical method, their different characteristics are discussed.

1. Introduction

Completing a nonlinear analysis requires a number of key concerns to be addressed, as well as various improvements to reduce the computational load. We review the principles of this approach, walk the reader through a practical example of its application, and discuss the tools we use to automate the calculations required for an analysis (such as IDA). Response spectrum analysis (RSA) is a popular tool for building design. This approach is a simplified version of modal analysis, i.e., response history (or time history) analysis (RHA) using modal decomposition, which uses properties of the response spectrum concept. The purpose of this method is to provide a quick estimate of the peak response without the need to analyze the response history. This is important because RSA relies on a quick and simple sequence of calculations, while time history analysis needs solving the differential equation of motion over time. Despite its imprecise nature, this approach is very valuable because it allows the use of the response spectrum, which is a very easy way to characterize the seismic hazard. Since seismic loading is characterized by a response spectrum, RSA is of particular interest to practicing engineers.

* **Corresponding Author:** Hasan Dilek
E-mail address: 21170039@std.eul.edu.tr

Academic Editor: Mohammad Nikookar

Received: 15 June 2022; **Revised:** 4 August 2022; **Accepted:** 10 August 2022
https://doi.org/10.52547/engt.3.2208102112805

Citation: H. Dilek, A. Sadeghpour, "A comparison of different linear and non-linear structural analysis methods," *ENG Transactions*, vol. 3, pp. 1-9, August 2022.

There are nine types techniques of structural dynamics mentioned in the study. They are Eigenvalue Analysis, Static Analysis (non-variable loading), Static Pushover Analysis, Static Adaptive Pushover Analysis, Static Time-History Analysis, Dynamic Time-History Analysis, Incremental Dynamic Analysis – IDA, Response Spectrum Analysis – RSA and Buckling Analysis.

2. Different Type of Analysis Methods

2.1. Eigenvalue Analysis

By explaining the typical equation consisting of a mass matrix and a stiffness matrix, eigenvalue analysis offers dynamic features of a structure. Natural modes (or mode shapes), natural periods (or frequencies), and modal participation factors are among the dynamic features [1-2]. There are two fundamental techniques to modal analysis. The study of eigen-problems is produced by the definition of the eigenvalues and eigenvectors. The creation of basis vectors is the second technique. It is based on E.L. Wilson's Load Dependent Ritz Vectors technique, which was implemented in SAP2000. This method is used in seismic analysis and is effective when getting significant mass percentages is challenging. Selective orthogonalization, block subspace iteration (BLSI), subspace iteration (SI) when direct solvers (skyline or SPDS) are used, Lanczos and basis reduction are applied. The process of subspace iteration is generally slow. When a high number of Eigen pairs is required, using BLSI or Lanczos is strongly suggested for the study of medium-sized and especially large-scale issues. For a professional engineer, basis reduction can be quite effective; however, it need extra information concerning basis nodes and proper basis directions [3-5].

2.2. Static Pushover Analysis

Pushover analysis is a static procedure that assessments seismic structural deformations using a reduced nonlinear performance. During seismic activity, structures re-design themselves. The dynamic forces on a structure are stimulated to other components as specific components of a structure yield or fail. A pushover study repeats this phenomena by applying loads up to the weak link in the structure is exposed, then changing the model to account for the structural changes caused by the weak link. The redistribution of the loads is seen in a second iteration. The structure is "pushed" once again until a second weak connection is originate. This approach is repeated until a yield form for the whole structure is found under seismic stress. Pushover analysis is a classic method for determining the seismic capacity of existing structures, and it is specified in various current guidelines for seismic retrofit design. It can also help with performance-based design of new structures that rely on ductility or redundancy to withstand seismic effects [6-8].

