International Journal of Modern Achievement in Science, Engineering and Technology (IJSET)
ISSN 3023-459X
DOI: 10.63053/ijset.76

Assessment of the Efficiency of the Rapid Visual Assessment Method for Hospitals Based on Nonlinear Structural Analysis Results

Sahar Shafaghi [1] *, Bahman Shafaghi [2], Sholeh Shafaghi [3]

1. Master of Science, Civil Engineering, Structural Engineering, Al-Taha Non-Profit University,Iran
2. Master of Science, Architecture, Islamic Azad University Marivan Branch,Iran
3. Master of Science Student, Architecture, Payame Noor University Hormozgan International Center Kish,Iran

ARTICLE INFO

Keywords:
Rapid Assessment, Vulnerability, Incremental Load Analysis, Collapse, Hospital

ABSTRACT

This project investigates the effectiveness of the proposed method for assessing the seismic vulnerability of the main building of the 160-bed Malard Hospital. Initially, this structure is analyzed using Etabs 19 software through incremental load analysis, and based on the obtained results, a quantitative vulnerability index is derived. By analyzing the capacity curves at points corresponding to various performance levels, some of which align with four conventional performance levels—continuous serviceability, continuous usability, life safety, and threshold for collapse—these points are established. Following their identification, statistical analyses are conducted to ascertain the mean and standard deviation, thus facilitating a comparison of the quantitative impact of vulnerability-inducing factors. By applying 21 damage scenarios to the reference structure and repeating the aforementioned process, both quantitative and qualitative vulnerability indices are computed, and the statistical correlation between these two indices is monitored. The calculations revealed that the method existing in the technical literature has a correlation coefficient of 0.63 with the nonlinear analysis results, and with the proposed modifications in this research, an improvement of 33 percent in this coefficient can be anticipated

Introduction

In contemporary times, reducing damages and ensuring a faster and more effective recovery post-earthquake are among the prominent issues in high-level disaster management. This subject necessitates efficient management across all sectors of the country's construction industry. Hospitals, given their crucial role following an earthquake, require effective management. Resilience can be defined as the system's engineering, economic, and social capability to return to its original state, and if possible, to a better condition than prior to the event, following a significant impact or disaster such as an earthquake or flood.

During occurrences such as earthquakes, hospitals must not only remain operational but also serve as an essential service provider. This aspect is of utmost importance and can significantly influence the casualty rates post-disaster. Furthermore, various regulations emphasize the roles of hospitals and service centers as crucial, necessitating their design with heightened safety factors. Thus, the attention to these centers is critically important.

Given this context, it is essential that different agencies possess the requisite preparedness for diverse scenarios, coordination, and the necessary knowledge, which is an international matter that is debated and discussed globally. Additionally, financial considerations must also be taken into account to ensure the best decisions are made on these issues since access to resources for a nation is finite, and managerial priorities must be transparently examined. Therefore, quantifying various factors through the application of statistical science and probabilistic methods, as well as practical definitions, constitutes one of the most crucial efforts that must be undertaken. Below are several examples of prior research.

Web et al. analyzed business characteristics that influence long-term recovery following a catastrophic event. Vasiliski et al. (2011) investigated how physical damage to infrastructure, the destruction of vital arteries, and various business characteristics, among other factors, can affect business closures or relocations following significant disasters. Pent et al. (2013) developed a specific method for assessing interdependence among multiple infrastructures that can support resource allocation and decision-making. Although the studies mentioned relate to the economic impacts of severe events on communities, they all focus on specific dimensions of the subject matter.

In the event of structural failure, healthcare facilities are classified as a serious threat to human life (occupancy classification III, according to each ICC IBC, 2012). Therefore, the necessary conditions regarding their design are more stringent compared to residential and commercial buildings. Generally, during significant recent earthquakes in Chile, New Zealand, and Japan, healthcare facilities performed well. However, the closure of healthcare centers due to extensive structural and non-structural damage has resulted in service disruptions.

Assessment Methods for Building Vulnerability

RVS Methods: Numerous RVS methods have been developed worldwide. Given the differences in regulations and construction practices, the systems and scoring parameters for assessing the vulnerability of buildings also vary by location. One of the fundamental steps to identify and develop the most effective scoring method for hospitals is to utilize the most common RVS methods, which must be duly investigated.

RVSP Method: This modified method is based on FEMA 154. The final score is calculated using the vulnerability scoring sheet in FEMA 154, while the interpretation of the vulnerability degree for each score depends on five levels of destruction classification. If this score ranges between 2 and 2.5, it indicates a likelihood of level one or two damage, which is considered moderate damage. For these two levels of destruction, a more detailed assessment is not required, and only minor repairs are needed. If the score is below 2, it signifies severe structural damage. Typically, a score lower than 0.7 indicates serious and extensive damage, necessitating a thorough evaluation and reconstruction of the building.

Methodology and Research

The PBEE Method: The Pacific Earthquake Engineering Research Center (PEER) has developed a methodology for assessing the seismic probabilities of buildings, bridges, and other infrastructure. The objective of this approach is to provide relevant stakeholders with necessary information for informed decision-making based on lifecycle considerations rather than solely on costs. The conventional method for measuring structural performance involves quantitative assessments of forces and deformations.

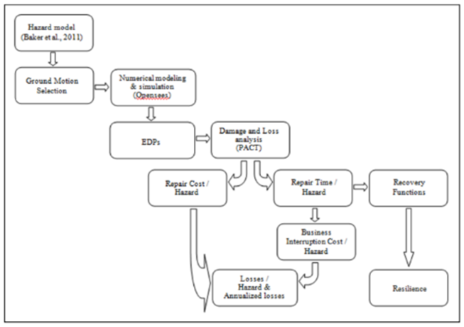
Considering the characteristics of the structure, a flowchart delineates the process and evaluates the building's response following ground motion, as well as the potential damage that may affect structural components, alongside related losses. This process comprises four logically progressive stages, incorporating four general variables.

The four variables considered in this process are: Intensity Measure (IM), Engineering Demand Parameter (EDP), Damage Measure (DM), and Decision Variable (DV). Each quantity is defined as the conditional probability of not exceeding a specific demand by a fixed value.