To evaluate seismic demands, estimated nonlinear static procedures (NSPs) are becoming more widely held in engineering practice. In reality, certain seismic codes, such as the Eurocode and the Japanese Building Code, have begun to integrate them to support in structural system performance assessment. Although Nonlinear Time-History (NTH) studies are optimal for estimating seismic demands, NSPs are utilized in everyday engineering presentations to avoid the problems of picking ground movements and the increased calculating work required by NTH models. However, it is now extensively acknowledged that simplified procedures based on consistent load patterns are insufficient to predict inelastic seismic demands in buildings when modes other than the first contribute to the response and inelastic effects change the height-wise distribution of inertia forces. A variety of developed approaches based on different loading vectors (derived from mode shapes) have been developed to solve some of these deficiencies. These techniques employ elastic modal combination rules to accommodate for higher mode effects while still using invariant load vectors. For example, the Multi-Mode Pushover (MMP) takes into account several pushover curves produced from various modal force patterns. This method is also used in the Modal Pushover Analysis (MPA) and Upper-Bound Pushover Analysis (UBPA) procedures. Adaptive pushover procedures are another type of improved pushover method, in which the load vectors are changed over time to account for changes in system modal properties during the inelastic phase. Using instantaneous mode shapes, comparable seismic loads are estimated at each pushover stage in this approach. The lateral loads that are supplied to the structure in each mode are scaled using the relevant elastic spectral accelerations. Several alternative adaptive load pattern-based force or displacement-based pushover processes have also been presented. Other alternative methods for pushover analysis include using story forces proportional to the deflected shape of the structure or developing force patterns based on mode shapes derived from the secant stiffness at each load step, or using methods where deformation levels and/or stiffness state determine the load pattern, such as using story forces proportional to the deflected shape of the structure or developing force patterns based on mode shapes derived from the secant stiffness at each load step [9-14].

2.3. Static Adaptive Pushover Analysis

The impacts of higher modes and changes in dynamic qualities are taken into account in adaptive pushover analysis. SAP 2000, ETABS, MIDAS, and other standard software products are examples [15-16]. One of the main problems of traditional nonlinear static methods in present guidelines and codes is that they use a constant lateral load form during the study, which means that changes in the structure's modal properties aren't taken into account. Consequently, when the building behaves nonlinearly and the structure's modes and stiffness matrix are adapted, the analysis continues with the initial lateral load form. As a result, several academics have developed the adaptive load pattern in new years in an attempt to address the above-mentioned shortages. At each loading phase, the applied loading pattern is altered and tailored in accordance with the structure's modal characters. It involves that, unlike traditional pushover procedures, in which the structure is pushed to the target displacement in a single step with a constant load pattern, in the Adaptive Pushover analysis, the structure is pushed to the target displacement in multiple steps with a new load pattern (calculated using the structure's modal characteristics in the same step) applied at each step. Two novel approaches have been examined: SAP (Story Shear-based Adaptive Pushover) analysis and Code A-lateral load distribution-based Adaptive Pushover analysis. To simplify the procedure, the adaptation of lateral load was limited in some selected phases when the structure practiced considerable nonlinear deformation, based on the fact that the structure behaved mostly in the linear range in the first steps. To classify these phases, a non-adaptive push-over analysis is done first, and then the adaption steps are sensibly proven using the performance curve that resulted. Its means noting that the loading pattern attained at each adaption stage is maintained until the following adaption step [17-24].

2.4 Static Time-History Analysis

Time history analysis is quite popular in stress analysis as it provides the most realistic specification of dynamic loads. Accordingly, when the distinction between modes is not clear or nonlinear analysis is required, the Time History Analysis method is used to calculate the actual behavior (displacement, member forces, etc.) of the structure at any given time using the dynamic characteristics of the structure and the external forces applied. The 'Mode Superposition Method' and the 'Direct Integration Method' are two time history analysis approaches. When used for seismic analysis, time history analysis is a precise approach for determining the behavior of a building when the change in ground motion induced by an earthquake over time is known; nevertheless, it has the drawback of being difficult to precisely anticipate the predicted ground motion. The response spectrum analysis approach is more generally used in seismic analysis, as described above, and the time history analysis method should be utilized for railway bridge dynamic analysis, which involves periodic loads. The time variable is particularly essential in time history analysis. The analysis time should be sufficient for the train to pass entirely across the bridge from beginning to end. Because the time interval is a variable that has a big impact on the accuracy of analysis findings that are directly tied to the period of the higher-order mode and the period of the load, it's important to double-check the values given by the design criteria or the structural analysis software [25-27].

Direct Integration Method: When the behavior at one point in time is acquired, a technique of getting the structure's behavior for an entire time interval is achieved by continuing the process of obtaining the structure's behavior at the next point in time [28-29].

Mode Superposition Method: By splitting the structure's behavior into the behavior of each mode and superimposing the responses in all modes, a theoretically correct response time history analysis may be obtained [30-31].

2.5. Dynamic Time-History Analysis

A time history analysis is a step-by-step examination of a structure's dynamic reaction to a defined loading that may change over time. The seismic response of a structure under dynamic loading of a typical earthquake is determined using time history analysis [32]. The linear or nonlinear evaluation of dynamic structural reaction under loads that varies according to the defined time function is possible using time-history analysis. The modal or direct-integration methods are used to solve dynamic equilibrium equations. Initial conditions can be established by continuing the structural state from the prior analysis' conclusion. The following are some more notes [33-34]:

Step Size — Direct-integration methods are sensitive to time-step size, which should be reduced until no difference in results is observed.

HHT Value - This is a somewhat negative value. To dampen higher frequency modes and enhance convergence of nonlinear direct-integration solutions, the Hilber-Hughes-Taylor alpha value is also recommended.

Nonlinearity — during nonlinear direct-integration time-history analysis, material, and geometric nonlinearity, including P-delta and large-displacement effects, may be modelled.

Links — during modal (FNA) applications, link objects capture nonlinear behavior [35-37].

2.6. Incremental Dynamic Analysis – IDA

Incremental dynamic analysis (IDA) is a parametric analysis method that has recently emerged in several different forms to estimate more thoroughly structural performance under seismic loads. It involves subjecting a structural model to one (or more) ground motion record(s), each scaled to multiple levels of intensity, thus producing one (or more) curve(s) of response parameterized versus intensity level [38]. Vamvatsikos and Cornell [38] used various interpolation spline functions to simulate their IDA curves in a prior work. Such an estimate is thought to be inconvenient and ineffective for risk assessments in the future. As a result, numerous single functional relations were investigated, with the Ramberg-Osgood (R-O) equation emerging as the most appropriate. By doing a combined least squares analysis on interpolated 10th, 50th, and 90th percentile curves, a suitable value of r is determined, and the additional parameters K and I_{MC}, as well as their related dispersions K and I_{Mc}, are discovered. For one specific scenario, it shows the fit between the actual IDA data points and the fitted R-O curve [39-42].

2.7. Response Spectrum Analysis – RSA

Response spectrum analysis is a method to estimate the structural response to short, nondeterministic, transient dynamic events. Examples of such events are earthquakes and shocks. Since the exact time history of the load is not known, it is difficult to perform a time-dependent analysis. Due to the short length of the event, it cannot be considered as an ergodic ("stationary") process, so a random response approach is not applicable either. The response spectrum method is based on a special type of mode superposition. The idea is to provide an input that gives a limit to how much an eigen-mode having a certain natural frequency and damping can be excited by an event of this type [43-44].

Three "analysis techniques" are available to conduct the RSA:

• Technique 1, "Vary Mass": The SDOF elastic stiffness is held constant for each analysis, while the SDOF mass, M, and damping ratio, C, are recalculated each time depending on the initial stiffness, K, and the period under consideration.

• Technique 2: "Vary stiffness while maintaining F_y": In this method, the SDOF mass, M, is maintained constant while the system's elastic stiffness and yield displacement are modified. As a result, based on the revised K_e, the stability coefficient is modified. The yield force, as well as the other previously stated backbone parameters, are kept constant in this manner. As a result of the revised yield displacement, the backbone curve has been changed.

• Technique 3, "Change Stiffness but Maintain y": In this method, the SDOF mass, M, is maintained constant while the elastic stiffness and yield strength of the system vary. As a result, the stability coefficient changes depending on the new K_e. The yield displacement and the remainder of the previously determined backbone parameters are kept constant in this procedure [45-50].

2.8. Buckling Analysis

Buckling Analysis is a finite element analysis technique that can address any buckling issues that cannot be solved by human computations. The most frequent Buckling Analysis is Linear Buckling Analysis (LBA). Nonlinear Buckling, on the other hand, provides more stable results than Linear Buckling [51-52].