The aforementioned four stages of PBEE can be analytically summarized using a triple integral based on the total probability theorem. This integral expresses the probability that a decision variable exceeds a specified value, presented as an input intensity measure, P(dv ≥ DV | im = IM). Subsequently, based on the total probability, a combination of analysis stages is presented through the following relationship .

$$G(DV|IM) = \int_{allEDPs} \int_{allDMs} G\left(DV|DM\right)|dG(DM|EDP)\Big|dG\left(EDP|IM\right)\Big|d\lambda(IM)$$

As a result of this probabilistic analysis, it can be stated that the values of the decision-making variables are not deterministic and, due to the presence of various sources of uncertainty, they undergo changes



.

Figure 2-: Framework of
[8] Probabilistic Principles

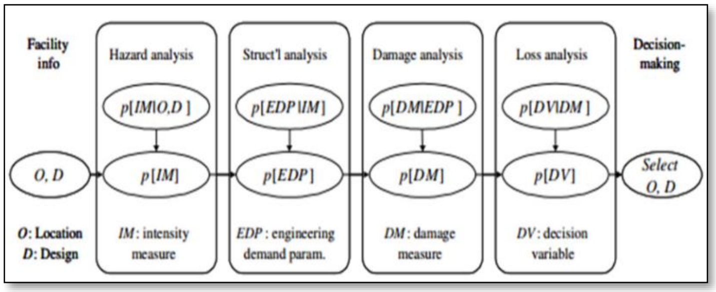


Figure 1: Flowchart Process for Lifecycle Cost
[7] Analysis

In this study, we aim to develop an advanced visual assessment method for structures utilized in medical settings. Initially, we will evaluate the significance of the vulnerability index in comparison to the results obtained from a three-dimensional nonlinear structural analysis. Subsequently, we propose modifications concerning the weighting of vulnerability sources within the assessment checklist, aiming for maximum alignment with nonlinear analysis outcomes.

Evaluation of Existing Methods

It is essential to note that quantifying the vulnerability of structural elements and equipment located within hospitals that are exposed to seismic events will be conducted through the definition and calculation of various quantitative variables. For example, definitions of some variables are provided below:

1- Loss: The degree of decline in the system at time t0. This index is calculated based on economic data and the valuation of assets at risk, as it is dependent on the local conditions of each country.

2- Vulnerability: These are the known weaknesses that a system possesses in the face of a specific hazard. The vulnerability of a hospital is influenced by its level of preparedness. Vulnerability can be classified into various forms, including structural, non-structural, and managerial-organizational vulnerabilities. Structural vulnerability encompasses the damage to the hospital building, as well as structural and architectural elements that require various types of physical protections, such as foundations, protective walls, and columns. These elements may represent points of weakness for the hospital when confronting diverse disasters such as earthquakes, floods, and storms.

Non-structural components: This includes damage to essential elements that are necessary for the hospital's functionality, such as heating and cooling systems, ventilation, communication systems, water supply, equipment, installations, decoration, and electricity. Managerial-organizational vulnerability pertains to human resources and organizational management that are critical for providing specialized services and fulfilling the hospital's operational duties.

Proposed Rapid Evaluation Method

Subsequently, a Rapid Vulnerability Assessment (RVA) method has been proposed for evaluating the seismic risk index of hospitals. The following elements have been considered for defining seismic hazard: vulnerability, exposure level, and risk. The assessment of the vulnerability of structural and non-structural elements, along with organizational aspects, has been taken into account. Specifically, the author has evaluated the most critical parameters for determining the level of seismic vulnerability, which are utilized in characterizing the damages of hospitals. The collected data enables us to identify structural weaknesses (which are subject to scrutiny) as well as non-structural elements that significantly impact hospital performance.

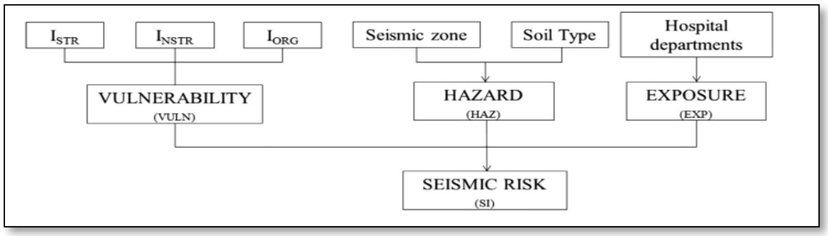


Figure 3: Overall Framework of RVA

$$x\ (\text{Item 1}, \text{Item 2}, \dots \text{Item n}) = \sum_{i=1}^{n} \text{Index}(\text{Item i})$$

Implementation of RVA: The evaluation of seismic vulnerability must be implemented in several steps. To determine the general characteristics and design threshold limits, existing design documents must be reviewed. Whenever feasible, components should be visually inspected to ensure that they have been constructed according to design documents, enabling the identification of attributes and characteristics not covered in the design documents, as well as assessing the as-is condition.

Checklist Format: The RVA checklist encompasses all structural items for both pre-visit assessments and field visits. Each item must be checked for the feasibility of a standard assessment, followed by an evaluation of the risk level in its as-is condition, categorized as low, medium, or high.

Pre-Screening Actions: Prior to the field visit, an inventory list should be compiled. If certain elements or subsets of the hospital are set to be removed soon, it is advisable to exclude them from the screening process.

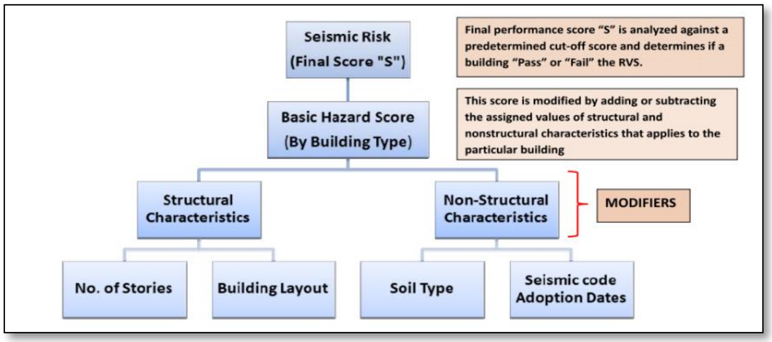
Prioritization Index: The post-earthquake performance of hospitals is of paramount importance. Prioritization plans are based on existing facilities for mitigating earthquake-related losses. Hospitals exemplify complex social systems. For this type of structure, the assessment of vulnerability must be conducted from a broader perspective. Vulnerability is not solely contingent upon the physical components of the structure; it also hinges on human and organizational factors.