3. Comparison of Different Methods

Within the case of the evaluation technique way, computing comprehensive structural characteristics calls for additional study, which is normally best viable through the use of the software. This factor is inadequately addressed in structural codes, and as an end result, the practicing engineer bears complete obligation. Additionally, the calculated elastic essential values are normally crucial and significantly effect the final stability layout result. The ability of eigenvalue evaluation for the computation of elastic essential values is examined in many papers from the attitude of well-known stability design in step with EN 1993-1-1, the maximum new edition. Various application strategies tailored to one of a kind layout strategies are supplied, and unique indicator variables representing the importance of the selected sort of eigenvalue evaluation are formulated. A utility example determines how the numerous methods reason in exercise [53-54].

The maximum significant sources that have given a simple nonlinear static analysis method that might be utilized to evaluate the dynamic needs placed on structures for the duration of an earthquake episode are FEMA356, ATC40, and vision 2000. As an end result, nonlinear processes are being given growing interest because they may provide a greater particular assessment of the demands created in various structural parts beneath earthquake loading than some other linear technique now to be had. The most particular approach of comparing those demands is nonlinear dynamic evaluation of state-of-the-art mathematical models of systems exposed to site-unique earthquakes. However, for the time being, such a technique isn't always possible for ordinary design usage. Simplified inelastic approaches appear to be the most practical analysis and overall performance assessment techniques for actual applications at the moment. As a result, nonlinear static approaches are gaining reputation as simple yet effective methods of comparing seismic needs in structures. In fact, the newly followed regulations for seismic design or retrofitting of structures are supposed to give professional engineers a few simple guidelines to comply with in their ordinary work. In the full-size majority of situations, this will obviate the requirement for an advanced linear or nonlinear time-history analysis of multi-story buildings. However, the introduction of such protections need to be based on a sensible method to assembly the structural seismic design requirements. The shortcomings of past seismic codes, as highlighted by using recent large earthquakes, should be taken under consideration in the advent of any new seismic code. Latest works have counseled, constructed, and analyzed nonlinear static analysis techniques in a spread of forms. A structural model with nonlinear fabric traits is displaced to aim displacement under monotonically increasing lateral pressure in this method. The demand for numerous structural factors is as compared to their relevant capacities due to such an evaluation [55-56].

As an end result, it is a reasonably truthful approach for estimating the nonlinear behavior of systems. First, a version to the traditional pushover evaluation is usually recommended wherein the lateral load sample has computed the use of the structure's first mode form and effective modal mass. Then, as the plastic hinges are produced inside the structure, every other method is used to modify the lateral load pattern for the duration of the analysis. Now not most effective does the cautioned adaptive approach automate the pushover evaluation, however, it also complements its efficacy in looking forward to gadget demand parameters. To evaluate the accuracy of different load patterns and to demonstrate the efficacy of the cautioned adaptive pushover evaluation, a numerical example is hired. Non-linear evaluation of strengthened frame systems research to this point has relied on finite element fashions produced the use of the stiffness method.

The fourth is to examine static nonlinear analysis and time history analysis utilizing flexibility-based totally finite elements according to Eurocode 8, as well as a sensitivity investigation of the time records analyses to seismic factors, the usage of a 3D model of an existent bolstered concrete building. Due to multiplied urbanization and population increase the world over, there is a big call for tall constructing development, and earthquakes have the ability to do the most harm to large structures. Due to the fact, that earthquake forces are random and unexpected, engineering techniques for assessing buildings underneath the impact of these forces ought to be refined. Earthquake loads need to be thoroughly studied so as to investigate the real conduct of a shape, with the awareness that damage is to be predicted but must be controlled. For the final numerous decades, analyzing the structure for diverse earthquake intensities and testing for many criteria at each stage has emerged as a necessary project [57-59].

Earthquakes create various levels of shaking in exceptional regions, as well as varying degrees of damage to systems in unique sites. As a result, it is required to construct a shape that is earthquake resistant at a specific intensity of shaking, in preference to the importance of an earthquake. Even if earthquakes of identical significance occur, their energy varies, resulting in differing devastating effects in numerous areas. As an end result, modifications in seismic behavior of multistory RCC body buildings for diverse seismic intensities in phrases of diverse reactions along with lateral displacement and base shear have to be investigated. Under exceptional earthquake intensities, it's far crucial to understand the seismic conduct of structures with the same layouts.

4. Conclusions

The study aimed to compare different types analysis methods such as Eigenvalue Analysis, Static Analysis (non-variable loading), Static Pushover Analysis, Static Adaptive Pushover Analysis, Static Time-History Analysis, Dynamic Time-History Analysis, Incremental Dynamic Analysis – IDA, Response Spectrum Analysis – RSA and Buckling Analysis. The analyses are applied in many different studies. Recent seismic design algorithms permit engineers to calculate design forces and displacements using both linear and nonlinear analysis. Simplified static analysis, modal analysis, nonlinear pushover analysis, and nonlinear time-history analysis are some of the four methods of assessment comprised in Eurocode 8. These techniques are used to design and analyze framed systems like buildings and bridges. To be absolutely usable through design engineers, the nonlinear methodologies require sophisticated fashions and advanced nonlinear approaches.

Conflict of Interest Statement

The authors declare no conflict of interest.

References

[1] A. Martin, and D. Gregory, "Structural topology optimization of tall buildings for dynamic seismic excitation using modal decomposition," *Engineering Structures*, vol. 216, p. 110717, Aug. 2020.

[2] Y. Lin, N. Zhen-Hua, and M. Hong-Wei, "Mechanism of principal component analysis in structural dynamics under ambient excitation," *International Journal of Structural Stability and Dynamics*, vol. 20, no. 12, Nov 2020.

[3] A. Tsipianitis, and Y. Tsompanakis, "Impact of damping modeling on the seismic response of base-isolated liquid storage tanks," *Soil Dynamics and Earthquake Engineering*, vol. 121, pp. 281-292, Jan 2019.

[4] I. Ojalvo, "Proper use of Lanczos vectors for large eigenvalue problems," *InAdvances and Trends in Structures and Dynamics*, vol 1, pp. 115-120, Jan 1985.

[5] K. Ikramov, "The CMV Matrix and the Generalized Lanczos Process," *Journal of Mathematical Sciences*, vol. 232, no. 6, pp.837-43, Aug 2018.

[6] A. Sadeghpour, G. Ozay, "Evaluation of Seismic Design Parameters for Reinforced Concrete Frames Retrofitted using Eccentric Steel Bracings, Computational Research Progress in Applied Science & Engineering," *CRPASE: Transactions of Civil and Environmental Engineering*, vol. 6, pp.173-178, 2020.

[7] M.A. Khan, "Earthquake-Resistant Structures: Design, Build, and Retrofit," *Butterworth-Heinemann*, 2013.

[8] A. Sadeghpour, G. Ozay, "Evaluation of reinforced concrete frames designed based on previous Iranian seismic codes*," Arabian Journal for Science and Engineering*, vol.45, no. 10, pp.8069-85, Oct 2020.

[9] A. Sahraei, F. Behnamfar, "A drift pushover analysis procedure for estimating the seismic demands of buildings," *Earthquake Spectra*, vol. 30, no. 4, pp. 1601-18, Nov 2014.

[10] B. Chikh, Y. Mehani, M. Leblouba, "Simplified procedure for seismic demands assessment of structures," *Structural Engineering and Mechanics*, vol. 59, no. 3, pp. 455-73, Jan 2016.

[11] M.R. Azadi Kakavand, M. Neuner, M. Schreter, G. Hofstetter, "A 3D continuum FE-model for predicting the nonlinear response and failure modes of RC frames in pushover analyses," *Bulletin of Earthquake Engineering*, vol. 16, no. 10, pp. 4893-917, Oct 2018.

[12] H.A. Mociran, and N. Cobîrzan, "Pushover analysis of RC framed structures with infill panels made of masonry having various properties," *InIOP Conference Series*, *Materials Science and Engineering*, vol. 1138, no. 1, p. 012030, Apr 2021.