Ranking Based on Risk Index: In the proposed simplified method, indices related to both structural and non-structural elements (FUNC) are integrated with organizational aspects to derive the overall vulnerability (VULN). The assessment of vulnerability is calculated through a linear combination of key indices, to which distinct weights are assigned. The evaluation of a key index is conducted via the following relationship.

$$I_{Primary} = \frac{\sum Unit\_Risk\_Index}{\sum Unit\_Risk\_Index\_Hig}$$

The concept of final score is derived from the basic hazard score; this score indicates the probability of building failure in the Maximum Considered Earthquake (MCE). The minimum score that may have a meaningful interpretation is zero; this implies that the probability is one or the probability of collapse is 100 percent.

$$S = -\log_{10}(P[Collapse|MCE_R\ ground\ motions])$$



Interpretation of the final score inFEMA 154 : -4Figure

A simplified process has been proposed that estimates the probability of an increase in other performance levels in comparison to the prevention of collapse. This process is as follows:

- •Obtain the revised RVA score.
- •Determine the probability of collapse under the MCE conditions based on Relationship 1.
- •Select the fragility curve of collapse to ensure proper matching of the IM-P collapse pairs (with a standard tolerance of 10 percent).
- •Calculate the IM corresponding to the desired risk levels.
- •Compute the drift values associated with the IM obtained in the previous step.
- •Utilize the overall modified fragility to execute your level of interest in order to calculate the probability of an increase in the drift value obtained from the previous step.

Specifications and Structural Analysis

References and Regulations:

In the design of buildings, the following references and regulations will be utilized:

1.Chapter Six of the National Building Regulations "Loads on Buildings[11] "
2. Earthquake Resistant Building Design Code, Standard No. 2800, Third Edition[12]
3. Iranian Concrete Code "ABA[13] "
4.Publications No. 55, 77, 94 from the National Management and Planning Organization, "Office of Research and Technical Standards[14] "
5.ACI318-99[15]
6.Reinforced Concrete Structure Design by Engineer Shahpour Tahouni[16]

General Project Specifications:

The discussed project building is divided into two blocks by an expansion joint:
1.Block A with two floors featuring reinforced concrete slabs.
2.Block B with four floors featuring reinforced concrete slabs.

Recommendations regarding the most suitable roof system, framework, and foundation are as follows:
1. Considering the advantages outlined in the report for selecting the roof system, a two-way slab roof system and secondary beams have been chosen. The minimum thickness is set at 13.5 centimeters due to
The fire resistance duration intended for this project is 150 minutes, which is derived from Table 9-19-6 of Section 9 of the National Building Regulations, estimating a value of 13.5 centimeters based on two values of 12 centimeters (120 minutes of resistance) and 15 centimeters (180 minutes of resistance).

Considering the advantages and disadvantages outlined for metallic and concrete frameworks, as well as the modularity of spans which significantly reduces formwork costs, the concrete framework has been preferred over the metallic one. In accordance with Clause 2-3-8-3 of Regulation 84-2800, it is required to employ special systems for selection of the type of system. Suitable special systems for the project may consist solely of special moment frames or a combination of special moment frames with shear walls. Given that the architectural design permits the incorporation of shear walls in an adequate quantity and distribution, the system utilizing special moment frames along with special shear walls has been adopted. The advantage of this system, compared to utilizing special frames alone, is that it significantly reduces lateral deformations while also allowing for more slender dimensions of beams and columns. This contributes to a reduction in construction costs and promotes more suitable architectural spaces. Therefore, the structural system of special moment frames accompanied by special shear walls has been selected.

Based on the permissible stress values provided in the geotechnical report for various widths of strip foundations and considering the effective performance of strip foundations in controlling uneven settlements and resisting lateral forces, as well as the reaction force values at the supports of columns and shear walls, the most suitable type of foundation has been identified as a combined strip foundation, with widths determined in proportion to the force values. It should be noted that the thickness of the foundation has been determined according to the force values: in Block A (two stories), the thickness of the foundation is set at 80 centimeters; in Block B, it is set at 100 centimeters; and at the locations of shear walls, a thickness of 150 centimeters is considered.

The dimensions obtained from the analysis of the structure with the aforementioned system are as follows: the dimensions of the columns (taking into account design considerations and cost-effective formwork) are set at 50*50 for the two-story block and at 65*65 and 55*55 for the four-story block. The dimensions of the primary beams in the two-story building are 50*45, while in the four-story building they are as follows:
Levels 4.94, 9.44, and 13.94 (60*65)
Level 18.44 (50*55)
Roof level (40*40)
The shear wall in the two-story block is designated at a thickness of 30 centimeters, while in the four-story block it is designated with a thickness ranging from 30 to 40 centimeters. Furthermore, considering that the structural system is of a special type, the regulations concerning the

determination of the cross-sectional dimensions and the amounts of longitudinal and transverse reinforcement, as well as their distribution, alongside the corresponding plans for beam layouts and the intensities of dead and live loads on the floors, will be subsequently provided.

Non-linear model analysis

Plastic hinge design: All the plastic hinges of this structure are assumed to be one-tenth of the -1 beginning and end of the beams and columns, with the characteristics of the hinges defined as default parameters within the program. For the walls, a similar approach has been adopted in accordance with the ASCE 41-17 code.