[13] M.R. Arasteh Taleshmekaiil, S.M. Khatibi, M. Mohemsaz, M.H. Azimi, A. Sadeghpour, "Investigating the effective factors of renewable energy development in tehran metropolis," *Mathematical Problems in Engineering*. Vol.8, Mar 2021.

[14] M. Naseri, G.R. Shobeyri, A. Rajabi, A. Sadeghpour, "Evaluation of groundwater resources potential using analytical hierarchy process (AHP) and remote sensing geographic information system (GIS), a case study: Garmsar's catchment basin," *Computational Research Progress in Applied Science & Engineering, CRPASE: Transactions of Civil and Environmental Engineering*, vol. 7 ,p p. 1 – 8, 2021.

[15] F. R. Rofooei, N. K. Attari, A. Rasekh, and A. H. Shodja, "Adaptive pushover analysis," pp. 343-358, 2007.

[16] A. Sivasuriyan, D. S. Vijayan, W. Górski, L. Wodzyński, M. D. Vaverková, E. Koda, "Practical implementation of structural health monitoring in multi-story buildings," *Buildings*, vol. 20, no. 11, p. 263, Jun 2021.

[17] A. Aziminejad, M. Zare, A. S. Moghadam, "Improvement of adaptive pushover procedure in performance assessment of steel structures,".

[18] Gupta B, Kunnath SK., "Adaptive spectra-based pushover procedure for seismic evaluation of structures," *Earthquake spectra*, vol. 16, no. 2, pp. 367-91, May 2000.

[19] B. Daee, and A. A. Aghakouchak, “Assessment of Nonlinear Static Procedures for Determination of Target Displacement in Asymmetric Buildings,” *Advances in Structural Engineering*, vol. 15, no. 8, pp. 1265-77, Aug 2012.

[20] M. Jalilkhani, S. H. Ghasemi, and M. Danesh, “A multi-mode adaptive pushover analysis procedure for estimating the seismic demands of RC moment-resisting frames,” *Engineering Structures*, vol. 21, no. 3, p. 110528, Jun 2020.

[21] M. A. Amini, M. Poursha, “Adaptive force-based multimode pushover analysis for seismic evaluation of midrise buildings,” *Journal of Structural Engineering*, vol. 44, no. 8, p. 04018093, Aug 2018.

[22] N. Tonekaboni et al., “Optimization of solar CCHP systems with collector enhanced by porous media and nanofluid,” *Mathematical Problems in Engineering*, vol. 2021, pp. 1-12, 2021.

[23] A. Addeh et al., “ Orca-RBFNN: A new machine learning method for control chart pattern recognition,” *ENG Transactions*, vol. 3, pp. 1-14, Feb 2022.

[24] S. M. Saleh, M. Ranjbar, “Experimental Investigation on Nano Oil Added Fluid Influence For the Machining of Hardened AISI H13 Hot Work Tool Steel,” *ENG Transactions*, vol. 3, pp. 1-10, 2022.

[25] A. Penna, M. Rota, S. Bracchi, M. Angiolilli, S. Cattari, and S. Lagomarsino, “Modelling and seismic response analysis of existing URM structures. Part 1: archetypes of Italian modern buildings,” *Journal of Earthquake Engineering*, vol. 8, pp.1-27, Jul 2022.

[26] S. Zareie, M. S. Alam, R. J. Seethaler, and A. Zabihollah, “Effect of shape memory alloy-magnetorheological fluid-based structural control system on the marine structure using nonlinear time-history analysis” *Applied Ocean Research*, vol.91, p. 101836, Oct 2019.

[27] M. Yazdi, and P. Shafie, “Short Communication: Can Game-theoretic Context Improve the Complex System Safety and Reliability Analysis Methods? ,” *ENG Transactions*, vol. 2, pp. 1-7, 2021.

[28] S. R. Kuo, and J. D. Yau, “A fast and accurate step-by-step solution procedure for direct integration,” *International Journal of Structural Stability and Dynamics*” vol. 11, no. 3, pp. 473-93, Jun 2011.

[29] A. Sharma, K .Tripathi, and G. Bhat, “Comparative performance evaluation of RC frame structures using direct displacement-based design method and force-based design method,” *Asian Journal of Civil Engineering*, vol. 21, no. 3, pp. 381-94, Apr 2020 Apr.