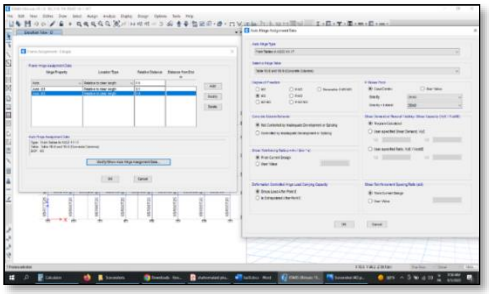


Figure 6: Demonstrating the location of the plastic .joint within a specific element

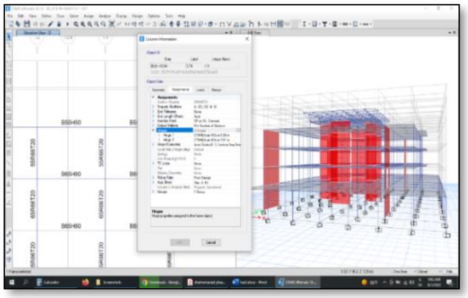


Figure 5: Location of the plastic joint .in the ITBZ

The following tables present the approximate performance values of joints as specified in the ASCE 41-17 standards. Tables 1 to 10 of the ASCE 41-17 guidelines .[17]

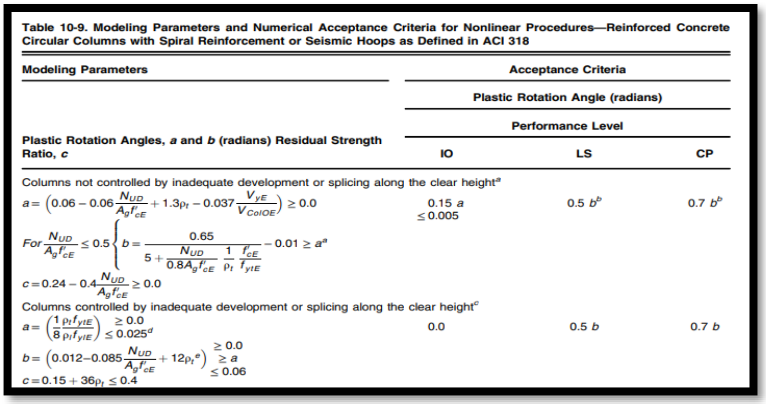


Table 10-9. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Circular Columns with Spiral Reinforcement or Seismic Hoops as Defined in ACI 318

Modeling Parameters	**Acceptance Criteria**		
	Plastic Rotation Angle (radians)		
	Performance Level		
Plastic Rotation Angles, *a* and *b* (radians) Residual Strength Ratio, *c*	**IO**	**LS**	**CP**
Columns not controlled by inadequate development or splicing along the clear height[a]			
$a=\left(0.06-0.06\frac{N_{UD}}{A_g f'_{cE}}+1.3\rho_t-0.037\frac{V_{yE}}{V_{ColOE}}\right)\ge 0.0$	0.15 a ≤ 0.005	0.5 b^b	0.7 b^b
$For\ \frac{N_{UD}}{A_g f'_{cE}}\le 0.5\left\{b=\frac{0.65}{5+\frac{N_{UD}}{0.8A_g f'_{cE}}\frac{1}{\rho_t}\frac{f'_{cE}}{f_{ytE}}}-0.01\ge a^a\right.$			
$c=0.24-0.4\frac{N_{UD}}{A_g f'_{cE}}\ge 0.0$			
Columns controlled by inadequate development or splicing along the clear height[c]			
$a=\left(\frac{1}{8}\frac{\rho_t f_{ytE}}{\rho_l f_{ylE}}\right)\begin{matrix}\ge 0.0\\ \le 0.025^d\end{matrix}$	0.0	0.5 b	0.7 b
$b=\left(0.012-0.085\frac{N_{UD}}{A_g f'_{cE}}+12\rho_t^{\,e}\right)\begin{matrix}\ge 0.0\\ \ge a\\ \le 0.06\end{matrix}$			
$c=0.15+36\rho_t\le 0.4$			

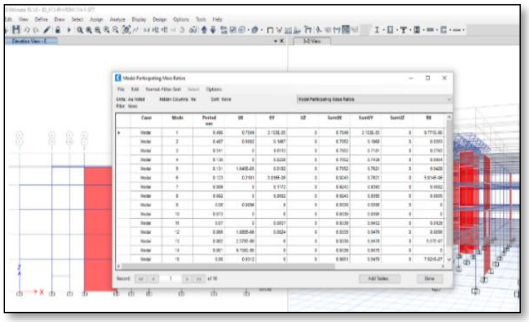


Figure 8: Definition of Plastic Joints in Shear Walls

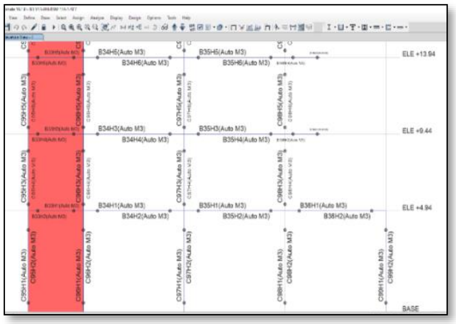


Figure 7: Building facade showing the location of plastic joints

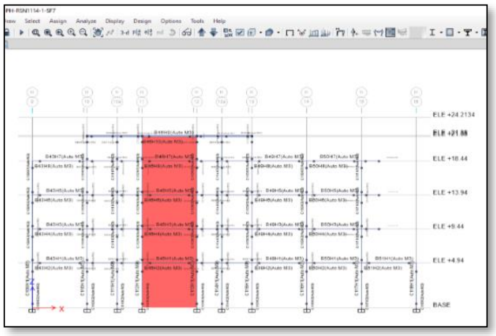


Figure 10: Representation of the location of plastic joints along with the names of the components.

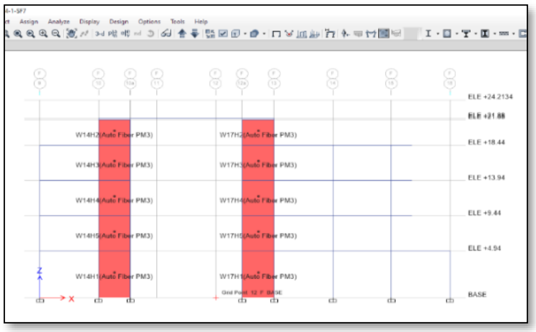


Figure 9: Modes one to fifteen of the structure obtained from the software.

Modal Analysis of Structures: In the above figure, you can observe the first to fifteenth modes of the structure. As you know, the initial modes, especially the first mode, are predominantly utilized.

Processing of Analyses and Their Evaluation

Obtaining the Capacity Curve:

Differences Between Linear and Nonlinear Analyses: The code for retrofitting essentially specifies two analytical methods: linear and nonlinear. Each of these methods can be executed in both static and dynamic forms.

Linear analysis assumes that during the analysis, beams and columns possess unlimited resistance and constant stiffness, representing methods based on force-controlled approaches. Linear analysis methods are structured under the assumption of the formation of plastic hinges at the endpoints of members, such that if a plastic hinge forms at a point other than the two ends (intermediate points), the results of the linear analysis will be considered unreliable. Therefore, after conducting a linear analysis for members subjected to significant gravitational loads, a moment diagram must be drawn to examine the potential formation of plastic hinges along the member.

Nonlinear analysis refers to the analysis of a structure considering the nonlinear behavior of its components due to the nonlinear behavior of materials, cracking, and geometric nonlinear effects. In nonlinear analysis methods, plastic hinges are anticipated at the points of maximum moments resulting from gravitational loads, and the analysis of the structural model is performed accordingly. After the analysis, using the results obtained, the moment diagram of the member must be redrawn, and the location of the plastic hinges must be verified. If the predicted location of the plastic hinge is incorrect, it is necessary to reanalyze the structure and alter the position of the plastic hinge. Additionally, in nonlinear analysis, all primary and secondary members of the structure are modeled, and the effects of reduced resistance and stiffness of components (deterioration) are incorporated into the model.

A seismic-resistant system must possess the following two general characteristics:

a) In mild to moderate earthquakes, the structure remains unscathed within the elastic range.

b) In severe earthquakes, the structure, while enduring damage up to a specified level, should not reach the failure threshold.

To ensure the first characteristic, the resistance and stiffness of the structure play a crucial role, while for the second characteristic, ductility and energy absorption capacity are imperative to prevent total collapse of the structure.

Nonlinear Behavior of Structures: Structures exhibiting nonlinear behavior can be classified as follows:

1. Geometrically Nonlinear: Geometric nonlinearity primarily arises from issues such as small and

large strains, rotations, etc., which compromise the stability of the structure. This can be classified into two cases:
a) Large deformations and rotations
b) Strain hardening
2. Material Nonlinearity: This method arises from independent behaviors such as ductility, time-dependent behaviors like creep, as well as viscoelastic and plastic effects, wherein both ductility and bending effects coexist.
3. Nonlinear Boundary and Contact Conditions: Nonlinearity arises from contact surface conditions; as boundary displacements are contingent upon the deformations of the structure.

Linear and Nonlinear Behavior of Steel: If a member is subjected to axial tension, its stress-strain curve is as depicted in the associated figure.

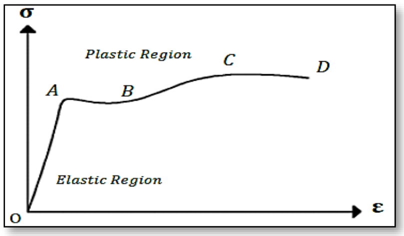


Figure 12: True Stress-Strain Curve of Steel

Figure 11: Idealized Stress-Strain Curve of Steel

The behavior of steel under cyclic loading (hysteresis curve or cyclic behavior)

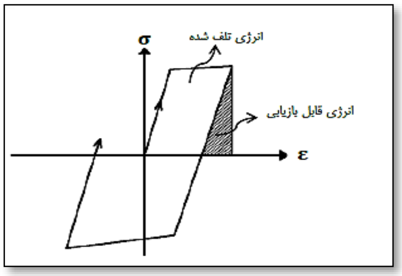


Figure 15: Curve in Linear Mode

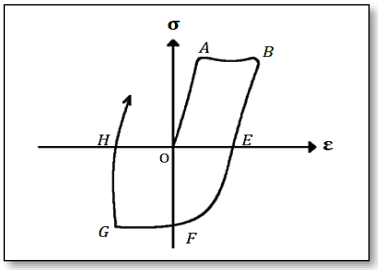


Figure 14: Curve in the Non-linear State

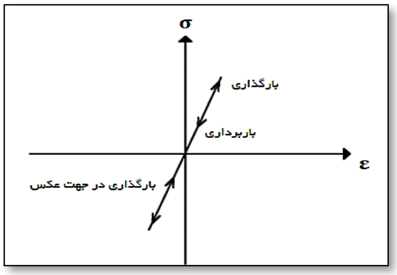


Figure 13: Wasted Energy and Recoverable Energy

What is obtained from the cyclic diagram of a structure under a specific earthquake is as follows: (1. Area under the curve (energy absorption), 2. Number of cycles of loading and unloading, 3. Slope of the stiffness curve of the structure in each cycle, 4. Amount of resistance of the structure in each cycle, 5. Ductility of the structure during its performance, 6. Stability and instability of the system)
As mentioned, the cyclic diagram is utilized to model the nonlinear and hysteretic behavior of earthquakes.

Types of Nonlinear Dynamic Analyses

In nonlinear analysis methods, plastic hinges are predicted at points of maximum moments induced by anticipated gravitational loads, and the analysis of the structural model is conducted based on this. After the analysis, the moment diagram of the member must be redrawn using the obtained results, and the location of the formation of plastic hinges must be verified. For this purpose, similar to linear methods, the moment diagram is obtained by summing the moment diagram of the gravitational loads and the moment resulting from the analysis under lateral seismic loads (unlike linear methods where the moment corresponding to the expected capacity of the member was placed at both ends), and it must be compared with the expected capacity of the member along its entire length. If the predicted position for the plastic hinge is incorrect, it is necessary to reanalyze the structure with the adjusted position of the plastic hinge.