[30] A. Martin, G. G. Deierlein, and X. Ma, “Capacity design procedure for rocking braced frames using modified modal superposition method,” *Journal of Structural Engineering*, vol. 145, no. 6, pp. 04019041, Jun 2019.

[31] D. De Domenico, and G. Ricciardi, “Dynamic response of non-classically damped structures via reduced-order complex modal analysis: Two novel truncation measures” *Journal of Sound and Vibration*, vol. 452, pp. 169-90, Jul 2019.

[32] A. S. Patil, and P. D. Kumbhar, “Time history analysis of multistoried RCC buildings for different seismic intensities,” *International Journal of Structural and Civil Engineering Research*, vol. 2, no. 3, pp. 194-201, Aug 2013.

[33] Z. Rizvi, R. K. Sharma , S. Khan, and Z.Khan, “Structural Strengthening And Damage Detection Using Time History And Response Spectrum Analysis,” *International Journal Of Research Review In Engineering Science & Technology*, vol. 2, no. 2, 2013.

[34] S. Rajasekaran, “Structural dynamics of earthquake engineering: theory and application using MATHEMATICA and MATLAB,” *Elsevier*, vol. 30, May 2009.

[35] Y. Yuan, H. Xue, and W. Tang, “Nonlinear dynamic response analysis of marine risers under non-uniform combined unsteady flows,” *Ocean Engineering*, vol. 213, p. 107687, Oct 2020.

[36] H. Xue, Y. Yuan, and W. Tang, “Numerical investigation on vortex-induced vibration response characteristics for flexible risers under sheared-oscillatory flows,” *International Journal of Naval Architecture and Ocean Engineering*, vol. 11, no. 2, pp. 923-38, Jul 2019 Jul 1;11(2):923-38.

[37] Y. C. Yuan, H. X. Xue, and W. Y. Tang, “Added mass variation effect on vortex-induced vibration for flexible risers based on force-decomposition model,” *Ships and Offshore Structures*, vol. 13, no. 1, Apr 2018.

[38] D. Vamvatsikos, C. A. Cornell, “Incremental dynamic analysis,” *Earthquake engineering & structural dynamics*, vol. 31, no. 3, pp. 491-514, Mar 2002.

[39] F. Di Trapani, and M. Malavisi, “Seismic fragility assessment of infilled frames subject to mainshock/aftershock sequences using a double incremental dynamic analysis approach,” *Bulletin of Earthquake Engineering*, vol. 17, no. 1, pp. 211-35, Jan 2019.

[40] F. Mohamed Nazri, M. A. Miari, M. M. Kassem, C. G. Tan, E. N. Farsangi, "Probabilistic evaluation of structural pounding between adjacent buildings subjected to repeated seismic excitations," *Arabian Journal for Science and Engineering*, vol. 44, no. 5, pp. 4931-45, May 2019.

[41] N. Aly N, M. AlHamaydeh, and K. Galal, "Quantification of the impact of detailing on the performance and cost of RC shear wall buildings in regions with high uncertainty in seismicity hazards," *Journal of Earthquake Engineering*, vol. 24, no. 3, pp. 421-46, Mar 2020.

[42] J. B. Mander, R. P. Dhakal, N. Mashiko, and K. M. Solberg, "Incremental dynamic analysis applied to seismic financial risk assessment of bridges," *Engineering structures*, vol. 29, no. 10, pp. 2662-72, Oct 2007.

[43] Y. Liu, B. Zhang, T. Wang, T. Su, and H. Chen, "Dynamic analysis of multilayer-reinforced concrete frame structures based on NewMark-β method*," Reviews on Advanced Materials Science*, vol. 60, no. 1, pp. 567-77, Jan 2021.

[44] D. De Domenico, G. Falsone, and G. Ricciardi, "Improved response-spectrum analysis of base-isolated buildings: A substructure-based response spectrum method," *Engineering Structures*, vol. 162, pp. 198-212, May 2018.