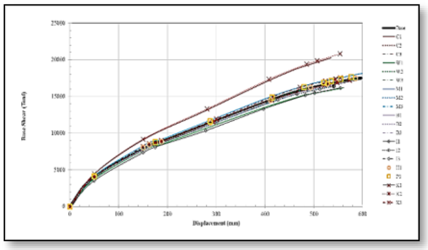
In general, the nonlinear dynamic analysis method provides greater accuracy compared to static nonlinear methods due to the avoidance of simplifications present in structural modeling. However, considering the extensive amount of input data required (ground motion accelerograms, hysteretic behavior of structural members, etc.) and the time-consuming and complex nature of this analysis for structures with many elements, the execution of such extensive and intricate calculations is only suitable for research work or the design of specific structures due to the limitations of available software and hardware and the sensitivity of this method.

Results of Structural Analyses:

Subsequently, a summary of the scenarios applied for calculating the vulnerability assessment index based on the Rapid Visual Screening (RVS) method and the output from nonlinear static analysis based on the lateral load pattern corresponding to the first mode of the structure is presented. Accordingly, the capacity curves are also presented in the following forms.

ردیف	شرح	نمایه
۱	سازه اصلی	Base
۲	ضعف در ستون طبقه اول (به صورت رندوم در ۲۰ درصد ستونها)	C1
۳	ضعف در ستون طبقه میانی (به صورت رندوم در ۲۰ درصد ستونها)	C2
۴	ضعف در ستون طبقه آخر (به صورت رندوم در ۲۰ درصد ستونها)	C3
۵	ضعف در دیوار برشی طبقه اول (ضخامت ۳۰ به جای ۴۰ سانتیمتر)	W1
۶	ضعف در دیوار برشی طبقه میانی (ضخامت ۲۵ به جای ۳۵ سانتیمتر)	W2
۷	ضعف در دیوار برشی طبقه آخر (ضخامت ۲۰ به جای ۳۰ سانتیمتر)	W3
۸	افزایش موضعی جرم طبقه اول (به میزان دو برابر به صورت رندوم در ۲۰ درصد چشمه ها)	M1
۹	افزایش موضعی جرم طبقه میانی (به میزان دو برابر به صورت رندوم در ۲۰ درصد چشمه ها)	M2
۱۰	افزایش موضعی جرم طبقه آخر (به میزان دو برابر به صورت رندوم در ۲۰ درصد چشمه ها)	M3
۱۱	ضعف در تیر طبقه اول (به صورت رندوم در ۲۰ درصد تیرها)	B1
۱۲	ضعف در تیر طبقه میانی (به صورت رندوم در ۲۰ درصد تیرها)	B2
۱۳	ضعف در تیر طبقه آخر (به صورت رندوم در ۲۰ درصد تیرها)	B3
۱۴	انقطاع سیستم باربر جانبی در طبقه اول (سه مورد دیوار به صورت راندوم حذف گردید)	I1
۱۵	انقطاع سیستم باربر جانبی در طبقه میانی (سه مورد دیوار به صورت راندوم حذف گردید)	I2
۱۶	انقطاع سیستم باربر جانبی در دو طبقه آخر (چهار مورد دیوار به صورت راندوم حذف گردید)	I3
۱۷	نامنظمی در ارتفاع؛ افزایش سختی در طبقه میانی (ضخامت دیوار در این طبقه دو برابر گردید)	H1
۱۸	نامنظمی در پلان افزایش بازشو در طبقه میانی (میزان بازشو به بیش از ۵۰ درصد مساحت طبقه میانی افزایش یافت)	P1
۱۹	افزایش سختی میانقابی در طبقه اول (حدود ۲۰ درصد ستونها افزایش سختی یافت)	K1
۲۰	افزایش سختی میانقابی در طبقه میانی (حدود ۲۰ درصد ستونها افزایش سختی یافت)	K2
۲۱	افزایش سختی میانقابی در کل سازه (حدود ۲۰ درصد ستونها افزایش سختی یافت)	K3

Figure 16: The Load Increase Curves in All Damage Scenarios.



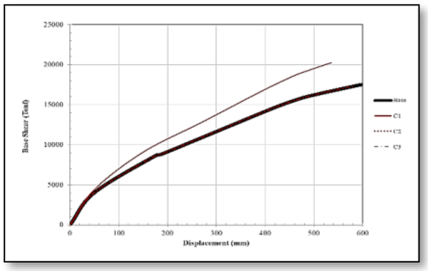


Figure 17: Overload curves in all damage scenarios in the column Load curve of the software in all scenarios

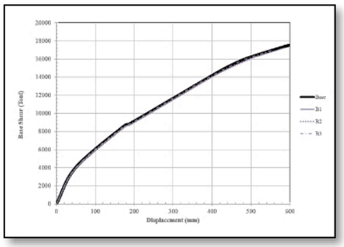


Figure 20: Damage in Beams

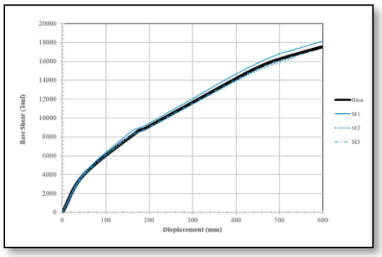


Figure 19: Damage in Shear Wall

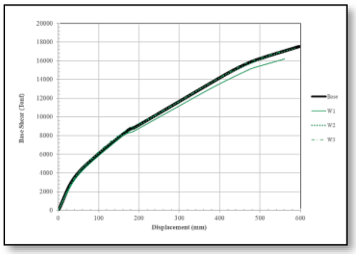


Figure 18: Scenarios of Mass Irregularities

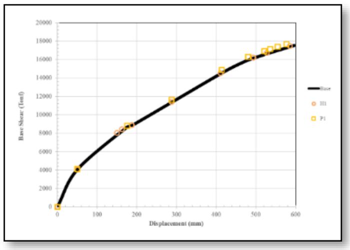


Figure 23: Damage Due to Hardness Changes at Elevation

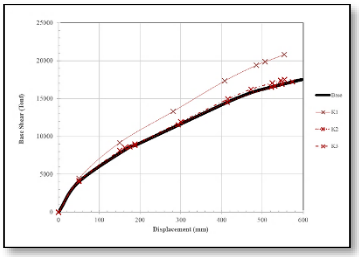


Figure 22: Irregular Damage Due to Height

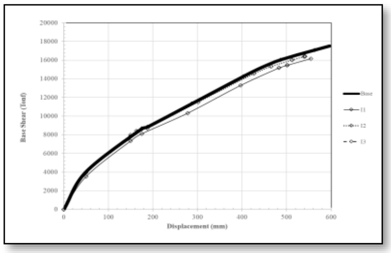


Figure 21: Damage due to Disruption

In the following, the correlation between the index derived from RVS and the results of the demand-to-capacity ratio at the threshold performance level of collapse will be examined.

Correlation and additive load for scenarios

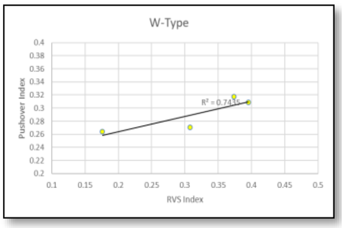


Figure 26: Weakening of Walls

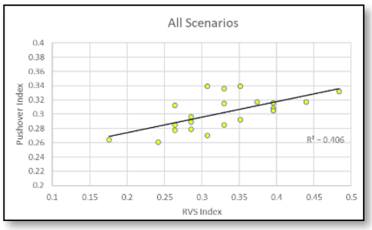


Figure 25: Correlation for All Scenarios

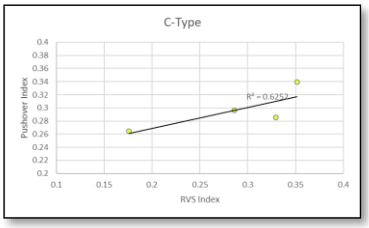


Figure 24: Weakening of Columns

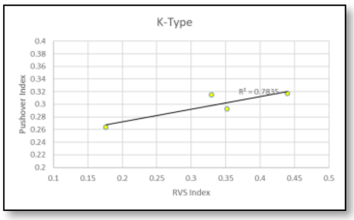


Figure 29: Hardness Irregularity

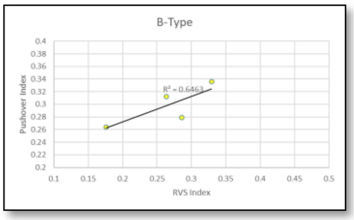


Figure 28: Damage in Beams

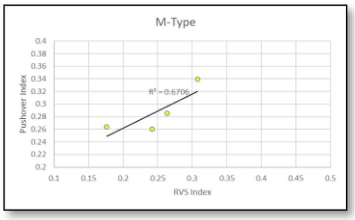


Figure 27: Mass Irregularity

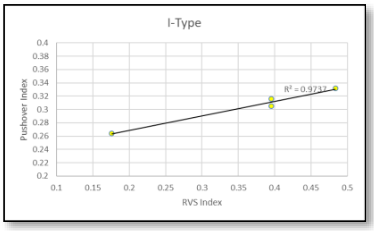


Figure 31: All scenarios after modification.

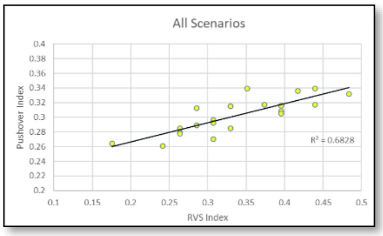


Figure 31: All scenarios after modification.

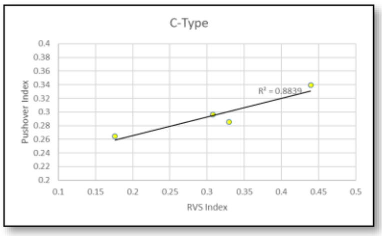


Figure 30: Columns after modification

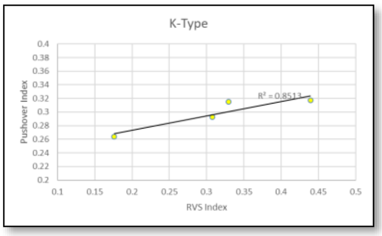


Figure 35: For the difficulties after the revision

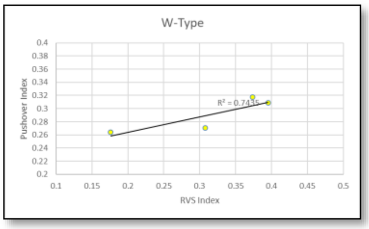


Figure 34: For the walls after modification

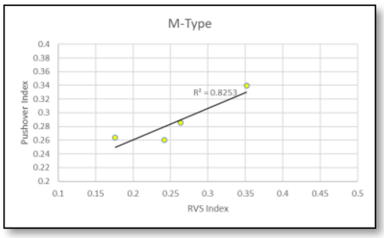


Figure 33: For masses after modification

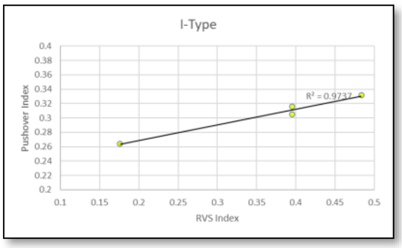


Figure 37: For interruption in the transportation path after modification.

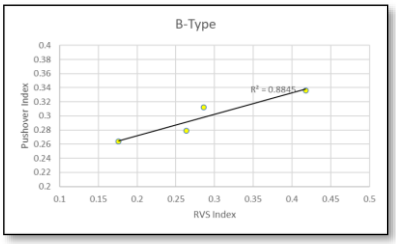
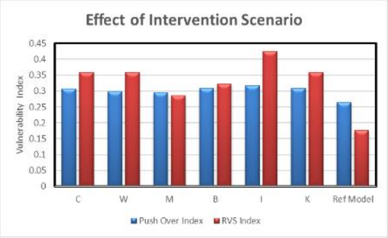
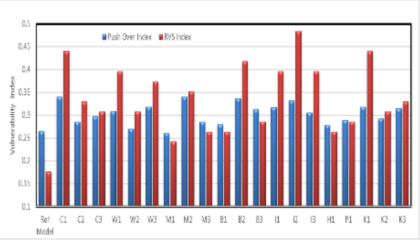


Figure 36: For beams after modification.