[45] Y. Reuland, P. Lestuzzi, and I. F. Smith, "A model-based data-interpretation framework for post-earthquake building assessment with scarce measurement data," *Soil Dynamics and Earthquake Engineering*, vol.116, no. 1, pp. 253-63, Jan 2019.

[46] S. S. Patil, S. A. Ghadge, C. G. Konapure, and C. A. Ghadge, "Seismic Analysis of High-Rise Building by Response Spectrum Method," *International Journal of Computational Engineering Research*, vol.3, no. 3, pp. 272-9, Mar 2013.

[47] S. Yaghmaei-Sabegh, and N. Jalali-Milani, "Pounding force response spectrum for near-field and far-field earthquakes," *Scientia Iranica*, vol.19, no. 5, pp. 1236-50, Oct 2012.

[48] J. R. Ramchandani, and M. N. Mangulkar, "Comparison between different shapes of structure by response spectrum method of dynamic analysis," *Open Journal of Civil Engineering*, vol.6 , no. 2, pp. 131-8, Mar 2016.

[49] M. Mirmozaffari, "An Improved Non-dominated Sorting Method in Genetic Algorithm for Bi-objective Problems;" *ENG Transactions*, 2021.

[50] F. J. Golrokh, G. Azeem, and A. Hasan, "Eco-efficiency evaluation in cement industries: DEA malmquist productivity index using optimization models," *Eng Transactions*, pp. 1-8, 2020.

[51] M. Taghizadeh, H. R. Ovesy, and S. A. Ghannadpour, "Beam buckling analysis by nonlocal integral elasticity finite element method," *International Journal of Structural Stability and Dynamics*, vol.16 , no. 6, p. 1550015, Aug. 2016.

[52] E. Rajabiani, M. R. Gharib, and A. Koochi, "Buckling Analysis of Groove Corroded Pipe Due to Axial Pressure with Finite Element Method," *International Journal of Steel Structures*, vol.21 , no. 5, pp. 1723-40, Oct 2021.

[53] F. Kiakojouri, V. De Biagi, B. Chiaia, and M. R. Sheidaii, "Progressive collapse of framed building structures: Current knowledge and future prospects," *Engineering Structures*, vol. 206, p. 110061, Mar. 2020.

[54] A. Penna, M. Rota, S. Bracchi, M. Angiolilli, S. Cattari, and S. Lagomarsino, "Modelling and seismic response analysis of existing URM structures. Part 1: archetypes of Italian modern buildings," *Journal of Earthquake Engineering*, vol. 8, pp. 1-27, Jul 2022.

[55] V. Cardinali, M. Tanganelli, and R. Bento, "Seismic assessment of the XX century masonry buildings in Florence: Vulnerability insights based on urban data acquisition and nonlinear static analysis," *Journal of Building Engineering*, vol. 57, no. 1, p. 104801, Oct 2022.

[56] R. S. Jalali, and M. D. Trifunac, "A note on strength-reduction factors for design of structures near earthquake faults," *Soil Dynamics and Earthquake Engineering*, vol. 28, no. 3, pp. 212-22, Mar 2008.

[57] Y. Ghaderpour, M. R. Arasteh Taleshmekaiil, B. Rouki, M. Mohemsaz, M. H. Azimi, A. Sadeghpour, "Analysis and Measurement of Parameters of Quality of Life in Informal Settlements Surrounding of Tehran Metropolis," *Mathematical Problems in Engineering*, vol. 24, Jun 2021.

[58] S. Costanzo, M. D'Aniello, and R. Landolfo , "Proposal of design rules for ductile X-CBFS in the framework of EUROCODE 8," *Earthquake Engineering & Structural Dynamics*, vol. 48, no. 1, pp. 124-51, Jan 2019.

[59] M. Kheirizadeh Arouq, M. Esmaeilpour, and H. Sarvar, "Vulnerability assessment of cities to earthquake based on the catastrophe theory: a case study of Tabriz city, Iran," *Environmental Earth Sciences*, vol. 79, no. 14, pp. 1-21, Jul 2020.

[60] A. Addeh, and M. Iri, "Brain tumor type classification using deep features of MRI images and optimized RBFNN," *ENG Transactions*, vol.39, no. 2, pp. 559-573, 2021;2:1-7.