RVS Vulnerability and Cumulative Load





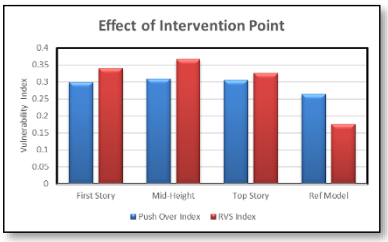


Figure 40: According to the Category of Damage Application

Figure 39: Based on the scenario

Figure 38: RVS Vulnerability and Overload

Results and Proposals

Most existing research has attempted to establish a descriptive relationship between the vulnerability index obtained from rapid visual assessment and the likelihood of collapse in structures, and there is insufficient laboratory analytical infrastructure to engage other performance levels within this framework .

Based on the aforementioned points, this study aims to develop an enhanced visual assessment method for therapeutic structures, initially evaluating the significance of the vulnerability index in comparison to the results of non-linear analysis of a three-dimensional structure, and subsequently proposing modifications related to weighting the sources of vulnerability in the assessment checklist to achieve maximum alignment with non-linear analysis results .

The research methodology to achieve the outlined goals is as follows :

- Selection of a rapid visual assessment method through a comprehensive review of technical literature that facilitates the creation of a quantitative vulnerability index .
- Determination of a general form for the relationship between the vulnerability index derived from rapid visual assessment and the results of non-linear analysis pertaining to an existing building's structure .
- Selection of a concrete building with details and therapeutic use, representing common execution types across our esteemed country, Iran .
- Non-linear three-dimensional modeling of an existing concrete building with a dual system of moment-resisting frames and special shear walls .
- Conducting incremental load analysis of the three-dimensional model based on standard methods extracted from earthquake engineering literature .
- Extraction of seismic demand values at proposed performance levels based on the site's risk level .
- Calculation of the structural capacity derived from the output of capacity spectrum analysis at the required performance levels .

•Introduction of targeted damages in the structural model and reproduction of the non-linear model to account for the damages .

•Repetition of steps one to seven for all models generated in step eight .

•Fitting a quantitative relationship between the qualitative and quantitative indices obtained from the two assessment methods and the non-linear analysis on twenty-one damaged and intact models .

•Identification of error factors in fitting as described in step ten, and proposals for revising scoring methods and calculating the vulnerability index to enhance statistical correlation .

Interpretation of Results

According to the chart presented in the figure below, the coefficient of correlation between the qualitative and quantitative vulnerability indices is 0.63, indicating the presence of a meaningful relationship, albeit with a less-than-optimal level of correlation between the data obtained in the current research .

As observed, higher levels of correlation have been achieved, demonstrating the effect of reduced uncertainty resulting from the similarity in the method of damage introduction in the structure. Based on the comparison of the data, the primary source of error in fitting and reduction of the correlation level has been identified, with suggestions for changes in the scoring method and index calculation provided to improve statistical correlation.

References

1. Cimellaro, G. P., Fumo, C., Reinhorn, A., & Bruneau, M. (2008, October). Seismic resilience of health care facilities. In 14th World Conference on Earthquake Engineering (14WCEE), Beijing, China (pp. 12-17).
2. Klein, R.J.T., Nicholls, R.J. and Thomalla, F. (2003), “Resilience to natural hazards: how useful is this concept?”, Global Environmental Change Part B: Environmental Hazards, Vol. 5 Nos 1-2, pp. 35-45.
3. Wasileski G., Rodríguez H., Diaz W. (2011). Business closure and relocation: a comparative analysis of the Loma Prieta earthquake and Hurricane Andrew, *Disasters*, 35(1): 102–129.

[4] Pant R., Barker K., Zobel C.W. (2013). Static and dynamic metrics of economic resilience for interdependent infrastructure and industry sectors, *Reliability Eng. Sys. Safety*, 125: 92–102.

[5] Miranda E., Mosqueda G., Retamales R., Pekcan G. (2012). Performance of nonstructural components during the 27 February 2010 Chile earthquake, *Earthq. Spectra*, 28: S453–S471.

[6] Zareian F., Krawinkler H., Ibarra L. (2006). Why and how to predict the probability of collapse of buildings, *Proceedings, 8th U.S. National Conference on Earthquake Engineerin*g, San Francisco, CA.

[7] Moehle J. (2003). A framework for performance-based earthquake engineering." *Proceedings, 10th U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices, Report ATC-15-9*, Applied Technology Council, Redwood City, CA.

[8] Cimellaro, G. P., Zamani-Noori, A., Kammouh, O., Terzic, V., and Mahin, S. A. (2016). "Resilience of Critical Structures, Infrastructure, and Communities." Pacific Earthquake Engineering Research Center (PEER), Berkeley, California, USA, pp. 318.

[9] Zarei, 2015, The relationship between the stability of crisis management and disaster accreditation with the level of preparedness in emergency situations in hospitals covered by the Social Security Organization in Tehran Province. Master's thesis. Islamic Azad University. Science and Research Branch.

[10] Khankeh et al., 2012. Hospital preparedness in disasters and crises (National Program). Tehran. Publisher: University of Social Welfare and Rehabilitation Sciences.

[11] Iranian Concrete Code "ABA", (2004), Organization for Planning and Management of the Country

[12] Publications No. 55, 77, 94 (2004), Organization for Planning and Management of the Country "Office of Research and Technical Standards"

[13] Building Code Requirements for Structural Concrete (ACI 318-99) Commentary on Building Code Requirements for Structural Concrete (ACI 318R-99) Reported by ACI Committee 318 (1999)

[14] Design of Reinforced Concrete Structures by Engineer Shapour Tahavoni (2004), Dehkhoda Publications, ISBN 9789646436169.

[15] ASCE. (2017). “Seismic Evaluation and Retrofit of Existing Buildings.” ASCE 41-17, Reston, Virginia.

.